LITHOSTRATIGRAPHY, DEPOSITIONAL ENVIRONMENTS AND SEDIMENTOLOGY OF THE PERMIAN VRYHEID FORMATION (KAROO SUPERGROUP), ARNOT NORTH, WITBANK COALFIELD, SOUTH AFRICA.

by

JOANNE UYS

submitted in fulfillment of the requirements for the degree

MASTER OF SCIENCE

in

GEOLOGY

in the

FACULTY OF SCIENCE

at the

UNIVERSITY OF JOHANNESBURG

SUPERVISOR: PROFESSOR B CAIRNCROSS

DECEMBER 2007
DECLARATION

I hereby declare that this dissertation is, with the exception of what has been acknowledged, my own, unaided work. It is being submitted for the degree of Master of Science in the Faculty of Science, University of Johannesburg, Johannesburg. It has not been submitted before for any degree or examination in any other University or institute of higher education.

__________________________
Joanne Uys

__________________________
Date
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acknowledgements</td>
<td>iii</td>
</tr>
<tr>
<td>Abstract</td>
<td>iv</td>
</tr>
<tr>
<td>List of Figures</td>
<td>vi</td>
</tr>
<tr>
<td>List of Tables</td>
<td>xiii</td>
</tr>
</tbody>
</table>

## CHAPTER 1

1. **INTRODUCTION**
   1.1 Location and Database
   1.2 Dissertation Objectives and Methods
   1.3 Regional Geology
   1.4 Previous Work

## CHAPTER 2

2. **STRATIGAPHY**
   2.1 Regional Stratigraphy
   2.2 Stratigraphy of Arnot Colliery

## CHAPTER 3

3. **FACIES DESCRIPTIONS**
   3.1 Facies Analysis
   3.2 Diamictite-Conglomerate Facies
   3.3 Massive Granulestone-Sandstone Facies
   3.4 Horizontally Bedded Granulestone-Sandstone Facies
   3.5 Tabular Cross-bedded Granulestone-Sandstone Facies
   3.6 Trough Cross-bedded Sandstone Facies
   3.7 Interlaminated Sandstone-Mudstone Facies
   3.8 Bioturbated Sandstone-Mudstone Facies
   3.9 Massive Mudstone Facies
   3.10 Shale Facies
   3.11 Coaly Shale Facies
   3.12 Coal Facies
## CHAPTER 4  

### 4 LITHOSTRATIGRAPHY AND FACIES ASSEMBLAGES  

4.1 Introduction 52  
4.2 The Basement Sequence 52  
4.3 The No. 1 Seam Sequence 59  
4.4 The Parting between the No. 1 Seam and No. 2 Seam Sequences 62  
4.5 The No. 2 Seam Sequence 69  
4.6 The Stratigraphy above the No. 2 Seam Sequence 81  

## CHAPTER 5  

### 5 DEPOSITIONAL ENVIRONMENTS  

5.1 Introduction to Depositional Models 90  
5.2 Glacial Facies Assemblages 92  
5.3 Fluvial Facies Assemblages 94  
5.4 Deltaic Facies Assemblages 95  
5.5 Palaeogeographic Synthesis 97  

## CHAPTER 6  

### 6 SUMMARY  

6.2 Facies Types 102  
6.3 Lithostratigraphy and Depositional Model 103  

## REFERENCES  

108
I would like to express my gratitude to Anglo Operations Limited for providing the geological data, without which this project would not have taken place. For their generous assistance and co-operation in this regard, I extend thanks to Mr. Ken Bell, Mr. David Dingemans, Mr. Malcolm Spurr and Mr. Ian de Klerk. Furthermore, the bulk data analysed in this dissertation was derived from boreholes that were logged over a period of 50 years by Anglo American Coal Division Geologists. These personnel are therefore all gratefully acknowledged for their valuable input to this data capture.

I would also like to thank Mr. Marius Smith for giving permission to use data gathered in previous years on properties where the mineral rights are now held by Xstrata Coal Limited.

Professor Bruce Cairncross (supervisor) has provided invaluable guidance during all phases of this study and is thanked for his constructive criticism and discussion.

The members of the Anglo Coal Geological Services team who provided direct and indirect support for this study include:

- Malcolm Spurr for his constructive editing and criticism of the content and write-up.
- Ian de Klerk for his assistance in understanding the computer modeling package.
- Boguslaw Wakerman for ensuring proper identification and complete understanding of specifically the bioturbated lithologies.

Finally, I would also like to thank my husband for believing in me, inspiring me to be more than I am and having the patience for me to get there in my own time.
ABSTRACT

This work documents the lithostratigraphy and interpreted depositional environments of the Permian Vryheid Formation in the most northern proximal setting yet studied in the Witbank Coalfield. Data from 924 boreholes from two mining companies (Anglo Operations Ltd. and Xstrata Coal Ltd.) drilled over 50 years, covering an area of 910km$^2$ revealed a 35m sequence of terrigenous clastic sedimentary rocks containing two coal seams. These seams are numbered No. 1 at the base and No. 2 at the top.

Delineation of facies type, facies assemblages, lateral facies distributions and computer-based three-dimensional modeling facilitated the interpretation of the palaeodepositional environments. Eleven lithofacies are defined and interpreted hydrodynamically. Facies classification is based primarily on grain size and sedimentary structures. The modeling of the borehole information uses the finite element method to interpolate the thickness, roof and floor surfaces and trend of each seam and inter-seam parting between boreholes. The spatial position of the boreholes is defined using a digital terrain model that represents the current surface topography. Lateral distributions were correlated by repositioning the boreholes using the base of the No. 2 seam as a datum.

Glaciofluvial, glaciolacustrine, bed-load (braided) fluvial and constructive progradational deltaic environments are interpreted in the study area. Fluvial channel sequences are dominant and cause the thinning of the coal seams below channel axes as well as splitting of both the No. 1 and No. 2 seams. Glaciofluvial influences also affect the lower portion of the No. 1 seam. Basement palaeotopography restricts the distribution of the lower splits of the No. 1 seam. The coals either ‘pinch-out’ or are absent above basement highs but blanket the adjacent low-lying areas.

In contrast to the greater Witbank Coalfield, but concurrent with other studies in the more northern proximal regions, fluvial systems dominate over deltaic systems in the study area. Glaciodeltaic, fluviodeltaic and anastomosed channel fluvial
systems recognized in the remainder of the Karoo Basin were fed by the braided fluvial systems in the study area.

The close proximity of the study area to the northern edge of the basin accounts for the subtle differences in lithostratigraphy and interpreted depositional environments when compared with more distal sites to the south. For example, glaciofluvial clastic sediment input in the lower portions of the No. 1 seam and post-Karoo erosion that has removed the overlying seams; the deltaic progradational sequence, above the No. 2 seam, occurs twice in succession and the bioturbation, that has become characteristic of sedimentary sequence of the Vryheid Formation above the No. 2 seam in the central and southern parts of the Karoo Basin, is not as identifiable. These differences are explained by the extreme proximal location of the study area on the northern basin margin relative to the remainder of the Karoo Basin.

**Key Words:** Karoo Basin, coal, peat, fluvial, deltaic
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 1</td>
<td>The Karoo Basin indicating the study area relative to the coalfields of South Africa.</td>
<td>2</td>
</tr>
<tr>
<td>Figure 2</td>
<td>Mineral rights owners for the farms across the Arnot North study area with the relevant geographic subdivisions.</td>
<td>3</td>
</tr>
<tr>
<td>Figure 3</td>
<td>Relevant geographic subdivisions showing borehole coverage of 924 boreholes.</td>
<td>4</td>
</tr>
<tr>
<td>Figure 4</td>
<td>Stratigraphic units within the Vryheid Formation in the Witbank coalfield showing lithologies, coal seams and interpreted depositional environments.</td>
<td>17</td>
</tr>
<tr>
<td>Figure 5</td>
<td>Generalised stratigraphic column at Arnot Colliery to the south of the study area.</td>
<td>19</td>
</tr>
<tr>
<td>Figure 6</td>
<td>Generalised stratigraphic column in the study area showing lithotypes, coal seams and inter-seam sequences.</td>
<td>26</td>
</tr>
<tr>
<td>Figure 7</td>
<td>Thickness frequency histogram of the diamictite-conglomerate facies.</td>
<td>28</td>
</tr>
<tr>
<td>Figure 8</td>
<td>Diamictite-conglomerate facies with pre-Karoo casts as observed in core (A) and in cross section (B).</td>
<td>28</td>
</tr>
<tr>
<td>Figure 9</td>
<td>Massive granulestone-sandstone facies showing the granulestone (A) and sandstone (B) end members.</td>
<td>30</td>
</tr>
<tr>
<td>Figure 10</td>
<td>Thickness frequency histogram of the massive granulestone-sandstone facies.</td>
<td>30</td>
</tr>
</tbody>
</table>
Figure 11 Thickness frequency histogram of the horizontally bedded granulestone-sandstone facies.

Figure 12 Tabular cross-bedded granulestone-sandstone facies as seen in core samples.

Figure 13 Thickness frequency histogram of the tabular cross-bedded granulestone-sandstone facies.

Figure 14 Thickness frequency histogram of the trough cross-bedded granulestone-sandstone facies.

Figure 15 Interlaminated sandstone-mudstone facies showing the interlaminated sandstone-mudstone in core samples (A) and in outcrop (B), wavy lamination (C) and lenticular laminated mudstone (D).

Figure 16 Thickness frequency histogram of the interlaminated sandstone-mudstone facies.

Figure 17 Soft sediment deformation has overprinted areas of bioturbation (A) although minor amounts of bioturbation are still observed (B).

Figure 18 Thickness frequency histogram of the bioturbated sandstone-mudstone facies.

Figure 19 Massive mudstone facies as seen in core samples.

Figure 20 Thickness frequency histogram of the massive mudstone facies.

Figure 21 Thickness frequency histogram of the shale facies.
Figure 22  Shale as seen and identified in core samples displaying higher fissility than the massive mudstone facies.

Figure 23  Coaly shale showing nodular pyrite (P) and oxidation (O).

Figure 24  Thickness frequency histogram of the coaly shale facies.

Figure 25  Thickness frequency histograms of the coal facies of all the seams within the study area, as well as the sub-facies, showing an abundance of dull coal and coal that has not been described.

Figure 26  The bright coal sub-facies (A) and dull coal sub-facies (B) Dull coal is the most commonly occurring coal sub-facies.

Figure 27  Arnot North area showing the elevations of the pre-Karoo basement with a general dip to the south-west. The lack of information in certain areas validates restriction of the depositional environment interpretation to the Springboklaagte area where more confidence in the borehole data is obtained.

Figure 28  Thickness frequency histograms showing the similarity between the bioturbated sandstone-mudstone facies and bright coal, dull coal and lustrous coal sub-facies of the Arnot North and Springboklaagte areas (figure 2).

Figure 29  Thickness frequency histograms showing the similarity between the non-descript coal sub-facies and the coaly shale, diamicrite-conglomerate and horizontally bedded granulestone-sandstone facies of the Arnot North and Springboklaagte areas (figure 2).

Figure 30  Thickness frequency histograms showing the similarity between the massive granulestone-sandstone, massive mudstone, shale and trough cross-bedded sandstone facies of the Arnot North and Springboklaagte areas (figure 2).
Figure 31  Thickness frequency histograms showing the similarity between the tabular cross-bedded granulestone-sandstone, interlaminated sandstone-mudstone and total coal facies of the Arnot North and Springboklaagte areas (figure 2).

Figure 32  Pre-Karoo elevation in the Springboklaagte area contoured at 2m intervals showing the limited coverage of borehole data and general north-east to south-west dip.

Figure 33  Top of Dwyka Group elevation in the Springboklaagte area contoured at 2m intervals showing the general north-east to south-west dip. The low area in the extreme north-west is a function of modeling and is not representative of borehole coverage.

Figure 34  Isopach of the No. 1 Lower-Lower seam in the Springboklaagte area contoured at 0.25m intervals showing isolated areas where this seam has developed and also pinched out against basement strata.

Figure 35  Isopach of the No. 1 Lower-Lower parting in the Springboklaagte area contoured at 0.25m intervals.

Figure 36  Isopach of the No. 1 Lower seam in the Springboklaagte area contoured at 0.25m intervals showing the thickening to the south-west. The thickening to the north-east is related to an anomalous single borehole.

Figure 37  Isopach of the No. 1 Lower parting in the Springboklaagte area contoured at 0.25m intervals showing thickening to both the north-east and the south-west.

Figure 38  Springboklaagte modelled area showing the plan view location of cross section lines and borehole coverage.
Figure 39  Cross-section AB showing the highly variable nature of the S1, S1L and S1LL in the Springboklaagte area.

Figure 40  Isopach of the No.1 seam in the Springboklaagte area contoured at 0.25m intervals showing the general thickness uniformity of the area with minor thickening to the north-east.

Figure 41  Diagrammatic representation of the typical strata comprising the No. 1 parting in the Springboklaagte sub-area from horizontally bedded granulestone-sandstone (A) to shale (G). The massive mudstone overlying and overlain by massive granulestone-sandstone (D) is the most common, while shale (G) is rarely present.

Figure 42  Diagrammatic representation of the composition and distribution of the No. 1 parting in the Springboklaagte area.

Figure 43  Isopach of the No. 1 seam sequence in the Springboklaagte area contoured at 0.5m intervals and showing thickening in the central portion.

Figure 44  Diagrammatic representation of the composition and distribution of the No. 1 parting superimposed on the No. 1 seam sequence isopach showing thinning of the coal seam below the coarser-grained facies.

Figure 45  Isopach of the No. 1 parting in the Springboklaagte area contoured at 0.25m intervals and showing a north-west to south-east trend in the central part of the area where thicknesses are greater than 2.25m.

Figure 46  Isopach of the No. 2 Select seam in the Springboklaagte area contoured at 0.25m intervals showing a well defined north-east to south-west trending zone with thicknesses greater than 3m.
Figure 47  Cross-section CD showing the laterally discontinuous nature of the No. 2 Select parting (red arrows) within the No. 2 seam.

Figure 48  Photo in the opencast operation on Springboklaagte showing the erosively-based, laterally discontinuous parting (P2S) within the No. 2 seam that is used as a marker horizon to separate the brighter, higher quality coal in the lower portion of the seam (S2S) from the dull coal in the top portion (S2T).

Figure 49  Isopach of the No. 2 Select parting in the Springboklaagte area contoured at 0.05m intervals showing the thin and erratic nature of these strata.

Figure 50  Isopach of the No. 2 Top seam in the Springboklaagte area contoured at 0.25m intervals. The erratic thicknesses are most likely caused by erosion or scouring of the peat by overlying sediments.

Figure 51  Isopach of the No. 2 seam sequence in the Springboklaagte area contoured at 0.5m intervals showing a north-east to south-west trend with slight thinning where the No. 1 parting is the thickest.

Figure 52  Stratigraphic sequence observed in the opencast operation on Springboklaagte with the No. 2 seam sequence (A) at the base overlain by the bioturbated sandstone-mudstone facies or interlaminated sandstone-mudstone facies (B). Overlying this, is a laterally persistent massive mudstone facies (C) capped by cross-bedded granulestone-sandstone (D).
Figure 53  Photo of the sharp contact observed between the No. 2 Top seam (S2T) at the top of the No. 2 seam sequence and the overlying interlaminated sandstone-mudstone (P2). This shows an abrupt termination of the No. 2 seam peat by influx of sediments.

Figure 54  Cross-section EF showing the repetition of the upward-coarsening sequence above the No. 2 seam sequence.

Figure 55  Persistent iron alteration evident in the opencast colliery on Springboklaagte that represents the weathered product of the siderite that formed as diagenetic alteration of a carbonate deposition at the edge of the basin (A). B shows the laterally restricted nature of the No. 2 Select parting.

