TR92-47

FACIES MAPPING OF THE VAAL REEF PLACER AS AN AID TO REMNANT PILLAR EXTRACTION AND STOPE WIDTH OPTIMISATION

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This assignment is submitted as partial fulfillment of the requirements for the degree of Master of Science (Exploration Geology) at Rhodes University, Grahamstown.

January, 1992.

ABSTRACT

The Vaal Reef placer is situated on the unconformable junction of the Strathmore and Stilfontein formations of the Johannesburg Subgroup. Within the South Division of the Vaal Reefs Exploration and Mining company lease, the Vaal Reef Placer is shown to be composed of several different units. Each unit exhibits its own specific characteristics and trend direction which can be used to establish distinct "Reef packages". These packages can be mapped in such a way as to provided a preliminary lithofacies map for the Vaal Reef Placer.

The delineation of such geologically homogenous zones, and the development of a suitable depositional model, can be utilised in several ways. The characteristics of a particular zone are shown to influence the control of stoping width, evaluation of remnant pillars and the geostatistical methodology of evaluating current and future ore reserve blocks.

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CHAPTER ONE

INTRODUCTION

AIMS OF THE PROJECT

The purpose of this project is not only to compile and assimilate the vast amounts of diverse data relating to the Vaal Reef Placer, but also to attempt to refine the current depositional model and apply this knowledge in a practical way within the production environment. To this end four goals or targets were set with the full knowledge that the achievement of such would doubtless create further questions or problems to be solved at a latter date. These targets were as follows:-

1. Sub-divide the Vaal Reef Placer (VRP) into its constituent units and create a database of information using a 500 metre grid across the South Division area.

2. Produce a localised (Vaal Reefs South Division) facies/lithofacies plan defining areas of different "Reef Type", for the benefit of mine planning and the optimisation of stope width control.

3. Contour individual units and investigate the possibilities of separate populations vertically and horizontally, with a view towards establishing more detailed trend directions.

4. Refine the depositional model for the VRP and comment on any changes that may be necessary to the method of statisticaly evaluating the ore zone. Investigate ways in which a more knowledgeable approach could be put to good effect in the evaluation of Remnant pillars in particular and new mining areas in general.

INTRODUCTION

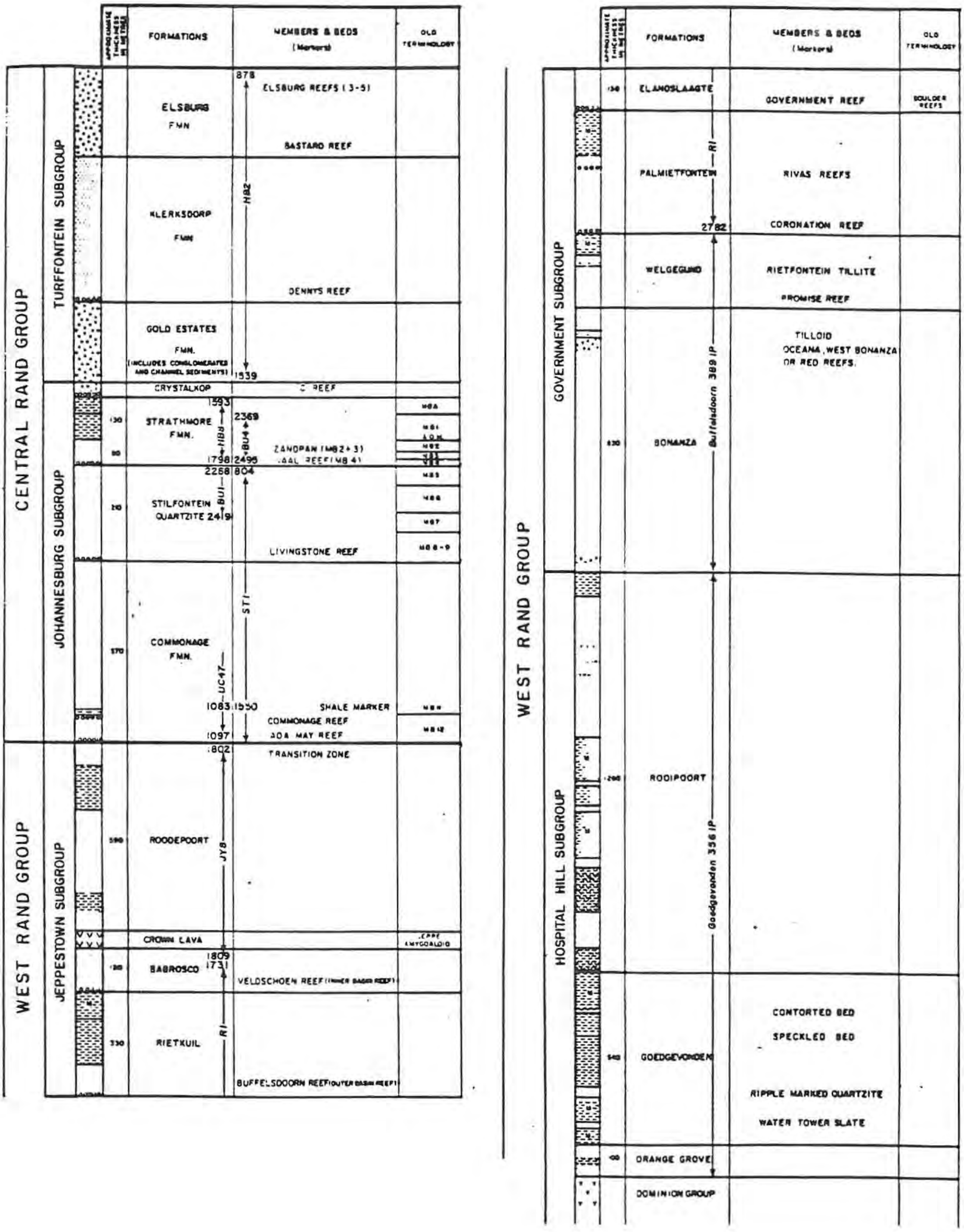
THE WITWATERSRAND BASIN

The Witwatersrand basin extends from Johannesburg in the North to The Orange Free State in the South, forming an elongate basin some 320 km along its axis. The nature of the sediments within the upper part of the basin has led many workers to propose several entry points to the basin each forming its own discreet "Gold-Field". The Volcano-Sedimentary package within the Witwatersrand basin is composed of three groups, the Dominion Group, the Witwatersrand Super-Group and the Ventersdorp Super-Group. The Witwatersrand Super-Group is of the most interest in this particular instance (Figure 1.1) and is in turn sub-divided into the West Rand Group (lower portion) and the Central Rand Group (upper portion). The majority of the gold producing placers occur within the Central Rand Group (CRG); the Vaal Reef Placer being no exception. The CRG attains a maximum thickness of 2880 metres in the Vredefort area, (Minter 1982) and consists predominantly of coarse grained Sub-greywackes with less than 10% conglomerates.

THE KLERKSDORP GOLDFIELD

Situated at the western edge of the Witwatersrand basin, some 160km WSW of Johannesburg, the active portion of the Klerksdorp Gold-Field is defined by the Vaal Reefs, Hartebeestfontein, Stilfontein and Buffelsfontein Gold Mines. Contiguous lease areas extend the aerial extent of the Gold-Field to approximately 450Km^2 (Figure 1.2).

THE WITWATERSRAND SUPERGROUP



Lithostratigraphic column for the Witwatersrand Supergroup. (after Antrobus et. al. 1986).

FIGURE 1.1

LOCALITY PLAN OF THE KLERKSDORP GOLDFIELD

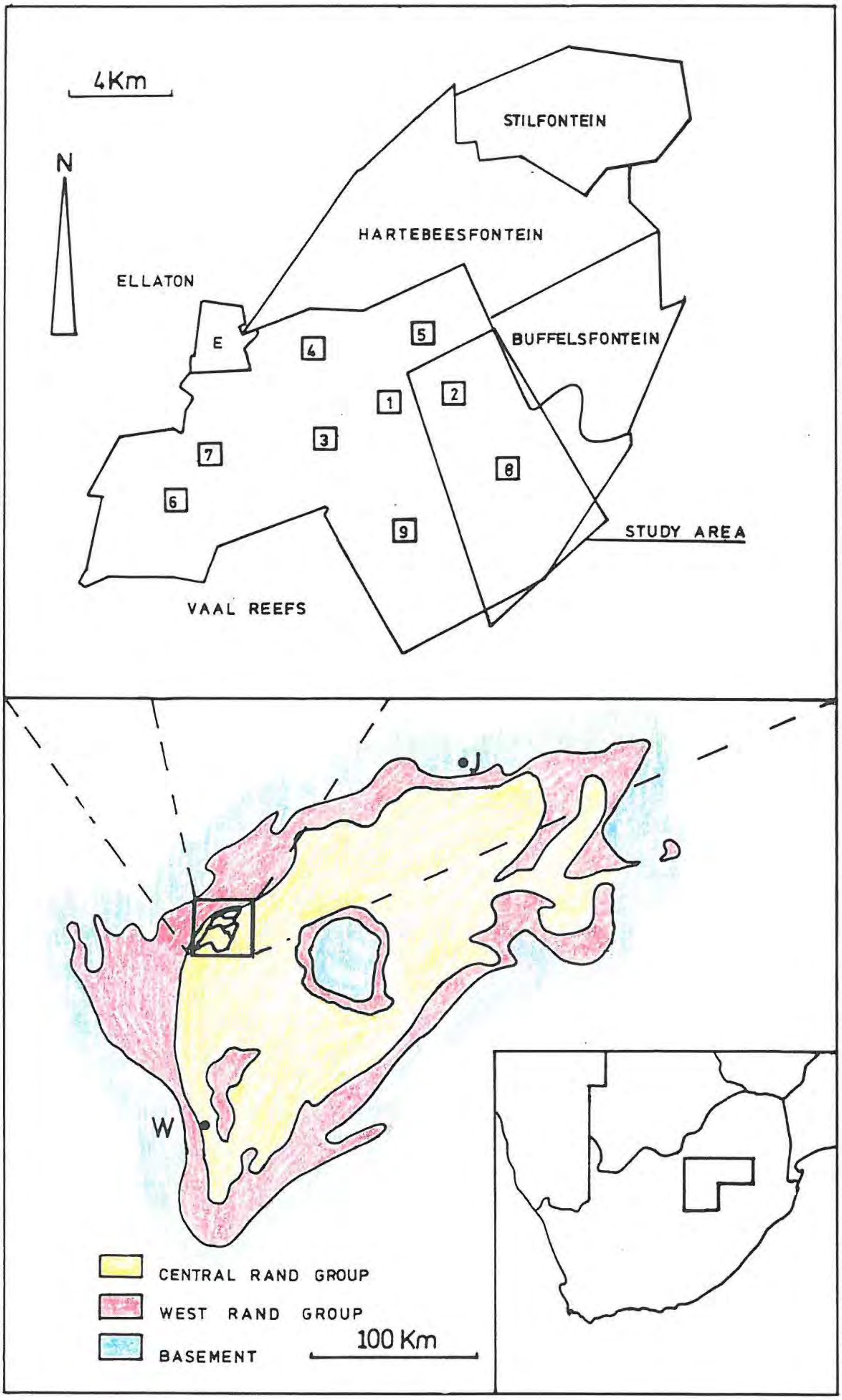


FIGURE 1.2

The principle Gold bearing conglomerate mined within the Gold-Field is the Vaal Reef. Several other horizons have also been exploited either currently or in the past, namely the Elsburg Reefs, the Ventersdorp Contact Reef and the CrystalKop Reef.

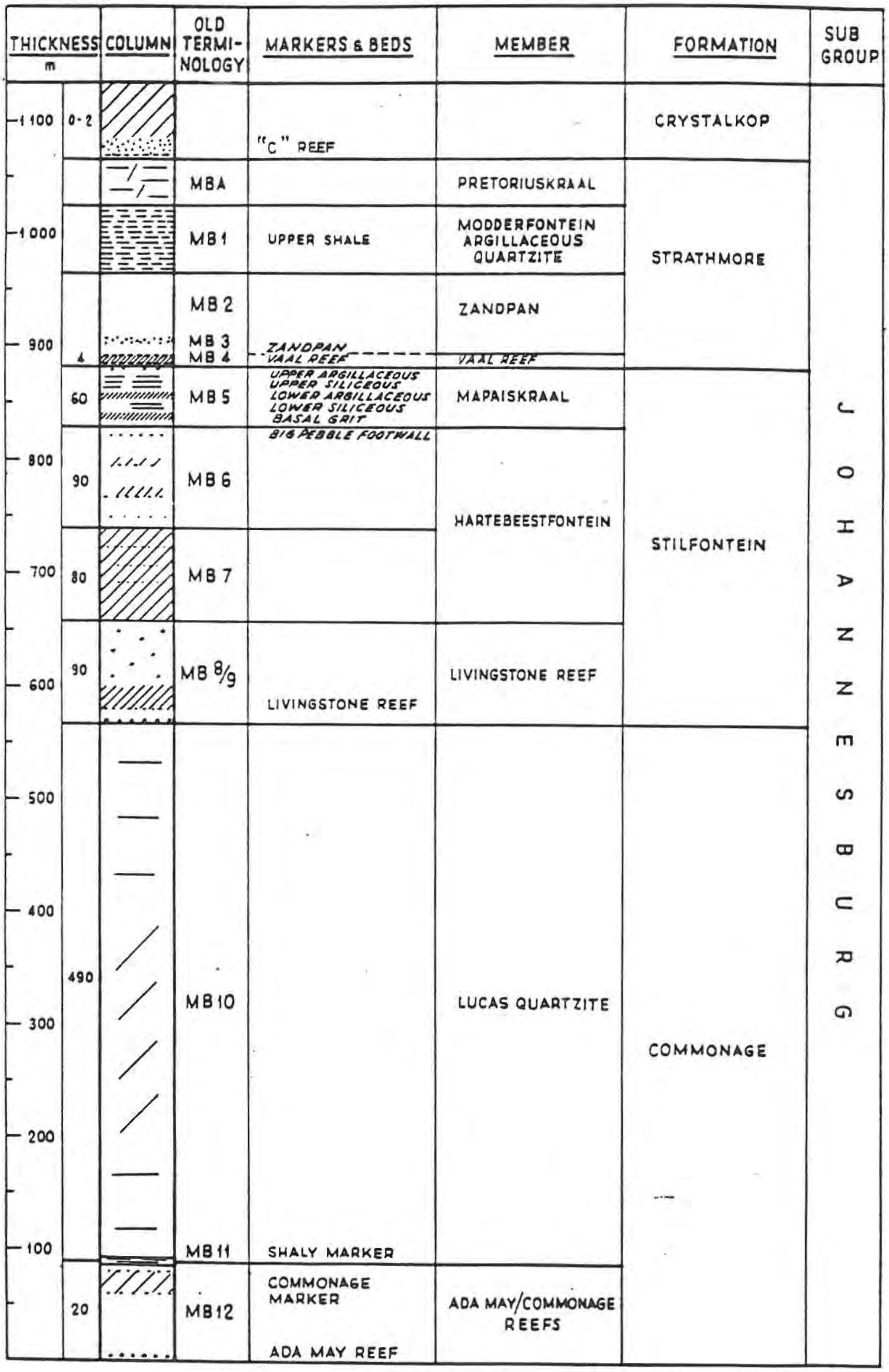
This study will concentrate on the Vaal Reef horizon and its associated conglomerates within the bounds of the South Division of the Vaal Reefs Exploration and Mining company Ltd. (Figure 1.2).

VAAL REEFS MINE

Vaal Reefs Exploration and Mining Company Ltd. is situated within the Klerksdorp Gold-Field (Figure 1.2) and is the world's largest, single regional gold mine, employing nearly 50,000 people and producing 70 to 80 metric tons of Gold annually. The nine producing shafts currently exploit three Witwatersrand Gold Reefs namely The Vaal, Crystalkop and Ventersdorp Contact Reefs.

THE VAAL REEF PLACER(VRP)

The VRP is situated on the unconformable junction of the Strathmore and Stilfontein formations of the Johannesburg Sub-Group (Figure 1.3). Three members are of interest in this study, namely the Zandpan, Vaal and Mapaiskraal forming the hanging wall, ore zone and footwall units respectively. Within the localised production environment the old terminology is still in use and for this reason will also be used within this report. Thus the Zandpan member consists of two units, the upper MB2 and lower MB3 packages, the Mapaiskraal consists of the MB5 unit and the Vaal Member or VRP is also known as the MB4



Lithostratigraphic column for the Johannesburg Subgroup. (after Antrobus et. al. 1986).

FIGURE 1.3

unit. (Figure 1.3)

The VRP was first recognised as an economically viable horizon when intersected in an exploration drilling programme conducted on the farm Strathmore. This discovery led to the establishment of the Ellaton Mine (Figure 1.2) At that stage the VRP was known as the Strathmore Reef and was not considered to be an extensive ore-body, this was due in part to it representing only a small faulted fragment. The VRP was again recognised in borehole V2 on the farm Vaalkop in 1942 by Dr. R.Waters of the Western Reefs Exploration and Development Company and was from then on referred to as the VRP. The early 1950's saw the establishment of the Stilfontein G.M.(1952), Vaal Reefs G.M. (1956), Hartebeestfontein G.M. (1956) and the Buffelsfontein G.M. (1957) and the establishment of the VRP as one of the World's largest known gold deposits. Since then The VRP has produced in excess of 4000 metric tons of Gold as well as significant quantities of Uranium oxide, Sulphur, Silver, Iridium and Osmium.

CHAPTER TWO

THE GEOLOGY OF THE VAAL REEF

STRUCTURE

LOCAL STRUCTURAL SETTING

For the most part the structure of the VRP horizon within the study area is dominated by large scale normal strike faults, producing a series of horsts and grabens as seen in Figure 2.1 and Figure 2.2. Within this framework there are a variety of cross cutting dykes and sills as well as dip faults, reverse faults and bedding planar faults. Minor "flexing" of the VRP has also occurred, adding to the complexity of the area.

Listric faulting has been proposed by a number of internal reports. These theories have proven difficult to prove for the VRP but recent work on the "C" Reef continues to support this theory. To some extent this may be a result of stratigraphy as the "C" Reef sits between the exceedingly coarse Gold Estates Formation and the argillaceous Quartzites of the Modderfontein formation. Normal faults have a tendency to flatten out in less competent units and would thus tend to be curvilinear within the stratigraphic window of the "C" reef environment. The Modderfontein unit is also prone to bedding plane movement due to its argillaceous nature and there are numerous recordings of major myolinite bands that are known to predate the major faults (Brink 1982). These bedding planar faults have little effect on the overall geometry of the area but may cause confusion when seen out of context and it is inherently possible to misinterpret these features as normal

Simplified Geological Plan of the Vaal Reef Horizon

Vaal Reefs South Division

FIGURE 2.1

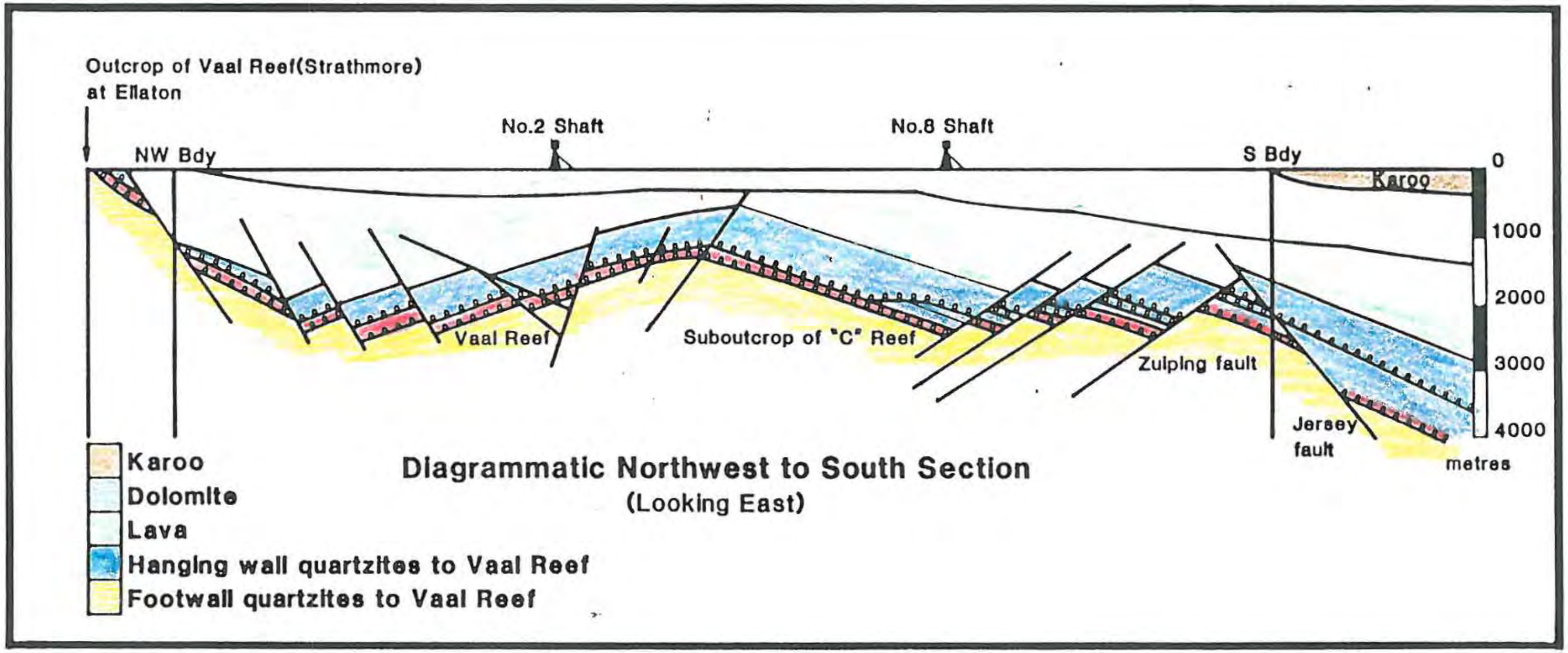

Outcrop of Vaal Reef(Strathmore)
at Ellaton
NW Bdy
No.2 Shaft
No.8 Shaft
S Bdy
Karoo
0
1000
2000
3000
4000
metres
Vaal Reef
Suboutcrop of "C" Reef
Zulping fault
Jersey fault
Karoo
Dolomite
Lava
Hanging wall quartzites to Vaal Reef
Footwall quartzites to Vaal Reef
Diagrammatic Northwest to South Section
(Looking East)

FIGURE 2.2

faults that have gone planar. Work continues on the possible geometry of listric faulting within the South Division and exploration models based on these assumptions are currently being tested.

FAULTING

To date there are no major faults which have categorically been identified as Witwatersrand age features. Faults previously recorded as having smaller displacement in the Ventersdorp than in the Witwatersrand are believed to be the result of misidentification of the Ventersdorp Supergroup (Brink 1982).

The majority of the faulting recorded in the study area is of either Ventersdorp or Transvaal age although later features believed to be related to the Vredefort event are also recorded. Without detailed analysis of a particular set of faults it is almost impossible to define different phases of faults. As a general rule of thumb the SE-dipping faults post-date the NW-dipping and the interaction of the two sets requires detailed study which has often led to the discovery of major blocks of ground within areas previously classified as fault loss. Also as a general rule the younger faults become lower angle, culminating in the numerous bedding plane faults thought to be related to the Vredefort event. Again these assumptions are often proven wrong and exist more as guidelines for the mine geologist to conduct exploration rather than rules that typify the structural evolution of the gold-field. For the most part there is little or no lateral component measured on any of the major NE-SW faults. There is however a lateral component in the NW-SE features which often behave as buffers. These features are sub-vertical and often intrusive filled and believed to be accommodation features for the extensional faulting of the basin. It is difficult to imagine there being no lateral component in a 400-500m. normal fault that clearly exhibits several phases of movement, yet it is often possible to trace geological features across from hanging wall to footwall with no displacement. For the sake of this study (and particularly contouring operations) it has been assumed (unless proven otherwise) that wrench tectonics were not in operation.

INTRUSIVES

A variety of intrusive dykes and sills are recorded throughout the study area. The ages of these intrusions ranges from Ventersdorp to Karoo. (Jacob 1966, Minter 1972, Brink 1982). Compositionally they are equally as variable, consisting of Diorites, Dolorites, Diabases's, Lamprophyres, Kimberlites and Carbonatites. Structurally these intrusives are of little importance except in the relative dating of other dykes and faults, they are however noteworthy from a value distribution point of view. Gold values are often seen to increase or decrease dramatically close to intrusive contacts, thereby supporting a remobilisation theory. Very little quantitative work has been conducted on this subject and the sphere of influence appears to be of the order of several metres only. For the purposes of evaluation and geostatistical work therefore it is often common practice to treat values close to major intrusives as un-representative.

TECTONIC SETTING

The Witwatersrand Supergroup represents a predominantly clastic terrigenous sequence interpreted as being deposited under epeirogenic conditions in an intracontinental basin, (Verrezen 1987). The basin is elongated in a SW-NE direction and although many differing tectonic settings have been formulated over the years two have been predominant; firstly the Foreland basin developed on the craton side of an andean type arc (Burke et.al. 1986) and secondly the Intracontinental rift system (Bickle and Erikson 1982).

Both models separate the West Rand from the Central rand by varying rates of subsidence. The former model envisages a rapid subsidence stage (West rand) due to crustal flexure, as a result of compression followed by a second slower stage of subsidence (Central rand) resulting from decreased compressional load due to the erosion of peripheral mountains. The Rift model envisages an early rapid subsidence phase related to isostatic compensation for the thinning of the lithosphere, whilst the slower second phase is related to thermal relaxation.

The model proposed by Stanistreet and McCarthy (1991) is the product of many different ideas and has been well-constrained by the dating work of Robb, Davis and Kamo (1991). The four stages of the model can be seen in figure 2.3. The first, extensional rift basin stage accounts for the Dominion volcano-sedimentary sequence at +/- 3100-3010 ma. The West rand and Lower Central rand groups are constrained between 2980-2900 ma. and are believed to occur within a foreland basin stage. The third stage is one of indentation producing the "shrinking" basin required for the formation of upper portion of the Central rand group at between 2840 and 2720 ma. The final impactogenal rift at 2710 ma lead to the formation of the Klipriviersberg flood basalts. The whole sequence is believed by most workers to have been initiated by the encroachment of the Zimbabwe and Kaapvaal cratons, this event being the mechanism behind much of the archean crustal evolution in Southern Africa.

