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THE SEDIMENTOLOGY OF THE MIDDELVELEI REEF ON DOORNPOINTEIN GOLD MINE

BG ELS
UNIVERSITY OF JOHANNESBURG
THE SEDIMENTOLOGY OF THE MIDDELVLEI REEF
ON DOORNFONTEIN GOLD MINE

by

BAREND GERHARDUS ELS

Dissertation
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ABSTRACT

Doornfontein Gold Mine is the westernmost member of a group of mines in the West Wits Line, extending from Westonaria to Carletonville. A study of the sedimentology and gold distribution of the Middelvlei Reef was carried out with the aim to acquire an understanding of the processes responsible for the economic concentration of gold.

An investigation of the palaeocurrent directions, grain size and stratification of the rocks of the footwall succession led to the conclusion that these were deposited in a dominantly aggradational sandy braided stream environment.

Palaeocurrent directions for the Middelvlei Reef were found to be south-south-east in the eastern part of the mine and towards the east in the western area. Analysis of the pebble composition showed that the assemblage in the western part differs from that in the east. The mean pebble size varies only slightly, but a gradual decrease in the palaeocurrent direction was found. Carbon is sometimes present in the thinner reef types. From the sedimentological data it was concluded that the Middelvlei Reef is fluvial in origin, deposited by braided stream processes in a depositional environment approaching equilibrium.

Analysis by Automatic Interaction Detection showed an antithetic relationship between gold grade and reef thickness, confirmed by a comparison of isocon and isopach maps. Pebble packing densities and mean pebble sizes in samples of the reef were compared to the gold grades and no proportional relationship was found. Certain isocon trends were found to correspond to the general direction of dykes and faults. The trapping of heavy minerals in an open framework gravel is proposed as a primary gold concentration mechanism, while further concentration is suggested to have been brought about by sediment reworking in the proposed depositional environment of low aggradation.

Doornfontein is die mees westelike myn in 'n goudveld bekend as die "Wes Wits Lyn", wat strek van Westonaria tot Carletonville. 'n Onderzoek van die sedimentologie en goudverspreiding van die Middelvleirif is onderneem ten einde 'n begrip te vorm van die prosesse wat verantwoordelik was vir die ekonomiese konsentrasie van goud.

'n Onderzoek van die paleostroomrigtings, korrelgrootte en gelaagheid van die vloergesteentes, het tot die gevolgtrekking geleë dat hierdie gesteentes afgeset is in 'n oorheersend aggraderende, sandige, vlegstroomomgewing.

Die paleostroomrigtings wat bepaal is vir die Middelvleirif, is suid-suid-oos in die oostelike deel en oos in die westelike deel. 'n Rolsteensamestellinganalyse het getoon dat die versameling in die westelike deel van die myn verskil van dié in die ooste. Slegs 'n klein verskil in gemiddelde rolsteengrootte is gevind, maar daar is 'n geleidelike afname in die rigting van die paleostrome. Koolstof is soms teenwoordig die dunne riftipes. Uit die sedimentologiese gegewens is die gevolgtrekking gemaak dat die Middelvleirif 'n fluviale oorpsorge het en afgeset is deur vlegstroomprosesse in 'n afsettingsomgewing waar toestande feitlik sedimentasie-ewewig bereik het.

'n Analise deur middel van Outomatiese Interaksie Opsporing ("Automatic Interaction Detection") het 'n teenstellende verhouding tussen goudkonsentrasie en rifdikte aangetoon, wat ook bevestig word deur 'n vergelyking van isokon- en isopachkaarte. Gemiddelde rolsteengroottes en rolsteenpakkingdigttheede in rifmonster is vergelyk met goudkonsentrasie en geen proporsionele verhouding kon gevind word nie. Sekere
rigtings op die isonkonkaart stem ooreen met die algemene rigting van gange en verskuiwings.

Die meganisme wat voorgestel word vir goudkonsentrasie is 'n ooropraamwerkgruis waarin die swaarminerale opgevang is. Dit word voorgestel dat verdere konsentrasie teweeggebring is deur sedimentherwerking in 'n vlegstroomomgewing waar 'n lae tempo van sedimentaggradasie 'n bevorderlike faktor was.
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INTRODUCTION

1.1. GEOGRAPHIC AND GEOLOGICAL SETTING

Doornfontein Gold Mine is the westernmost member of a group of mines forming the West Wits Line gold-field, situated in the Witwatersrand Supergroup between Westonaria and Carletonville in the Transvaal (Fig. 1). The mine is situated near the north-western apex of the oblong Witwatersrand basin which, in this area, is covered by the Transvaal Sequence.

On Doornfontein Mine the gold ore is derived from two placer ore bodies, termed "reefs", within the lower part of the Central Rand Group of the Witwatersrand Supergroup. The principal gold-bearing reef is the Carbon Leader which contributes about two thirds towards the total ore production of 120 000 tonnes per month. The Middelvlei Reef, previously known as the Main Reef (S A C S, 1980) has a lower average gold grade than the Carbon Leader and exhibits a more erratic lateral gold distribution pattern. Because of these characteristics it was uneconomical to mine at the low fixed gold price before 1972. However, the escalation of the gold price since then led to the Middelvlei Reef becoming a gold producing reef.

1.2. PREVIOUS WORK

Although some aspects of the Middelvlei Reef had been described by various authors, mainly in internal reports,
FIG. 1  LOCALITY MAP
the sedimentology of the reef has not been studied in detail before. The following is a listing of reports pertaining to investigations of the reef.

Baard (1964), assessing the economic potential of the Middelvlei Reef on Doornfontein Mine and the area west of the mine lease, states that the reef consists of two "bands" with roughly equal gold grades and that the upper "band" is unconformable to the lower one.

De Kock (1964), in his paper on the geology of the West Wits Line, gives lithological descriptions of the Middelvlei Reef in various parts of this gold-field, as well as a summary of a mineralogical investigation of the reef on Venterspost Mine (Fig. 1).

Davies (1972) examined the stratigraphy and gold content of the reef on Doornfontein Mine and is of the opinion that the reef comprises three "bands". He found a sympathetic relationship between gold content and reef thickness and records a single occurrence of carbon.

Swart (1980) lists a set of lithological criteria to facilitate identification of the Middelvlei Reef itself, the footwall and hangingwall quartzites on East Driefontein Mine (Fig. 1).

Body (1981) carried out a microscopic investigation of the footwall and hangingwall quartzites of the reef on
Doornfontein Mine and found that the latter quartzites have a significantly smaller grain size than the former.

Jolly (1982) investigated the sedimentology and economic potential of the reef on West Driefontein Mine (Fig. 1) and proposed a braided river depositional environment. He formulated two facies assemblage types and came to the conclusion that the gold "is concentrated along the main stream flow direction".

1.3. PURPOSE OF STUDY
From the summary of previous work it is clear that a detailed sedimentological study of the Middelvlei Reef on Doornfontein Mine was most desirable, especially in view of the current importance of the reef and its mentioned erratic lateral gold distribution. The purpose of this study was to acquire an understanding of the sedimentary processes responsible for the economic concentration of gold in the reef.

1.4. METHODS OF STUDY
The methods adopted for the collection and processing of data were mainly standard sedimentological techniques combined with conventional underground mapping and gold mine evaluation procedures (Table I).
TABLE I: METHODS ADOPTED FOR THE COLLECTION AND PROCESSING OF DATA

Initial familiarization and reconnaissance.
Detailed sedimentological examination of an exposure of footwall rocks.
Compilation of typical stratigraphic profiles.
Detailed mapping of certain reef exposures.
Determination of palaeocurrent directions.
Determination of mean pebble sizes.
Determination of pebble assemblages.
Detailed sampling of the reef and comparison of gold grade to facies types.
Collection of sedimentological data for analysis by Automatic Interaction Detection.
Compilation of gold grade and reef thickness maps.
Microscopic investigation of the reef matrix.
Interpretation of data.
Documentation.

1.5. DISSERTATION FRAMEWORK

CHAPTER 2: A stratigraphic classification of the rocks found in the mine is submitted and their lithology is described briefly. The structural features found in the mine are illustrated by a map of the plane of the Middelvlei Reef and discussed briefly. The relationship of the Witwatersrand Supergroup and the overlying Transvaal Sequence is illustrated by a simplified section.
CHAPTER 3: The lithology of the sequence between the Jeppestown Subgroup and the Middelvlei Reef is described. The methods adopted for a detailed sedimentological investigation of an exposure of the footwall rocks of the reef are described, the results are submitted diagramatically and are interpreted.

CHAPTER 4: The Middelvlei Reef is defined and its lithology described. The external geometry of the reef is illustrated by an isopach map. The lithofacies of the reef are listed and interpreted and the facies assemblage types formulated, are defined. The methods used to determine palaeocurrent directions, mean pebble size and pebble assemblages are described briefly and the results of these investigations are submitted and interpreted. The minerals present in the matrix of the reef are listed and their occurrence described. Certain sedimentological features of the reef are illustrated by mapped sections.

CHAPTER 5: A sampling project, aimed at investigating the gold distribution within the reef and its relationship to facies is described and the results are presented graphically and interpreted. The relationship between gold grade and sedimentological parameters, determined by means of the computer executed "Automatic Interaction Detection" analysis, is submitted in the form of a dendrogram and a gold concentration process is proposed. The lateral distribution of gold in the
Middelvlei Reef is illustrated by an isocon map and directional trends on this are interpreted.

CHAPTER 6: The interpreted sedimentological and gold distribution characteristics of the reef are summarized. A model for the stratigraphic - environmental setting of the Middelvlei Reef is proposed, as well as a depositional model for the reef itself. Finally the distribution of gold is related to the proposed model.
2. GENERAL GEOLOGY

2.1. SURFACE GEOLOGY AND STRATIGRAPHY

Most of the surface area of the mine lease is covered by the Chuniespoort Group of the Transvaal Supergroup, with small outliers of the Pretoria Group (Fig. 2). The topography is of low relief, as illustrated by surface contours (Fig. 2).

The rocks most frequently exposed in workings on Doornfontein Mine occur within the Witwatersrand sequence from the upper part of the Jeppestown Subgroup to the Middelvlei Reef (Fig. 3a). Since the lithology of this sequence is described in some detail in 3.1., the main stratigraphic boundaries only will be mentioned here and related to the local detailed stratigraphic column (Fig. 3b). The sequence above the Middelvlei Reef is not frequently exposed in mine workings and will only be described in broad terms. Formations appearing in the generalized stratigraphic column (Fig. 3a), but not mentioned in this description, are either not developed locally or have not been recognised.

The oldest rocks exposed in the mine belong to the upper part of the Jeppestown Subgroup. The shales of this subgroup become progressively coarser-grained upwards, transitional into the overlying Maraisburg Quartzite Formation. The latter is locally known as the "Square Pebble Zone", so-called because of the presence of small
FIG. 2 SURFACE GEOLOGICAL MAP OF THE DOORNFONTEIN MINE LEASE AREA

LEGEND

1. Alluvium
2. Shale
3. Quartzite
4. Shale
5. Giant Chert
6. Dolomite
7. Diabase sheet
8. Pilansberg type dyke

Faults

1600 Contours above mean sea level (metres)
FIG. 3  STRATIGRAPHIC POSITION OF MIDDLEVLEI REEF
angular chert pebbles in parts of the West Wits Line. On Doornfontein Mine, however, angular pebbles are extremely rare. Overlying this formation is the Main Conglomerate Formation, which contains both gold-producing reefs, the Middelvlei Reef being the top member (Fig. 3b).

The overlying Langlaagte Formation is locally known as "Hangingwall of Middelvlei Reef". The lowermost three metres consists of grey to dark grey, coarse-grained argillaceous quartzites. Overlying these is a thin zone of oligomictic small pebble conglomerates, known as "Top Bands". The top part of the Langlaagte Formation comprises medium-grained, evenly textured, grey quartzites with beds of fine-grained, light grey glassy (siliceous) quartzite. The latter formation is overlain by the Randfontein Quartzite Formation which consists of a central unit of medium-grained, evenly textured, grey quartzite, bounded at the top and bottom by two relatively thin zones of coarse-grained, light grey, siliceous quartzite known as the Upper- and Lower Hangingwall Glassy Zones. The overlying Luipaardsvlei Quartzite Formation is represented by medium-grained, evenly textured, grey quartzite with subordinate beds of light grey, more siliceous quartzite. Overlying this formation is the Bird Conglomerate Formation, so-called because of the presence of conglomerates, some containing cobble-sized clasts, in parts of the West Wits Line. On Doornfontein Mine, however, the formation is a rather
monotonous succession of fine-grained, grey, argillaceous quartzites with a zone of small pebble conglomerates near the base. There is a gradual transition between the quartzites of this formation and the overlying Booysens Shale Formation, manifested by an increasing proportion of shale beds and laminae upwards. The latter formation, which marks the top of the Johannesburg Subgroup, consists of alternating dark grey shale beds and laminae and dark grey, fine-grained, argillaceous quartzites. Overlying this is the Kimberley Conglomerate Formation, which is represented by both dark coloured argillaceous and light coloured siliceous quartzites. A group of small pebble conglomerates occurs near the base of this formation.

On Doornfontein Mine the Central Rand Group, described above, reaches a maximum thickness of about 1 800 metres at the southern boundary, where the lower part of the Turffontein Subgroup is truncated by the Transvaal Sequence (Fig. 4).

At the base of the latter is the Black Reef Formation which is locally only a few metres thick and consists of dark grey quartzites with interbedded small to medium pebble conglomerates. The overlying Chuniespoort Group consists of both chert-rich and chert-free dolomite with subordinate black shale beds and laminae. Overlying this group is the Giant Chert Member of the Rooihoogte
FIG. 4 SIMPLIFIED DIP SECTION THROUGH ANNAN SHAFT, LOOKING EAST
Formation, described as a chert-dolomite breccia in a dolomitic matrix. The overlying Timeball Hill Formation is represented by dark grey, mostly well laminated shales and an interbedded coarse-grained quartzite bed, the Pologround Quartzite Member.