Figure 56  Isopach of the clastic sequence above the No. 2 seam sequence in the Springboklaagte subdivision contoured at 0.5m intervals. The distinctive north-east to south-west trend coincides with thinner areas of the No. 2 seam sequence.

Figure 57  Isopach map of the No. 2 Top seam thickness and borehole positions where the base of the P2 is either a mudstone or a sandstone facies. This indicates a definite correlation between the erosive sandstone facies and the thinning of the underlying coal.

Figure 58  Graphical representation of the palaeogeographic sequence of events in the Springboklaagte sub-basin as representative of the Arnot North area.
# LIST OF TABLES

<table>
<thead>
<tr>
<th>Table I</th>
<th>Number of boreholes used per geographic subdivision.</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table II</td>
<td>Stratigraphic units of the Karoo Basin.</td>
<td>9</td>
</tr>
<tr>
<td>Table III</td>
<td>Genetic Increments of Strata in the Witbank Coalfield.</td>
<td>12</td>
</tr>
<tr>
<td>Table IV</td>
<td>Summary of the facies defined in the study area with their respective hydrodynamic interpretations.</td>
<td>23-24</td>
</tr>
<tr>
<td>Table V</td>
<td>Comparison of Anglo Coal standard description to the Wentworth grain-size classification.</td>
<td>25</td>
</tr>
</tbody>
</table>

UNIVERSITY OF JOHANNESBURG

xiii
CHAPTER 1

1 INTRODUCTION

1.1 Location and Database

The Arnot North study area is located north of the Eyesizwe-owned Arnot Colliery in Mpumalanga, South Africa. It lies within the Witbank Coalfield of the Karoo Basin (figure 1). Information for this study has been obtained from Anglo Operations Ltd as well as Xstrata Coal Ltd and the area is therefore limited to the regions where these two companies hold mineral rights and have conducted prospecting operations (figure 2). The database consists of 924 borehole logs that were personally selected from a total of 5737 boreholes. The selection criteria were the amount of stratigraphy drilled as well as the quality of the log description. In addition, 180 of these boreholes were personally logged in the field. These cored holes were used to supplement and verify the lithologies described in the existing borehole logs. Minor verification was conducted on a mini-pit opencast operation as the only source of exposure.

For ease of manageability, the study area has been further subdivided into smaller geographic sub-zones as shown in figure 2. The spatial relationship of the data within the defined zones as well as the reliability of the data is illustrated in figure 3. Table I details the number of boreholes per zone.

1.2 Dissertation Objectives and Methods

The objectives of this dissertation are:

- To document the lithologies of the Arnot North study area.
- To define, describe and hydrodynamically interpret the lithofacies types in the succession.
- To interpret depositional environments based on vertical borehole lithological descriptions and lateral 3D facies assemblages based on cross-sections and isopach plans within the study area.
Figure 1. The Karoo Basin indicating the study area relative to the coalfields of South Africa (Cairncross et al., 1990). Note that the Eastern Transvaal coalfield has since been renamed the Mpumalanga coalfield (DME, 2006) (study area marked by star).
Figure 2. Mineral rights owners for the farms across the Arnot North study area with the relevant geographic subdivisions.
Figure 3. Relevant geographic subdivisions showing borehole coverage of 924 boreholes.
Table I. Number of boreholes used per geographic subdivision.

<table>
<thead>
<tr>
<th>Geographic Subdivision</th>
<th>No. Boreholes Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belfast</td>
<td>14</td>
</tr>
<tr>
<td>Nooitgedacht</td>
<td>75</td>
</tr>
<tr>
<td>Rietvlei</td>
<td>21</td>
</tr>
<tr>
<td>Springboklaagte</td>
<td>307</td>
</tr>
<tr>
<td>Wildfontein</td>
<td>60</td>
</tr>
<tr>
<td>Wonderfontein</td>
<td>84</td>
</tr>
<tr>
<td>Zonnebloem North</td>
<td>221</td>
</tr>
<tr>
<td>Zonnebloem South</td>
<td>142</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>924</strong></td>
</tr>
</tbody>
</table>
To compare the data obtained with existing facies models and make interpretations in terms of depositional models.

The methods and data used to achieve the objectives listed above include:

- Personally logging 180 borehole cores in the field.
- Describing facies types from the borehole core in the study area.
- Personally selecting representative boreholes from a dataset of over 5000 logged boreholes.
- Personally capturing the data from 924 boreholes for use in computer modelling.
- Creating graphic representation of selected borehole logs in order to create detailed cross-sections that can be ‘hung’ on a datum representative of the base of the No. 2 seam in order to allow for correlation of seams as well as individual facies units.
- Constructing subsurface stratigraphic isopach maps of selected sedimentary packages and coal seams using Stratmodel (Mincom, 2001). Stratmodel is a layer type stratigraphic geological modelling package distributed by Mincom (Australia). It uses borehole data loaded in their correct spatial orientation with each borehole containing an appropriate set of correlated stratigraphic intervals and single surface horizons. Structural modelling of the lithostratigraphic intervals is carried out by first building a table model that interpolates missing intervals and surfaces into the loaded borehole data table according to a set of defined rules. The second step is to build a 3-dimensional grid model that interpolates the table model data into regularly spaced grid model of the specified intervals and horizons. A typical interpolator used in building the structural model is the finite element method. Thickness, trend and roof and floor surfaces are all modelled using this interpolator. Interburden thicknesses are also taken into account during the interpolation.

The limitations during the interpretation of these data include:

- Boreholes from various mining houses have been used and limited information has been recorded over the years, thus determining that lithology and grain size were the consistent factors used to determine facies types with primary sedimentary structures used when available.
An LO29 Cape Datum co-ordinate system has previously been used during the surveying of borehole collars. There has therefore been no attempt to change these into geographical co-ordinates. The geographical co-ordinates shown on figure 1 have been converted using X-Form version 4.1; a program to convert co-ordinates between the datums as well as Gauss Conform to Geographical co-ordinates and vice-versa. Due to the global nature of this program and slight errors that may be encountered at a smaller scale, all data has been kept in the originally surveyed co-ordinate system except for very recent boreholes that were converted to LO Cape datum Gauss Conform co-ordinates by a detailed programme designed specifically for the Arnot North area and using Helmert transformation parameters.

Although boreholes intersecting dolerite or displaying features often associated with faulting have been removed from this exercise, the effect of these structures on the surrounding stratigraphy in terms of displacement and increases depth of erosion. This imparts a degree of uncertainty with regard to interpretations made.

An opencast mining mini-pit has been used as an exposure site. This site was established after the bulk of the data had been processed and is therefore only used as reference. The size of the operation does not allow for large scale correlations in the stratigraphy to be made.

1.3 Regional Geology

The Karoo Basin is a south-westerly dipping, retroarc foreland basin (Cairncross and Cadle, 1988a; 1988b; Falcon, 1989; Cadle et al., 1993), bound on the south by the Cape Fold Belt and underlain in the north by the Kaapvaal Craton (Falcon, 1986a; Johnson, 1991; Cadle et al., 1993; Catuneanu et al., 1998; Cairncross, 2001; Johnson et al., 2006) and in the south by the Namaqua-Natal Metamorphic Belt. It developed in relation to the Late Palaeozoic – Early Mesozoic subduction of the palaeo-Pacific plate underneath the Gondwana plate (Catuneanu et al., 1998; 2005). In more recent times Catuneanu et al. (1998) have proposed flexural behaviour to this retroarc foreland model in explaining the deposition within the proximal and distal parts of the basin. This flexural foreland basin theory is
incorporated in later studies of the depositional environments of the sub-Saharan Karoo age basins (Catuneanu et al., 2005).

The Karoo Supergroup can be subdivided into the Dwyka, Ecca, Beaufort and Drakensberg Groups and the Molteno, Elliot and Clarens Formations. Table II defines the stratigraphic units in the north and north-eastern part of the Karoo Basin (figure 1). In general, due to the asymmetrical nature of the basin, the strata described for the main Karoo Basin thin and pinch out to the north (Grodner and Cairncross, 2003). Lateral correlation of the Ecca Group lithostratigraphic units from north to south of the basin is difficult due to irregular thicknesses and complex facies relationships (Johnson et al., 1996; Johnson et al., 1997). These complexities are related to the various modes of deposition within the Ecca, deep water vs. shallow water fluvial deltas in the north and marine turbidites and submarine fan deposits in the south (Catuneanu et al., 2005). For instance, Le Blanc Smith (1980a) notes that the Pietermaritzburg Formation is not deposited in the north of the basin and the Volksrust Formation is not present due to erosion.

The Dwyka Group consists of diamictite, conglomerate, fluvioglacial pebbly sandstone, rhythmite and mudstone with dropstones (Johnson et al., 1996). The Ecca Group consists of dark clastic sedimentary strata such as shale, siltstone, fine to very coarse, pebbly sandstone and economically significant coal in the Vryheid Formation with minor coal in the Volksrust Formation. These sediments were deposited under aqueous to sub-aqueous reducing conditions and have been interpreted as marine, lacustrine, deltaic and fluvial deposits (op. cit.). The Ecca Group attains its maximum 3000m thickness in the southern part of the Karoo Basin (Catuneanu et al., 2005) but is approximately 30m in the study area (Cairncross, 1986). The Beaufort Group and overlying Molteno, Elliot and Clarens Formations are terrestrial and consist of lighter coloured mudrocks, sandstones and occasional conglomerates (Johnson et al., 2006). In simplistic terms, this represents predominantly overbank fluvial deposition that accumulated sub-aerially under oxidising semi-arid to arid conditions (Smith et al., 1993). These upper Karoo Supergroup lithologies are characterised by terrestrial vertebrate fossils and attain a combined maximum thickness of 7000m in the main basin (Johnson et al., 1996) but also thin rapidly northwards away from the foredeep (Catuneanu et al., 2005).
Table II. Stratigraphic units of the Karoo Basin (after SACS, 1980 and Catuneanu et al., 2005).

<table>
<thead>
<tr>
<th>GROUP</th>
<th>FORMATION</th>
<th>NORTH-EASTERN MPUMALANGA / STUDY AREA</th>
<th>FACIES DESCRIPTION</th>
<th>AGE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drakensberg</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Clarens</td>
<td>not present - weathered away</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Elliot</td>
<td>not present - weathered away</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Molteno</td>
<td>not present - weathered away</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Balfour</td>
<td>not present - weathered away</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Volksrust</td>
<td>not present - weathered away</td>
<td>shale, sandstone and minor coal</td>
<td>Jurassic</td>
</tr>
<tr>
<td></td>
<td>Vryheid</td>
<td>of most significance</td>
<td>sandstone, shale and coal</td>
<td>Late Triassic</td>
</tr>
<tr>
<td></td>
<td>Pietermaritzberg</td>
<td>not present / not previously recognised</td>
<td>shale</td>
<td>Early Permian</td>
</tr>
<tr>
<td></td>
<td>Dwyka</td>
<td>present</td>
<td>tillite and varved shale</td>
<td>Late Carboniferous</td>
</tr>
</tbody>
</table>
The entire Karoo Supergroup is capped by the basaltic and rhyolitic lavas of the Drakensberg Group. The Drakensberg and Beaufort Groups as well as the Volksrust Formation have completely eroded away in the study area.

1.4 Previous Work

Cairncross (1989), in a study of the northern Karoo Basin coals, concludes that coal distribution was directly controlled by tectonic setting, the nature and palaeotopography of the pre-Karoo basement palaeotopography as well as the palaeodepositional systems associated with and following peat formation. He further concluded that coal where a suitable stable intracratonic setting allowed for peat accumulation. This concurs with the findings of Smith and Whittaker (1986a) who state that the distribution of the lower coal seams in the Vryheid Formation was initially controlled by glacial, pre-Karoo valleys and topographic highs, while that of the upper seams were controlled by the basinward migration of fluvio-deltaic progradation and distribution of pre-Karoo highs around the basin margin. Pre-Ecca erosion preserved topographic highs in the resistant felsite basement lithology and formed valleys in the easily eroded Archaean granite basement (Stavrakis, 1986). The differential compaction of fine sediment deposited over this original irregular basement topography provided further subtle controls for coal seam thickness (Cairncross et al., 1990). These palaeovalley coals were further affected by multiple seam splits produced by fluvial channels that contemporaneously occupied the lowland areas (Cairncross and Cadle, 1988a).

Broad studies of the coalfields and coal characteristics in each of the coalfields of South Africa (figure 1) were compiled by Wybergh (1925; 1922). In the late 1980’s, studies of the Karoo Basin coalfields in terms of depositional environment, lithological units, coal quality and utilisation were compiled (Anhauesser and Maske, 1986; Taverner-Smith, et al., 1988). Stratigraphically, the lithological units in the Karoo Supergroup were studied in detail and compiled into a single work in 1980 by the Geological Survey (SACS, 1980). Prior to this study, Le Blanc Smith and Eriksson (1979) documented a fluvioglacial, glaciolacustrine and deltaic depositional model for the coals within the north-eastern part of the Witbank Coalfield that remains relatively unchanged in subsequent studies (Cadle et al.,
1993). Other facies studies were undertaken applying standard facies model techniques (Walker, 1984; Walker and James, 1992) in order to interpret depositional environments of each coalfield (Cairncross and Cadle, 1988a; Roberts, 1988; Smith et al., 1993; Roberts et al., 1994; Key et al., 1998; Holzforste et al., 1999; Kosters et al., 2000).

Winter et al. (1987) and Cadle et al. (1993) divided the sedimentary environments of the Early Permian coal deposits of the Karoo Basin (figure 1) into lower and upper delta plain, backbarrier and fluvial environments. Le Blanc Smith (1980b) defined genetic increment stratigraphy for the Witbank Coalfield proposing a more detailed subdivision of the stratigraphy (Table III). In Le Blanc Smith's (op. cit.) classification the Dwyka Group is further subdivided into two genetic strata increments (GIS0 and GIS1) with massive, matrix supported conglomerates at the base representing glacial tillites (GIS0). These are overlain by glaciolacustrine deltaic and glaciofluvial outwash sediments that are broadly upward-coarsening from mudstone or siltstone to sandstone and conglomerate that may contain plant remains but does not host any coal seams (GIS1). The overlying genetic strata increment (GIS2) begins with the coalesced No. 1 and No. 2 seams, the first element of the Vryheid Formation (Ecca Group). These strata have however been split by sandstone, with subordinate siltstone and gravel or sandstone lenses, frequently as upward-fining sequences, capped by siltstone. The GIS2 is interpreted as deposits of a fluvioglacial peat swamp intercalated with in-seam siliciclastic channel-fill units.

