Safety in Mines Research Advisory Committee

Final Project Report

Evaluation and Upgrading of Records of Stress Measurement Data in the Mining Industry

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Executive summary

The safety of mining operations is significantly influenced by the in situ stress fields in which the mining excavations are created. Many in situ stress measurements have been carried out for mining and civil engineering projects in Southern Africa over the past 30 to 40 years. Some of these data have been published, but many are contained in mine, company and owner organisation records. A collated and evaluated record of these data will provide a valuable input source for the planning of mining operations, allowing more valid stress calculations to be made.

This report describes such a record, which has been compiled into a computer database. Data on stress measurements and observations have been obtained, evaluated, reanalysed where necessary, and graded. The project described in this report is SIMRAC Project GAP 511b, "Evaluation and upgrading of records of stress measurement data in the mining industry".

A standard spreadsheet program has been used for capturing of the database. The database is available on a stiffy disc in standard DBASE format. In this format it can be accessed using any of the common database or spreadsheet packages such as ACCESS, QUATTRO PRO, EXCEL, LOTUS 123 etc, at least one of which should be available on every mine.

Various GIS and other graphical/map packages were investigated for possible use for visual display and interrogation of data. Ultimately, the package ArcExplorer was chosen. This is an easy to use Windows based package which provides all the functionality considered to be necessary for the project. ArcExplorer has been developed by the Environmental Systems Research Institute (ESRI), the organisation responsible for the development of the ARC/INFO and ArcView systems. The main reason for the choice of ArcExplorer, however, was that it is freely available on the Internet, and can therefore be downloaded at no cost by any user who wishes to make active use of the database. Instructions for downloading of the system from the Internet are given.

ArcExplorer uses shape files containing the spatial information of each data point in the database, and a DBASE file containing the alphanumeric data of each data point. Copies of these files are provided on the stiffy disc which accompanies the report.

Where possible, the data for each measurement entered into the database include:

- the location (coordinates and depth below surface);
- the mine or project;

- the rock type in which the measurement was made, and its deformation properties;
- the geology of the area;
- the in situ stress components in the north-south, east-west and vertical directions, and the corresponding shear stress components;
- the in situ principal stresses and their orientations relative to north;
- an estimate of the overburden stress;
- comments relevant to the measurement;
- gradings of the qualities of the individual measurements and the groups of measurements on a subjective/quantitative basis.

The purpose of the database is to allow users to extract the information that they require or may have an interest in. It is therefore somewhat superfluous to present any results from the database. However, in the report, some results are presented, which are of interest from the mining viewpoint and also serve to demonstrate the capabilities of the system. The results available from the database indicate that the horizontal principal stresses in Southern Africa commonly trend approximately north west - south east and north east - south west. The major horizontal stress magnitudes are almost always equal to or greater than the vertical stress magnitudes.

Based on evaluation of the information it is considered that there is little to be gained by carrying out in situ stress measurements for the specific purpose of filling in "gaps" in the stress database. Sufficiently reliable extrapolation of data, based on existing trends, can be achieved from the information in the database and from observations of dog earing behaviour in boreholes, shafts and raise bores. It is recommended that data from future in situ stress measurement exercises, if available, should be added to the database from time to time, to maintain the database as up to date as possible.

It is concluded that the availability of the database will contribute to the goal of safer mining conditions in South Africa.

1 Introduction Introduction

The safety of mining operations is significantly influenced by the in situ stress fields in which the mining excavations are created. In a physical sense, the stresses may have a beneficial effect in being of sufficient magnitude to confine the rock mass well and thus promote stability. However, if the stress magnitudes are too low, this confinement effect is reduced and instability may result. Conversely, if the stresses are too high, fracture and failure of the rock mass may be induced, again potentially causing instability.

From the point of view of planning of mining operations, the in situ stress field is a most important input parameter for modelling of excavations. If the assumed input values for the stresses are incorrect, it is possible that layout or other modelling, and conclusions therefrom, may be invalid. This may have significant and adverse implications for stability and safety.

Many in situ stress measurements have been carried out for mining and civil engineering projects in Southern Africa over the past 30 to 40 years. Some of these data have been published, but many are contained in mine, company and owner organisation records. A collated and evaluated record of these data will provide a valuable input source for the planning of mining operations, allowing more valid stress calculations to be made. This report describes such a record, which has been compiled into a computer database.

The project described in this report is SIMRAC Project, Number GAP 511b, "Evaluation and upgrading of records of stress measurement data in the mining industry" awarded to Steffen, Robertson and Kirsten (SRK). For record purposes, the research proposal for this project is included in Appendix 1.

The primary outputs defined for the project are:

- database of evaluated stress measurements made in the industry;
- evaluation of stress data to provide recommendations for improving and sharing data and understanding of the virgin stress conditions and the influence of mining on stress levels;
- recommendations for additional stress measurement data to be procured for improved understanding of stress conditions in all areas where mining is taking place.

2 Sources of data2 Sources of data

Many of the in situ stress measurements that have been carried out in Southern Africa have been carried out by the CSIR, which has therefore provided a very valuable source of such data. Other measurements have been carried out by other organisations and by mines themselves. In the civil engineering field, most of the measurements have been carried out for specific projects such as the Drakensberg Pumped Storage Scheme and the Ruacana Falls Hydroelectric Scheme. Other data of value to the project include observations of stress effects such as borehole breakouts or "dog earing" in holes, shafts and orepasses. Sourcing of the data has come directly from literature searches, searching of internal libraries to locate technical reports (particularly the CSIR and SRK libraries), from knowledge of the location of project file information (such as the Lesotho Highlands Water Project), and from knowledge of problems which have occurred on mines, such as stress spalling in shafts, which could yield relevant information. The sources of the data which have been included in the database are recorded in the reference list to this report. It was discovered that there was duplication of data in some of the sources, and that some information of interest could not be used in the database. These sources are recorded as Additional References in the reference list. Other information dealing with methods of in situ stress measurement in South Africa and related fields, but which does not include results of actual measurements or observations, has been excluded from the reference list.

3 Database of records of in situ stress in Southern Africa Database of records of in situ stress in Southern Africa

In this section the background is given to the choice of the database system and the choice of method of display of the data. A description is given of the extent of data actually input, and the system adopted for the grading of the quality of the data.

3.1 Database system.1 Database system

A standard spreadsheet program has been used for capturing of the database. The database is available on a stiffy disc in standard DBASE format. In this format it can be accessed using any of the common database or spreadsheet packages such as ACCESS, QUATTRO PRO, EXCEL, LOTUS 123 etc, at least one of which should be available on every mine.

3.2 System for presentation and display of data.2 System for presentation and display of data

Various GIS and other graphical/map packages were investigated for possible use for visual display and interrogation of data. Ultimately, the package ArcExplorer was chosen. This is an easy to use Windows based package which provides all the functionality considered to be necessary for the project. ArcExplorer has been developed by the Environmental Systems Research Institute (ESRI), the organisation responsible for the development of the ARC/INFO and ArcView systems. The main reason for the choice of ArcExplorer, however, was that it is freely available on the Internet, and can therefore be downloaded at no cost by any user who wishes to make active use of the database. Instructions for downloading of the system from the Internet are given in Appendix 3. The Instruction Manual for the use of ArcExplorer is part of the information that is downloaded. Since this manual is copyrighted, it cannot be included as part of this report. However, the instructions for downloading and interpreting the manual are also given in Appendix 3.

ArcExplorer uses shape files (*.shp and *.shx) containing the spatial information of each data point in the database, and a DBASE file (*.dbf) containing the alphanumeric data of each data point. Copies of the necessary files are provided on the stiffy disc which accompanies this report. The files provided are the following:

- Sasm.shp/shx/dbf - Full database;
- ABCavg.shp/shx/dbf - Database of averages and single data point with an A, B or C grading ;
- Towns.shp/shx/dbf - Database of the major towns in Southern Africa;
- aacntry.shp/shx/dbf and awswrlda.shp/shx/dbf - A map of Southern Africa. These files were downloaded from the ESRI website using of ArcExplorer;
- Sasm.aep - ArcExplorer project file;
- AEP.bak - Backup file of Sasm.aep.

3.3 Data entered into the database.3 Data entered into the database

All the desired amount of data on in situ stress measurements is not always available for each measurement. However, where possible, the following information has been captured into the database:

- X identification number in the database (sequential number for each measurement as the data are captured);
- X the country in which the record, observation, measurement was made (for example, Zimbabwe);
- X the province in the country (for example, Northern Cape);
- X the locality of the record (for example, Kloof Mine);
- X the site of the record (for example, Shaft 6);
- X the location of the record (for example, 63 level, 19 west crosscut);
- X the longitude;
- X the latitude;
- X the date of the measurement, observation, record;
- X the method of in situ stress measurement or observation (for example, Doorstopper strain cell; flat jack; borehole breakout etc);
- X the depth of the record below surface in metres;
- X the three principal stresses (S1, S2, S3 in MPa), their bearings and dip angles;
- X the estimated overburden stress (SOB);
- X the normal stress components in the east, north and vertical up axes (SX, SY, SZ, SXY, SYZ, SXZ stress components);
- X the two horizontal secondary principal stresses (SH1, SH3) and the bearing (BSH1);
- X the ratios between these horizontal secondary principal stresses and the estimated overburden stress (K1, K3);
- X the ratios between the SX and SY horizontal stresses and the estimated overburden stress (KX, KY);
- X the quality grading for the individual record (see below);
- X the quality grading for the combined record resulting from a group of individual records (see below);
- X the number of measurement points contributing to a record;
- X the modulus of elasticity of the rock material at the measurement point (E in GPa);
- X the value of Poisson's ratio of the rock material at the measurement point (pr);
- X the rock type in which the record originated;
- X the geologial sequence relevant to the record;
- X the reference to the source of the record;

X comments regarding the record (for example, measurement point close to a fault contact; measurement could be influenced by variable topography; measurement in valley bottom; measurement within the influence of excavations, etc).

Measurements or observations have been captured into the database as individual records. When a set of records has been obtained at a single site, which is often the case, a combined or "average" record for the set has also been captured into the database. It is envisaged that most users will make use of the average values, but the individual records have been included to ensure that all data can be accessed if required.

For information purposes, an example page from the database is included in Appendix 2.