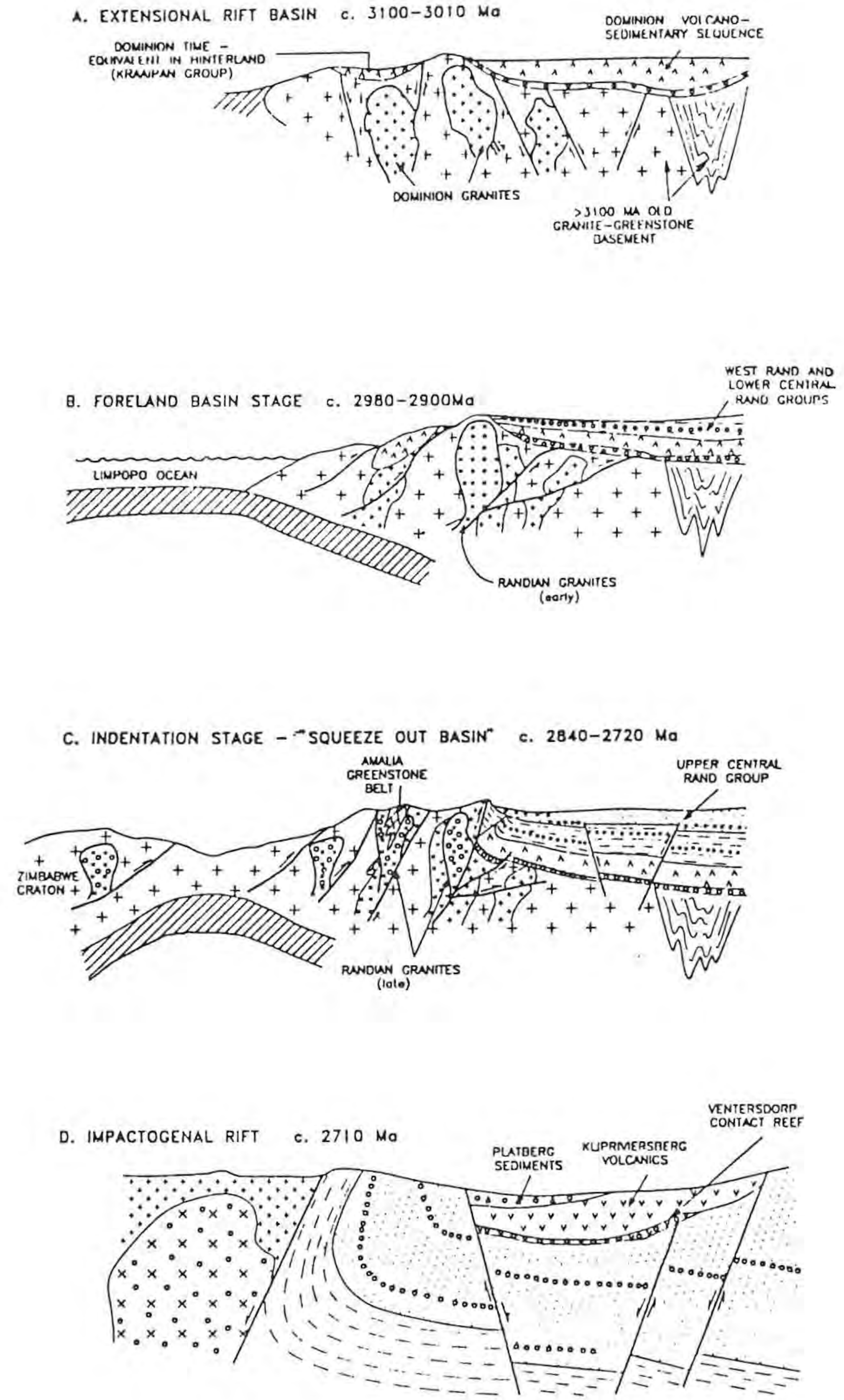
SEDIMENTOLOGY

LITHOLOGIES

MB5 - FOOTWALL

Throughout the study area the MB5 unit forms the immediate footwall lithology to the VRP, to the north however the MB5 sub-crops against the VRP and the MB6 forms the immediate footwall. Generally the MB5's are argillaceous-siliceous medium grained proto-quartzites. They can be sub-divided into four basic zones all but one of which are laterally inpersistant. The base of the MB5's is marked by a basal grit band locally known as the Millar Reef. This unit is a thin (10-30 cm) polymictic, small to medium pebble conglomerate/pebbly quartzite,

FIGURE 2.3



Tectonic and depositional framework for the Witwatersrand triad as envisaged by Stanistreet and McCarthy(1991), (after Robb et. al. 1991).

generally poorly mineralised. Directly above the basal grit zone is the lower siliceous zone or Millar quartzite. This zone is a medium to coarse grained cross-bedded ortho-quartzite reaching up to 5 metres in thickness and forms one of the few laterally persistent marker horizons in the footwall. Above the Millar quartzite is a thick sequence of medium grained grey-brown-green argillaceous proto-quartzites. Shale bands are rarely seen and the zone is generally pebble free. Locally developed "footwall markers" are occasionally seen consisting of small polymictic pebble bands. These bands are very inpersistant and rarely extend more than a few tens of metres horizontally. Siliceous zones within the MB5's are not uncommon but more often occur towards the top of the unit forming the immediate footwall to the Vaal Reef Basal Contact (VRBC). In these instances an apple green to white medium grained, cross-bedded ortho-quartzite reaching a thickness of 2-3 metres is observed.

MB4/VRP - ORE ZONE

From the literature it is clear that there is a great deal of confusion regarding the VRP. Many workers regard only the basal contact as the Vaal Reef and neglect the associated upper conglomerates. This study considers all the units between the basal contact of the Vaal Reef and the Zandpan member as belonging to the Vaal Reef Placer or MB4 member. Specific beds or markers occurring in the hangingwall and footwall to the VRP are also considered to be within the ore zone as and when they interfere with the VRP.

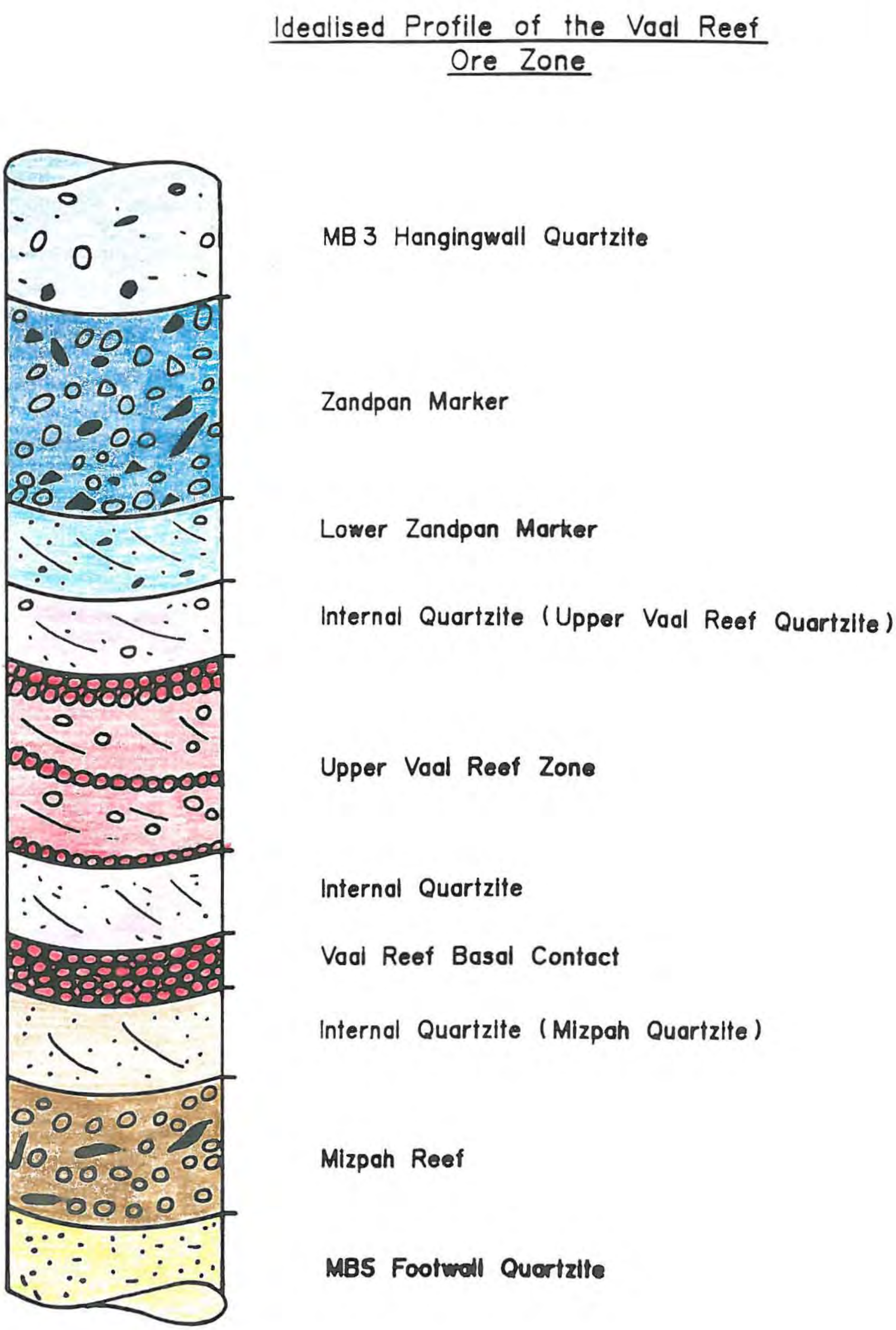

Idealised Profile of the Vaal Reef Ore Zone
MB 3 Hangingwall Quartzite
Zandpan Marker
Lower Zandpan Marker
Internal Quartzite (Upper Vaal Reef Quartzite)
Upper Vaal Reef Zone
Internal Quartzite
Vaal Reef Basal Contact
Internal Quartzite (Mizpah Quartzite)
Mizpah Reef
MBS Footwall Quartzite

FIGURE 2.4

There are thus eight separate units which make up the "Ore Zone", i.e the VRP and its immediate hanging and footwall. These units can be seen in figure 2.4, which is an idealised Reef profile. It is a rare occurrence when all eight units are recorded at one station, and more common for only 4 or 5 to be noted. The differences between each of the conglomeratic or quartzitic units is often subtle, and sometimes impossible to quantify without direct visual comparison. Within the limited stratigraphic window that is often presented in the underground environment, identification of Vaal Reef internal quartzites or Mizpah quartzites for example, is often left to deduction and a backup knowledge of what should be present in the local area. Quite obviously the correct decisions are essential within the production environment and in these cases a good knowledge of the local Reef profile is required.

Brief descriptions of the individual units are given below whereas regional variations in the Reef profile will be dealt with in a later section.

ZANDPAN MARKER (ZM)

The Zm is regarded as the true hanging wall to the VRP and consists of a well-developed and often mineralised polymictic conglomerate (Plate 2.1) with an erosional contact. The ZM often sits directly on top of the VRP but usually is separated by either an upper Vaal Reef quartzite or a lower ZM quartzite. The ZM conglomerate generally carries low gold values and is treated as waste over the majority of the study area. There are however discreet areas in which the ZM is in direct contact with the UVRZ and has to be mined at the same time. In these instances it is not unusual for high, yet sporadic gold values to be recorded within the ZM. In the north of the study area the ZM is seen to remove the majority of the VRP and appears to carry the gold values of the main ore body. This has led to the general contention that values within the ZM are related to the cannibalization of the underlying VRP by the ZM. This theory fits well within the overall depositional model, however there appears to be little displacement of gold values along the anticipated ZM palaeoslope, i.e. gold values within the ZM occur only in areas where the VRP has been partially removed and not down stream from its point of removal as would be expected.

LOWER ZANDPAN MARKER (LZM)

The LZM is a coarse grained, dirty quartzite with scattered polymictic grits and occasional pebbles. It is often confused with the Vaal reef Quartzites but has a definite scour contact. The LZM is more commonly noted in the north of the study area where the Zandpan member cuts into the Vaal Reef.

UPPER VAAL REEF QUARTZITE (UVRQ)

The UVRQ is often referred to as Vaal Reef Quartzite as it virtually identical to the other Internal Quartzite (IQ) units and takes the form of a coarse grained siliceous proto-quartzite, very often gritty with occasional scattered quartzite pebbles. The UVRQ is differentiated from the LZM by its

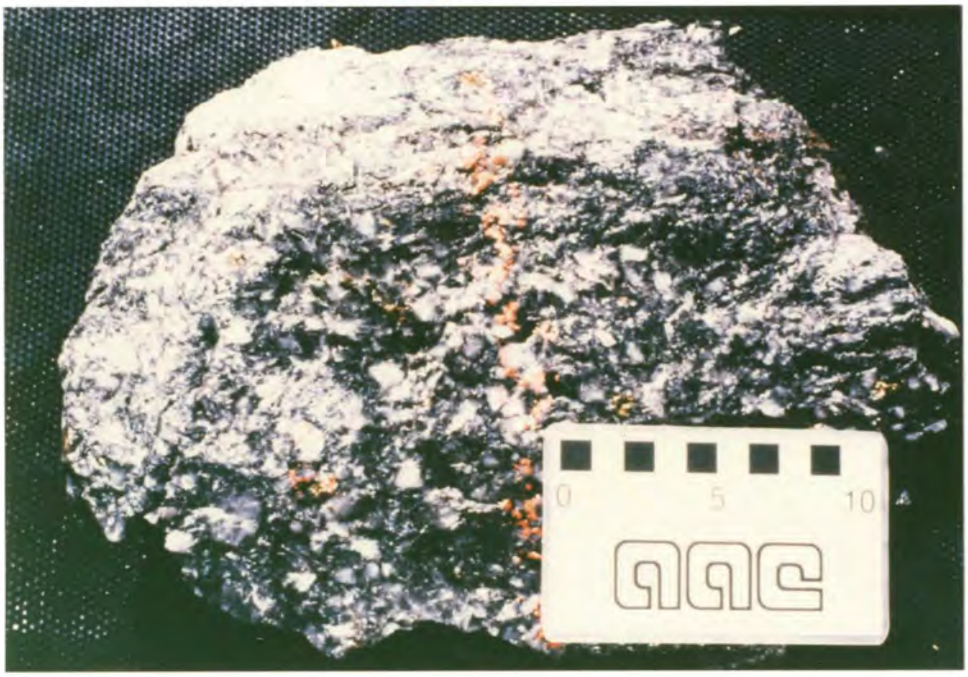


PLATE 2.1

Hand Specimen of the Zandpan Marker.

PLATE 2.2

Hand Specimen of the Upper Vaal Reef Zone.

oligomictic nature. Pyrite mineralisation is sometimes noted on foresets in well-developed examples.

UPPER VAAL REEF ZONE (UVRZ)

This zone is the most difficult to define and for this study consists of all the conglomerates and quartzites from the base of the UVRZ to the last conglomerate band. The UVRZ is often more than one conglomerate band with intercalated quartzite lenses. The base of the UVRZ is reasonably easy to define, and is often marked by a scour surface. The top however is more difficult to define and is usually taken as the last conglomerate band before the ZM. The nature of the UVRZ is highly variable ranging from a single well-developed clast-supported small-pebble oligomictic conglomerate (Plate 2.2) to a thick sequence of pebbly quartzites. Up to six individual conglomeratic units have been recorded although they appear to have no lateral consistency.

For the purposes of this study three types of UVRZ are defined and numbered 1 - 3, it should however, be noted, that they are part of continuous sequence changing along strike, and clear-cut boundaries between the various zones are difficult to establish. The UVRZ1 consists of a relatively thick (100 cm) unit of poorly developed pebbly quartzites. The base of the unit is often difficult to define with the change from clean, siliceous internal quartzites being almost gradational rather than erosional. Generally speaking mineralisation within the UVRZ1 is poor. The UVRZ2 is characterised by a thinner well-developed oligomictic small pebble conglomerate. The UVRZ2 is normally one single clast-supported unit which is usually well mineralised. The UVRZ3 returns to a thicker more composite package but is differentiated from the UVRZ1 by well developed oligomictic bands intercalated with clean siliceous quartzites. These conglomerate bands are normally well mineralised and it is common for three or four laterally inpersistant bands to occur in 1 to 1.5 metre thick package.

INTERNAL QUARTZITE (IQ)

The internal quartzite occurring between the VRBC and the UVRZ is a clean, medium-to coarse-grained ortho-quartzite often cross bedded. Pyrite mineralisation is occasionally seen along the foreset boundaries. When the IQ is particularly thick it bears a strong resemblance to the upper siliceous zone of the MB5 member and is often mistaken for footwall. This is obviously a grave error and will lead to the misguided assumption that the UVRZ is in fact THE VRBC and the main ore body will be left behind in the footwall of stoping operations. In general the IQ thicknesses are of the order of 10 to 50 cm and are thus not a problem, they have however been recorded at over 2 metres and in these instances are of course a hindrance to the removal of the complete VRP.

THE VAAL REEF BASAL CONTACT (VRBC)

The Vaal Reef Basal Contact ranges from a pebble free kerogen seam to 50 cm of well developed oligomictic small pebble conglomerate. Most commonly it is seen as a thin well mineralised conglomerate band with kerogen occurring as a basal seam and as "fly speck" material within the matrix (Plate2.3). The overall relief of the VRBC is of the order of 1 - 2 metres and although channels within the VRBC are occasionally noted the reef thickness is more often controlled by the footwall morphology i.e. an infilled drainage system. The VRBC grades rapidly into the IQ when present. Gold mineralisation within the VRBC is related to kerogen and to a lesser extent heavy mineral concentrations.

MIZPAH REEF (MZ)

The Mizpah is defined as a polymictic unit because of the presence of occasional shale and porphyry clasts. In hand specimen however, it can have a distinctly oligomictic appearance (Plate 2.4) and is similar to the UVRZ. The Mizpah is differentiated from the overlying conglomerates by its colour, which is lighter than the Vaal Reef and often yellowish due to a very high pyrite content. Elongate lath-shaped cherts are also indicative of the Mizpah reef. To the South of the study area the Mizpah grades upwards into a medium-to coarse-grained siliceous proto-quartzite not dissimilar to the UVRQ. The MZ is generally well mineralised in terms of pyrite but low in gold and is therefore commonly treated as waste. The small proportion of

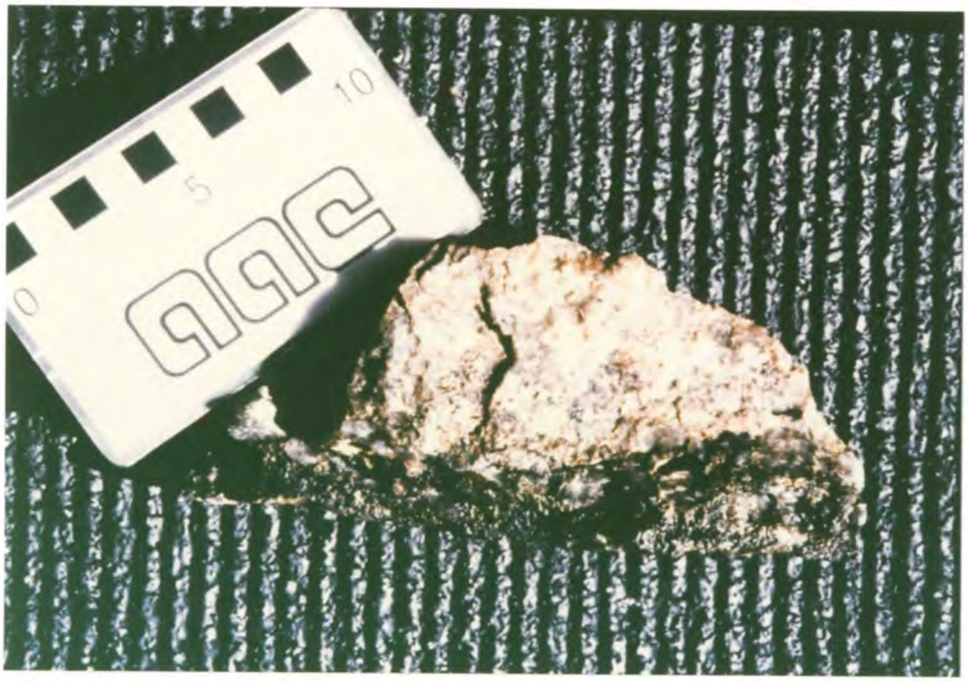


PLATE 2.3

Hand Specimen of the Vaal Reef Basal Contact.

PLATE 2.4

Hand Specimen of the Mizpah Reef.

gold that does occur is thought to be intimately associated with the pyrite and thus is often not recoverable by the same metallurgical processes as required for the Vaal Reef.

MB3 - HANGINGWALL

The hanging wall to the VRP is formed by the MB3/2 or Zandpan formation. In general the MB3 unit consists of grey-brown coarse-grained proto-quartzites with scattered polymictic pebbles and pebble bands. Argillaceous or shale partings are fairly common particularly towards the base of the sequence. The base of the MB3's is marked by the Zandpan marker.

PEBBLE ASSEMBLAGE

The pebble assemblage of the Vaal Reef is oligomictic with Vein Quartz, chert and quartzite pebbles, composing 99% of the population, (Minter 1972). The proportion of chert has been used by Minter (1972) and many other workers to differentiate between the Stilfontein and Witkop facies of the Vaal Reef. The Witkop facies occurs in the Western portion of Vaal Reefs Gold Mine, and is marked by lower gold values and chert percentages of approximately 5%. The richer Stilfontein facies contains 12% chert. The Stilfontein/ Witkop boundary is linear to the South East and parallel to the palaeoslope and current direction. This apparent facies change is reflected by the work of Henckel et al.(1990), who analysed detrital zircons and chromite from both facies and reached a similar conclusion to Minter in that they anticipate different provenance areas for the two facies. The proposed depositional model discussed in a later section is not at odds with this assumption as the possibility of the Witkop facies being related to the Mizpah reef has yet to be investigated.

Pebble sizes within the Vaal Reef are fairly uniform at between 12-20mm, (Verrezen 1987 and Minter 1972), and there is little indication of any change downslope. Both the quoted authors noted differences between the Witkop and Stilfontein facies with the Witkop exhibiting a larger mean pebble size.

Pebble sorting coefficients quoted by Minter 1972 also indicate a well-sorted homogenous package. The pebbles within the Vaal Reef package have undoubtedly been reworked by a braided fluvial system and the well-sorted nature of the pebbles is therefore no surprise. The shape of the vein quartz pebbles is predominantly that of elongated, well rounded coasters. The chert pebbles exhibit a more angular lath-like appearance. The occurrence of ventifacts or driekanters within the Vaal Reef package is evidence of wind abrasion. These ventifacts are rarely found in situ and occur mostly over-turned or imbricated and are very often rounded by transportation. The role of the wind in the formation of Witwatersrand reefs has been generally overlooked, yet driekanters are noted in several other reefs. It is uncertain what effect a wind deflated surface would have on gold distribution. This author is however convinced that its role in the formation of the VRBC is important, as will be seen in a latter section. As the study area is centered on the Stilfontein facies only those characteristics exhibited by the Stilfontein facies are noteworthy in this context. The overall mineralogy, pebble assemblage and matrix is incredibly consistent with very little regional change being noted over a distance of 10km. Localised variations have however been observed and these have been related to local changes in environment (channel to sand bar).

MINERALOGY

The detailed mineralogy of Witwatersrand Reefs was adequately discussed by Feather and Koen (1975) and most of the 70 or so ore minerals recorded in their study have been noted within the Vaal Reef. Based on the work of Viljoen (1963), Feather and Koen subdivided the various minerals into three paragenetic stages. The first stage represents the primary detrital mineralisation, the second stage corresponds to the main period of secondary pyrite formation while the third stage is one of gold remobilisation and the production of rare secondary sulphide minerals.

Twelve of the 70 minerals contribute 99% of the ore minerals and these are:- Pyrite, Gold, Uraninite, Kerogen, Brannerite, Arsenopyrite, Cobaltite, Galena, Pyrrhotite, Gersdorfite, Chromite and Zircon. Gold , Pyrite, Kerogen and Uraninite are probably the most noteable of these as they undoubtedly show some degree of association. High concentrations of gold are very often associated with high concentrations of the other three. Many attempts have been made over the years to holisticaly quantify this relationship, unfortunately to no avail.

Zircon and Chromite although of lesser importance are often used for the geochemical "fingerprinting" of provenance areas and the differentiation of facies. An example of this technique was recently presented by Henckel and Schweitzer(1990).

Pyrite

Pyrite contributes as much as 90% of the total ore mineralogy and is seen in several forms. Buck-shot pyrite or concretionary nodules and idiomorphic to hypidiomorphic grains formed by remobilisation during metamorphism are the most common forms.

Gold

Gold is the least abundant of the heavy minerals and exhibits the highest variance. Much of the gold in the Vaal Reef still exhibits a detrital nature, however there is little doubt that large amounts have been remobilised to some extent or another. There are many recorded instances of gold being remobilised and moved over great distances in many Witwatersrand placers but for the VRP movement appears to have been minimal and gold is still intimately related to original sedimentary features, for example basal scours.

Uranium

Uranium occurs as uraninite fragments and rounded grains and as with pyrite shows a tendency to concentrate on the basal contact or along cross-bed foresets.

Hydrocarbon

Hydrocarbon is present in several forms. Columnar or bladed kerogen seams have been recorded ranging from 1 - 50mm in thickness. They occur generally on the basal contact but are also seen along cross-bed foresets and scour surfaces within the VRP as well as along bedding planes with no associated pebbles. Seams are often seen to "drape" over or envelope quartz pebbles, thus providing strong support for in situ formation. Granular or fly-speck kerogen is also present within the matrix of the basal contact and also within the upper Reef conglomerates.

The origin of the Kerogen within Witwatersrand Reefs is currently under scrutiny. However, early work by Hallbauer (1972), Minter (1972), Zumberge et. al. (1978) and Wheelock (1987), to name but a few, envisages the Kerogen seams forming by in situ growth of algal mats or some other eukaryotic life-form.

The association of the above minerals has led to heated discussion about the environment required for the coexistence of oxide and sulphide minerals and has been one of the major levers for the hydrothermal origin theories. Although there is no doubt that the existence of Uraninite and Pyrite is problematic they fit quite easily into the modified placer model formed during atmospheric conditions somewhat different to the present day.

CHAPTER THREE

REGIONAL PATTERNS OF THE VAAL REEF

DATA COLLECTION

The data used for this project comes from a variety of sources. Initially it was intended to collect lithological sections from stations on a 500 metre grid, this however proved problematic for a variety of reasons, but mostly due to the lack of useable data in some of the older areas of the mine. However, over 100 stations were recorded in this manner and this was regarded as sufficient for this study.

Within each block historical data was scanned to locate a "representative" section with enough information to adequately differentiate between the various units present. These sections were recorded by a variety of colleagues past and present from underground mapping of stoping and development, and consequently they are of a highly varied nature. Sections logged from both surface and underground boreholes were used in areas where detailed mapping was unavailable.

The collection of much of the historic data was hampered by several factors. Firstly the lack of detail in many of the early sections (some dating back in excess of 20 years) either due to production pressures or more likely a lack of appreciation for the variability of the VRP over space; something that may only have become apparent after many years of mining activity. Secondly the diverse spectrum of descriptive terminology much of which has long since departed from the modern geological vocabulary.

The main aim of this particular part of the study was to attempt to quantify the variability of the channel width, and , on a more subjective note, to spatially locate the various Reef "types" that have been noted over the years. The geographical distribution of the current workings was of considerable assistance as was the personal communication with the geologists in charge of the various areas of the mine. The individual logs were recorded on a standard data sheet, (figure 3.1), numbered and their positions plotted on a locality plan (figure 3.2). The widths of the eight individual units known to exist were recorded and tabulated as the first step in the formation of a more complete database. (Appendix I) The two major units of the VRP, the VRBC and the UVRZ are fairly ubiquitous and of the most economic significance, and were therefore chosen as the two sets of data to be used for contouring.