The third genetic increment strata (GIS3) consists of the upward-coarsening siltstone and sandstone inter-seam parting between the No. 2 and No. 3 seams as well as above the No. 3 seam which are interpreted by Le Blanc Smith (1980b) as being derived from high-constructive, shallow water deltaic sedimentation that was capped by the No. 4 seam. The No. 4 seam forms part of the fourth genetic increment of strata and Le Blanc Smith (op. cit) interprets the sediment above No. 4 seam but below the No. 4 seam splits as deposited in delta plain-braided bed-load channel deposits formed within a high constructive, shallow water deltaic depositional environment (Cairncross and Winter, 1984). This is represented by a
Table III. Genetic Increments of Strata in the Witbank Coalfield (adapted from Grodner, 2001 and Le Blanc Smith, 1980a)

<table>
<thead>
<tr>
<th>Genetic Increment of Strata</th>
<th>Lithological description</th>
<th>thickness (m)</th>
<th>seams</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marker 10</td>
<td>Upper surface of No. 6 seam zone or base of carbonaceous shale or base of overlying glauconitic sedimentary rocks</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GIS 9</td>
<td>Upward coarsening sequence of shales, siltstones and sandstones terminated by the argillaceous zone that contains isolated lenses of the No. 6 seam</td>
<td>20-32</td>
<td>No. 6</td>
</tr>
<tr>
<td>Marker 9</td>
<td>Upper surface of glauconitic sedimentary rocks or Marker 8 position</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GIS 8</td>
<td>Sporadically deposited glauconitic sedimentary rocks</td>
<td>&lt;=3</td>
<td></td>
</tr>
<tr>
<td>Marker 8</td>
<td>Roof of No. 5 seam or carbonaceous shale equivalent or base of overlying glauconitic sedimentary rocks</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GIS 7</td>
<td>Upward coarsening sandstone and siltstones capped by the No. 5 seam</td>
<td></td>
<td>No. 5</td>
</tr>
<tr>
<td>Marker 7</td>
<td>Roof of glauconitic sedimentary rocks or Marker 6 position</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GIS 6</td>
<td>Glaucnitic sandstone and siltstone</td>
<td>&lt;=19</td>
<td></td>
</tr>
<tr>
<td>Marker 6</td>
<td>Roof of No. 4 Upper seam or base of overlying glauconitic sedimentary rocks</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GIS 5</td>
<td>Upward coarsening sequence of siltstone and sandstone that may be overlain by gravels, capped by the No. 4 Upper, No. 4A and No. 4B coal seams that are separated by thin sandstone and siltstone lenses</td>
<td>6-20</td>
<td>No. 4 Upper, No. 4A and No. 4B</td>
</tr>
<tr>
<td>Marker 5</td>
<td>Roof of No. 4 seam (or in shale-outs, the base of the carbonaceous shale)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GIS 4</td>
<td>Thickest localities reflect small pebbly sandstones or sandstones fining upward (abruptly) into siltstone and capped by the No. 4 seam</td>
<td>1-&gt;30m</td>
<td>No. 4</td>
</tr>
<tr>
<td>Marker 4</td>
<td>Roof of the No. 3 seam (or roof of uppermost split of No. 3 seam)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GIS 3</td>
<td>Upward-coarsening siltstones and sandstones</td>
<td>8-28</td>
<td>No. 3</td>
</tr>
<tr>
<td>Marker 3</td>
<td>Roof of the No. 2 seam (or base of shale roof beds)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GIS 2</td>
<td>Ideally a single coal zone comprised of coalesced No. 1 and No. 2 seam but frequently split by siliciclastic units of siltstone with subordinate sandstone lenses or a combination of gravel and siltstone that fines upwards to siltstone</td>
<td>1-30</td>
<td>No. 2, No. 2 Lower, No. 1 and No. 1 Lower</td>
</tr>
<tr>
<td>Marker 2</td>
<td>Floor of No. 1 seam or it's carbonaceous shale equivalent</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GIS 1</td>
<td>Mudstone and siltstone grading into conglomerates</td>
<td>&lt;=36</td>
<td></td>
</tr>
<tr>
<td>Marker 1</td>
<td>Upper contact of massive diamictite (pre-Karoo surface)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GIS 0</td>
<td>Massive matrix supported conglomerates</td>
<td>&lt;=25</td>
<td></td>
</tr>
</tbody>
</table>
single arrangement of upward-coarsening siltstone and sandstone. The various splits above the No. 4 seam (No. 4 Upper, No. 4A and No. 4 B) cap this sequence and make up the fifth genetic increment of strata (GIS5).

Glaucnitic sandstone and ripple cross-laminated siltstone above the No. 4 seam splits form the sixth genetic increment of strata (GIS6) representing sedimentation within a shoreline and barrier island setting and for which a transgressive model of delta destruction has been proposed (Winter, 1985). From the roof of the No. 4 seam splits to the roof of the No. 5 seam is the siltstone and sandstone of the seventh genetic strata increment (GIS7) that is interpreted as lagoonal and shallow-water high constructive delta-fill capped by organic peat deposits of the No. 5 seam. Above the No. 5 seam, glauconitic sandstone and siltstone is again present as GIS8.

The peat of the Witbank Coalfield No. 1 and No. 2 coal seams accumulated in post-glacial and glaciofluvial environments contemporaneously with braided fluvial systems that caused the splitting of the seams (Cairncross and Winter, 1984; Holland et al., 1989; Cairncross et al., 1990). According to Cairncross and Cadle (1988a; 1988b), the lower No. 1 coal seam originated under near-optimal conditions, in a lacustrine swamp that blanketed an underlying succession of braided and anastomosing glaciofluvial sediment that was not subjected to syndepositional clastic contamination. The overlying No. 2 coal seam peat was, however split by clastic sediments derived from braided fluvial and anastomosing channels transecting the swamp at the time of peat accumulation (Cairncross, 1980). Holland et al. (1989) concluded that, at the Middelburg Collieries, the No. 3 and No. 4 coal seam sequences represent upward-coarsening deltaic deposits. The thin, laterally discontinuous No. 3 coal seam developed in the peat swamps in a lower delta plain environment, while the No. 4 coal seam represents peat accumulation in an upper delta plain environment (Horne et al., 1978). The No. 4 coal seam is commonly split by embayments of fine-grained inter-distributary as well as fluvial channel-fill sandstone into the No. 4 Upper and No. 4 Upper A sub-seams. The No. 3 coal seam and overlying No. 4, No. 5 and No. 6 coal seams, including their clastic partings, are associated with deposition in deltaic and fluvial
environments (Le Blanc Smith, 1980b; Cairncross and Winter, 1984; Cairncross, 1989).

In a study area, directly south of the Arnot North region, Cairncross and Cadle (1987) show that at this northern extremity of the Witbank Coalfield, the Vryheid Formation is characterised by a high sandstone/siltstone ratio compared to the remainder of the Witbank Coalfield, as well as the Highveld and Mpumalanga Coalfields. The differences in the lithotypes between these areas have been attributed to the predominance of proximal bed-load fluvial and upper delta plain systems in this northern part of the Witbank Coalfield (Cairncross, 1986). From this nearby previous work, it is hypothesised that the sequences encountered within the present Arnot North area would be of similar origin, i.e. namely bedload fluvial and upper-delta plain.
2.1 Regional Stratigraphy

The Karoo Supergroup hosts all of the South African coal deposits (Snyman and Botha, 1993). Coal seams are present in this southern hemisphere basin in the Lower Permian Vryheid Formation and the Triassic Molteno Formation (Cadle et al., 1993). The lithostratigraphy of the Karoo Supergroup can be subdivided into the Dwyka, Ecca and Beaufort Groups capped by the Drakensberg Basalt Group (table II).

The Dwyka Group consists of rudaceous material of glacial origin accumulated as ground moraine and glaciomarine moraine. The Group was named for an exposure along the Dwyka River east of Laingsberg, South Africa by Dunn (1875). The Dwyka Group generally consists of diamicrite, varved shales and mudstones with dropstone pebbles as well as fluvioglacial gravel and conglomerates (op. cit.). To the north and north-east of the Karoo Basin, the Dwyka Group consists of tillite accumulated as ground moraine associated with continental ice sheets and is generally massive with occasional crude horizontal bedding (Tankard et al., 1982). Visser (1992) subdivided the Group into a northern valley/highland facies and a southern shelf facies. These subdivisions appear to correspond with the stable intracratonic platform to the north and subsiding basin to the south (Cairncross, 1989). The southern shelf facies is laterally continuous and thickens to the south where it attains a maximum of 600m to 750m (SACS, 1980). This southern facies consists of massive diamicrite with very few interbedded mudstones and clasts that are mostly distally derived (Visser, 1992). The northern valley facies generally consists of a basal diamicrite unit, a sandstone conglomerate unit associated with thin interbedded diamicrite in the middle and a dropstone argillite unit at the top.

The Ecca and Beaufort Groups can be distinguished from each other by a gradational transition from open marine deep ocean water conditions, in the south and shallow marine coastal conditions, in the north, during the Ecca Group
sedimentation; to more terrestrially dominated depositional environments during Beaufort Group sedimentation (SACS, 1980). The term “Ecca” was introduced by Jones (1867) for an argillaceous sedimentary exposure at the Ecca Pass near Grahamstown in the Eastern Cape Province, South Africa.

Generally, the Ecca Group consists of dark-grey, carbonaceous mudrocks, with lamination and displaying weathering. In the north of the Karoo Basin (figure 1), this sequence of clastic sediments, coal and minor fresh-water carbonates is subdivided into the Pietermaritzburg, Vryheid and Volksrust Formations; these units cannot be directly correlated to stratigraphic units to the south. The basal Pietermaritzburg Formation was named by Griesbach in 1871 for a city in KwaZulu Natal (SACS, 1980) but is not developed within the northern part of the Karoo Basin. This predominantly shale formation attains a maximum thickness of over 400m (SACS, 1980) and has a gradational upper contact where the sandstone/shale ratio is greater than 0.5. The overlying Vryheid Formation (previously Coal Measures/Middle Ecca after Du Toit, 1954) consists of sandstone, shale and subordinate coal beds with a maximum total thickness of 500m in the main Karoo Basin. The Volksrust Formation is a transgressive argillaceous succession that conformably overlies the Vryheid Formation and is not present in the study area. The Ecca Group is of most economic significance within the Karoo Supergroup and its detailed stratigraphically depicted in figure 4.

The coal seams within the Karoo Basin (figure 1) have been assigned to a number of coalfields (figure 1) that are mined across the northern part of the basin for power generation in the domestic market as well as for use in the steel industry (DME, 2006). However, some of the coalfields have been renamed since 1994. The Witbank Coalfield forms the northern portion of the eastern side of the Karoo Basin and is bordered to the south and east by the Highveld and Mpumalanga Coalfields (figure 1). The stratigraphic differences within the Ecca Group in the northern Highveld and central Witbank Coalfields can be directly attributed to pre-Karoo palaeotopography and in particular the fact that the former experienced greater fluvial deposition above the glacial and glaciolacustrine deposits (Winter et al., 1987).
Figure 4. Stratigraphic units within the Vryheid Formation in the Witbank coalfield showing lithologies, coal seams and interpreted depositional environments (Cairncross et al., 1990).
The Vryheid Formation (figure 4) in the north-eastern Witbank Coalfield (directly to the south of the study area) is 80m to 90m thick (Cairncross, 1986) and contains five coal seams, with the sixth coal seam present in other parts of the Karoo Basin, here being weathered away or undeveloped. These seams are numbered from No. 1 at the base to No. 5 at the top (op. cit.). The clastic partings separating these seams are predominantly sandstone and range from glacial to fluvial and deltaic in origin (Le Blanc Smith, 1980b; Cairncross and Winter, 1984; Cairncross, 1989). A single marine transgression, produced siltstone directly above the No. 2 seam, followed by a well-defined upward-coarsening succession in the area (Cairncross, 1986).

In an attempt at resource classification, Smith and Whittaker (1986b) used borehole information and quality data from operating collieries across the Witbank and Mpumalanga Coalfields to define five plies within the No. 2 seam in the Witbank area. The basal three plies of this subdivision constituted the majority of mined coal at the time, to provide low ash metallurgical coal and steam coal for the export market. From the base upwards, the plies consisted of bright coal, dull to dull lustrous coal, bright and lustrous coal mixed, dull and lustrous coal and lustrous to dull mixed coal. This zoning was observed to be less consistent elsewhere in the Witbank basin, but selective mining of the lower portion of the No. 2 seam generally took place (op. cit.). The No. 4 seam was also recognised to have importance, in terms of providing a power station feedstock, due to its thin and sporadic development (op. cit.). The limited No. 5 seam resource available for blend coking coal was described and its low swell index identified.

2.2 Stratigraphy of Arnot Colliery

Arnot Colliery is an operating colliery located in the northern Witbank Coalfield providing coal to Eskom’s Arnot Power Station, approximately 50km from Middelburg. The No. 2 seam is mined by shortwall and bord-and-pillar mining methods (Arnot Colliery, Five Year Forecast, 1998). Figure 5 is a generalised stratigraphic column of the coal-bearing sequence at Arnot Colliery immediately to the south of the study area (op. cit.).
Figure 5. Generalised stratigraphic column at Arnot Colliery to the south of the study area (after Arnot Colliery, Five Year Forecast, 1997).
The pre-Karoo lithologies consist of pink, finely crystalline felsite and greyish-green, medium to coarsely crystalline diabase that together form the undulating pre-Karoo topography upon which the Karoo sediments were deposited. Unconformably overlying the pre-Karoo surface is a conglomerate with sand and/or clay matrix containing angular pebbles, cobbles and boulders. This unit is up to two metres thick, is generally absent over palaeohighs and has been interpreted as tillite of the Dwyka Group. Conformably overlying the tillite is the Vryheid Formation, with conglomerates grading into granule-grade sandstones and minor shale lenses capped by the No. 1 seam. The No. 1 seam is not fully developed over the Arnot Colliery area attains a maximum one meter thickness but tends to shale out against pre-Karoo highs. Above the No. 1 seam, the P1 parting consists of interbedded siltstone, sandstone and granulestone capped by shale, and a maximum thickness of six metres. The overlying No. 2 seam is continuous over the Arnot Colliery area and has been sub-divided by internal partings into the No. 2 Lower (S2L), No. 2 Upper (S2U) and No. 2A (S2A) seams.

The parting between S2L and S2U consists of coarse-grained sandstone and minor siltstone lenses attaining a maximum thickness of 15m. A carbonaceous siltstone separates the S2U from the S2A. Both S2L and S2U are sometimes split by internal shale and sandstone partings into the No. 2 Lower-Lower (S2LL), No. 2 Lower-Upper (S2LU), No. 2 Upper-Lower (S2UL) and the No. 2 Upper-Upper (S2UU) seams respectively. Where not split by internal partings, the No. 2 seam attains a maximum thickness of 7m.

Overlying the No. 2 seam is an approximate 12m interbedded unit of sandstone, siltstone and shale that is capped by the No. 4 seam. The No. 4 seam occurs erratically in the Arnot Colliery area and attains an average thickness of 0.4m, and is often split by internal clastic partings into No. 4 Lower and No. 4 Upper seams. The No. 4 seam is separated from the overlying No. 5 seam by interlaminated units of siltstone and shale (Arnot Colliery, Five Year Forecast, 1998).
CHAPTER 3

3  FACIES DESCRIPTIONS

3.1  Facies Analysis

Although ‘facies’ can be applied in a genetic (e.g. fluvial facies), tectonic (e.g. molasse facies) or lithological (e.g. sandstone facies) context, its most widely accepted definition is that proposed by Moore (1949):

“Sedimentary facies is defined as any aerially restricted part of a designated stratigraphic unit which exhibits characteristics significantly different from those of other parts of the unit”.

McCabe (1987) discusses facies and facies models at length and suggests that varying degrees of success have been attained with the use of facies models and focuses on the description of Walker (1984), where a facies model can be defined as:

“A general summary of a specific sedimentary environment”.

McCabe (op. cit.) summarises this definition into a useable format, where a facies model:

- Acts as a norm, for purposes of comparison
- Acts as a framework and guide for future observation
- Acts as a predictor in new geological situations, and
- Acts as an integrated basis for interpretation of the environment or systems that it represents

Walther’s Law of correlation of facies provides information on the method used to interpret any facies succession’s depositional environment and is summarised in Prothero and Schwab (1996) as:
“Facies that occur in conformable vertical successions of strata also occur in laterally adjacent environments.”

Table IV summarises the facies defined in the study area with the various facies grain sizes based on the Wentworth grain size scale (table V) (Prothero and Schwab, 1996). The lettering coding described by Le Blanc Smith (1980a) has not been used, but lithological descriptions used as Anglo Coal standards have been used to define the facies in the study area.

Galloway and Hobday (1996) list six assessments that contribute to a successful genetic stratigraphic analysis:

1. The characteristics of the depositional basin, such as size, shape, water depth and sediment source.
2. Regional genetic stratigraphic units or depositional episodes and their depositional architecture.
3. The three-dimensional geometry of the depositional system sequence and their component facies.
4. Recurring vertical sequences within the genetic intervals and within specific facies types.
5. Vertical and lateral facies associations and cross-sectional distribution and geometry of facies sequences.
6. Internal bedding and sedimentary structures of the main facies.