3.4 Evaluation and upgrading of records3.4 Evaluation and upgrading of records

It has been assumed that the basic strain data (for overcore measurements) was assessed by the measurement practitioners at the time the measurements were conducted, and a judgement made on their validity before their use in the calculation of stresses. The calculation of the normal stress components from these data has been checked in a number of cases and found to be correct. In such cases, the recalculation has been carried out using a different method from that commonly applied in the reduction of the strain data, and therefore represents an independent check on the data reduction.

Inconsistencies in the coordinate axes and in the magnitudes and orientations of the principal stresses corresponding with the normal stress components were found in some cases in the material collected for the database. It was therefore considered necessary to recalculate the principal stresses and orientations in all records in which the complete state of stress had been determined. A consistent set of coordinate axes in the north, east and vertical up directions has been adopted. The recalculated and consistent set of data has been included in the database. In a few cases, however, there was insufficient information available to explain the inconsistencies, and these cases have been given the lowest grading in the database (see Section below).

3.5 Grading of data3.5 Grading of data

Gradings of record quality have generally been made for both the individual records and the group records, although it was not always possible to do this. Individual and average gradings may differ. The following are the descriptions of the various data grades.

3.5.1 Grading system for a data group3.5.1 Grading system for a data group

Grade A

a) Physical measurements, such as overcore, rock slotter, hydrofracture, etc, in which measurements were carried out in two or more boreholes beyond excavation influence, and the results of at least 80% of the measurements are in close agreement (normal stress components (Sx, Sy, Sz) generally within approximately 10% of the average).

b) Direct physical measurements of breakout (dog ear) orientations (where breakouts can be seen visually, not by remote observation) in vertical or sub-vertical circular excavations such as bored shafts or ore passes, and where the breakouts persist over a length of at least three diameters.

Grade B

a) Physical measurements, such as overcore, rock slotter, hydrofracture, etc, in which measurements were carried out in two or more boreholes beyond excavation influence, and the results of at least 50% of the measurements are in close agreement (normal stress components (Sx, Sy, Sz) generally within approximately 20% of the average), or where the measurements are of Grade A quality, but have been carried out in a single borehole.

b) Remote physical measurements in vertical or subvertical shafts or ore passes in which breakouts persist over a length of at least three diameters, or in boreholes in which breakouts persist over a length of at least 10 metres.

Grade C

a) Physical measurements, such as overcore, rock slotter, hydrofracture, etc, in which measurements were carried out in two or more boreholes beyond excavation influence, and the results of at least 50% of the measurements are in reasonable agreement (normal stress components (Sx, Sy, Sz) generally within approximately 35% of the average), or where the measurements are of Grade B quality, but have been carried out in a single borehole.

b) Direct or remote physical measurements or good quality estimates in vertical or subvertical shafts or ore passes in which breakouts persist over a length of less than three diameters, or in boreholes in which breakouts persist over a length of less than 10 metres.

Grade D

a) Physical measurements, such as overcore, rock slotter, hydrofracture, etc, in which measurements were carried out in two or more boreholes beyond excavation influence, and the results are indicative of trends in both stress and orientation components (normal stress components Sx, Sy, Sz generally within 50% of the average), or where the measurements are of Grade C quality, but have been carried out in a single borehole.

b) Direct or remote physical measurements or estimates in vertical or subvertical shafts, ore passes or boreholes in which breakouts are very localised.

Grade E

a) Physical measurements, such as overcore, rock slotter, hydrofracture, etc, in which results are too variable to indicate trends in both stress and orientation components.

b) Direct or remote physical measurements or estimates of breakout orientations which give contradictory indications.

c) Measurement data with inconsistencies which could not be resolved.

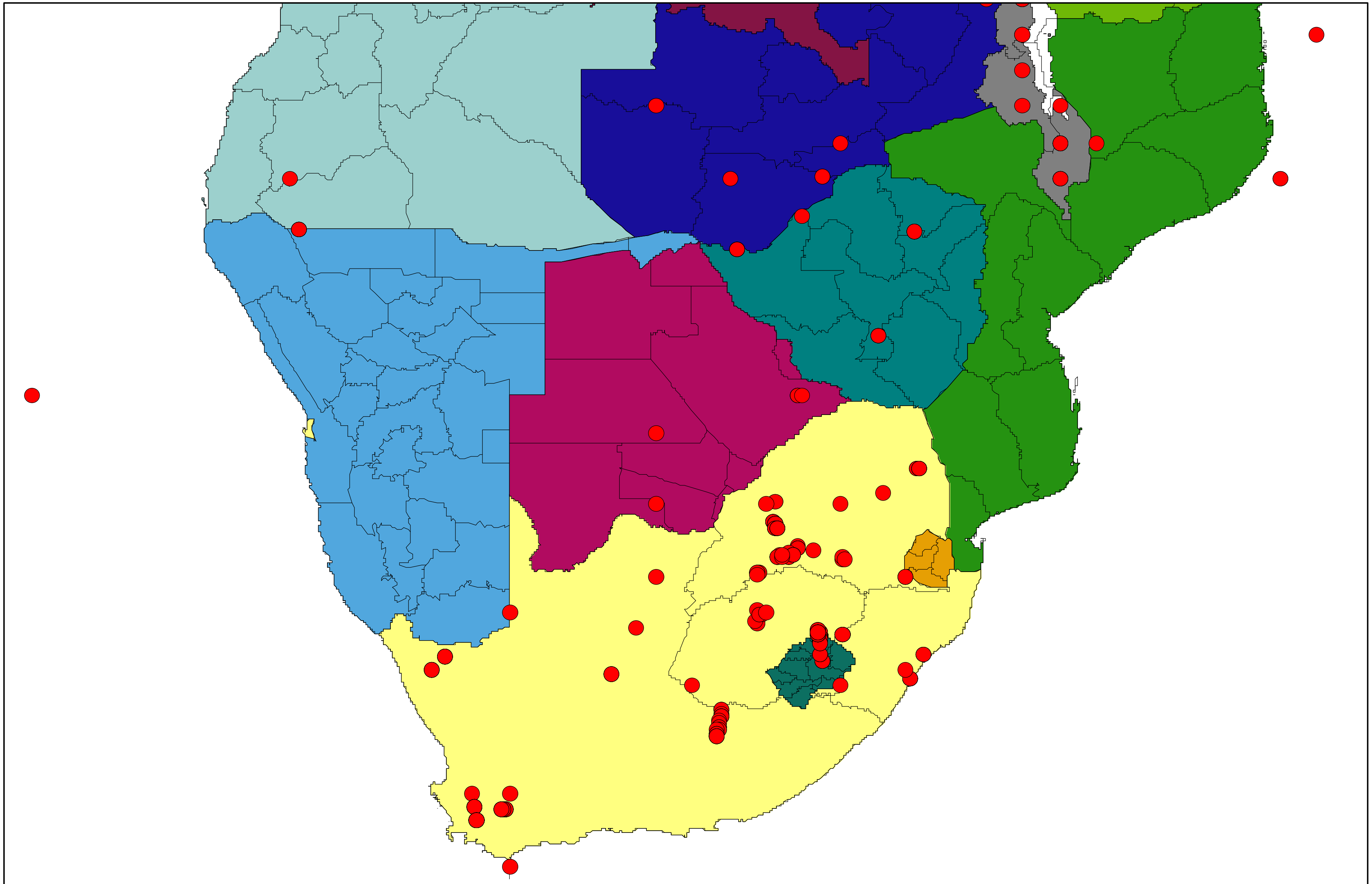
3.5.2 Grading system for individual data points3.5.2 Grading system for individual data points

For overcore stress measurements it is possible to calculate a standard deviation for the normal stress components. Where the values of the standard deviations were provided in the sources of data, the following system was used to grade the indiviual measurements. The maximum value of standard deviation of each of the normal stress components as a percentage of the normal stress component (Sx, Sy, Sz), was used as the grading parameter. The grades were assigned according to the following ranges in the grading parameter:

Grade	Grading Parameter
A	< 20%
B	20% - 30%
C	30% - 40%
D	40% - 50%
E	> 50%

4 Observations made from a review of the information in the database Observations made from a review of the information in the database

The available information on in situ stresses in Southern Africa is greater than had been envisaged at the time of submission of the research proposal. The result is that there is a reasonable distribution of data across the sub-continent. This is illustrated in Figure 1, which is a plot of stress measurement locations from the ArcExplorer system.



Stress measurement locations

Figure 1

The purpose of the database is to allow users to extract the information that they require or may have an interest in. It is therefore somewhat superfluous to present any results from the database. However, it was considered that it would be of interest to illustrate some of the results, which also serves to demonstrate the capabilities of the system.