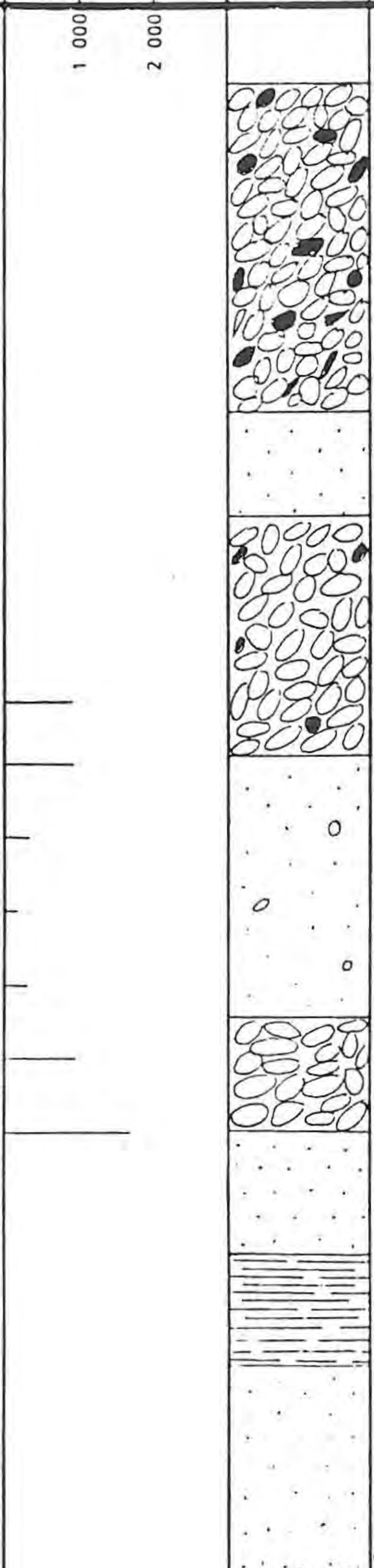
Most of the remaining data, such as gold and uranium values are collected as run of mine sampling. Specific values are used only with extreme discretion, firstly for the more obvious confidentiality of such information and secondly the methodology behind their collection is of little use for the purposes of this work.

Run of mine data for evaluation purposes consists of channel samples taken at 4m. intervals in Reef development and 5m. intervals in stopes every month during mining operations. The net result is a rough 5 x 10m. grid of samples throughout the mined-out area. The sampling process itself has very little geological input, consequently the database contains

SECTION	
LOCATION	12 S W 1 13 E/C
SCALE	1 10
MEASURED BY	
DATE	
DATUM	

VAAL REEFS

GOLD & URANIUM DIVISION



ADDITIONAL INFORMATION	SCINTILLOMETER READING COUNTS/SEC (1 000, 2 000)	BED THICKNESS	OTHER DATA EG. SAMPLES PALAEO-CURRENT	DIP	MINERALISATION	ALTERATION	REMARKS & INTERPRETATION
		45			10% PY		(Z.P.M.) POLYMICTIC, WELL SORTED CONGLOM. WITH ROUNDED/SUB ROUNDED PEBBLES OF VEIN QTZ BIF AND BLACK CHERTS WITH YELLOW SHALEY FRAGMENTS. MED/S. CLAST SUPP, WITH FAIR MIN. PYRITE.
					10% PY		MINERALISED BEDD. PLANE.
		14					MED-GRAINED GREYISH QUARTZITE NO MINERALISATION. O/QTZITE.
		33					(VRZ) DOMINANTLY OLIGOMICTIC QTZ CONG WITH ODD DK. CHERTS CLAST SUPP AND MATRIX SUPP PEBBLY QTZITE.
		35					(INTERNAL QTZITE) WITH SMALL SCATTERED PEBBLES.
		15			5% PY		(VR) LGE/MED WHITE QTZ PEBBLES CLAST. SUPP. CONGLOM. OLIGOMICTIC WEAK DISSEM. MINERALISATION
		17					QTZITE BAND C-M/g. GREY-BROWN.
SHALE BANDS APPEAR TO THIN LATERALLY		15					SHALEY BAND - APPEARS DISCONTINUOUS MORE QUARTZITIC TOWARDS BASE.
		35					(F.W) C-M/G GREY SPECKLY GRITTY P.QTZITE.
		OBSCURED ↓					

FIGURE 3.1

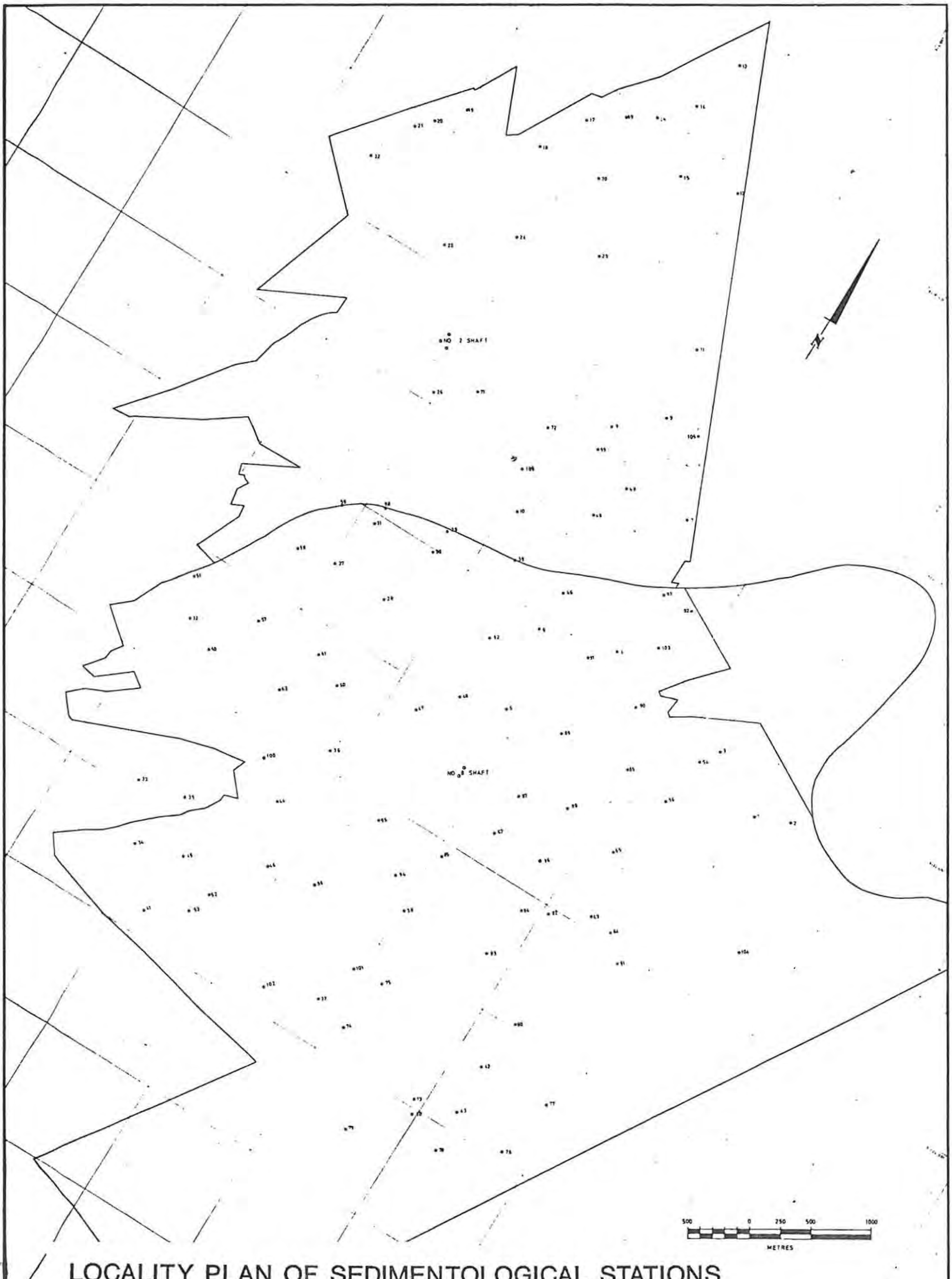
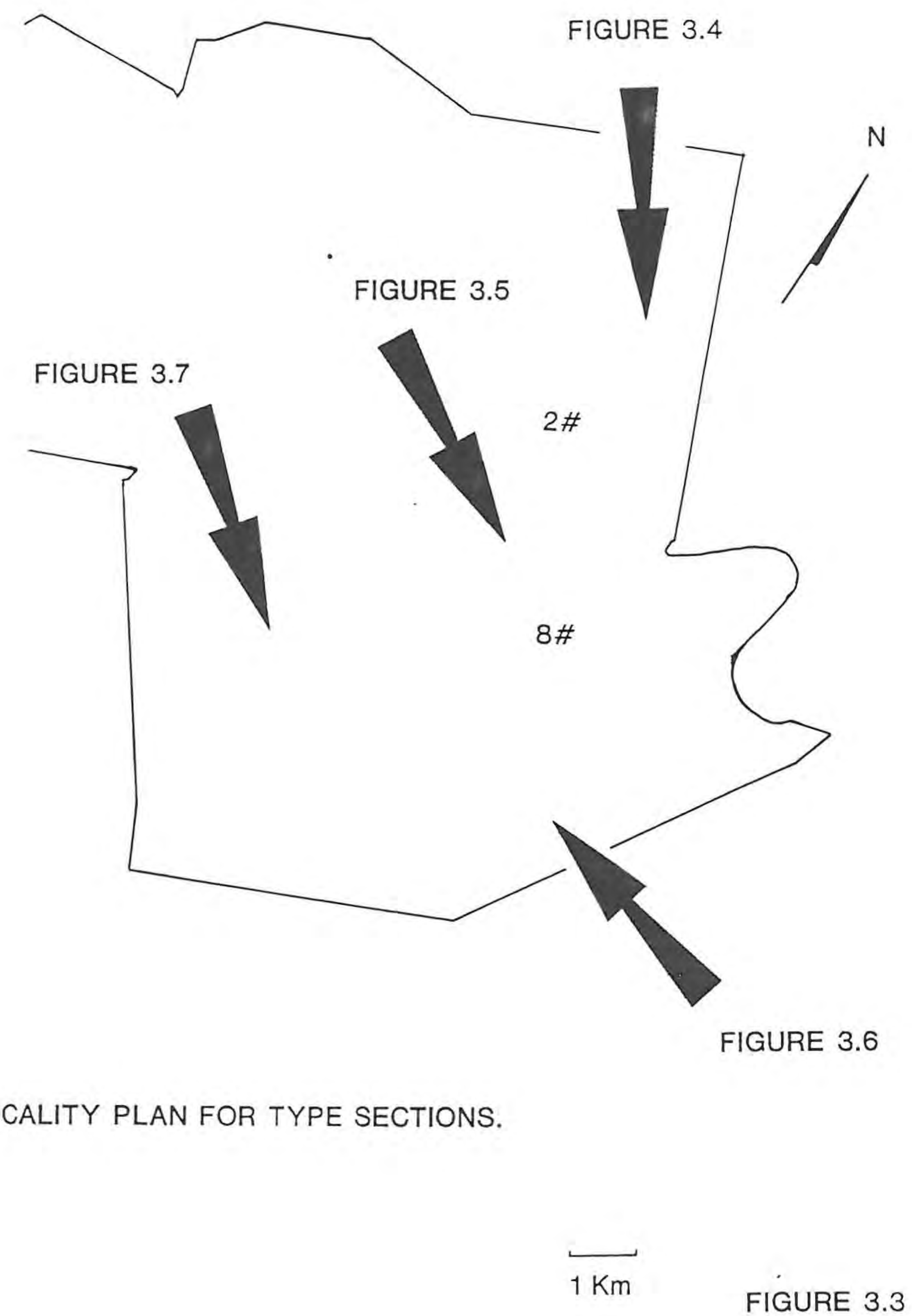

NO 2 SHAFT
METRES
LOCALITY PLAN OF SEDIMENTOLOGICAL STATIONS

FIGURE 3.2

erroneous values produced by sampling hangingwall, footwall and intrusives. The immense volume of true data however serves to swamp out false values. Data collected in this fashion includes g/t c/w (channel width, or from the VRBC to the top of the UVRZ), s/w (stope width)and kg/t (of U_3O_8) and is used to calculate the cmg/t and gold content values at each station. Total cmg/t, c/w, s/w and cmKg/t are then entered into a computerised database and can be used for statistical and ore evaluation purposes. On a small scale these values may be used individually to produce a "spotted dog" for contouring purposes. The high variability however tends to make this data rather coarse and often unsuitable in this format. More commonly 100m. moving averages are produced in an attempt to smooth the data.

LATERAL VARIATIONS

Lateral variations in the VRP have been common knowledge within the local geological community for some time. The differentiation between Witkop and Stilfontein facies VRP was made early on by workers such as Minter, as was the consistency of the sedimentary characteristics of each facies. Much of the early work centered on the VRBC and this unit is indeed the most consistent across large areas of the goldfield. In recent years more detailed investigations have shown that the nature of the VRP is more complex than was first envisaged. The western edge of Vaal Reef's mine contains the transition from Witkop to Stilfontein facies and colleagues working in this area are discovering numerous "sub-facies" as their knowledge increases.



LOCALITY PLAN FOR TYPE SECTIONS.

FIGURE 3.3

Typical Reef Section 2K area

FIGURE 3.4

Typical Reef Section 8A area

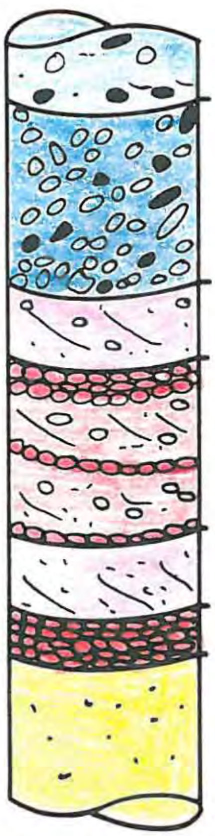


FIGURE 3.5

The Eastern edge of Vaal Reefs, represented by the study area is marked by a thicker Reef package and the added complexity of multiple Reef interaction.

To emphasize the extremes of the variation in the Vaal Reef through space, four typical sections are shown in figures 3.4 to 3.7 the locations of which can be seen in figure 3.3.

Figure 3.4 is a section taken from the 2K area of Vaal Reefs No.2 Shaft in the far North of the study area. In this particular section there are only three of the eight main units; the ZM, LZM and VRBC.

The basic assumption in this area is that all the major units were deposited and removed rather than not deposited at all. The "pre- Vaal Reef" or Mizpah units are thought to have been reworked by the VRBC and evidence for its existence is seen in the occasional observation of a polymictic channelised unit preserved below the VRBC. The UVRZ and Internal Quartzites have been removed and reworked by the ZM and LZM units. The ZM unit in the north is very channelised and once again small remnants of the pre-existing UVRZ have been observed. The ZM in the north is also a much more mature conglomerate, well-mineralised in places and often bordering on oligomictic in its assemblage. An average channel width from VRBC to the top of the ZM in the 2K area would be in the order of 1.0 to 1.2 metres.

Moving south, figure 3.5 is a representative section for the central portion of the study area. In this example five of the eight units are commonly observed, with the UVRZ and associated quartzites being preserved below the ZM. The ZM is generally a poorly developed, immature, matrix-supported conglomerate with little mineralisation. The apparent non-existence of the LZM owes itself more to non-recognition or confusion amongst the geologists collecting data, than to any geological feature. Variations within the UVRZ are more noteable across the palaeoslope than down it. The double reef package is believed to exist throughout most of the study area and again failure to recognize the two packages when not separated by Internal Quartzite is the most common reason for the recording of only one conglomerate package. Common channel widths in this area are of the order of 1.6 to 3 metres.

Continuing further south, figure 3.6 is a typical section from the 8L area of No. 8 Shaft and is representative of the type of reef package to be expected as mining progresses south. The total package often exceeds 4,5m and once again the non-existence of the LZM is thought to be due to non-recognition. The preservation of the Mizpah units below the VRBC is of major interest and investigations into this unit in the future will enable the depositional model to be fine-tuned. The VRP is often recorded as one thick unit and in this area it is virtually impossible to visually separate the VRBC and UVRZ when there is no Internal Quartzite. Gold and Uranium values within the UVRZ are however considerably higher in this region than in the north and sampling and scintilometer data enables the two units to be separated. The quartzites between the UVRZ and ZM are much thicker and observations of the ZM are often restricted, it

Typical Reef section 8L area

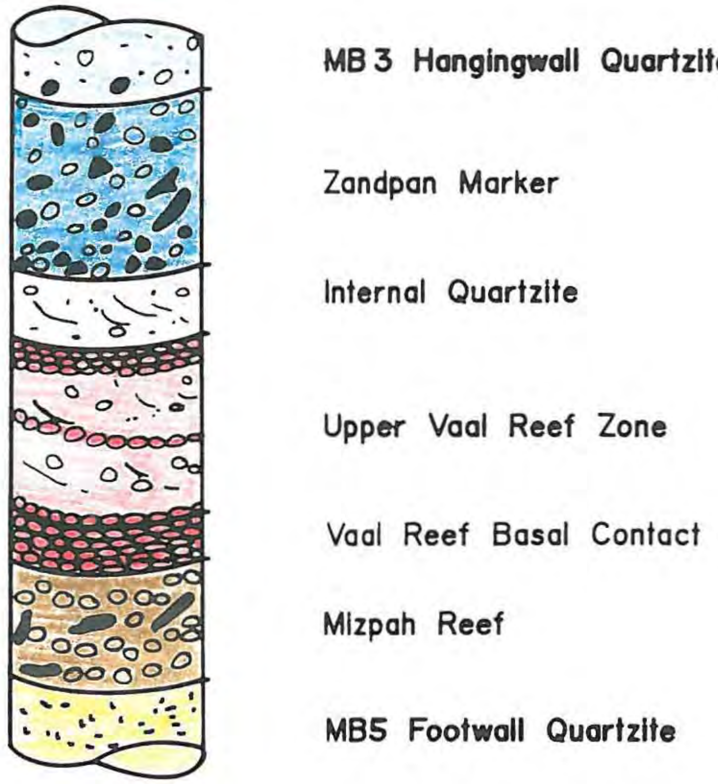


FIGURE 3.6

Typical Reef Section 9 # area

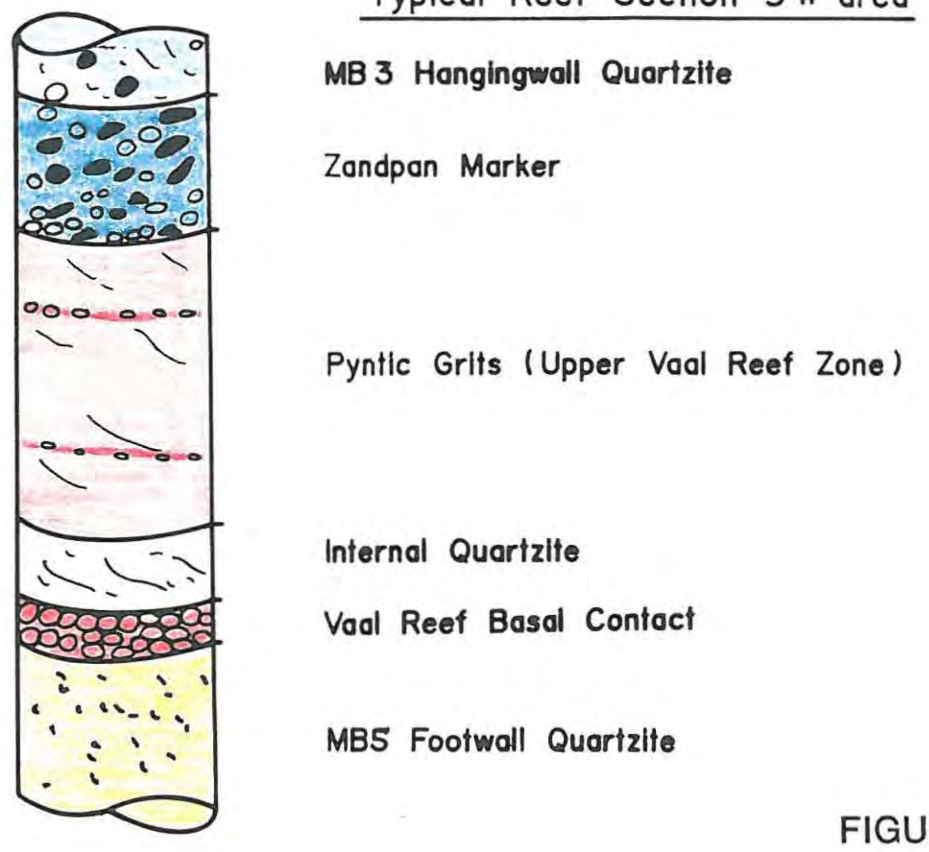


FIGURE 3.7

is generally immature and of little economic or logistical interest in this area.

Figure 3.8 is a simplified N-S section showing the variation within the previously described areas and an interpretation of the sub-cropping nature of the Mizpah and UVRZ units and the development of the multiple reef package towards the south.

Variations along an E-W direction are not quite as obvious and concentrated mostly around the development within individual units rather than the appearance of new units. Figure 3.7 is a typical section taken from Vaal Reefs No.9 Shaft, and represents possibly the western-most extreme of the Stilfontein facies of the VRP. The main point of note in this instance is the lack of a well-defined UVRZ. The unit separating the VRBC from the ZM is a thick quartzitic unit with occasional mineralised grit bands. This unit is believed to be a distal expression of the UVRZ. The development of the "pyritic grits" into the UVRZ can clearly be traced from W to E across the palaeoslope. Figure 3.9 is an idealised representation of the development of the VRP and particularly the UVRZ from W to E.

Having established the basic premise of the variation and development of the VRP and associated conglomerates both down and across the palaeoslope an attempt was made at geographically defining the areas of certain reef "types".

Of the 106 data points collected many were at odds with the general model but only three were excluded as totally unacceptable. No. 49 was excluded due to

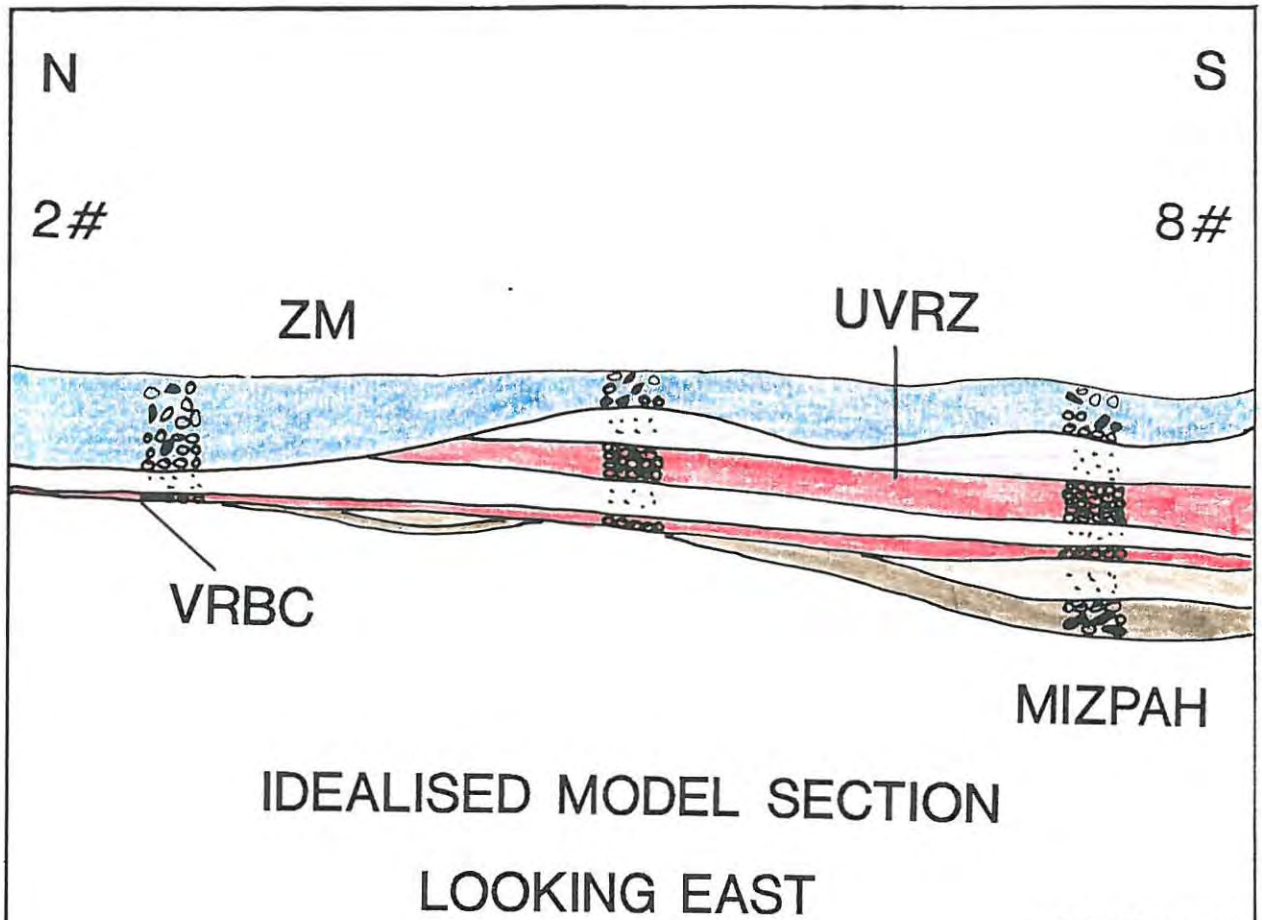


FIGURE 3.8

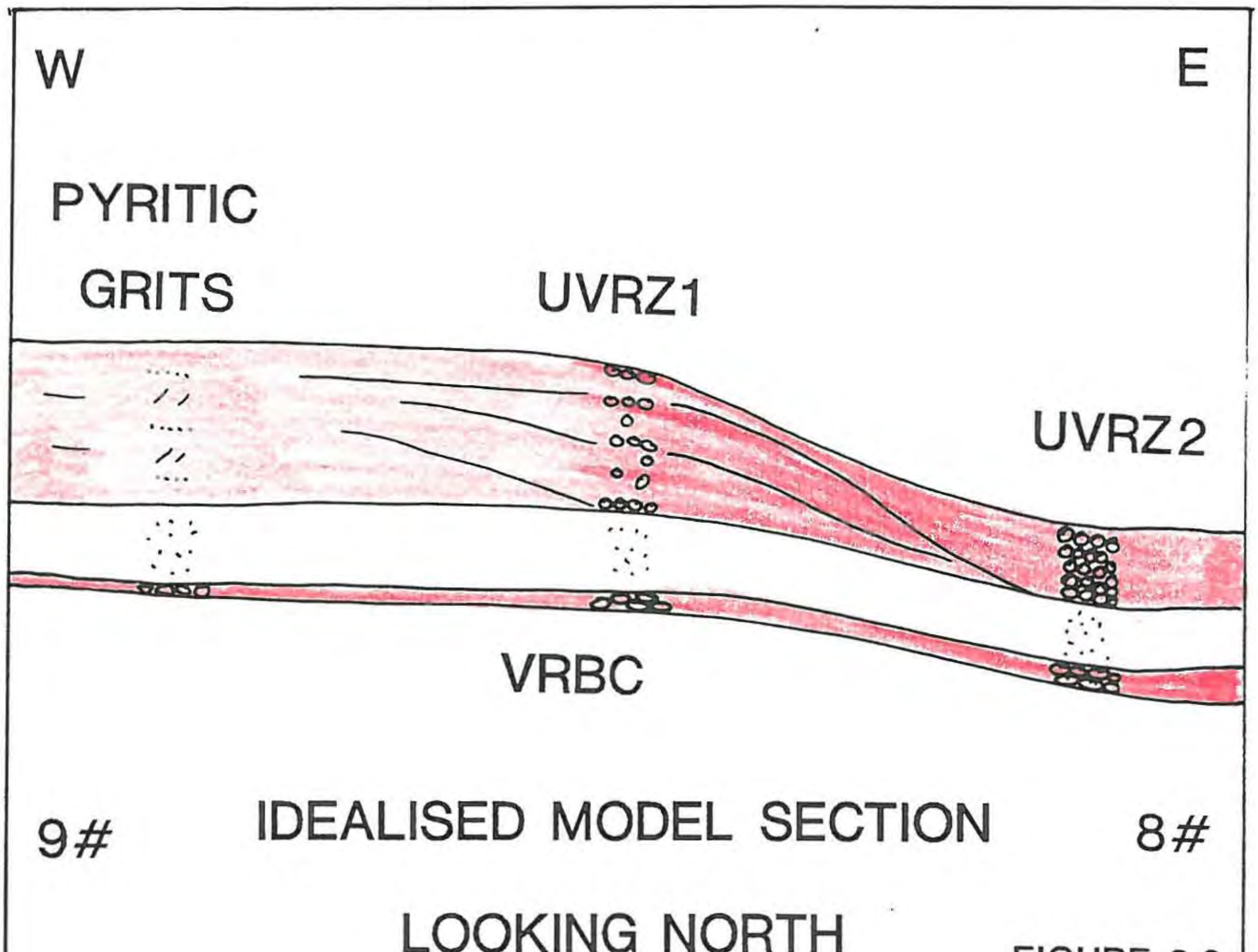


FIGURE 3.9

the exceptionally thick VRBC, this is possibly due to the existence of a pre-Vaal Reef or Mizpah channel that was not recognized as such. No's 78 and 79 were also excluded as the VRBC and UVRZ were not separated by the operator and there is little doubt from assay results in the area that both units exist. The remaining 103 stations provided an adequate base from which to begin mapping out various lithofacies of the VRP.