Based on the information gained from borehole data as well as the assessments made of points 3 to 6, a composite stratigraphic column was generated depicting the average thicknesses of the most common lithologies within the stratigraphic succession in the study area (figure 6). The definition of the sequences in the study area is similar to that defined by Cairncross (1986) in that the main coal-bearing sequences terminate in a coal seam. There are five sequences defined in the study area; the coal bearing sequences, namely the No. 1 seam sequence and No. 2 seam sequence, are surrounded and separated by clastic partings that have also been defined. The basement sequence occurs below the No. 1 seam sequence that is separated from the No. 2 seam sequence by a clastic parting sequence.
Table IV. Summary of the facies defined in the study area with their respective hydrodynamic interpretations (continued on the next page).

<table>
<thead>
<tr>
<th>Facies</th>
<th>Thickness (m)</th>
<th>Anglo Coal Grain Size (matrix)</th>
<th>Sorting</th>
<th>Bedding</th>
<th>Structure</th>
<th>Other</th>
<th>Hydrodynamic Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>min</td>
<td>ave</td>
<td>max</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diamictite Conglomerate</td>
<td>0.02</td>
<td>2.34</td>
<td>20.41</td>
<td>very coarse to gritty sandy matrix</td>
<td>poor</td>
<td>more upward-fining than upward-coarsening but both are present</td>
<td>rapid deposition from suspended load or ablation till</td>
</tr>
<tr>
<td>Massive Granulestone-Sandstone</td>
<td>0.01</td>
<td>2.50</td>
<td>27.71</td>
<td>coarse grained to granule-grade sand</td>
<td>moderate to poor</td>
<td>more upward-fining than upward-coarsening but both are present</td>
<td>feldspathic, micaceous</td>
</tr>
<tr>
<td>Horizontally Bedded Granulestone-Sandstone</td>
<td>0.03</td>
<td>2.16</td>
<td>13.12</td>
<td>coarse to fine and occasionally granule-grade sand</td>
<td>horizontal bedding</td>
<td>mostly upward-coarsening but both gradings are present</td>
<td>unidirectional flow in the upper flow-regime by horizontal accretion of sediments</td>
</tr>
<tr>
<td>Tabular Cross-bedded Granulestone-Sandstone</td>
<td>0.07</td>
<td>3.26</td>
<td>17.20</td>
<td>very coarse sand</td>
<td>poor</td>
<td>tabular cross-bedding</td>
<td>downstream migration of 2D or straight crested sand dunes in a unidirectional current with fluctuating current velocity</td>
</tr>
<tr>
<td>Trough Cross-bedded Sandstone</td>
<td>0.87</td>
<td>1.38</td>
<td>1.88</td>
<td>Fine sand</td>
<td>well to poor</td>
<td>trough cross-bedding</td>
<td>micaceous</td>
</tr>
</tbody>
</table>
Table IV. Summary of the facies defined in the study area with their respective hydrodynamic interpretations (continued from the previous page).

<table>
<thead>
<tr>
<th>Facies</th>
<th>Thickness (m)</th>
<th>Anglo Coal Grain Size (matrix)</th>
<th>Sorting</th>
<th>Bedding</th>
<th>Structure</th>
<th>Other</th>
<th>Hydrodynamic Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interlaminated Sandstone-Mudstone</td>
<td>0.11 1.79 6.90</td>
<td>fine sand</td>
<td>moderate</td>
<td>planar cross-lamination; lenticular and flaser lamination</td>
<td>upward-coarsening is more prevalent than upward-fining sequences</td>
<td>erosive contacts at base more common than gradational</td>
<td>downstream migration of ripples in a multidirectional flow environment; alternating suspension settling (mudstone) and bedload deposition (sandstone)</td>
</tr>
<tr>
<td>Bioturbated Sandstone-Mudstone</td>
<td>0.10 1.77 5.98</td>
<td>coarse to fine sand or clay</td>
<td>moderate to well</td>
<td>mostly upward-coarsening but both gradings are present</td>
<td>when described bioturbation is vertical</td>
<td>biogenic activity preserved in rapidly moving substrate in high energy settings and low energy sand and silt</td>
<td></td>
</tr>
<tr>
<td>Massive Mudstone</td>
<td>0.01 1.54 21.0</td>
<td>clay</td>
<td>massive</td>
<td>an equal amount of sharp and gradational contacts at base</td>
<td>often carbonaceous with scattered granules, micaceous, calcitic</td>
<td>suspension settling or flocculation in a low energy environment</td>
<td></td>
</tr>
<tr>
<td>Shale</td>
<td>0.04 2.17 14.5</td>
<td>clay</td>
<td>planar horizontal laminae</td>
<td>micaceous, occasionally gritty</td>
<td>slow, steady suspension-settling in a low energy environment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coaly Shale</td>
<td>0.01 0.50 5.08</td>
<td>-</td>
<td></td>
<td>pyritic - often in the form of nodules</td>
<td>periodic suspension settling of clay in a peat swamp environment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coal</td>
<td>0.01 0.74 7.32</td>
<td>-</td>
<td></td>
<td>pyritic - often in the form of nodules</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table V. Comparison of Anglo Coal standard description to the Wentworth grain-size classification (Prothero and Schwab, 1996).

<table>
<thead>
<tr>
<th>Anglo Coal standard description</th>
<th>diameter (mm)</th>
<th>Wentworth grain-size class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gritty</td>
<td>4 2</td>
<td>granule</td>
</tr>
<tr>
<td>Very coarse</td>
<td>2 1</td>
<td>very coarse sand</td>
</tr>
<tr>
<td>Coarse</td>
<td>1 0.5</td>
<td>coarse sand</td>
</tr>
<tr>
<td>Medium</td>
<td>0.5 0.25</td>
<td>medium sand</td>
</tr>
<tr>
<td>Fine</td>
<td>0.25 0.125</td>
<td>fine sand</td>
</tr>
<tr>
<td>Very fine</td>
<td>0.125 0.0625</td>
<td>very fine sand</td>
</tr>
<tr>
<td>Clay</td>
<td>0.0625 0.0313</td>
<td>coarse silt</td>
</tr>
<tr>
<td></td>
<td>0.0313 0.0156</td>
<td>medium silt</td>
</tr>
<tr>
<td></td>
<td>0.0156 0.0078</td>
<td>fine silt</td>
</tr>
<tr>
<td></td>
<td>0.0078 0.0039</td>
<td>very fine silt</td>
</tr>
<tr>
<td></td>
<td>0.0039</td>
<td>clay</td>
</tr>
</tbody>
</table>
Figure 6. Generalised stratigraphic column in the study area showing lithotypes, coal seams and inter-seam sequences.
The sequence above the No. 2 seam has also been defined despite the absence of the No. 3 seam.

3.2 Diamictite-Conglomerate Facies

**Description**

Orthoconglomerates, by definition (Prothero and Schwab, 1996) are

‘true conglomerates’ with an ‘intact, gravel sized grain supported framework’ where the percentage matrix is 15 or less”.

As opposed to orthoconglomerates, paraconglomerates are:

‘sandstone or mudrock in which pebbles, cobbles and boulders are scattered’.

In the study area, the paraconglomerates described as tillite, diamictite or diamictitic sandstone occur in all geographic sub-divisions across the study area reaching a maximum of 20.41m in the Wildfontein geographic area (figure 2) but averaging 2.34m with a range of values as indicated in figure 7. The low count (in terms of the total number of boreholes analysed) indicates that the lateral extent of this facies is limited relative to the borehole spacing while the wide range of thicknesses and high maximum thickness indicates that this facies is very common vertically. In isolated pockets where the pre-Karoo basement is elevated, the Vryheid Formation sedimentary strata rest directly on the pre-Karoo basement with no intermediate Dwyka Group.

This facies includes sub-rounded to angular clasts consisting of pre-Karoo material that is poorly sorted in a massive (figure 8A), or occasionally interbedded, matrix of coarse-grained sand and mud. Reworked diamictite consists of diamictitic material that has been eroded and resedimented with a higher degree of sorting and occasionally displaying interbedding. The reworked diamictite class are however not imbricate. Diamictite, and reworked diamictite, (figure 8B) occur stratigraphically above the pre-Karoo and below the No. 1 seam or even the No. 2 seam. In some
Figure 7. Thickness frequency histogram of the diamictite-conglomerate facies.

Figure 8. Diamictite-conglomerate facies with pre-Karoo casts as observed in core (A) and in cross section (B) (core diameter is 75mm).
cases diamicrite also splits the No. 1 seam into a No. 1 Lower and No. 1 Lower-Lower seams. Massive mudstone occurs most often above and below the diamicrite facies. Interbedding is more prevalent to the south, together with a greater degree of sorting and coarse to medium matrix grain sizes. The facies is also occasionally described as crudely upward-fining and is mostly grey to light grey in colour.

**Interpretation**

The massive structure of conglomerates indicates a process whereby the clasts experience restrictive forces relative to each other so that they cannot respond individually to the fluid stresses (Harms et al., 1975). The prevalence of paraconglomerates indicates mass movement deposition (Prothero and Schwabb, 1996). The interbedding noted in the reworked diamicrite is a potential indicator of reworking by glacial meltwater.

### 3.3 Massive Granulestone-Sandstone Facies

**Description**

This massive facies is characterised by white to light creamy white granule sized (figure 9A) and very coarse-grained feldspathic sandstone (figure 9B) consisting mostly quartz grains, that has a moderately sorted matrix and is occasionally micaceous. Both upward-coarsening and upward-fining sequences have been described but the latter is more prevalent with erosive contacts at the base of the unit.

Although this facies occurs throughout the area it attains a maximum of 27.71m in the Zondagsfontein South area (figure 2). The average thickness of the massive granulestone sandstone facies across the study area is 2.50m with a thickness range as indicated in figure 10. The combination of a large number of borehole intersections (shown by count on figure 10) and the limited thickness of this facies indicates that it as thin bands that are widespread. This facies generally occurs, but is not limited to, the clastic strata below the No. 1 seam. It can also be found in the sequence above the No. 2 seam where it is more often enveloped by massive mudstone, coal or a combination of these and occasionally above the horizontally bedded granulestone sandstone facies.
Figure 9. Massive granulestone-sandstone facies showing the granulestone (A) and sandstone (B) end members (core diameter is 75mm).

Figure 10. Thickness frequency histogram of the massive granulestone-sandstone facies.
**Interpretation**

Homogeneous bedding may develop due to diagenetic alteration, the destruction of bedding features by bioturbation, the presence of well-sorted constituent grains or deposition by debris flow processes (Cairncross, 1986). No bioturbation is noted in the core observed but the coarse-grained nature of this facies precludes biogenic alteration. Moderate to poor sorting of particles and a massive lithology indicates rapid dumping of sediment down a steep slope, but as steep slopes were generally not present after the deposition of the diamictite facies in the Witbank coal basin (Cairncross, 1986) the deposition by debris flow processes is not favoured. Considering then the white to greyish-white colour of the massive granulestone-sandstone facies (figure 9) and the hence texturally and mineralogically relatively mature lithology, a “clean” source is proposed; the very coarse-grained Bushveld Complex granites, in the source area to the north of the basin would, have provided the granule grade quartz sediment, while the remaining feldspar and mica broke down chemically at the source to yield clay that was washed/transported further basinward. A bedload deposition is therefore favoured for the formation of the massive granulestone-sandstone facies.

The lateral continuity and vertical lack of thickness of this facies, as indicated by the count and thickness ranges in figure 10, indicate many vertical occurrences of this facies that could be related to inter-fingerling of strata at the edge of a basin where depositional environments rapidly change.

3.4 Horizontally Bedded Granulestone-Sandstone Facies

**Description**

This grey to white feldspathic sandstone facies that is coarse to fine-grained, displays horizontal bedding defined by siltstone laminae. It is moderately sorted and occasionally micaceous or sideritic. Both upward-coarsening and upward-fining sequences are described although the former is more prevalent. Erosive contacts are also more common than gradational contacts.

The horizontally-bedded granulestone-sandstone facies is laterally persistent across the study area while vertically, this gritty sandstone occurs above the
massive granulestone-sandstone facies (figure 9) in the sequence above the No. 2 seam. It attains a maximum thickness of 13.2m in the Zonnebloem South area (figure 2) and an average of 2.16m exists across the study area with a thickness range as indicated in figure 11. The low borehole count (figure 11) indicates that the facies is restricted in lateral extent to isolated areas while the broad range of thicknesses shows vertical repetition of this facies.

No core was personally observed with clearly defined horizontal bedding; hence no photograph is available for this facies.

**Interpretation**

Horizontal (or planar) bedding can form in almost all environments and under a variety of conditions; sedimentation from suspension, horizontal accretion from a moving bed due to a change in the competence of flow or encroachment into the lee of an obstacle (Prothero and Schwab, 1996). Planar bedding also forms from unidirectional current in the upper flow regime when high flow velocities have washed out bedforms (Harms et al., 1982). Sand travels in discrete thin sheets along the bed and the net sand input and vertical aggradation preserves this high energy structure. As this facies exhibits coarse grains that cannot be carried in suspension, the horizontally bedded granulestone-sandstone facies formed by horizontal accretion.

### 3.5 Tabular Cross-bedded Granulestone-Sandstone Facies

**Description**

This tabular cross-bedded granulestone-sandstone consists of light grey to greyish-white granule-sized grains, coarse-grained sandstone and minor mudstone. The angle between the foresets and bottomsets is generally low and the sets within the cross-bedding appear very similar to planar bedding due to the limited lateral range of a borehole core intersection. It is well to moderately sorted with the finer grain-sizes defining the cross-bedding (figure 12). This facies does not occur in the Wildfontein and Zonnebloem North and South areas (figure 2). A maximum logged thickness of 17.20m occurs in the Belfast geographic area (figure 2) with an average thickness of 3.26m (see figure 13 for thickness ranges). Stratigraphically,
Figure 11. Thickness frequency histogram of the horizontally bedded granulestone-sandstone facies.
Figure 12. Tabular cross-bedded granulestone-sandstone facies as seen in core samples.

Figure 13. Thickness frequency histogram of the tabular cross-bedded granulestone-sandstone facies.
the tabular cross-bedded granulestone-sandstone can be found above the massive granulestone-sandstone (figure 9) or massive mudstone in the sequence above the No. 2 seam. The increased erosion at the top of this sequence is potentially the reason for the very low count (figure 13) and hence limited lateral extent for this facies.

**Interpretation**

Tabular cross-bedding forms by the downstream migration of two dimensional, straight crested sand dunes (Harms *et al.*, 1982; Holland *et al.* 1989). These bedforms form under relatively high flow velocities in the lower flow regime (Harms *et al.*, 1982) of a unidirectional current (Prothero and Schwab, 1996). The coarser-grained foresets form in a high energy environment while the fine grained mud that is draped over the foreset requires a lower energy environment. The intercalation of these sedimentary strata indicates fluctuating current velocity.

### 3.6 Trough Cross-bedded Sandstone Facies

**Description**

Fine-grained, dark grey to brownish grey sandstone and minor amounts of mudstone form the trough cross-bedded sandstone facies, although there are only two logged intersections in the Springboklaagte area (figure 2). The maximum intersection of 1.88m and an average thickness of 1.38m exist with a range of thicknesses as indicated in figure 14. This facies is occasionally micaceous and is found directly above massive mudstone and below the bioturbated sandstone-mudstone, horizontally cross-bedded granulestone-sandstone facies or planar cross-laminated sandstone-mudstone facies above the No. 2 seam.

No core was personally observed with clearly define trough cross-bedding, hence no photograph is available of this facies.