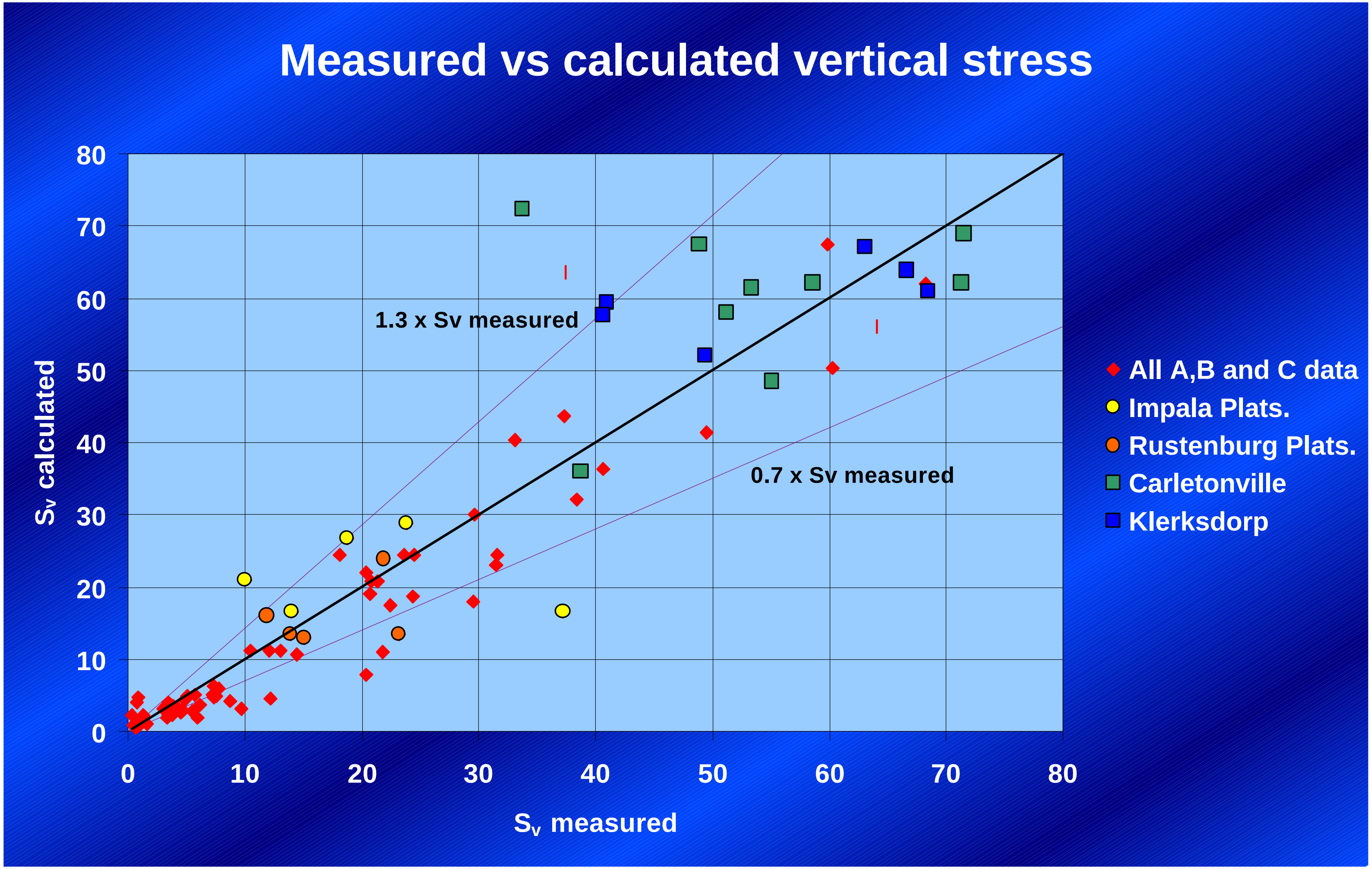
A comparison of the measured vertical stresses with the vertical stresses calculated from the overburden depth is shown in Figure 2. It can be seen that there is about a 30% scatter on either side of the ideal 1:1 relationship.

With regard to mining activities, of interest are the orientations of the horizontal secondary principal stresses, and the ratios of these horizontal stresses to the vertical stresses. Figure 3 shows the orientations of the A, B and C grade data, and the average orientations, in Southern and Central Africa. It can be seen that the horizontal principal stresses tend to be aligned approximately in the NW-SE and NE-SW directions in South Africa. Figure 4 shows a zoom into the Carletonville-Klerksdorp-Free State area, and illustrates that the horizontal stress orientations in the Klerksdorp area are significantly different from those in the other two regions.

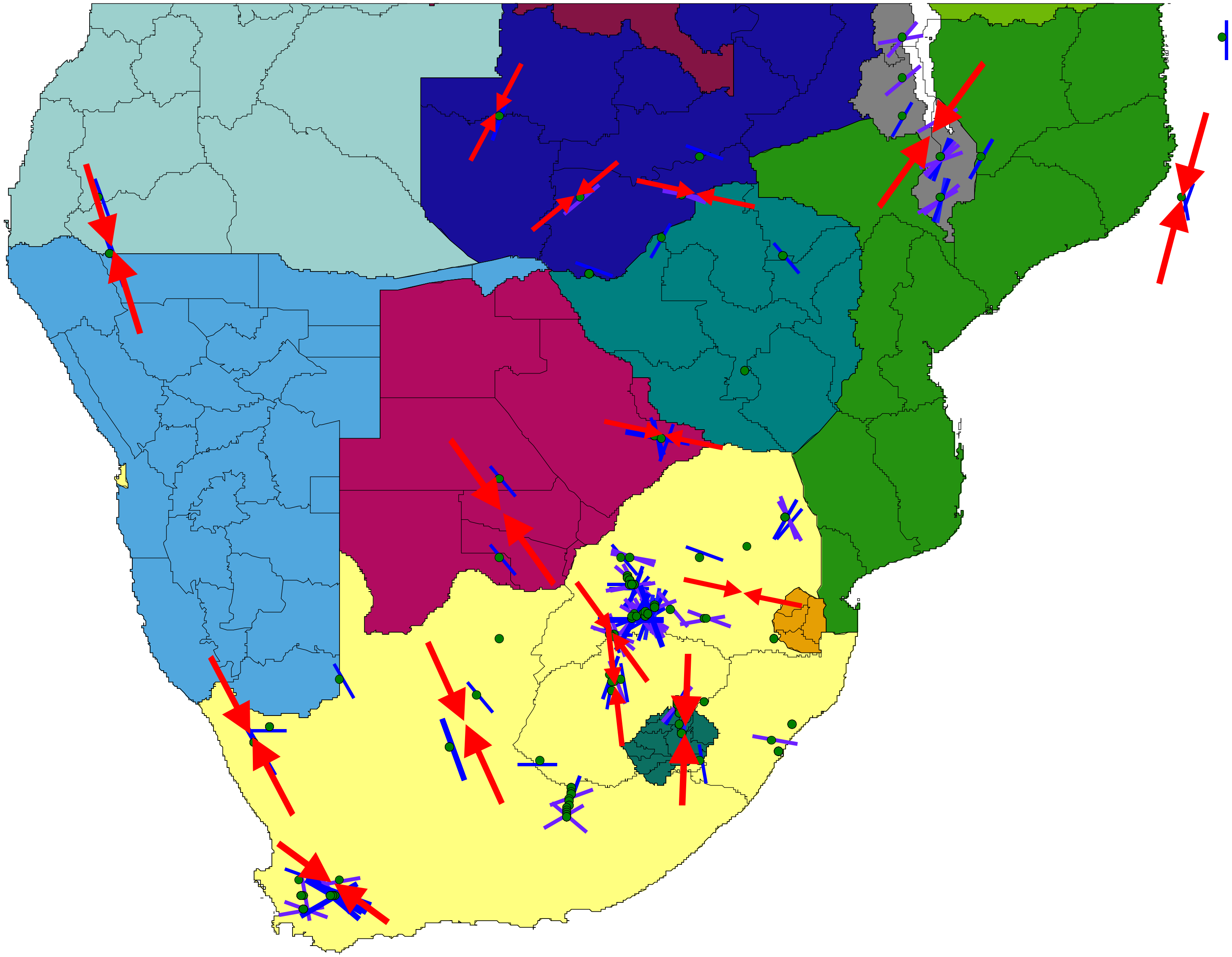
Another area of particular interest is the Bushveld Complex. Figure 5 shows the horizontal stress orientations from measurements in the area - Rustenburg Platinum Mine, Impala Platinum Mine and Northam Mine. A general trend in the orientations, interpreted by eye, has been superimposed in this figure, and appears to correspond with the general circular geometry of the Bushveld Complex.

The variations of the major and minor horizontal principal stresses with depth are shown in Figures 6 and 7. There appear to be two trends in these data - the Carletonville-Klerksdorp area fits one trend and the Rustenburg area another. Regression lines have been fitted to the major horizontal stress data in Figure 6 for interest, not to indicate confirmed trends.

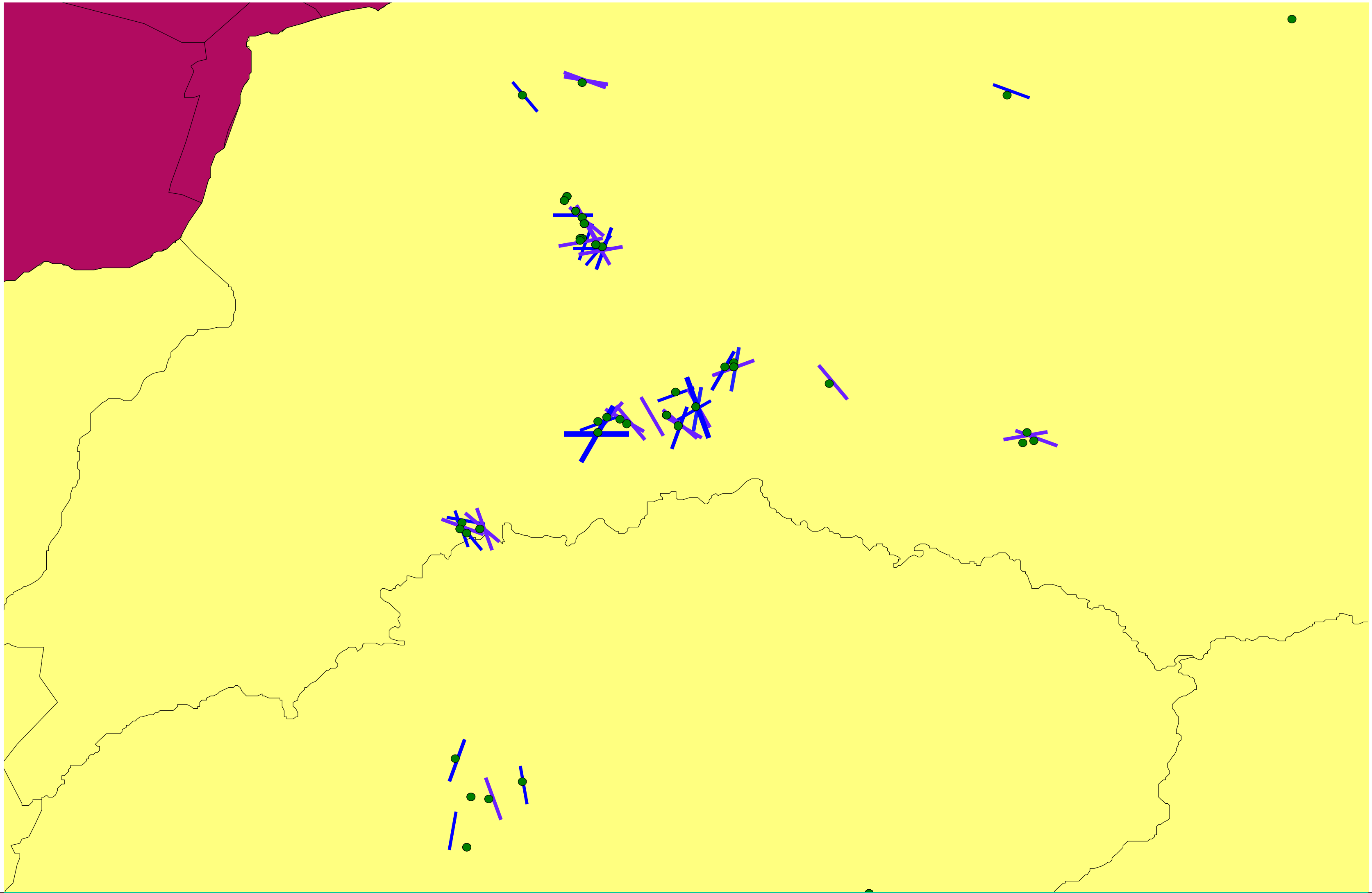
The ratios (K1) of major horizontal principal stress to vertical stress are plotted in Figure 8 as a function of depth. The general trend is that the horizontal values are equal to or greater than the vertical stresses. The data show that in the Carletonville and Klerksdorp areas the common assumption of a horizontal to vertical stress ratio of 0,5 is not valid, a value of about 0,9 being more realistic. K1 values for the Rustenburg area are much higher. The corresponding data for the minor horizontal principal stress (K3) are shown in Figure 9. The minimum value of K3 is about 0,3 and an average value of about 0,5 is applicable for the Carletonville and Klerksdorp areas.