The VRBC proved to be fairly consistent across the study area which tended to agree with the descriptive and value data available. The UVRZ showed a more marked variation which also tied up well with the descriptive data and backed up the depositional model envisaged for this unit.

The channel widths for VRBC and UVRZ, being the most consistent and most economically important units, were contoured using palaeocurrent and value trends as a general bias.

ISOPACHS AND FENCE DIAGRAMS

Figure 3.10 shows the isopachs for the VRBC in 5 cm intervals. The overall trend is roughly parallel to the palaeocurrent direction, however there is also a secondary trend almost normal to the main direction. This secondary trend is believed to be a reflection of the footwall topography, producing a pattern of an infilled drainage network. There are two wide channels in the north and south of the area separated by a 1-2 km zone of thin channel or palaeohigh environment.

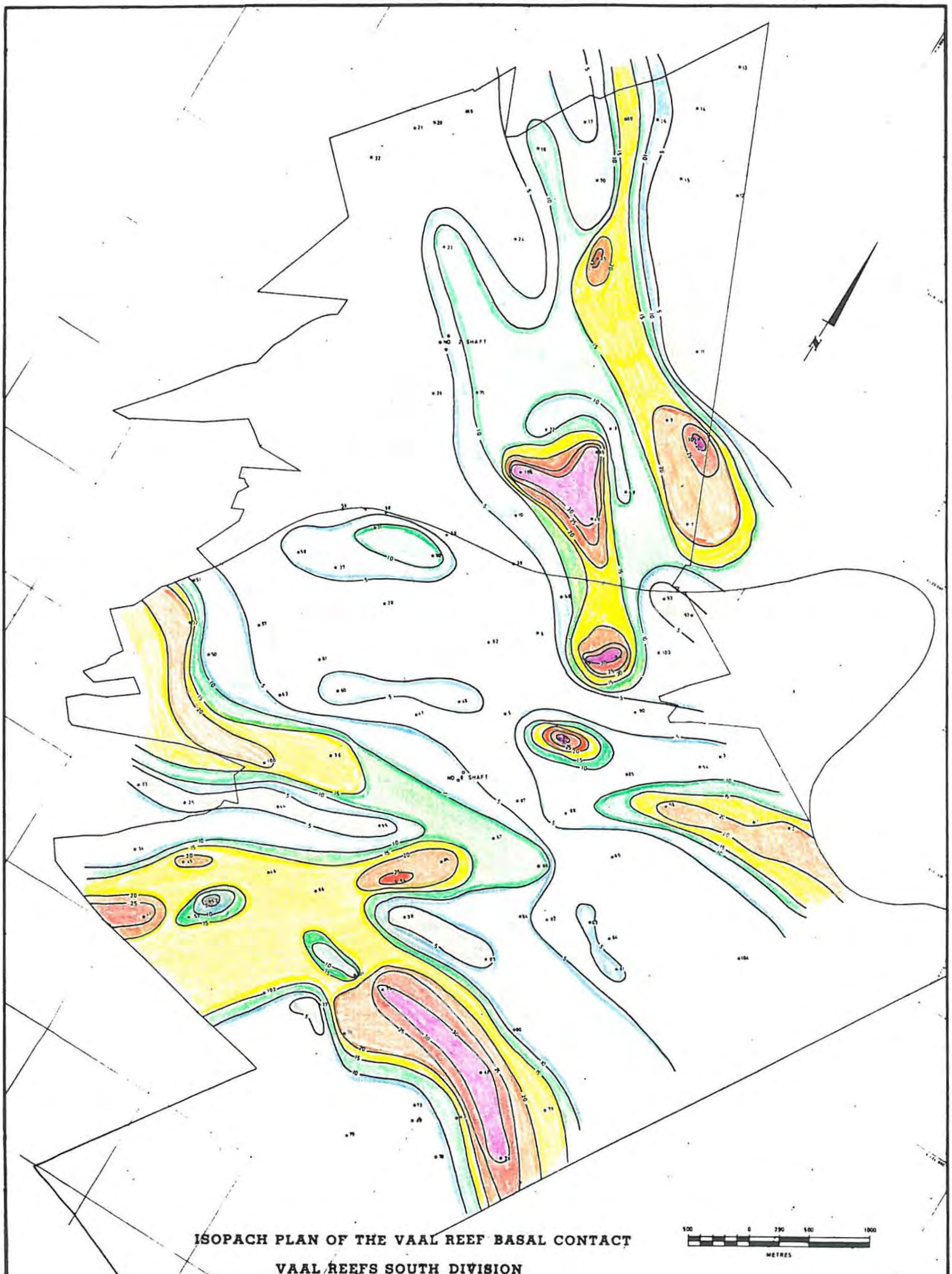

ISOPACH PLAN OF THE VAAL REEF BASAL CONTACT
VAAL REEFS SOUTH DIVISION
METRES
NO 7 SHAFT
NO 8 SHAFT

FIGURE 3.10

Isopachs for the UVRZ were drawn using 10 cm intervals and as can be seen from figure 3.11 they exhibit a trend very close to that of the VRBC. The thin reef in this instance is not however related to a palaeohigh or channel edge but a main channel environment. The linear boundary between the central channel and the slightly thicker UVRZ2 in the west is quite clear if not particularly prominent. There appear to be divergent channels in the south-east sector, this however may be a result of the density of data in this area.

The subject of data density is a particularly thorny issue. Current geostatistical work has indicated that for gold values a range of influence of less than 10 metres is to be expected, i.e. over that distance samples show no relationship. This assumption is quite possibly valid for gold distribution, it is felt however, that the spatial relationship of the unit thickness or channel width is in excess of the 10 metre limit imposed by gold values. There is of course little doubt that samples on a smaller grid would produce a more detailed picture, yet the main aim at this juncture is to establish broad trends or zones and not the finer details of a braided system.

Fence diagrams were produced along N-S and E-W section lines (figure 3.12) to test the model as proposed by figures 3.8 and 3.9. There are several problems that surface when constructing diagrams of this sort. Firstly the use of a datum from which to base unit thicknesses; in both cases the top of the VRBC is used as a datum. Secondly, the vastly different vertical and horizontal scales produce a

ISOPACH PLAN OF THE UPPER VAAL REEF ZONE
VAAL REEFS SOUTH DIVISION

FIGURE 3.11

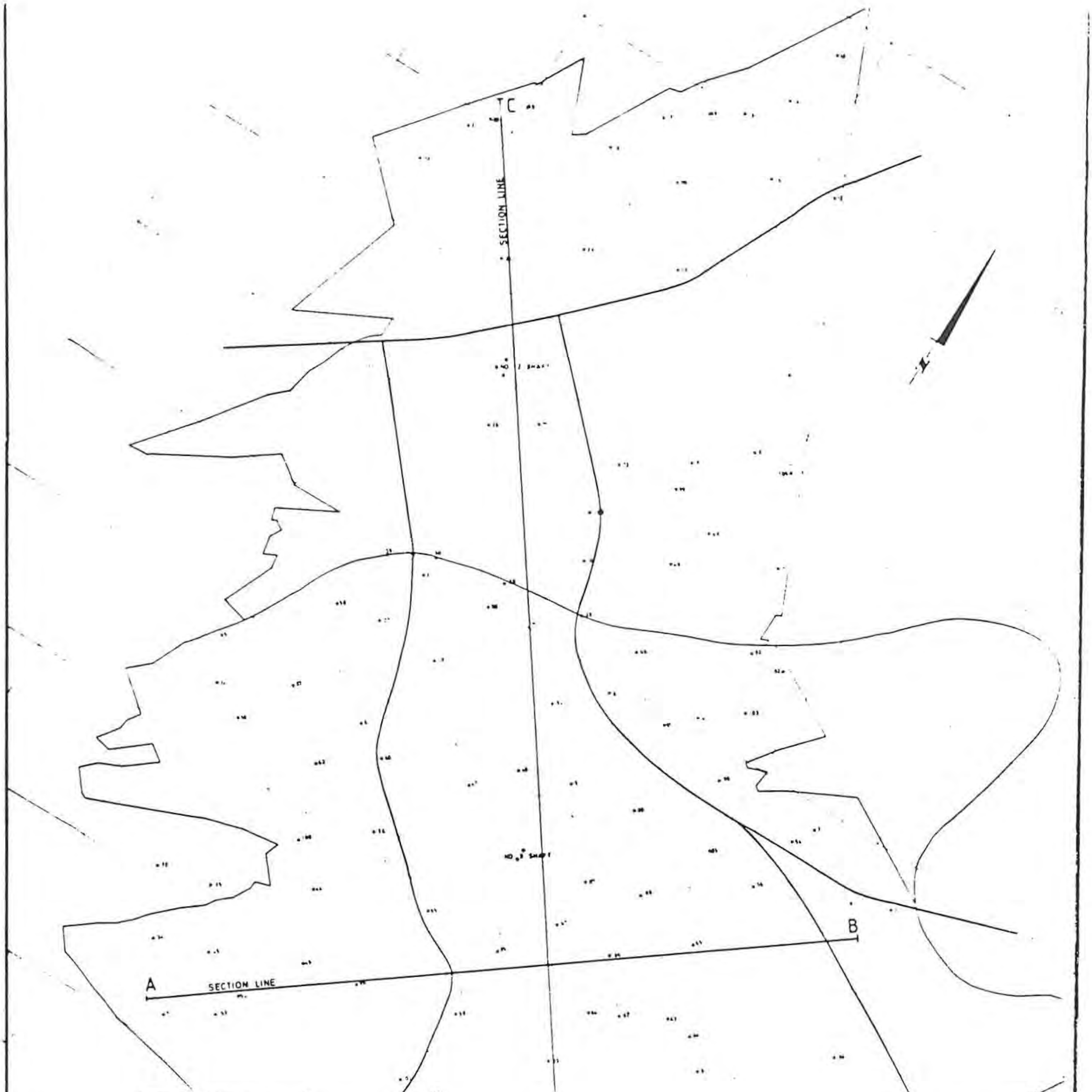
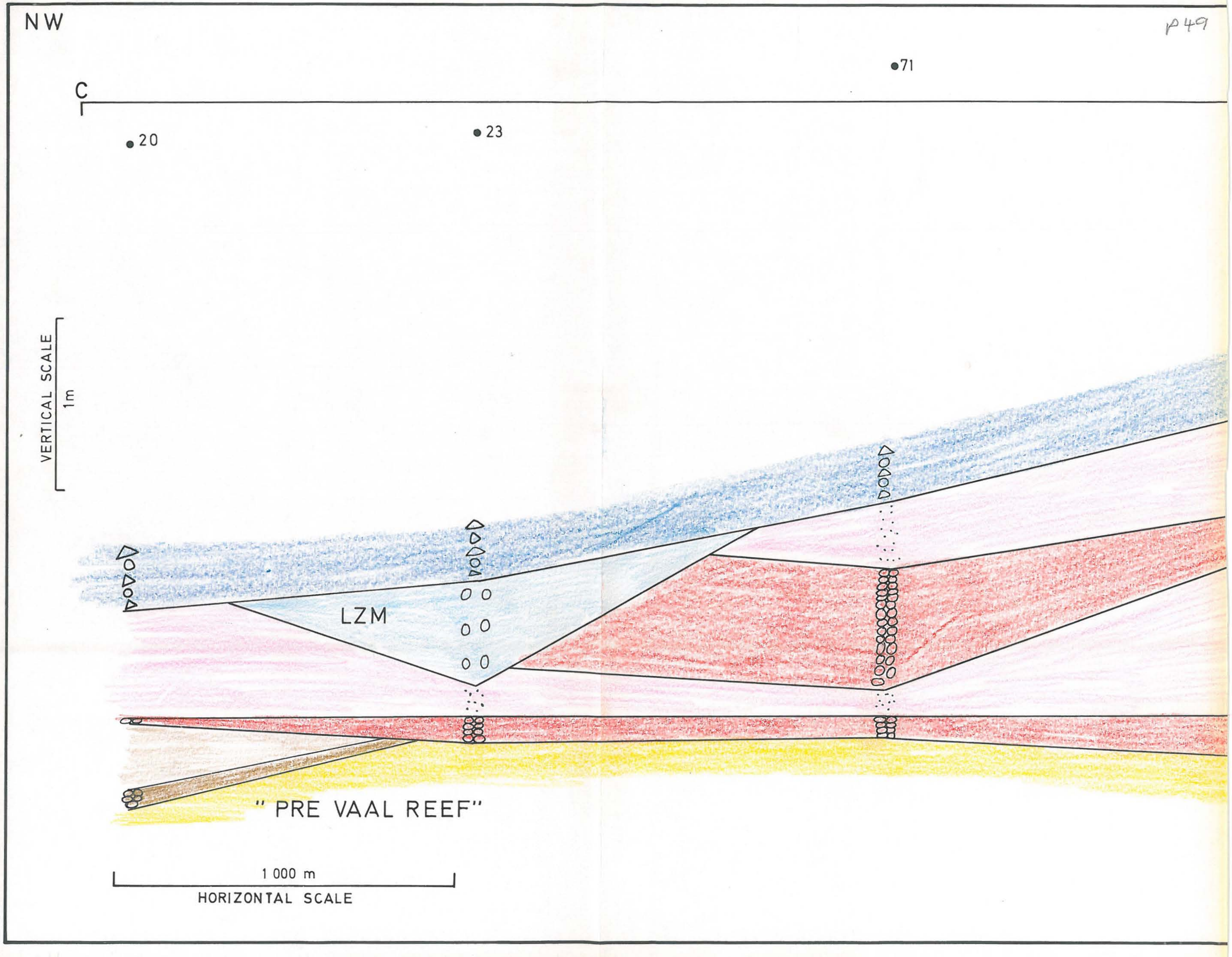
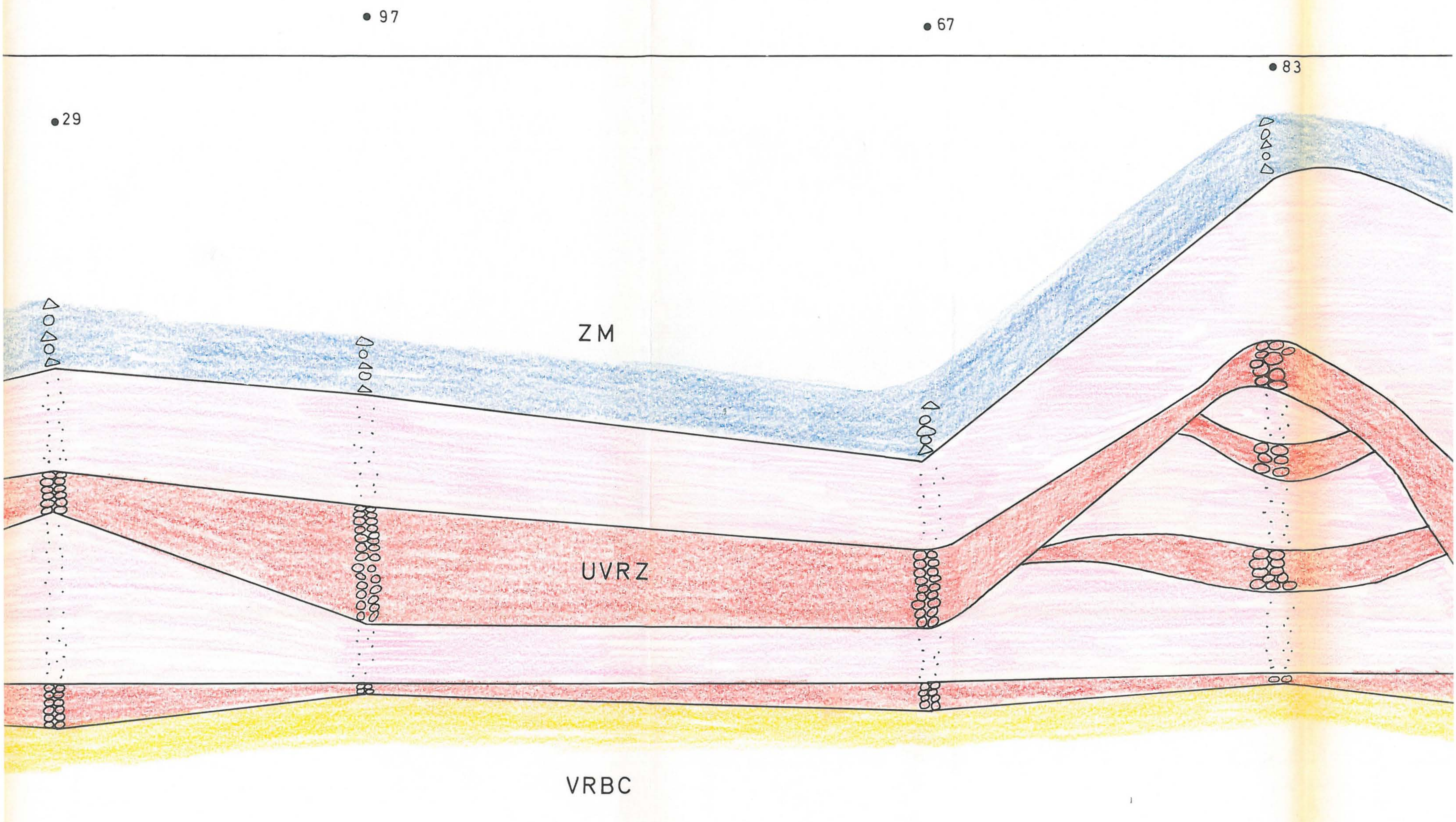

C
SECTION LINE
A
SECTION LINE
B
D
LOCALITY PLAN OF SEDIMENTOLOGICAL STATIONS
ZONE BOUNDARIES AND SECTION LINES
VAAL REEFS SOUTH DIVISION
METRES

FIGURE 3.12


NW
C
• 20
• 23
• 71
VERTICAL SCALE
1m
LZM
" PRE VAAL REEF"
1 000 m
HORIZONTAL SCALE



SCHEMATIC FENCE DIAGRA

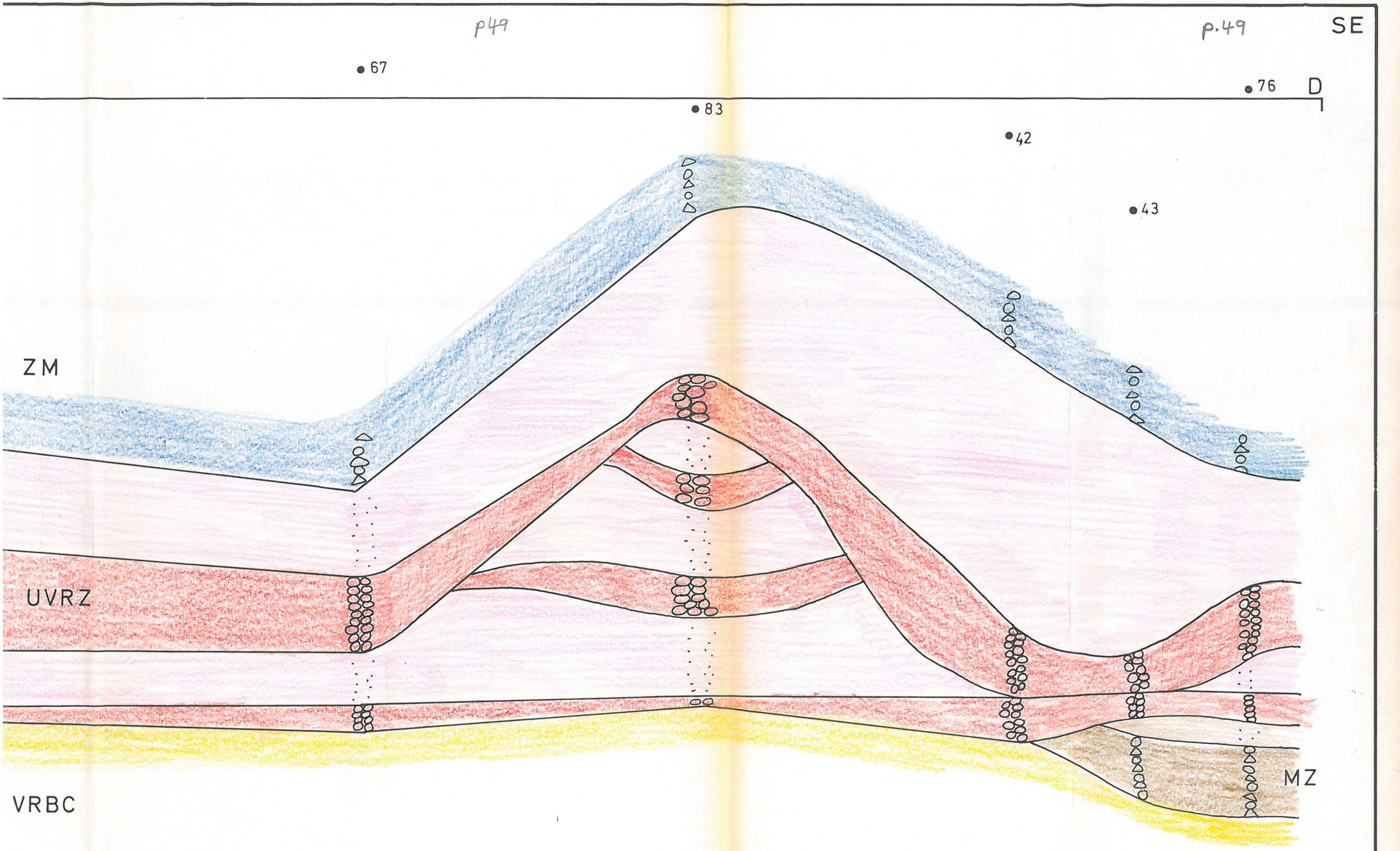
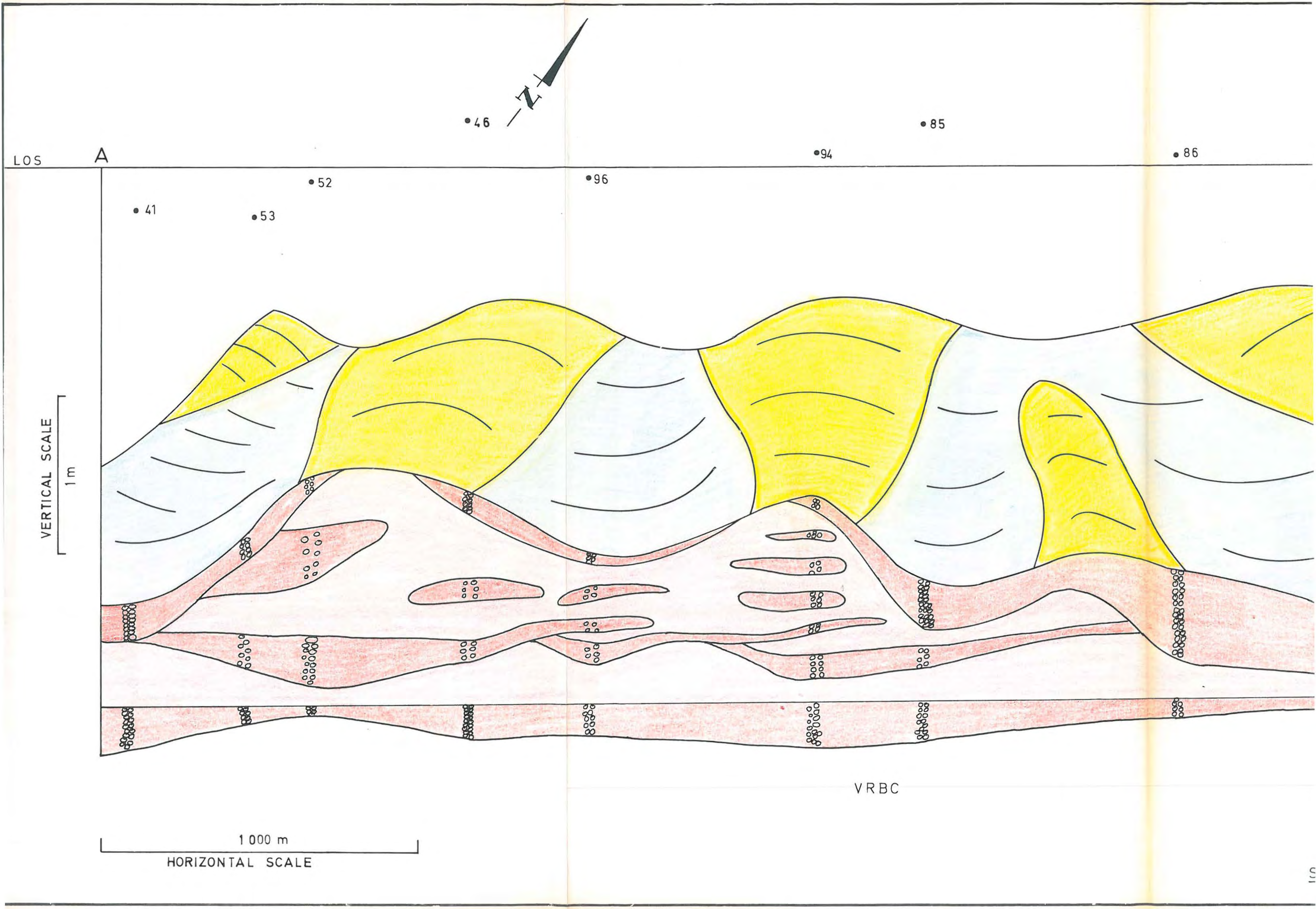


FIGURE 3.13

SCHEMATIC FENCE DIAGRAM ALONG SECTION LINE C – D



N
LOS
A
46
85
94
86
96
52
41
53
VERTICAL SCALE
1 m
VRBC
1 000 m
HORIZONTAL SCALE

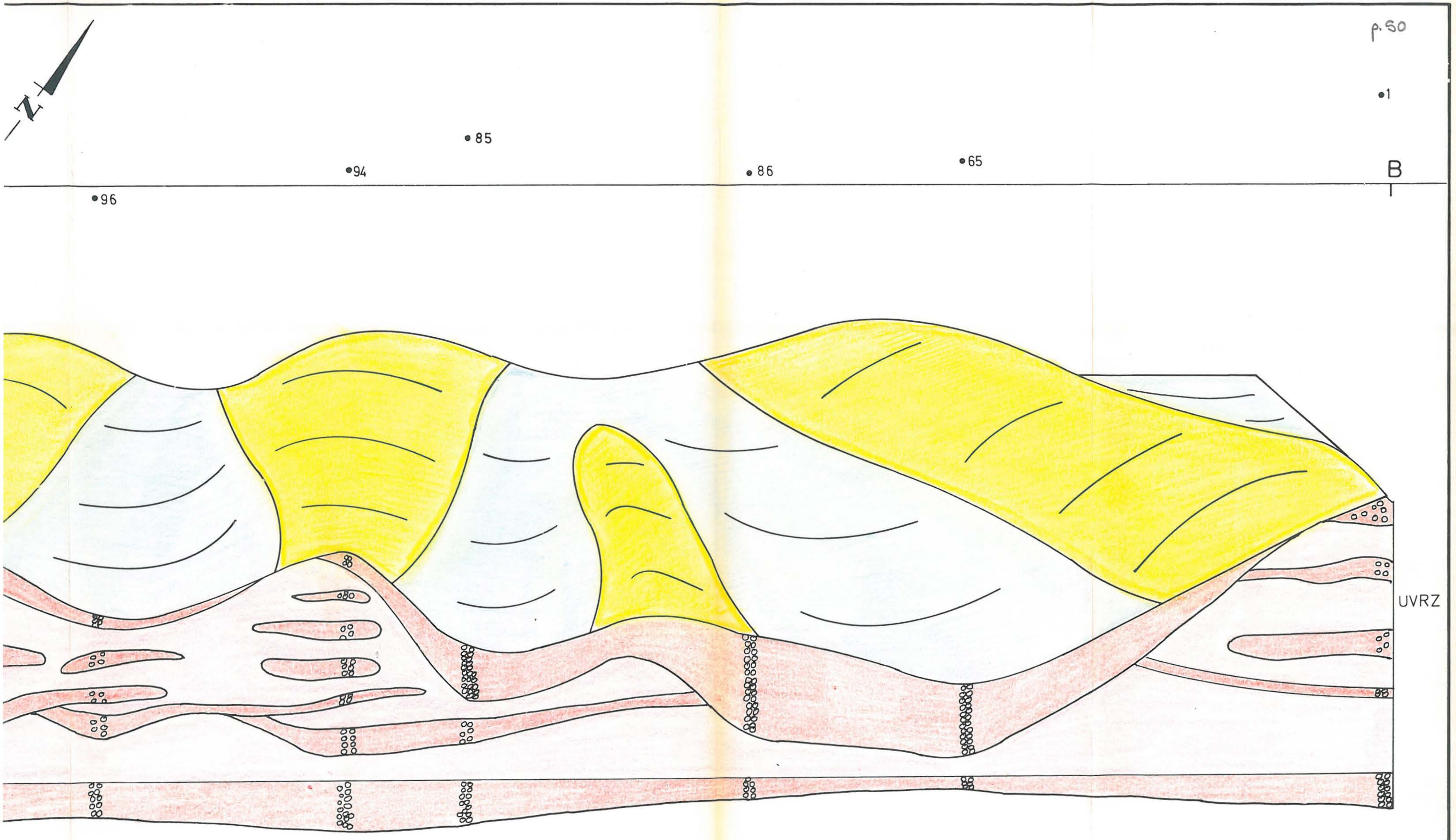


FIGURE 3.14

SCHEMATIC FENCE DIAGRAM ALONG SECTION LINE A-B somewhat misleading image. Thirdly, the interpolation of unit boundaries over such distances produces more of an idealised or interpretational section than a factual one. None-the-less both sections were produced and both supported the suggested models to a greater or lesser extent. Figure 3.13, drawn NW-SE looking NE clearly shows the sub-crop of the UVRZ and MZ units. Figure 3.14 shows the lateral variation of the UVRZ with a three dimensional attempt at interpreting the environment of deposition.

