THE SEDIMENTOLOGY AND DEPOSITIONAL ENVIRONMENT OF THE BEATRIX REEF : WITWATERSRAND SUPERGROUP

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DECLARATION

I declare that this dissertation is my own, unaided work. It is being submitted for the degree of Master of [illegible]e in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any other degree or examination in any other University.

J. H. Genis

28th day of December, 1990.

ABSTRACT

Beatrix Mine is located 35 km south of the city of Welkom in the Welkom Goldfield and as such forms the most southerly of the Witwatersrand-type gold mines.

The Beatrix Reef overlies an angular unconformity at the base of the Turffontein Subgroup, Central Rand Group. Significant, southerly truncation of over 600 m of the Johannesburg Subgroup, and the lower formations of the Turffontein Subgroup, occur at this unconformity in the Beatrix area.

Characteristics of the Beatrix Reef conglomerates such as the morphology, sorting and packing of clasts, and the arrangement of the sediments in various sedimentary structures and facies sequences, suggest deposition within a braided, fluvial environment on a coarse-grained braid-delta. Sedimentation occured after the fluvial degradation of previously deposited units, and culminated in a marine/ lacustrine transgression. Low aggradation rates led to significant reworking and concentration of placer materials in a depositional model probably typical of Central Rand Group placer formation. Heavy minerals (and gold) are concentrated in response to hydraulic conditions and show a close association with large and small scale sedimentary features. Transport directions deduced from the sedimentary structures suggest a north to south dispersal of sediment down the braid plain.

Sedimentary structures in the finer grained units at the

base of the Eldorado Formation are indicative of tidal influences and document the marine transgression as the culmination of the degradational events.

The lithology, sedimentary structures and facies sequences of the coarser grained units of the Eldorado Formation, as well as the overall coarsening upward of these lithologies indicate sedimentation in a braided, fluvial system on an alluvial fan prograding across the previously deposited units. Sedimentary structures and lithologic variations confirm a continued north to south dispersal pattern.

In the area south of the Sand ; ver the period of fluvial degradation and transgression after the formation of the Beatrix Reef was followed by more rapidly aggrading fluvial progradation due t a major change in base level in response to compressional tectonics and uplift along the Western Margin Structure. Only in post-Central Rand Group times did relaxation and extensional tectonics result in the outpourings of the Ventersdorp Supergroup lavas and the cessation of active Witwatersrand Supergroup sedimentation.

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1 INTRODUCTION

1.1 LOCATION

Beatrix Mine is located in an area of rolling grasslands some 35 km south of Welkom and 25 km south of Virginia in the Orange Free State, and is the most southerly of the Witwatersrand-type gold mines (Fig. 1). The topography of the area has an average elevation of 1380 m above sea level and is underlain by a thick sequence of flat lying Karoo sediments which overlie the underlying Archaen Witwatersrand and Ventersdorp Supergroups.

The Mine is located on the southwestern margin of the Witwatersrand Basin as it is presently known, some 340 km southwest of Johannesburg (Fig. 1).

1.2 GENERAL GEOLOGICAL SETTING

The Witwatersrand Supergroup consists almost entirely of clastic, sedimentary deposits preserved in structurally downwarped or downfaulted parts of an extensive basin that extends from Johannesburg for some 340 km to south of Welkom in the southwest (Fig. 1). It overlies and onlaps both the Dominion Group and the granite-gneiss and greenstone terrain of the Kaap Vaal craton (Tankard et al., 1982), and is overlain by basaltic lavas and metasediments of the Ventersdorp Supergroup (Tankard et al., 1982).

The age of the Witwatersrand Supergroup has been constrained by the recent dating of zircons by ion-microprobe analysis (Armstrong et al., 1986, Armstrong et al., 1989) with a maximum age of 3060 Ma for underlying Dominion Group lavas and 2708 Ma

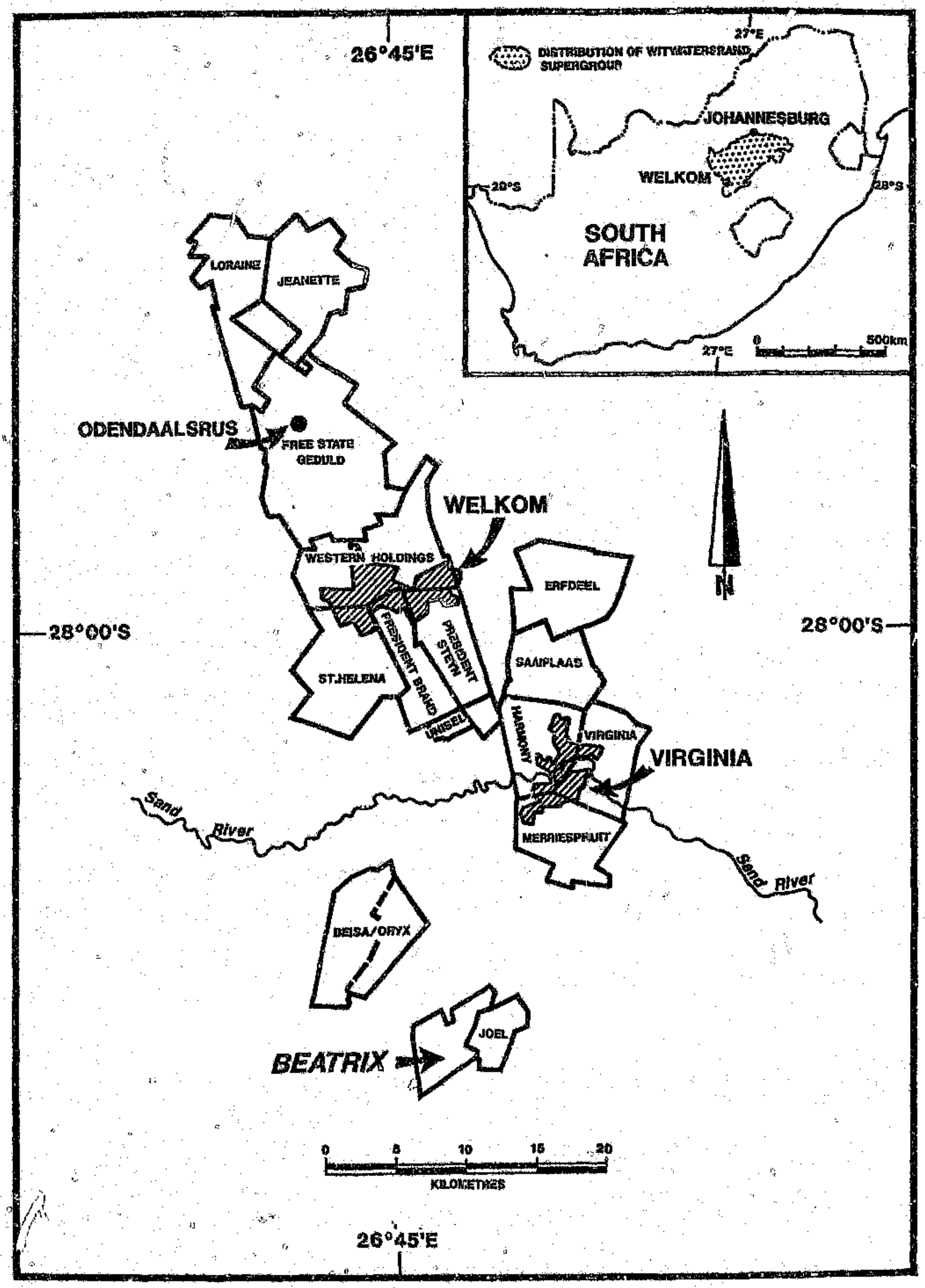

FIGURE 1: PLAN SHOWING THE LOCATION OF BEATRIX MINE IN THE O.F.S. GOLDFIELD

for overlying Ventersdorp Supergroup lavas. The maximum age has been further constrained at 2894 Ma by U-Pb ages on single, detrital zircon grains from conglomerates within the Witwatersrand sediments (Robb et al., 1989).

The Witwatersrand Supergroup forms an overall coarsening-upward sedimentary sequence and is subdivided into a lower, West Rand Group comprising an argillaceous to arenaceous sequence (5 km thick), which is overlain by the upper, Central Rand Group, an arenaceous to rudaceous sequence (3 km thick). Most of the gold production (about 618 t/annum) is derived from conglomerates of the Central Rand Group.

Only about 10% of the Central Rand Group outcrops, the rest being concealed by younger Proterozoic and Phanerozoic cover rocks. In the Welkom area all the Witwatersrand Supergroup sediments and the Ventersdorp Supergroup are overlain by a thick succession (300 - 500 m) of Permo-Triassic aged sediments of the Karoo Sequence. All deductions on the geology of the area are thus based on borehole data and underground exposures.

The Beatrix Reef is situated on an unconformity surface within sediments of the upper part of the Central Rand Group. In the area south of the Sand River the Central Rand Group is subdivided into the Johannesburg Subgroup and the overlying Turffontein Subgroup at the position of the Beatrix Reef.

Post Transvaal tectonics in the northern parts of the Witwatersrand Basin are usually reflected in the formation of broad folds, bedding parallel faults and low angle cleavage (McCarthy et al., 1986.), but are not evident or obvious in the areas south of the Sand River where the Archaen rocks are only overlain by the Permo-Triassic aged Karoo Sequence. Other Proterozoic aged deposits are not developed or preserved.

The structure of the Archaen rocks in the area south of the Sand River is dominated by overturned strata and thrust faulting associated with the "Western Margin Structure" along the western margin of the Witwatersrand basin at Beisa Mine, and documents major east-west compression. Throughout the Witwatersrand Basin compressional tectonics were dominant, at least during late Central Rand Group times (Olivier,1965; Minter et al., 1986.). An extensional regime prevailed during Ventersdorp times giving rise to the formation of normal and wrench faults (Stanistreet et al.,1986; Myers et al., 1989). In the area south of the Sand River the Klippan Formation (Ventersdorp Supergroup) sedimentation, associated with major normal fault scarps, dates this extension as pre-Platberg. This pre-Platberg extension results in north-south trending normal faults with both east and west downthrow and is the dominant fault pattern in this part of the basin.

Winter (1987) has proposed a foreland basin plate tectonic model for the development of the Witwatersrand Basin. Clendenin et al. (1988) have suggested that oblique collision of the Zimbabwe and Kaapvaal cratons resulted in low angle subduction of the Zimbabwe Craton and the development of a series of "successor" basins on the Kaapvaal Craton of which the Witwatersrand and Ventersdorp basins form part of the succession.

Either of the plate tectonic models proposed by these authors fit the available evidence from the Welkom Goldfield.

Recent studies of Witwatersrand meta-pelites by Phillips (1986, 1987) have demonstrated regionally persistent greenschist facies metamorphism of 2 Kbar and 350° C throughout the Witwatersrand basin. Phillips (1987, 1988) and Law (1990), in these studies, suggest that gold and uranium mineralisation in the Witwatersrand is due to hydrothermal alteration and the channelling of the hydrothermal fluids along conglomeratic horizons. The hydrothermal alteration/modification of original placer mineral assemblages during this metamorphism forms gold and uranium ore deposits and the pervasive greenschist facies metamorphic character.

1.3 HISTORY OF EXPLORATION

Two factors contributed to an intensification of exploration activity during the 1930's in this part of the Orange Free State, far removed from the then known goldfields. Firstly, the abandonment of the gold standard in 1932 led to an intensification of exploration throughout all areas of the Witwatersrand. Second, was the success of the Aandenk borehole, drilled by Allen Roberts of Witwatersrand Extensions near Loraine during the period 1933 to 1935, in locating Central Rand Group sediments below the Karoo Sequence cover. The main areas of exploration activity were centered around, and to the north of Odendaalsrus (Fig. 1) where outcropping conglomerates (of the Ventersdorp Supergroup) provided the initial focus of exploration. With time the area of exploration extended south to the Sand River. In July 1938 Western Holdings Ltd. (Union Corporation Ltd.) commenced exploration of a large block of ground extending some 18 km south of the Sand River (Tweedie, 1984). Geophysical investigations revealed a north-south trending "heavy" magnetic body in the west, flanked to the east by a lighter, non-magnetic body and a heavier, non-magnetic body. These had been interpreted to be West Rand Group shales in the west flanked in the east by shallow, Central Rand Group sediments and Ventersdorp lavas (Frost et al., 1946). Borehole SH1 on the farm St Helena commenced drilling in February 1938 to prove this hypothesis and was successful in locating quartzites and payable gold-bearing conglomerates at moderate depths below the Karoo Sequence. Borehole UC 27, drilled in 1947 on the farm Palmietkuil some 12 km south of the Sand River near the southern limit of the Union Corporation Ltd. holdings, penetrated through Karoo sediments and Ventersdorp lavas into conglomerates at a depth of 1062 m. This borehole confirmed that shallow lying Central Rand Group strata extended well south of the Sand River at moderate depths below the Karoo and Ventersdorp rocks. A 24 cm oligomictic conglomerate ata depth of 1729 m in Borehole UC 27 returned minor gold values but its correlation with the then known reef sequences of the "new" goldfield around St Helena and north of the Sand River was unclear. By mid 1945 a major unconformity at the base of the "Ventersdorp Lower Sediments" (Eldorado Formation) was recognised and a stratigraphic zonation of these sediments was proposed (McKeown, 1944; McKeown, 1945a; McKeown, 1945b).

By 1950 some 14 boreholes had been drilled in the area south of the Sand River (Fig. 2), but no payable gold deposits were found. It was thus concluded that if auriferous conglomerates occurred

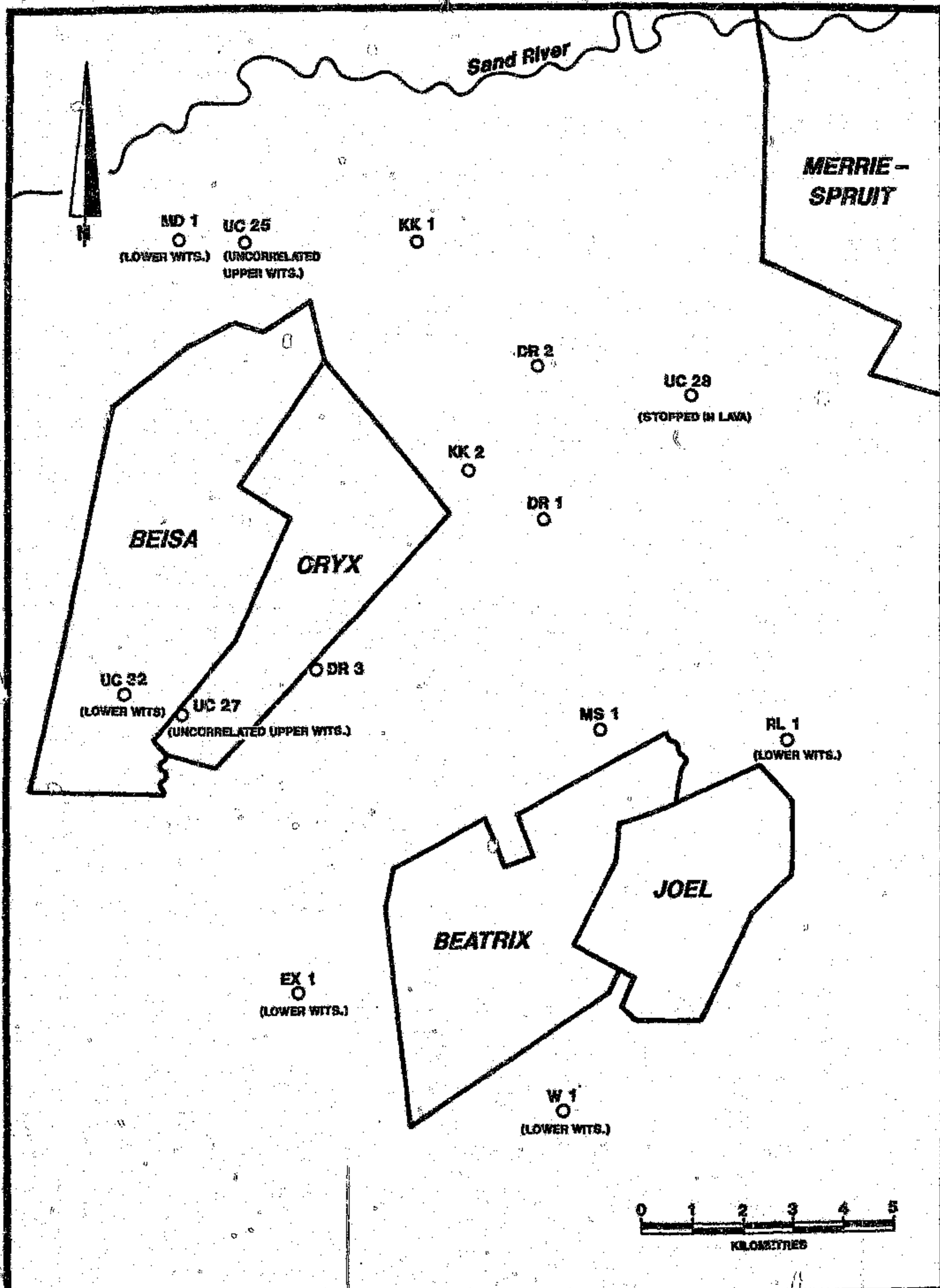

FIGURE 2: PLAN SHOWING BOREHOLES COMPLETED SOUTH OF THE SAND RIVER BY 1950

in the area they were below the then economic mining depth of 1500 m. No further drilling was therefore justified and the option holdings in the area south of the Sand River were abandoned (Tweedie, 1984).

Mining operations in the western areas of St Helena Mine during the early 1960's gave a better understanding of the stratigraphic relationships and the structure along the Western margin of the goldfield. This prompted Moubray (1965) to suggest a re-examination of the area south of the Sand River to investigate the Main Reef (Ada-May or Beisa Reef) and the "Uncorrelated" Reef of UC 27. Based on Moubray's (1965) recommendations, drilling in the area recommenced in 1969 after sufficient ground had been secured.