**Interpretation**

Trough cross-bedding is formed by the downstream migration of three-dimensional, sinuous or lingoid megaripples or dunes (Harms *et al.*, 1982, Holland *et al.*, 1989) and can be found in most sedimentary environments. It is representative of a
Figure 14. Thickness frequency histogram of the trough cross-bedded granulestone-sandstone facies.
relatively high flow velocity, above the conditions which form two dimensional
dunes (op. cit.). Under these higher flow velocities, sediment is scoured from the
previous dune and deposited in the trough of the downstream dune (Miall, 2000).
The association of this facies with the tabular cross-bedded granulestone-
sandstone facies (figure 12) is explained by the continuous gradation in
stratification between tabular and trough cross-bedding corresponding to a gradual
change in current dynamics (Harms et al., 1982).

3.7 Interlaminated Sandstone-Mudstone Facies

Description
Brown to light greyish-brown mudstone and minor amounts of fine-grained
sandstone form the interlaminated sandstone-mudstone facies that can be found in
the Belfast, Springboklaagte, Wildfontein and Wonderfontein areas of the study
area (figure 2). Planar cross-laminated sandstone-mudstone facies (figures 15A
and 15B) is occasionally micaceous. Cross lamination produced by predominantly
asymmetrical ripples (figure 15C) and lenticular lamination (figure 15D) are also
evident. Flaser lamination has not been recorded in the study area but is common in
other areas of the Coalfield. Flaser lamination is recognised by isolated clay lenses
within a sandy substrate, while lenticular lamination is the opposite; “starved
ripples” contained in a predominantly muddy substrate (Nichols, 1999). The
interlaminated sandstone-mudstone facies is well to moderately sorted but as there
is often no distinction made between the type of interlamination found within the
sandstone-mudstone facies and this facies will hence not likely be used for
depositional environment interpretations.

This facies occasionally overlies the trough cross-bedded sandstone but mostly
occurs above the massive mudstone and is overlain by the bioturbated sandstone-
mudstone in the sequence above the No. 2 seam. A maximum logged thickness of
6.90m occurs in the Belfast geographic area (figure 2) but an overall average of
1.79m exists with a thickness range as indicated in figure 16. Although this figure
indicates a limited lateral extent (due to the low count), this is very likely a function
of the requirements of the logging of core during the different phases of drilling;
where the interlamination is not noted as it is not considered relevant to mining.
Figure 15. Interlaminated sandstone-mudstone facies showing the interlaminated sandstone-mudstone in core samples (A) and in outcrop (B), wavy lamination (C) and lenticular laminated mudstone (D) (core diameter is 75mm).
Figure 16. Thickness frequency histogram of the interlaminated sandstone-mudstone facies.
Interpretation

Planar laminated sandstone-mudstone forms due to the alternating sedimentation of bedload and suspended load particles and can occur in a variety of depositional environments. Cross-lamination forms in a similar manner to which cross-bedding forms, i.e. the downstream migration of sand as ripples. The term ‘lamination’ is used when the sets are less than 1cm. Deposition occurs under periodic alternations of low and very low energy conditions (Holland et al., 1989). The lenticular lamination observed (figure 15D) forms when sand is deposited in the trough as the ripples migrate across a muddy substrate (Prothero and Schwab, 1996) and indicates more mud-sized particles in suspension. Wavy lamination forms (figure 15C) where there is equal supply and alternating deposition of clay and sand.

3.8 Bioturbated Sandstone-Mudstone Facies

Description

Any sandstone-to-mudstone lithology displaying bioturbation has been grouped into the bioturbated sandstone-mudstone facies with the dominant lithology being sandstone. This facies is mostly upward-coarsening and moderately to well sorted. It is not found in the Wildfontein and Zonnebloem North areas (figure 2). The bioturbation, where described, is expressed as vertical to semi-vertical although from the core personally observed the bioturbation is rarely noticeable and is often a misnomer for soft sediment deformation (figure 17A) and has only been personally rarely observed at a very small scale (figure 17B).

In all cases the bioturbated sandstone-mudstone facies displays an erosive or sharp contact with massive mudstone as the predominant lithology found below and above this facies respectively. Coal and occasionally horizontally cross-bedded granulestone-sandstone are also found associated with this facies in the sequence above the No. 2 seam. A maximum logged thickness of bioturbated sandstone-mudstone of 5.98m exists in the Rietvlei area with an average 1.77m found across the study area. The thickness range of this facies is indicated in figure 18 and, like the interlaminated sandstone-mudstone facies, indicates a limited lateral extent of
Figure 17. Soft sediment deformation has overprinted areas of bioturbation (A) although minor amounts of bioturbation are still observed (B) (core diameter is 75mm).

Figure 18. Thickness frequency histogram of the bioturbated sandstone-mudstone facies.
this facies that is hypothesised to be related to the logging requirements for mining rather than representation of depositional extent.

**Interpretation**

Bioturbation is a collective term for the evidence of the disturbance of sediment caused by organisms living in or on the sediment that leave tracks, trails or burrows and borings as they move around creating holes for protection or sift sediment for nutrients (Nichols, 1999). Vertical burrows may represent a single trace or an arm of a U-shaped burrow. In the study area, the lack of descriptions for the bioturbation observed makes identification of the trace fossil difficult. Based on the previous work on the bioturbation identified by Stanistreet et al., (1980) in the Witbank Coalfield, the predominance of vertical to near-vertical, unbranched burrows, in the study area suggests the existence of *Siphonicnus eccaensis*, as originally defined by Stanistreet et al. (op. cit.). This ichnogenis is found ubiquitously throughout the Vryheid Formation bioturbated units in the northern Karoo Basin. These trace fossil assemblages are strongly indicative of organic activity in marine to brackish water conditions (op. cit.).

### 3.9 Massive Mudstone Facies

**Description**

Mudstone that does not display any recognisable layering or bedding has been grouped into the massive mudstone facies (figure 19). It is often carbonaceous, micaceous or calcitic and occasionally contains gritty lenses. It is found below the massive granulestone-sandstone facies (figure 9) and above the coal and interlaminated sandstone-mudstone or bioturbated sandstone-mudstone in the sequence above the No. 2 seam. It is also associated with the massive granulestone-sandstone between the No. 1 and No. 2 seams. The maximum logged intersection of 21.00m occurs in the Wonderfontein area (figure 2) but an average 1.54m is laterally persistent across the study area with a thickness range as shown in figure 20. The fact that most of the thicknesses for this facies are less than 0.5m and high count of massive mudstone indicates that this facies is thin and laterally extensive.
Figure 19. Massive mudstone facies as seen in core samples (core diameter is 75mm).

Figure 20. Thickness frequency histogram of the massive mudstone facies.
**Interpretation**

A mudstone devoid of all structure and texture is formed by either bioturbation or flocculation of silt and clay-sized particles (Prothero and Schwab, 1996). Flocculation occurs when silt and clay sized particles clump together due to electrostatic attraction of opposite charged material (op. cit.). During this process the size of the particles to be transported in suspension becomes significantly larger than the individual grains of these clumps. The flocculant settles because the velocity and viscosity of the medium is unable to support and transport the clumped material (Sabah and Erkon, 2006).

### 3.10 Shale Facies

**Description**

This mudstone displays planar horizontal laminae and is therefore termed shale. It is often micaceous and occasionally contains scattered granule-sized grains reaching a maximum thickness of 14.50m in the Wildfontein area (figure 2) and a laterally persistent average of 2.17m over the entire study area with a thickness range as indicated in figure 21. Vertically this facies is associated with the massive granulestone-sandstone facies (figure 9) and massive mudstone facies (figure 19) above and below the No. 2 seam. The shale is differentiated from mudstone by its highly fissile nature (figure 22).

Based on the fact that the mudstone has been logged as highly micaceous, together with uncertainty in the use of the sedimentological differences between shale and mudstone being recognised through all drilling / logging programs, the shale and mudstone facies have been used interchangeably in the depositional environment chapter.

**Interpretation**

Laminae in muds are formed by slow, steady suspension settling of clay and silt particles (Prothero and Schwab, 1996) in a low energy environment (Holland et al., 1989) and in this case the laminae are easily visible due to the high concentration of the sheet silicate muscovite on the bedding surfaces. The presence of pyrite
Figure 21. Thickness frequency histogram of the shale facies.

Figure 22. Shale as seen and identified in core samples displaying higher fissility than the massive mudstone facies (core diameter is 75mm).
supports the peat swamp setting which is characterised by acidic, low pH water conducive to pyrite formation.

3.11 Coaly Shale Facies

*Description*

The coaly shale facies (figure 23) consists of carbonaceous, fissile mudstone containing coal lenses and nodular and disseminated pyrite. This facies is intricately related to the massive mudstone facies (figure 19) and coal facies as well as occasionally erosively cut by the massive granulestone-sandstone facies (figure 9). It can be mostly found associated with the coal in the No. 2 Select seam or the No. 1 seam. A wide range of thicknesses have been logged (figure 24) but an average 0.50m is found across the study area and a maximum logged intersection of 5.08m that can be found in the Zonnebloem South area (figure 2).

*Interpretation*

This facies forms in a peat swamp where organic peat accumulation is sporadically interrupted by suspension settling of clay, producing the shale component. The carbonaceous content of this facies also indicates a high percentage of organic matter relative to the mudstone facies.

3.12 Coal Facies

*Description*

The coal facies reaches a maximum total thickness of 7.32m in the Nooitgedacht geographic area but averages 1.06m and has a range of thicknesses as indicated in figure 25. The massive mudstone (figure 19), coaly shale (figure 23) and coal facies are closely associated. In some instances the coal is erosively cut by the massive granulestone sandstone facies. The coal facies can be loosely divided into bright coal, dull coal and lustrous coal sub-facies where descriptions have been given. The thickness ranges of all of the sub-facies of the coal facies (figure 25) clearly show, by virtue of the relative counts, that un-described coal is most prevalent with dull coal, bright coal and lustrous coal following respectively.
Figure 23. Coaly shale showing nodular pyrite (P) and oxidation (O) (core diameter is 75mm).

Figure 24. Thickness frequency histogram of the coaly shale facies.
Figure 25. Thickness frequency histograms of the coal facies of all the seams within the study area, as well as the sub-facies, showing an abundance of dull coal and coal that has not been described.
Any coal described as bright or having greater than 60% bright material has been placed in the bright coal sub-facies (figure 26A). Bright coal is occasionally laminated and sometimes contains disseminated pyrite. It is found in all geographic subdivisions across the study area averaging 0.31m and having a maximum of 2.81m thickness in the Zonnebloem North geographic area (figure 2). Dull coal has less than 60% bright material (figure 26B) and includes coal described as dull lustrous. Dull coal is often described as gritty or granular and occasionally contains pyrite or siderite nodules. The Springboklaagte geographic area (figure 2) has a maximum dull coal thickness of 6.50m but the average across the study area is 0.69m. Lustrous coal has a waxy or silky appearance and often a conchoidal fracture. This sub-facies is often interlaminated with the bright coal sub-facies (figure 26A) and occurs throughout the study area. The maximum logged interval of 7.32m is found in the Nooitgedacht geographic sub-division (figure 2) with an overall average across the area of 0.56m. The remaining coal that has not been described or has been expressed as a non-definite combination of bright, dull and/or lustrous coal has been grouped into the coal sub-facies. This coal sub-facies has a maximum logged intersection of 5.94m in the Springboklaagte geographic sub-division and an average of 0.80m across the study area.

**Interpretation**

Coal forms from the accumulation of organic vegetation in a waterlogged swamp or marsh environment that is not subjected to large volumes of clastic influx (Dutcher, 1980; Falcon, 1986a). The preservation of organic material is enhanced by rapid descent into anaerobic and acidic conditions (Falcon, 1986a; Cadle *et al*., 1993). The coal-forming peat swamps of southern Africa were initially colonised by sub-arctic mosses to cold-temperate conifers and cool-temperate deciduous forests (Falcon, 1986a). This is opposite to the Northern hemisphere plants that flourished in a humid climate and this difference in vegetation results in generally higher inertinite content of southern African coal (Falcon, 1986a). Bituminous coal can be classified according to a number of characteristics including vitrinite reflectance, volatile matter content, reflectance, inertinite content calorific value or free swelling index (Falcon, 1986b). For the purposes of this study, the coal has only been described by visual inspection and hence vitrinite content, as representing the proportion of bright material, has been used in the classification of the coal.
Figure 26. The bright coal sub-facies (A) and dull coal sub-facies (B) Dull coal is the most commonly occurring coal sub-facies.
The brightness of coal is taken to represent the vitrinite content (Crelling, 1980; Falcon and Snyman, 1986) and hence has a higher proportion of the vitrinite maceral formed from woody tissue such as stems, bark, roots and twigs (Crelling, 1980) that have formed in aqueous reducing conditions (Falcon, 1986a; 1986b).

Due to its non-reactive nature, dull coal (figure 26B) belongs to the inertinite group of macerals that consist of organic matter that has undergone alteration under aerobic and oxidising conditions (Falcon, 1986b; Falcon and Snyman, 1986; Cadle et al., 1993). This alteration from oxidising to reducing atmosphere may have been brought about by fluctuating water levels in the swamp at the time of peat deposition (Falcon, 1986a; Falcon, 1989). This coal facies is thus interpreted to indicate a subtly changing swamp environment from tranquil, that permitted the accumulation of peat, followed by a more dynamic, but not destructive phase, where the peat was exposed to a greater degree of oxidation. This may have been caused by a drop in water level and the associated increase in oxygen in the atmosphere of formation.

The waxy or silky appearance of lustrous coal indicates that it contains the lithotype clarain, composed chiefly of exinite (Falcon and Snyman, 1986). Exinite macerals form from algae, resins, leaf cuticles and the outer cases of spores and pollens (Crelling, 1980; Falcon, 1986a). The presence of these maceral types suggests a densely vegetated area with restricted drainage that would have otherwise destroyed the algal structure and spore cases. Hydrodynamically, a tranquil, low energy environment is interpreted for this sub-facies.
CHAPTER 4

4 LITHOSTRATIGRAPHY AND FACIES ASSEMBLAGES

4.1 Introduction

The borehole coverage (figure 3) and separation of the study area into smaller sub-basins by pre-Karoo highs (figure 27) coupled with deep weathering has limited the facies interpretation to the Springboklaagte subdivision. The Belfast and Wildfontein areas are specifically excluded due to faulting with throws up to 40m in the south-east (figure 2). To support interpretation of the facies assemblages in the Springboklaagte area only and hence have more control and confidence in the interpretation, the following factors were considered:

- Springboklaagte has a denser borehole spacing (figure 3).
- An opencast exposure exists in this area to confirm correlations.
- All of the boreholes personally logged were from this area.
- The similarity in the frequency histogram plots of this area when compared to the entire Arnot North area (figures 28 - 31) also indicate that Springboklaagte (figure 2) is representative of the Arnot North area under study.