The maximum thickness of the Transvaal Sequence on Doornfontein Mine is about 1 370 metres.

2.2. STRUCTURE

Overall, the most striking aspect of the structure of Doornfontein Mine is the angular unconformity between the rocks of the Witwatersrand Supergroup and those of the overlying Transvaal Sequence. The latter dips at about 7° towards the south, while the Witwatersrand strata have dips of 20° to 35°, mostly in a direction about 170°. This angular unconformity causes the Middelvlei Reef to suboutcrop against the Black Reef Formation near the northern boundary of the mine (Fig. 5) as illustrated in the simplified section (Fig. 4).

The structure of the Witwatersrand rocks is illustrated by a map (Fig. 5) on which the major faults and dykes exposed in the underground workings, as well as their projected extensions, are shown on the plane of the Middelvlei Reef. There are two broad regions of the mine with differing structural distributions. The part east and south of fault complex A A' (Fig. 5) is relatively
FIG. 5 SIMPLIFIED STRUCTURAL MAP OF THE MIDDLEVELI REEF
uncomplicated and although several dykes occur here, little or no vertical displacements are associated with them. The reef dip in this area is almost constant at 22° in a direction of 170°. In the area north and west of the mentioned fault complex there is an increase in fault density and the reef dip is more variable. This phenomenon is probably related to one of the most dominant structural features on Doornfontein Mine, the Master Bedding Fault (Fig. 4), which is discussed in some detail by Bertram (1979). This normal fault dips on average slightly steeper than the Witwatersrand strata and possibly has a horizontal displacement of some kilometres. Because the Middelvlei Reef is closer to the Master Bedding Fault in the area in question than in the south-east, there is a higher degree of disruption.

Two sets of normal faults are present, grouped according to their orientation. The first set strikes from 020° to 035° and the majority dip at 70° towards the south-south-east. The second set strikes 125° and virtually all dip at 65° towards the south-south-west. Reverse faults are rare and belong to the latter set. Faults belonging to this set are younger than those of the first mentioned set and one fault, the major tear fault (B B', Fig. 5), is of post-Transvaal age.

Dykes in the mine are grouped according to their attitude into two sets with the same general strikes as the two fault sets. The majority of dykes are probably
of Ventersdorp age and only one dyke, the Oberholzer dyke, is possibly of Pilansberg Complex age (De Kock, 1964). This dyke, present as a single structure north of the West Wits Line, branches into two dykes east of the eastern boundary of Doornfontein Mine.

A noteworthy phenomenon, illustrated in Figure 6, is that many faults and dykes occurring in the plane of the Middelvlei Reef, cannot be correlated with those on the Carbon Leader horizon. A satisfactory explanation is that the faults and dykes in question have been laterally displaced by younger bedding plane faults. It is the general opinion of geologists working on the mine that, because of the lateral continuity of the Green Bar, either or both of the contacts are likely bedding planes along which movement could have taken place.
FIG. 6  SIMPLIFIED SECTION ON LINE AA' (FIG. 7) SHOWING FAULTS AND DYKES ON THE PLANES OF THE MIDDLEVLEI REEF AND THE CARBON LEADER
(courtesy of W. Marczewski)
3. GENERAL SEDIMENTOLOGICAL SETTING

3.1. LITHOLOGY OF THE JEPPESTOWN SUBGROUP – MIDDELVELI REEF SEQUENCE

On Doornfontein Mine the top part of the Jeppestown Subgroup consists of dark grey shales, mostly well-laminated. The succession coarsens upwards through a transitional zone, known as "Deep Footwall / Deep Footwall and Shale", into the "Lower Square Pebble" zone. The former zone is a succession of alternating dark grey shales and fine-grained, argillaceous quartzites which occur progressively more frequently upwards. The "Lower Square Pebble" zone consists entirely of dark grey, fine-grained, argillaceous quartzite. This is overlain by the "Middle Square Pebble" zone; a mature, light grey to slightly green tinged, very well cross-bedded quartzite. The overlying "Top Square Pebble" zone is a narrow, dark grey, fine-grained, argillaceous quartzite which is overlain by "Footwall of North Leader" zone. This consists of fairly mature, medium-grained quartzites, often cross-bedded. Overlying this is the North Leader; a small pebble oligomictic conglomerate, usually no more than 15 centimetres thick, which sporadically contains economic gold concentrations. This conglomerate is overlain by the "Footwall of Carbon Leader" zone, which is an inhomogeneous succession of siliceous and argillaceous coarse-grained quartzites.

The overlying Carbon Leader has been described in considerable detail by De Kock (1964) and Nami (1982) and
only a summary of their findings will be given here. The latter author recognises two subfacies of the reef namely a single conglomerate type and a multiple conglomerate type, with the occurrence of carbon restricted to the former. De Kock (1964) does not make a facies classification, but recognises the existence of the mentioned reef types. The Carbon Leader is overlain by an exceptionally mature light to very light grey, fine- to medium-grained quartzite, known as "Hangingwall of Carbon Leader". Overlying this is the "Rice Pebble" zone; a dark, pyritic quartzite with small white quartz pebbles and granules. This is overlain by the "Green Bar"; a dark grey to khaki-coloured, chloritoid-rich (De Kock, 1964) argillite, apparently structureless in the top part, but well laminated at the bottom. Overlying this is a zone known as "Immediate Hangingwall of Green Bar", which consists of mature and fairly mature grey to light grey quartzites, often well cross-bedded. This zone is overlain by "Hangingwall of Green Bar", which comprises grey, medium- and coarse-grained quartzites, usually fairly argillaceous. Overlying this is a group of oligomictic small pebble conglomerates known as "No. 1 Hangingwall S P C's".

These are overlain by a succession of coarse- to very coarse-grained quartzites, mostly fairly argillaceous, known as "Footwall of Middelvlei Reef". The various aspects of the overlying Middelvlei Reef are discussed in
3.2. SEDIMENTOLOGY OF THE GREEN BAR - MIDDELVLEI REEF CYCLE

3.2.1. PURPOSE
To acquire a better understanding of the depositional environment of the Middelvlei Reef and its sedimentological setting, a study of the succession between the reef and the Green Bar was carried out. The latter horizon was chosen because of its widespread lateral occurrence and its importance as a local and regional marker.

3.2.2. METHODS
To be able to examine a complete stratigraphic succession of the footwall rocks, a cross-cut in which the strata have not been disturbed by faults or dykes, was selected (9 - 31 MR Cross-cut, Fig. 7). A stratigraphic section along the line of the cross-cut was compiled by mapping of the sidewalls. The succession was divided into 95 rock units (beds), using mainly bedding planes as basis for subdivision. A brief lithological description of each unit was made and a mean maximum clast size estimated by comparison of the texture of the rock with a scale of diagrammatic textures of various grain sizes. Grain size for the fine-grained units could not be determined this way because of their fine texture. The type and scale of stratification was recorded in each unit and cross-bedding directions were determined as
<table>
<thead>
<tr>
<th>Facies identifier</th>
<th>Lithofacies</th>
<th>Sedimentary structures</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gm</td>
<td>gravel, massive or crudely bedded, minor sand, silt or clay lenses</td>
<td>ripple marks, crossbeds in sand units, gravel imbrication</td>
<td>longitudinal bars, channel-lag deposit</td>
</tr>
<tr>
<td>Gt</td>
<td>gravel, stratified</td>
<td>broad, shallow trough crossbeds imbrication</td>
<td>minor channel fills</td>
</tr>
<tr>
<td>Gp</td>
<td>gravel, stratified</td>
<td>planar crossbeds</td>
<td>linguoid bars or deltaic growths from older bar remnants</td>
</tr>
<tr>
<td>St</td>
<td>sand, medium to very coarse, may be pebbly</td>
<td>solitary (theta) or grouped (pi) crossbeds</td>
<td>dunes (lower flow regime)</td>
</tr>
<tr>
<td>Sp</td>
<td>sand, medium to very coarse, may be pebbly</td>
<td>solitary (alpha) or grouped (omikron) planar crossbeds</td>
<td>linguoid bars, sand waves (upper and lower flow regime)</td>
</tr>
<tr>
<td>Sr</td>
<td>sand, very fine to coarse</td>
<td>ripple marks of all types, including climbing ripples</td>
<td>ripples (lower flow regime)</td>
</tr>
<tr>
<td>Sh</td>
<td>sand, very fine to very coarse, may be pebbly</td>
<td>horizontal lamination, parting or streaming lineation</td>
<td>planar bed flow (lower and upper flow regime)</td>
</tr>
<tr>
<td>Sa</td>
<td>sand, fine to coarse, may be pebbly</td>
<td>broad, shallow scours (including eta-cross-stratification)</td>
<td>minor channels or scour hollows</td>
</tr>
<tr>
<td>Fl</td>
<td>sand (very fine), silt, mud, interbedded</td>
<td>ripple marks, undulatory bedding, bioturbation, plant rootlets, caliche</td>
<td>deposits of waning floods, overbank deposits</td>
</tr>
<tr>
<td>Fm</td>
<td>mud, silt</td>
<td>rootlets, desiccation cracks</td>
<td>drape deposits formed in pools of standing water</td>
</tr>
</tbody>
</table>
described in 4.5., wherever suitable three-dimensional exposures were found. From the mapped section a vertical profile was constructed (Fig. 8).

3.2.3. DESCRIPTION AND RESULTS

To facilitate the description of the lithofacies of modern and ancient braided stream deposits Miall (1977) devised a letter code system based upon clast size and type of stratification (Table II). Since these criteria were also used in this investigation, it was decided to adopt Miall’s (1978) system. Because the conglomerates present are all very thin, their stratification could not be identified. For this reason the code Gu is used, denoting gravel with undifferentiated stratification. The lithofacies are listed in Table III.

TABLE III : LITHOFACIES PRESENT IN THE JEPPESTOWN SUBGROUP - MIDDELVLEI REEF SEQUENCE

<table>
<thead>
<tr>
<th>CODE</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>St</td>
<td>Trough cross-bedded quartzite</td>
</tr>
<tr>
<td>Sp</td>
<td>Planar cross-bedded quartzite</td>
</tr>
<tr>
<td>Fm</td>
<td>Massive siltstone or mudstone</td>
</tr>
<tr>
<td>Fl</td>
<td>Laminated siltstone or shale</td>
</tr>
<tr>
<td>Gu</td>
<td>Conglomerate</td>
</tr>
<tr>
<td>Gi</td>
<td>Pebble lag</td>
</tr>
</tbody>
</table>

The code Gi was not proposed by Miall (1977) but introduced by the Gold Fields Sedimentology Unit and is defined as follows: "A single pebble conglomerate layer, immediately overlying an erosional surface".
FIG. 7  LOCALITIES OF MAPPED SECTIONS
FIG. 8 SEDIMENTOGICAL DATA OF THE GREEN BAR - MIDDELVLEI REEF SEQUENCE
From the stratigraphic profile (Fig. 8) it is clear that the major lithofacies is trough cross-bedded quartzite, while the planar cross-bedded units are subordinate, both in number and total thickness. A few quartzite units are fining-upwards, but in the majority of cases no difference in grain size within the beds could be detected. Conglomerate beds are not uncommon, but in terms of thickness, they constitute a very small fraction of the sequence. The fine-grained facies i.e. massive or laminated siltstone, occurs rarely and the units are thin. The various lithofacies types are mostly arranged in fining-upward sequences. The upward-fining sedimentary increments are not always complete, indicating that some scouring or non-deposition took place. Scouring, however, is not common. Some units were found to be lenticular, a phenomenon that was not always noticeable in the direction of the section, but evident when comparing thicknesses on the two sidewalls.

Because of the lack of suitable three-dimensional exposures, cross-bedding directions were determined at only three levels in the succession. The transport direction was found to be consistently towards the south (Fig. 8).

3.2.4. INTERPRETATION AND DISCUSSION

Trough cross-bedded sand has its origin in migrating dunes, formed in a minimum water depth of approximately
twice the thickness of the individual cross-bed sets. Planar cross-bedded sand is deposited by migrating sand waves and sand bars (Harms, 1975; Smith, 1970).

Hein (1974) refers to pebble lags as "diffuse gravel sheets" and considers them to be the coarsest fraction of the bedload which moves only at the highest discharges and is deposited at slightly lower flows.

The laminated lower part of the Green Bar (Facies Fl) is classified as a shale, while the apparently structureless top part (Facies Fm) should be termed a mudstone or siltstone. These sediments are known to be deposited under quiet conditions that prevail at intermediate and great depths (Pettijohn, 1957, p593, p596). It is therefore concluded that the Green Bar was deposited in a lacustrine environment. The lamination exhibited in the lower part of this unit is interpreted as the result of repetitive cyclic deposition, probably seasonal as suggested by Blatt et al. (1972, pl16). The phenomenon of absence of lamination, as found in the top part of the Green Bar, is suggested by the latter authors to be the result of one of the following mechanisms:

(a) Extensive bioturbation
(b) Rapid deposition
(c) Deposition from highly concentrated sediment dispersals.

In the case of the Green Bar, being of early Proterozoic or late Archean age, the first alternative can be
discarded. The massive structure is therefore thought to be the result of either rapid deposition or highly concentrated sediment dispersals.

Sharp stratigraphic boundaries such as those observed for both lower and upper contacts of the Green Bar, are considered by Blatt et al. (1972, p112) to be the result of a sudden change in depositional conditions or diagenetic accentuation of an originally gradational boundary. Another possibility is that an originally gradational boundary has been eliminated by structural deformation, caused by bedding plane movement on either or both contacts of the Green Bar.

The thin massive siltstone beds and laminae present in the sequence are also classified as facies Fm, which are interpreted by Miall (1977) as mud and silt drape deposits formed in pools of standing water.

The cyclic repetition of lithofacies types, the lenticular nature of the sedimentary units and the unimodal palaeocurrent direction are criteria that led to the conclusion that the depositional environment was a sandy braided stream system. An alternative environment considered was a meandering river, but this was ruled out, mainly because of the infrequent occurrence in the profile of siltstone and mudstone, which are deposited as vertical accretions in the overbank areas of meandering rivers. Walker and Cant (1979) point out that the
vertical and lateral accretion deposits of meandering rivers are on average roughly equal in thickness.