In the period 1973 to 1980 drilling was concentrated in the Beisa Mine area, but also towards the southeast of Beisa where interesting gold values were being obtained in the UC 27 Reef, (the "uncorrelated" reef of Borehole UC 27).
By 1980 an economic, auriferous conglomerate at the base of the Eldorado Formation had been proved in the area 14 km to the southeast of Beisa Mine, and shaft sinking for Beatrix Mine commenced here in April 1981. The reef mined became colloquially known as the Beatrix Reef.

1.4 PREVIOUS WORK

Since the discovery of the Witwatersrand Goldfields in 1886 controversy has raged as to the origin and mode of formation of these deposits. Exton (1895) in his inaugural address to the Geological Society of South Africa, noted that ...." the probability that the gold-bearing conglomerate has been laid down by an aqueous medium becomes more probable"....., and since that time the fact that the economic mineralisation in the Witwatersrand Basin was hosted in clastic sediments has not been in dispute. The origin of the gold and its mode of deposition has however not been fully resolved even to this day (Pretorius, 1989).

The work of Reinecke (1927, 1930) on the "paystreaks" of the East Rand Goldfield was one of the first to document the intimate relation of the gold to sedimentary features. His work illustrated the value of sedimentology in understanding the mode of formation of the Witwatersrand reefs. It was only after the work of Steyn (1963) in the early 1960's however that systematic sedimentological investigations were carried out in trying to resolve the origin of the reefs. The depositional environments commonly interpreted for the Witwatersrand sediments are tidal - marine for the West Rand Group (Eriksson et al., 1981) and alluvial and fluvial for much of the Central Rand Group (Minter, 1978), although recent research suggests significant marine influence in the formation of reefs even in the Central Rand Group (eg. Bailey et al., 1990, Verrezen, 1987).

The modified placer model is one of the more popular theories on the genesis of the Witwatersrand gold-bearing reefs and suggests that gold, uranium and pyrite were deposited as detrital grains with the sediments and concentrated by hydraulic processes to form palaeoplacers which were later modified by <u>in-situ</u> recrystallisation (Pretorius, 1976, 1981 and Minter, 1978, 1987).

A revival of the hydrothermal theory (Phillips et al., 1987; Phillips and Myers, 1989) suggests that gold was precipitated from metamorphic fluids, and Phillips and Myers (1989) contend that precipitation was by selective, epigenetic replacement of iron and carbon bearing phases accumulated preferentially in response to sedimentary processes. The model would thus account for the close relationship of gold to sedimentary features. In all models on the genesis of the gold-bearing conglomerates the close relationship between gold distribution and sedimentary structures is not in dispute, and sedimentological investigations are thus fundamental to the understanding of the Witwatersrand reefs.

Early publications on the geology of the Welkom Goldfield were largely descriptive (eg Borchers and White, 1943, Baines, 1949, Coetzee, 1960 and Winter, 1964a and 1964b) and the geology of the Welkom Goldfield is summarised in the Geological Society's Mineral Deposits volume (Minter et al., 1986). It was only in the 1980's however that sedimentologic and genetic studies on the reef zones of the Welkom Goldfield became more prevalent in the literature (eg. Buck, 1983, Kingsley, 1984 and 1987, Minter et al., 1988).

Because the Beatrix Reef has only recently been discovered and exploited, the only literature dealing with this reef is in confidential company records.

Minter et al. (1988) carried out sedimentological and mineralogical investigations of the conglomerates at the base of the Eldorado Formation (upper parts of the Central Rand Group) intersected in exploration boreholes south of the Sand River.

They concluded that fluvial and debris flow sediments on the Eldorado palaeosurface contain placer concentrates derived by the repeated erosion of subcropping placers (Minter et al., 1988).

Kingsley (1987) in his detailed study of the Eldorado Formation in the Welkom Goldfield extended his study to cover the area immediately south of the Sand River. He postulated that the Eldorado Formation gravels and sands were deposited from west to east as alluvial fans and then redistributed longitudinally as gravel and sand bars on a broad braid plain down a southeastward palaeoslope (Kingsley, 1987). Although the same model for deposition of the Eldorado Formation and the reef in the Beatrix Mine area would apply, no mention of the Beatrix Reef or gold-bearing conglomerates at the base of the Eldorado Formation was made by Kingsley.

1.5 AIM OF THE STUDY AND METHODOLOGY

The aim of this study is, by means of a detailed sedimentological investigation, to determine the palaeoenvironment of deposition of the Beatrix Reef, its correlation with the stratigraphic sequences of the rest of the Orange Free State Goldfield and its relationship to the overlying Eldorado Formation. In addition this investigation determines the tectono-sedimentary controls on the formation of the Beatrix Reef as a possible model for Witwatersrand reef formation.

The data base from which deductions are made was collected by the author during sedimentological investigations as part of the routine geological work on Beatrix Mine where some 3.6 million square metres of the Beatrix Reef have been exposed during mining operations. Data were collected mainly from the detailed geological mapping of the reef exposed on the face of selected stope panels. Included in the database are the results from 230 prospect boreholes drilled from the underground development on Beatrix Mine during the routine evaluation of the reef. Facies analysis was carried out to determine depositional environments. The data from underground are supplemented by the information from exploration boreholes drilled in the area south of the Sand River. This data was used to construct isopach maps and together with palaeocurrent data was used in the determination of syntectonic basin evolution.

2 STRATIGRAPHY OF THE WITWATERSRAND SUPERGROUP IN THE BEATRIX AREA AND THE WELKOM GOLDFIELD SOUTH OF THE SAND RIVER

2.1 INTRODUCTION

The Welkom Goldfield and the area south of the Sand River (Fig. 1) is underlain by a thick cover of Karoo Sequence rocks which overlie the [illegible]r Ventersdorp and Witwatersrand Supergroups. All deductions and interpretations on the geology of the area are thus based on borehole data.

The sub-Karoo geology in the area south of the Sand River is deduced from the exploration boreholes (Fig. 3), and the stratigraphic zonation and nomenclature in use at Beatrix Mine is summarised in Figure 4.

West Rand Group rocks overlie the Archaen basement lithologies in the area south of the Sand River where they suboutcrop along the western margin of the Witwatersrand basin, brought closer to surface by the overturn of the Western Margin Structure.

The Central Rand Group, overlying the West Rand Group, varies from 1000 m thick in the Beatrix Mine area to over 2015 m thick in the Welkom Goldfield. This change in stratigraphic thickness is due to truncation of parts of the Johannesburg Subgroup (lower parts of the Central Rand Group) by onlapping unconformities towards the south.

Lavas and sediments of the Ventersdorp Supergroup overlie the Witwatersrand strata and their occurrence and thickness is largely controlled by the tectonic structure of the area and by pre-Karoo erosion.

The Witwatersrand Supergroup and the Ventersdorp Supergroup are

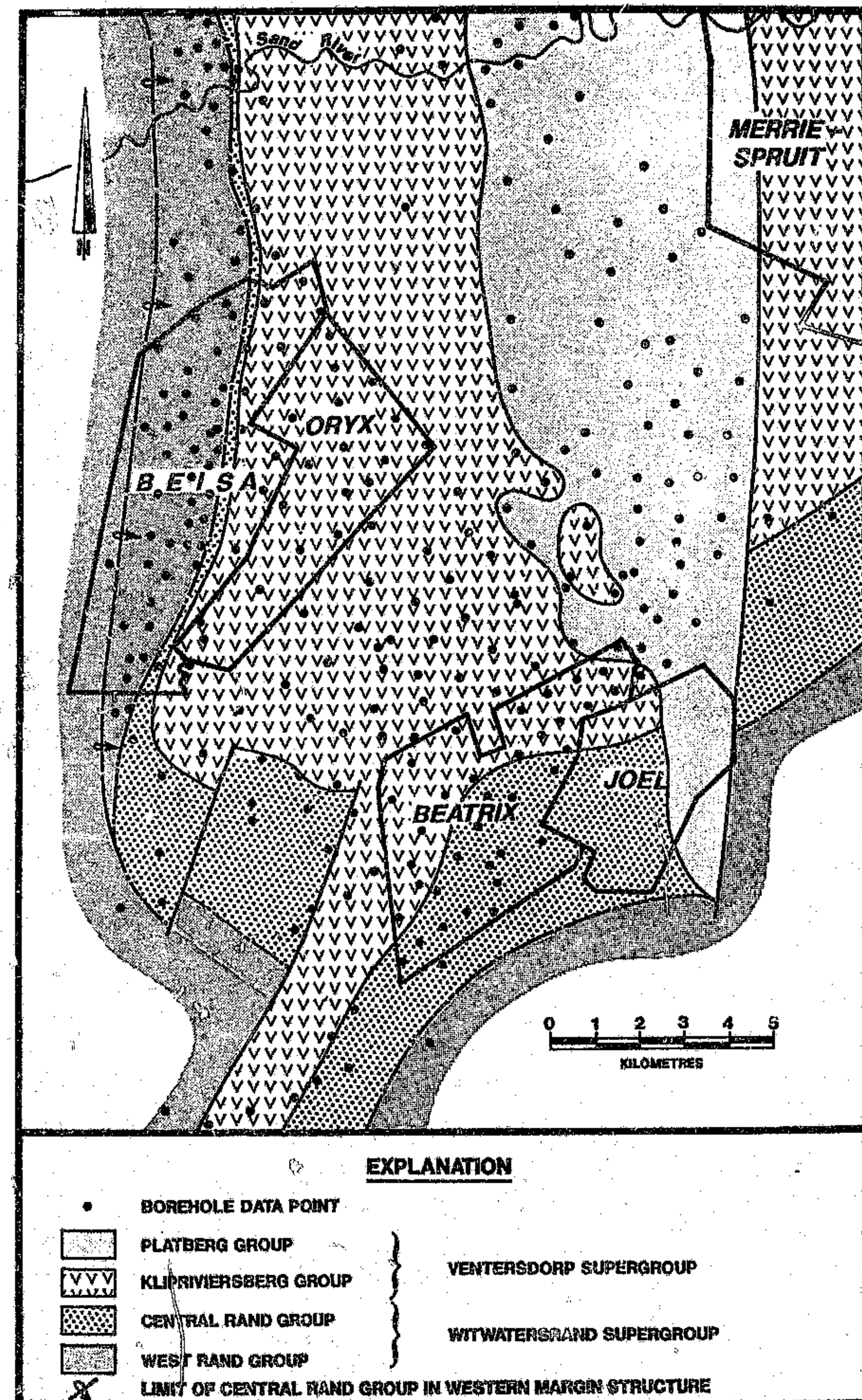

FIGURE 3: SUB-KAROO GEOLOGY

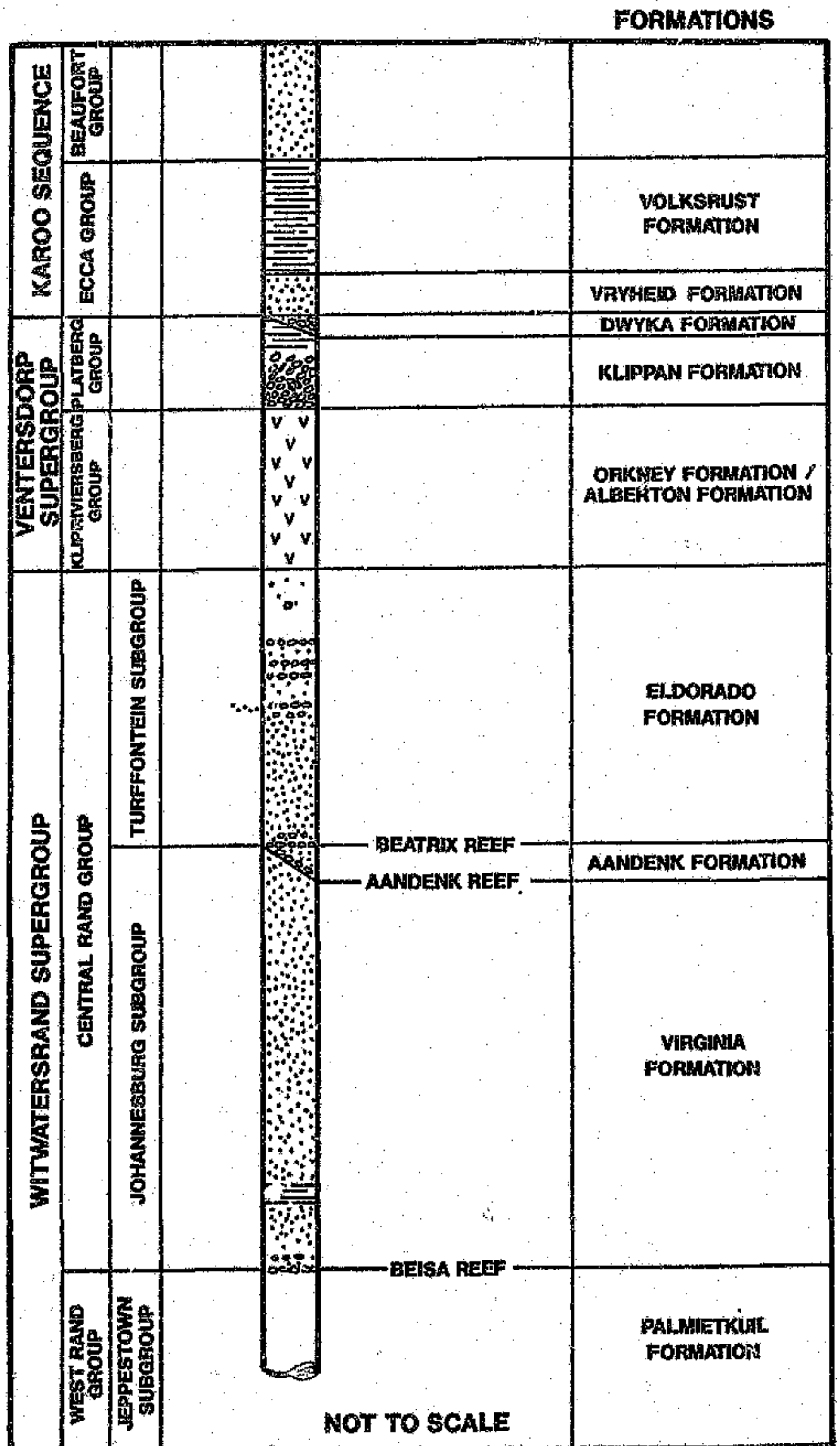

FIGURE 4: STRATIGRAPHIC ZONES AND NOMENCLATURE AT BEATRIX MINE

overlain by Karoo Sequence sediments.

Since the first intersections of Witwatersrand strata in boreholes in the Orange Free State in the late 1930's, attempts were made to subdivide the intersected rock sequences into recognisable units, chiefly as an aid to stratigraphic correlation. Early stratigraphic zoning was naturally descriptive, based on visually identifiable variations in physical characteristics such as lithology, grain size, colour and matrix content. This descriptive zonation was then accorded rank names similar to the chronostatigraphic terminology prevalent at the time.(ie. System, Series, Stage)

Borchers and White (1943) were among the first workers to write on the stratigraphy of the new Orange Free State Goldfield, and their subdivision used many of the names and terms in use at the Klerksdorp Goldfield at the time. Frost et al. (1946) in their paper on the Orange Free State Goldfield recognised that correlations with other goldfields were tentative, and introduced the terms "St Helena Series", "Leader Reef" and "Basal Reef" to describe parts of the succession and reefs of the Welkom Goldfield. Further development of thoughts on the stratigraphic zoning of the Orange Free State Goldfield are summarised by Coetzee (1960), who proposed a scheme of terminology and correlation widely used at the time.

By the late 1960's and early 1970's it was realised that retaining chronostratigraphic nomenclature for lithological units was incorrect. Subsequently the stratigraphic description is based on a lithostratigraphic classification formalised by

S.A.C.S. (1980). This replaced the traditional scheme in which chronostratigraphic terms (System, Series, Stage) are applied to lithological units. New names were proposed for many of the units in the Orange Free State Goldfield in keeping with the new nomenclature, and this terminology is in use today (eg. Minter et al., 1986), and is used in this study.

Winter (1984) has suggested that in Witwatersrand stratigraphic zoning, more use should be made of tectono-stratigraphic units which, by definition, are "unconformity-bounded units of genetically related sequence of sedimentation . . . . in which tectonic control and depositional response can be related." Most of the formations in the southern Orange Free State Goldfield are unconformity-bounded units of 'genetically-related' strata and could thus be classified in terms of tectono-stratigraphic units (Winter, 1984), or as Synthems as proposed by the International Subcommission on Stratigraphic Classification (I.S.S.C.) and discussed by Johnson and Rust, (1988). In terms of the I.S.S.C. proposals the Beatrix Reef would be considered a Miosynthem -- "a relatively local and minor unconformity-bounded unit situated within a Synthem" (Johnson and Rust, 1988).

As per the recommendations of Johnson and Rust, (1988) the lithostratigraphic subdivision of the Witwatersrand Supergroup (S.A.C.S., 1980) is retained for all discussion on the stratigraphy within the southern Orange Free State Goldfield and Beatrix Mine area.

2.2 THE WITWATERSRAND SUPERGROUP WITH SPECIAL REFERENCE TO THE CENTRAL RAND GROUP

Very early correlations of the Witwatersrand strata intersected in the Orange Free State Goldfield (Borchers and White, 1943) placed the "Ventersdorp Sediments" (upper part of the Central Rand Group, or Eldorado Formation) as part of the Ventersdorp Supergroup because of the similarity of the Eldorado Formation conglomerates to the Platberg agglomerates.

McKeown (1945a) working in the Welkom Goldfield suggested that the "Ventersdorp Sediments" and the underlying reefs of the "St Helena Series" were conformable ...."since the succession is usually complete in proceeding from the Ventersdorp Sediments to the Reef Horizon." The base of the "Ventersdorp System" was then placed at a distinctive white quartz pebble conglomerate (V.S.5?) due to ....."the marked change in sedimentation at this point." (McKeown, 1945a).