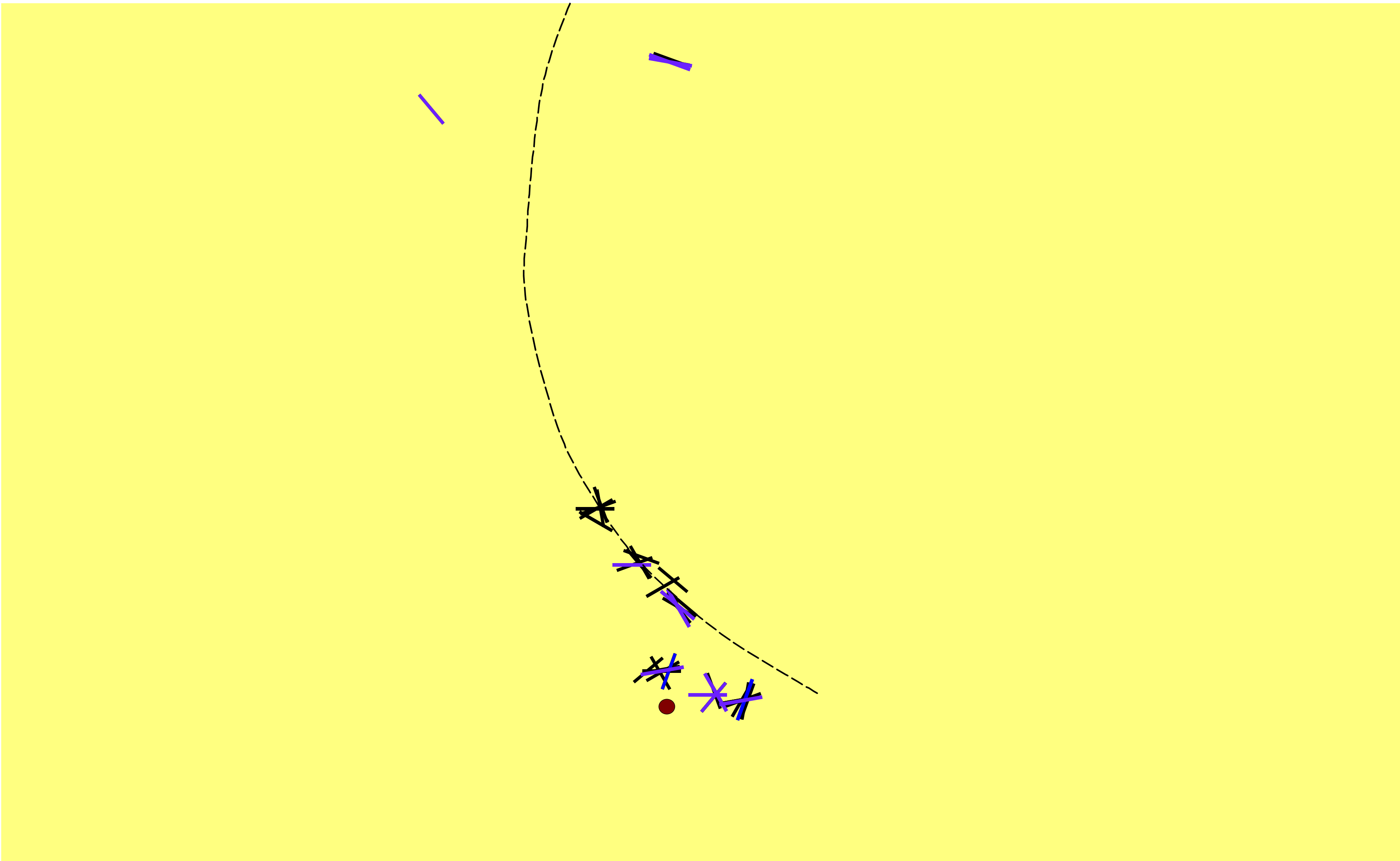
Comparison of the measured vertical stresses with the	Figure 2