The vertical profile (Fig. 8), when compared with those of the six types of braided deposits proposed by Miall (1978), corresponds to the South Saskatchewan type in that lithofacies are cyclically arranged and trough cross-bedded sand / quartzite dominates the sequence. Alternatives considered in this classification were the Platte and Bijou Creek types introduced by Miall (1978). Both these are profiles of sandy braided environments. The former was ruled out because it is virtually non-cyclic and dominated by planar cross-bedded sands. The Bijou Creek type facies assemblage is considered to be the result of high energy ephemeral discharges, similar to modern catastrophic floods. Its vertical profile is dominated by horizontal stratification (Facies Sh), formed in the upper flow regime (Harms, 1975).

To summarize, a lacustrine depositional environment is proposed for the Green Bar and a sandy braided environment for the quartzite sequence above it.
4. SEDIMENTOLOGY OF THE MIDDELVLEI REEF

4.1. LITHOLOGY AND DEFINITION

The Middelvlei Reef (Fig. 9) comprises one or more oligomictic quartz pebble conglomerate beds, overlain by quartzite (often pebbly) and thin khaki to dark grey coloured mudstone beds or laminae. For the purpose of this study the Middelvlei Reef was defined as the entire succession between the lower contact of the bottom conglomerate bed and the first bedding plane, scour surface or shale lamina above the uppermost conglomerate bed.

The quartzite matrix of the conglomerates varies in colour from light to dark grey. Pyrite occurs commonly, as fine detrital grains in the matrix while carbon is present in places. The quartzites interbedded with conglomerate beds are mostly coarse-grained and lithologically identical to the hangingwall quartzite overlying the reef.

4.2. EXTERNAL GEOMETRY

4.2.1. THICKNESS

The thickness of the Middelvlei Reef varies from a few centimetres to just over two metres. The reef is present in the entire area studied except where it has been eliminated by faults and intrusives. The lateral variation of thickness is illustrated by an isopach map of the reef in the eastern part of the mine (Fig. 10).
Exposures in the western part of the mine are limited and the compilation of a reliable isopach map of this area was not possible. The thickness data used to compile the map were extracted from sampling records and the data processing and contouring was done by computer, applying the methods devised by Krige. These are discussed in detail by Journel and Huijbregts (1978).

4.2.2. RESULTS

The isopachs reveal the following:

(a) A north-south trend of thicker and thinner reef zones, most noticeable east and south-east of No. 1 Shaft.

(b) An area of relatively thin, uniform thickness south-east of Annan Shaft.
**LEGEND**
(thickness shown in metres)

- >1.20
- 0.80 - 1.20
- 0.40 - 0.80
- <0.40

**CATEGORIES 3 AND 4 OF ISOCON MAP**

**FIG. 10** ISOPACH MAP OF THE MIDDLEVELI REEF. NO INFORMATION AVAILABLE IN BLANK AREAS
4.2.3. INTERPRETATION
Krumbein and Sloss (1963, p444, p448), in their discussions on the interpretation of isopach maps, point out that an isopach map, based upon an interval with a conformable top, indicates the structure of the lower surface at the time of deposition. Since there is no evidence of interruption of deposition at the top of the Middelvlei Reef, this can be considered a conformable surface and the lateral variation of reef thickness can therefore be attributed to a variation in footwall relief. This appears to be due to scouring of the footwall during deposition, and an uneven predepositional footwall relief. An example of basal scouring is shown in figure 11, which illustrates a thickening of the reef in the scour. No conspicuous isopach trends occur within the area of uniform thickness (Fig. 10) and the thin reef present here is attributed to a more elevated predepositional footwall relief.

An alternative interpretation of the lateral variation of reef thickness is that areas of low palaeorelief produced a thin lag-type reef, as a result of more prolonged winnowing, while areas of higher relief were subjected to this process only during peak floods. Areas of thin reef are therefore interpreted as channels and areas of thicker reef as palaeo-gravel bars.
Facies Assemblage
Type A

8  9  10  11

6 ASSEMBLAGE TYPES B AND A
4.3. SEDIMENTARY LITHOFACIES

4.3.1. INTRODUCTION

For the sake of uniformity, the letter code system of Miall (1977, Table II), used in the investigation of the Green Bar - Middelvlei Reef sequence, was also adopted for the sedimentological study of the Middelvlei Reef itself.

During the study, very faint stratification in many cases, combined with relatively poor illumination underground, made identification of the lithofacies difficult. Therefore, in cases where the type of stratification could not be identified confidently, the letter "u" is used, for example Su, denoting quartzite with undifferentiated stratification.

4.3.2. LISTING, DESCRIPTION AND INTERPRETATION

The lithofacies recognised in the Middelvlei Reef are listed in Table IV.

Facies Gl (Fig. 12a) consists of a single pebble layer, overlain by quartzite or sometimes by another pebble layer. This is interpreted as a single layer lag deposit.

Facies Gm (Fig. 12b), clast-supported conglomerate, is apparently devoid of any internal structure and the units are typically less than 15 centimetres thick. Rust
### TABLE IV: CLASSIFICATION OF LITHOFACIES IN THE MIDDELVELI REEF AND THEIR PROBABLE EQUIVALENTS IN RECENT SEDIMENTARY SYSTEMS

<table>
<thead>
<tr>
<th>Code</th>
<th>Miall's (1977) definition</th>
<th>Equivalent Middelveli Reef Facies</th>
<th>Interpretation (Miall, 1977)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gm</td>
<td>massive clast-supported gravel</td>
<td>clast-supported conglomerate</td>
<td>longitudinal bars: channel lag deposits</td>
</tr>
<tr>
<td>Gp</td>
<td>planar cross-bedded gravel</td>
<td>planar cross-bedded conglomerate</td>
<td>linquoid bars</td>
</tr>
<tr>
<td>Gt</td>
<td>trough cross-bedded gravel</td>
<td>trough cross-bedded conglomerate</td>
<td>minor channel fills</td>
</tr>
<tr>
<td>*Gl</td>
<td>trough cross-bedded sand</td>
<td>single pebble conglomerate</td>
<td>single layer lag deposits</td>
</tr>
<tr>
<td>St</td>
<td>trough cross-bedded sand</td>
<td>trough cross-bedded quartzite</td>
<td>dunes</td>
</tr>
<tr>
<td>Sp</td>
<td>planar cross-bedded</td>
<td>planar cross-bedded pebbly quartzite</td>
<td>linquoid bars; sand waves</td>
</tr>
<tr>
<td>Fm</td>
<td>massive mud or silt</td>
<td>massive siltstone</td>
<td>drape deposits formed in pools of standing water</td>
</tr>
</tbody>
</table>

* The code G1 was not proposed by Miall (1977). See 3.2.3 for origin of definition.
(a) Facies Gl (1), overlying footwall quartzite (2).
   (Length of the scale-board is 20 cms.)

(b) Facies Gm: Massive clast-supported conglomerate.
    (Centimetre divisions on tape measure)

FIG. 12: SOME LITHOFACIES OF THE MIDDELVELI REEF
FIG. 12: SOME LITHOFACIES OF THE MIDDELVLEI REEF
(Length of scale-board is 20cms)
(1972) suggested that massive gravels form in migrating longitudinal bars. Hein, quoted by Walker (1975), is of the opinion that all gravel bars originate from lag deposit nuclei and that the type of bar that develops, depends mainly on the fluid and sediment discharge. He suggests that longitudinal bars are formed from a lag nucleus at sustained high fluid and sediment discharge.

Facies Gp (Fig. 12c), planar cross-bedded conglomerate, occurs rarely and only in solitary sets. According to Miall (1977) and Smith (1980), this facies is deposited in migrating transverse bars. According to Hein op. cit., these are formed by accretion on a lag nucleus at relatively low fluid and sediment discharge. An alternative interpretation by Eynon and Walker (1974) is that this facies is the product of delta-like growth from an eroded bar remnant.

Facies Gt, trough cross-bedded conglomerate, comprises small scoops or troughs which commonly cut into each other, laterally and vertically. Miall (1977) interprets this facies as minor channel fills which are according to him similar to scour hollows described by Williams and Rust (1969). Both authors are of the opinion that the scours are related to lee face erosional hollows of dunes and bars.

Facies St, trough cross-bedded quartzite, is almost
invariably pebbly. This facies is interpreted to have its origin in migrating dune fields.

Facies Sp (Fig. 12d), planar cross-bedded quartzite, was found only in solitary sets and can contain pebbles or be devoid of any. This facies is interpreted to have formed in migrating sand waves and sand bars.

Facies Fm, massive siltstone, occurs as beds and laminae which are seldom thicker than 10 centimetres and often lenticular. Miall (1977) interprets this facies as drape deposits formed in pools of standing water and considers it the equivalent of Facies A of Williams and Rust (1969), which is "laminated silty clay". The latter authors found that this facies is formed in "low-lying water-logged areas".

4.4. FACIES ASSEMBLAGES

4.4.1. CLASSIFICATION AND DISTRIBUTION

The lithofacies (Table IV) ideally occur in fining upward sequences, commencing with conglomerate at the base, followed by quartzite and terminating in a siltstone lamina at the top. Such sequences may be repeated in the vertical profile. The cycles are often incomplete, due to partial erosion during the deposition of a subsequent cycle. This is illustrated by basal scours into the footwall quartzite or into previously deposited cycles.
A set of typical profiles of the Middelvlei Reef was obtained by combining those recorded during a pebble size analysis (Appendix Ia to Iz) with profiles recorded specially to investigate the variation of facies assemblages. The profiles indicate that two types of facies assemblage are present; a single-cycle type A and a multi-cycle type B (Fig. 13). Type B is by far the most common, while the occurrence of Type A is restricted to parts of the north-eastern area of the mine.

Laterally the two facies assemblage types display a very intimate relationship and transitions from one type to the other take place within a few metres (Fig. 11).

4.4.2. INTERPRETATION

The fining upward sequences represent decreasing energy levels of deposition from high energy currents which transported the gravel, to low energy or standing water, in which the silt fraction was deposited. The repetition of these sequences in vertical profile illustrates the cyclic nature of the depositional processes. Both features were found by Miall (1977) to be characteristic of some modern braided stream environments. Scouring is another feature mentioned by Miall (1977).

The vertical profiles recorded for the Middelvlei Reef (Appendix Ia to Iz) are comparable to the Donjek type of Miall (1978) which is characterised by a gravel content
of 10% to 90% and fining upward sedimentary cycles with scour bases.

The reason for the occurrence of a single cycle type facies assemblage in certain parts of the mine could be one of the following:–

(a) This type was deposited in areas of higher relief, during a flood when the water level was higher than during previous and/or subsequent
floods.

(b) All previous sedimentary cycles deposited in these areas were eroded and reworked during the deposition of a final cycle.

(c) The sediments were continually reworked to a gravel lag in active channels.

The first alternative requires, as a prerequisite, exceptionally high energy levels during flood. Because no evidence of the existence of stratigraphically continuous sedimentary units, representing such energy levels, exists, this hypothesis considered unlikely.

It was shown in 3.2.3. that the lateral variation of reef thickness may be attributed to a variation in footwall relief. The interpretation of the sudden lateral increase in reef thickness, shown in figure 11, as the result of channel scouring, is therefore justified. The section (Fig. 11) clearly shows the presence of a thicker, multicycle reef type in the channel and a thin single-cycle type outside its edges. This situation suggests that the third alternative interpretation of single cycle reef types, mentioned above, seems unlikely.

In the section (Fig. 11) it can be seen that the multicycle sequence in the scour is truncated by the continuous thin uppermost conglomerate, illustrating that the latter is younger. The phenomenon of conglomerate
units within the scour cutting into each other laterally and vertically, is interpreted as produced by laterally shifting braid streams and/or bar dissection, which are the basic elements of braiding (Smith, 1970).

4.5. PALAEOCURRENT DIRECTIONS

4.5.1. PURPOSE

A palaeocurrent analysis of the Middelvlei Reef was undertaken to aid the identification of the depositional environment, to determine the location of the source area(s) and to predict sedimentological changes in more distal or more proximal parts of the depositional environment.

4.5.2. CROSS-BEDDING

Palaeocurrent directions were determined at 13 localities by measuring the directions and maximum dips of foresets of cross-bedding. Readings were next individually corrected for tectonic dip on a stereographic net, as described by Potter and Pettijohn (1963, p259). An arithmetic mean was calculated for each locality by dividing the sum of the azimuths by the number of readings, as suggested by Selley (1976, p235). The results (Fig. 14 and Appendix II) reveal a unidirectional southerly orientated flow in the eastern part of the mine and a unidirectional easterly directed flow in the western part of the mine. This suggests that two populations of transported material were present. The
mine lease area was therefore subdivided by an arbitrary north-south line through No. 1 shaft and two mean directions were calculated (Fig. 14). Mean flow direction in the eastern part of the mine was 150.5° and 092° in the western part (Fig. 14).

4.5.3. TRENDS OF BASAL SCOURS

Basal scours like that shown in figure 11, were used to determine flow trends at four localities, where the scours could be observed in three dimensions (Figure 14 and Appendix III). The direction of a line joining points of equal thickness was taken as the trend of flow. The orientations in question yield only the sense of current flow and it is not possible to distinguish the direction towards which the current flowed. However, if the results are examined together with structures that yield both sense and direction, such as cross-bedding, the direction of flow can be deduced. The long axes of scours are parallel to the flow direction of the cross-bedding and scours therefore also suggest a southerly orientated flow in the eastern part of the mine. This direction corresponds to the north-south trend of thicker reef zones on the isopach map (Fig. 10).
4.5.4. INTERPRETATION

Cross-bedding directions and basal scour orientations which have a general direction south-south-east in the eastern part of the mine, indicate transport of sediment from the north. In the western part of the mine where the mean direction is 92°, transport was from the west and the source area may have been situated in that direction as well.