Baines (1949) however, included all beds between the Ventersdorp Lower lavas and the Reef Zone in the "Upper Division of the Witwatersrand". This upper limit to the Witwatersrand Supergroup was accepted by all subsequent workers (Eg. Coetzee, 1960; S.A.C.S., 1980; Minter et al., 1986)

The Witwatersrand Supergroup in the Welkom Goldfield has, as per convention, been subdivided into the West Rand Group and the Central Rand Group (Fig. 4). Only the upper parts of the West Rand Group (viz. the Jeppestown Subgroup) have been intersected in boreholes, predominantly along the Western Margin Structure at Beisa Mine (Fig. 3), and relatively little is known of the formations comprising this Group. On Beatrix Mine only a few of the early exploration boreholes were extended to the base of the Central Rand Group to intersect the Ada-May (Beisa) Reef, and in these only the top 50 m of the West Rand Group was intersected. Consequently, the West Rand Group stratigraphy is not reviewed.

The Central Rand Group is about 1000 m thick in the Beatrix area compared with 2015 m in the Welkom Goldfield, and 2865 m in the type section around Johannesburg (Brock and Pretorius, 1964).

Baines (1949), commenting on the rock units at the base of the "agglomerate-type Ventersdorp Sediments" intersected in borehole VDH 1 in the Loraine area, concluded that a break occurs at the base of this sequence and that uncorrelated beds in Borehole VDH1 had been eroded elsewhere in the Goldfield. He also recognised that in the Sand River area to the west of Merriespruit Mine a new reef, tentatively called the "B" Reef, resting on an unconformity had removed the Basal Reef and the Leader Reef (Baines, 1949). This premise was expanded by Pritchard-Davies and Moubray (1951) who suggested that south of the Sand River the "St Helena Series reef zones" (Basal and Leader Reefs) had been truncated by this unconformity at the base of the "B" Reef. Futhermore, the uncorrelated reef in borehole UC 27 (cf. Section 1.3) was therefore not part of the "St Helena Series Reef Zones", but was probably part of the footwall formations (Pritchard-Davies and Moubray, 1951).

By the early 1950's it was recognised that south of the Sand River the Leader and Basal Reefs had been truncated by a major unconformity at the base of the "B" Reef, and that a significant break also occurred at the base of the "Ventersdorp Sediments".

The unconformity at the base of the "B" Reef was used by Baines (1949) to separate the "Main-Bird Series" from the overlying "Elsburg Series" in his subdivision of the upper part of the Witwatersrand stratigraphy. Later workers (Coetzee, 1960) also divided the "Kimberley-Elsburg Series" from the "Main-Bird Series" at the "B" Reef, but the Kimberley-Elsburg Series was further subdivided into a "Kimberley Stage" and an "Elsburg Stage" at the unconformity at the base of the Ventersdorp Sediments.

The unconformity at the base of the "B" Reef is now taken as the stratigraphic position at which the Central Rand Group is subdivided into the Johannesburg Subgroup and the overlying Turffontein Subgroup (S.A.C.S., 1980; Minter et al., 1986), which would correlate with the Main-Bird and Kimberley-Elsburg Series of previous workers.

Successive, overlapping unconformities due to repeated uplift and erosion of the rocks, document an unconformable onlapping of formations of the Central Rand Group and the truncation of much of the Johannesburg Subgroup (Figs. 5a and b) (Tankard et al., 1982) in the area south of the Sand River. This accounts for the change in Central Rand Group stratigraphic thickness from 2015 m at Welkom to 1000 m at Beatrix Mine in the south. These onlapping unconformities result in successively younger formations of the Turffontein Subgroup overlying successively older formations of the Johannesburg Subgroup to the south in the area south of the Sand River (Fig. 5b).

The Johannesburg Subgroup is represented only by the lower formations (viz. The Virginia Formation and the St Helena

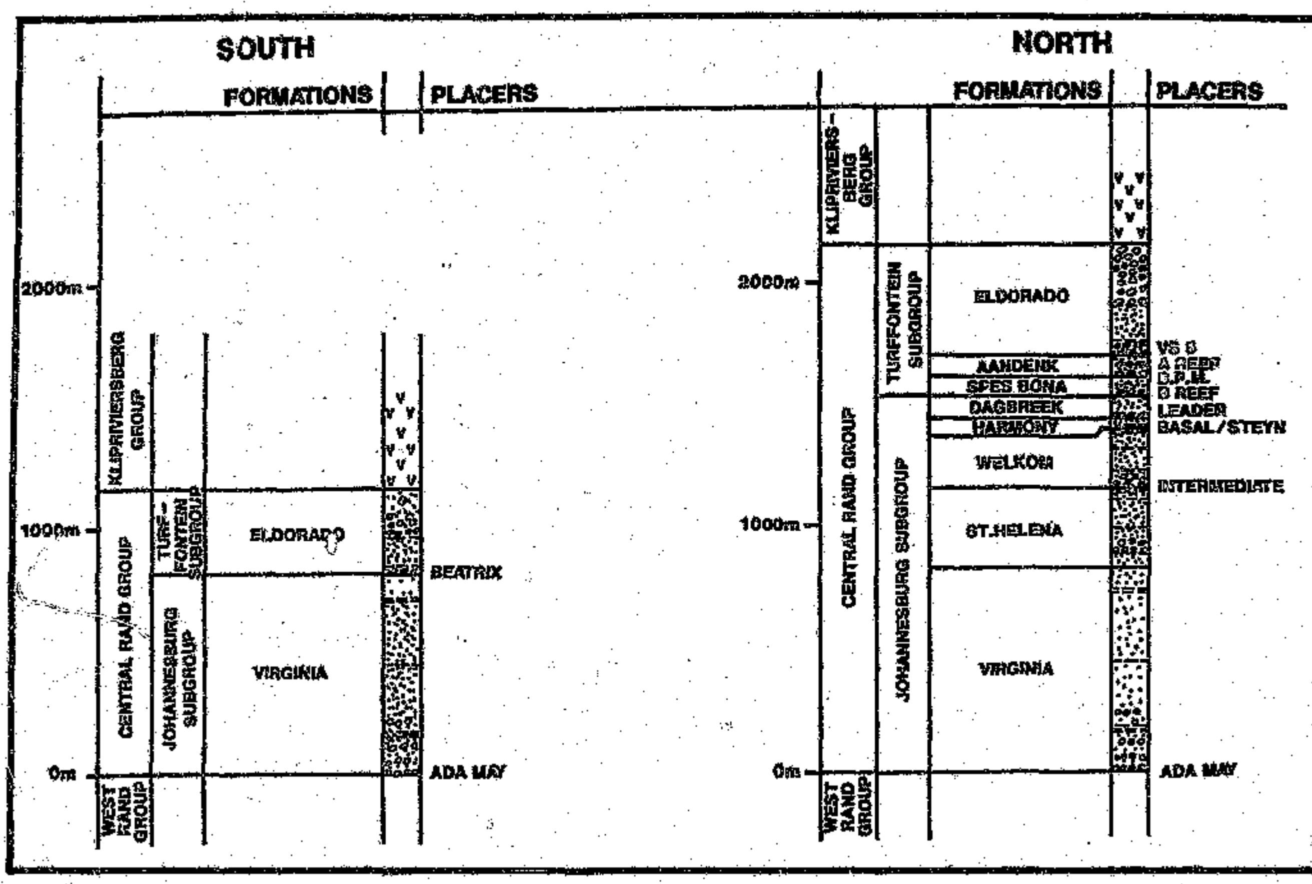

FIGURE 5a: STRATIGRAPHY OF THE CENTRAL RAND GROUP IN THE NORTH AND SOUTH OF THE WELKOM GOLDFIELD SHOWING THE ELIMINATION OF FORMATIONS SOUTHWARD.

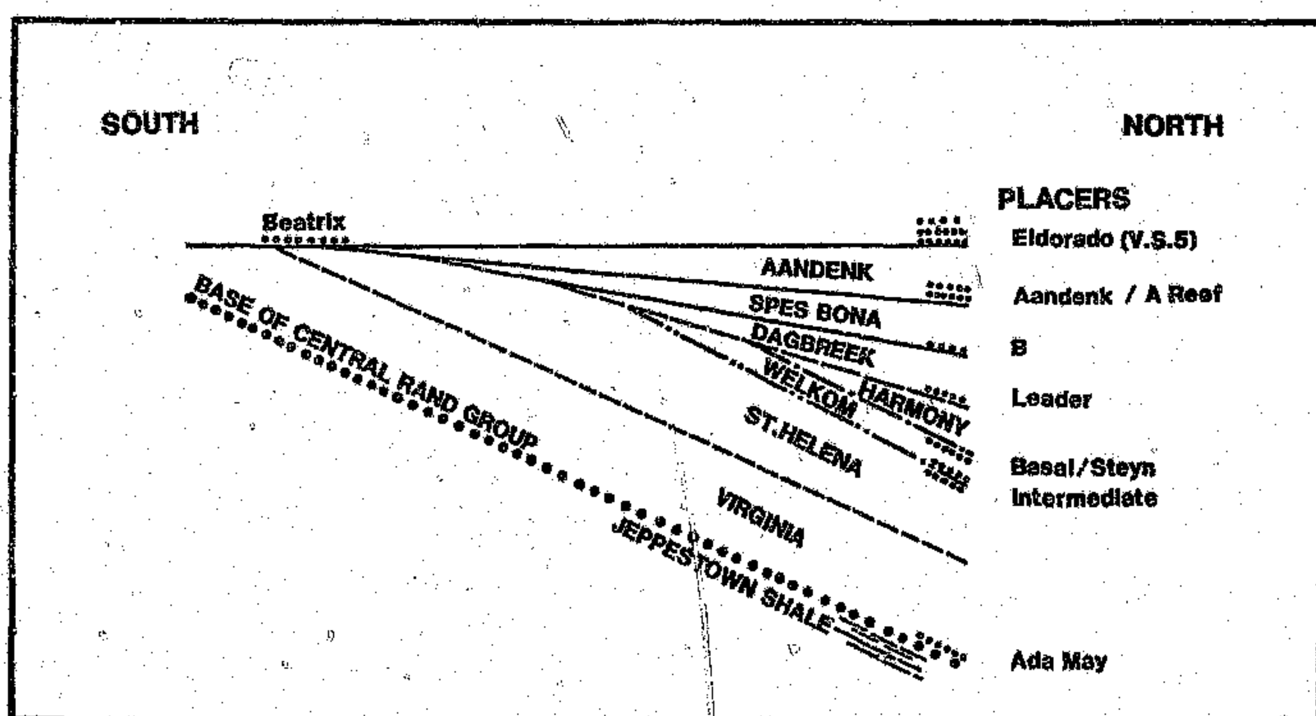

FIGURE 5b: SECTION THROUGH THE WELKOM GOLDFIELD ILLUSTRATING THE UNCONFORMABLE ONLAPPING NATURE OF THE FORMATIONS (TANKARD ET AL.,1982)

Formation) in the Beatrix Mine area (Fig. 6). The upper parts of the St Helena Formation (320 m), the Welkom Formation (240 m) and the Harmony and Dagbreek Formations (165 m) are removed through erosion (Fig. 5). For this reason the upper formations of the Johannesburg Subgroup are not reviewed.

In the Beatrix Mine area the Turffontein Subgroup is represented largely by the Eldorado Formation. Remnants of the Aandenk Formation occur below the Beatrix Reef and the Eldorado Formation in the northeastern parts of the Beatrix Mine Lease, and in areas to the north of the mine (Fig. 7). The lower formations of the Turffontein Subgroup (Spes Bona and Aandenk Formations) are truncated by the unconformities at the base of the Aandenk and Eldorado Formations respectively (Figs. 5 and 7).

In the Welkom Goldfield south of the Sand River the Eldorado Formation and the Virginia Formation are further subdivided into a number of Members based on lithological variations (Fig. 8).

2.3 THE VIRGINIA FORMATION (JOHANNESBURG SUBGROUP)

Early workers in the Orange Free State Goldfield (Borchers and White, 1943; Frost et al., 1946) referred to all the rock units below the Basal Reef as the "Speckled Quartzite Footwall Beds". Winter (1957) was the first to formalise a subdivision of these footwall units into "Upper -", "Middle -" and "Lower - Footwall Beds". The "Lower Footwall Beds" were divided into an "L.F. 2 Zone" and an overlying "L.F. 1 Zone" (Winter, 1957). As the Orange Free State Goldfield developed, individual mining groups devised their own schemes of subdivision of the "Footwall Succession", but the proposals of Winter (1957) were largely