Orientations of the A,B and C grade data and the averages.	Figure 3

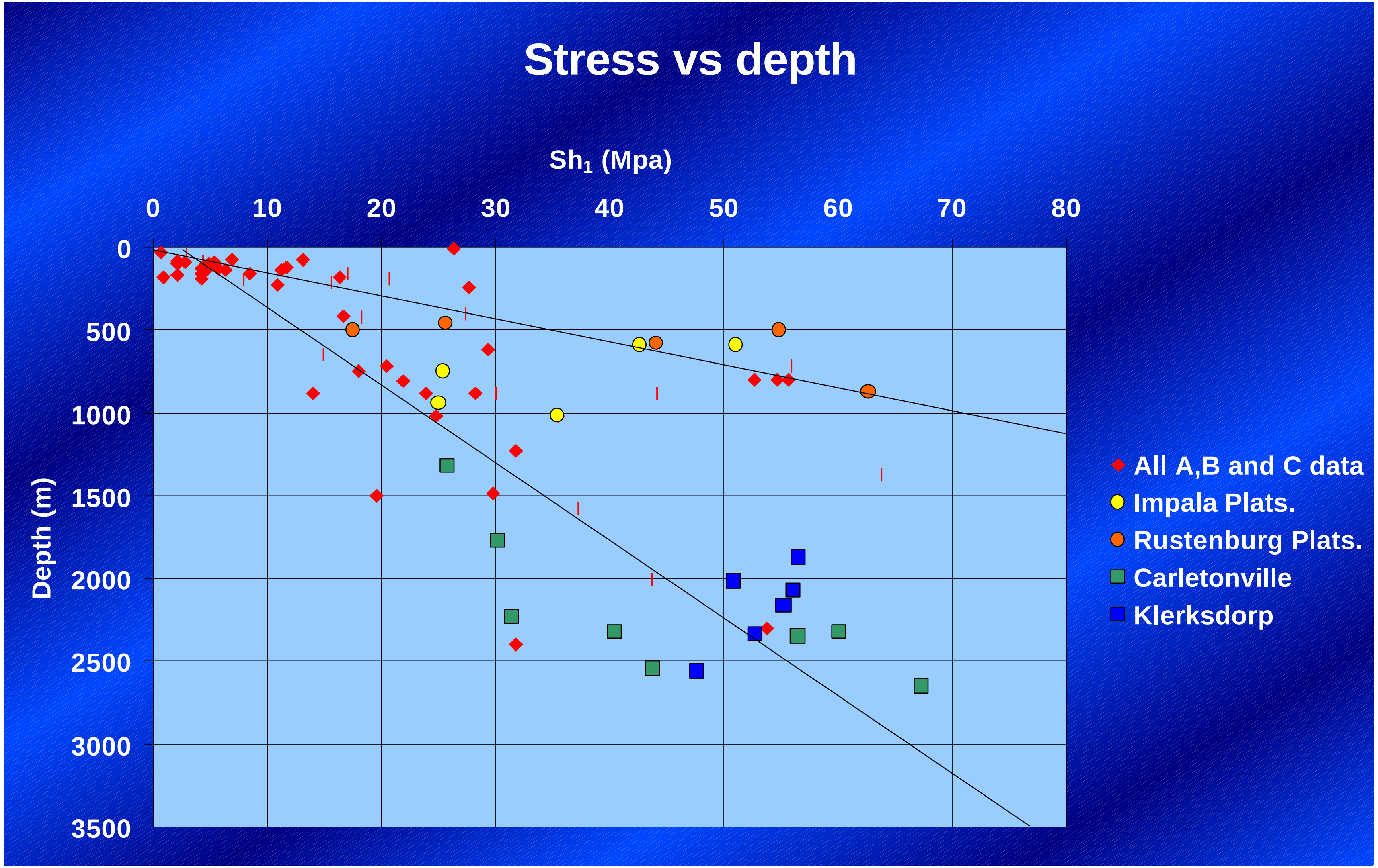


Horizontal stress orientations - Carletonville- Klerksdorp- Free	Figure 4



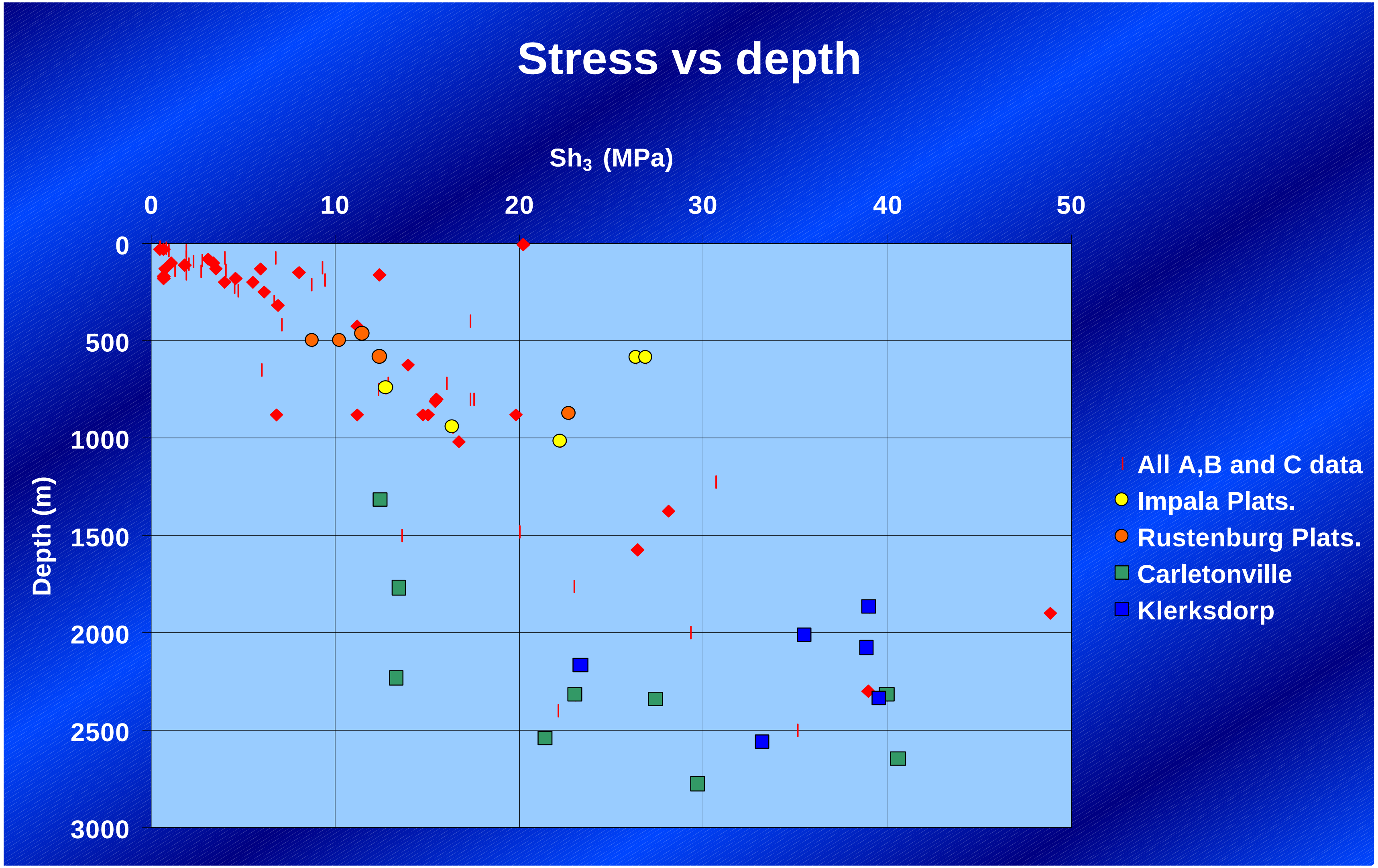
Horizontal stress orientations from Rustenburg Platinum Mine, Impala Platinum Mine and Northam Mine.

Figure 5

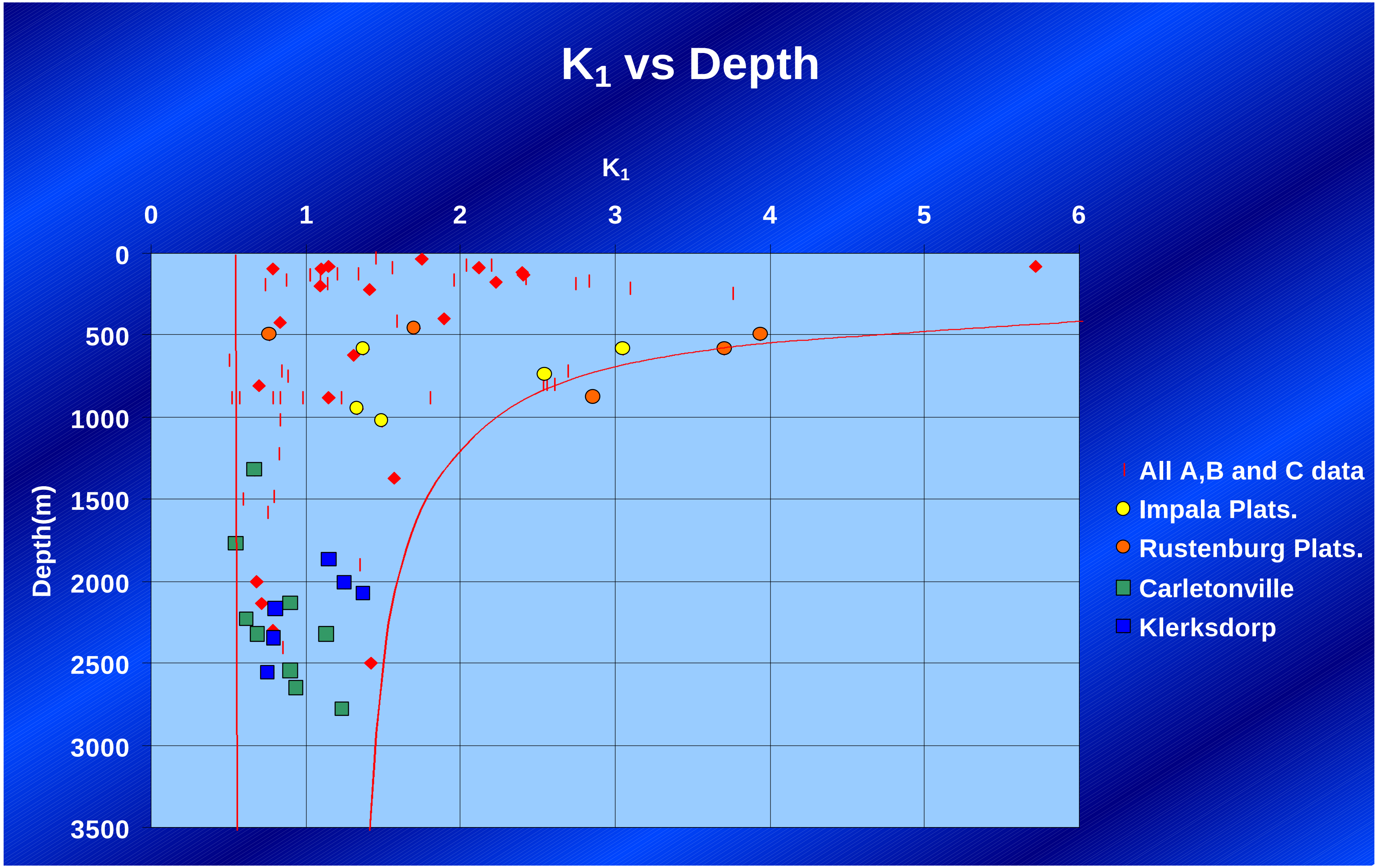


Variation of major horizontal principal stress with depth.