The palaeocurrent distribution in both the eastern and western parts of the mine is unimodal and according to Selley (1976, p237) this may be indicative of a fluvial depositional environment.

4.6. MEAN PEBBLE SIZE AND SORTING

4.6.1. PURPOSE

The aims with the investigation of pebble sizes were the following :-

(a) To obtain mean sizes which can be compared to those of the Middelvlei Reef in other areas and to those of other Witwatersrand conglomerates.

(b) To determine a lateral size variation pattern on the mine for possible correlation with gold values.

4.6.2. METHODS

Blatt et al. (1972, p44) consider the basic concept of size to be either a linear dimension or the volume of the particle. In the case of a very well consolidated
sedimentary rock such as the Middelvlei Reef, determination of the volume of the clasts is completely impractical and a linear dimension has to be adopted to express size. Size determination by this method in section has the disadvantage of apparent, rather than true linear dimensions being observed. Blatt et al. (1972, p55) therefore suggested a standardized method of size measurement in section. Most researchers of Witwatersrand conglomerates (e.g. Minter, 1976) have chosen the apparent long axis as a way of expressing size and it was decided to follow this convention.

Two methods are being used by researchers to obtain mean pebble sizes for Witwatersrand conglomerates. One technique is to determine an arithmetic mean of a specified minimum number of pebbles of all sizes, that is, the entire population (Armstrong, 1968). An alternative method, which is faster in producing results, is that of ignoring the smaller size fraction and determining a mean for a specified number of the largest pebbles of the population (Armstrong, 1965; Minter, 1978). Both methods were used in this study.

To determine the minimum number of pebble sizes to be measured in order to obtain a reliable, meaningful mean size, preliminary tests were carried out. The mean sizes and standard deviations were determined for 25, 50, 75 and 100 pebbles in 15 - 15 MR Dr E (Fig. 7) and the
FIG. 15 PRELIMINARY TEST OF PEBBLE SIZE DETERMINATION METHODS
results plotted graphically (Fig. 15). From the graphs it can be seen that there is little variation in the parameters after 50 measurements. This figure was therefore chosen as a minimum.

4.6.3. MEAN OF THE ENTIRE POPULATION

A mean pebble size was determined by measuring the long axes of at least 50 pebbles, in traverses normal to tectonic dip, at each of 27 localities. For each locality a stratigraphic profile was recorded, pebble size histograms and cumulative curves constructed and the mean size, standard deviation and sorting coefficient calculated (Appendix Ia - Iz). The following formulae were applied to calculate parameters:

Mean Size: \[ x = \frac{\sum x}{n} \]

Standard deviation: \[ s = \sqrt{\frac{n\bar{x}^2 - \left(\frac{1}{n}\sum x^2\right)^2}{n(n-1)}} \]

where \( x \) is the apparent long axes of pebbles and \( n \) the number of pebbles.

Sorting coefficient: \[ S_o = \frac{\phi_70 + \phi_80 + \phi_90 + \phi_97 + \phi_3}{\sqrt{\phi_{10} - \phi_{20} - \phi_{30}/9,1}} \]

where \( \phi_3, \phi_{10}, \ldots, \phi_{97} \) are percentiles on the cumulative curves.

The latter formula is considered by McCammon (1962) to be the most efficient to express sorting.

The results of the investigation (Appendix IV), plotted on a map and contoured, show a gradual decrease in size towards the south in the eastern part of the mine and a decrease towards the south-east in the western part of the mine (Fig. 16).
4.6.4. MEAN OF THE LARGEST PEBBLES

A mean of the coarse fraction of the pebble population was determined by measuring the long axes of the 20 largest pebbles occurring in a stratigraphic section with arbitrary surface area of 200 square centimetres of conglomerate and calculating an arithmetic mean. The width of the stratigraphic section in which the pebble axes were measured, was determined by dividing the total thickness of conglomerate beds into 200.

The results (Appendix IV, Fig. 17) display a distribution which is very similar to that obtained from the total population (Fig. 16).

4.6.5. INTERPRETATION

A gradual decrease in mean pebble size in the direction of the palaeocurrent (Fig. 14) is considered axiomatic by Smith (1980), and provides additional support for a fluvial origin of the Middelvlei Reef. The different size distribution patterns found in the eastern and western parts of the mine are in agreement with the different mean cross-bedding directions in these areas (Fig. 14).

Minter and Kingsley (1980) consider sorting, expressed by the standard deviation, as an indicator of proximal versus distal depositional environments and quote figures for conglomerates in the Orange Free State gold-field,
ranging from 1.34 φ (proximal Elsburg conglomerate) to 0.34 φ (distal Steyn Reef). If these figures are compared with the mean standard deviation for the Middelvlei Reef (0.64 φ), the depositional environment of the latter can be classified as intermediate to distal.

4.7. COMPOSITION OF PEBBLE ASSEMBLAGE

4.7.1. PURPOSE

The aims of this investigation were:

(a) To determine the various pebble types and their relative proportions in the Middelvlei Reef.

(b) To determine lateral variations, if any, of pebble composition.

4.7.2. METHOD AND RESULTS

Pebble assemblages were determined at 27 localities by recording the composition of at least 50 pebbles at each locality (Appendix V). This was done simultaneously with the mean pebble size determination.

To investigate a possible lateral variation of the pebble assemblage, the mine lease was again subdivided into an eastern and western area by a north-south dividing line through No. 1 shaft, and average compositions of pebble assemblage computed for each area (Table V, Fig. 14). In the eastern part there is a higher proportion of smoky quartz pebbles and a smaller percentage of chert and quartzite pebbles.
TABLE V: AVERAGE COMPOSITION OF PEBBLE ASSEMBLAGE FROM THE EASTERN AND WESTERN PARTS OF THE MINE

<table>
<thead>
<tr>
<th>PEBBLE TYPE</th>
<th>EASTERN PART</th>
<th>WESTERN PART</th>
</tr>
</thead>
<tbody>
<tr>
<td>White quartz</td>
<td>44,49 %</td>
<td>51,14 %</td>
</tr>
<tr>
<td>Smoky quartz</td>
<td>47,54 %</td>
<td>32,26 %</td>
</tr>
<tr>
<td>Opalescent blue quartz</td>
<td>2,76 %</td>
<td>4,87 %</td>
</tr>
<tr>
<td>Dark grey massive chert</td>
<td>3,64 %</td>
<td>5,56 %</td>
</tr>
<tr>
<td>Layered chert</td>
<td>0,53 %</td>
<td>0,83 %</td>
</tr>
<tr>
<td>Quartzite</td>
<td>1,16 %</td>
<td>5,31 %</td>
</tr>
</tbody>
</table>

4.7.3. INTERPRETATION

The differences in composition of the pebble assemblages of the eastern and western parts of the mine (Table V) supports the hypothesis of two geographically different source areas.

The pebble assemblages listed in Appendix V illustrate a remarkable maturity of the Middelvlei Reef conglomerates. Pettijohn (1957, p510) points out that maturity is the combined record of the time through which processes that drive a sediment towards its ultimate stable end-type, operated, and the intensity of such processes. An additional factor influencing maturity is the rock types present in the source area, an unknown factor in the case of the Middelvlei Reef.
4.8. CONGLOMERATE MATRIX

4.8.1. INTRODUCTION
A brief microscopic investigation was carried out on Middelvlei Reef specimens, taken at five localities in the mine. The aim was to acquire some knowledge of the minerals present in the reef matrix. Specimens were examined in both thin and polished section and the pebbles, which were studied macroscopically earlier, were ignored.

4.8.2. DETRITAL MINERALS
Quartz is the dominant detrital constituent, occurring as sub-rounded to sub-angular grains.

Pyrite is the most common heavy mineral. At least two types of rounded pyrite were recognised, a compact type and a porous variety (Fig. 18a).

Rutile is a very common detrital constituent in the Middelvlei Reef and the grains are commonly well rounded.

Chromite occurs less frequently than rutile, but these grains, too, are well rounded.

Uraninite is abundantly present in a sample taken in 7–8 Cross-cut South (Fig. 7), but occurs less frequently elsewhere. The mineral always has small inclusions of galena and is invariably associated with carbon, either
(a) Two types of detrital pyrite: compact (1) and porous (2).

(b) Uraninite (1), carbon (2), galena (3) and gold (4).

FIG. 18: PHOTOMICROGRAPHS OF SOME CONSTITUENTS OF THE REEF MATRIX
enclosed in the latter, or itself having internal carbon veinlets (Fig. 18b).

Zircon occurs fairly commonly. Crystals are all pink and rounded, except where the grains are fractured. The mineral was observed in greater numbers in samples taken in the western part of the mine than in the east.

Arsenopyrite and cobaltite grains occur rarely. Their observed maximum sizes are smaller than the maximum pyrite grain size.

Sericite is present in all specimens examined, occurring as small flakes which are usually yellow under crossed nicols.

Gold grains (Fig. 18c) are present in small numbers sometimes associated with carbon. Some rounded grains were observed, but others are often deformed.

4.8.3. INCLUSIONS
Chalcopyrite, pyrrhotite and sphalerite do not occur as detrital grains, but are common inclusions in rounded, compact pyrite. Gold is occasionally found enclosed in compact detrital pyrite (Fig. 18d).

4.8.4. AUTHIGENIC MINERALS AND UNDIFFERENTIATED CONSTITUENTS
Chlorite is present as pale green scaly aggregates in
FIG. 18: PHOTOMICROGRAPHS OF SOME CONSTITUENTS OF THE REEF MATRIX
all thin sections examined. Chloritoid is a common authigenic mineral, occurring as needle-like crystals.

Galena is closely associated with uraninite and is present in grains of the latter and/or in an aureole surrounding the grain.

Authigenic pyrite is found as overgrowths on detrital pyrite grains.

Carbon occurs together with galena as veinlets in and as aureoles surrounding uraninite. It also occurs independently as round grains, dark grey and anisotropic in polished section. Microscopically, carbon could not be classified without doubt.

4.8.5. DISCUSSION

All the minerals found in the Middelvlei Reef are listed by Feather and Koen (1975). Saager (1970) recognised five types of rounded pyrite in the Basal Reef in the Orange Free State. It is possible that more of these varieties are present in the Middelvlei Reef, in addition to the two mentioned, but not be recognised. Gold inclusions in detrital pyrite were also recorded by Saager (1970), Ramdohr (1958) and Liebenberg (1955).

Because the specimens examined represent only a limited number of localities, conclusions regarding a lateral
variation of the mineral assemblages cannot be drawn. There are, however, indications that these may be different in the eastern and western parts of the mine.

4.9. CARBON

4.9.1. OCCURRENCE

In contrast to the Carbon Leader, carbon is not often conspicuous in the Middelvlei Reef. The usual mode of occurrence is small nodules known as "fly specks". These are found on pebble surfaces and in the matrix of the uppermost centimetre or less of conglomerate beds. The vast majority of occurrences of carbon were found in the area of thin reef south-east of Annan Shaft. The best development of carbon here was found in 15 - 7 MR Cross-cut (Fig. 7) where a carbon lamina reaches a thickness of two millimetres (Fig. 19). It is noteworthy that this relatively thick lamina is overlain by quartzite, rather than conglomerate, which is the common mode of occurrence.

4.9.2. INTERPRETATION

Carbon in Witwatersrand rocks is well-studied and various theories on its origin have been formulated. Hallbauer (1975) has provided convincing evidence that at least some of the carbon in Witwatersrand rocks represents the remains of primitive algae. It has been suggested by Pretorius (1966) and Nami (1982) that these primitive organisms grew and multiplied under relatively quiet
FIG. 19  SECTION AND PROFILES SHOWING MODE OF OCCURRENCE OF CARBON
environmental conditions. The mode of occurrence of carbon in the Middelvlei Reef supports the abovementioned hypothesis. The occurrence in the uppermost portions of conglomerate beds is interpreted as evidence for periods of non-deposition between successive sedimentary cycles (Smith and Minter, 1980). During these periods, environmental conditions were sufficiently quiet to permit the growth of algae. The fact that the carbon lamina shown in figure 19 is stratigraphically correlatable with a siltstone lamina, which was deposited under quiet conditions, supports this hypothesis.

The anomalous thickness of carbon in 15 - 7 MR Cross-cut can be attributed to better preservation of the algal remains because the carbon lamina is overlain by quartzite, indicating lower energy conditions and less erosion.

The reason for the infrequent occurrence of carbon in the Middelvlei Reef, compared to the Carbon Leader could be due to one or both of the following:

(a) Stable conditions with little sediment influx, suitable for algal growth, prevailed in only small areas in the depositional environment.

(b) Most of the algae and their remains were washed away during the high energy peaks of sedimentary cycles.
An important implication of the occurrence of carbon is that it represents a period of little deposition, approaching the state of equilibrium (Selley, 1976 p247), during which extensive reworking of sediments could take place.

The fact that carbon occurs predominantly in areas of thin reef suggests that these are areas of higher palaeorelief in which quiet conditions prevailed between sedimentary cycles. The alternative interpretation that thin reef was produced in channel areas by prolonged winnowing, therefore seems unlikely.

4.10. SYNDEPPOSITIONAL FAULTING

4.10.1. OBSERVATIONS

During this study several examples of syndepositional faulting which affected the lithology and/or thickness of the reef, were observed. One locality was mapped in detail (Fig. 20) and indicates thinning of the reef towards the faults with one fault not penetrating the top of the reef. The strikes of the faults shown are roughly 045°, which corresponds to the trend of the older set of faults and dykes discussed in chapter 2.