FACIES MAP

As this was a preliminary attempt at producing a facies map it was decided to avoid over-complicating the process and therefore only the most noteable variations were utilised. To this end the existence or non-existence of the Mizpah and UVRZ was utilised down the palaeoslope and the nature of the UVRZ where present across the palaeoslope. In total seven broad zones were established and these can be seen in figure 3.15, each with its own characteristics. Zones 1, 2A, 3, 4 and 6 have been established from fairly dense sample coverage, whereas Zones 2B and 5 are projected from relatively sparse data:

Zone 1, represented by the profile seen in figure 3.4 is bounded in the south by the estimated sub-crop of the UVRZ. In this area two factors are of importance to the production environment. Firstly the existence of the ZM directly above the VRBC, and its gold-carrying ability, requires its removal during mining. The frequency of argillaceous partings within the MB3 above the ZM unit very often

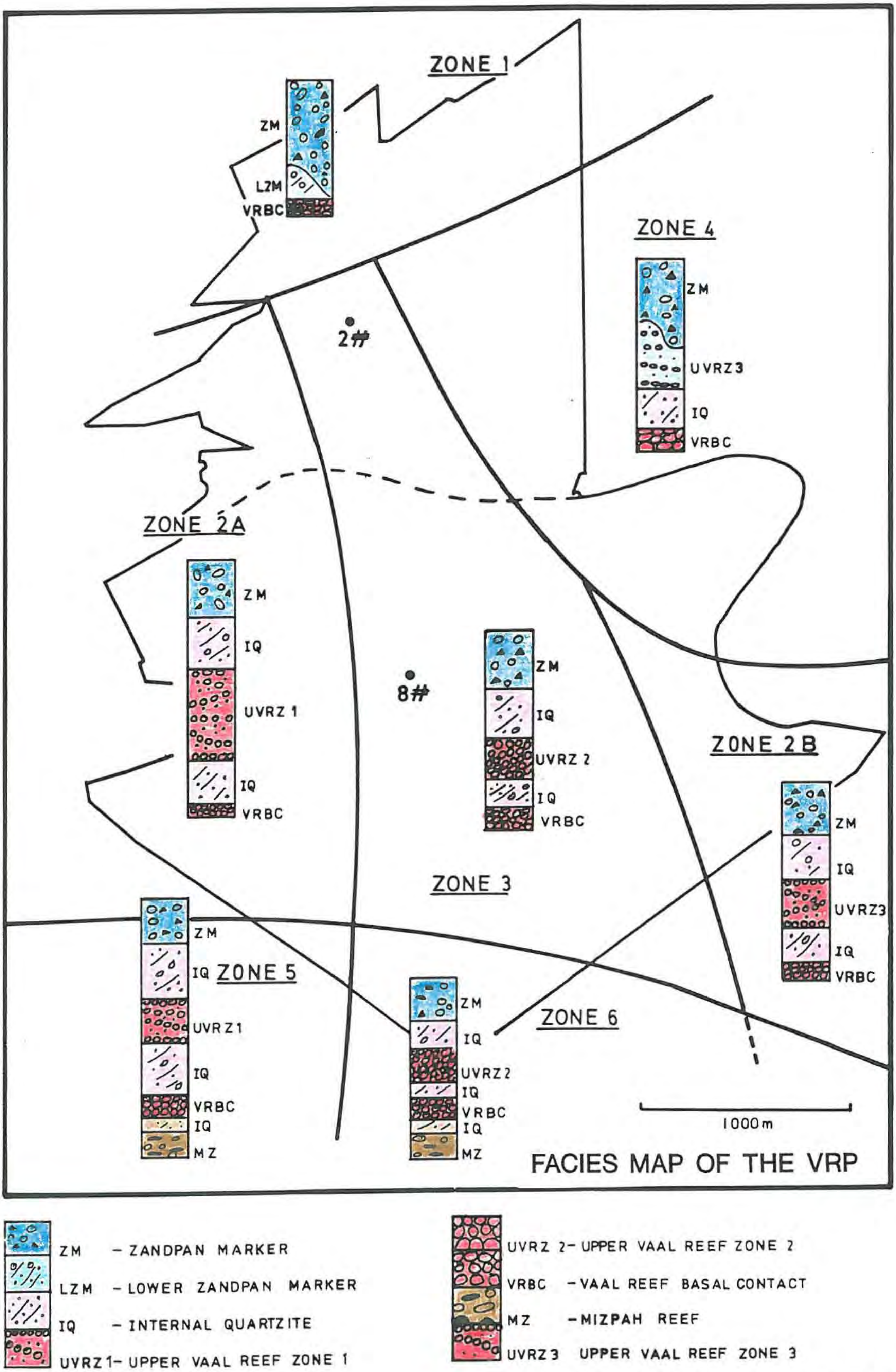

ZONE 1
ZM
LZM
VRBC
ZONE 4
ZM
UVRZ3
IQ
VRBC
2#
ZONE 2A
ZM
IQ
UVRZ 1
IQ
VRBC
8#
ZM
IQ
UVRZ 2
IQ
VRBC
ZONE 2B
ZM
IQ
UVRZ3
IQ
VRBC
ZONE 3
ZM
IQ
ZONE 5
UVRZ1
IQ
VRBC
IQ
MZ
ZM
IQ
UVRZ2
IQ
VRBC
IQ
MZ
ZONE 6
1000m
FACIES MAP OF THE VRP
ZM - ZANDPAN MARKER
LZM - LOWER ZANDPAN MARKER
IQ - INTERNAL QUARTZITE
UVRZ1- UPPER VAAL REEF ZONE 1
UVRZ 2- UPPER VAAL REEF ZONE 2
VRBC - VAAL REEF BASAL CONTACT
MZ - MIZPAH REEF
UVRZ3 UPPER VAAL REEF ZONE 3

FIGURE 3.15

leads to unstable hanging wall conditions and results in excessive stope widths. Secondly value trends for the upper ore zone (ZM) are the result of combined UVRZ and ZM trends and therefore require more detailed investigation to improve on block valuation techniques.

Zone 2A and 2B: Both zones are characterised by a "two Vaal Reef" package, and by a fairly thick UVRZ unit, resulting in fairly high total channel thicknesses. The main distinction lies in the nature of the UVRZ. Zone 2A is characterised by a poorly developed UVRZ consisting of a basal conglomeratic unit and pebbly quartzites. The unit is generally poorly mineralised and represents the edge of a channel or longitudinal bar-type of environment. Zone 2B is also characterised by a thick UVRZ unit but in this instance it comprises several fairly well-developed conglomeratic units intercalated with clean siliceous quartzites. This sub-facies is more likely to represent a mid-channel bar. The UVRZ 3 of Zone 2B, being better mineralised, has a greater potential value than the UVRZ 1 of Zone 2A and therefore requires more detailed study before "undercutting" is carried out during mining, i.e.. it is normally economically viable to remove the complete channel thus resulting in higher stope widths than in Zone 2A.

Zone 3: This zone is also characterised by two reefs. In this case however the UVRZ 2 unit is generally thinner and often well-developed. Kerogen seams at the base of the UVRZ 2 are regularly noted and the total channel width is generally less than 100cm. This sub-facies is believed to represent a central braided channel environment. This type of profile is probably the most common, and as it covers the majority of the mined-out area constitutes a large portion of the overall database.

Zone 4: This zone is similar to Zone 2B excepting that the UVRZ 3 has been partially removed by the ZM. This produces two main areas of concern; firstly, hangingwall problems similar to those of zone 1, and secondly, the dilution of the ore zone by low grade ZM.

Zones 5 and 6 are equivalents to Zones 2A and 3 respectively, but with the added complication of the sub-cropping Mizpah units below them. The occurrence of the Mizpah units close to the VRP again raises the problem of identification and philosophy of mining. The untrained eye will easily mistake Mizpah for the VRP and convention has taught the production team that the value is at the base of the reef. This problem is however easily alleviated by close geological supervision and a campaign of re-educating the face-workers. Additional problems when mining the Mizpah (and indeed the ZM) are encountered at the metallurgical plant, as the detailed geochemical composition of the four conglomeratic units is undoubtedly different.

These zones are obviously generalised and sub-division within each zone is more than likely possible. They do however form a useful platform from which to develope A, the depositional model and B, more detailed local facies variations.

PALAEOTRENDS

VALUE DISTRIBUTION

There appear to be two major methods of concentrating gold within a conglomerate package such as the VRP. One is the more conventional trapping of gold mechanically or chemically at the base of the package, the other by winnowing of existing conglomerate package resulting in the concentration of gold towards the top of the system.

The vertical distribution of gold within the VRP is therefore directly controlled by sedimentary processes. There are four fairly distinct distribution profiles as well as a host of more complicated combined profiles.

The first and by far the most common distribution is the bottom loaded system where high gold values are recorded at the basal contact. (Figure 3.16.A.)

Figure 3.16.B. describes a bottom loaded profile which has been top winnowed to give high gold values at the top and bottom of the profile.

The random system seen in Figure 3.16.C. is not particularly common and is often a product of incomplete or poor sampling (i.e. the basal contact was incorrectly sampled). This type of value profile is however recorded in "low grade" or poorly developed reef where there has been little or no scour action.

BOTTOM LOADED VAAL REEF PROFILE

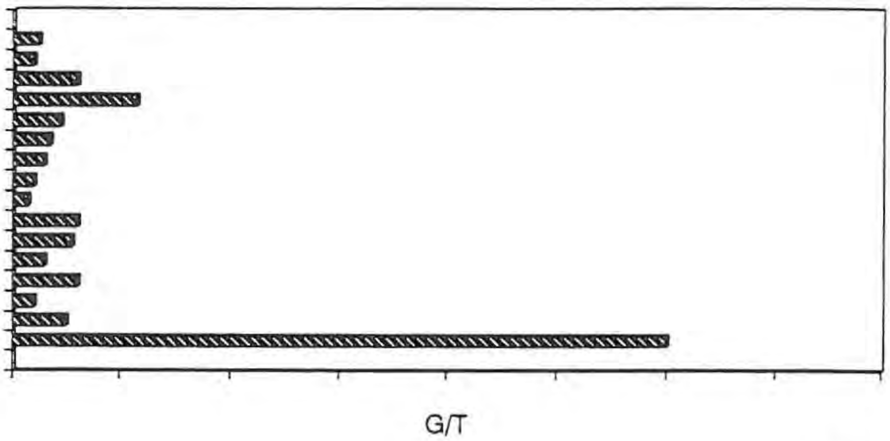


FIGURE 3.16A

TOP AND BOTTOM LOADED VAAL REEF PROFILE

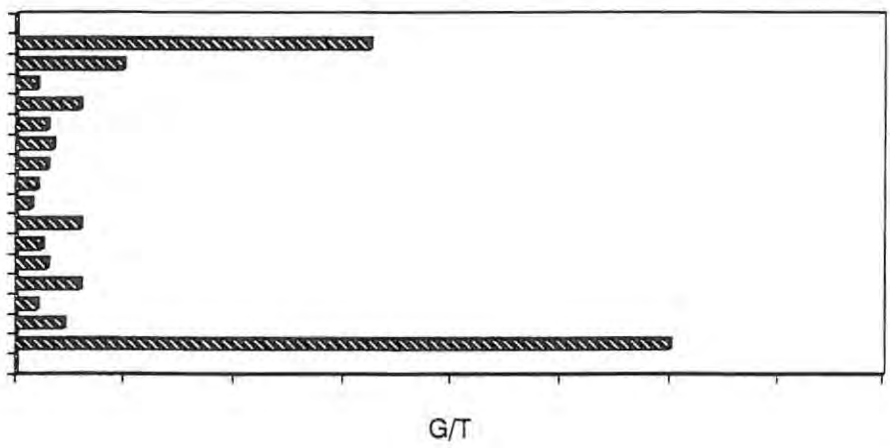


FIGURE 3.16B

Vertical distribution of gold values within the VRP.

RANDOM VAAL REEF PROFILE

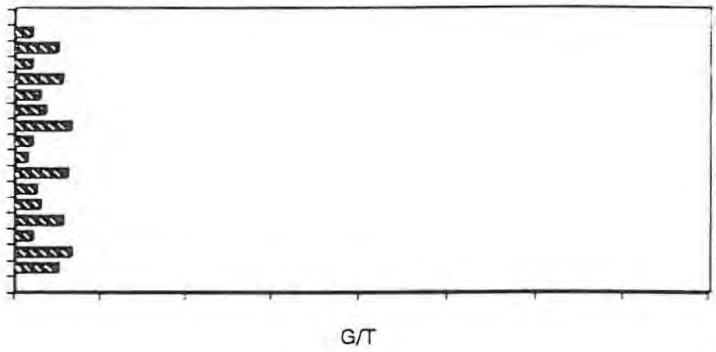


FIGURE 3.16C

TOP LOADED VAAL REEF PROFILE

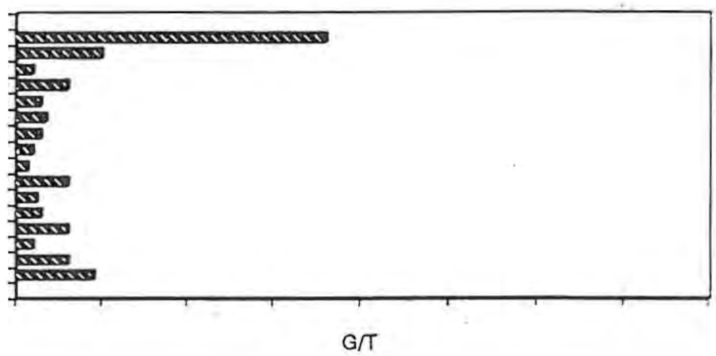


FIGURE 3.16D

BOTTOM AND MIDDLE LOADED VAAL REEF PROFILE

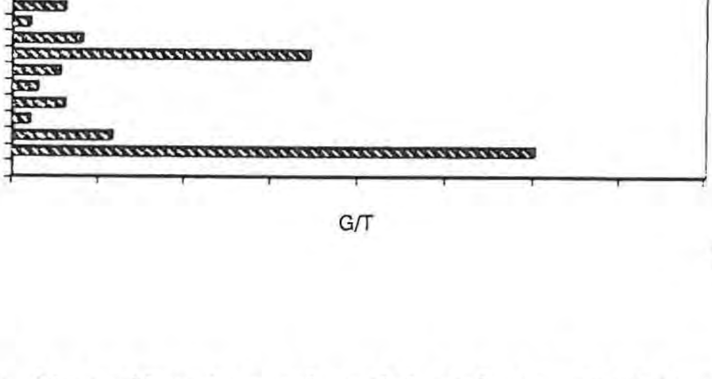


FIGURE 3.16E

Vertical distribution of gold values within the VRP.

The top loaded profile seen in Figure 3.16.D. is a result of winnowing of a random profile. Here again it is not uncommon for this profile to be a result of poor sampling of the basal contact.

The fifth system shown in figure 3.16.E. is common in certain sections of the lease and is in effect a combination of two bottom loaded systems on top of each other.

It is possible to correlate high Gold values with sedimentological features such as scours or Kerogen in 95% of cases. The remaining cases may very often be ascribed to sampling or assay inaccuracies. To be fair when one considers the number of samples that are processed daily on a mine of this size it is not in the least bit surprising that values get transposed from time to time.

The horizontal distribution of gold and uranium values appears at first glance to be relatively simple, however closer scrutiny reveals that cmg/t distribution may in fact be much more complex. Figure 3.17. is a simplified 100m moving average of cmg/t over the whole of the Vaal Reefs area. The highly erratic nature of the gold values within the Vaal Reef make trend analysis difficult and it is common practice to utilise the "smoothing effect" of the moving average method and the "patchy" nature of the values is notable. It is however quite obvious that higher values are to be expected to the eastern side of the area.

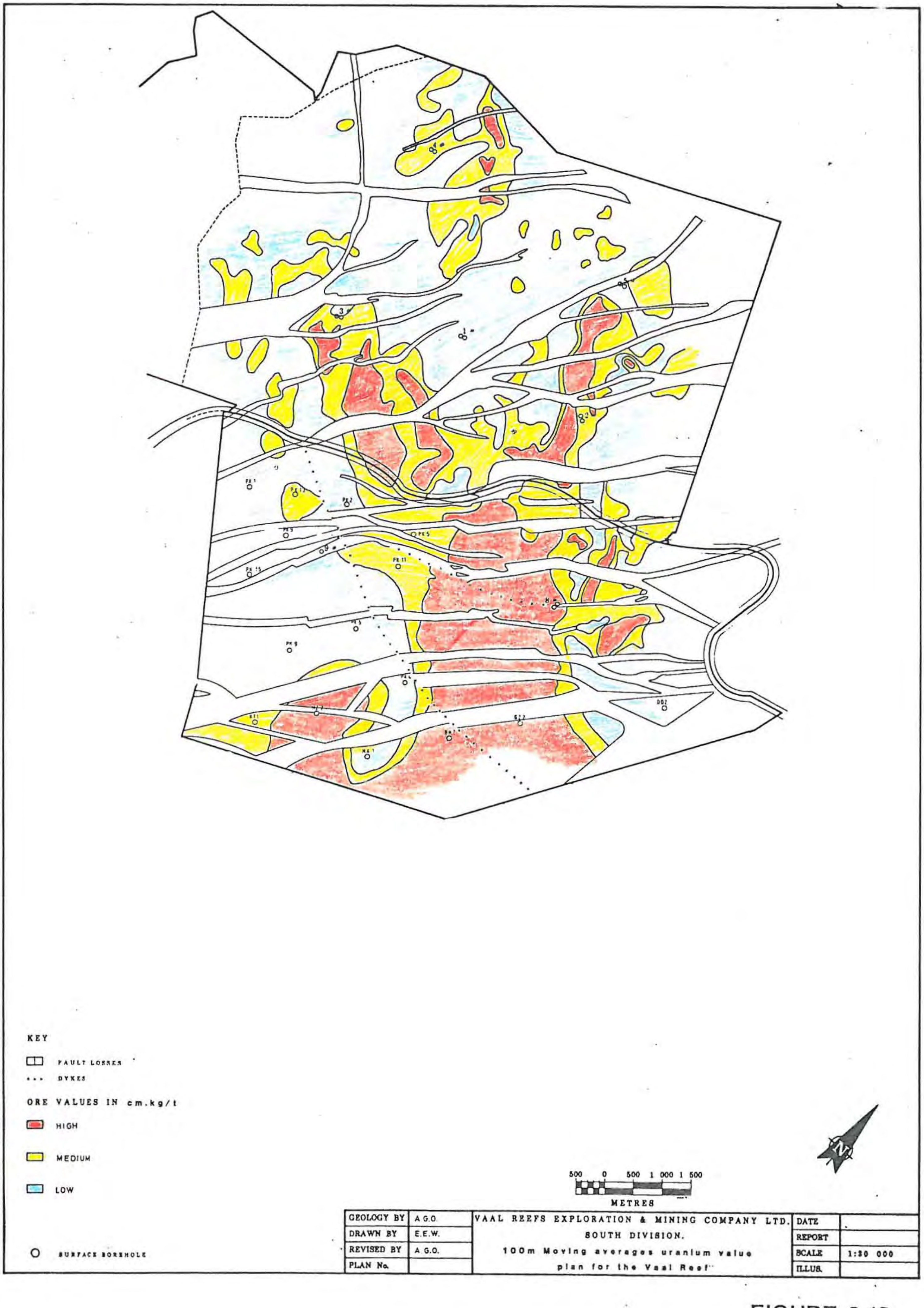
Cmg/t is a measure of the total gold content and is a function of both channel width and g/t. It is


KEY
FAULT LOSSES
DYKES
ORE VALUES IN cm.g/t
HIGH
MEDIUM
LOW
SURFACE BOREHOLE
500 0 500 1 000 1 500
METRES
GEOLOGY BY A.G.O.
DRAWN BY E.E.W.
REVISED BY A.G.O.
PLAN No.
VAAL REEFS EXPLORATION & MINING COMPANY LTD.
SOUTH DIVISION.
100m Moving averages gold value plan for the Vaal Reef.
DATE
REPORT
SCALE 1:30 000
ILLUS.
N

FIGURE 3.17

therefore possible for a 10cm channel with a tenor of 100g/t to be represented in the same manner as a 100cm. thick channel with a tenor of only 10g/t. Therefore although the VRP in the eastern portion of the mine (South Division) appears to have a higher gold content it is quite possible for the VRP in the west to have a similar overall grade. The values shown here are representative of the exposed or mined channel. Although the volume of data and the moving average technique helps to smooth out irregularities (such as off-reef mining etc.), there are large areas where historically the VRP was mined on an undercut basis and in these the values are therefore not representative of the complete VRP.

The uranium values are expressed as cmkg/t in much the same fashion as the gold values, see figure 3.18. On the whole uranium values are more consistent and display a lower variance. Quantitative relationships between the gold and uranium are difficult to establish yet the two are obviously associated. Gold:Uranium ratios have been calculated and contoured on the same principle as the Au and U_3O_8 values, however no trends were evident. According to Minter (1972) the scalar proportions of Au: U_3O_8 ratios can be used as a palaeoslope indicator i.e.; the ratios of Au to U_3O_8 should decrease downslope. This would make sense in a single reef deposit, however there is no apparent trend for the VRP at Vaal Reefs and this may be evidence (albeit tenuous) for the existence and interaction of multiple reef bands.


KEY
FAULT LOSSES
DYKES
ORE VALUES IN cm.kg/t
HIGH
MEDIUM
LOW
SURFACE BOREHOLE
500 0 500 1 000 1 500
METRES
GEOLOGY BY A.G.O.
DRAWN BY E.E.W.
REVISED BY A.G.O.
PLAN No.
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SOUTH DIVISION.
100m Moving averages uranium value plan for the Vaal Reef
DATE
REPORT
SCALE 1:30 000
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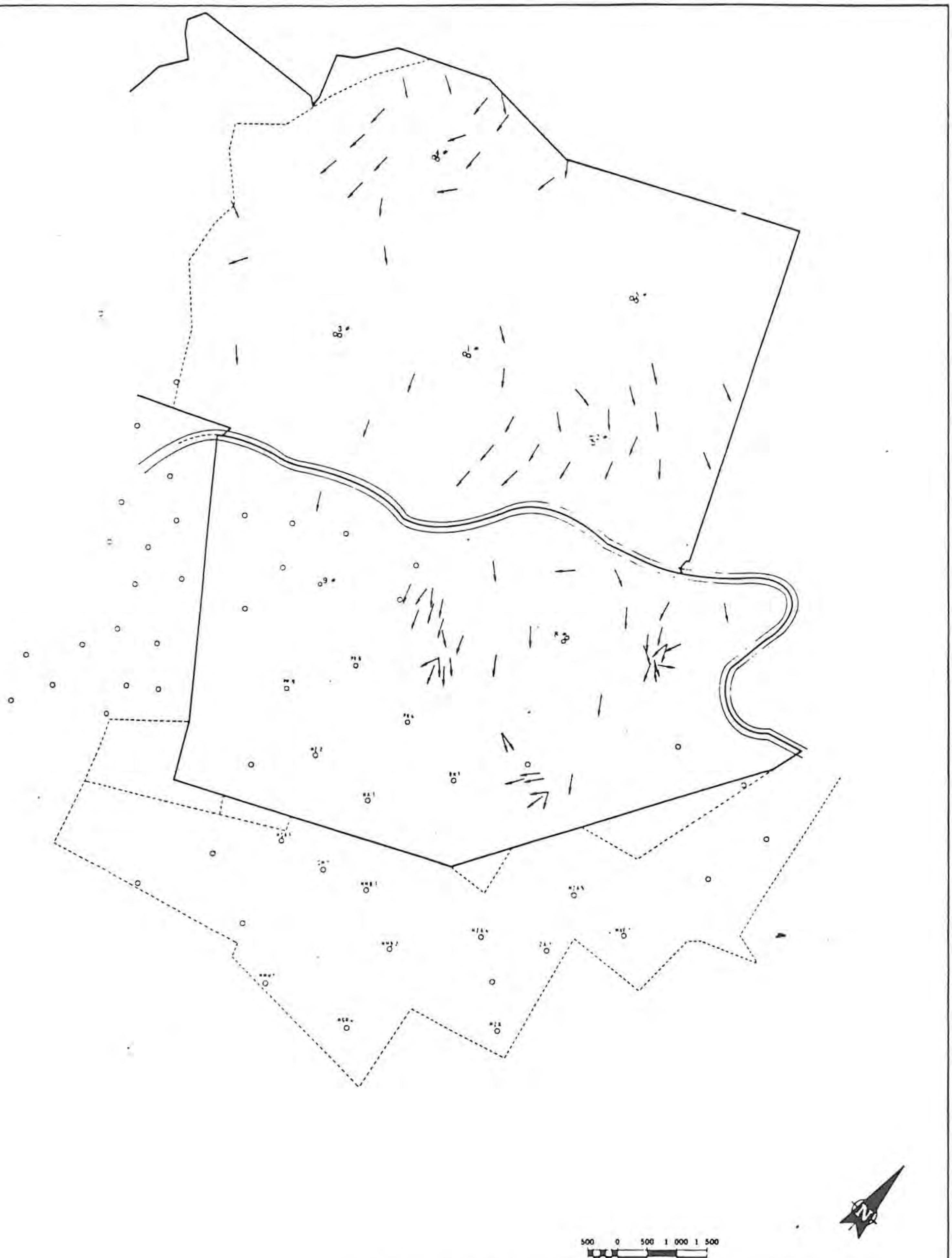
FIGURE 3.18

PALAEOCURRENT DATA

Figure 3.19. shows a selection of palaeocurrent data that is available for the VRP and as well as occasional spurious values believed by this author to representative of a pre-Vaal Reef unit or Mizpah facies.