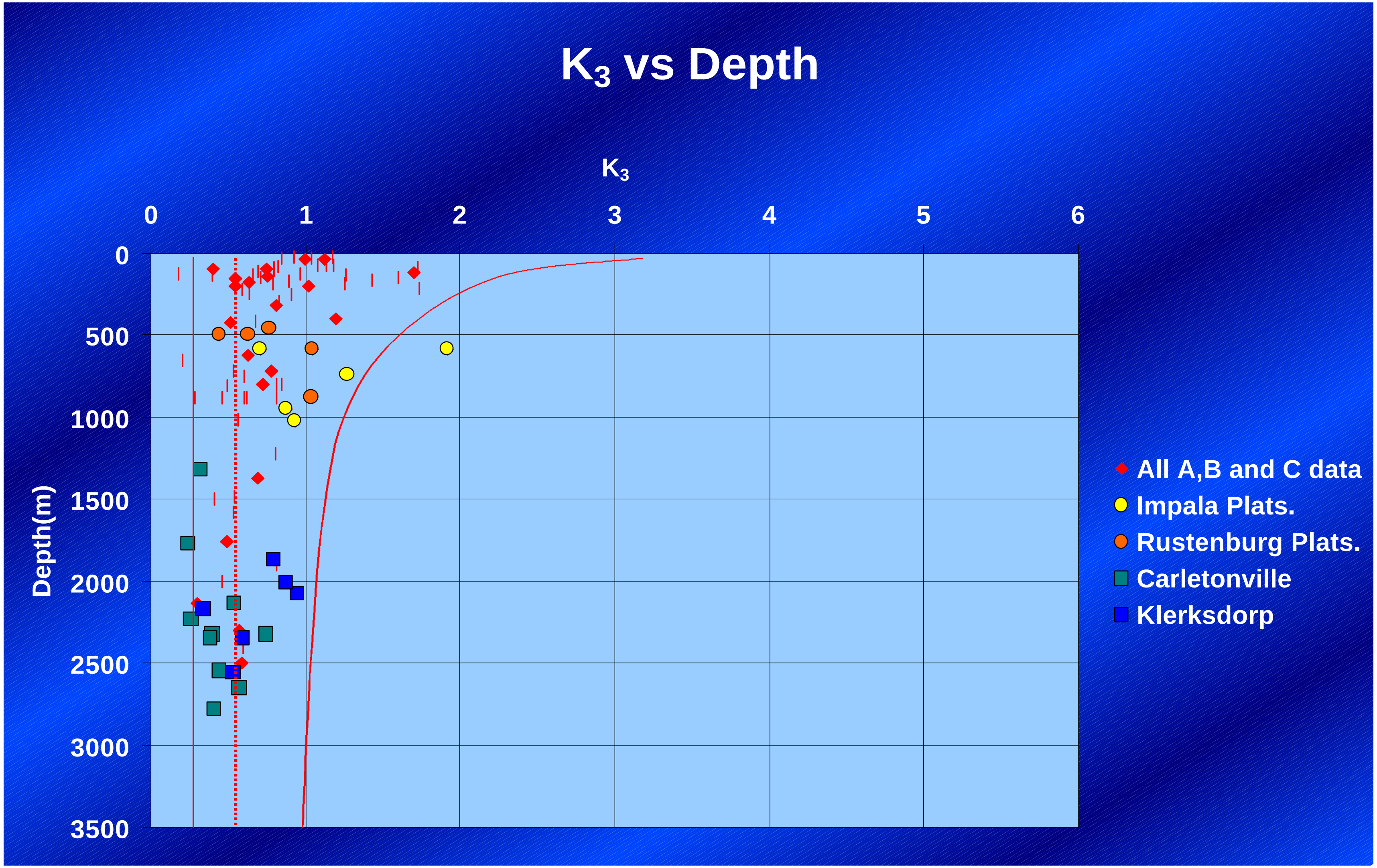
Figure 6



Variation of minor horizontal principal stress with depth	Figure 7



Ratio of major horizontal principal stress to vertical stress	Figure 8



Ratio of minor horizontal principal stress to vertical stress	Figure 9

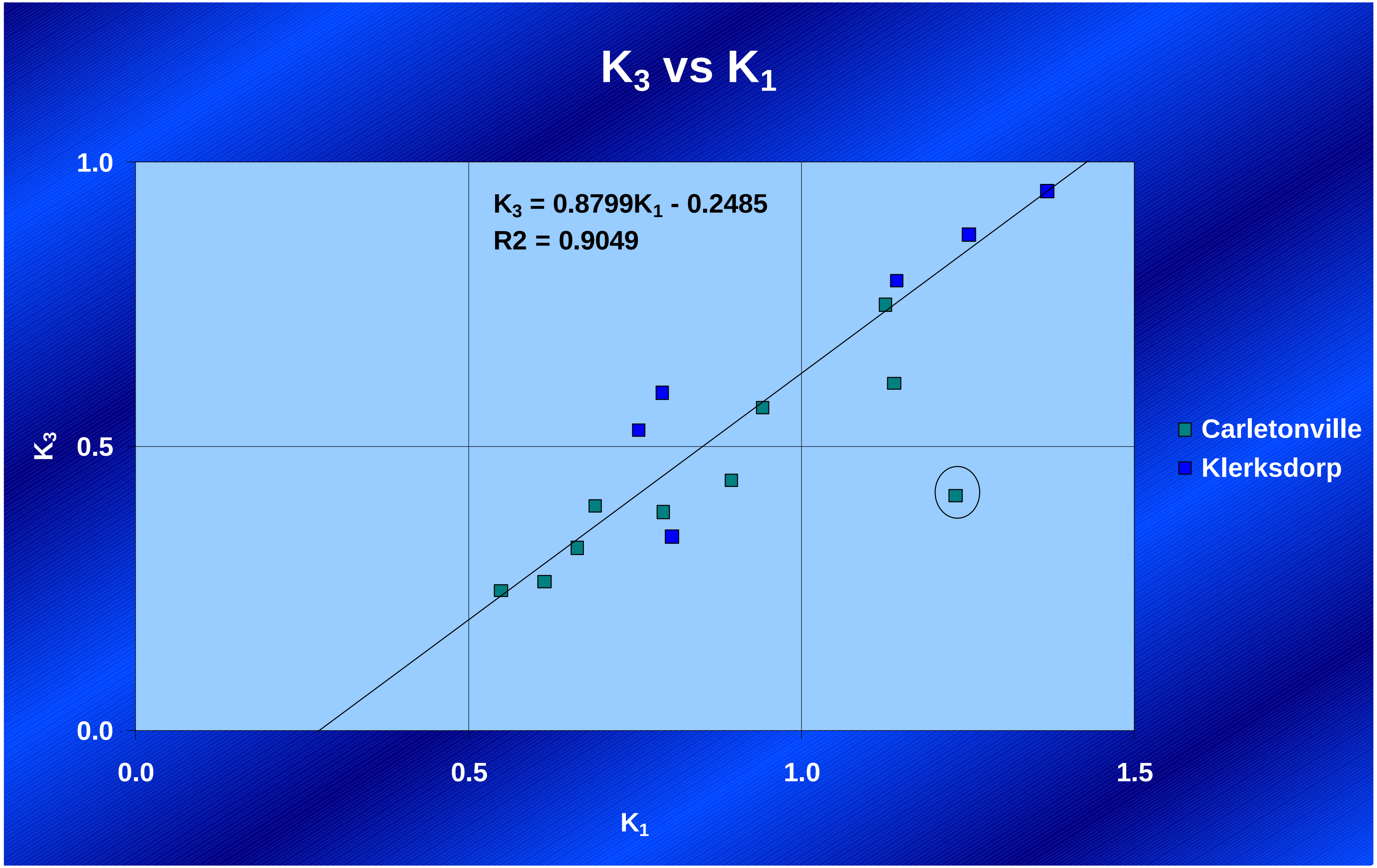
The relationship between K1 and K3 for data from the Carletonville and Klerksdorp areas is shown in Figure 10. This relationship is remarkably consistent, and, for interest, a regression line has been fitted to the graph, giving a high correlation coefficient.

5 Assessment of requirements for further in situ stress measurements5 Assessment of requirements for further in situ stress measurements

As can be seen from Figure 1 there is a reasonable spread of data across the southern African region. The data provide a reasonable indication of horizontal stress orientations, and the variations in these for the different areas (see Figures 3, 4 and 5). In addition, the magnitudes of the horizontal stresses compared with the vertical stresses are shown in Figures 6, 7, 8 and 9. What is immediately apparent from these figures is that there is a considerable amount of scatter in the data. Some of this scatter is clearly due to experimental "error", but it is considered that a lot of it is real, being the result of local variations in geology (measurements in different rock types), geological structure (such as measurements close to faults and dykes), and surface topography (such as shallow measurements adjacent to valleys).

Based on evaluation of this information it is considered that there is little to be gained by carrying out in situ stress measurements for the specific purpose of filling in "gaps" in the stress database. There are no obvious gaps in the areas where significant mining is taking place except, perhaps, at the deepest levels. At this stage, however, it is believed that sufficiently reliable extrapolation of data, based on existing trends, can be achieved from the information in the database and from observations of dog earing behaviour in boreholes, shafts and raise bores. It is therefore recommended that additional in situ stress measurements, for the specific purpose of adding information to the database, are not carried out.

It is likely that, in the future, additional in situ stress measurements will be carried out on mines for feasibility studies, development of new areas, or other purposes, and this is strongly supported. It is recommended that these data, if available, should be added to the database from time to time, to maintain the database as up to date as possible.



Relationship between K_1 and K_3 for data from Carletonville and	Figure 10

6 Conclusions6 Conclusions

The main output of the research project is the database of stress measurement and observational data that has been developed, which is provided on the computer disc which accompanies this report. This database will provide the mining industry with a valuable source of information which will permit:

- estimation of likely stress conditions in new areas of mining;
- a basis for evaluation of results from additional in situ stress measurement exercises;
- a basis for comparison of observed behaviour with expected behaviour;
- a source of data on which realistic design and layout analyses can be based.

It is concluded that the availability of the database will contribute to the goal of safer mining in South Africa.

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APPENDIX 1

GAP511b RESEARCH PROPOSAL

DEPARTMENT OF MINERALS AND ENERGY
PROPOSAL FOR A PROJECT TO BE FUNDED IN TERMS OF THE MINERALS ACT
-CONFIDENTIAL-

DME REFERENCE NUMBER (FOR OFFICE USE ONLY)

1. **PROJECT SUMMARY**

PROJECT TITLE: Evaluation and upgrading of records of stress measurement data in the mining industry

PROJECT LEADER: T R STACEY

ORGANISATION: STEFFEN, ROBERTSON AND KIRSTEN
ADDRESS: PO BOX 55291, NORTHLANDS, 2116

TEL: (011) 441 1143 **TELEFAX**: (011) 880 8086 **TELEX**:

PRIMARY OUTPUT[1]: Easy to use database of stress measurement information

HOW USED[2]**?**: Accessing of database

BY WHOM[3]**?** Rock mechanics engineers or any other interested persons

CRITERIA FOR USE[4]**?** None

POTENTIAL IMPACT[5]**?** Improved data for the application of all numerical stress analyses leading to more accurate assessment of conditions and hence improved measures for the amelioration of rock related hazards

FUNDING REQUIREMENTS (R000S)	YEAR 1	YEAR 2	YEAR 3
TOTAL PROJECT COST	368		
TOTAL SUPPORT REQUESTED FROM SIMRAC	368		

DURATION (YY/MM) 1998 (Jan - June)

SIMRAC SUB-COMMITTEE:

AU\PT	X	**COAL**		**OTHER**		**GENERIC**	

2. PROJECT DETAILS

2.1 Primary Output[1]

1. Database of evaluated stress measurements made in the industry.
2. Evaluation of stress data to provide recommendations for improving and sharing data and understanding of the virgin stress conditions and the influence of mining on stress levels.
3. Recommendations for additional stress measurement data to be procured for improved understanding of stress conditions in all areas where mining is taking place.

2.2 Other Outputs (deliverables)[6]

None

2.3 Enabling Outputs[7]

NO.	ENABLING OUTPUT	MILE-STONE DATE	MAN DAYS
1.	Collection of stress measurement data from published literature, mines and other organisations	Month 5	30
2.	Establishment of a suitable database system	Month 3	20
3.	Data capture	Month 5	20
4.	Evaluation of quality of data	Month 5	25
5.	Assessment of requirements for further in situ stress measurements	Month 5	5
6.	Compilation of final report and database user manual	Month 6	15
7.	Workshops to industry groups	Month 6	5
	TOTAL		120

2.4 **Methodology**[8]

NO. OF ENABLING OUTPUT	STEP NO.	METHODOLOGY TO BE USED TO ACCOMPLISH THE ENABLING OUTPUT (INDICATE STEPS/ ACTIVITIES)
1 to 7		Clear from section 2.3

3. FINANCIAL DETAILS[9]

3.1 Financial Summary

	R000s		
	YEAR 1	**YEAR 2**	**YEAR 3**
Project staff costs (from 3.2)	304		
Operating costs (from 3.3)	19		
Capital & plant costs (from 3.4)	-		
Sub-contracted work (from 3.5)	-		
Value added tax*	45		
Total cost of project	368		
Less funding from other sources (from 3.6)			
Support requested from SIMRAC	368		

*Only for VAT registered concerns

3.2 Project Staff Costs

	MAN DAYS		
NAME AND DESIGNATION	**YEAR 1**	**YEAR 2**	**YEAR 3**
T R Stacey - Project Leader	50		
Engineer/Technologist	30		
Database/GIS Scientist	20		
Data Capture Operator	20		
	120		

3.3 **Operating Costs (Running)**

	COST (R000s)		
ACTIVITY/ EQUIPMENT (Items above R10 000)	**YEAR 1**	**YEAR 2**	**YEAR 3**
Database software	10		
Travelling	5		
Copies, plotting, etc	4		
	19		

3.4 **Capital and Plant Costs**[10]

	COST (R000s)		
(i) ITEMS TO BE PURCHASED OR DEPRECIATED FOR MORE THAN R10 000 PER ITEM	**YEAR 1**	**YEAR 2**	**YEAR 3**
Other miscellaneous items			
TOTAL			

(ii) ITEMS TO BE MANUFACTURED WITH ASSEMBLED COST OF MORE THAN R10000 INCLUDING MATERIAL AND LABOUR	COST (R000s)		
	YEAR 1	YEAR 2	YEAR 3
Other miscellaneous items			
TOTAL TOTAL (i) and (ii)			

3.5 **Sub-contracted Work**

SUB-CONTRACTOR	ACTIVITY	COST (R000s)		
		YEAR 1	YEAR 2	YEAR 3

3.6 **Other Funding**

ORGANISATION	NATURE OF SUPPORT/ COMMITMENT	AMOUNT (R000s)

4. MOTIVATION

(Provide a clear and quantified motivation or justification for the proposal, as well as the main conclusions of a literature survey and the findings of related local and international research. The motivation should include a synthesis of previous work in the project area, both locally and overseas, why the project is proposed, what the primary output will achieve and a cost benefit analysis, if applicable. Use continuation pages where necessary but in most cases it should be possible to clearly present the key and arguments in the space provided).