4.10.2. INTERPRETATION

The syndepositional faulting described above could be proof of tectonic activity during the deposition of the Middelvlei Reef. It is, however, possible that the
FIG. 20  SECTION SHOWING THE EFFECT OF FAULTING UPON REEF ZONE THICKNESS
faults were formed because of differential compaction of sand and silt present in the footwall succession. Clay- and silt-sized particles undergo a higher degree of compaction than sand (Friedman and Sanders 1978, p145). It is also possible that the faults in question represent a type of growth fault (Elliot 1981, pl41). However, the mechanism proposed by Bruce (1973) for the origin of the classical growth faults associated with prograding deltas, requires relatively thick silt layers overlain by sand of higher density. This situation is not found in the footwall of the Middelvlei Reef. Whatever the origin of the faults in question, it is certain that they had an effect upon the sedimentological micro-environments. The primary result of the faulting was a variation in relief of the depositional surface which resulted in variations in stream velocities and the forming of vortices (Allen 1977, p40-42).
5. RELATIONSHIP BETWEEN GOLD DISTRIBUTION AND SEDIMENTOLOGICAL PARAMETERS

5.1. INTRODUCTION

In this chapter the distribution of gold in the Middelvlei Reef is illustrated by means of maps and statistical procedures and, where possible, interpreted geologically.

Because the gold grades of a mine are considered confidential information, all those mentioned in this and subsequent chapters are expressed in terms of units derived by multiplying the actual grades by a non-standard factor. In the case of the isocon map (Fig. 32) confidentiality is maintained by not specifying the contour values and intervals.

5.2. GOLD DISTRIBUTION IN VERTICAL PROFILE

5.2.1. PURPOSE AND METHOD

To investigate the gold distribution in vertical profile and the relationship between gold grade and lithofacies, detailed sampling of the reef zone was combined with the recording of sedimentological data at seven localities. At each locality lithofacies boundaries were used to divide the reef into units to be sampled. In each unit the mean size of the ten largest pebbles occurring in a section with a surface area of 100 square centimetres was determined by measuring the long axes. Next a measure of the pebble packing density in each unit was obtained by
superimposing a one centimetre grid on the section area and determining the proportion of pebbles present at the intersection points of lines. This method was used by Theis (1979). Sampling was done by chipping and the samples assayed for gold by the Assay Laboratory of West Driefontein Mine.

5.2.2. RESULTS

Scatter diagrams were constructed by combining the results of the seven localities (Appendix VI) and plotting the data graphically (Figures 21 and 22). The method of least squares was used to determine the coefficient of determination ($r^2$) for the pairs of variables substituted into linear, exponential, logarithmic and power equations. The theory of these statistical exercises is described by Spiegel (1972) and the results listed in Table VI.

### Table VI: Correlation between Gold Grade, Pebble Packing Density and Mean Pebble Size for Linear, Exponential, Logarithmic and Power Best Curves

<table>
<thead>
<tr>
<th>VARIABLES</th>
<th>COEFFICIENT OF DETERMINATION ($r^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LINEAR EXPONENTIAL LOGARITHMIC POWER</td>
</tr>
<tr>
<td>Pebble packing density</td>
<td>Gold Grade</td>
</tr>
<tr>
<td>Mean pebble size</td>
<td>Gold Grade</td>
</tr>
</tbody>
</table>
FIG. 21  SCATTER DIAGRAM OF GOLD GRADE AGAINST PEBBLE PACKING DENSITY

FIG. 22  SCATTER DIAGRAM OF GOLD GRADE AGAINST MEAN PEBBLE SIZE
5.2.3. CONCLUSIONS AND INTERPRETATION

The very low values of the calculated coefficients of determination (Table VI) indicate that there is no sound proportional relationship between either gold grade and pebble packing density or gold grade and pebble size. However, the low density of points above the arbitrary lines \( xx' \) and \( yy' \) in Figures 21 and 22, suggests that samples with low pebble packing densities or small pebble sizes yield predominantly low gold grades. Minter (1978), in his investigation of the Basal and Steyn Reefs in the Orange Free State, found a regional lateral decrease in gold concentration, accompanied by a sympathetic decrease in pebble size. Theis (1979), reporting on the Elliot Lake uranium deposits, Ontario, Canada, found a weak positive correlation between pebble size and the uranium content of the conglomerates. He also found a weak positive correlation between pebble packing density and pebble size and combined the mentioned relationships to arrive at the conclusion that the better packed, coarser-grained conglomerates have the highest uranium content.

The fact that no proportional relationship exists between pebble size and gold grade, sympathetic or antithetic, leads to the conclusion that the gold particles and the pebbles are not in hydraulic equilibrium and were not deposited together. It is suggested that the pebbles were deposited first from bedload, thus creating an open
framework gravel, with the rest of the sediment load still in suspension or saltating. During waning of the flood, this open framework gravel acted as a trap to capture the gold and other heavy minerals. This concentration process was proposed for the Ventersdorp Contact Reef on South Roodepoort Mine by Minter and Toens (1970). The occurrence of open framework gravels and the above-mentioned sequence of deposition of size fractions have been found by Rust (1978) in the braided stream environment.

5.3. CORRELATION BETWEEN GOLD VALUES AND SEDIMENTARY PARAMETERS BY AUTOMATIC INTERACTION DETECTION

5.3.1. INTRODUCTION

Automatic Interaction Detection (A I D) is a form of multivariate analysis where a dependant variable, for example gold grade, is related to a number of independant (predictor) variables, such as sedimentary parameters. The system itself is purely statistical and has a wide application, mainly in the financial and business world. It has, however, been used successfully to investigate the gold distribution characteristics of the Carbon Leader (Nami, 1982).

A computer programme, designed by Heymann (1981) was used to execute the analysis through the Chamber of Mines Research Organization.

The aim with the analysis is the construction of a
dendrogram (tree diagram) which provides a quantitative relationship between the mean gold grade of an area, such as a mine lease, and sedimentary parameters of the reef.

The main application of a dendrogram for a gold-bearing reef is in the field of exploration, where it can be used to assist in the assessment of the economic potential of an area. It also serves the purpose of revealing relationships between geological parameters and gold grade which can then be further investigated and interpreted. The A I D analysis is illustrated by a flow diagram (Fig. 23).

5.3.2. COLLECTING OF DATA

The A I D analysis, as applied to a placer gold-bearing reef, requires the collection at different localities of various sedimentary parameters which can be compared to gold grades. It is therefore essential that the gold grades are known at the exact localities where the parameters are recorded and ideally the recording should be done at the same time as sampling. Alternatively, previously sampled sites can be re-located and their sedimentological parameters recorded. Both methods were used during this analysis.

The data were recorded underground on standard forms, which also served as a checklist. At each locality a stratigraphic profile was drawn to scale and the
Data collection (100–several thousand cases required).

Correlation and regression analysis.

Dependant variable data and predictor variables showing significant correlation with dependant data fed into computer.

**f-test**

The best possible division of dependant variable data is determined by analysis of variance (f-test) performed on the split/merged predictor groupings. If the most significant predictor is smaller than the built-in program significance level then splitting can take place.

**split/merge operation**

Subcategories of each predictor variable are tested against each other for homogeneity (t-test).

split/merge operation

**f-test**

if the most significant predictor is larger than the built-in significance then this group cannot be split and is a TERMINAL one.

split/merge operation

**f-test**

if the most significant predictor is smaller than the program significance then the splitting takes place again.

**FIG. 23. A.I.D. FLOW DIAGRAM** (COURTESY OF R.N. McNEILL).
sedimentary features, listed in Table VII, recorded. The different lithofacies were classified as follows:

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>PEbble Packing Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clast-supported conglomerate</td>
<td>30 %</td>
</tr>
<tr>
<td>Matrix-supported conglomerate</td>
<td>20 - 30 %</td>
</tr>
<tr>
<td>Quartzite with scattered pebbles</td>
<td>15 - 20 %</td>
</tr>
<tr>
<td>Quartzite with occasional pebbles</td>
<td>15 %</td>
</tr>
<tr>
<td>Quartzite (no pebbles)</td>
<td>-</td>
</tr>
<tr>
<td>Siltstone</td>
<td>-</td>
</tr>
</tbody>
</table>

**TABLE VII**: LIST OF SEDIMENTARY PARAMETERS RECORDED FOR EACH LOCALITY IN THE A I D ANALYSIS

(a) Type of lithofacies
(b) Colour of conglomerate matrix or quartzite
(c) Type of cross-bedding, if noticeable
(d) Grading of conglomerates
(e) Mean maximum pebble size
(f) Degree of pyrite mineralization (absent, poor, good or very good)
(g) Mode of occurrence of pyrite (disseminated or concentrated)
(h) Position of pyrite concentration, if any, within the particular unit
(i) Presence of carbon

From the recorded profiles additional parameters, such as thicknesses, were calculated. The complete list of parameters considered can be seen in Table VIII. The
total number of samples used in the analysis was 150.

5.3.3. PRELIMINARY REGRESSION AND CORRELATION ANALYSIS

After collection of the data a regression and correlation analysis was carried out to test the significance of the possible predictor variables.

The first action was an investigation of the frequency distribution of the gold grades by drawing a cumulative percentage frequency curve on logarithmic probability paper (Fig. 24). A straight line was obtained indicating that the gold grades have a log-normal distribution, which is a requirement for use in the computer. A gold grade frequency histogram was constructed for the grades converted to common logarithms (Fig. 25). This too indicates a close approach to the ideal log-normal distribution.

The potential predictor variables were next each fed, together with the logarithmic gold grades, into a pocket calculator, which calculated the following statistics for each predictor variable for linear regression:

\[(y = A + Bx)\]

Mean gold grade : \( \bar{x} \)

Mean of predictor variables : \( \bar{y} \)

Covariance : \( s_{xy} = \frac{\sum xy}{n} \)

Correlation coefficient : \( r = \sqrt{\frac{s_{xy}}{s_x s_y}} \)
FIG. 24 GOLD GRADE CUMULATIVE FREQUENCY CURVE

FIG. 25 GOLD GRADE FREQUENCY HISTOGRAM
"Student's t" : \( t = r \sqrt{\frac{n-2}{1-r^2}} \)

Regression coefficient A : \( A = \frac{\Sigma Y(\Sigma X^2 - (\Sigma X)^2)}{n(\Sigma X^2 - (\Sigma X)^2)} \)

Regression coefficient B : \( B = \frac{\Sigma XY - (\Sigma X)(\Sigma Y)}{\Sigma X^2 - (\Sigma X)^2} \)

The theory of the above statistics and the derivation of the above formulae are discussed by Spiegel (1972, pp45, 243-245, 188, 242). The above statistics for each predictor variable, paired with the gold grade, are listed in Table VIII. The level of significance, discussed by Spiegel (1972, p168) was read from a table presented by Siegel (1956, p248), in which the values for "t" are listed against the number of samples.

In addition to the above linear regression analysis, reef thickness was tested for an exponential correlation with gold grade and a slightly better t-value was obtained.

Because some of the above-mentioned variables are closely related, for example (a) and (b), some were omitted from the final A I D analysis.

5.3.4. CATEGORIZING OF THE PREDICTOR VARIABLES

A requirement of the A I D analysis is that all predictor variables be in categorized form, before the data are fed into the computer. It was therefore necessary to transpose those predictors which are on a continuous scale (e.g. reef thickness) into categorized form. This was done through the construction of cumulative percentage frequency curves for reef thickness (Fig. 26),
FIG. 27 PEBBLE SIZE CUMULATIVE FREQUENCY CURVE

FIG. 26 REEF THICKNESS CUMULATIVE FREQUENCY CURVE
FIG. 28 PERCENTAGE CONGLOMERATE CUMULATIVE FREQUENCY CURVE

FIG. 29 PERCENTAGE "DARK" CONGLOMERATE CUMULATIVE FREQUENCY CURVE
mean maximum pebble size (Fig. 27), percentage conglomerate (Fig. 28), percentage conglomerate with a dark matrix (Fig. 29) and percentage internal quartzite (Fig. 30). In most of the curves one or more changes in the gradients occur which possibly indicates different groups or populations of the samples and this was taken as the best basis for determining the limits of the categories. In Figure 29, for example, changes occur at 25% and 62% cumulative frequency, corresponding to 0% and 55% internal quartzite respectively. Therefore, in this case the samples were grouped into three categories:—

Samples with no internal quartzite (Category 1)
Samples with 0,5% to 55% internal quartzite (Category 2)
Samples with more than 55% internal quartzite (Category 3)

"Correct" categorizing of the predictor variables is not critical in the A I D analysis, since one of the functions of the computer is the combination or subdivision of categories where necessary.
# TABLE VIII: Levels of Significance of Predictor Variables Tested Against Gold Grade

## Positive Correlation

<table>
<thead>
<tr>
<th>Predictor Variable</th>
<th>Level of Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) Percentage conglomerate with a dark matrix</td>
<td>0.001</td>
</tr>
<tr>
<td>(b) Percentage conglomerate with a dark matrix plus dark quartzite with scattered pebbles</td>
<td>0.001</td>
</tr>
<tr>
<td>(c) Percentage conglomerate</td>
<td>0.01 to 0.001</td>
</tr>
<tr>
<td>(d) Thickness of conglomerate with a dark matrix</td>
<td>0.02 to 0.01</td>
</tr>
<tr>
<td>(e) Number of conglomerates, directly overlain by another</td>
<td>0.1 to 0.05</td>
</tr>
<tr>
<td>(f) Mean maximum pebble size</td>
<td>0.2 to 0.1</td>
</tr>
<tr>
<td>(g) Thickness of conglomerate with a dark matrix plus dark quartzite with scattered pebbles</td>
<td>0.20</td>
</tr>
</tbody>
</table>

## Negative Correlation

<table>
<thead>
<tr>
<th>Predictor Variable</th>
<th>Level of Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>(h) Reef thickness</td>
<td>0.001</td>
</tr>
<tr>
<td>(i) Number of conglomerate beds</td>
<td>0.001</td>
</tr>
<tr>
<td>(j) Number of sedimentary cycles</td>
<td>0.001</td>
</tr>
<tr>
<td>(k) Number of horizons of pyrite concentration</td>
<td>0.01 to 0.001</td>
</tr>
<tr>
<td>(l) Number of beds with very good pyrite concentration</td>
<td>0.01 to 0.001</td>
</tr>
<tr>
<td>(m) Total conglomerate thickness</td>
<td>0.02 to 0.01</td>
</tr>
<tr>
<td>(n) Percentage internal quartzite</td>
<td>0.05 to 0.02</td>
</tr>
</tbody>
</table>
The categories of the selected predictor variables were coded and entered, together with the gold grades onto computer data input forms. These were submitted to the Chamber of Mines Research Organization for entry into the computer and processing.