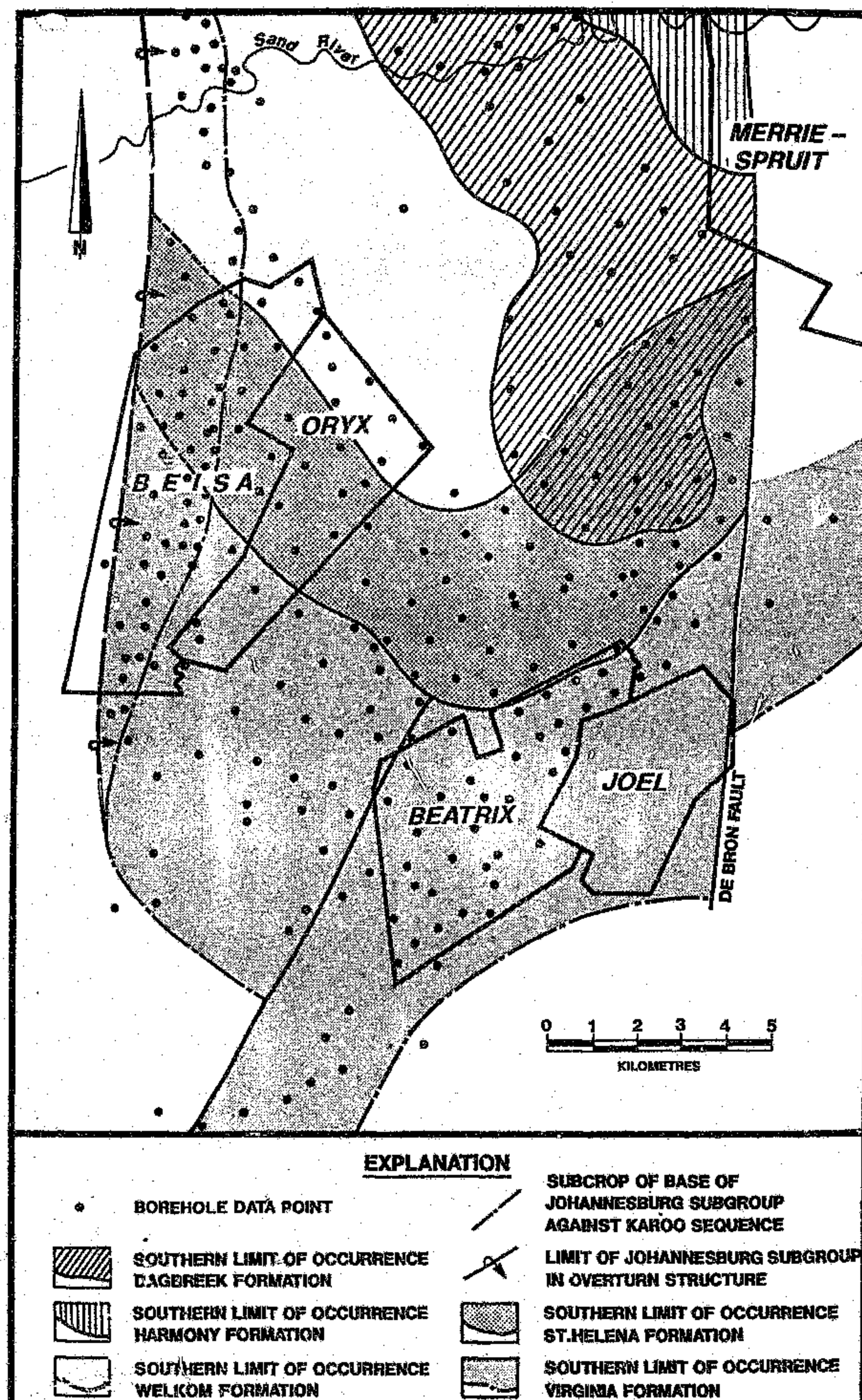

FIGURE 6: LIMITS OF OCCURRENCE OF FORMATIONS OF THE JOHANNESBURG SUBGROUP

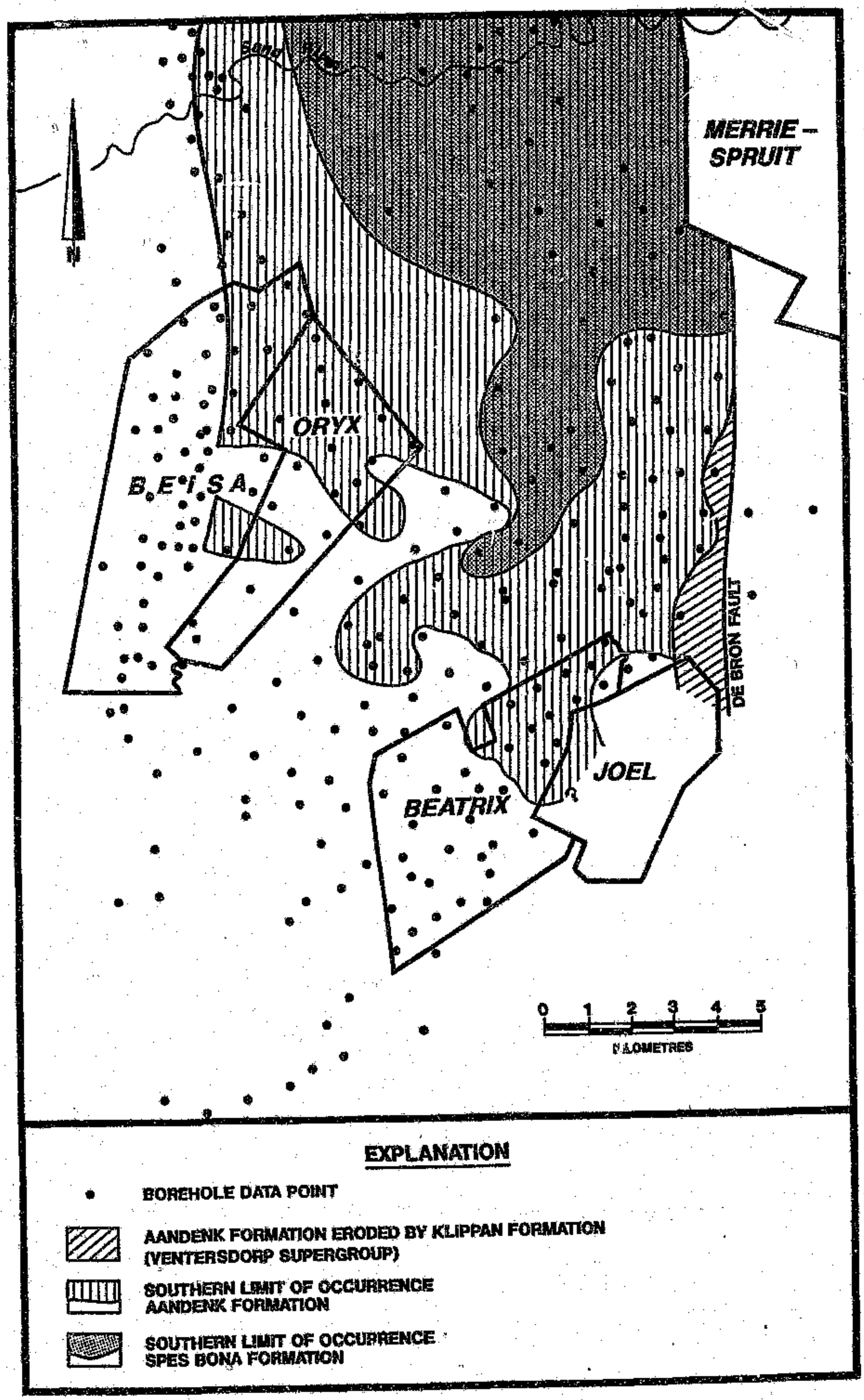

FIGURE 7: LIMITS OF OCCURRENCE OF AANDENK AND SPES BONA FORMATIONS

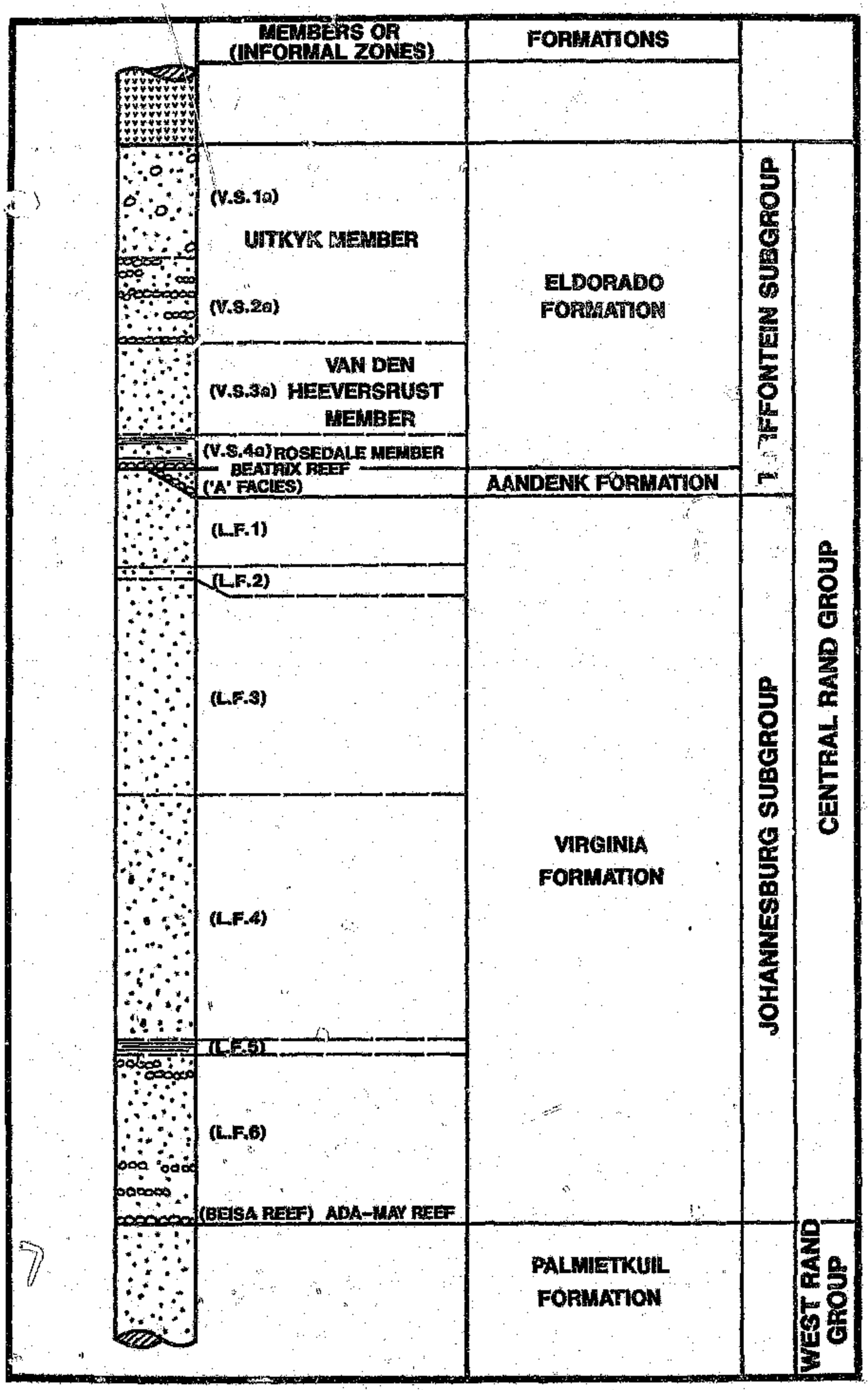

FIGURE 8: **DETAILED STRATIGRAPHIC ZONING OF THE WITWATERSRAND SUPERGROUP IN THE BEATRIX MINE AREA**

retained. With the formalisation of the lithostratigraphic nomenclature by S.A.C.S. (1980) the names Virginia Formation, St ...ma Formation and Welkom Formation were introduced for the "Lower -" "Middle -" and "Upper - Footwall Beds" respectively. The subdivision of the "Lower Footwall Beds" was subsequently refined, and six, informal units can be recognised (Minter et al., 1986). The upper parts of the Virginia Formation are eroded and truncated by the the unconformity at the base of the Beatrix Reef over much of the Beatrix Mine lease area.

The subdivision into the six, informal units which constitute the Virginia Formation is based on lithologic variations. The units have been labelled L.F. 1 to L.F. 6 in increasing order with depth (Fig. 8), and are described from the base upwards.

L.F. 6

The L.F.6 is the lowermost unit of the Virginia Formation. The change from the underlying, finer grained, Jeppestown Subgroup arenites at the base is transitional and coarsens upward into coarse-grained arenite with scattered small pebble layers. The first pebble layer mineralised with uranium and traces of gold (Ada-May or Beisa Reef) is taken as the base of the Virginia Formation (Minter et al., 1986). The L.F. 6 coarsens upward for 150 m above the Ada-May Reef to thin, small pebble lag layers and lithic arenites. The upper 10 m of the L.F.6 fine upwards and become less pebbly, and the top part is dominated by interbedded shale and siltstone. The appearance of shale beds marks the transition to the L.F. 5 unit.

L.F. 5

Although only 2 - 8 m in thickness the L.F. 5 forms a very useful marker as it is the only dark coloured shale or very fine-grained lithology in the Johannesburg Subgroup throughout the area south of the Sand River. The L.F. 5 is dominated by interbedded shale and siltstone which contains evidence of soft sediment deformation. An erosional surface truncates the top of the L.F. 5 and marks the transition to the L.F. 4.

L.F. 4

The L.F. 4 comprises a monotonous sequence of medium to coarse-grained lithic arenite 250 to 300 m thick. It characteristically contains angular granules and small pebbles of chert. The sequence fines upwards and the transition to the L.F.3 is arbitrarily taken at the point where the chert fragments are no longer conspicuous and the grain size of the arenites decreases.

L.F. 3

In the southwestern parts of Beatrix Mine the L.F. 3 forms the immediate footwall to the Beatrix Reef. The L.F. 3 varies in thickness from 100 to 300 m, and consists of medium - grained, grey coloured, sub-lithic arenite. The variation in thickness of the L.F. 3 interval is caused by the erosion and truncation of the upper part of the zone by the unconformity at the base of the Beatrix Reef. Quartz and coarse-grained quartzite are the predominant grains, comprising some 70% of the rock. Fine-grained (cherty) quartzite, quartz schist and fine-grained wacke grains are also common. The average grain size varies from 0,2 to 1,0 mm (medium sand). Scattered larger grains and small granules (4 mm) of quartz, chert and yellow silicified shale occur throughout, but are not common except in the lower parts of the zone where they rarely accumulate in granule or conglomeratic layers. The matrix material is sericitic with some metamorphic recrystallisation to muscovite.

L.F. 2

The L.F. 2 varies from 1 to 3 m in thickness and consists of grey, medium-grained quartz arenite, but is remarkably consistent throughout the area and forms a very useful marker bed. The quartz arenite is well-sorted and consists of subrounded quartz grains 0,2 to 1,0 mm (medium sand) in size. Sericite matrix, partly recrystallised to muscovite forms less than 5% of the rock. Dark grey, fine-grained silty material as partings on bedding features highlights crossbedding.

L.F. 1

The L.F. 1 forms the immediate footwall to the Beatrix Reef over most of the Beatrix Mine area. The thickness of the L.F. 1 varies from 0 - 90 m. The upper part of the unit is eroded and truncated by the unconformities at the base of the Aandenk and Eldorado Formations, and in the southwestern part of the lease area the L.F. 1 is completely removed.

The L.F. 1 consists predominantly of medium to coarse-grained, sub-lithic arenite with quartz and coarse-grained quartzite as the predominant grains forming some 60% of the rock. Fine-grained (cherty) quartzite and fine-grained quartz-schist grains are also fairly common. Other rock fragment grains such as muscovite-schist or fine-grained wacke (shale) form a minor component. The average grain size varies from 0,2 to 1,5 mm (medium to coarse sand) but granule size clasts up to 4 mm in length are common in parts. The matrix (20 - 25%) consists predominantly of sericite which documents alteration and secondary metamorphic recrystallisation to muscovite. The sericite matrix and fine-grained, yellow schist fragments impart a characteristic yellowish colour to the sediments. In spite of the high matrix content these rocks are classified as arenites and not wackes because of well developed sorting and stratification. In terms of the Witwatersrand quartzite classification scheme proposed by Law et al., (1989) this would place these rocks as arenites because of the evidence of deposition by traction currents.

The L.F. 1 coarsens upward from medium-grained arenite at the base to coarse-grained arenite which is conglomeratic in part. Conglomerates are polymictic and consist of sub-angular fragments (4 - 10 mm) of quartz, chert, yellow silicified shale and other rock fragments. Conglomerates are moderately packed and are usually less than 50 cm in thickness. The conglomerates do not generally occur on marked scour surfaces. Thin shaley beds up to 10 cm thick, comprising yellow-grey argillaceous or silty material are common, particularly in the lower parts of the zone.

2.4 AANDENK FORMATION (TURFFONTEIN SUBGROUP)

In the area south of the Sand River the Aandenk Formation thins rapidly towards the south because of truncation by the unconformity at the base of the Eldorado Formation (Fig. 5). On

Beatrix Mine only thin remnants of the Aandenk Formation occur below the Beatrix Reef or Eldorado Formation in the northeastern part of the Lease area (Fig. 7). Here the Aandenk Formation unconformably overlies the L.F. 1 unit of the Virginia Formation with a pronounced scour surface.

Because of the rapid southward thinning of formations due to erosion and truncation by successive, overlapping unconformities, problems exist with the correlation and nomenclature of the placers at the base of the Aandenk Formation in areas south of the Sand River. The detailed stratigraphy of the lower Turffontein Subgroup in the Welkom Goldfield north of the Sand River is illustrated in Figure 9.

By the early 1950's it was recognised that a major unconformity existed at the base of the "B" Reef (Spes Bona Formation) (Baines, 1949; Pritchard-Davies, 1952), and this was subsequently used as the division between the Johannesburg and Turffontein Subgroups (S.A.C.S., 1980). A significant break at the base of the "Big Pebble Marker" (B.P.M.) (Aandenk Formation) was also noted (Baines, 1949). Pritchard-Davies (1952), reporting on personal communication with Baumbach, noted the occurrence of a major "channel" of Big Pebble Conglomerate (B.P.M.) age eroding through 140 m of the succession, had removed the Basal and Leader Reefs on large portions of Merriespruit Mine (Pritchard-Davies, 1952). These "Channels" were subsequently documented by Winter (1964b) and correlated with the Aandenk Formation. Jordaan (1986) (incorrectly) places the B.P.M. as the terminal phase of the Spes Bona Formation and suggests that the Aandenk Formation paraconformably overlies the Spes Bona Formation. He does however

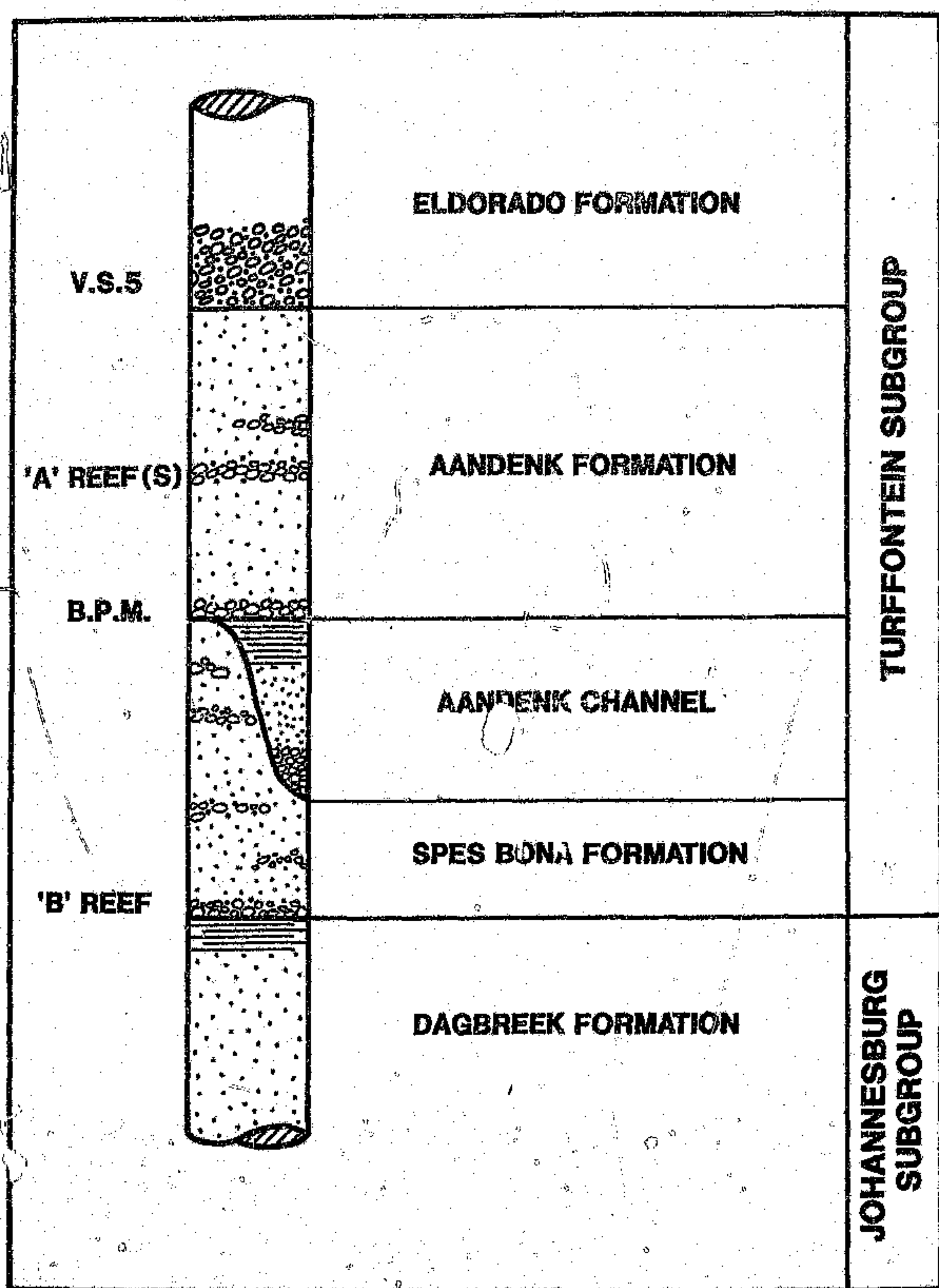

FIGURE 9: DETAILED STRATIGRAPHY OF THE LOWER TURFFONTEIN SUBGROUP IN THE WELKOM GOLDFIELD

admit that a placer can occur ......"occupying a locally developed, intraformational unconformity in parts of the basin." (Jordaan, 1986). Winter (1964); Bailey et al. (1989) and this study have shown that the Aandenk Channel, at the base of the Aandenk Formation, unconformably overlies the Spes Bona Formation, and in fact erodes channels with considerable relief into the underlying lithologies. The Aandenk Channel may completely remove the Spes Bona Formation and parts of the Dagbreek Formation in some areas of St Helena and Merriespruit Mines. Bailey et al. (1989) have further shown that the B.P.M. overlies the Aandenk Channel (or the Spes Bona Formation in areas where the Channel is not developed). The Big Pebble Marker (B.P.M.) is therefore taken as the base of the Aandenk Formation per se (Bailey et al., 1989). In the extreme areas south of the Sand River (Beatrix Mine area) the placers at the base of the Aandenk Formation can therefore be correlated with the B.P.M.

A thin, quartz pebble lag conglomerate invariably occurs on the scour surface. Overlying this thin basal lag conglomerate the Aandenk Formation consists of lithic arenite to sub-lithic arenite very similar in appearance and mineralogy to the L.F.1 arenites.

Subrounded quartz and quartzite clasts are the predominant component forming some 70% of the rock. Schist clasts are however much less common than within the L.F.1. Clasts vary in size from 0,2 to 1,5 mm (medium sand). The matrix (15 - 20%) consists of sericite with some metamorphic recrystallisation to muscovite. Again, in spite of the relatively high matrix content, these rocks are classified as arenites in terms of the classificaton proposals of Law et al., (1989), because of the well developed stratification features and sorting as evidence of deposition by traction currents. In parts, especially where the conglomerate layer becomes thicker and better developed, the Aandenk Formation arenites are much "cleaner" and quartz grains form over 80% of the rock with the matrix content dropping to less than 10%.