Many in situ stress measurements have been carried out for mining and civil engineering projects in Southern Africa over the past 30 to 40 years. Some of these data have been published, but many are contained in mine, company and owner organisation records. A collated and evaluated record of these data will be a very valuable input source for numerical stress analyses, allowing more valid stress calculations to be made.

A search of published literature will be carried out, and organisations known to have carried out, or been involved with, in situ stress measurements in Southern Africa will be contacted. In addition, reference will be made to the World Stress Map, which is being compiled internationally, to determine whether any of the data contained in that record are relevant to Southern Africa. The data obtained from these sources will be evaluated and recorded in a database. An assessment will be made of the quality and validity of the data.

It is intended that a standard database system, which could be a Geographic Information System (GIS) database if found to be most applicable, will be used. Depending on the availability, it is expected that the data entered will include a description of the measurement location (eg the mine and shaft), the geographical location and elevation of the measurement site, the date of the measurement, the measurement method, the depth below surface, the rock type in which the measurement took place, the in situ stress results in both graphical and tabular form, and comments on the measurement site including the geometry, the extent of mining and excavation in the surrounding area, and the geology. A standard database or GIS system will be used which will facilitate wide use of the database within the industry. It will also enable the system to be updated easily as additional data become available.

It is envisaged that the system will enable users to view a map of Southern Africa, choose the location of interest to them, home in on that area and then interrogate the system for the data in their area of specific interest. This will mean that the data will be available to any user in a standard format, which is then a permanently available, easily accessible and easily updatable database.

5. CURRICULA VITAE OF PROJECT LEADER AND RESEARCH STAFF

5.1 Summary Information

Project leader

NAME & INITIALS: T R STACEY **AGE**: 54 **QUALIFICATIONS** (eg. degree/ diploma, issuing institution and date): See CV attached **SPECIAL AWARDS**: See CV

Principal Project Team Members

NAME & INITIALS: **AGE**: **QUALIFICATIONS** (eg. degree/ diploma, issuing institution and date): See CV attached **SPECIAL AWARDS**:

NAME & INITIALS: **AGE**: **QUALIFICATIONS** (eg. degree/ diploma, issuing institution and date): **SPECIAL AWARDS**:

NAME & INITIALS: **AGE**: **QUALIFICATIONS** (eg. degree/ diploma, issuing institution and date): **SPECIAL AWARDS**:

Use a continuation sheet if necessary

5.2 **Relevant Experience and Publications (one page for each individual listed in 5.1)**

NAME: T R Stacey

Relevant Experience:

1. Hands on experience with CSIR doorstopper and triaxial stain cells in-situ stress measurements.

2. Developed computer programme to calculate 3D state of stress from 3 doorstopper measurements.

3. Involvement in stress measurement programmes, in a supervisory and evaluation position, with doorstopper, CSIRO HI cell, and borehole slotter methods.

4. Involved, at an expert consultant level, with hydrofracture stress measurements and large diameter overcore measurements (in a bored tunnel).

5. Familiarity with literature on all the above methods, as well as other lesser used methods such as borehole deepening, back analysis from measured deformations, flat jacks, and others.

6. Project leader on SIMRAC project GAP 314 "Reliable practical technique for in situ ground stress measurements in deep level gold mines".

Relevant Publications:

1. Slotter stress measurements at Palabora Mine, Interfels News, No. 7, February 1993, pp 15-16.

2. Measurement of in situ stresses at Palabora Mine, Restricted Reports 179447/2 and 179447/5.

3. Practical method of in situ stress measurement for deep level mines, Proc. 1st Southern African Rock Engineering Symposium, SARES, Johannesburg, S.Afr. National Group of ISRM, pp 502-514

6. DECLARATION BY THE PROPOSING ORGANISATION

I, the undersigned, being duly authorized to sign this proposal, herewith declare that:

- The information given in this proposal is true and correct in every particular.
- This Organisation has the basic expertise and facilities required for satisfactory completion of the project and will adhere to the program of activities as set out in this proposal.
- The costs quoted are in accordance with the normal practice of this Organisation and can be substantiated by audit.

Signed on this 15th day of October 1997 for and on behalf of Steffen, Robertson and Kirsten

SIGNATURE

NAME T R Stacey

DESIGNATION Director

G:\proj\202778\simrac100.a

APPENDIX 2

DATABASE PAGE

SM_ID	A1_AVG	A2_GG	A3_IG	B1_COUNTRY	B2_PROVINC	B3_LOCALIT	B4_SITE	B5_LOCATIO	LON	LAT	DATE	B7_METHOD	B6_DEPTH
459	*	C	B	South Africa	NW	Rustenburg Platinum Mine	Paardekraal	19 inter-West	27.2983	25.6522	92/06/01	CSIR triaxia	500.00
460	*	C	C	South Africa	NW	Rustenburg Platinum Mine	Paardekraal	19 inter-West	27.2983	25.6522	92/06/01	CSIR triaxia	500.00
461	*	B	A	South Africa	NW	Rustenburg Platinum Mine	Paardekraal	19H-East	27.2983	25.6522	86/07/01	CSIR triaxia	462.00
462	*	B	A	South Africa	NW	Rustenburg Platinum Mine	Paardekraal	19H-East	27.2983	25.6522	86/07/01	CSIR triaxia	462.00
463	*	B	A	South Africa	NW	Rustenburg Platinum Mine	Paardekraal	19H-East	27.2983	25.6522	86/07/01	CSIR triaxia	462.00
464	*	C	A	South Africa	NW	Rustenburg Platinum Mine	Paardekraal	41/18 Panel 61	27.2983	25.6522	92/06/01	CSIR triaxia	500.00
465	*	C	A	South Africa	NW	Rustenburg Platinum Mine	Paardekraal	41/18 Panel 61	27.2983	25.6522	92/06/01	CSIR triaxia	500.00
466	A	C		South Africa	NW	Rustenburg Platinum Mine	Paardekraal	19 inter-West	27.2983	25.6522	92/06/01	CSIR triaxia	500.00
467	A	B		South Africa	NW	Rustenburg Platinum Mine	Paardekraal	19H-East	27.2983	25.6522	86/07/01	CSIR triaxia	462.00
468	A	C		South Africa	NW	Rustenburg Platinum Mine	Paardekraal	41/18 Panel 61	27.2983	25.6522	92/06/01	CSIR triaxia	500.00
469	A	E		South Africa	FS	Unisel Gold Mine	11 level		26.7872	28.0633	87/08/01	Doorstopper	1925.00
470	A	E		South Africa	FS	Unisel Gold Mine	4 level		26.7872	28.0633	87/08/01	Doorstopper	1335.00
471	A	C		South Africa	NW	Vaal Reefs	Shaft 5	62 Haulage E	26.7719	26.9122	87/08/01	Doorstopper	1868.00
472	A	C		South Africa	NW	Venterspost	No 3 tertiary shaft	32 level	27.6333	26.3000	90/01/01	CSIR triaxia	2346.00
473		C		South Africa		W of Johannesburg			27.0000	28.0000	19000100	Earthquake	0.00
474	*	A	A	South Africa	G	WAGM	265 Level	BH1	27.7108	26.3622	19000100	CSIRO triaxi	2650.00
475	*	A	A	South Africa	G	WAGM	265 Level	BH2	27.7108	26.3622	19000100	CSIRO triaxi	2650.00
476	A	A		South Africa	G	WAGM	265 Level	BH1 & 2	27.7108	26.3622	19000100	CSIRO triaxi	2650.00
477		B'		South Africa	G	WAGM	80 Haulage East		27.7108	26.3622	84/11/01	Doorstopper	2230.00
478	*	C	A	South Africa	G	WAGM	90 Level	BH1	27.7108	26.3622	19000100	CSIR triaxia	2543.00
479	*	C	A	South Africa	G	WAGM	90 Level	BH2	27.7108	26.3622	19000100	CSIR triaxia	2543.00
480	A	C		South Africa	G	WAGM	90 Level	BH 1 & 2	27.7108	26.3622	19000100	CSIR triaxia	2543.00
481			B	South Africa	G	WAGM	Raise Borehole		27.7108	26.3622	88/10/01	Break Out	2743.00
482			B	South Africa	G	WAGM	Raise Borehole		27.7108	26.3622	88/10/01	Break Out	2890.00
483			B	South Africa	NW	Western Deep Levels Gold Mine	SVC Raisebore		27.4286	26.4356	19000100	Break Out	0.00
484	A	B'		South Africa	NW	Western Deep Levels Gold Mine			27.4036	26.4206	68/01/01	CSIR triaxia	1770.00
485	A	B'		South Africa	MP	Winkelhaak Mine			29.1167	26.5083	70/01/01	Doorstopper	1226.00
486	A	B		South Africa	MP	Winterveld	23 level		30.1817	24.6667	19000100	Hydrofractur	150.00