5.3.5. COMPUTER FUNCTIONS

The various computer functions are described by Heymann (1981) and McNeill (1983) and only a summary of the sequence of actions will be given here.

The first stage is the merge operation. The computer lists all gold grades associated with each category of all predictor (sedimentary) variables. In the case of the predictor variable "percentage internal quartzite" mentioned in 5.3.4., for example, there are three groups of grades, corresponding to the three categories, that is:

- Group 1 corresponding to category 1
- Group 2 corresponding to category 2
- Group 3 corresponding to category 3

The computer then calculates variances and levels of significance for each group and compares these statistics to those of adjacent groups. In the example above, the statistics of group 1 are compared to those of group 2 and those of the latter to those of group 3. If any two groups are not significantly different, they will be merged. The criterion for this action was a level of
significance of 0.05 which was fed into the computer beforehand.

The computer next moves into the split part of the operation. Within groups of gold grades of the predictor variables, all possible combinations of two or more grades are examined for possible two-way splits. The criterion was a given level of significance (0.049), which is slightly smaller than that for merging to prevent infinite looping. If there are any significant splits in any group, the group will be subdivided. The split/merge procedure continues until no more splitting or merging can take place, at which stage grouping is finalized.

During the next stage all groups of predictor variables are subjected to analysis of variance (f-test, Fig. 23) to determine if there is a significant difference in the mean values of the groups. The predictor variable with the most significant results is then used as basis for subdivision of the population into two groups. The variance analysis is now applied to each of the newly formed subgroups, which are in turn subdivided into two. This procedure is continued until no further subdivision of groups is possible.

5.3.6. RESULTS AND CONCLUSIONS
Based upon the subdivision of the population as described in 5.3.5., a dendrogram was constructed (Fig. 31), which
FIG. 31 MIDDELVLEI REEF A.I.D. DENDOGRAM
indicates the splitting variable (the basis for each subdivision), the mean gold grade of each class and the frequency of samples in each class.

The A I D dendrogram indicates a strong antithetic relationship between gold grade and reef thickness. The subdivision based upon the presence of internal quartzite illustrates the "diluting" effect that quartzite beds within the reef have upon gold grade. An antithetic relationship between gold grade and the number of conglomerate beds is also suggested.

It is noteworthy that pebble size is not a splitting variable in the dendrogram, illustrating the low importance of this predictor.

5.4 LATERAL VARIATION OF GOLD GRADE

5.4.1. TRENDS

An isocon map of the eastern part of the mine, showing gold concentration over reef thickness (Fig. 32), was constructed from data extracted from sampling records, applying the methods devised by Krige, mentioned in 4.2.1. The map reveals the following:

(a) An area of relatively high gold concentration in the north-east,

(b) A distinct north-north-east to south-south-west trend, particularly noticeable between No. 1 shaft and No. 1 sub-vertical shaft.

When the isocon map (Fig. 32) is compared to the isopach
map (Fig. 10), it can be seen that areas of higher grade correspond to areas of thin reef. This finding is in correspondence with the A I D analysis. To facilitate comparison, a simplified isocon map, which may be superimposed on the isopach map, is submitted.

Superposition of a simplified structural map on the isocon map indicates that the north-north-easterly trend of gold grades corresponds well to that of faults and dykes. This direction is roughly perpendicular to the palaeocurrent direction.

5.4.2. INTERPRETATION
The antithetic relationship between gold grade and reef thickness can be attributed to two factors, namely a higher proportion of quartzite beds in the thicker reef zones, and winnowing and reworking.

Data presented in Appendix VI and discussed earlier indicate that the quartzite facies of the reef is usually almost devoid of gold and the quartzite can therefore be considered to have a "diluting" effect upon the gold grade. The variation of stream competencies during the deposition of the Middelvlei Reef is manifested by the typical fining upward sedimentary cycles described. It is proposed that the quartzite beds in question have their origin in the deposition of sand during waning floods in parts of lower relief of the depositional area, while parts of higher topography were no longer covered
by water. Trough cross-bedded quartzite units were formed by migrating dune fields in channels while planar cross-bedded units have their origin in migrating transverse bars.

Winnowing and reworking probably played an important role in the concentration of gold in areas of thin reef. Winnowing is considered to be a process where lighter (finer grained or lower density) material is removed from an already deposited sediment by the transporting agent. This is considered by Gary et al. (1974, p795) as an aeolian process and they prefer the term "washing" for the aqueous analogue. Applied to a gravel such as that of the Middelvlei Reef, the process would result in a concentration of heavy minerals, among them gold, and a reduction in the thickness of the bed.

Reworking is considered a process during which previously deposited sediments are subjected to additional cycles of local erosion, transport and deposition. In highly aggradational braided stream environments this process may not be very effective, because older sediments are continuously buried by younger sediment. A decrease in aggradation, however, would lead to better reworking and sorting of the sediment. This condition may be a prerequisite for gold concentration in certain reefs and the principle can be applied to explain why most other conglomerate beds in the succession, described in chapter
3, are barren. If a succession of interbedded gold-bearing gravels and barren sand layers is reworked, a single gravel layer, containing all the gold from the original multiple succession, is deposited, while the sand layers are eliminated (Fig. 33). The A I D dendrogram (Fig. 31) reveals a striking difference in gold grade between reef types with one or two conglomerate beds and types containing more than two. The reason for this phenomenon could be that two main events of reworking occurred between situations 1 and 2 and between 3 and 4 in Figure 33, which resulted in the concentration of gold into no more than two conglomerates in the higher grade reef types.

Areas favourable for effective reworking and winnowing would be either in very shallow water on gravel and sand bars or alternatively in zones of flow convergence in braid channels. A situation produced by the latter alternative was found by Smith and Beukes (in press) when studying magnetite concentrations in two South African rivers. Smith and Minter (1980) proposed this mechanism for gold concentration in Witwatersrand placers. It has been concluded in 4.9.2. that areas of thin reef do not represent channels. This, viewed together with the association of thin reef and higher gold grades, leads to the conclusion that the latter mechanism was not an important gold concentration process of the Middelvlei Reef.
1. Deposition of 4 cycles

2. Deposition of 3 additional cycles

3. Re-working

4. Continued re-working

5. Legend

- Silt
- Sand
- Gravel

Not to scale

Fig. 33 Schematic representation of reworking process
The coincidence of certain isocon trends with structural features can be explained by postulating that minor syndepositional faulting, described in 4.10., created a series of grabens and horsts. Winnowing on the latter produced a thinner, higher grade gravel, while reduced stream competency in the grabens resulted in the deposition of barren sand on gravel with a lower gold grade, because of the lack of winnowing (Fig. 34).
1) Deposition of a Gravel Layer

2). No Deposition. Minor faulting

3) Winnowing of Reef Material on the Horst. Deposition of sand in the grabens

4) Deposition of a Second Gravel Layer

5) No Deposition Continued Movement along Faults

6) Further Winnowing and Deposition in Grabens, followed by the deposition of an additional gravel layer

NOT TO SCALE

FIG. 34  SCHEMATIC PRESENTATION OF PROPOSED SECONDARY GOLD CONCENTRATION PROCESS
6. SEDIMENTOLOGICAL MODEL

6.1. SUMMARY OF THE INTERPRETED SEDIMENTOLOGICAL AND GOLD DISTRIBUTION CHARACTERISTICS

To facilitate the compilation of a sedimentological model necessary to conclude this dissertation, the following summary of the interpreted sedimentological and gold distribution characteristics is given.

The footwall succession: It was concluded that the Green Bar was deposited in a lacustrine environment. The lithofacies, typical facies assemblages and unimodal palaeocurrent direction of the quartzites and conglomerates of the succession indicate a fluvial origin for these. It was concluded that the depositional environment was a sandy braided stream system.

Variation of reef thickness: The variation of reef thickness is attributed to:

(a) Scouring of the footwall during deposition of the reef
(b) An uneven predepositional footwall relief.

Lithofacies: The lithofacies found in the Middelvlei Reef are interpreted in terms of processes typical of the braided stream environment.

Lithofacies Assemblage: Stratigraphic profiles recorded for the Middelvlei Reef are similar to the Donjek type of Miall (1978). The occurrence of a single
cycle type facies assemblage is interpreted to be mainly the result of erosion and reworking of previously deposited sequences. A condition approaching equilibrial sedimentation is implied.

Palaeocurrent direction: The different mean palaeocurrent directions found in the eastern and western parts of the mine possibly indicate two geographically different entry points into the basin. The unidirectional nature of the palaeocurrents found in both mentioned areas, supports the hypothesis of a fluvial environment.

Pebble size and sorting: The gradual decrease in mean pebble size in the palaeocurrent directions provides additional support for a fluvial origin of the Middelvlei Reef. Based upon the sorting of the pebble population, the depositional environment can be classified as intermediate to distal, relative to environments of other gold-bearing conglomerates.

Composition of pebble assemblage: The different mean pebble assemblages found in the eastern and western parts of the mine supports the hypothesis of two geographically different entry points.

Carbon: The carbon present in the Middelvlei Reef is proposed to be the fossil remains of primitive algae. The occurrence of carbon at the top of conglomerates is
interpreted as indicative of periods of non-deposition between sedimentary cycles. This implies a relatively low rate of sedimentation. The relative infrequent occurrence of carbon is suggested to be partially due to the elimination of much of the algae and their remains during the high energy peaks of sedimentary cycles.

Syndepositional faulting: This phenomenon was shown to have had an effect upon the deposition of the reef. The syndepositional faulting could be a manifestation of early tectonic activity and can be interpreted as indicative of a relatively long period of deposition of the Middelvlei Reef (low aggradation).

Gold distribution within the stratigraphic profile: It was found that the gold is concentrated predominantly in the conglomerate facies. It was concluded that the gold particles were not in hydraulic equilibrium with the pebbles and deposited after the latter, trapped in an open framework gravel. An antithetic relationship between gold grade and reef thickness, revealed by Automatic Interaction Detection, was attributed to reworking and winnowing as well as a higher proportion of quartzite in thicker reef types.

Lateral variation of gold grade: Comparison of isocon and isopach maps of the same area confirmed the antithetic relationship between gold grade and reef
thickness. The coincidence of certain isocon trends with structural features was interpreted as the result of sediment winnowing in areas of higher relief, created by minor syndepositional faulting.

6.2. MODEL FOR STRATIGRAPHIC/ENVIRONMENTAL SETTING OF THE MIDDENVLEI REEF

The transition from the proposed lacustrine environment in which the Green Bar was deposited to the interpreted fluvial environment of the footwall succession, requires regression of the lake. The law of Succession of Facies of Walther, quoted by Blatt et al. (1972), states that "only those facies and facies areas can be superimposed primarily, that can be observed beside each other at the present time". A shoreline deposit should therefore separate the lacustrine shale from the fluvial quartzite in the stratigraphic profile. In the recorded profile of the footwall succession (Fig. 8) a number of very mature siliceous quartzite units occur, which can be interpreted to be the result of washing by wave action. Collinson (1981, p67), however, points out that shoreline deposits of lakes are neither thick nor compositionally mature. It can therefore be expected that it would be difficult to distinguish them from fluvial deposits. Based upon the sharp upper contact of the Green Bar it is concluded that regression, or at least its initial stage, was rapid.

The vertical profile of the succession from the top of the Green Bar to the base of the Middelvlei Reef (Fig. 8)
indicates that there is very little evidence of breaks in deposition and of erosion. Features that would indicate such conditions are:–

(a) Prominent scours.
(b) Frequent occurrence and greater thickness of siltstone beds and laminae (Facies Fm), interpreted to form in pools of standing water.
(c) The presence of carbon, which indicates stable conditions with little or no sediment influx.

In terms of an environmental classification by Selley (1976, p246) the succession can therefore be classified as a dominantly depositional (aggradational) sandy braided stream environment.

3. DEPOSITIONAL MODEL FOR THE MIDDELVLEI REEF

Based upon the sedimentological data (section 6.1.), it is concluded that the depositional environment of the Middelvlei Reef was an alluvial plain, bounded by a distant area of high relief, which stretched in an arc from the west to the north. Depositional directions were towards the south-south-east in the eastern part and towards the east in the western region. The area of high topography yielded abundant coarse-grained sediment, which was fed into the alluvial plain, via several distant alluvial fans and dispersed in the plain by braided stream processes. Deposition took place in cycles by consecutive high energy floods, decreasing
gradually to low energy or possibly zero flow. The gravel facies were deposited during high energy stages, when relatively large areas were covered by water. During such periods erosional scours developed in the footwall and previously deposited reef material. During ebb stages, flow was restricted to streams in areas of lower relief where the sand facies were deposited. During these stages, pools of stagnant water occurred in abandoned channels and shallow depressions where laminae and beds of silt were deposited. Primitive algae grew in quiet parts of the system during the mentioned low energy periods.

The high relief postulated for the source area is considered by Miall (1977) and Rust (1978) to be essential to create the relatively steep stopes required for the transport of coarse-grained sediments.

The sedimentary processes acting in the braided river environment are considered by Rust (1978) to be identical to those present in the alluvial plain environment. The latter term, however, is preferred to describe the Middelvlei Reef environment, because of the geometry of the deposit. According to Rust, (1978) "braided rivers are essentially linear, whereas alluvial plain deposits are two dimensional, the latter being much more extensive". Another significant difference between the two environments in question is the location of alluvial fans. Rust (1978) points out that alluvial plains are
transitional upslope to alluvial fan deposits, whereas fans present in braided river systems occur as lateral tributaries. This author also suggests that alluvial plain deposits are more likely to be preserved in the geological record.

From the above discussion, it can be seen that the proposed depositional environment for the Middelvlei Reef on Doornfontein Mine is considered part of a system which consisted of the following elements in order of decreasing relief: (Fig. 35).