The majority of the data for the VRP and ZM has been collected and presented by Minter (1991), however data collected within the South Division Geology department matches that of Minter with few exceptions. The general palaeo-trend of the VRP is SE and as such parallel to the majority of the on-Reef development of the mine. As a result channels are rarely measured during development mapping. Those channels that are measured however trend roughly 90^0 to the regional trend and are thought to represent either a pre-Vaal Reef facies such as the Mizpah or the palaeo-topography over which the VRP was deposited. The two conglomeratic units of the VRP, the VRBC and the UVRZ, are believed to have similar palaeo-trends however the braided nature of both units may result in directions for each unit being as much as 90^0 apart at any one particular station. Channel orientation data is very likely to be representative of the VRBC whereas the trough cross-bedding measurements are often taken within the quartzites of the UVRZ and are thus more representative of that unit.

The ZM direction is particularly well defined and as Minters data shows, has a very low variability, something which is a little at odds with the depositional model envisaged for this unit.



MEASURED PALAEOCURRENT DIRECTION

SURFACE BOREHOLE

GEOLOGY BY	A G O	VAAL REEFS EXPLORATION & MINING COMPANY LTD.	DATE	
DRAWN BY	E E W	SOUTH DIVISION.	REPORT	
REVISED BY	A G O	PALAEOCURRENT PLAN FOR THE VAAL REEF	SCALE	1:30 000
PLAN No.		VAAL REEF MINE	ILLUS.	

FIGURE 3.19

The palaeocurrent direction for the Mizpah facies is very poorly documented but what little information there is indicates a dirtection similar to that of the pre-vaal reef and witkop facies direction i.e. NW - SE.

Figure 3.20 shows the anticipated palaeotrends for the MZ, VRBC, UVRZ and ZM units based on a variety of sedimentological data and personal observation of value and channel width data.

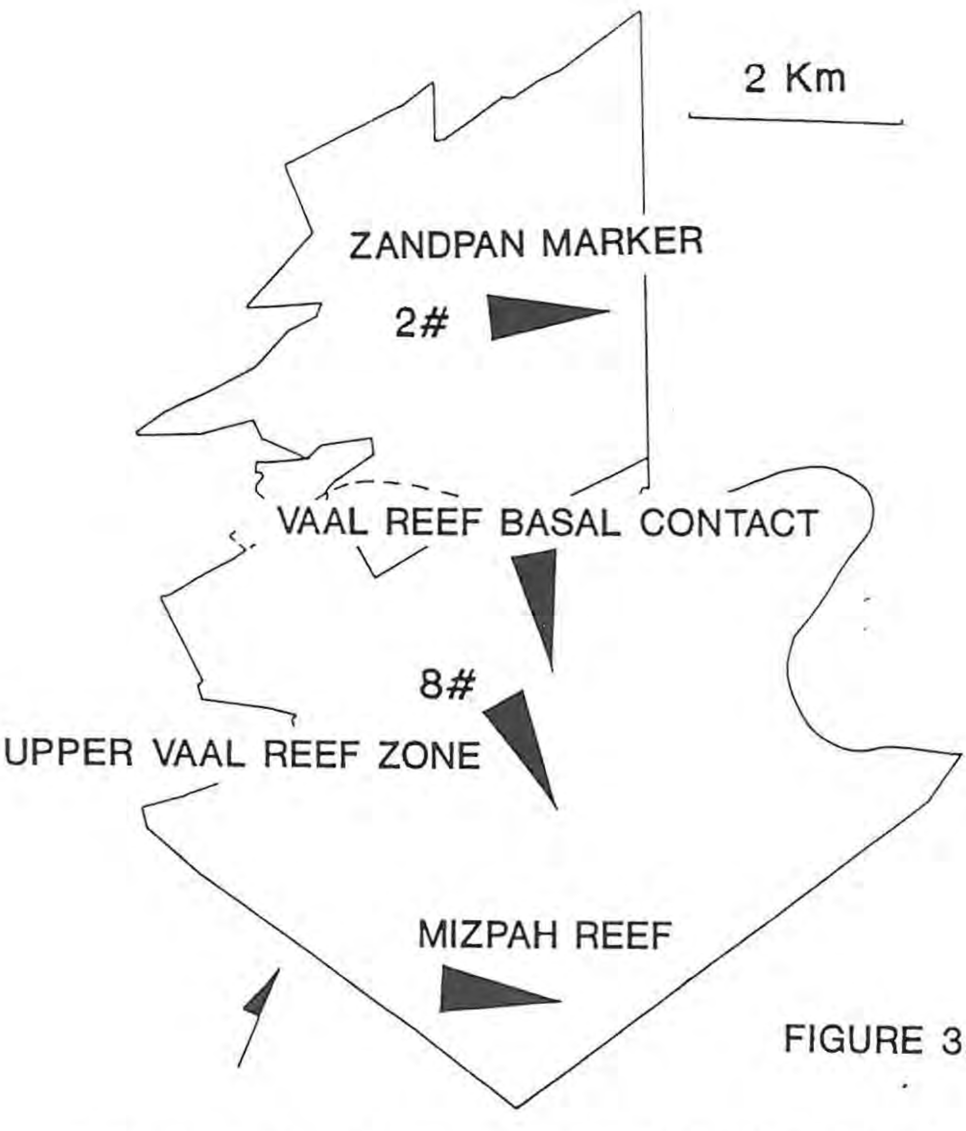


FIGURE 3.20

Anticipated palaeotrends for the Mizpah Reef, vaal Reef Basal Contact, Upper Vaal Reef Zone, and Zandpan marker at Vaal Reefs South Division.

CHAPTER FOUR

DEPOSITIONAL MODEL

Depositional Model.

The depositional model proposed here involves the formation of the Mizpah, Vaal Reef and Zandpan units, and not the whole of the Witwatersrand basin. The model is based on a variety of data sources, personal experience and the thoughts of many of my predecessors, and current colleagues. An attempt at incorporating all valid information has been made, however as with most models of this sort there are certain features which are either problematic or not within the bounds of our current understanding.

Stage 1.

Deposition of Mizpah Conglomerates and Quartzites

Within the southern portion of the study area the Mizpah Conglomerate forms the base of the "ore" horizon. Whether it belongs to the VRP or not is debateable, as is whether or not it belongs to the Mapaiskraal formation. Figure 4.1 shows the Mizpah as an alluvial fan system. Strictly speaking this unit is a polymictic unit, however, it does exhibit a mature texture and has obviously been reworked by migrating alluvial channels. Figure 4.1 also shows an anticipated source area to the west. This however is not proven and comes only from the alignment of channel axes that appear to have no directional component. The Mizpah Quartzites represent the late stages of a fining upward sequence.

There is still a great deal to be learnt about the Mizpah Reef not least of which is whether it is part of the Witkop facies or some other unit. This author believes that the Witkop and Mizpah are two examples of one unit which develops laterally in much the same fashion as the Upper Vaal Reef Zone.

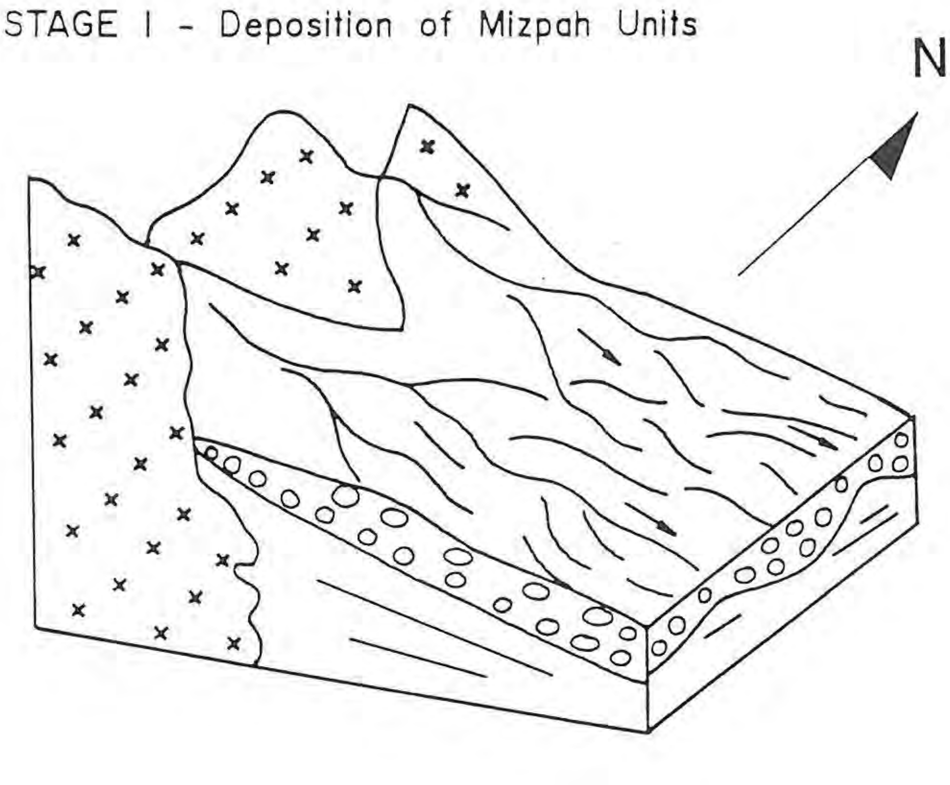


FIGURE 4.1

Stage 2.

Deposition of the VRBC.

The deposition of the VRBC is thought to be the product of a longitudinal braidplain and results in a major change in palaeoslope direction, (figure 4.2). Channels in the VRBC are not particularly common, in fact the footwall relief appears to have had more of an effect on the formation of the VRBC. This leads one to suspect a low energy braid system with palaeohighs and lows of the pre-Vaal Reef producing variations in Reef thickness normal to the palaeocurrent direction. Despite this, much of the Mizpah unit is believed to have been reworked or removed with only small windows preserved over the central areas and sub-croping below the VRBC in the South and Western edges of Vaal Reefs Mine. The Shifting channels and bars of the braided environment produce the well sorted and mature sediments that are observed as well a variety of palaeocurrent directions.

Stage 3.

Deflation of the VRBC

Stage three involves the deflation of the VRBC and in places possibly the Mizpah by aeolian processes, (figure 4.3). The action of wind is not particularly well documented for the Witwatersrand sequences yet its presence is supported by the "driekanters" or "ventifacts" noted by Minter and many other workers. Exactly what effect wind deflation has on the gold distribution is uncertain and is currently the

STAGE 2 - Deposition of VRBC

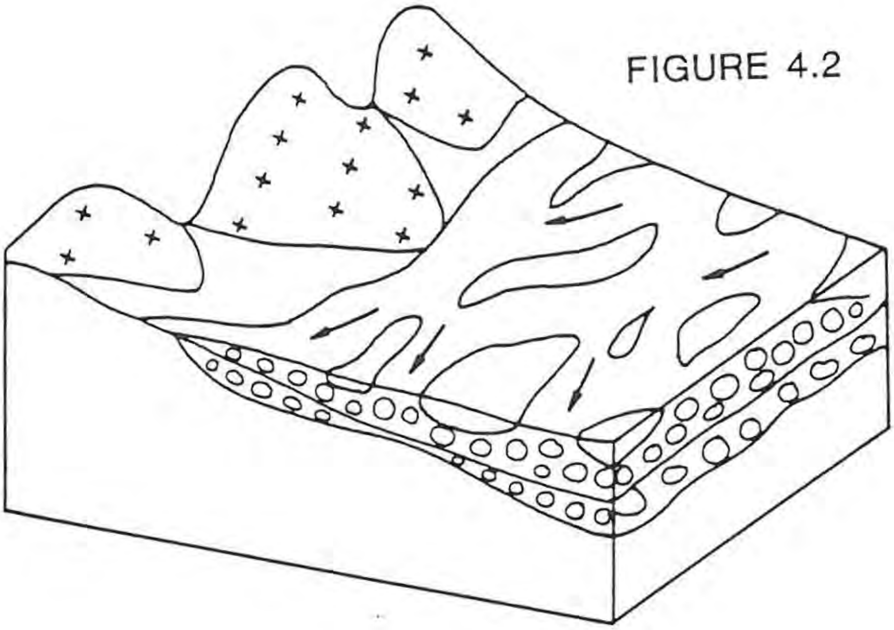


FIGURE 4.2

STAGE 3 - Deflation of VRBC

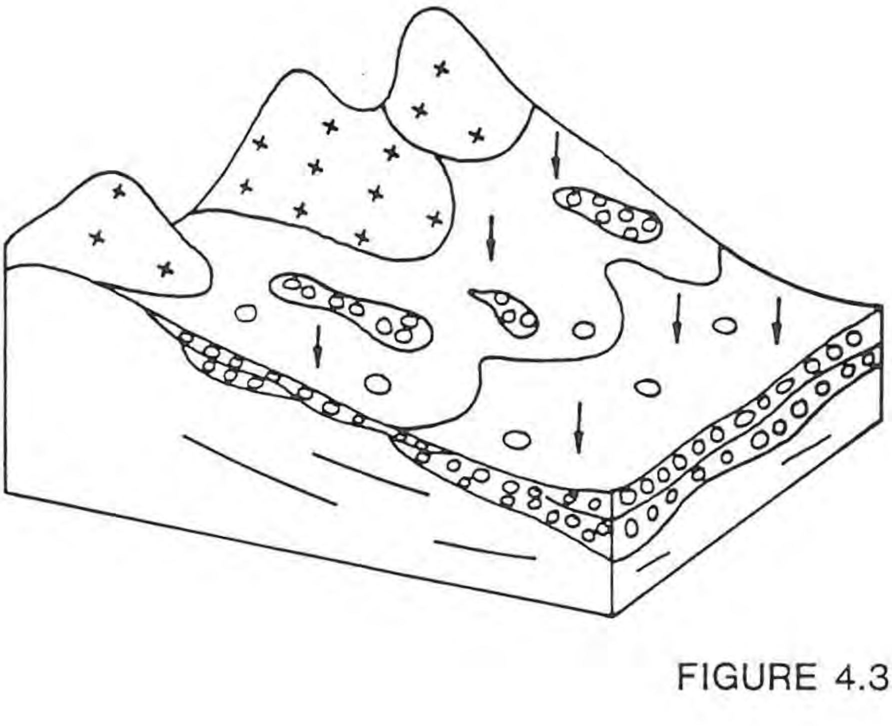


FIGURE 4.3

subject of research into the formation of the Crystalkop Reef.

It is anticipated that numerous shifts between stages 2 and 3, during what is undoubtedly a major hiatus, led to the formation of the relatively thin and well developed VRBC. This shift from fluvial to aeolian conditions may perhaps have been a seasonal feature; possibly accounting for the lack of well developed aeolian attributes as they would be virtually wiped clean with each new influx of material. The formation of lichen or algal mats is also believed to have taken place during stages 2 and 3, but it is not certain whether these were dry condition creations i.e.. palaeohigh surfaces or wet conditions i.e.. channels or palaeolows. More than likely a combination of both environments led to the formation of the variety of kerogen seams that are recorded today. Likewise the concentration of gold is also likely to be the product of multiple processes i.e.. washing and winnowing, deflation, mechanical and chemical entrapment, thus leading to the variety of theories concerning the origin of the gold in the Witwatersrand Reefs.

Stage 4.

Deposition of internal quartzite

The deposition of the internal quartzites of stage four marks a waning in the flow regime and allows for the preservation of the VRBC over most of the area, (figure 4.4).

STAGE 4 - Preservation of VRBC by deposition of Quartz Arenites

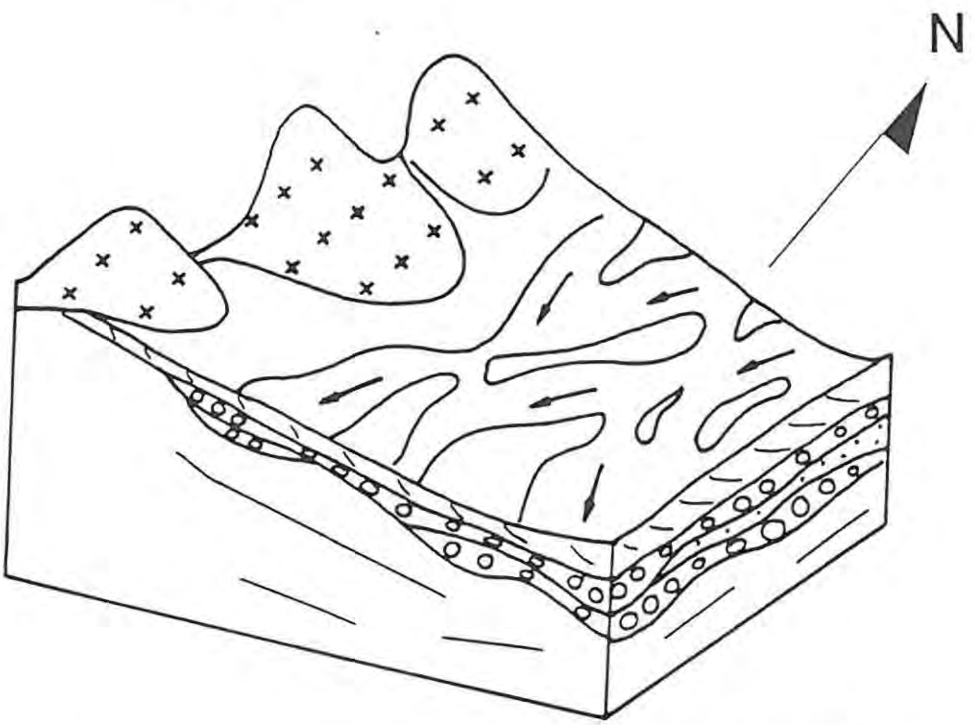


FIGURE 4.4

Stage 5.

Deposition of the UVRZ

This stage signals the start, albeit slow, of an increase in the hydraulic energy of the fluvial system. A relatively thick sequence of channelised conglomerates and quartzites producing a well

STAGE 5 - Deposition of UVRZ

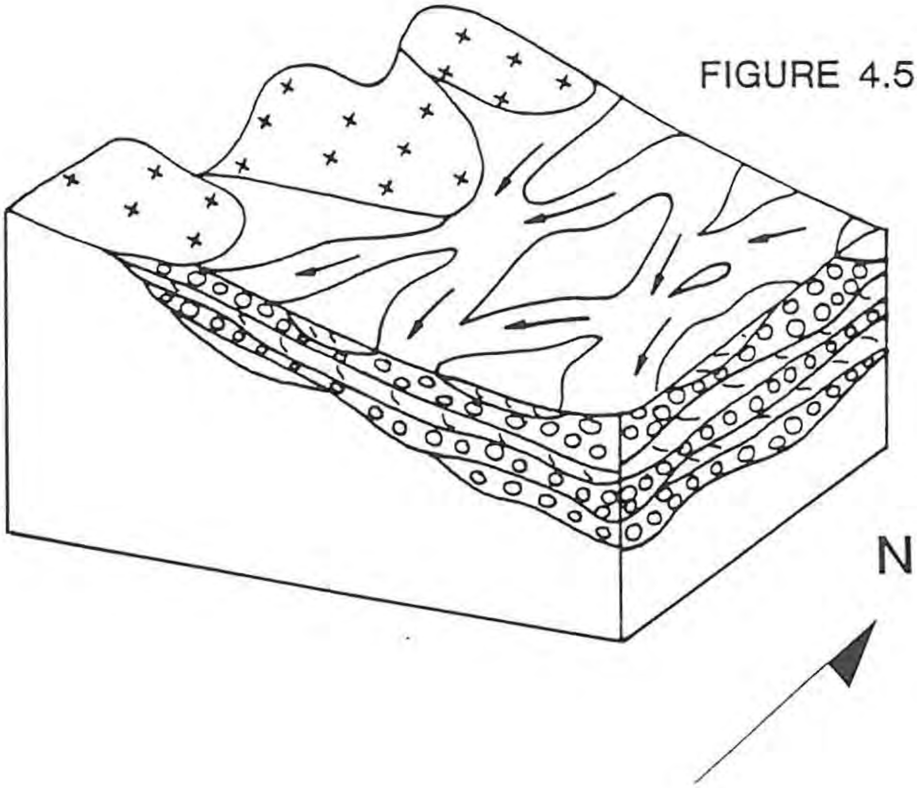


FIGURE 4.5

STAGE 6 - Preservation of UVRZ by deposition of Quartz Arenites

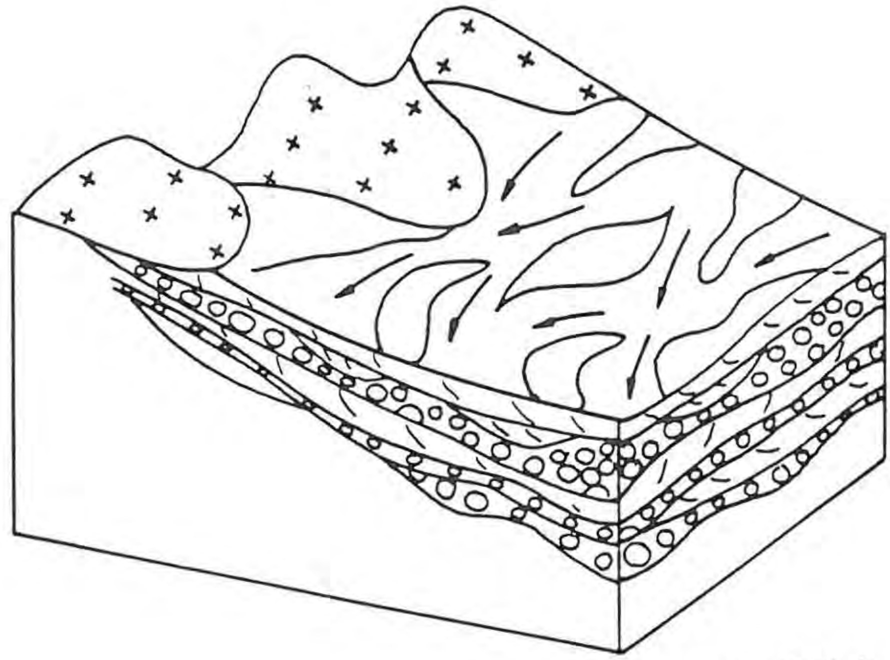


FIGURE 4.6

developed braidplain environment of the UVRZ, (figure 4.5).

Stage 6.

Deposition of UVRQ

Stage six is a repetition of stage four in that a lower energy environment prevailed allowing protective layer of quartz arenites to be produced, (figure 4.6).

Stage 7.

Deposition of the Zandpan units.

The deposition of the alluvial fan system of the Zandpan units marks the end of a relatively stable period, (figure 4.7). The channelised ZM, being poorly developed and immature for most of its area, is the basal unit of a 300 metre thick fining upward sequence. The palaeocurrent directions for the ZM are exceptionally uniform and exhibit a very low variance. The envisaged alluvial fan should produce a much wider range of directions. This concept is still problematic and requires further study. A possible explanation is one of high energy fluids in unconsolidated sediments that do not develop into a braided environment.

The general picture that evolves therefore calls for a series of alluvial fans overlain by a longitudinal braidplain followed by further alluvial fan sequences. The four packages of basal conglomerates overlain and preserved by quartzitic units are not uncommon but it is the prolonged hiatus at the VRBC horizon that is responsible for the development of the well mineralised and mature conglomerates. The main processes of gold concentration are the continued re-working and winnowing of gold bearing gravels by fluvial, and more importantly aeolian processes.

STAGE 7 - Deposition of Zandpan Units.

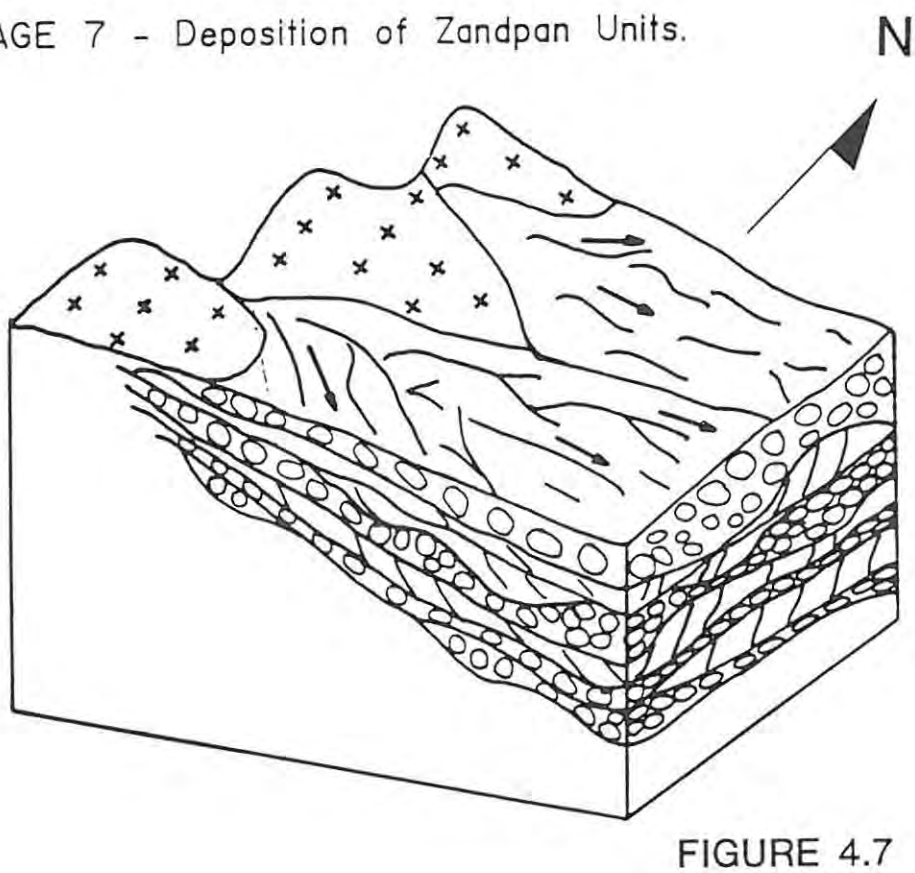


FIGURE 4.7

The combination of alluvial fans and longitudinal braidplains is not unusual and modern analogies exist in the form of the Cibee trough , Pakistan and Death valley, California, U.S.A. (plate 4.1). Death valley is a particularly good example as the arid climate (and more importantly the associated processes) is believed to be similar to that existing during the deposition of the VRP.