4.2 The Basement Sequence

The basement sequence constitutes all strata below any coal seam and above the pre-Karoo basement (figure 6). A major problem in defining the pre-Karoo basement was the lack of borehole intersections and this accounted for majority of the boreholes that were excluded from the modelling process. The pre-Karoo surface in the Springboklaagte area has a general north-east to south-west dip with localised highs to the south (figure 32). The portions of this plan that are not filled in represent areas where borehole spacing is too wide to interpret the pre-Karoo surface with confidence. Another reason is that the boreholes did not intersect the pre-Karoo and the model interpolators are honouring this fact by not extrapolating this surface at the borehole position.
Figure 27. Arnot North area showing the elevations of the pre-Karoo basement with a general dip to the south-west. The lack of information in certain areas validates restriction of the depositional environment interpretation to the Springboklaagte area where more confidence in the borehole data is obtained.
Figure 28. Thickness frequency histograms showing the similarity between the bioturbated sandstone-mudstone facies and bright coal, dull coal and lustrous coal sub-facies of the Arnot North and Springboklaagte areas (figure 2).
Figure 29. Thickness frequency histograms showing the similarity between the non-descript coal sub-facies and the coaly shale, diamicite-conglomerate and horizontally bedded granulestone-sandstone facies of the Arnot North and Springboklaagte areas (figure 2).
Figure 30. Thickness frequency histograms showing the similarity between the massive granulestone-sandstone, massive mudstone, shale and trough cross-bedded sandstone facies of the Arnot North and Springboklaagte areas (figure 2).
Figure 31. Thickness frequency histograms showing the similarity between the tabular cross-bedded granulestone-sandstone, interlaminated sandstone-mudstone and total coal facies of the Arnot North and Springboklaagte areas (figure 2).
Figure 32. Pre-Karoo elevation in the Springboklaagte area contoured at 2m intervals showing the limited coverage of borehole data and general north-east to south-west dip.
This basement sequence consists of the Dwyka Group tillite that conformably overlies the pre-Karoo and displays a north-east to south-west dip (figure 33), although not as steep as the pre-Karoo. This material is approximately 2.94m thick and is largely represented by the diamictite facies that is massive and matrix supported. This stratum is overlain by an approximately 20cm veneer of massive mudstone facies (figure 19) that is overlain by reworked diamictite where the angular clasts are not imbricate. The reworked material is generally arenitic and granule-rich with occasional mudstone and shale facies (figure 22) bands that result in crude horizontal bedding. This reworked tillite averages 3.09m and is crudely upward-fining.

The low count of diamictite-conglomerate intersections, coupled with the wide range of thicknesses (figure 7) implies that this facies is vertically thickened but laterally restricted at borehole spacing level (figure 3). This translates well to over-deepening by glacial erosion. The overall description of the basement sequence in the study area correlates well to the description of the first genetic strata increment defined by Le Blanc Smith (1980b) for the Witbank Coalfield (table III).

The glaciofluvial interpretation of the partings below the No. 1 seam are the result of diamictite lag deposits in the braided fluvial plains that formed to the south as the up-palaeoslope equivalents of the glaciodeltaic settings and high-constructive delta plains that are present below the No. 1 seam further basinward.

4.3 The No.1 Seam Sequence

The No. 1 seam sequence includes all strata from the lowermost seam logged up to and including the No. 1 seam (figure 6). The lowermost seam logged is the No. 1 Lower-Lower seam (S1LL) that averages 29cm and consists of dull coal (figure 26B) with occasional thin bands of bright coal sub-facies (figure 26A) at the base or roof of the seam. It occurs in isolated patches that pinch out against the basement and is anomalously thickest in the central western portion of Springboklaagte (figure 34). Overlying the No. 1 Lower-Lower seam is either the massive granulestone-sandstone facies (figure 9) or the horizontally-bedded granulestone-sandstone facies averaging 1.96m and 2.36m respectively. This No. 1 Lower-Lower
Figure 33. Top of Dwyka Group elevation in the Springboklaagte area contoured at 2m intervals showing the general north-east to south-west dip. The low area in the extreme north-west is a function of modeling and is not representative of borehole coverage.
Figure 34. Isopach of the No. 1 Lower-Lower seam in the Springboklaagte area contoured at 0.25m intervals showing isolated areas where this seam has developed and also pinched out against basement strata.
parting (P1LL) occasionally includes lenses of the diamicrite-conglomerate facies (figure 8) and is thickest in the central portion (figure 35). There is either a north to south and east to west thickness trend or a north-west to south-east thickness trend that is split into two sections. The No. 1 Lower seam (S1L) occurring above the P1LL also occurs in patches that are isolated due to basement highs and is thickest in the south-west portion of Springboklaagte (figure 36). S1L averages 36cm and consists mainly of dull coal (figure 26B) with an occasional massive-mudstone at the base. Overlying the S1L is the No. 1 Lower parting (P1L) that averages 43cm and is also restricted due to pinching out against the basement lithologies (figure 37). P1L consists mostly of massive granulestone-sandstone facies (figure 9) or massive mudstone facies (figure 19) but is also occasionally a combination of these facies with the massive granulestone-sandstone facies (figure 9) occurring both above and below the massive mudstone facies (figure 19). P1L also occasionally is described as diamicritic and is more often described as upward-fining.

The S1L is thinnest where the P1L is thickest. When comparing the isopachs however, this appears to be an anomalous case as both the S1L and P1L are thicker to the south. It can be seen from cross-section AB (figures 38 and 39), running across the southern portion of Springboklaagte from south-west to north-east, that the S1L and S1LL coalesce to the north-east.

The No. 1 seam (S1) is laterally persistent across the study area and appears relatively unaffected by the pre-Karoo basement topography (figure 32) but thins in the central portion of Springboklaagte (figure 40) and remains relatively constant to the south. The position at which the S1 thins and becomes uniform to the south can also be marked by the positioning of the thickening of the overlying clastic material. The No. 1 Lower-Lower seam and the No. 1 Lower seam consist of a higher proportion of dull coal (figure 26B) than the No. 1 seam.

4.4 The Parting between No.1 Seam and No.2 Seam Sequences

The descriptions of the parting between the No. 1 seam and No. 2 seam vary from horizontally-bedded granulestone-sandstone facies to shale facies (figure 22)
Figure 35. Isopach of the No. 1 Lower-Lower parting in the Springboklaagte area contoured at 0.25m intervals.
Figure 36. Isopach of the No. 1 Lower seam in the Springboklaagte area contoured at 0.25m intervals showing the thickening to the south-west. The thickening to the north-east is related to an anomalous single borehole.
Figure 37. Isopach of the No. 1 Lower parting in the Springboklaagte area contoured at 0.25m intervals showing thickening to both the north-east and the south-west.
Figure 38. Springboklaagte modelled area showing the plan view location of cross section lines and borehole coverage.
Figure 39. Cross-section AB showing the highly variable nature of the S1, S1L and S1LL in the Springboklaagte area.
Figure 40. Isopach of the No.1 seam in the Springboklaagte area contoured at 0.25m intervals showing the general thickness uniformity of the area with minor thickening to the north-east.
averaging 48cm and 43cm respectively (figure 41). In some cases, the massive granulestone-sandstone facies (figure 9) occurs on the top or, more often, at the bottom of this package. The most commonly observed sequence for the No. 1 parting (P1) is an average 22cm massive granulestone-sandstone sharply overlain by 39cm massive mudstone facies (figure 19) and erosively cut by a 15cm massive granulestone-sandstone facies (figure 41D).

There does not appear to be any identifiable trend in the different variations of these strata combinations within the P1 (figure 42) although the No. 1 seam sequence (figure 6) thins (figure 43) where the P1 thickens and consists of coarser sediment (figure 44). The P1 is thickest in the centre of Springboklaagte in a well-defined north-west to south-east trend (figure 45). This thicker section separates the thicker S1 (figure 40) to the north and the thicker S1L (figure 36) and S1LL (figure 34) to the south. The clear lack of any trend or lateral continuity of individual facies types of P1 (figure 42) suggest the absence of any distinctive channel system here, as opposed to other sections of the Witbank Coalfield where linear channel systems have been described (Le Blanc Smith, 1980b).

However, it is hypothesised, based on both the massive granulestone (figure 10) and massive mudstone thickness frequency histograms (figure 20); that the P1 is formed in a rapidly changing environment at the edge of the basin that would allow for thin veneers of coarse-grained sediment to be deposited in close proximity to very fine-grained sediment. The coarser sediment deposited from the northern source by deltaic processes that are rapidly replaced by the finer sediment deposition in a lacustrine environment.

4.5 The No.2 Seam Sequence

This sequence encompasses the No. 2 seam (S2) as well as an erratic intra-seam parting that splits the seam into a No. 2 seam Select (S2S) at the base, a No. 2 Select parting (P2S) and a slightly lower quality No. 2 Top seam (S2T) (figure 6).

The average thickness of the S2S is 3.65m; it is uniformly thick with isolated patches of thinner material to the south (figure 46) generally coinciding with thicker
Figure 41. Diagrammatic representation of the typical strata comprising the No. 1 parting in the Springboklaagte sub-area from horizontally bedded granulestone-sandstone (A) to shale (G). The massive mudstone overlying and overlain by massive granulestone-sandstone (D) is the most common, while shale (G) is rarely present.
Figure 42. Diagrammatic representation of the composition and distribution of the No. 1 parting in the Springboklaagte area.
Figure 43. Isopach of the No. 1 seam sequence in the Springboklaagte area contoured at 0.5m intervals and showing thickening in the central portion.
Figure 44. Diagrammatic representation of the composition and distribution of the No. 1 parting superimposed on the No. 1 seam sequence isopach showing thinning of the coal seam below the coarser-grained facies.
Figure 45. Isopach of the No. 1 parting in the Springboklaagte area contoured at 0.25m intervals and showing a north-west to south-east trend in the central part of the area where thicknesses are greater than 2.25m.
Figure 46. Isopach of the No. 2 Select seam in the Springboklaagte area contoured at 0.25m intervals showing a well-defined north-east to south-west trending zone with thicknesses greater than 3m.
P2S. There are up to five bands of dull and bright coal facies (figure 26A and 26B) evident that appear to coincide to the zones described by Smith and Whittaker (1986b), Cairncross (1986) and Cairncross (1990); however they are rarely logged and could not be successfully correlated in the study area. As a generalization the most noticeable differences in the coal that could be correlated is an average 45cm bright coal sub-facies (figure 26A) underlying an average 2.62m dull coal sub-facies (figure 26B). The shale facies (figure 22), coaly shale facies (figure 23), bright coal sub-facies (figure 26A) and occasionally massive or horizontally-bedded granulestone-sandstone facies lenses occur within the S2S but do not form laterally continuous partings that can be correlated in the study area.

These thinner, isolated partings within the No. 2 seam are typically erratic and occur as lenses of coaly shale, shale or massive mudstone within the coal. This is consistent with modern-day peat swamps that often have irregular surfaces with isolated, ponded areas in which sediment accumulates (Cairncross, pers. comm. 2007). These are sites of fine grained clastic deposition that produce isolated, irregular clastic lenses within the coal. The coarse-grained partings within the No. 2 seam sequence (figure 6) are the proximal trunk streams that bifurcated basinward into anastomosed channels.

The P2S is one such erratic parting (figure 47) that is relatively thin and occurs as laterally discontinuous, isolated lenses (figure 48) within the coal. It consists of the massive granulestone-sandstone facies (figure 9) or massive mudstone facies (figure 19) with a maximum logged thickness of 1.86m but averaging 26cm (figure 49) and represents a period of widespread clastic input via a low sinuosity fluvial system. Where the position of this parting has been observed, there is a marked difference in the quality between the overlying and the underlying coal seams. This quality variation has been used to correlate this parting across the areas where the clastic sediment has not been deposited.

The top portion of the S2 is the No. 2 Top seam (S2T) and has an average thickness of 1.18m in the Springboklaagte area but appears patchy due to areas of deep weathering (figure 50). It is due to this weathering that a definite trend can not be identified.
Figure 47. Cross-section CD showing the laterally discontinuous nature of the No. 2 Select parting (red arrows) within the No. 2 seam.
Figure 48. Photo in the opencast operation on Springboklaagte showing the erosively-based, laterally discontinuous parting (P2S) within the No. 2 seam that is used as a marker horizon to separate the brighter, higher quality coal in the lower portion of the seam (S2S) from the dull coal in the top portion (S2T).
Figure 49. Isopach of the No. 2 Select parting in the Springboklaagte area contoured at 0.05m intervals showing the thin and erratic nature of these strata.
Figure 50. Isopach of the No. 2 Top seam in the Springboklaagte area contoured at 0.25m intervals. The erratic thicknesses are most likely caused by erosion or scouring of the peat by overlying sediments.
Considering the No. 2 seam sequence (figure 6), there is a north-east to south-west trend in the thickness with a patchy distribution in the south (figure 51). This appears to be a function of the interpolation of data at the specific drilling density in the area to the south and not represent a change in depositional environment or conditions.

4.6 The Stratigraphy above the No.2 Seam Sequence

The facies succession located directly above the No. 2 seam has been termed, for ease and convenience despite the absence of the No. 3 seam. The loss of core during drilling and the increased depth of erosion and weathering in the Springboklaagte area have however made further correlation above the previously described P2 unit unreliable. The No. 2 parting (P2) and consists, almost uniformly, of 52cm massive mudstone facies (figure 19) that is erosively overlain by either the interlaminated or the bioturbated sandstone-mudstone facies (figure 17). This is in turn overlain by a massive mudstone and/or shale facies (figure 22) unit that averages 7.73m. This is overlain by either 3.51m of horizontally-bedded granulestone-sandstone facies or 5.45m of massive granulestone-sandstone facies (figure 9) and 6.45m cross-bedded granulestone-sandstone (figure 52).

Although not occurring in exactly the same order, the overall stratigraphy of the study area is similar to the one described by Cairncross (1986), with the exception that all contacts are either erosive or sharp (figure 53). A vertical repetition of the upward-coarsening strata above the No. 2 seam (figure 54) also differentiates the study area from the remainder of the Witbank Coalfield and the bioturbation seen is not as distinctive or prevalent in the study area. Cairncross (1986) describes, for the region directly south of the study area, a very clear upward gradation from highly carbonaceous siltstone into interlaminated sandstone-siltstone to fine- to medium-grained cross-laminated sandstone and finally coarse- to very-coarse grained cross-bedded sandstone above the No. 2 seam. Cairncross (op. cit.) also notes a distinctive cross laminated medium-grained sandstone-siltstone at the base of the P2 containing cross- and lenticular lamination. The bioturbated zones are also noted by Cairncross (op. cit.) to occur in the bottom 8m of this sequence.
Figure 51. Isopach of the No. 2 seam sequence in the Springboklaagte area contoured at 0.5m intervals showing a north-east to south-west trend with slight thinning where the No. 1 parting is the thickest.
Figure 52. Stratigraphic sequence observed in the opencast operation on Springboklaagte with the No. 2 seam sequence (A) at the base overlain by the bioturbated sandstone-mudstone facies or interlaminated sandstone-mudstone facies (B). Overlying this, is a laterally persistent massive mudstone facies (C) capped by cross-bedded granulestone-sandstone (D) (vertical scale is approximately 25m).
Figure 53. Photo of the sharp contact observed between the No. 2 Top seam (S2T) at the top of the No. 2 seam sequence and the overlying interlaminated sandstone-mudstone (P2). This shows an abrupt termination of the No. 2 seam peat by influx of sediments.
Figure 54. Cross-section EF showing the repetition of the upward-coarsening sequence above the No. 2 seam sequence.
A thin band of strata that is purplish red and is interpreted to be a post-depositional weathering effect due to alteration of iron carbonate-rich sediment is evident in the strip mining exposed at Mafube Colliery in the southern portion of the Springboklaagte sub-division. This lithology has been personally observed in the boreholes drilled. It occurs in the massive granulestone-sandstone facies (figure 9) found at the top of the P2 and occasionally in the interlaminated or bioturbated sandstone-mudstone facies (figure 17) unit directly above the No. 2 seam (figure 55). It has undergone extensive weathering but is consistent enough to be used as a cut-off for the P2 description for the purposes of this study. This stratum, in the study area, correlates to the laterally persistent carbonate alteration to the south of the study area (Cairncross, 1986) and is consistent with primary carbonate precipitation and secondary diagenetic alteration resulting in extensive siderite formation occurring in the siltstone in the sequence above the No. 2 seam.