(a) A source area of high relief.
(b) An alluvial fan system.
(c) A proximal braided stream environment with gravel as dominant facies.
(d) An intermediate braided stream area.
(e) A distal, sandy sub-environment.
(f) A lake.

Of these, the first three sub-environments were situated to the north and west of the mine lease area and were not preserved. Based upon an observed increase of the proportion of quartzite in the reef in the southern parts of the mine, it is possible that the fifth sub-environment is represented south of the southern boundary (Fig. 35). All the above-mentioned elements have been recognized by Miall (1977, 1978) and the last three are represented by his Scott, Donjek and South Saskatchewan profiles. Vos (1975), in his proposed regional model for
FIG. 35  DIAGRAMMATIC REPRESENTATION OF THE PROPOSED DEPOSITIONAL ENVIRONMENT OF THE MIDDELVLEI REEF
(Not to scale)
the Witwatersrand Supergroup, suggests a lacustrine environment as the terminal phase of the above-mentioned sequence.

From the sedimentological data summarized in 6.1. it is concluded that the depositional environment of the Middelvlei Reef was one of low aggradation, approaching equilibrium. Features indicating this are:--

(a) Prominent scours, which indicate periods of erosion.
(b) Frequent occurrence of siltstone beds which were deposited in standing water.
(c) The occurrence of carbon, suggesting periods of non-deposition or low sediment influx.
(d) The occurrence of syndepositional faults, which may imply a relatively long period of deposition.

Therefore, in terms of the processes of erosion and deposition, the depositional environment of the Middelvlei Reef is in sharp contrast to that of the footwall succession, which represents a dominantly aggradational sequence.

The transition from the sandy braided environment proposed for the footwall succession to the pebbly braided environment postulated for the Middelvlei Reef, is interpreted as a distal to proximal one. This interpretation is based mainly upon the higher proportion of conglomerate and larger pebble size of the reef.
6.4. GOLD DISTRIBUTION IN THE PROPOSED MODEL

The trapping of gold particles in an open framework gravel was proposed as the primary gold concentration process. Winnowing and reworking are proposed as secondary concentration processes. The first stage of reworking is erosion of previously deposited material and this is an integral part of braiding. Minter (1980) considers the reworking process in terms of upstream "point sources" of heavy minerals, which supplied sediment to a deposit formed downstream.

During winnowing only the low mass fraction of a previously deposited sediment layer is removed; a situation which requires a rather special stream velocity. Nami, (1982) states that gold grains, once settled, tend to remain where they are on the stream bed, while hydraulically equivalent quartz grains can relatively readily be transported again. If this finding is accepted, the proposed concentration of gold by winnowing, seems feasible.

The trapping of gold grains in an algal mat was proposed by Nami (1982) as a mechanism for gold concentration in the Carbon Leader. In the case of the Middelvlei Reef, however, the relatively rare occurrence of carbon and the mode of occurrence ("fly specks"), suggest that the process in question played a negligible role, if any.
An important implication of the proposed alluvial plain model is the probability that each alluvial fan in the system supplied sediment with a different initial gold concentration. It is obvious that the latter inherent characteristic is a factor in determining the final gold grade after reworking. This hypothesis can be applied to explain the phenomenon of sedimentologically similar reef types, with vastly different gold grades.

In conclusion, reworking is considered a major process in the economic concentration of gold in the Middelvlei Reef. The most important depositional condition for reworking was a state of near equilibrium, resulting in a low net rate of sedimentation.
REFERENCES


DAVIES, R D (1972). The stratigraphy and gold and uranium content of the Main Reef on Doornfontein Mine. Gold Fields of S A internal report.


APPENDIX 1a

PEBBLE SIZE - AND ASSEMBLAGE DATA

LOCATION 2-14 MR Raise

CO-ORDINATES X = 2 920 538m
Y = 33 581,5m

STRATIGRAPHIC PROFILE
SCALE 1:10

PEBBLE SIZE HISTOGRAM

FAÇIES

PEBBLE SIZE CUMULATIVE CURVE

Mean Size: -3,47\(\text{\(\phi\)}\)
Standard Deviation: 0,78\(\text{\(\phi\)}\)
Sorting Coefficient: 0,79

PEBBLE ASSEMBLAGE

White Quartz: 94,0%  Dark grey massive chert: ----
Smoky Quartz: 4,0%    Layered chert: ----
Opalescent Blue Quartz: 2,0%  Orthoquartzite: ----
APPENDIX 1b

PEBBLE SIZE - AND ASSEMBLAGE DATA

LOCATION 2/21 X/C S

CO-ORDINATES X + 2 920 763m
                      Y - 33 007,0m

STRATIGRAPHIC PROFILE
SCALE 1:10

FACIES

- Metres
  - 2,0
  - 1,75
  - 1,5
  - 1,25
  - 1,0
  - 0,75
  - 0,5
  - 0,25

Pebble Size and Assemblage Data

White Quartz: 27,0%
Smoky Quartz: 65,1%
Opalescent Blue Quartz: 6,3%

Dark grey massive chert: 1,6%
Layered chert: -----
Orthoquartzite: -----

Mean Size: -3,30
Standard Deviation: -0,68
Sorting Coefficient: 0,65
APPENDIX 1c

PEBBLE SIZE AND ASSEMBLAGE DATA

LOCATION 4 - 5 MR Dr E

CO-ORDINATES X + 2.920 942.5m
               Y = 34 553m

STRATIGRAPHIC PROFILE
SCALE 1:10

PEBBLE SIZE HISTOGRAM

PEBBLE SIZE CUMULATIVE CURVE

Mean Size: -3,470
Standard Deviation: 0,690
Sorting Coefficient: 0,70

PEBBLE ASSEMBLAGE

White Quartz: 45,8%
Smoky Quartz: 49,1%
Opalescent Blue Quartz: 3,4%

Dark grey massive chert: 1,7%
Layered chert: ----
Orthoquartzite: ----
APPENDIX 1d

PEBBLE SIZE AND ASSEMBLAGE DATA

LOCATION 4-13 Diag. Raise

CO-ORDINATES X + 2 920 883m
               Y - 33 847m

STRATIGRAPHIC PROFILE
SCALE 1:10

PEBBLE SIZE HISTOGRAM

Mean Size: 3.47
Standard Deviation: 0.67
Sorting Coefficient: 0.76

PEBBLE ASSEMBLAGE

FM
White Quartz: 27.1%
Smoky Quartz: 67.8%
Opalescent Blue Quartz: 3.4%

GM
Dark grey massive chert: 1.7%
Layered chert: ----
Orthoquartzite: ----
APPENDIX 1e

PEBBLE SIZE - AND ASSEMBLAGE DATA

LOCATION  6-14 Mr Dr E

CO-ORDINATES  X + 291 417m
               Y - 33 715 m

STRATIGRAPHIC PROFILE
SCALE 1:10

FACIES

METRES

Silt
Sand
Gravel

STRIANIQUITE PROFILE

PEBBLE SIZE HISTOGRAM

% FREQUENCY

0 10 20 30 40 50

Ø UNITS

-6,0 -5,5 -5,0 -4,5 -4,0 -3,5 -3,0 -2,5 -2,0

PEBBLE SIZE CUMULATIVE CURVE

% FREQUENCY

0 10 20 30 40 50 60 70 80 90 100

Ø UNITS

-6,0 -5,5 -5,0 -4,5 -4,0 -3,5 -3,0 -2,5 -2,0

PEBBLE ASSEMBLAGE

White Quartz: 30,5%
Smoky Quartz: 54,2%
Opalescent Blue Quartz: 6,9%

Dark grey massive chert: 4,2%
Layered chert: ----
Orthoquartzite: 4,2%
APPENDIX 1f

PEBBLE SIZE - AND ASSEMBLAGE DATA

LOCATION 7-8 X/C 5

CO-ORDINATES
X + 2 921 363m
Y - 34 328 m

STRATIGRAPHIC PROFILE
SCALE 1:10

PEBBLE SIZE HISTOGRAM

PEBBLE SIZE CUMULATIVE CURVE

Mean Size: -3,670
Standard Deviation: 0,640
Sorting Coefficient: 0,63

PEBBLE ASSEMBLAGE

White Quartz: 58,0%  Dark grey massive chert: 6,0%
Smoky Quartz: 32,0%  Layered chert: 2,0%
Opalescent Blue Quartz: 2,0%  Orthoquartzite: 2,0%

APPENDIX 1

PEBBLE SIZE - AND ASSEMBLAGE DATA

LOCATION 9-6 X/C S

CO-ORDINATES X + 2 921 586 m
Y - 34 552 m

STRATIGRAPHIC PROFILE

SCALE 1:10

PEBBLE SIZE HISTOGRAM

Mean Size: -3,67ø
Standard Deviation: 0,70ø
Sorting Coefficient: 0,70

PEBBLE SIZE CUMULATIVE CURVE

White Quartz: 41,1%
Smoky Quartz: 54,9%
Opalescent Blue Quartz: ----

Dark grey massive chert: ----
Layered chert: 2,09%
Orthoquartzite: 2,0%

PEBBLE ASSEMBLAGE

Facies

Silt
Sand
Gravel

0
0,25
0,5
0,75
1
1,25
1,5
1,75
2
2,5

METRES

0
10
20
30
40
50

% FREQUENCY

0
10
20
30
40
50
60
70
80
90
100

% FREQUENCY

-6,0
-5,5
-5,0
-4,5
-4,0
-3,5
-3,0
-2,5
-2,0

Ø UNITS

-6,0
-5,5
-5,0
-4,5
-4,0
-3,5
-3,0
-2,5
-2,0

Ø UNITS
APPENDIX 1g

PEBBLE SIZE - AND ASSEMBLAGE DATA

LOCATION 7-19 MR Dr E

CO-ORDINATES X + 2 921 557 m
Y - 33 441 m

STRATIGRAPHIC PROFILE
SCALE 1:10

PEBBLE SIZE HISTOGRAM

PEBBLE SIZE CUMULATIVE CURVE

PEBBLE ASSEMBLAGE

White Quartz: 25,3%
Smoky Quartz: 65,1%
Opalescent Blue Quartz: 7,2%

Dark grey massive chert: 1,2%
Layered chert: 1,2%
Orthoquartzite: ----
APPENDIX

PEBBLE SIZE AND ASSEMBLAGE DATA

LOCATION 9-19 MR Dr. W

CO-ORDINATES X + 2 921 811 m
Y = 33 229 m

STRATIGRAPHIC PROFILE
SCALE 1:10

PEBBLE SIZE HISTOGRAM

PEBBLE SIZE CUMULATIVE CURVE

FACIES

Mean Size: 3,33ø
Standard Deviation: 0,70ø
Sorting Coefficient: 0,70

PEBBLE ASSEMBLAGE

White Quartz: 67,8%  Dark grey massive chert: 1,2%
Smoky Quartz: 28,6%  Layered chert: ----
Opalescent Blue Quartz: 2,4%   Orthoquartzite: ----
APPENDIX

PEBBLE SIZE AND ASSEMBLAGE DATA

LOCATION 9-31 X/C S

COORDINATES
X + 2 921 994m
Y - 32 293m

STRATIGRAPHIC PROFILE
SCALE 1:10

FACIES

PEBBLE SIZE HISTOGRAM

PEBBLE SIZE CUMULATIVE CURVE

Mean Size: -3,22ø
Standard Deviation: 0,55ø
Sorting Coefficient: 0,53

PEBBLE ASSEMBLAGE

White Quartz: 50,0%
Smoky Quartz: 48,3%
Smoky Quartz: ----
Opalescent Blue Quartz: ----
Dark grey massive chert: 1,7%
Layered chert: ----
Orthoquartzite: ----
APPENDIX 1k

PEBBLE SIZE - AND ASSEMBLAGE DATA

LOCATION 11-17 MR Dr W

CO-ORDINATES X + 2 922 005m
Y = 33 446m

STRATIGRAPHIC PROFILE
SCALE 1:10

PEBBLE SIZE HISTOGRAM

PEBBLE SIZE CUMULATIVE CURVE

Mean Size: -3,050
Standard Deviation: 0,64Ø
Sorting Coefficient: 0,64

PEBBLE ASSEMBLAGE

White Quartz: 40,0% Dark grey massive chert: 8,0%
Smoky Quartz: 50,0% Layered chert: 2,0%
Opalescent Blue Quartz: ---- Orthoquartzite: ----
APPENDIX 11

PEBBLE SIZE - AND ASSEMBLAGE DATA

LOCATION 13-26 STOPE

COORDINATES X + 2 922 087m
Y - 32 836m

STRATIGRAPHIC PROFILE

SCALE 1:10

FACIES

PEBBLE SIZE HISTOGRAM

PEBBLE SIZE CUMULATIVE CURVE

Mean Size: -3.35\(\sigma\)
Standard Deviation: 0.68\(\sigma\)
Sorting Coefficient: 0.67

PEBBLE ASSEMBLAGE

White Quartz: 43.1%  Dark grey massive chert: ----
Smoky Quartz: 56.9%  Layered chert: ----
Opalescent Blue Quartz: ----  Orthoquartzite: ----
APPENDIX

PEBBLE SIZE AND ASSEMBLAGE DATA

LOCATION 15-5 MR Dr E

CO-ORDINATES
X + 2 922 182,5m
Y - 34 910,5m

STRATIGRAPHIC PROFILE
SCALE 1:10

PEBBLE SIZE HISTOGRAM

PEBBLE SIZE CUMULATIVE CURVE

Mean Size: -3,39\(\phi\)
Standard Deviation: 0,60\(\phi\)
Sorting Coefficient: 0,65

PEBBLE ASSEMBLAGE

White Quartz: 23,2%
Smoky Quartz: 60,7%
Opalescent Blue Quartz: 5,4%
Dark grey massive chert: 5,4%
Layered chert: 1,8%
Orthoquartzite: 3,5%
APPENDIX