50 Km

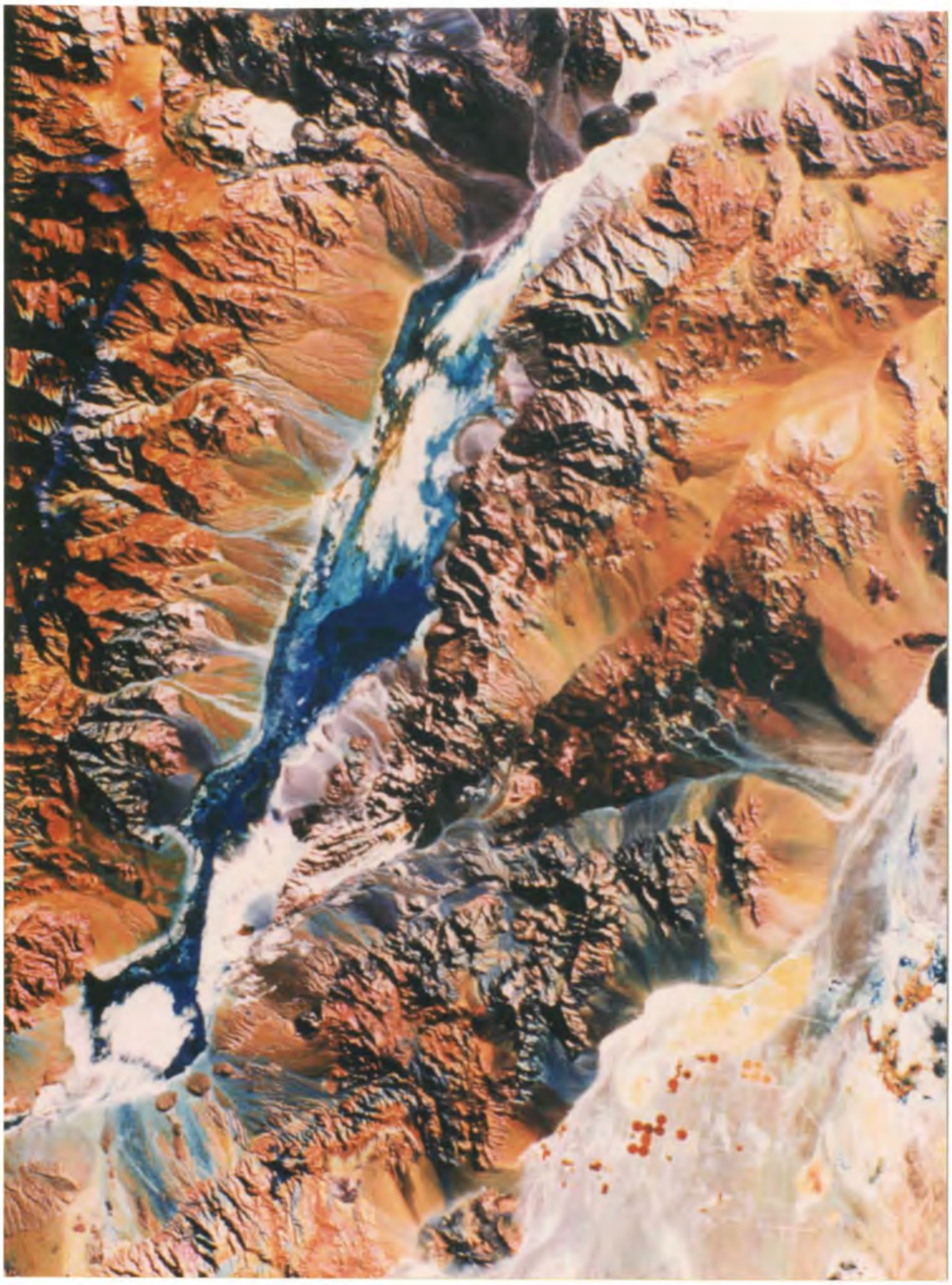


PLATE 4.1

Death Valley, California, U.S.A..

CHAPTER FIVE

APPLICATIONS

APPLICATIONS

There are many applications for the facies map discussed in Chapter 3, and apart from the obvious academic interest in improving the understanding of the depositional environment, several of these are of direct benefit in the production environment.

STOPE WIDTH

First and foremost a detailed knowledge of the formation of the ore horizon is of great benefit in the control of stope width and the optimization of the grade of the mined ore. The vertical height of a stope; the stope width, plays a vital role in the tonnage of material to be removed as well as the amount of material required to support the workings. It is therefore one of the critical factors in establishing the cost of mining an area of Reef. The stope width also affects the overall grade of the mined ore. To optimize the stope width therefore involves balancing total costs against revenue in such a way as to maximise the profit margin.

Most gold mines operate on a cut-off grade expressed as a g/t value, ie. the amount of gold required to make a ton of rock profitable. Quite obviously within this framework the intention is also to remove the maximum amount of ore.

The current economic climate has forced cut-off grades to new levels making many marginal mines unpay and it is in these areas in particular that geological control over stope width pays dividends. It should also be borne in mind that in multiple reef situations, reducing stope width will be of no use unless the correct "cut" is taken. To this end the knowledge of the various reef packages, their lateral extent and the vertical distribution of gold within the profile must all be applied.

In the case of the Vaal Reef the theoretical optimum stope width would be the basal few centimetres of the VRBC for, as we have shown, this is where the majority of the gold is found. In practice this is not possible (yet) and we therefore have to mine at least 90cm. of excess material. Choosing which 90cm. is not only a question of economics, but also mining practicalities, such as hangingwall conditions etc.. The process of choosing target stope widths is something which needs to be conducted on a very localised scale as changing the particular cut during mining operations is often not feasible. An awareness of what to expect as the mining operations progress is therefore equally as important in the decision making process.

Figure 5.1. shows an example of how stope width can be reduced to increase the grade of a stope. The sedimentological profile is investigated and a representative section of the area to be mined is chosen. Average, or stretch, values are applied to each sedimentological unit or part there-of to produce an estimate of total cmg/t and the vertical distribution of gold within the profile.

The VRP in this example is 124 cm thick and the removal of the full channel would require stope widths of the order of 160 cm. As can be seen from

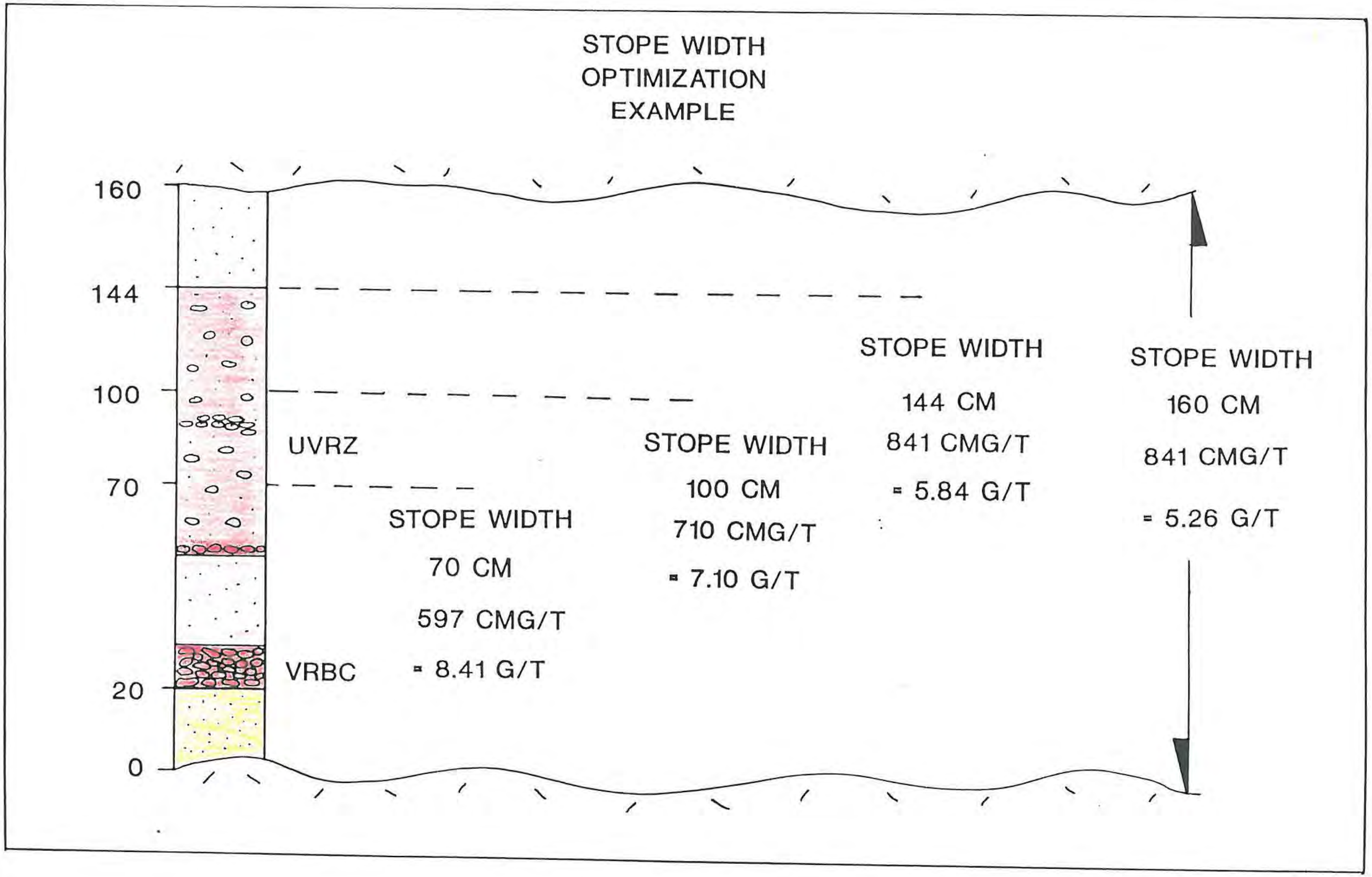

STOPE WIDTH
OPTIMIZATION
EXAMPLE
160
144
100
70
20
0
UVRZ
VRBC
STOPE WIDTH
70 CM
597 CMG/T
= 8.41 G/T
STOPE WIDTH
100 CM
710 CMG/T
= 7.10 G/T
STOPE WIDTH
144 CM
841 CMG/T
= 5.84 G/T
STOPE WIDTH
160 CM
841 CMG/T
= 5.26 G/T

FIGURE 5.1

the figure the total cmg/t is 841 thus resulting in a grade of 5,26 g/t. Geologically we are aware that the area falls within zone 2A and that the UVRZ1 is poorly developed. The regional vertical distribution of gold is bottom loaded and we are confident of the horizontal extent of the profile. In order to ensure that the VRBC is correctly removed and to facilitate the mining process 20 cm of footwall waste is required. With the background details thus established a variety of stope cuts can be calculated to establish what would be the most economic and practical cut to make. These cuts are shown in figure 5.1 emphasizing the effect on the overall g/t value. Undercutting the UVRZ to a 100cm stope width in this example results in a 37% reduction in tonnage (and therefore the variable cost component) and almost 35% increase in ore grade. The total gold recovered is obviously reduced but only by about 15%.

On marginal mines or indeed marginal areas of non-marginal mines an increase of a few g/t can be dramatic, particularly when accompanied by reduced costs.

The use of a facies map such as that in figure 3.15 provides some form of spatial distribution of the reef type and therefore the required cut which, when coupled with the localised value plans, should provide adequate grounds for optimising the stope width of the area.

PILLARS

Remnant pillars are a feature of most of the Witwatersrand gold mines, left behind as the major production effort moved on to pastures new. Vaal Reefs is no exception to this general rule and as a shaft progresses into it's final stages the contribution of these remnant pillars to the overall production increases. Each pillar will be different in many respects from other pillars, yet they all share one common feature; they were left behind for a reason !. There are of course occasions when these reasons may seem vague or non-existent, yet somebody at some time took the decision not to mine that particular block of reef. Newly discovered slivers of ground caught up in a major fault system can also be treated in much the same fashion although their existence owes itself to other factors.

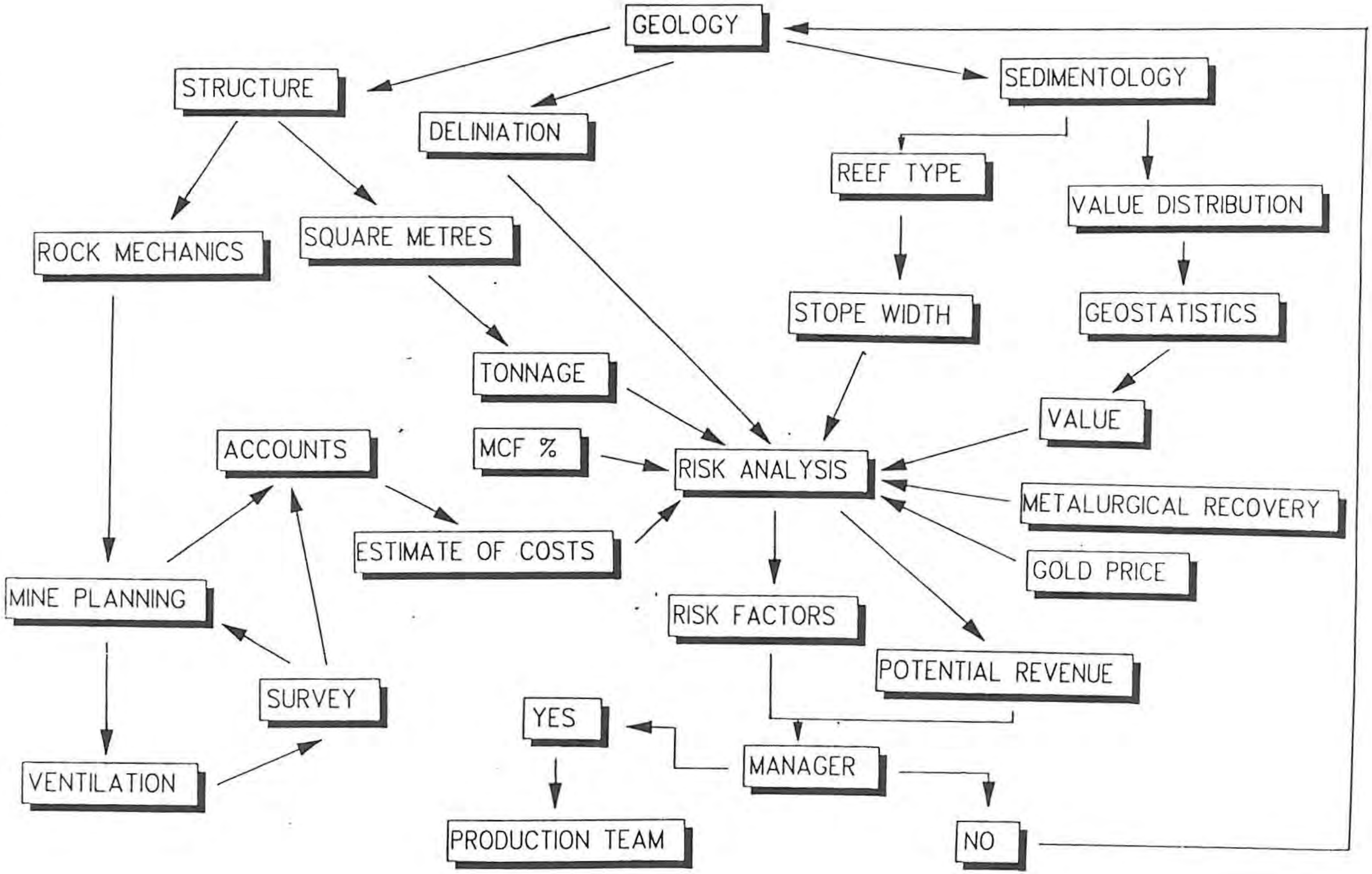
Historically it is often difficult to establish why a remnant pillar was created as documentation of such events is sparse. Complex geological structure is not the least of these reasons and here again data on the Reef horizon is often limited to simple statements, such as "Off Reef". Low grades are also common reasons for leaving blocks of ore behind. In these instances it is important to establish the reason for these low grades. Geological input into stoping operations was particularly low 15-20 years ago and low grades may be due to mining the wrong horizon and being unaware of the fact.

It is apparent therefore that instigating the removal of Remnant Pillars is not simply a matter of choosing a pillar from a plan and removing it. A correct and detailed strategy is required for the removal of each and every pillar and it is during the first and final stages of mining a Witwatersrand Reef that the geologist can have the greatest impact.

What follows is an example of a suggested strategy for removing Remnant Pillars on Vaal Reefs. The correct sequencing of events is of particular importance as is the need for correct and exhaustive planning. The planning process may be costly in terms of man hours and salaries but it is beyond doubt far cheaper than proceeding along an incorrect and incomplete path.

As can be seen from the simplified flow chart in figure 5.2, the initial stages of the programme rest almost exclusively with the geologist and require that a reason for the existence of the pillar be found and that the structural and sedimentological models are defined. Some measure of certainty must be applied to the resulting interpretation and if necessary a programme for improving the interpretation or delineating the extent of a block via exploration drilling and mapping must be established.

In essence the process involves going back to an exploration mentality and treating each pillar as a discrete ore body albeit on a somewhat reduced scale. As with a new prospect it is the geological features of a pillar, and the knowledge of these features which ultimately decide whether it is a Go or No-go situation.



Simplified flow chart of the remnant pillar evaluation programme.

FIGURE 5.2

Once a structural plan is produced (with an estimate of the certainty.) an estimate of the amount of ore available can be given. For the Vaal Reef this would also involve the particular type of reef or reef profile that is to be expected and consequently an estimate of the stope width that would be required and the grade that would be achieved.

We now have an outline of a pillar along with tonnage and grade estimates. The next step is to plan the required development necessary for accessing the ground and the support requirements based on investigation by the Rockmechanics department.

Eventually all investigations are complete and we are left with a list of estimated costs and revenues, accompanied by associated disclaimers, based on the possibility of variance in the original estimates. All this information is then handed over to the upper management of the mining department to decide on whether the risk is a good one or a bad one. This type of decision is of course made every day in any large Witwatersrand Gold mine and with a certain degree of skill (or luck), the good ones out-weigh the bad ones. The current economic climate that the gold mines find themselves operating in, is however taking it's toll, and a system of filtering out the "bad risks" is required. In essence a quantitative analysis of the risk involved and some method of comparison with other options is the order of the day.

The simplified risk analysis presented here has been adapted from more complex versions originally designed for evaluating exploration targets, Mallinson (1987). As previously stated the basic principles of pillar extraction are allied to those of new deposits, although many of the decision variables of exploration targets have already been fixed in a pillar scenario.

The idea of this risk analysis is to use PC technology to produce a series of possible results utilising the estimates of grade tonnage, costs etc. along with the possible variances and produce them in a graphical format for comparison with other pillars as an aid to the decision making process. The Total Potential Revenue or percentage profit can be plotted against any particular variable. This not only allows for visual comparison between pillars but also indicates which particular variable has the most influence on the profitability of a particular block.

As an example of how this process operates and the methods of visual comparison a series of examples are presented using the data that was discussed previously under stope width. This not only shows how a pillar can be evaluated but how more detailed geological input can produce a good risk from a bad one.

EXAMPLE 1

As can be seen from Table 5.1, pillar A consists of 1000 square metres of Reef with an average value of 841 cmg/t and an anticipated stope width of 160 cm. Other values inserted are for the purposes of this exercise and bear no relation to the true figures

TABLE 5.1

	EXAMPLE 1.			EXAMPLE 2.		
VARIABLE	ESTIMATE	STD DEV	EXAMPLE	ESTIMATE	STD DEV	EXAMPLE
SQUARE METRES	1000	100	984	1000	100	915
S/W CM	160	10	175	100	5	99
CMG/T	841	100	1004	710	50	680
TONS	4448		4791	2780		2525
CONTENTS KG	23		27	20		17
MCF %	90	5	88	90	5	94
RECOVERY %	97	1	97	97	1	96
RECOVERED AU KG	20		23	17		16
AU PRICE KG	31000	1000	29393	31000	1000	30059
TOT POT REV	632728		689271	534169		470321
DELINIATION	8000	1000	6626	8000	1000	9682
DEVEL COST	100000	5000	107404	100000	5000	97227
MINING COST TON	75	10	73	75	10	84
METALURGICAL TON	55	10	68	55	10	40
TOT POT COSTS	686370		789266	469530		421315
NET PROFIT	-53642		-99996	64639		49007

Input data for examples 1. and 2.

within Vaal Reefs South Division. In all the following examples 100 calculation were conducted as this was deemed adequate for the purpose. It is however possible to produce any number of calculations depending on the required accuracy. The histogram of potential profits can be seen in figure 5.3, and as expected it displays a normal distribution centered around the expected mean potential profit, which in this case is a loss of approximately R60,000. A more useful graphical display is the cumulative frequency distribution shown in figure 5.4. From this graph it is possible to read off a variety of figures, such as the percentage chance of making a loss or the percentage chance of making R40,000 profit. This type of graph is particularly useful when minimum returns are required. If, for example, management decides that they require either a minimum of 25% profit or a Rand value of R50,000 it is feasible to extract the possibility of achieving these targets instantly. Figure 5.4 has an X axis expressed as potential profit in Rand terms but it could just as easily be expressed as percentage profit terms, depending on the requirements of mine management.

A scatter plot of the percentage profit against any particular variable can also be used for the comparison of several different pillars. Figure 5.5 shows a variety of these plots using the different variables of Pillar A. Again the particular plot that is produced is dependent on the requirements of upper management. In figure 5.6 the total tonnage is used as this is proves a useful measure of the pillar size and its probable life span.

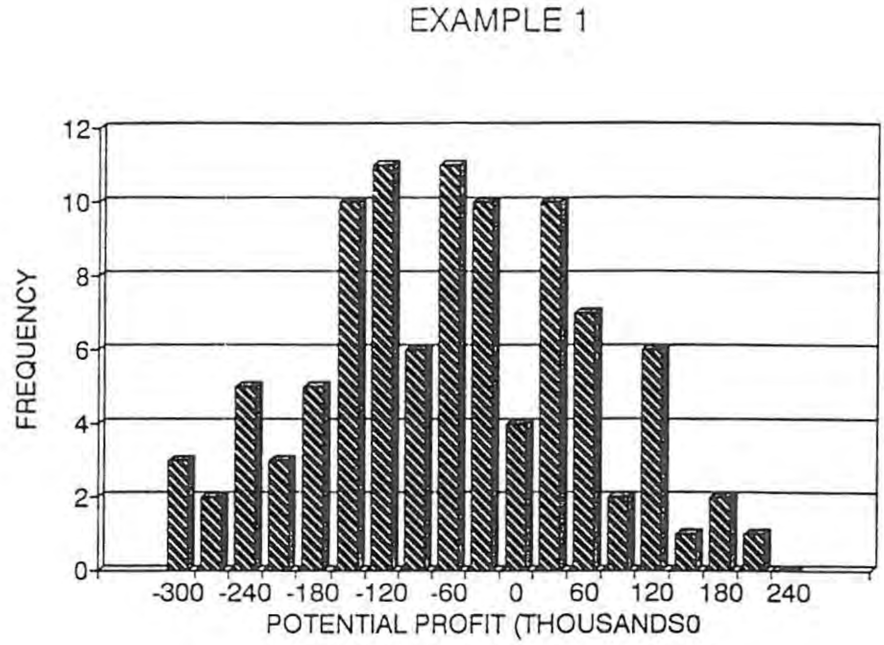


FIGURE 5.3

Histogram of potential profits - Pillar A.

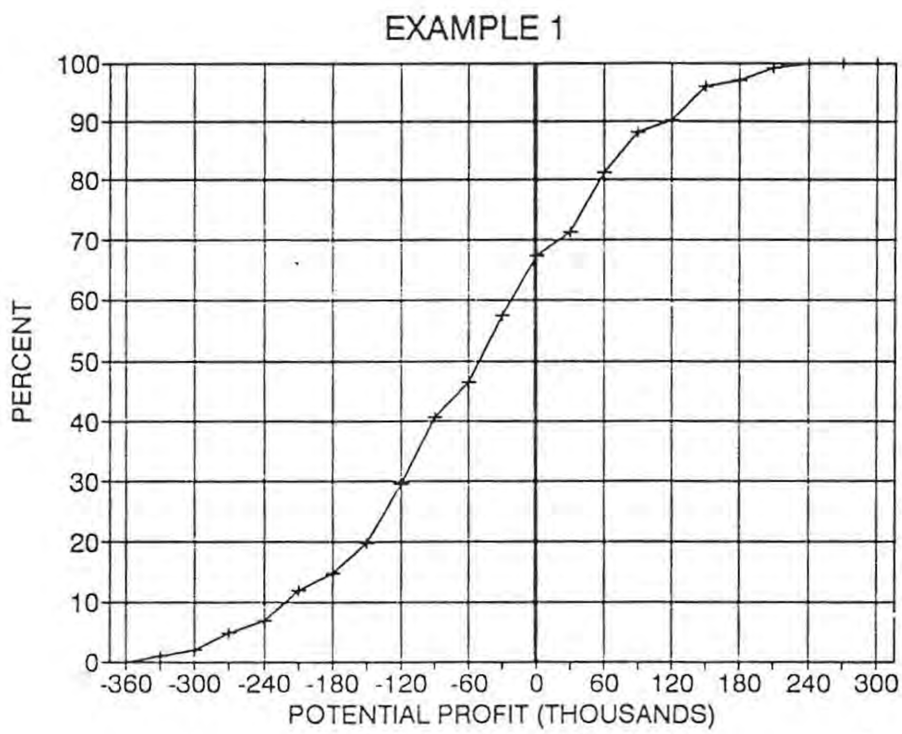


FIGURE 5.4

Cumulative percent frequency distribution of potential profits - Pillar A.

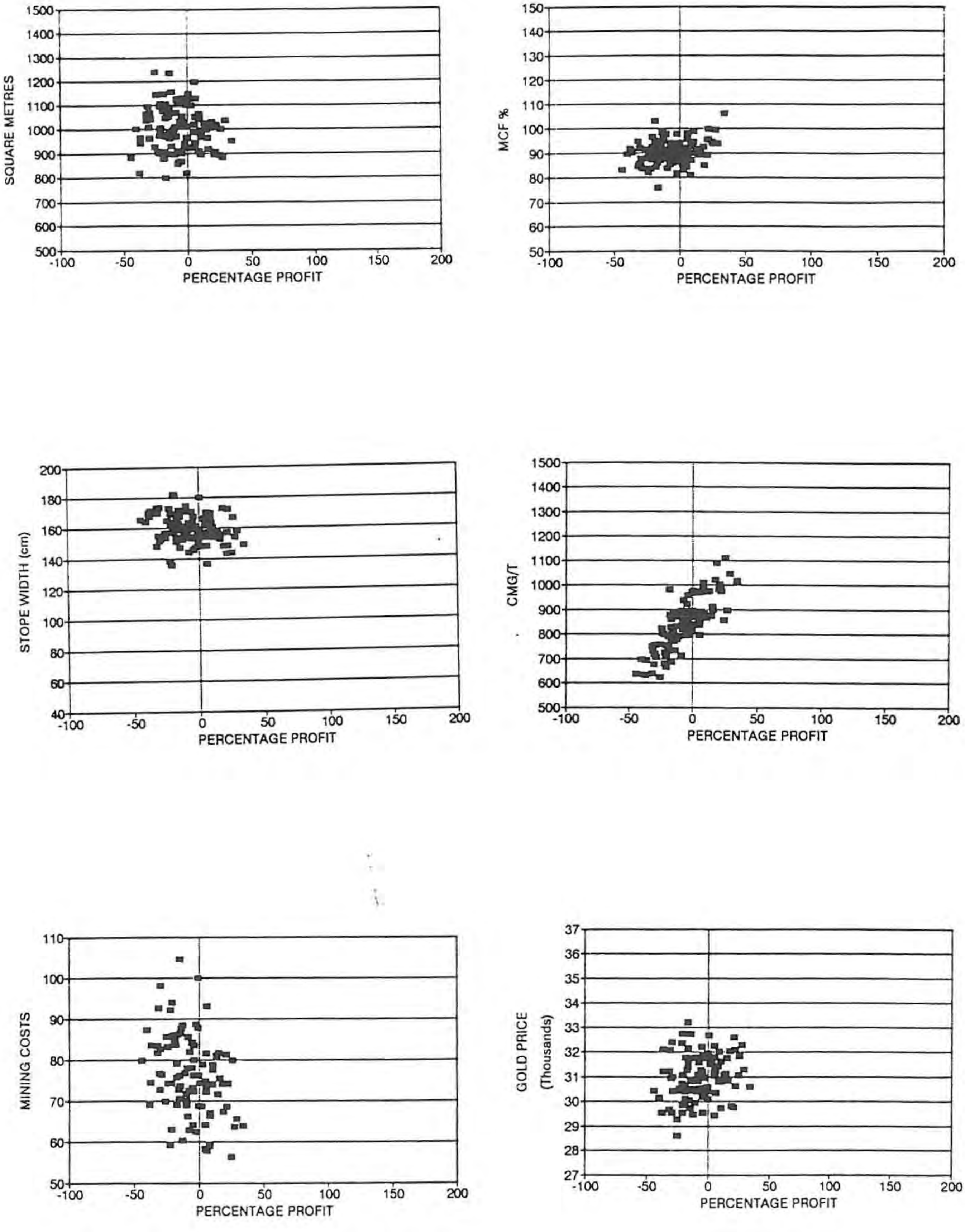


FIGURE 5.5

Scatter plots for a variety of variables - Pillar A.