The isopach of the P2 (figure 56) shows thicker units in the north-east and south-west portions. This coincides with the thinner portions of the No. 2 seam sequence (figure 51). Figure 57 gives an indication of the lithology in the roof of the No. 2 seam and shows that there is a definite thinning of the No. 2 Top seam (figure 50) in the areas where the roof material is composed of the coarser grained sediments that erosively cut into the coal seam.
Figure 55. Persistent iron alteration evident in the opencast colliery on Springboklaagte that represents the weathered product of the siderite that formed as diagenetic alteration of a carbonate deposition at the edge of the basin (A). B shows the laterally restricted nature of the No. 2 Select parting.
Figure 56. Isopach of the clastic sequence above the No. 2 seam sequence in the Springboklaagte subdivision contoured at 0.5m intervals. The distinctive north-east to south-west trend coincides with thinner areas of the No. 2 seam sequence.
Figure 57. Isopach map of the No. 2 Top seam thickness and borehole positions where the base of the P2 is either a mudstone or a sandstone facies. This indicates a definite correlation between the erosive sandstone facies and the thinning of the underlying coal.
CHAPTER 5

5 DEPOSITIONAL ENVIRONMENTS

5.1 Introduction to Depositional Models

Early work on the coalfields of South Africa, involved facies studies in order to define the stratigraphy of the six coal seams and their interburdens (Wybergh, 1922; 1925).

Le Blanc Smith and Eriksson (1979) concentrated on the No. 1 and No. 2 seam in the Witbank Coalfield and confirmed a paraglacial sedimentation model where frequent floods followed glacial retreat resulting in maximum sedimentation rate and active delta progradation. The rate of sediment influx then slowed due to vegetation encroachment and the stabilisation of sediment resulting in the progressive abandonment of the delta plain and the formation of vegetated swamps. Sedimentary influx was restricted to a network of anastomosing channels that drained the No. 2 seam peat swamp (Cairncross, 1979). Using subsurface investigations for facies analysis, Holland et al., (1989) deduced that the No. 1 and No. 2 seams were deposited in glacial to glaciofluvial environments, while the sequence above the No. 2 seam is characterised by sediments deposited in a deltaic sequences by coarse-grained, upward-coarsening sequences. This interpretation is consistent with the interpretations of Le Blanc Smith (1980b), Cairncross and Winter (1984), Cairncross (1989) and Cairncross et al (1990).

Holland et al. (1989) further identified the No. 1 Lower seam, which is separated from the No. 1 Upper seam (previously No. 1 seam) by a 1.5m upward-fining sequence interpreted as a bedload fluvial channel that locally contains a 20 to 30cm sandy siltstone parting. The No. 1 Upper seam is separated from the No. 2 seam by a three to four metre thick upward-fining bedload fluvial sandstone parting that may contain an upward-coarsening bioturbated crevasse splay. The six metre parting splitting the No. 2 Lower from the No. 2 Upper seams consists of bedload fluvial conglomerate overlain by sandstone and capped by siltstone. Interlaminated
siltstone and sandstone-siltstone within this parting represents periodic low energy still-stands in channel flow.

Cairncross and Cadle (1987) further correlated syn-depositional intra-seam and inter-seam splits and plies in the coal seams; the No. 1 seam has a brighter ply at the base and a dull coal sub-facies at the top, a 2m sandstone parting separates the No. 1 seam from the No. 2 seam and the No. 2 seam consists of 5 plies. These plies are differentiated as a lowermost bright coal, dull coal, cross-bedded granulestone-sandstone to very coarse-grained sandstone parting that can be up to 15m thick, followed by bright coal and capped by a dull coal. The basal two plies constitute the No. 2 Lower seam and the upper two plies the No. 2 Upper seam. The vertical decrease in coal quality in the No. 2 seam in the north-east is attributed to the elevated basement palaeotopography and increased parting thickness that, together with fluctuating water table levels, resulted in variations in the peat oxidation and hence coal quality (Cairncross, 1986). Syn-depositional inorganic contamination and dilution from clastic influx would also result in a lower quality coal (Cairncross et al., 1990).

Cairncross (1986) and Cairncross and Cadle (1987) undertook a facies analysis of the Vryheid Formation directly south of the present study area and concluded that the succession is reduced in thickness to approximately 80m (figure 4). This area is further characterised by a higher sandstone/siltstone ratio than in the central Witbank Coalfield. Furthermore, the clastic sequence below the No. 1 seam is much thinner and less complex consisting of massive and cross-bedded granulestone and sandstone. Cairncross (1986) also observed that the sequences above the No. 3, No. 4 and No. 5 as well as below the No. 1 seams all consist of coarse-grained clastic sandstone and granulestone and interpreted these as low sinuosity bedload dominated fluvial systems. In this north-eastern part of the basin, there is a significant absence of glauconitic sandstone or siltstone above the No. 4 and No. 5 seams and this is attributed to the predominance of fresh water fluvial deposits as opposed to marine transgressive sequences (op. cit.).

Cairncross (1990) summarised the previous work completed on sedimentary depositional environments within the northern Karoo Basin coalfields (figure 1) and
geographically groups the coals of the Witbank, Highveld and Mpumalanga Coalfields together in the extreme northern proximal region of the basin. The depositional environments in the proximal region constitute basal coals overlying post-glacial reworked tillite, glaciofluvial outwash braidplain conglomerates and sandstones and minor glaciolacustrine and glaciodeltaic sequences (Cairncross, 1979; Le Blanc Smith and Eriksson, 1979). Coals overlying the glaciogenic strata are often interbedded with lobate delta and bed-load (braided) fluvial sequences (Winter, 1985; Cadle and Cairncross, 1993).

Based on these findings, to the south of the study area, it can be expected that the depositional sequences present within the Arnot North study area would be a combination of fluvial and deltaic depositional sequences as well as glacial at the base of the succession. Due to the extreme proximity of the study area to the sediment source, braided systems are far more likely to be present than the meandering rivers. A typical sandy bed load fluvial deposit is defined by Walker (1984) as either meandering or braided, where high slopes, coarser load and more easily eroded banks together with rapid fluctuations in discharge rate result in braided rivers often forming upstream to meandering rivers. Some typical features of a braided bedload system include trough cross-bedded sandstone and planar tabular cross-bedded sandstone facies. A deltaic sequence is wave, river or tide dominated but in the study area, considering the low palaeotopographic relief and distance to the northern edge of the basin, river dominated deltas were more prevalent. River dominated deltas are most easily defined by measuring the total sandstone/shale ratio in a stratigraphic unit where areas of high sandstone content representing lobate areas perpendicular to the basin margin and corresponding to the principal path of deltaic progradation (Galloway and Hobday, 1996).

### 5.2 Glacial Facies Assemblages

When a glacier reaches continental proportions, the glacial deposits formed are dependant on whether or not the ice sheet is thin, inactive and frozen to the substrate or a wet based margin where the glacier continues to slide and abrade over the bedrock (Walker, 1984). The thin, inactive glacier substrate is aggregated in situ as the sediment-laden ice base melts and the englacial debris is
resedimented downslope by sediment gravity flows into local depressions *(op. cit.)*

A typical profile in this environment would consist of underlying bedrock rafts overlain by crudely stratified diamictite and capped by resedimented massive, graded or stratified diamictite or reworked diamictite interbedded with glaciofluvial and glaciolacustrine deposits (Eyles and Eyles, 1992). In a wet based margin the debris is transported within the basal layer resulting in intense abrasion between the particles and the base layer in the traction zone. The clasts show a strongly preferred direction when deposited as massive lenticular beds of dense overconsolidated diamict (Walker, 1984). In a glaciofluvial environment the continental ice sheet meltwater drains as braided outwash plains that rework the glacial debris in typically braided channels of low sinuosity due to the abundance of coarse bedload material (Walker, 1984). The depositional sequence would consist of coarse grained, crudely bedded or massive proximal outwash gravels that are typically upward-fining *(op. cit.)*.

Over-deepening by glacial erosion and the release of large volumes of meltwater results in lacustrine ponding while narrow ‘alpine’ basins in areas of high relief and isostatically depressed continental interiors evacuated by ice sheets also result in glaciolacustrine environments. Two types of glaciolacustrine environments exist, namely periglacial and proglacial. A periglacial lake is not in direct contact with the ice margin and is fed by braided streams. Sedimentation in periglacial lake environments is dominated by rapid growth of arcuate delta lobes forming normal graded sequences where bioturbation and trace fossils are commonly present (Walker and James, 1992). Diamict is a minor component in the periglacial environment with graded and stratified diamict occurring as thin channelised lenses within a predominantly deltaic sequence. Varved clay and silt is characteristic of a periglacial environment. Sedimentation in proglacial lacustrine environments occurs in low relief areas and the sediment is derived from direct contact with the ice margin where substantial sediment is derived from meltwater conduits and subaqueous fans (Walker, 1984). Proglacial sequences are characterised by upward-coarsening, ripple laminated or planar and trough cross-bedded sands. Laminated silt and clay of turbiditic origin containing dropstones and occupying broad channels is also a feature of proglacial lakes.
The massive and matrix-supported nature, crudely upward-fining, reworked diamictite (figure 8) in the basement sequence resembles the typical profile described by Walker (1984); hence the basement sequence (figure 6) is interpreted to be glacial in origin. The lowermost diamictite-conglomerate facies may be a result of the aggregation of englacial debris from the glacier to the north that has been resedimented downslope. The absence of any striations or imbrication of clasts indicates that the glacier was frozen to the substrate and meltwater originated from the ice base of the glacier. The overlying reworked diamictite that is crudely upward-fining and occasionally horizontally-bedded, resulted from morainal sediments reworked and deposited in a glaciofluvial or glaciolacustrine environment (Cadle et al., 1993; Le Blanc Smith and Eriksson, 1979). Although a proglacial lacustrine environment could have resulted in the reworked diamictite and massive granulestone-sandstone facies (figure 9) above the Dwyka tillite, laminated silts and clays with dropstones are not evident and neither are upward-coarsening sequences. A periglacial lacustrine environment of deposition is therefore inferred despite the lack of obvious bioturbation.

5.3 Fluvial Facies Assemblages

Le Blanc Smith (1980b) groups the No. 1 and No. 2 seams as well as all of the intra- and inter-seam partings into a fluvioglacial setting where the clastic parting between these seams was deposited as intercalated siliciclastic channel-fill by fluvioglacial action between two major peat swamps. The partings within the No. 2 seam have been interpreted as being slightly sinuous bed-load fluvioglacial systems and/or anastomosing fluvioglacial deposits (Le Blanc Smith and Eriksson, 1979; Cairncross, 1980; 1986; Cadle, 1995). The more proximal to the edge of the basin, the larger the fluvial system; Le Blanc Smith and Eriksson (1979) and Cairncross (1986) document a definite trend from proximal, large-scale bed-load slightly-sinuous channels, narrowing and bifurcating down-dip into a network of interconnected anastomosed channels with low width-to-depth ratios (Cairncross et al., 1988). Braided fluvial systems differ from meandering fluvial systems in that there are rapid discharge fluctuations, a greater absolute lateral magnitude, steeper depositional slopes, coarser loads that are easier to erode than meandering rivers with no clay plugs from ox-bow lakes or levees (Miall, 2000). Braided rivers also
have multiple channels of variable depth and width, although width-to-depth ratios are characteristically high, often 100:1 or greater (op. cit.). Furthermore, anastomosed channels are common in peat swamps that are undergoing limited drainage (Smith, 1976; 1986; Smith et al., 1997; Makaske, 2001)

Bars in braided rivers tend to occur within the channel as longitudinal and transverse bars that start as a nucleus of the coarsest bedload fractions deposited in mid-channel, as flow diminishes they grow by addition of finer sediment in a downstream direction (Leopold and Wolman, 1957). Although many sedimentary structures are not defined in the partings within and between the No. 1 and No. 2 seam sequences (figure 6) the massive mudstone surrounded by coarse-grained sandstone or grit with sharp contacts is very distinctive. Based on the thin, laterally continuous nature of these strata, the sediment may have been deposited in a shallow, wide braid plain transporting coarse clastic sediments.

The laterally discontinuous nature of the P2S (figure 48), the upward-fining gradation and having both very coarse-grained to fine grained particles, results in the interpretation of a fluvial channel that invaded the peat swamp and is preserved as the P2S massive granulestone-sandstone facies (figure 9) in the channel areas and massive mudstone facies (figure 19) in the flood plain areas between the channels (Le Blanc Smith, 1980b). Where this P2S parting has not been logged represents areas away from the fluvial influx where no clastic sediment was deposited.

5.4 Deltaic Facies Assemblages

Previous studies in the Witbank (Cairncross, 1979; Le Blanc Smith, 1980b), Highveld (Winter, 1985; Cadle, 1995) and Mpumalanga (Greenshields, 1986) Coalfields have interpreted a shallow water high constructive progradational deltaic depositional environment where fluvial processes dominate over basinal processes, for the strata above the No. 2 seam.

Deltas are partly sub-aerial deposits formed around the point where a river flows into or against a standing body of water. The distribution, orientation and internal
geometry of a delta are dependent on climate, water discharge, sediment load, river mouth processes, waves, tides, currents, winds, shelf slope, tectonics and the geometry of the basin. The climate, water discharge rate and variability as well as sediment load quality and grain size determines the variability of the sediment input (Walker, 1984). In temperate or post-glacial climatic regimes, such as expected for South African coals, (Falcon, 1986a) precipitation is erratic and vegetation is sparse resulting in larger bed-loads and braided river patterns where mechanical weathering dominates over chemical weathering resulting in an increase in feldspathic sandstones.

River dominated deltas form distributary channels perpendicular to the coastline where rapid seaward progradation of the distributary mouth bars form characteristically fluvially dominated sequences associated with sub-aqueous levees. The main sedimentary load is deposited as the distributary mouth bar that fines seaward (Nichols, 1999). A river-dominated delta succession is an upward-coarsening sequence characterised by high-angle cross-beds and a unimodal palaeocurrent direction. They tend to form more rapidly and therefore have less bioturbation and relatively poor sediment sorting. The rapid loading of sand onto unconsolidated pro-deltaic muds results in convolute bedding preserved as mud lumps and diapers. The lithostratigraphic units present from bottom to top within a river dominated delta are (Walker, 1984):

- Pro-delta organic rich clay that may be laminated and sparsely fossiliferous
- Interbedded clay and silt or fine sand with small scale ripple marks and bioturbation
- Distributary mouth sand bars and sheet sands with planar and trough-cross beds and ripple marks and strong unimodal current indicators. Organic remains other than fragmented and transported debris are rare.
- Delta marsh sediments, including palaeosols and distributary channel sands that may be of finger or shoestring shape.
- Coal beds cap river dominated delta successions.

The overall upward-coarsening trend in the sequence above the No. 2 seam and the comparison to the river dominated delta facies description above supports a
progradational river dominated delta environment (Walker, 1984) for the P2. The significantly sharper contacts between the lithologies in the study area and the lesser occurrence of the ubiquitous *Siphonicnus eccaensis* ichnogen, when compared to the remainder of the Witbank Coalfield may be explained due to the proximal nature of the study area to the northern sediment source area and hence dominance of the river in this part of the delta. Distributary channels in river dominated deltas tend to deliver sediment in pulses that are flood related (*op. cit.*) and hence result in the sharp contacts between the facies types (figure 53).

The massive-mudstone at the base of the P2 represents the fine sediments deposited in the prodelta overlain by the distal mouth bar sediments making up the interlaminated sandstone-mudstone facies (figure 15) or bioturbated sandstone-mudstone facies (figure 17) in the study area. This is composed of alternating bedload traction fine sand, interlaminated with thin clay or silt layers settled from suspension (Walker and James, 1992; Galloway and Hobday, 1996). There is a repetition of this delta progradation in the study area where the delta becomes abandoned and prodeltaic muds overlie this interlaminated or bioturbated facies as a thick transgressive massive mudstone facies (figure 19) that is usually observed directly above the No. 2 seam (figure 54). These sediments are overlain by distal mouth bar coarser sands and progressively overlain by distributary channel fill sands (Nichols, 1999) as described in the remainder of the Witbank Coalfield.