2.5 BEATRIX REEF

The Beatrix Reef unconformably overlies the Virginia Formation (and Aandenk Formation) in the Beatrix Mine area. It is in turn overlain by the Eldorado Formation, apparently disconformably as there is no marked large scale angular discordance between the Beatrix Reef and the overlying Eldorado. Local scouring of the Beatrix Reef by the Eldorado Formation, and a marked lithological facies change suggest a disconformable relationship. The Beatrix Reef varies from a very thin unit (less than 1 cm) to a maximum thickness in the order of 3 m. In parts the Beatrix Reef has been completely removed by the Eldorado Formation.

In terms of the International Subcommission on Stratigraphic Classification's proposals (Johnson and Rust, 1988), the Beatrix Reef would be considered a Miosynthem --- " a relatively local and minor unconformity-bounded unit within a Synthem " (the Eldorado Formation) (Johnson and Rust, 1988). In terms of sequence stratigraphic classification (tectonostratigraphy) each package of sediment between unconformities represents a para-sequence or sequence.

The South African Committee for Stratigraphic Nomenclature

(1980) makes no mention of the Beatrix Reef in their proposals on stratigraphic classification in the Welkom Goldfield. In the mining area the Beatrix Reef is recognised as an individual entity between unconformities. It is thus proposed that the Beatrix Reef be accorded status as a separate sequence (Formation ?), or at least be correlated as a separate member of the Eldorado Formation.

The nature of the unconformity surface at the base of the Beatrix Reef was mapped out in detail in the underground workings at No. 2 Shaft at Beatrix Mine. In this area the L.F. 1 unit of the Virginia Formation is relatively thin and all footwall development is situated within the L.F. 3. Routine diamond prospect and evaluation drilling thus intersects the full, preserved sequence of the L.F. 1. The angular relationship of the unconformity between the Beatrix Reef and the Virginia Formation was determined by using isopachs of the L.F. 1 between the unconformity at the base of the reef and the L.F. 2 marker to quantify the degree of truncation (Fig. 10). The isopachs show a pronounced west-northwesterly to east-southeasterly trend and confirm an angular relationship between reef and footwall beds of just over two degrees (Fig. 10). On a local scale the unconformity surface displays considerable relief of up to two metres due largely to small scale erosional scouring and channeling by the Beatrix Reef (Figs. 11a and 11b).

The Beatrix Reef comprises a thin sequence of oligomictic conglomerates and quartz arenites with significant concentrations of detrital heavy minerals, particularly pyrite. It rarely exceeds 3 m in thickness and is usually 1 - 2 m thick. The

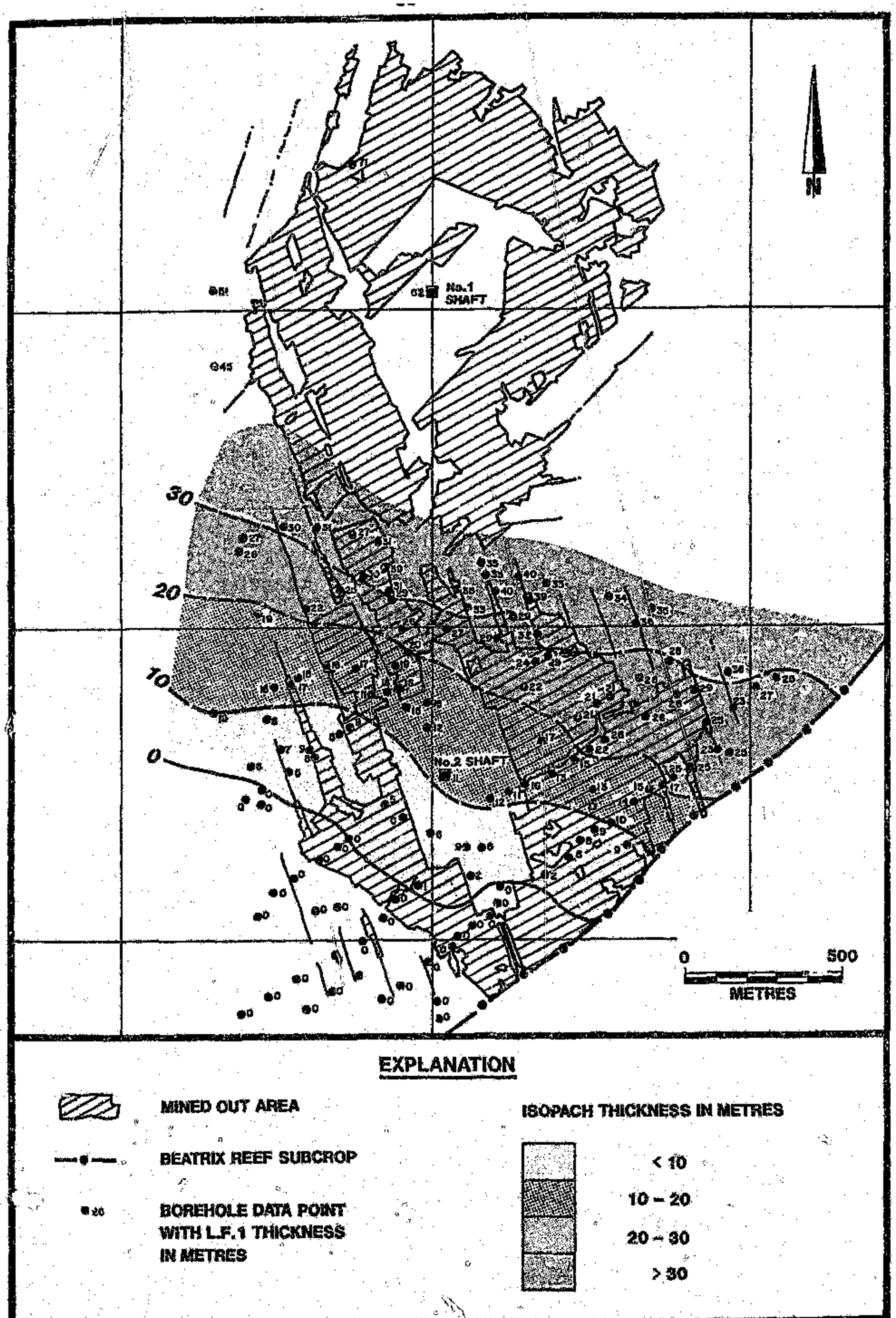

FIGURE 10 : L.F.1 ZONE ISOPACHS AT No.2 SHAFT, BEATRIX MINE

FIGURE 11a: PRONOUNCED CHANNEL SCOURS AT THE BASAL CONTACT OF THE BEATRIX REEF

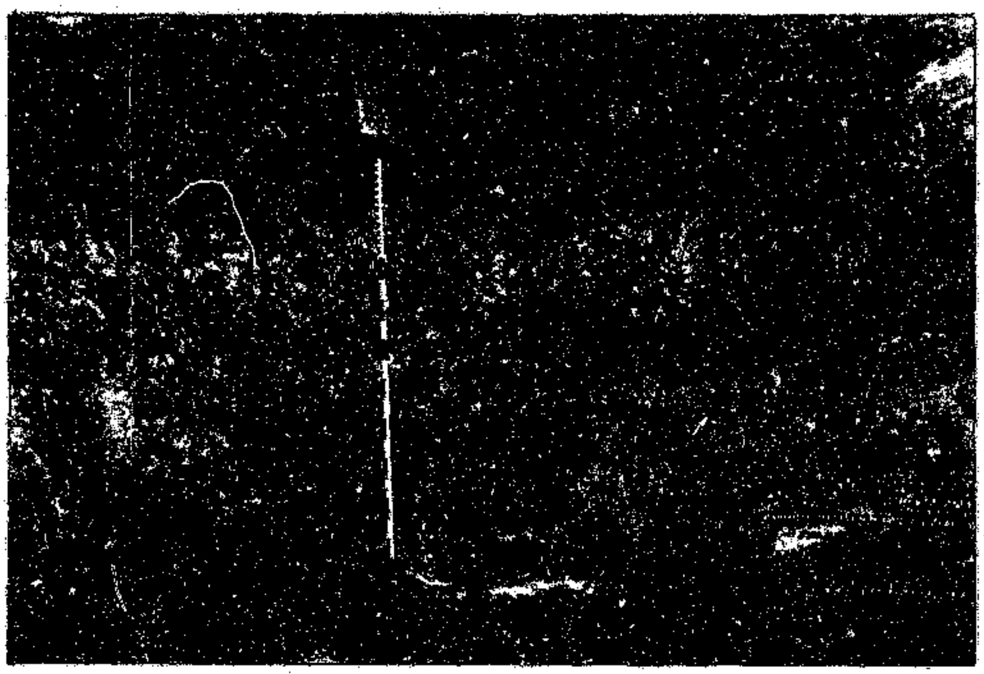

FIGURE 11b: A DEEPLY INCISED CHANNEL EDGE FEATURE AT THE BASE OF THE BEATRIX REEF

oligomictic conglomerate layers are frequently overlain by a dark grey to black "diamictite" containing unsegregated quartz pebbles or polymictic clasts with black shaly material. These layers grade upwards to black shale laminae up to 10 cm thick or to fine-grained, polymictic lithic wackes, and mark the transition to the overlying Eldorado Formation.

2.6 ELDORADO FORMATION (TURFFONTEIN SUBGROUP)

Borchers and White (1943) were among the first workers in the Orange Free State Goldfields to propose a subdivision of the "Ventersdorp Sediments" into 5 zones, designated V.S. 1 - V.S. 5. This early zonation was based largely on lithological characteristics and the relative abundance of conglomerate beds. Baines (1949) correlated these "Ventersdorp Sediments" with the upper Elsburg Series, a correlation carried through by Coetzee (1960) who proposed that they be named the Elsburg Stage of the Kimberley - Elsburg Series to fit with Mellor's (1917) subdivision of the upper Witwatersrand. The subdivision V.S 1 - V.S. 5 (Borchers and White, 1943) was, however, retained by all workers (Baines, 1949, Pritchard-Davies, 1952, Winter, 1957 and Coetzee, 1960).

During the first exploration drilling in the Beatrix area during the late 1960's and early 1970's, it was recognised that a stratigraphic zoning of the sediments of the upper parts of the Witwatersrand Supergroup below the Ventersdorp lavas could be equated with that in the Welkom area in spite of the marked lithological differences caused by facies changes.
Pritchard-Davies (1952) first recognised that significant

differences in facies occurred within the "Ventersdorp Sediments" with conglomerate more abundant in the west and the succession comprising almost entirely quartzite in the east. The Eldorado Formation in the Beatrix area was subdivided into four members labelled V.S. 1a to V.S. 4a (Fig. 8) based broadly on the subdivision V.S. 1 to V.S. 5 first introduced by Bancroft for the "Ventersdorp Sediments" in the Welkom Goldfield (Borchers and White, 1943 and McKeown, 1945). The suffix "a" was introduced by Union Corporation geologists working in the area to emphasise the lithological difference between the Eldorado Formation in the areas south of the Sand River to that of the Welkom Goldfield. It was also thought that the V.S. 5 conglomerate was not developed and hence the subdivision into only four units (Fig. 12).

Subsequently the South African Committee For Stratigraphic Nomenclature (1980) has suggested the subdivision of the Eldorado Formation into three formal members viz. Rosedale Member, Van Den Heeversrust Member and Uitkyk Member (Figs. 8 and 12). This zonation into members is based on type sections from the Welkom and Loraine areas. However, facies changes to predominantly arenaceous sequences in the area southeast of the Sand River make it difficult to reconcile the accepted zonation of four units (V.S. 1a - V.S. 4a) used on Beatrix Mine and in the area south of the Sand River with the new Members (Fig. 12).

In this study the subdivision into four distinct units, viz. V.S. 1a, V.S. 2a, V.S. 3a and V.S. 4a, is retained for the description of the stratigraphy of the Eldorado Formation in the Beatrix Mine area. The nomenclature proposed by S.A.C.S. (1980)

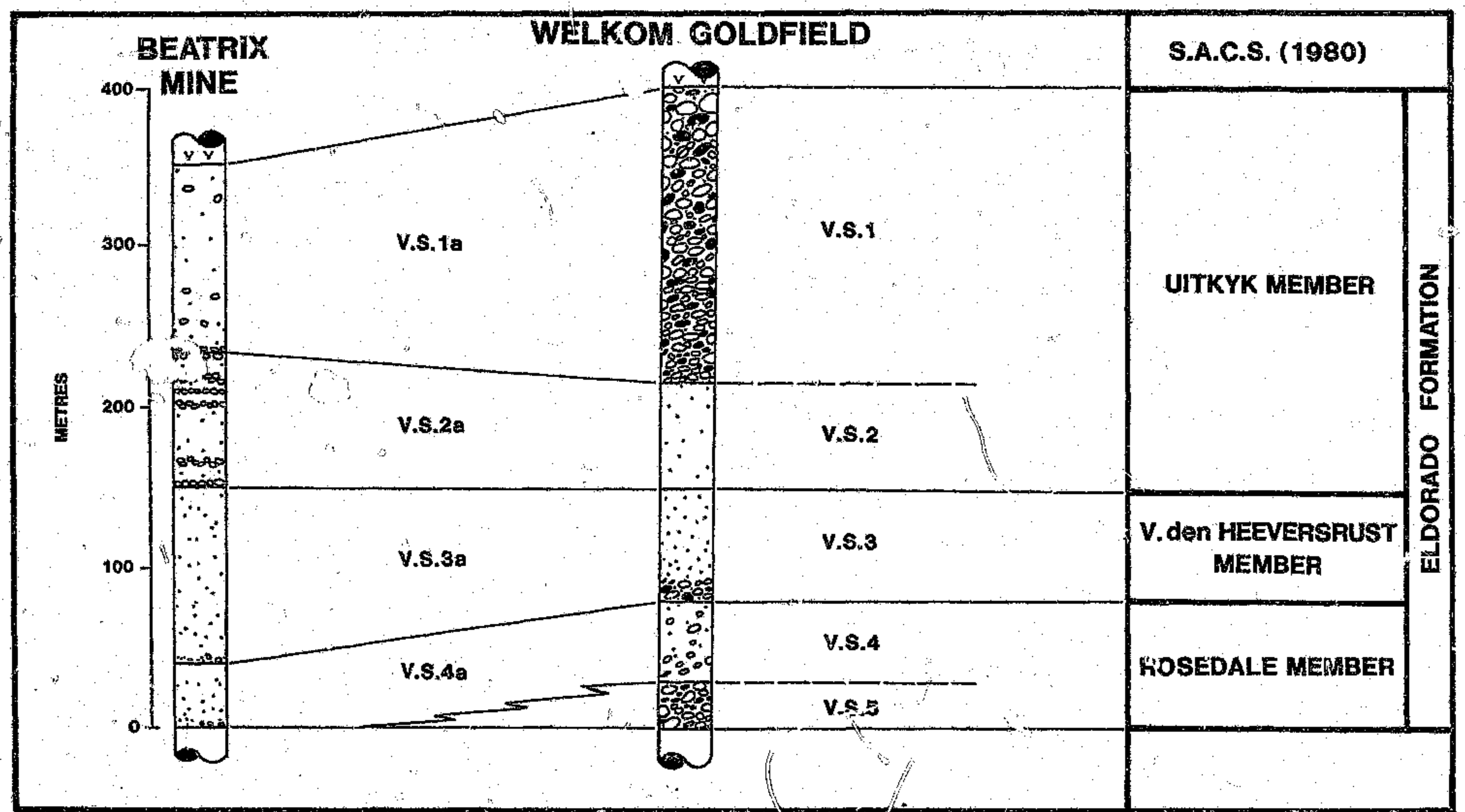

FIGURE 12 : CORRELATION OF THE ELDORADO FORMATION STRATIGRAPHY BETWEEN BEATRIX MINE AND THE WELKOM GOLDFIELD

(Rosedale, Van Den Heeversrust and Uitkyk Members) is also included for correlation (Figs. 8 and 12).

The Eldorado Formation comprises a succession of lithic arenites and conglomerates in an overall coarsening-upward sequence about 300 m thick. Because of pre-Karoo erosion the full thickness of the succession is only preserved in the northwestern parts of the Mine Lease area (Fig. 13). The upper members are truncated towards the south and southeast by the pre-Karoo erosion.

The isopach pattern of the Eldorado Formation south of the Sand River (Fig. 13) is dominated by a north-northeasterly trending zone of thin Eldorado Formation. Much of this thinning may be due to shortening of the succession by major easterly or westerly downthrow faulting but, because the isopach maps were constructed from summary information supplied by other companies, it is not possible to quantify the thinning or exclude the data. The thickest Eldorado Formation occurs in a broad trough along the eastern edge of the area, just west of Merriespruit Mine (Fig. 13). The thick Eldorado Formation along the western margin on Beisa Mine (Fig. 13) is due to duplication of the succession associated with thrust faulting and folding in the overturned limb of the Western Margin Structure.