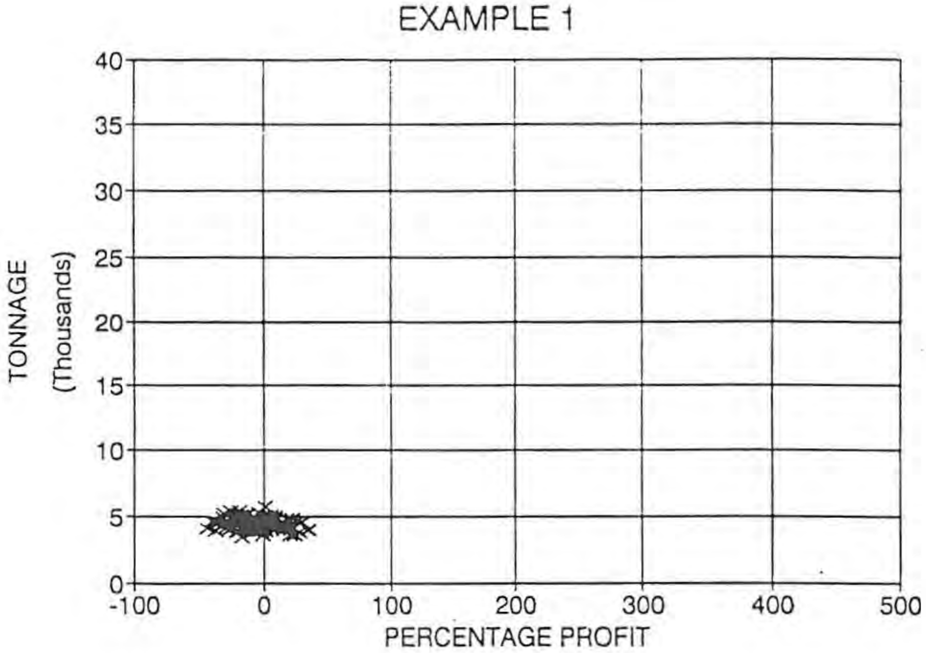


FIGURE 5.6

Scatter plot - Total tonnage Vs. Percent profit Pillar A.

EXAMPLE 2

This example is used to emphasise the effects of stope width reduction on pillar A. All the variables for pillar B are the same as for pillar A (table 5.1) except the stope width and cmg/t values. The cumulative distribution shown in figure 5.7 indicates how the overall profitability of the pillar has improved (there is now a 86% chance of making a profit). Figure 5.8 is a scatter plot of tonnage for pillar B showing the affect that reduced tonnage has on the overall profitability of the pillar.

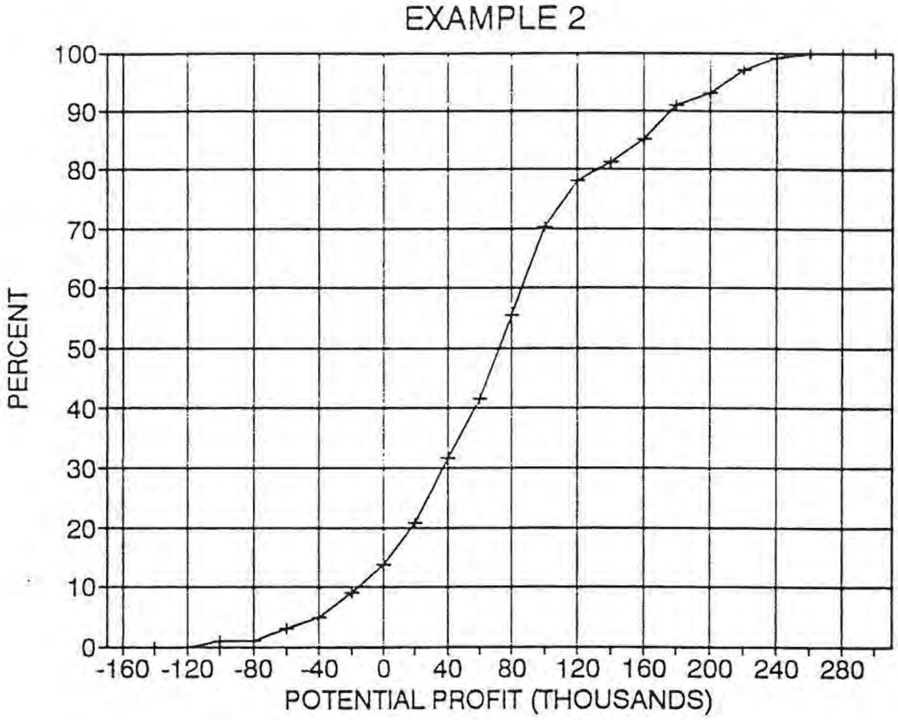


FIGURE 5.7

Cumulative percent frequency distribution of potential profits - Pillar B.

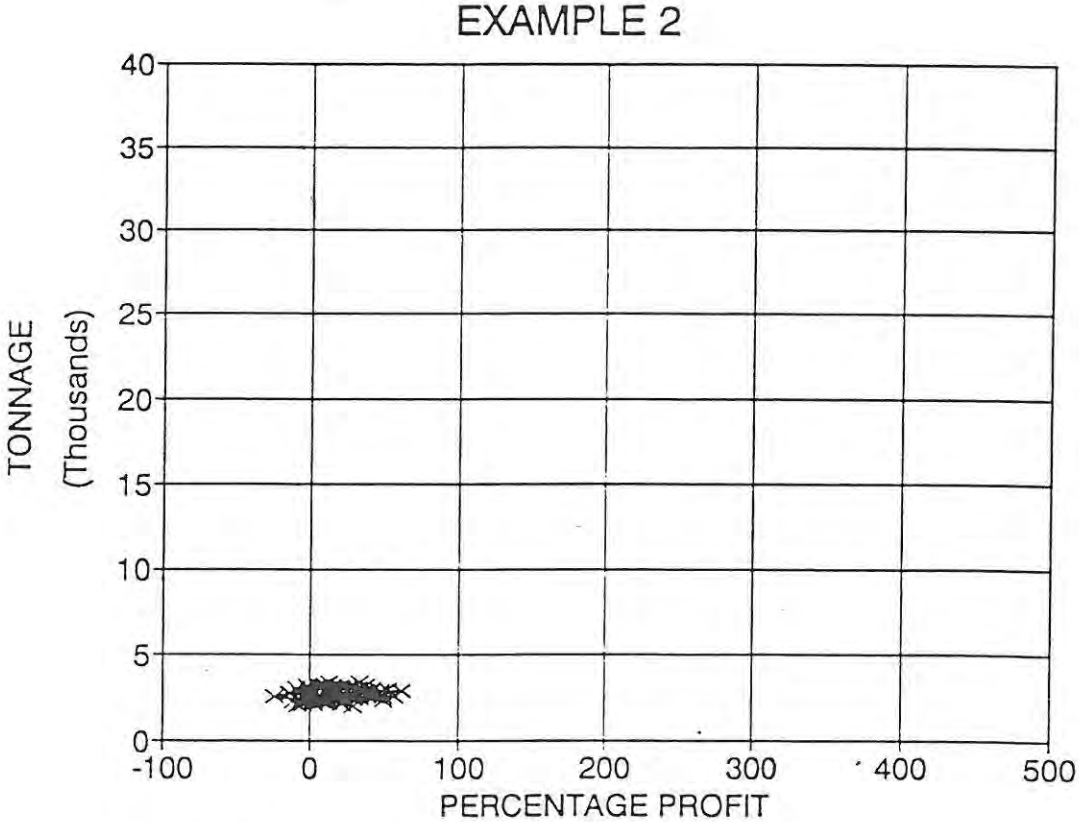


FIGURE 5.8

Scatter plot - Total tonnage Vs. Percent profit Pillar B.

EXAMPLE 3.

In this example two further pillars have added to the equation. Pillar C is a large low grade area and pillar D is a small high grade pillar. Input data for both pillars can be seen in Table 5.2. The main purpose of this particular exercise is to show how this method of treating individual pillars allows them to be viewed from a common stand point, (figure 5.9). It is therefor possible to prioritise pillar extraction on the basis of a particular variable (such as tonnage or potential revenue) and also to highlight the variables that need to be further constrained to improve the overall results.

The programme used to produce the above examples is relatively simple and easy to use. The programme calculates values for each variable using the estimated mean and standard deviation, within the confines of a normal distribution. By iterative calculations a series of possible results is then produced. Its main advantages, however, are its compatibility with readily available software packages and the speed at which results can be produced. These results are obviously only guidelines but they provide a much better method than the "one off" costing exercises that are so often utilised.

NEW AREAS

For new areas the basic principle of projecting the model beyond its current boundaries, and calculating the possible risk factors, is still valid. The

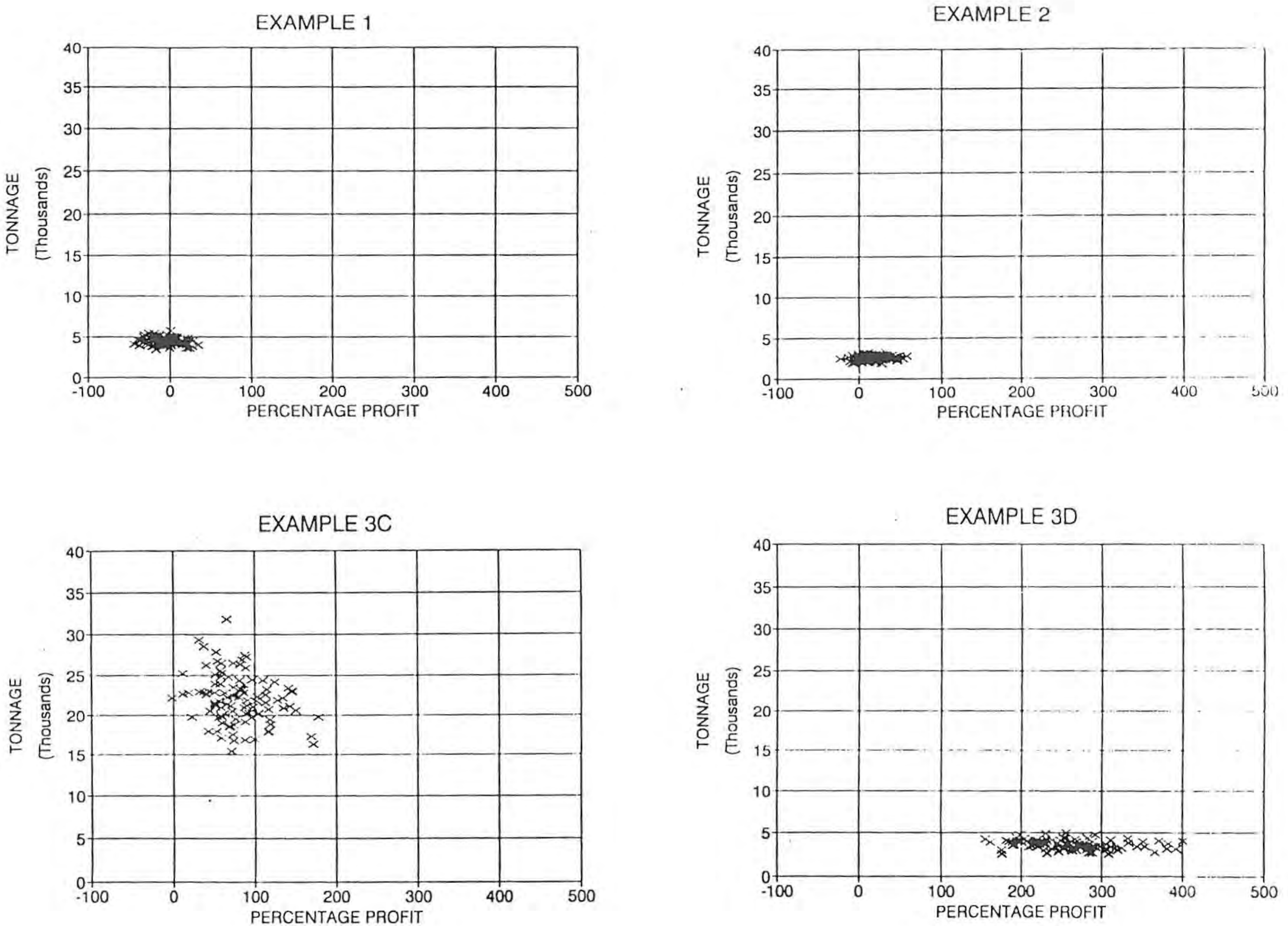
TABLE 5.2

	EXAMPLE 3C.			EXAMPLE 3D.		
VARIABLE	ESTIMATE	STD DEV	EXAMPLE	ESTIMATE	STD DEV	EXAMPLE
SQUARE METRES	8000	800	7349	1000	100	1068
S/W CM	100	10	98	130	13	127
CMG/T	950	100	911	2900	290	3057
TONS	22240		20100	3614		3761
CONTENTS KG	211		186	81		91
MCF %	90	5	93	90	5	91
RECOVERY %	97	1	98	97	1	98
RECOVERED AU KG	184		169	70		81
AU PRICE KG	31000	1000	30902	31000	1000	30399
TOT POT REV	5717871		5233395	2181819		2460126
DELINIATION	30000	3000	23460	10000	1000	9838
DEVEL COST	300000	30000	331974	150000	15000	150109
MINING COST TON	75	10	67	75	10	78
METALURGICAL TON	55	10	43	55	10	69
TOT POT COSTS	3221330		2559336	629950		711641
NET PROFIT	2496541		2674060	1551869		1748485

Input data for example 3. Pillars C and D.

FIGURE 5.9

Scatter plots - Total tonnage Vs. Percent profit
Pillar A - D.



variables however become more uncertain as the projection moves away from fixed data points, and as the influence of time becomes more important to factors such as costs and gold price. Thus the calculation of the possible risks also become more complex.

When considering the viability of a new area, one of the key factors is the gold content. Geostatistical methods of evaluating ore reserve blocks using Kriging techniques have proven very successful, and are used to good effect on most Witwatersrand gold mines. One of the key components of the Kriging technique is the concept of geologicaly homogenous areas, such as those defined in chapter three.

It has been shown that the VRP consists of several units that behave in different ways. It is essential therefore, that the database used for the geostatistical evaluation separates the data into homogenous zones both horizontally and vertically. The composite nature of the VRP would become even more problematic if the VRBC and UVRZ prove to have different value trend directions.

The bayesian approach to evaluating new leases with little information, utilises the characteristics of areas known to be geologicaly similar to that of the area for which an evaluation is sought. For example, six surface boreholes within an exploration lease may be supplemented with data from similar, nearby mines to assist in the estimation procedure. The more detailed the knowledge of the existing areas the more use that information will be to the prediction of contiguous areas. To this end the detailed lithofacies maps and the differentiation of distinct zones can be utilised to provide infill detail for areas of little information.

The influence of stope width on the ore reserves of new areas can be equally as dramatic. Reducing the anticipated stope width of an area by 40% will have a similar effect on tonnage and therefore on the infrastructure requirements of a new shaft.

CONCLUSIONS

To adequately draw conclusions from this project it is first necessary to establish whether it achieved what it set out to do.

The first goal of the project was to "sub-divide the Vaal Reef Placer (VRP) into its constituent units and create a database of information using a 500 metre grid across the South Division area". To a greater extent this was achieved. Some of the older and undeveloped areas had very little information available, however a database of over one hundred stations has been created, (Appendix 1.).

The second goal was to "produce a localised facies/lithofacies plan defining areas of different "Reef Type". This was achieved as shown in figure 3.15, and the applications of this plan are many and far reaching.

The contouring operations of goal three were also achieved but here it is felt that further work is required to satisfactorily define trend directions. The existence of separate populations both vertically and horizontally has been proven but again further work is required to quantify these assumptions.

The depositional model has been refined to an acceptable and useful concept, and only time will tell whether it is accurate or not.

The development of a workable method of evaluating and comparing remnant pillars has been established as has the application of facies type to the optimisation of stope width control.

Overall this preliminary study has shown that the VRP at South Division is a composite reef package that is variable across the study area. These variations are to some extent quantifiable and can be utilised effectively in the production environment.

RECOMMENDATIONS

As a result of the studies documented above I would like to make the following recommendations for further study:-

1. Geostatistical investigation of individual zones to establish the concept of separate populations.

2. Separation of the sampling values vertically and horizontally into various units and zones.

3. Continued capture of sedimentological data allied to the detailed assay results at each station.

4. The continued development of the Risk analysis programme and fine tuning of the pillar evaluation methodology.

5. Investigate the Mizpah and Witkop facies with a view to establishing positive links between the two and establishing more accurate trend data.

ACKNOWLEDGMENTS

There are many people to whom I owe a great deal of thanks. Some have contributed directly or in directly to my understanding, others to the logistical hurdles and still others have offered advice or moral support as needed. To all these people, and there are too many to mention I am eternally grateful. There are a few people, however, whose contribution warrants individual acknowledgment.

I would like to thank the management of Vaal Reefs South Division for their permission to conduct and present this project, as well as leave of absence to attend the various modules over the years.

The Anglo American Corporation of South Africa is gratefully acknowledged for financial and logistical support.

My colleagues in the South Division geology department also deserve special mention for participating in numerous discussions and providing a solid platform on which to conduct my investigations. Mr. P.F.P.Pretorious whose fate it was to cover for me whilst I was away and for showing a particular interest in this study as well as sharing many years of experience. Mr.P.F.Woodhouse for his continued support, interest and directional guidance.

Mrs. E.E.Wessels also deserves a special note of thanks for the drafting of most of the plans and diagrams, as do Marina Lubbe and Rene Farmer who where on hand when things got hectic.

Chris Prior deserves mention for his excellent companionship during the many late nights and Charles Glass whose contribution only begins as the others cease.

I owe my deepest and sincerest thanks to my wife Gillian, who typed the majority of this manuscript, valiantly trying to show an interest in matters that are totally foreign to her. Gillians greatest contribution, however has been on the domestic front where, apart from functioning as a single parent family for prolonged periods, she has provided unending physical and emotional support in my darker moments.

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REFERENCES

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APPENDIX 1

SEDIMENTOLOGICAL DATABASE

39	74 S 43 X/C2	21740	-3280	3			3	18	101		70	47
42	58 FE 50 RSE	25420	-5240	3			27		31			
47	64 AW 50 X/C	23190	-3230	3			5	40	60			
48	64 HLG N	22991	-3490	3			7	15	93	70		74
55	71 DE 58 X/C	22680	-4990	3	10	100	10	20	75	45		70
56	71 DE 2 59 X/C	22730	-5380	3			25	40	75		45	100
63	64 EE 55 X/C N	23850	-5355	3			8	11	65	80		60
64	64 EE 56 X/C S	23910	-5600	3			5	6	35	15		38
65	73 DE 56 X/C	23340	-5230	3			4	11	40	120		120
67	71 DE 49 N	23710	-4320	3			15	30	40	50		30
71	53 43A X/C S	20700	-2300	3			12	15	70	40		30
75	64 EW 46 X/C	25280	-4200	3			50	100	30	40		80
77	61 FE 53 X/C S	25380	-5860	3			20	10	40			
80	54 FE 52 X/C S	24960	-5280	3			6	35	10	38		150
81	64 EE 56 X/C S	24105	-5750	3			10	45	65	45		30
82	68 EE 53 X/C	24040	-5020	3			2			220		110
83	64 EE 50 X/C S	24600	-4800	3			1	55	145	90		45
84	68 EE 52 X/C S	24140	-4860	3			10	10	95		80	50
85	73 DW 47 X/C	24120	-4040	3			24	24	48			
86	74 DE 53 WNZ	23720	-4760	3			11	18	60			
87	71 DE 53 X/C	23360	-4320	3			2	41	100			
88	71 DE 55 X/C	23240	-4720	3			10	30	50			115
89	74 AE 56 X/C	22720	-4360	3			54	46	55			
94	73 DW 46 X/C S	24440	-3840	3			28	13	115			
95	71 AW 46 INT	24120	-3480	3			5	60	50	100		40
97	68 BE 55 X/C S	22360	-3440	3			5	28	65			
98	72 S 37 X/C	21940	-2160	3			5	65	60	90		100
101	61 EW 45 X/C S	25280	-3960	3			10	140				80
104	DO2	23500	-6760	3			3		18	54		39
106	74 S 44 A	21060	-2960	3			40	18	15	17		60
2	73DE 63 X/C S	22360	-6360	4			26	8	86			120
3	71 DE 62 X/CN	22140	-5530	4			10	30	60	80		130
4	70AE 59 X/C S	21940	-4400	4			2	130	195			100
7	73 S 51 X/C	20700	-4360	4			21	38	28	64	86	20
8	62 S 47 X/C	20400	-3400	4			6	8	38	45		14
9	62 S 49 X/C	20080	3720	4			22	13	59			14
11	53 N 48 52B X/C	19560	-3640	4			4	18	52	9	40	17
54	70 DE 61 X/C	22320	-5440	4			10	10	100	20		65
66	70 BE 58 INT X/	21720	-3760	4			10	26	15	15		65
68	72 S 48 X/C	20760	-3760	4			7	9	57	61		16
72	59 S 44 X/C	20640	-2975	4			10	53	63			50
90	73 AE 59 X/C S	22200	-4760	4			1	130	50	70		175
91	73 BE 58 X/C	22080	-4200	4			40	50	50			
92	73 BE 63 X/C S	21280	-4260	4			5	5	55			87
93	73 BE 62 X/C S	21320	-4480	4			2	5	60	42		65
99	65 S 47 X/C	20550	-3380	4			36	20	60	49		41
103	74 AE 61 X/C N	21680	-4680	4			10	80	105			80
105	65 S X/C	20050	-4040	4			40		67			
40	61 FW 47 RSE	26060	-4960	6	70	10	8	8	41			
43	61 F 49 RSE	25860	-5180	6	37	11	13		27			
73	61 FW 47 RSE	25960	-4920	6	70	10	8	8	41	60		150
74	64 EW 44 RSE	25720	-4120	6	32	15	25	18	26	90		80
76	64 FE 51 X/C S	25920	-5760	6			50	20	40	65		105

FILENAME: ALLZONES
VAAL REEF DATABASE

			CO-0RDINAT			THICKNESS IN CM'S							
	NUMB	LOCATION	X	Y	ZONE	MIZP	M-QT	VRBC	VR-QT	UVRZ	UVR-	LZM	ZM
	12	53 N 53 X/C	18200	-3260	1			3	21	121		150	70
	13	73 N HLG	17300	-2720	1			2				40	28
	14	72 N 55 RSE2	17800	-2600	1			1	10				120
	15	72 N HLGE	18300	-2800	1			3				167	48
	16	70 N 54 P10	18000	-2400	1			7	49			78	80
	17	74 N 51 X/C E	18340	-1900	1			5	90				85
	18	74 N 49 X/C N	18700	-1680	1			13	27			19	
	19	71 NW2 42 X/C	18800	-1000	1			4	20	104		34	82
	20	71 NW2 41A X/	19000	-840	1	10	38	2	63				57
	21	71 NW2 40 RSE	19120	-700	1			2	23	10	15		128
	22	71 NW2 38 X/C	19520	-520	1			2	32				20
	23	73 42 X/CN	19800	-1420	1			14	18			62	100
	24	65 N 45 X/C	19460	-1900	1			2	47	4	15	110	66
	25	50 N 47A X/C	19240	-2560	1			27				27	63
	69	73 N 52 X/C	18130	-2130	1			17				6	50
	70	73 N 50 X/C	18680	-2200	1			10	60	30			
	27	68 BW1 50 X/C	22530	-2040	2A			10	72	98	90		72
	32	59 BW 43 S	23560	-280	2A			24	18	26	83		104
	33	70 AE 37 X/C S	+24920	-1600	2A			2	110	100	170		40
	34	COMBINED	+25340	-1870	2A			9	46	83	37	52	100
	35	70 AE 39 X/C S	+24840	-2000	2A			5	12	78			
	36	2560 A 45 RSE1	23900	-2820	2A			20	10	76	109		53
	37	64 43 X/C	25660	-3800	2A			3	20	71	180		84
	41	71 DW 36 RSE	25800	-2220	2A			30	40	20	180		100
	44	71 AW 43 X/C	24440	-2670	2A			2	38	100	100		95
	45	COMBINED	+25250	-2250	2A			23	8	57	66	97	29
	46	71 DW 42 X/C S	24930	-2900	2A			20	30	100	80		120
	50	61 BW 43 X/C S	23680	-1520	2A			7	80	100			
	51	59 BW1 44 X/C	23240	-1120	2A			10	50	60			
	52	71 DW 39 X/C S	+25390	-2590	2A			5	10	133	25		
	53	73 DW 38 X/C S	+25590	-2530	2A			12	22	88			
	57	61 BW 45 X/C S	23270	-1800	2A			5	9	61	70		80
9	58	64 BW 48 A IN	22580	-1720	2A			8	12	108	55		80
	59	70 S 35 X/C	22090	-1[illegible]44	2A			1	40	100	120		120
9	60	65 BW 47 X/C S	23370	-2[illegible]30	2A			10	75	35			
	61	64 BW 47 X/C S	23240	-23[illegible]0	2A			3	45	114			
	62	68 BW 44 X/C S	23650	-2200	2A			2	30	45			
	96	74 DW 43 X/C	24870	-3300	2A			18	25	68	130		90
	100	64 AW 43 X/C S	24120	-2400	2A			25	60	90	150		140
	102	61 EW 41 X/C	25800	-3400	2A			20	20	70	80		100
	1	71 DE 2 62 X/C	22470	-6045	2B			19	46	112	25	50	120
	5	2750 DE 54 X/C	22820	-3900	3			2	25	68	27		25
	6	2650 57 X/C S	22100	-3760	3			4	10	106			50
	10	74 S 43 X/C	21380	-3080	3			8	80	17			
	26	53 42 WNZE	20940	-1980	3			2	194				100
	28	70 S 36 X/C W4	22560	-2520	3			2	120	76			
	29	72 S 40 X/C	21840	-2700	3			25	100	20	56		100
	30	72 S 39	22020	-2700	3			15	35	33	14		45
	31	72 S 36 TRAM	22080	-2134	3			11	45	81	140		80
	38	68 EW 48 P7	24700	-4030	3			5		87			90