PEBBLE SIZE - AND ASSEMBLAGE DATA

LOCATION 15-15 MR Dr W

CO-ORDINATES X + 2 922 432m
Y - 33 861m

STRATIGRAPHIC PROFILE
SCALE 1:10

PEBBLE SIZE HISTOGRAM

PEBBLE SIZE CUMULATIVE CURVE

Mean Size: -3,30 φ
Standard Deviation: 0,73 φ
Sorting Coefficient: 0,71

PEBBLE ASSEMBLAGE

White Quartz: 64,0%
Smoky Quartz: 18,0%
Opalescent Blue Quartz: ----

Dark grey massive chert: 10,0%
Layered chert: ----
Orthoquartzite: 8,0%
APPENDIX 1b

PEBBLE SIZE - AND ASSEMBLAGE DATA

LOCATION 15-61 X/C N

CO-ORDINATES X + 2922 251m
Y - 29 552m

STRATIGRAPHIC PROFILE
SCALE 1:10

PEBBLE SIZE HISTOGRAM

PEBBLE SIZE CUMULATIVE CURVE

Mean Size: -2.85φ
Standard Deviation: 0.60φ
Sorting Coefficient: 0.56

PEBBLE ASSEMBLAGE

White Quartz: 59.6%
Smoky Quartz: 28.9%
Opalescent Blue Quartz: 3.8%

Dark grey massive chert: 3.8%
Layered chert: 1.9%
Orthoquartzite: 1.9%
APPENDIX

PEBBLE SIZE AND ASSEMBLAGE DATA

LOCATION 19-63 MR Dr E

CO-ORDINATES X + 2 923 841m
Y - 29 817,5 m

STRATIGRAPHIC PROFILE
SCALE 1:10

FACIES

PEBBLE SIZE HISTOGRAM

PEBBLE SIZE CUMULATIVE CURVE

Mean Size: \(-3,38\)
Standard Deviation: 0,640
Sorting Coefficient: 0,64

PEBBLE ASSEMBLAGE

White Quartz: 52,0%
Smoky Quartz: 23,0%
Opalescent Blue Quartz: 3,0%

Dark grey massive chert: 2,0%
Layered chert: ----
Orthoquartzite: 20,0%
APPENDIX 1q

PEBBLE SIZE - AND ASSEMBLAGE DATA

LOCATION 19-63 MR Dr E

CO-ORDINATES X + 2 923 809m
                                  Y - 29 839m

STRATIGRAPHIC PROFILE
SCALE 1:10

FACIES

Silt
Sand
Gravel

% FREQUENCY

50
40
30
20
10
0

% UNITS

PEBBLE SIZE HISTOGRAM

PEBBLE SIZE CUMULATIVE CURVE

-6,0 -5,5 -5,0 -4,5 -4,0 -3,5 -3,0 -2,5 -2,0

Ø UNITS

Mean Size: -3,34Ø

Standard Deviation: 0,58Ø

Sorting Coefficient: 0,54

PEBBLE ASSEMBLAGE

White Quartz: 56,6%
Smoky Quartz: 36,8%
Opalescent Blue Quartz: 1,3%

Dark grey massive chert: 1,3%
Layered chert: ----
Orthoquartzite: 3,9%
APPENDIX

PEBBLE SIZE - AND ASSEMBLAGE DATA

LOCATION: 21-45 MR Dr W

CO-ORDINATES: X + 2923 715m
Y - 31 480m

STRATIGRAPHIC PROFILE
SCALE 1:10

FACIES
Silt
Sand
Gravel

PEBBLE SIZE HISTOGRAM

% FREQUENCY
50
40
30
20
10
0

Ø UNITS
-6,0 -5,5 -5,0 -4,5 -4,0 -3,5 -3,0 -2,5 -2,0

PEBBLE SIZE CUMULATIVE CURVE

% FREQUENCY
100
90
80
70
60
50
40
30
20
10
0

Ø UNITS
-6,0 -5,5 -5,0 -4,5 -4,0 -3,5 -3,0 -2,5 -2,0

PEBBLE ASSEMBLAGE

White Quartz: 47,0%
Smoky Quartz: 32,0%
Opalescent Blue Quartz: 8,0%

Dark grey massive chert: 9,0%
Layered chert: 2,0%
Orthoquartzite: 2,0%

Mean Size: -3,00Ø
Standard Deviation: 0,55Ø
Sorting Coefficient: 0,54
LOCATION 23-15 Diag. Raise

CO-ORDINATES
X + 2 923 260m
Y - 34 375,5m

STRATIGRAPHIC PROFILE
SCALE 1:10

PEBBLE SIZE HISTOGRAM

PEBBLE SIZE CUMULATIVE CURVE

MEAN SIZE: -3,15μ

STANDARD DEVIATION: 0,54μ

SORTING COEFFICIENT: 0,48

PEBBLE ASSEMBLAGE

White Quartz: 56,0% Dark grey massive chert: 4,0%
Smoky Quartz: 34,0% Layered chert: ----
Opalescent Blue Quartz: 6,0% Orthoquartzite: ----
APPENDIX 1

PEBBLE SIZE - AND ASSEMBLAGE DATA

LOCATION  23-43 MR Raise

CO-ORDINATES  X = 2923 702m  
Y = 31 671,5m

STRATIGRAPHIC PROFILE
SCALE 1:10

PEBBLE SIZE HISTOGRAM

Pebble Size Histogram

PEBBLE SIZE CUMULATIVE CURVE

Mean Size: 2,92

Standard Deviation: 0,56

Sorting Coefficient: 0,53

PEBBLE ASSEMBLAGE

White Quartz: 54,0%  Dark grey massive chert: 5,0%
Smoky Quartz: 28,0%  Layered chert: ----
Opalescent Blue Quartz: 11,0%  Orthoquartzite: 2,0%
APPENDIX

PEBBLE SIZE AND ASSEMBLAGE DATA

LOCATION 25-10 MR Dr E

COORDINATES
X + 2 923 368m
Y = 34 935m

STRATIGRAPHIC PROFILE
SCALE 1:10

PEBBLE SIZE HISTOGRAM

PEBBLE SIZE CUMULATIVE CURVE

PEBBLE ASSEMBLAGE

White Quartz: 34.0%
Smoky Quartz: 52.8%
Opalescent Blue Quartz: 1.9%
Dark grey massive chert: 11.3%
Layered chert: ----
Orthoquartzite: ----

Mean Size: 3.18
Standard Deviation: 0.59
Sorting Coefficient: 0.60
APPENDIX lv

PEBBLE SIZE - AND ASSEMBLAGE DATA

LOCATION 27-46 MR Dr W

CO-ORDINATES X + 2 924 421m
Y - 31 392m

STRATIGRAPHIC PROFILE
SCALE 1:10

PEBBLE SIZE HISTOGRAM

PEBBLE SIZE CUMULATIVE CURVE

PEBBLE ASSEMBLAGE

White Quartz: 49.2%
Smoky Quartz: 35.6%
Opalescent Blue Quartz: 5.1%
Dark grey massive chert: 8.4%
Layered chert: ----
Orthoquartzite: 1.7%

Mean Size: -3.19ø
Standard Deviation: 0.68ø
Sorting Coefficient: 0.68
APPENDIX

PEBBLE SIZE AND ASSEMBLAGE DATA

LOCATION  29-10 MR Dr E

COORDINATES  X + 2 923 932m
              Y - 34 851m

STRATIGRAPHIC PROFILE

SCALE 1:10

PEBBLE SIZE HISTOGRAM

PEBBLE SIZE CUMULATIVE CURVE

Mean Size: -3.04Ø

Standard Deviation: 0.62Ø

Sorting Coefficient: 0.60

PEBBLE ASSEMBLAGE

White Quartz: 29.4%  Dark grey massive chert: 3.9%
Smoky Quartz: 66.7%  Layered chert: ----
Opalescent Blue Quartz: ----  Orthoquartzite: ----
APPENDIX 1x

PEBBLE SIZE - AND ASSEMBLAGE DATA

LOCATION  29-46 MR Dr W

COORDINATES  X + 2 924 624,5m
               Y - 31 554m

STRATIGRAPHIC PROFILE
SCALE 1:10

PEBBLE SIZE HISTOGRAM

PEBBLE SIZE CUMULATIVE CURVE

Mean Size: -3,080
Standard Deviation: 0,650
Sorting Coefficient: 0,64

PEBBLE ASSEMBLAGE

White Quartz: 39,6%
Smoky Quartz: 41,5%
Opalescent Blue Quartz: 1,9%

Dark grey massive chert: 9,4%
Layered chert: 1,9%
Orthoquartzite: 5,7%
APPENDIX Iy

PEBBLE SIZE - AND ASSEMBLAGE DATA

LOCATION  11-13 MR X/C

CO-ORDINATES  X + 2 921 931m
               Y - 34 016m

STRATIGRAPHIC PROFILE
SCALE 1:10

PEBBLE SIZE HISTOGRAM

PEBBLE ASSEMBLAGE

White Quartz:  38.5%  Dark grey massive chert:  3.8%
Smoky Quartz:  51.9%  Layered chert: -----
Opalescent Blue Quartz:  1.9%  Orthoquartzite:  3.9%
APPENDIX 1x

PEBBLE SIZE - AND ASSEMBLAGE DATA

LOCATION 11-31 MR X/C

CO-ORDINATES
X + 2 922 242m
Y - 32 314m

STRAITIGRAPHIC PROFILE
SCALE 1:10

PEBBLE SIZE HISTOGRAM

PEBBLE SIZE HISTOGRAM

PEBBLE SIZE HISTOGRAM

PEBBLE SIZE HISTOGRAM

Mean Size: -3.26 φ
Standard Deviation: 0.65 φ
Sorting Coefficient: 0.64

PEBBLE ASSEMBLAGE

White Quartz: 41.3%
Smoky Quartz: 55.6%
Opalescent Blue Quartz: 1.6%

Dark grey massive chert: 1.6%
Layered chert: ----
Orthoquartzite: ----
APPENDIX II

CROSS-BEDDING DIRECTIONS IN THE MIDDENVLEI REEF

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<thead>
<tr>
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<th>CO-ORDINATES</th>
<th>READINGS</th>
<th>CORRECTED</th>
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<td>Y</td>
<td>FORESET DIRECTION</td>
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<tr>
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<td>15-15 MR Dr E</td>
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### CROSS-BEDDING DIRECTIONS IN THE MIDDELVLEI REEF

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<td>FORESET DIP</td>
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<tr>
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<tr>
<td>27-46 MR Dr W</td>
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<td>155°</td>
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## Appendices III

### Basal Scour Orientations in the Middelvlei Reef

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<th>Co-ordinates</th>
<th>Scour Orientation</th>
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<td>Y: -33 715 m</td>
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<td>X: 2 921 420 m</td>
<td>Y: -33 611 m</td>
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<td>9-6 MR Dr E</td>
<td>X: 2 921 563 m</td>
<td>Y: -34 571 m</td>
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<td>15-5 MR Dr E</td>
<td>X: 2 922 171 5m</td>
<td>Y: -34 842 m</td>
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## APPENDIX IV

### PEBBLE SIZE DATA

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<tr>
<th>LOCALITY</th>
<th>X CO-ORDINATES</th>
<th>Y metres</th>
<th>MEAN SIZE</th>
<th>STANDARD DEVIATION</th>
<th>SORTING COEF.</th>
<th>MEAN OF 20 LARGEST PEBBLES</th>
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<td></td>
<td></td>
<td></td>
<td>(\phi) units</td>
<td>mm</td>
<td>(\phi) units</td>
<td>mm</td>
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<td>0,53</td>
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<td>0,64</td>
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<td>0,67</td>
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<td>0,65</td>
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## APPENDIX IV (Cont.)

### PEBBLE SIZE DATA

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<th>LOCALITY</th>
<th>CO-ORDINATES X (metres)</th>
<th>Y (metres)</th>
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<th>STANDARD DEVIATION UNITS</th>
<th>SORTING COEF.</th>
<th>MEAN OF 20 LARGEST PEBBLES (mm)</th>
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<tbody>
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<td>8,00</td>
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## APPENDIX V

### PEBBLE ASSEMBLAGE

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<td>- 33 446</td>
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<td>13-26 Stope</td>
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## APPENDIX V (Cont.)

### PEBBLE ASSEMBLAGE

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## Detailed Sampling Data

**Locality:** 2-14 MR Dr W  
**Coordinates:**  
- X + 2 920 715m  
- Y - 33 490m  

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# Detailed Sampling Data

**Locality:** 7-8 X/C S  

**Coordinates:**  
- X = 2921 363 m  
- Y = 34 328 m  

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## APPENDIX ViC

### DETAILED SAMPLING DATA

**Locality:** 9-8 MR Raise  
**Coordinates:**  
- \( X = 2921,297m \)  
- \( Y = 34,320m \)

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APPENDIX VId

DETAILED SAMPLING DATA

LOCALITY: 15-15 MR Dr W

CO-ORDINATES: X + 2 922 430m
                  Y - 33 861m

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### LOCALITY:
19-63 MR Dr E

### CO-ORDINATES:
- X = 2,923,853m
- Y = 29,804,5m

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- **Su**: 7, 12.6, T15, 0.09
- **Gu**: 39, 19.8, T14, 3.79
- **Su**: 26, 14.2, T13, 1.00
- **Gu**: 39, 15.7, T12, 34.92
**APPENDIX**

**DETAILED SAMPLING DATA**

**LOCALITY:** 23-12 Diag. Raise  
**COORDINATES:** X + 2 923 2 60m  
Y - 34 375,5m

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**DETAILED SAMPLING DATA**

**LOCALITY:** 23-12 Diag. Raise  
**COORDINATES:** X + 2 923 2 60m  
Y - 34 375,5m

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**LOCALITY:** 23-12 Diag. Raise  
**COORDINATES:** X + 2 923 2 60m  
Y - 34 375,5m

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# APPENDIX V

## DETAILED SAMPLING DATA

**LOCALITY:** 29-46 MR Dr W

**COORDINATES:**
- X = 2 924 624,5 m
- Y = 31 554 m

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