The Eldorado Formation shows a distinct change from the underlying formations in terms of mineralogy and chemistry (Law,1990). The Eldorado Formation lithologies are enriched in FeO, MnO and MgO relative to the underlying formations and this is reflected in the stability of chlorite and chloritoid as the dominant phyllosilicates. The rocks are also enriched in Cr, Co,

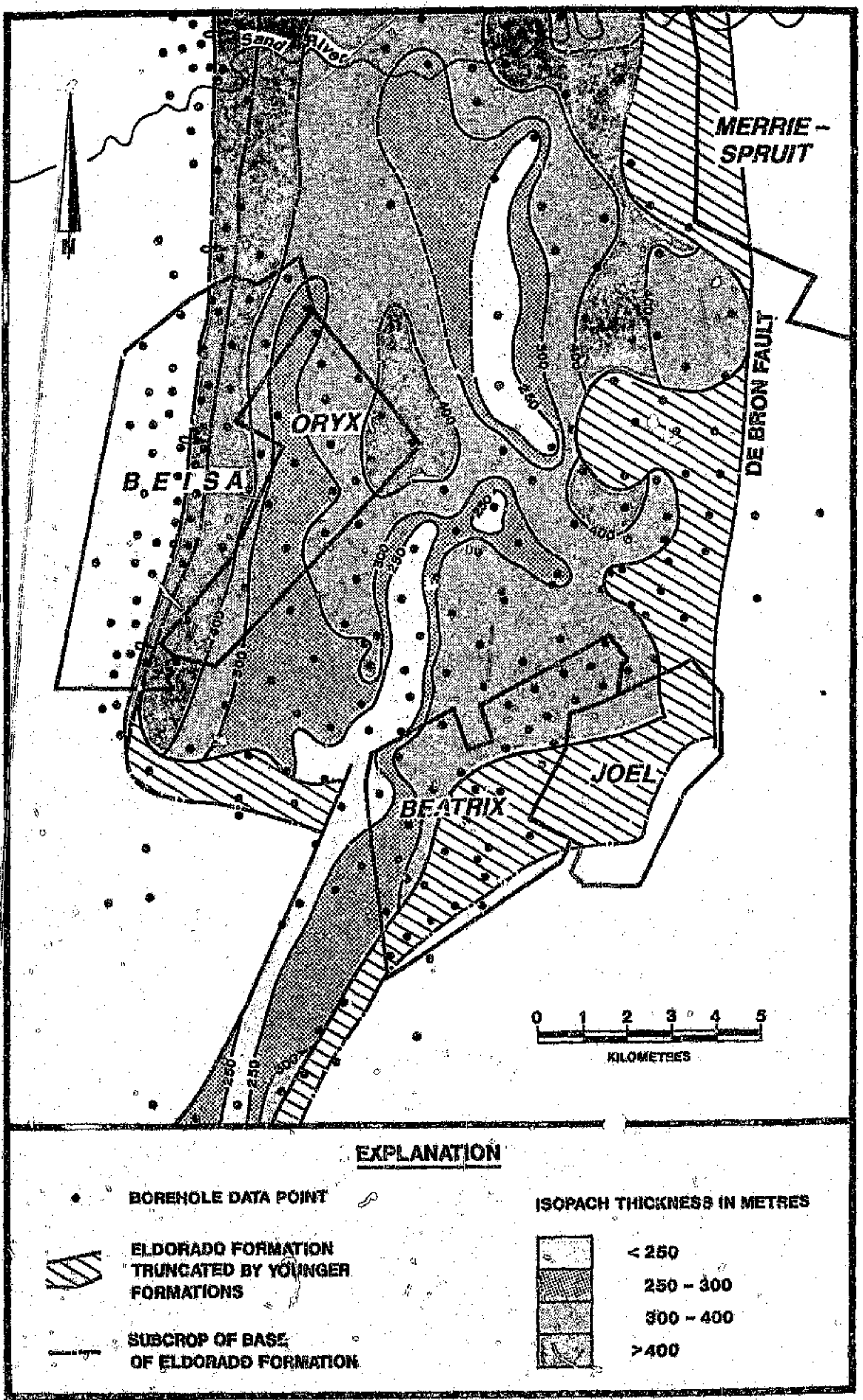

FIGURE 13: ELDORADO FORMATION ISOPACHS

Ni and Cu, probably in the chlorite (Law, 1990).

Based essentially on grain size variation and abundance of conglomerate the Eldorado Formation is subdivided into four distinct zones informally named V.S.1a to V.S.4a in increasing order with depth (Figs. 8 and 12). These zones are described from the base upward.

ROSEDALE MEMBER (V.S. 4a)

The basal 30 m of the Eldorado Formation is termed the Rosedale Member (Fig. 8), and comprises an upward-fining sequence of lithic arenites with conglomerates at the base. It correlates with the old V.S. 4 and V.S. 5 Zones of Borchers and White (1943). In the Beatrix Mine area where no robust V.S. 5 conglomerate is developed the Rosedale Member is taken to comprise the V.S.4a zone, although this may, in places contain a basal, small pebble lag conglomerate.

The Rosedale Member forms the immediate hangingwall to the Beatrix Reef and the basal few metres are thus frequently exposed in the underground workings on the mine. Rapid facies changes result in a wide range of lithologies in the basal parts of the Rosedale Member with a mixed sequence of black shale, black diamictite, polymictic, granule-grade conglomerate and lithic arenite being the most common. The Rosedale Member fines upward from lithic arenite to dark-grey or black, fine-grained lithic arenite and shale which marks the top of the Member. Conglomerates are rare and occur mainly as granule-grade conglomerate beds in the lower parts of the Member. In areas to the north of Beatrix Mine a robust, medium- to large-pebble, polymictic conglomerate (V.S. 5), up to 3 m thick, is present at the base of the Member, but due to facies changes is not developed in the Beatrix Mine lease, except as local, isolated channels.

Quartz and quartzite are the predominant component (50% - 80%) varying in grain size from 0,05 mm (in shales) to over 4 mm in the coarser grained zones. Other clasts such as siltstone, silicified yellow and grey shale and schist clasts are also common. The matrix material (5% - 10%) is of similar composition to the grains and merely of a much finer grain size. Sericite and chlorite are also fairly common in the matrix.

VAN DEN HEEVERSRUST MEMBER (V.S. 3a)

The Van Den Heeversrust Member comprises the middle 120 m of the Eldorado Formation and consists of a monotonous sequence of upward-coarsening lithic arenite. The base of this Member displays an erosional contact with the Rosedale Member and is occasionally defined by a thin, granule-grade conglomerate. In the basal part of the zone thin, black shaly or silty laminae are common, but decrease in frequency upwards as the arenites become coarser grained. Towards the top of this member polymictic granule-grade conglomerates become more prevalent. Clasts are generally angular to sub-rounded and consist predominantly of quartz, chert, silicified shale and other rock fragments. The lithic arenites are interbedded with more mature sub-lithic arenites, but don't reach the maturity of quartz arenites. Fine-grained, rounded pyrite grains frequently concentrate on foreset laminae in the more mature arenites.

THE UITKYK MEMBER (V.S.2a.)

The Uitkyk Member as defined by S.A.C.S. (1980) comprises the uppermost 200 m of the Eldorado Formation. In the area south of the Sand River and east of the Western Margin Structure two fairly distinct stratigraphic intervals are recognised based on the presence or absence of conglomerates.

The basal part of the Uitkyk Member, colloquially called the V.S. 2a Zone, form an essentially conglomeratic unit approximately 80 - 100 m thick and is correlated with the EA Zone (Kingsley, 1987). In the area north of the Sand River and close to the Western Margin Structure no subdivision is possible as here the Uitkyk Member comprises large pebble or boulder conglomerates.

The V.S. 2a Zone characteristically contains well-packed small-pebble conglomerate beds interbedded with sub-lithic arenites. The conglomerates show a tendency to have a larger average clast size in the conglomerates nearer the top of the member. Both oligomictic and polymictic conglomerate occurs within the V.S. 2a Zone. The small-pebble, polymictic conglomerates comprise moderately packed beds up to 30 cm thick. Clasts are sub-rounded and consist of vein quartz, chert, silicified shale and quartzite. The oligomictic conglomerates occur in moderate- to well-packed beds up to 25 cm thick. Clasts are moderately- to well-rounded and consist of vein quartz up to 3 cm in size. Rounded pyrite grains are common associated with the oligomictic conglomerates. The contact between the V.S. 1a and V.S. 2a is arbitrarily taken at the last well developed conglomerate bed.

THE UITKYK MEMBER (V.S.1a.)

The upper portion of the Uitkyk Member, although not rec ...sed as a separate member by SACS (1980), is sufficiently different in the Beatrix and other areas to be separated from the underlying conglomeratic unit. It consists predominantly of a lithic wacke or lithic arenite with scattered pebbles up to 5cm in size. The pebbles consist of vein quartz, chert, quartzite and silicified shale randomly scattered in a medium to coarse-grained arenite or lithic wacke. The sediment has a characteristic greenish colour, particularly towards the top of the member where it is overlain by lavas of the Klipriviersberg Group.

2.7 THE VENTERSDORP SUPERGROUP

The Ventersdorp Supergroup in the area south of the Sand River comprises a lower, essentially volcanic, Klipriviersberg Group unconformably overlain in the east by an essentially sedimentary Platberg Group.

Post Klipriviersberg faulting and pre-Karoo erosion have resulted in the Ventersdorp Supergroup having restricted distribution and preserved thickness (Fig. 14).

Andesitic lavas (Pillay, 1986) of the Klipriviersberg Group form the lowermost units of the Ventersdorp Supergroup and overlie the Witwatersrand sediments in the northernmost parts of Beatrix Mine (Fig. 14). These lavas are truncated in the south by pre-Karoo erosion.

Intense, Post Klipriviersberg Group tectonic activity resulted in the formation of horst and graben topography in the area south of the Sand River. The De Bron fault forms the western flank of a

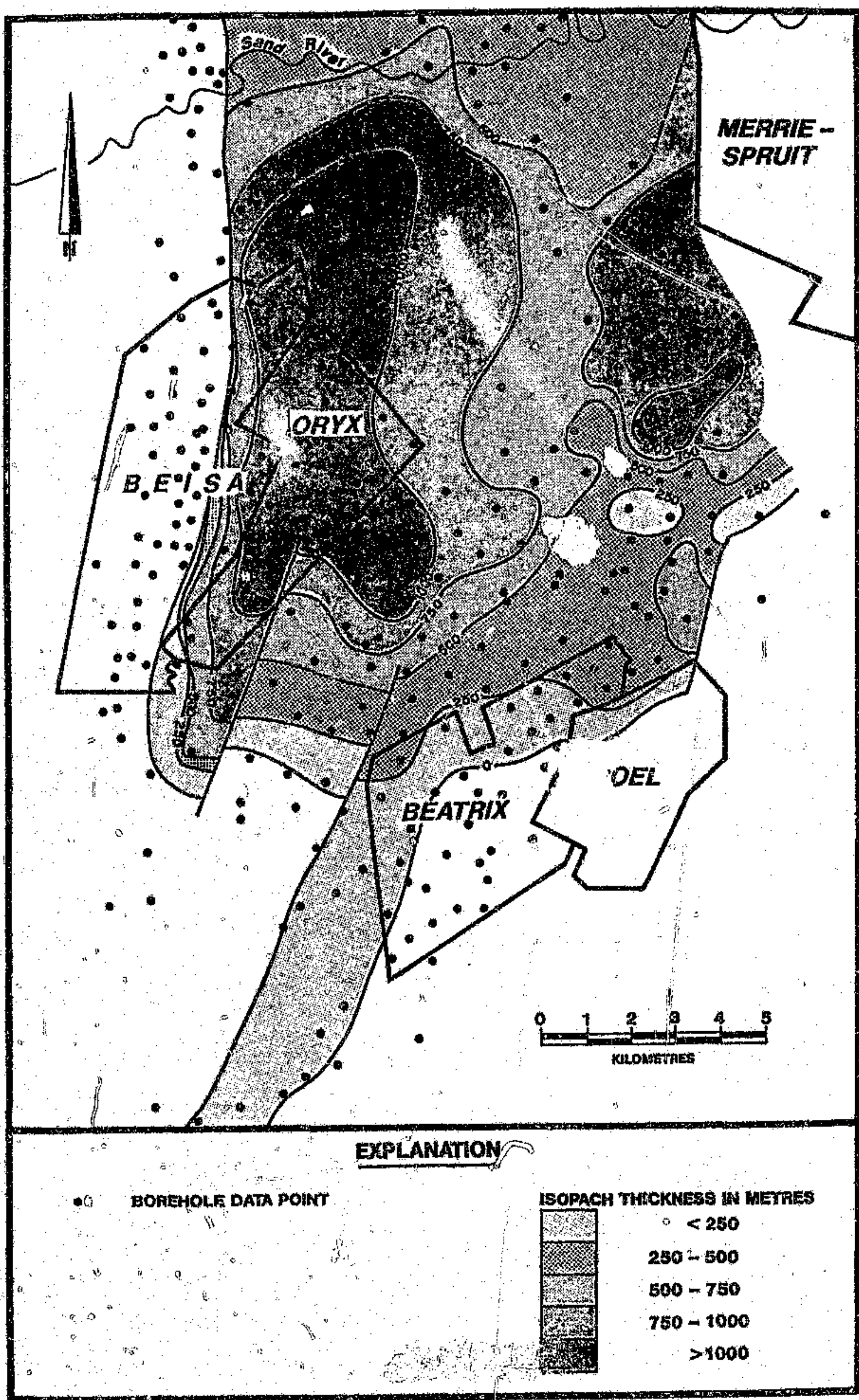

FIGURE 14: VENTERSDORP SUPERGROUP ISOPACHS

horst block dominating the eastern edge of the goldfield (Fig.15) Clastic debris eroded from the horst block along the fault scarp was transported and deposited as clastic wedges of sediment deposited by alluvial fans into the graben. These Platberg Group clastic deposits, which are locally known as the Klippan Formation in the area south of the Sand River (Meintjies, 1988), thicken eastwards towards the De Bron fault scarp (Fig. 15). In parts erosion by fluvial systems during Klippan Formation sedimentation has resulted in incision into the underlying Klipriviersberg Group and Turffontein Subgroup. This resulted in truncation of parts of the Eldorado Formation along the western flank of the De Bron fault (Fig. 13). The Klippan Formation sediments show rapid facies variation from coarse, polymictic boulder conglomerates close to the fault scarp to black shales and fine-grained lacustrinal facies in the more distal areas. (Meintjies, 1988).

2.8 THE KAROO SEQUENCE

Flat lying sediments of the Permo-Triassic Karoo Sequence blanket the whole area of the Welkom Goldfield. The thickness of the Karoo Sequence in the area south of the Sand River varies from less than 350 m thick in the west to just over 1000 m thick in the east (Fig. 16). The surface is currently fairly flat at an average elevation of 1380 m above sea level and the variation in Karoo thickness is due to pre-Karoo faulting and Dwyka glaciation and erosion. The pre-Karoo topography resulting from this glacial erosion to a large extent reflects the lithology of the underlying Archaen rocks. The Witwatersrand quartzites in the