### 5.5 Palaeogeographic Synthesis

The sequence of depositional events that took place in the current study area can be classified into a number of terrigenous clastic pulses punctuated by periods of non-clastic deposition and peat accumulation resulting in the formation of coal seams (Falcon, 1986a). These pulses are summarised in figure 58.
Figure 58. Graphical representation of the palaeogeographic sequence of events in the Springboklaagte sub-basin as representative of the Arnot North area.
Following the retreat of the Permo-Carboniferous main ice sheets (Stratten, 1968; Crowell and Frakes, 1975), the study area was still affected by a relatively stable ice sheet that allowed the contaminated ice base to melt and the grounded moraine of angular pre-Karoo clasts and fine-grained sediments to be resedimented downslope to the south. This formed the Dwyka Group diamictite-conglomerate facies (figure 8). Continued retreat of the ice sheet and the outflow of meltwater reworked coarse sand and gravel in glaciofluvial channels (Cadle et al., 1993) depositing reworked Dwyka Group tillite and constructing a new basement topography. Areas of low relief in this basement topography (figure 32) were loci for periglacial meltwater lakes where peat swamps that later formed into the No. 1 Lower-Lower (figure 34) and No. 1 Lower (figure 36) seams accumulated (op. cit.). Contemporaneous with the formation of the periglacial lakes, glaciofluvial sediment was brought into the basin from the north by meltwater forming the partings that separate these lowermost coal seams.

Le Blanc Smith and Eriksson (1979) mapped two major glaciofluvial entry points into the basin, one west of the present-day Witbank and one between Witbank and Middelburg. Cairncross (1986) and Cairncross and Cadle (1988b) document a third major entry point for clastic material into the Karoo Basin (figure 1) for the area directly south of this study area. The relatively small amount of glacial material within the P1LL and P1L, as opposed to well-sorted granulestone-sandstone, indicates that a third source entry point is relevant here as well. The presence of both north-south and east-west trending channels within the P1L is an indication of this third clastic material source, possibly located westwards of the basin. This entry point was therefore an area similar to that described by Le Blanc Smith and Eriksson (1979) located west of Witbank. The units below the No. 1 seam are therefore a combination of glaciofluvial and proximal low-sinuosity bed-load fluvial deposits feeding more distal deltaic and lacustrine systems to the south.

High water tables from glacial retreat and continued seasonal runoff would have allowed for sustained plant growth bordering the alluvial outwash plain. This together with the abandonment of the river system, perhaps by upstream divergence, and the resultant reduction in clastic input followed by the encroachment of vegetation and accumulation of peat, gave rise to the No. 1 seam
The No. 1 and No. 2 seams coal were autochthonously derived (Cairncross, 1979; Le Blanc Smith, 1980b; Winter, 1985; Stavrakis, 1989; Cadle, 1995). There is overwhelming sedimentological and petrological evidence for this (Falcon and Snyman, 1986), notwithstanding highly selective alternative petrographic evidence that suggest the peats were hypoautochthonous-allochthonous (Glasspool, 2003).

A brief period of instability related to either short lived basin subsidence and/or transgression, caused drowning of the No. 1 seam peat (Cairncross, 1986) and formation of the parting between the No. 1 and No. 2 seam sequences. Coarse to very coarse-grained sand and granule grains were subsequently transported into the basin from a northern source, across the No. 1 seam peat swamp and deposited in a thin, laterally persistent veneer. This was overlain by a massive mudstone facies (figure 19) that was probably deposited as relative stability was returning to the basin but a second clastic pulse occurred depositing another unit of coarse to very coarse-grained sediments above this shale (figure 41D). The absence of the coarse-grained material at the base and top of this unit in some instances indicates that the periods of instability were not widespread and are therefore more representative of short lived transgression related to storm events where volumes of water and sediment influx could have been greatly increased to form the coarser units. The fine-grained unit in the middle of the parting represents a period of lower energy and settling between the storm events.

Swamp impingement followed, with the simultaneous reduction in the clastic input into the basin giving rise to increased vegetation and the deposition of the No. 2 seam peat. This peat swamp was periodically inundated with clastic sediment resulting in numerous laterally continuous and discontinuous partings. Although not laterally persistent, the P2S (figure 48) can be correlated across the interpreted area and represents a period of widespread clastic input via a low sinuosity fluvial system. These fluvial channels correlate to the smaller scale fluvial channels are interpreted by Le Blanc Smith and Eriksson (1979) and Cairncross (1979; 1980) as anastomosed river deposits, as defined by Smith (1976; 1986). The larger-scale braided channel that splits the No. 2 seam into a No. 2 Upper and No. 2 Lower portion in the area to the south (Cairncross, 1986) is not observed in this study.
area. In addition to the P2S, isolated small-scale clastic partings randomly occur in the seam. They resulted from either overbank flooding from the fluvial channels forming coarse-grained partings or deposition of suspended sediment in ponded areas in the peat swamp forming the finer-grained sediment partings.

Gradual drowning of the No. 2 seam swamps by basin subsidence or transgression (Cairncross, 1986) explains the decrease in the quality of the coal and the transition of the uppermost peat into carbonaceous mudstone in places. Unlike the areas previously studied in the remainder of the Witbank Coalfield, a laterally persistent coarse-grained interlaminated or interbedded sandstone-mudstone facies (figure 15) overlies this peat swamp. This is capped by a larger scale repetition of the same upward-coarsening sequence that consists of massive mudstone facies (figure 19) or shale facies (figure 22) overlain by massive granulestone-sandstone facies (figure 9) or cross-bedded granulestone-sandstone facies. This second succession in the sequence above the No. 2 seam concurs with the previous descriptions of this interval above the No. 2 seam in the remainder of the Witbank Coalfield. The clastic sequence above the No. 2 seam is therefore also interpreted as a regressive deltaic progradation that is repeated in the study area due to its proximal location. The altered carbonate to siderite that is highly weathered in this study area and described in the area to the south by Cairncross (1986) re-occurs in the sequence above the No. 2 seam in the coarser-grained upper portions of the upward-coarsening sequences (figure 55) and supports the interpretation that a repetition of the deltaic progradational sequence.
CHAPTER 6

6 SUMMARY

A lithostratigraphic and sedimentological investigation of the Early Permian Vryheid Formation in the most proximally located colliery in the northern Karoo Basin (figure 1) revealed an approximate 30m sequence of terrigenous clastic lithologies containing two main coal seams. The results of this study concur broadly with other studies undertaken previously in the neighbouring coalfields.

The coal-bearing strata in the study area overlie either the Dwyka Formation tillite (figure 33) or the pre-Karoo basement (figure 32). The categorisation of the rock types into eleven lithofacies facilitated the description and hydrodynamic interpretation of the lithologies. The palaeoenvironmental interpretation was based on the vertical facies assemblages and lateral facies distribution. Borehole cross-sections and isopach-maps delineated the three-dimensional distribution of the stratigraphic sequences, while using FEM geological modelling interpolation of the thicknesses and roof and floor values further aided palaeoenvironmental interpretation. Correlation between the basement topography, depositional systems and coal seam distribution was established. The lowermost coal seams pinch out against the basement highs while penecontemporaneous and bed-load fluvial systems caused thinning of the coal below channel axes.

6.1 Facies Types

This study is based primarily on a selection of subsurface borehole data sourced from mining companies drilled over the past 50 years personally interpreted and computer interpolated. In addition, 180 borehole cores were personally logged in this study and an opencast strip mining exposure sourced for reference. Lithology and grain size played a dominant role in classifying the facies while sedimentary structures and bioturbation added to the detail of these descriptions. The eleven facies and four sub-facies present in the study area are described in detail in Chapter 3 and summarised, together with their hydrodynamic interpretations, in table IV.
The diamictite-conglomerate facies (figure 8) consists of diamictite at the base of the sequence resting directly on the pre-Karoo basement (figure 32), but includes strata described as lenses within the intra-seam partings of the No. 1 seam sequence (figure 6) formed due to erosion of deposited tillite that is resedimented downslope. This is an important lithostratigraphical discovery because SACS (1980) define the Dwyka Group as being of glacial origin, with no coal seams, and the Vryheid Formation (figure 4) as being the unit containing coal. Yet this study shows that this dividing line is not that clear-cut and that glaciogenic (Dwyka) material is interbedded in a major coal seam (Vryheid Formation).

The massive granulestone-sandstone (figure 9) and massive mudstone facies (figure 19) are the most common. Horizontally bedded granulestone-sandstone facies and cross-bedded granulestone-sandstone facies are also prevalent. The interlaminated sandstone-mudstone facies (figure 15) is a collective lithofacies used to group the interlaminated facies as differentiation in the type of interlamination has often not been observed in the borehole logs. Bioturbation is described on numerous logs and is included as a separate facies (figure 17) although it commonly occurs in the interlaminated sandstone-mudstone facies.

The coal facies has been subdivided into four sub-facies in order to provide some indication on the quality variation in the coal seams. These are bright, dull, lustrous and undifferentiated coal (figure 26). As the mining environment often relies on sample analysis for quality information, there are numerous boreholes where the coal has not been described in detail and hence the undifferentiated coal is most common. The coal seams in this area are generally dull with a selective brighter portion at the base of the No. 2 seam.

6.2 Lithostratigraphy and Depositional Model

A specific portion of the overall study area, Springboklaagte (figure 2), was focused on to undertake the depositional environment interpretation. Pre-Karoo basement highs separate the study area into smaller sub-basins and post-depositional faulting and erosion further limit these sub-basins. Due to an increase
in the borehole spacing in the Springboklaagte sub-area (figure 3) and opencast mining exposure of the stratigraphy, a higher level of confidence can be placed in the depositional environment interpretation for Springboklaagte. The similarity in the thickness frequency histograms of the entire Arnot North study area and the interpreted Springboklaagte area (figures 28-31) indicates that this interpretation applies to the entire Arnot North area.

The general stratigraphy of the study area is depicted in figure 6 and is similar to the Vryheid Formation in other parts of the Witbank Coalfield but is limited in thickness by post-Karoo erosion and palaeohighs at this northern extremity. Two coal seams exist in the study area and are split into three sub-seams for correlation purposes, namely the No. 2 Select seam, No. 2 Select parting and the No. 2 Top seam (figure 6). The Vryheid Formation in the present study area has been informally subdivided into five sequences (figure 6). These are the basement sequence, the No. 1 seam sequence, The No. 1 parting sequence, the No. 2 seam sequence and the No. 2 parting sequence above the No. 2 seam.

The basement sequence rests on the pre-Karoo basement (figure 32). Where the pre-Karoo basement palaeohighs (figure 32) did not allow for the accumulation of sediment, both the Dwyka tillite and reworked Dwyka tillite are not present and the coal seams rest directly on the pre-Karoo basement. In palaeolows where sediment accumulated in situ below the continental glacier, the coal bearing strata rests directly on the Dwyka Group tillite. In most cases reworking of the Dwyka Group tillite and deposition in a braided stream glaciofluvial to glaciolacustrine environment allowed for the accumulation of reworked tillite that separates the pre-Karoo basement and Dwyka Group from the coal seam sequences above.

Although the No. 1 and No. 2 seams are known to have formed contemporaneously (Le Blanc Smith and Eriksson, 1980), these sequences have been separated in the study area due to a higher degree of diamictitic material occurring as lenses in the partings within the No. 1 seam. The No. 1 seam sequence comprises the interval of strata from the base of the lowest coal seam intersected and the top of the No. 1 seam. The lowest coal seam intersected is the No. 1 Lower-Lower seam (figure 6) and is highly restricted by the basement palaeotopography. This is separated from
the overlying No. 1 Lower seam by massive granulestone-sandstone facies (figure 9) or horizontally-bedded granulestone-sandstone facies that occasionally includes lenses of diamictite allowing for a glaciofluviol interpretation of this clastic parting. Overlying the No. 1 Lower seam is the No. 1 Lower parting that also occasionally contains diamictite lenses, formed by the reworking of previously deposited tillite or slumping, in the massive granulestone-sandstone facies (figure 9) or massive mudstone facies (figure 19) and is therefore also interpreted to be glaciofluviol in origin. The marked absence of clear channel axis trends in the isopachs of the partings in the No. 1 seam sequence (figures 35 and 37), together with the glaciofluviol interpretation of this sequence, indicates that the valley entry point was not confined to a single point.

The No. 1 parting seam sequence (figure 6) has been considered separately in the study area due to its very consistent granulestone-sandstone facies at both the top and base of a massive mudstone facies (figure 19), although some variations from an entire massive granulestone-sandstone facies (figure 9) to a massive mudstone are also present (figure 41). The two channel axes being defined by the isopach (figure 45) indicate that the valley entry point as described by Le Blanc Smith (1980b) to the west of Witbank has played a role in the deposition of the sediments in this parting. The upward-fining nature of the P1 is indicative of a fluvial environment and the overall interpretation for this sequence is overprinting of sediment from a fluvial and glaciofluviol source from the north and north-west of the study area.

The No. 2 seam sequence (figure 6) comprises the No. 2 seam as well as the contemporaneous deposition of clastic intra-seam splits. There are numerous erratic clastic lenses defined within the No. 2 seam that is also further subdivided, based on a lower quality portion at the top of the seam, into a No. 2 Select seam (S2S) at the base and a No. 2 Top seam (S2T) at the top. The transition from S2S to S2T is often marked by a massive granulestone-sandstone facies (figure 9) or massive mudstone facies (figure 19) parting that is erratic (figure 48) but can be correlated across the Springboklaagte area. This parting is interpreted as bedload fluvial channel-fill rather than anastomosing deposits due to the northern basin edge proximal nature and shape and size of the study area.
The clastic sequence above the No. 2 seam has been termed the No. 2 parting despite the absence of the No. 3 seam. The characteristic upward-coarsening lobate delta progradation described in the rest of the Witbank Coalfield also occurs in the study area. The major difference in the sedimentary succession, with respect to the remainder of the Witbank Coalfield, is that two superimposed sets of the upward-coarsening sequence are evident (figure 54) and correlated by the presence at the top of each sequence of a weathered siderite-rich alteration (figure 55). Deep surface weathering and erosion has altered and removed all of the remaining coal-bearing sequence of the Vryheid Formation thereby precluding this upper succession from this study.

Le Blanc Smith’s (1980b) genetic strata increments are largely similar to the stratigraphic subdivisions in the study area, which is anticipated as both fall within the Witbank Coalfield. However, several differences are present within the clastic sequences between the coal seams in the study area with respect to the coarser nature of the sediment and the reduced thickness of the partings. These concur with the work of Cairncross (1986) in an area due south of the present study site. The major differences are:

- The Arnot North area is characterised by a high sandstone/siltstone ratio and granulestone-sandstone is the most common lithofacies in the No. 1 and No. 2 seam sequences (figure 6). This is concurrent with the area to the south of the study area (Cairncross, 1986).

- The basement sequence is thinner than in the remainder of the Witbank Coalfield and is glaciofluvial in origin. This is similar to the work of Cairncross (1986) but too differs from the remainder of the Witbank Coalfield in which the material below the No. 1 seam is glaciodeltaic and glaciolacustrine in origin (Le Blanc Smith and Eriksson, 1979) with fluvial sedimentation confined to low lying areas.

- Dwyka tillite interpreted as glacial material is found as clastic parting between the lowermost coal seams and hence there is no clear distinction in the study area between the Dwyka Group and the overlying traditionally coal-bearing Vryheid Formation.
• The bioturbation that has become characteristic of the clastic unit above the No. 2 seam in the Witbank Coalfield is markedly reduced in the study area.
• The clastic sequence above the No. 2 seam is interpreted as progradational deltaic but has at least one stacked bimodal set as indicated by the repetition of the weathered, sideritic alteration of a carbonate lithology that occurs at the top of two separate upward-coarsening sequences.
• Post-Karoo erosion has removed lithofacies above the immediate roof of the No. 2 seam.

Concurring with Cairncross (1986), these discrepancies in the stratigraphy and interpreted depositional environments are explained as the result of the extreme proximal setting of the study area to the northern edge of the Witbank Basin.
REFERENCES