E1_BS1	E4_BS2	E7_BS3	E5_DIPS1	E2_DIPS2	E8_DIPS3	E3_S1	E6_S2	E9_S3	C1_SOB	D1_SX	D2_SY	D3_SZ	D4_SXY	D5_SYZ	D6_SZX	C2_SH1	C3_SH3	C4_BSH1	C5_K1
92	178	4	2	-57	-32	64.52	15.63	7.55	13.50	64.33	13.39	9.98	-2.35	-3.57	-2.33	64.43	9.88	92	4.81
92	160	9	13	-58	-29	47.15	15.27	5.10	13.50	45.27	14.51	7.75	-7.75	-4.03	-2.26	45.41	7.61	93	3.13
154	69	63	2	-66	24	29.77	17.72	11.02	13.00	15.61	16.61	26.29	2.03	1.56	-7.00	29.75	12.15	154	1.79
157	36	73	-15	-62	23	20.70	14.38	9.28	13.00	11.31	14.05	19.00	2.37	-0.95	-3.32	20.24	10.07	160	1.44
152	23	67	-16	-66	18	31.76	13.56	11.85	13.00	16.03	14.77	26.37	2.74	-4.03	-7.58	30.38	12.02	152	2.06
41	40	130	-64	26	0	24.46	18.91	11.95	13.50	15.29	23.39	16.64	1.48	1.62	3.96	19.98	11.95	40	0.85
68	37	129	-72	15	9	23.95	14.47	8.25	13.50	11.56	22.94	12.17	3.27	0.42	3.27	15.15	8.58	42	0.66
92	171	6	7	-59	-30	55.49	15.71	6.43	13.50	54.80	13.95	8.87	-5.05	-3.80	-2.30	54.91	8.75	93	3.94
151	33	67	-14	-63	23	26.35	15.17	10.75	13.00	14.42	15.10	22.75	2.69	-1.62	-5.78	25.71	11.46	153	1.70
54	38	130	-70	19	5	24.10	16.75	10.16	13.50	13.43	23.17	14.41	2.38	1.02	3.62	17.56	10.27	41	0.76
3	111	32	-50	-14	36	63.70	51.43	36.57	55.50	48.70	53.60	49.40	4.10	12.00	-4.09	53.15	44.95	137	0.99
102	21	113	-69	4	21	45.44	31.15	29.41	38.10	31.60	43.40	31.00	5.20	-1.20	0.17	31.64	30.96	75	0.73
145	121	52	-21	67	-8	57.76	48.42	38.82	52.00	45.31	49.40	50.29	0.70	-3.40	-8.40	56.56	39.04	143	1.14
32	75	162	-69	15	-14	75.90	54.40	24.90	62.20	52.33	71.25	31.61	2.13	12.46	10.18	56.49	27.45	68	0.79
0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	169	0.00
150	14	88	48	33	-22	86.93	57.39	39.85	69.00	45.65	71.19	67.32	-13.45	12.54	-6.22	68.98	43.99	165	0.97
136	172	72	55	-29	-17	80.64	60.52	33.53	69.00	41.16	71.82	61.71	-13.65	4.57	-10.37	66.03	36.84	157	0.92
144	2	79	51	33	-19	83.54	58.78	37.11	69.00	43.41	71.51	64.52	-13.55	8.56	-8.30	67.38	40.54	161	0.94
111	155	67	-87	7	8	50.51	31.80	13.60	58.00	16.96	51.17	27.78	-5.49	3.51	-7.24	31.41	13.33	153	0.61
87	57	152	-63	23	12	65.88	35.51	16.97	67.50	37.69	58.99	21.68	13.91	-2.73	7.64	40.75	18.62	68	0.69
69	17	135	-36	40	29	55.18	36.14	18.60	67.50	40.17	38.77	30.98	13.74	-2.00	10.83	47.34	23.81	56	1.22
79	42	144	-52	31	18	58.98	36.59	18.57	67.50	38.93	48.88	26.33	13.83	-2.36	9.24	43.81	21.45	62	0.90
0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10	0.00
0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5	0.00
0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	140	0.00
100	126	28	-70	26	11	55.20	30.60	13.00	48.50	25.20	55.10	18.50	6.57	1.86	-7.67	30.22	13.48	123	0.55
100	77	167	79	-10	-5	38.60	31.20	31.00	32.10	31.65	38.37	30.78	-1.32	-0.17	-0.35	31.77	30.66	109	0.83
0	0	0	0	0	0	0.00	0.00	0.00	5.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.00	0	0.00

C5_K1	C6_K3	D7_KX	D8_KZ	F1_NO	F2_E	F3_PR	F5_ROCK	F6_SEQ	F7_REFF	F8_NOTES
4.81	0.74	4.80	0.75	0	63.10	0.20	Norite / Anorthosite	BIC	EMA-P-I-92029	
3.13	0.52	3.12	0.53	0	63.10	0.20	Norite / Anorthosite	BIC	EMA-P-I-92029	
1.79	0.73	0.94	1.58	0	35.40	0.11	Anorthosite	BIC	ME 1982	
1.44	0.72	0.80	1.35	0	35.40	0.11	Anorthosite	BIC	ME 1982	
2.06	0.81	1.09	1.79	0	35.40	0.11	Anorthosite	BIC	ME 1982	
0.85	0.51	0.65	0.71	0	135.60	0.22	Merensky Reef	BIC	EMA-P-I-92029	
0.66	0.37	0.50	0.53	0	135.60	0.22	Merensky Reef	BIC	EMA-P-I-92029	
3.94	0.63	3.93	0.64	2	63.10	0.20	Norite / Anorthosite	BIC	EMA-P-I-92029	
1.70	0.76	0.95	1.51	3	35.40	0.11	Anorthosite	BIC	ME 1982	
0.76	0.44	0.58	0.62	2	135.60	0.22	Merensky Reef	BIC	EMA-P-I-92029	
0.99	0.84	0.91	0.92	0	67.00	0.20		Witwatersrand Supergroup	PK van Der Heever	Cor.Coef=90.8%
0.73	0.71	0.73	0.71	0	65.00	0.20		Witwatersrand Supergroup	PK van Der Heever	Cor.Coef=97%
1.14	0.79	0.92	1.02	4	73.00	0.18		Witwatersrand Supergroup	PK van Der Heever	Near fault. Cor.Coef=91%.
0.79	0.39	0.73	0.44	3	65.00	0.18	Quartzite	Witwatersrand Supergroup	Nieuwoudt and Rosendaal	Could be affected by nearby stoping
0.00	0.00	0.00	0.00	0	0.00	0.00			WSM - HARVARD	
0.97	0.62	0.64	0.95	0	0.00	0.00	Quartzite	Witwatersrand Supergroup	Smallbone, James & Isaac	
0.92	0.51	0.57	0.86	0	0.00	0.00	Quartzite	Witwatersrand Supergroup	Smallbone, James & Isaac	
0.94	0.57	0.61	0.90	0	0.00	0.00	Quartzite	Witwatersrand Supergroup		
0.61	0.26	0.33	0.54	0	0.00	0.00	Quartzite	Witwatersrand Supergroup	166564	
0.69	0.32	0.64	0.37	0	74.30	0.14	Quartzite	Witwatersrand Supergroup	EMA-C-90168	
1.22	0.61	1.04	0.80	0	74.30	0.14	Quartzite	Witwatersrand Supergroup	EMA-C-90168	
0.90	0.44	0.80	0.54	2	74.30	0.14	Quartzite	Witwatersrand Supergroup	EMA-C-90168	
0.00	0.00	0.00	0.00	0	0.00	0.00			166564	
0.00	0.00	0.00	0.00	0	0.00	0.00			166564	
0.00	0.00	0.00	0.00	0	0.00	0.00			RE 15/96	
0.55	0.24	0.00	0.00	0	0.00	0.00	Quartzite	Witwatersrand Supergroup	N.C. Gay 1975	Several faults
0.83	0.80	0.00	0.00	0	0.00	0.00	Quartzite	Witwatersrand Supergroup	N.C. Gay 1975	Negative stresses unacounted for
0.00	1.60	0.00	0.00	0	0.00	0.00	Pyroxinite	BIC	Ortlepp and Bristow	

APPENDIX 3

DOWNLOADING OF ArcExplorer

FROM THE INTERNET

APPENDIX 3

INSTRUCTIONS FOR DOWNLOADING AND INSTALLING OF ArcExplorer

To download the ArcExplorer software, follow steps 1 to 9 or steps 6 to 9.

1. Visit the home page of the Enviromental Systems Research Institute (ESRI) at http://www.esri.com/.

2. Under the heading "*Downloads",* click on the line "- *Free! ArcExplorer GIS Data Browser".* This will bring you to another page giving you information on ArcExplorer.

3. Click on the heading "*Download ArcExplorer".* This will bring you to another page stating the minimum and recommended system requirements for running ArcExplorer.

4. Click on the line "*Download ArcExplorer version 1.0 (6.5Mb)*". This will bring you to a page that will ask for your registration.

5. Click on the underlined word "*register*" to obtain the online registration form.

6. You can go directly to the register form at the following address http://nt1.esri.com/scripts/production/esri/marketing/download/register.cfm?downloadid=55

7. Fill in the registration form and click on the "register" button below the form. This will bring you to a page giving you a choice of sites from which to download the software.

8. Choose one of the sites by clicking on it.

9. Your Web browser will start downloading the file. After a few seconds it will ask you whether to open or save the file. Choose the "save" option.

To install the software and data follow the instructions below:

1. Double click on the file you have downloaded from the internet. The file is called aesetup.exe. This will start the setup program that will interactively guide you through the rest of the installation procedures.

2. Copy the Southern African Stress Map data files into the directory in which ArcExplorer has been installed. If you followed the default options of the ArcExplorer setup program this will be the directory:

c:\Program files\ESRI\ArcExplorer\

ArcExplorer User manual

The ArcExplorer User Manual is protected under copyright law and is therefore not reproduced in this report. The file ArcExplorer.pdf containing the user manual in Adobe Acrobat format, is downloaded and installed as part of ArcExplorer and can be found under the directory:

c:\Program files\ESRI\ArcExplorer\.

This file can be viewed and printed through Adobe Acrobat Reader. Acrobat Reader is free software and can be downloaded from the Adobe web site. Instructions for downloading the Acrobat Reader are given on the following web page:

http://www.adobe.com/prodindex/acrobat/readstep.html.