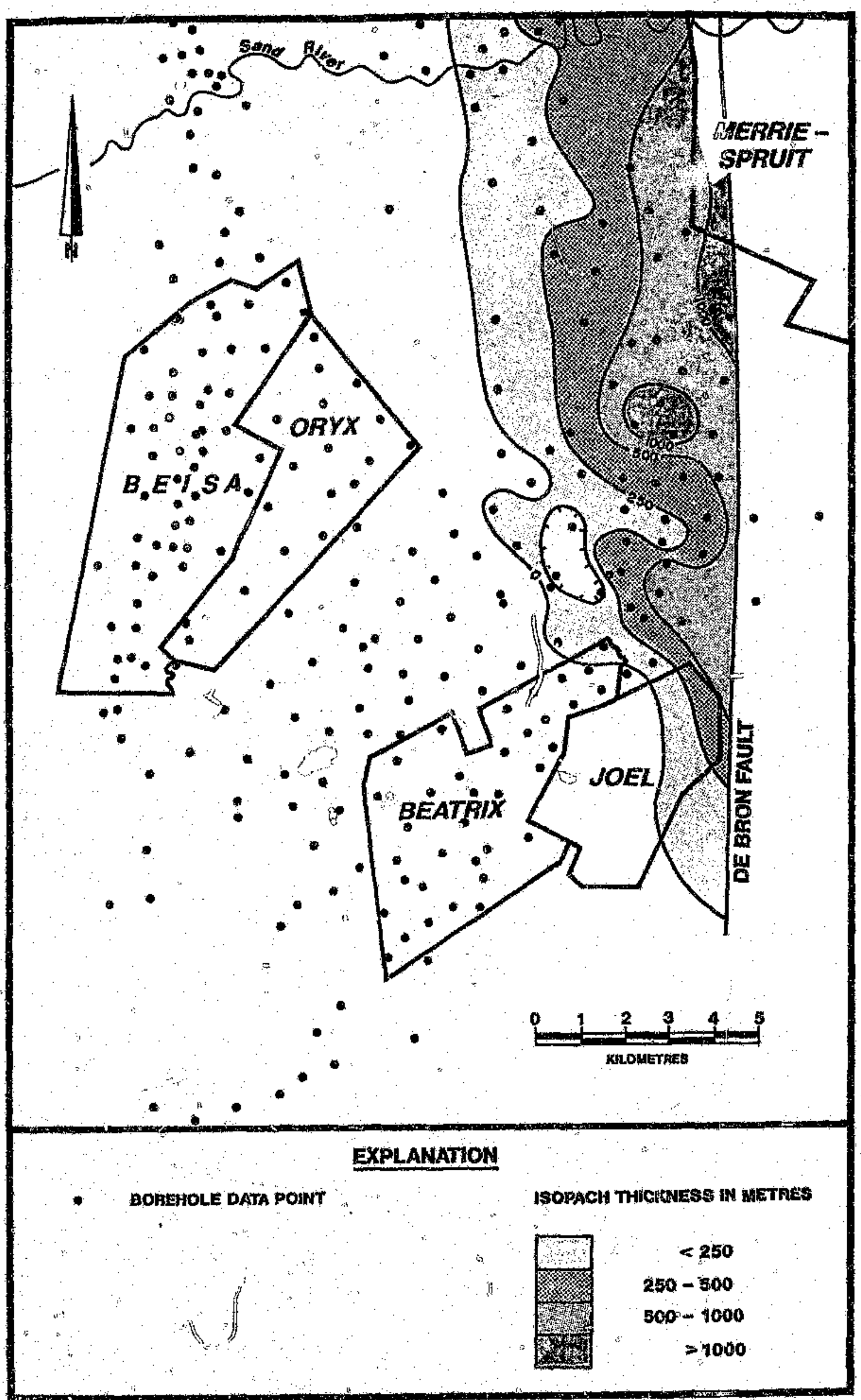

FIGURE 15: KLIPPAN FORMATION ISOPACHS

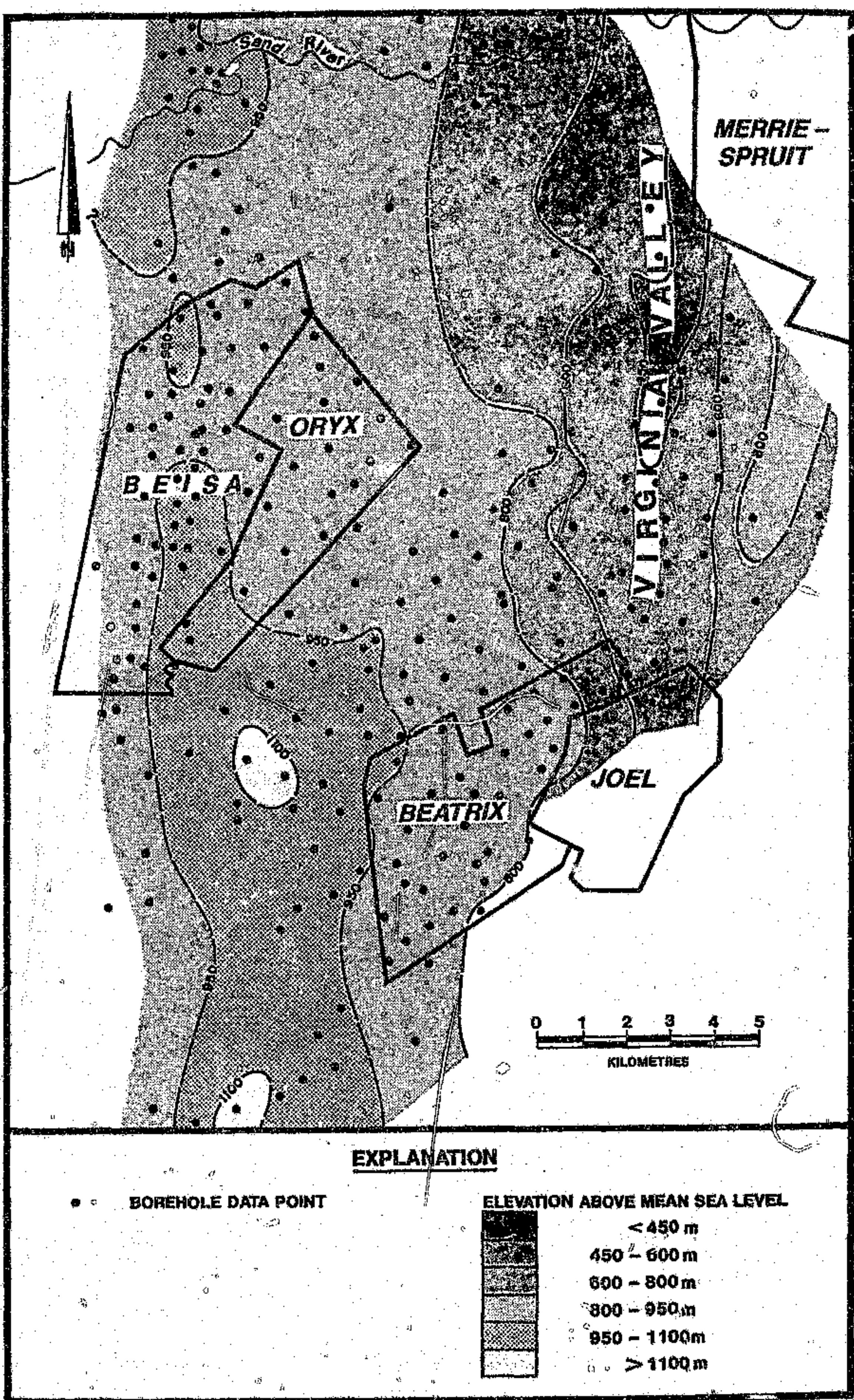

FIGURE 16: BASE OF KAROO SEQUENCE TOPOGRAPHY

overturned Western Margin Structure form a resistant ridge and are covered by a thin sequence of Karoo sediments. In contrast, the softer sediments of the Klippan Formation along the De Bron fault have acted as the locus for a deeply incised glacial valley, colloquially known as the Virginia Valley (Visser and Kingsley, 1982). The Virginia Valley is filled with Dwyka- aged fluvially reworked glacial outwash material up to 350 m thick giving a total Karoo Sequence thickness in excess of 1000 m (Fig. 16).

Overlying the Dwyka Formation the remainder of the Karoo Sequence comprises alternating sandstones and shales of the Vryheid Formation and a thick succession of shales of the Volksrust Formation. These three formations (Dwyka, Vryheid and Volksrust) constitute the Ecca Group in this area.

3 SEDIMENTARY FACIES OF THE BEATRIX AREA

3.1 INTRODUCTION

There is a distinct difference between the lithologies comprising the Beatrix Reef and the overlying Eldorado Formation in terms of their mineralogy and chemistry (Law, 1990). Sedimentary facies in the Beatrix Reef and the Eldorado Formation may thus be similar in grain size and sedimentary structures, but are lithologically different and could therefore represent different depositional models. For this reason the facies of the Beatrix Reef and the Rosedale Member (Eldorado Formation) are described separately.

Pebble form indices are thought to be useful diagnostic environmental indicators (Dobkins and Folk, 1970 and Stratten, 1974). Pebble size and shape data are thus presented separately for the Beatrix Reef conglomerates. Other factors such as Beatrix Reef isopachs, bed lenticularity and pebble segregation data which may be environmentally diagnostic is also included in this chapter.

3.2 FACIES AND THE FACIES MODEL CONCEPT

The concept of facies has been used ever since geologists and miners recognised that features found in particular rock units were useful in correlation and the prediction of mineral deposits. The ambiguity and arguments regarding the use of the term "facies" have been summarised in recent sedimentological publications (eg. Reading, 1978; Walker, 1979 and Miall, 1984). A facies is a body of rock with specified characteristics which, in the case of sedimentary rocks, is defined on the basis of colour, bedding, composition, texture, fossils and sedimentary structures (Reading, 1978). It should thus refer to an objectively described rock unit. Reading (1978) and Miall (1984) have noted that the term facies is however used in many different senses:

- in the strictly observational sense of a rock product, eg "sandstone facies"
- in a genetic sense for the products of a process, eg. "turbidite facies"
- in an environmental sense for the environment in which the rocks are formed, eg. "fluvial facies"
- in a tectonic sense, eg. "post-orogenic facies"

A facies should ideally be a distinctive rock that forms under certain conditions of sedimentation reflecting a particular process or environment (Reading, 1978). Although it is understood that facies will ultimately be given an environmental interpretation, many, if not most, have ambiguous interpretations. The key to interpretation is to analyse all of the facies communally (Walker, 1979) and the sequence in which they occur contributes as much environmental information as the facies themselves.

Facies models aim to provide a general summary of a specific sedimentary environment (Walker, 1979). Allen (1963, 1964, 1965) established the classic upward-fining point bar depositional model demonstrating the use of facies sequences in defining facies models. Allen (1970a) voiced the need for a quantitative basis for facies modelling procedures and proposed tree-diagram analysis of actual facies transitions as a means to evaluate the probability of certain sequences being found. Miall (1973) used Markov analysis to differentiate between actual and predicted upward facies transitions, thereby deriving the most likely sequence of occurrence of a set of facies. The introduction of lithofacies coding schemes (Miall, 1977) enabled comparable models to be constructed for a wide range of fluvial depositional environments. Miall (1978) and Rust (1978) proposed six facies models for the braided river environment, but as field research continues it appears that each new situation demands a new facies model (Miall, 1985), thereby negating the synthesizing role of the facies model concept. The utility of facies models is limited mainly by their inherent one-dimensional approach. Recent methods have turned to three-dimensional models wherein the architecture of a depositional body is evaluated in terms of the shape of the larger-scale geometry (eg. Miall, 1985, 1987; Ethridge et al., 1987). Facies modelling procedures however remain widely used, particularly in circumstances where three-dimensional exposure is limited, and have been used in this study.

3.3 LITHOLOGIC AND SEDIMENTARY FACIES OF THE BEATRIX REEF

3.3.1 INTRODUCTION

At Beatrix Mine the Beatrix Reef, in the mining sense, is taken to be the conglomerate and interbedded arenite deposited on the unconformity surface overlying the Virginia Formation. The upper contact of the Reef is taken as the scour surface at the base of the first dark-grey lithic arenite/wacke, or at the base of the first black argillite parting. As such the Beatrix Reef zone, in the definition used on the mine, incorporates the conglomeratic remnants of the Aandenk Formation, which occur in the northeastern part of the mine, the Beatrix Reef per se, and the V.S.5 conglomerate which is sporadically developed at the base of the Eldorado Formation. Conglomerates of the different formations are, however, easily distinguished and in this study the investigation has concentrated on the Beatrix Reef per se and its relationship to the facies at the base of the Eldorado Formation.

Three distinct associations of lithologic, conglomerate facies are recognised in the Beatrix Mine area, based on variations in the clast assemblages and matrix lithology. The three conglomerate facies associations equate with the three Turffontein Subgroup formations represented on the mine, viz. Aandenk Formation, Beatrix Reef proper and Eldorado Formation (V.S. 5). Facies associations of the Eldorado Formation are further discussed in Section 3.4.

The Beatrix Reef proper consists of oligomictic quartz-pebble conglomerates and quartz arenites and a number of facies are defined based on the dominant sedimentary structures and the conglomerate to arenite ratio.

3.3.2 "A" FACIES CONGLOMERATE (AANDENK FORMATION)

The "A" Facies conglomerate is characterised by oligomictic medium quartz-pebble conglomerates with a distinctly yellow (sericitic), quartz sublithic arenite matrix (Fig. 17).

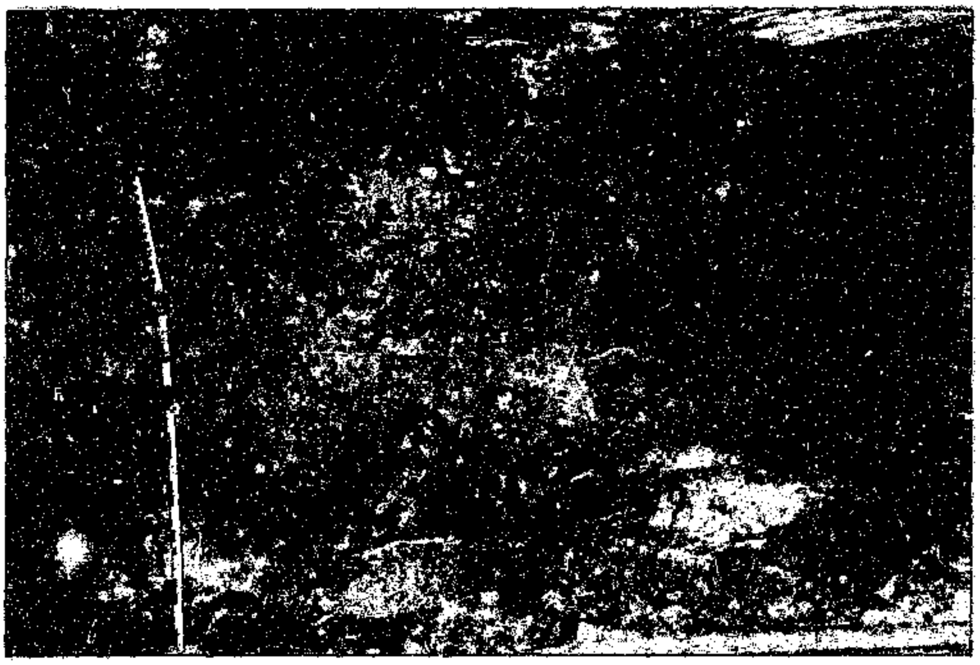

FIGURE 17a: "A" FACIES REEF. NOTE THE CHARACTERISTIC YELLOW-GREY MATRIX.

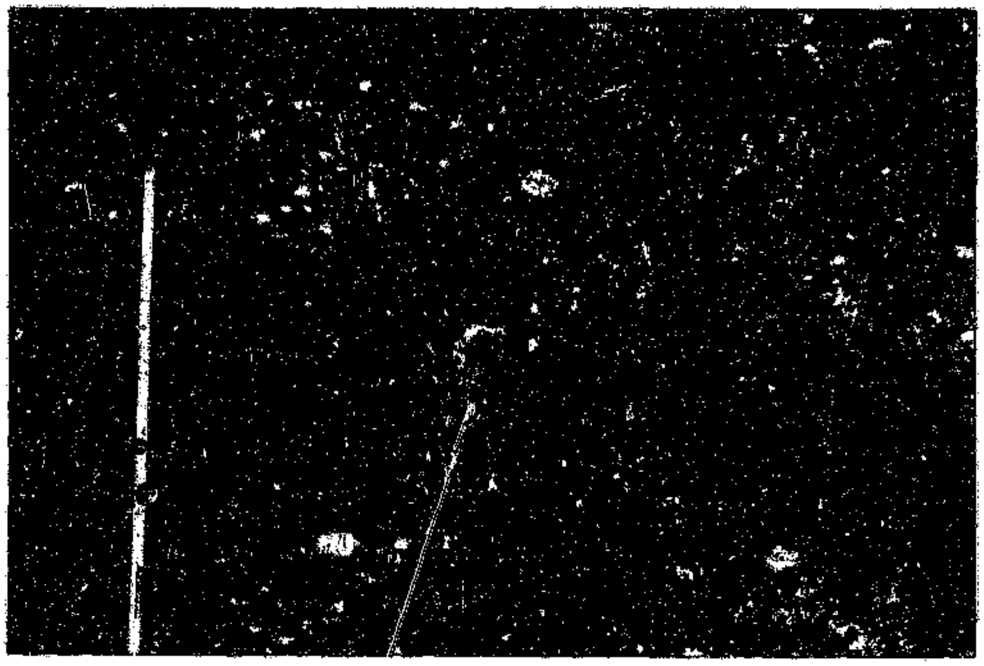

FIGURE 17b: "A" FACIES REEF

FIGURE 17: "A" FACIES REEF

Although the conglomerates are oligomictic, yellow silicified "shale" fragments are fairly common and distinctive. Well-packed, clast-supported conglomerate and very poorly-packed, matrix-supported pebbly arenite form two distinct end-member subfacies, but variations between the two end-members are gradational. These "A" Facies conglomerates are very similar to the Aandenk Formation placers such as the Big Pebble Marker or the "A" Reef of the Welkom Goldfield in appearance. The "A" Facies Reef is confined to the northern parts of Beatrix Mine where it has been intersected during stoping in the northeastern parts of Number 1 Shaft (Fig. 18). The distribution of the "A" Facies reef shown on Fig. 18 coincides with the inferred distribution of the Aandenk Formation, confirming that the "A" Facies represents remnants of the Aandenk Formation preserved beneath the unconformity at the base of the Beatrix Reef. In places where the Beatrix Reef per se and the "A" Facies reef occur together, the normal Beatrix Reef overlies the "A" Facies.

3.3.3 OLIGOMICTIC CONGLOMERATE FACIES (BEATRIX REEF)

The Beatrix Reef proper is characterised by small to medium oligomictic, quartz-pebble conglomerates with a grey quartz-arenite matrix (Fig. 19) and occurs throughout the mine area. Well-packed, clast-supported conglomerate (Fig. 19a) and very poorly-packed, matrix-supported pebbly arenite (Fig. 19b) again form two distinct end-member subfacies. The variation between these subfacies is gradational.

The conglomerates are oligomictic and more than 98 % of the

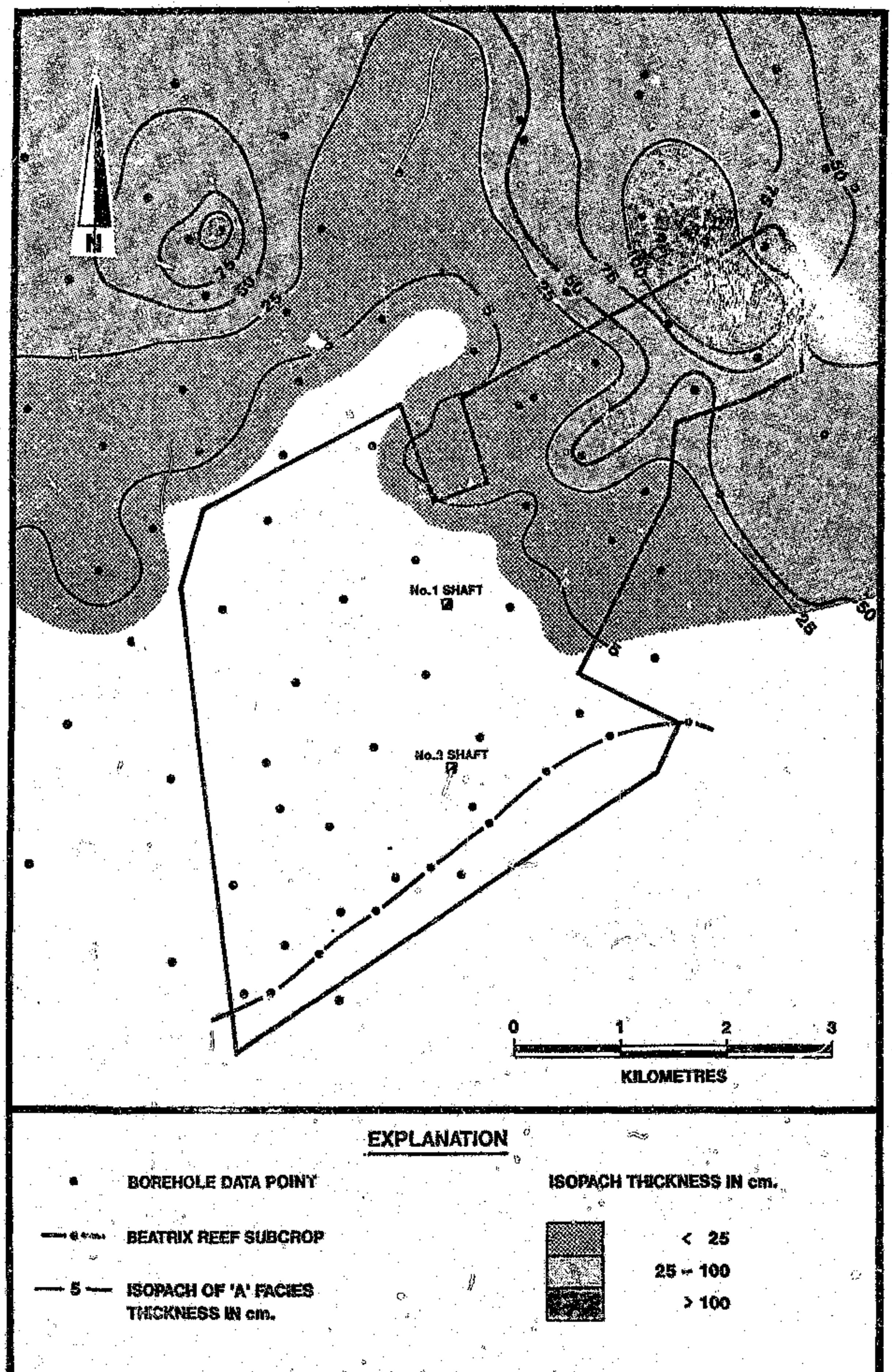

FIGURE 18: 'A' FACIES REEF (AANDENK FORMATION) ISOPACHS IN THE BEATRIX MINE AREA

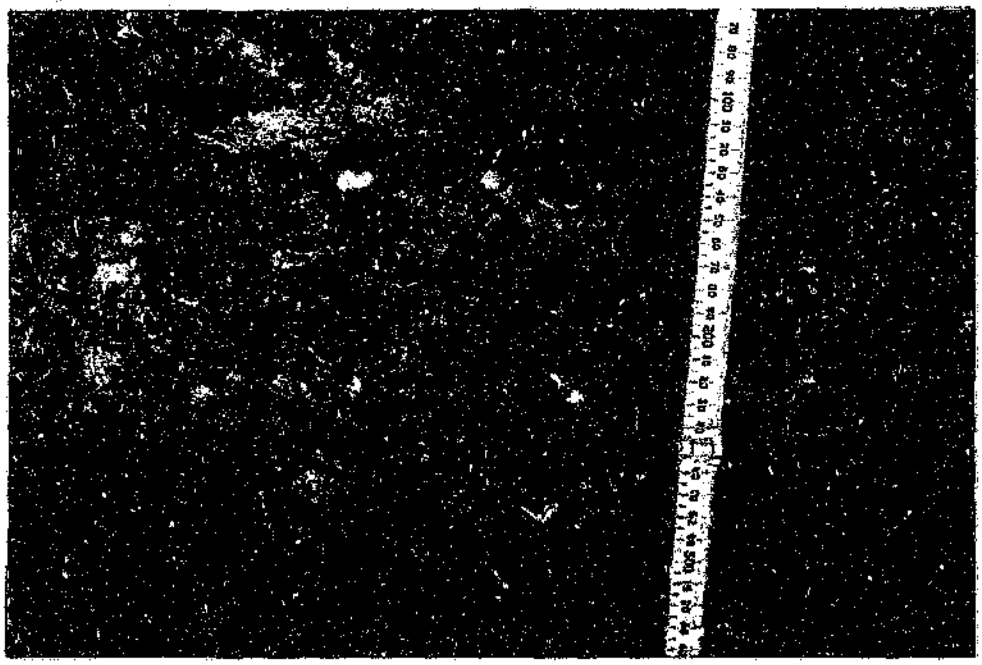

FIGURE 19a: OLIGOMICTIC BEATRIX REEF. NOTE THE WELL ROUNDED CLASTS, GOOD PACKING AND PYRITE MINERALISATION.

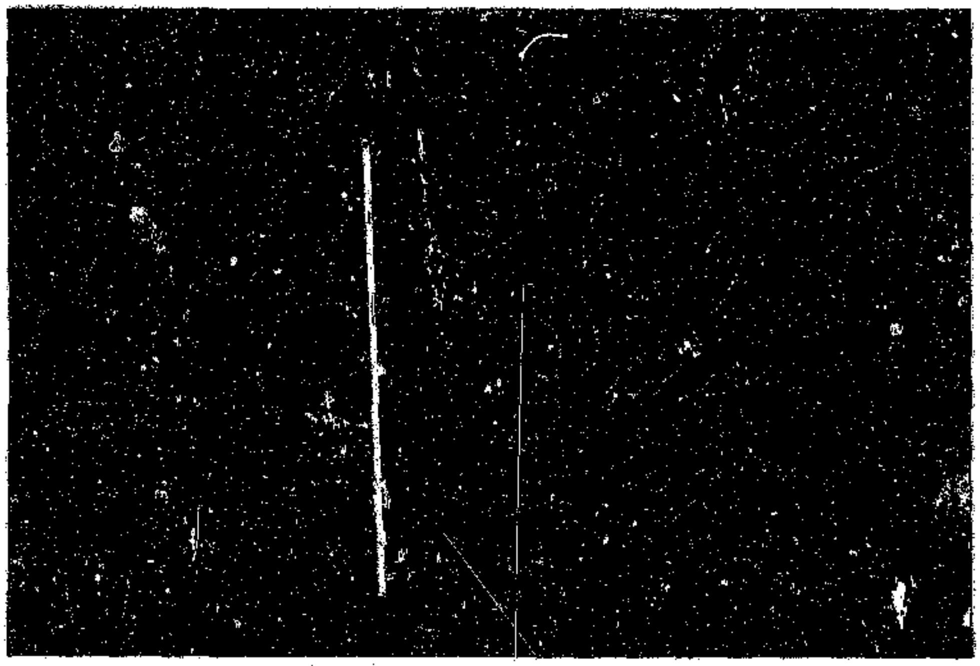

FIGURE 19b: MATRIX SUPPORTED BEATRIX REEF. NOTE THE POOR PACKING AND THE QUARTZ ARENITE MATRIX

FIGURE 19: OLIGOMICTIC CONGLOMERATE FACIES (BEATRIX REEF)

clasts consist of white or smokey vein quartz. The clasts are moderately to well-rounded and are generally of a prolate spheroid shape with the three principle axes easily recognisable. Variations in clast size and morphology are discussed in greater detail in Section 3.3.8. The conglomerate matrix consists of varying proportions of quartz arenite and heavy mineral grains such as pyrite. Other lithic clasts such as silicified shale are rare. Pyrite may, in parts, form as much as 85% of the matrix material. The pyrite grains vary in diameter from 0,2 mm to occasional pyrite "pebbles" up to 18 mm in size, but the average size is in the order of 0,5 to 1,5 mm. Pyrite grains are frequently sorted according to size, and an upward-fining grading is common.

Beds of crossbedded quartz arenite are commonly interbedded with the conglomerate, particularly in the thicker reefs. The arenite comprises rounded quartz grains 0,2 to 1,5 mm in size. Other rock fragments are rare although some quartz schist and fine-grained chert do occur. The matrix material consists of sericite, largely recrystallised to muscovite, and some chlorite, and comprises less than 2 % of the rock. Heavy mineral grains, particularly pyrite, are also common within the arenites and show marked sorting into discrete layers on bedding surfaces.

Crossbed foreset laminae are marked by accumulations of fine-grained pyrite (Figs. 20, 21, 22 and 23). Granules and small quartz pebbles may also occur on the toes of foresets. The upper parts of quartz arenite lenses are truncated by the scour surface and lag conglomerate of a succeeding channel-fill.

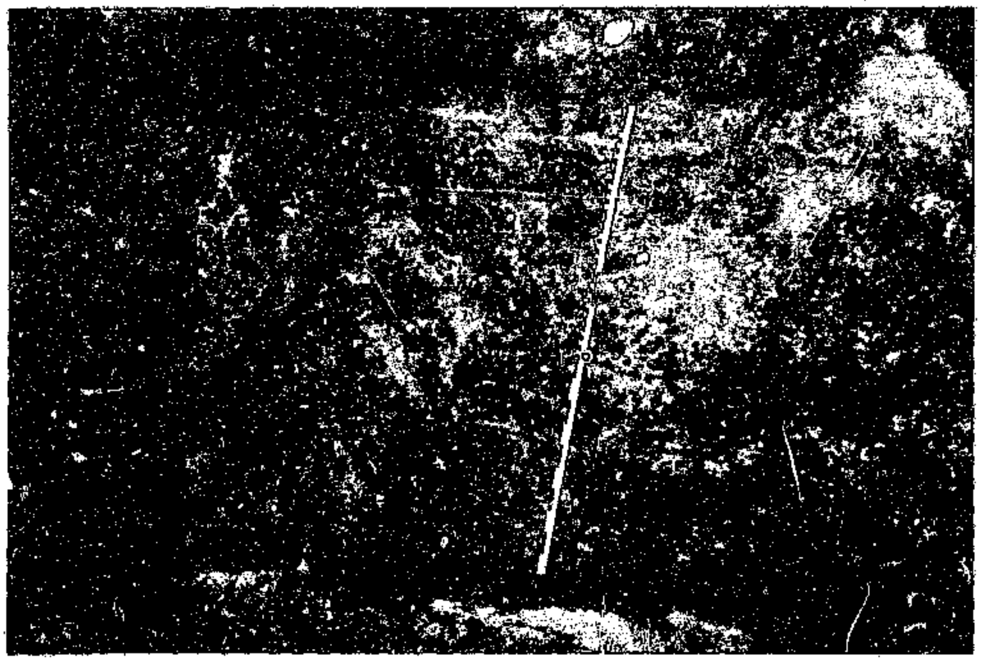

FIGURE 20: HORIZONTAL AND LOW ANGLE INCLINED STRATIFICATION IN THE BEATRIX REEF CONGLOMERATES

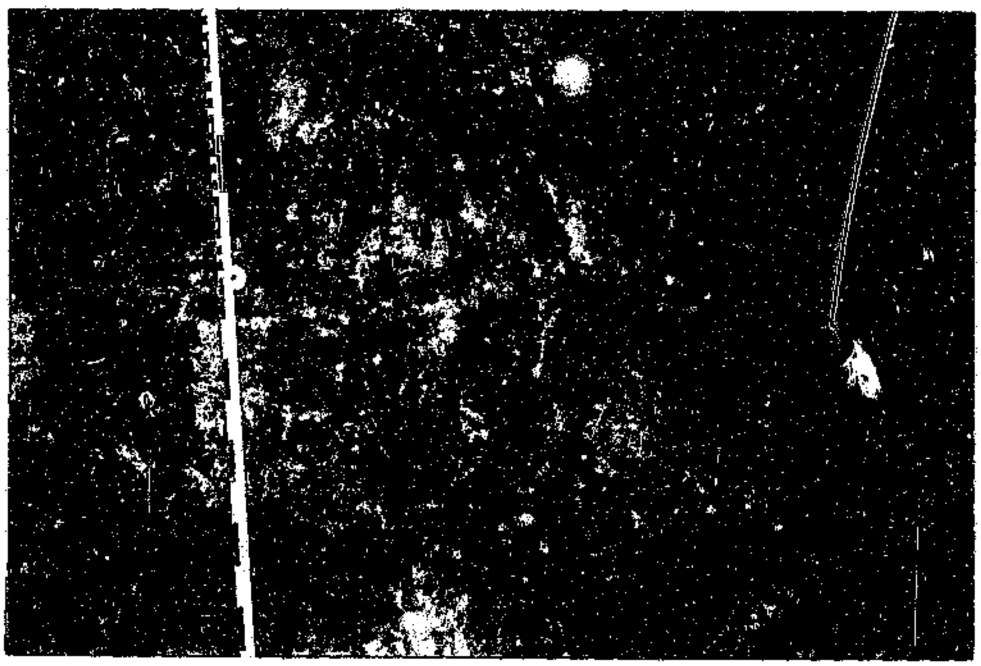

FIGURE 21: LARGE SCALE TROUGH CROSSBEDDING IN THE BEATRIX REEF

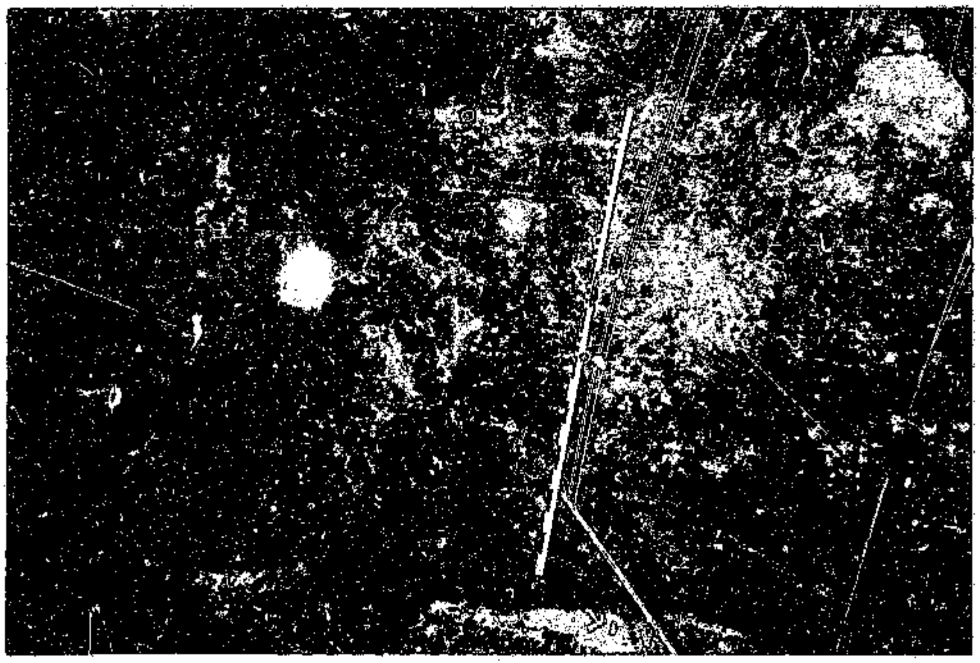

FIGURE 20: HORIZONTAL AND LOW ANGLE INCLINED STRATIFICATION IN THE BEATRIX REEF CONGLOMERATES

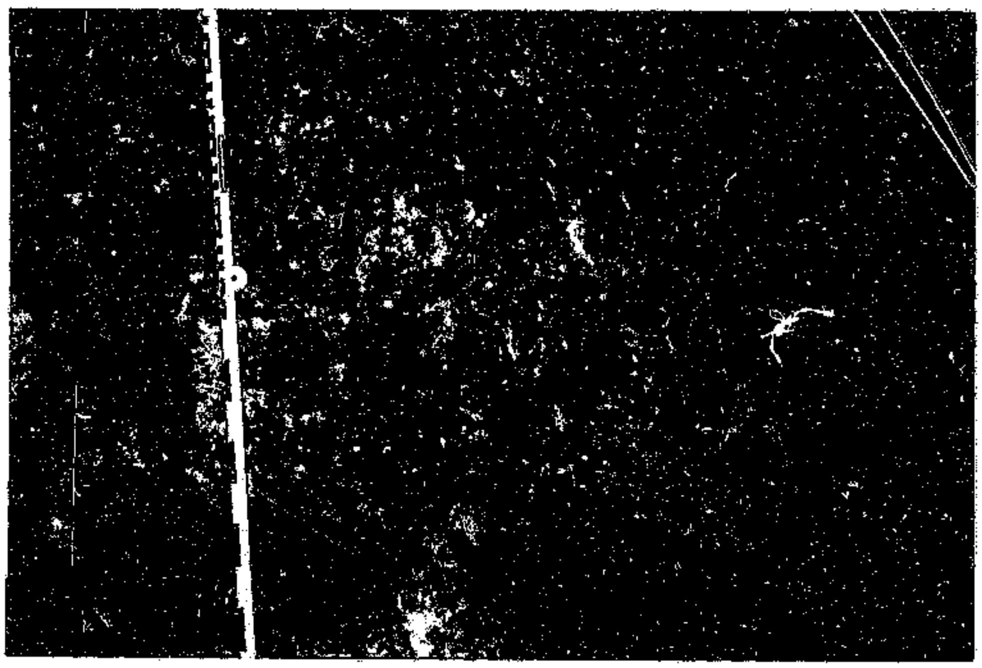

FIGURE 21: LARGE SCALE TROUGH CROSSBEDDING IN THE BEATRIX REEF

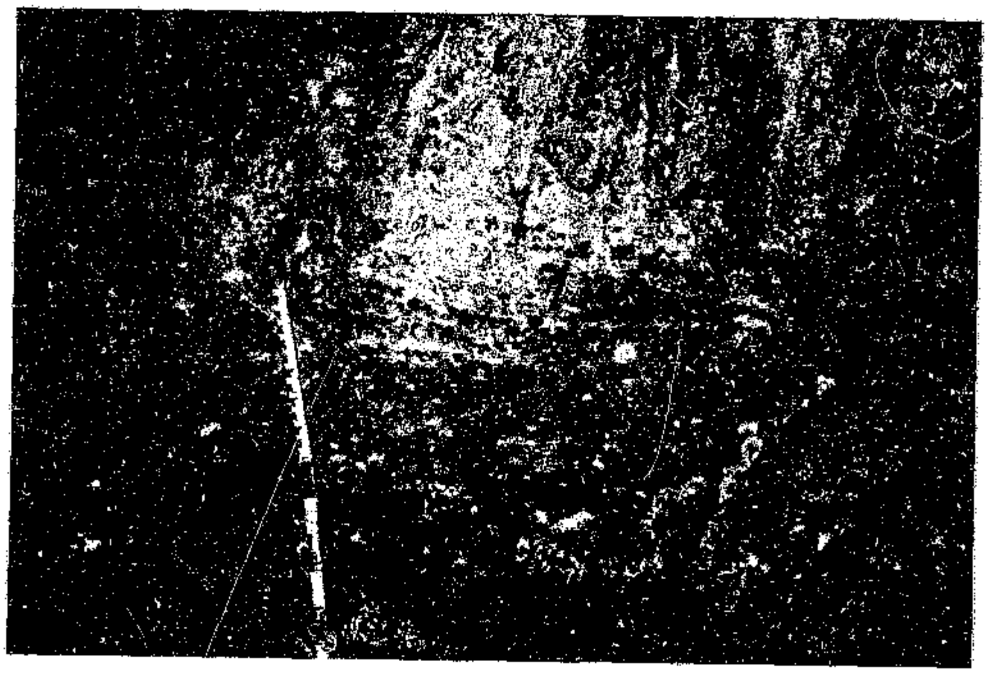

FIGURE 22: SMALL SCALE TROUGH CROSSBEDDING IN THE BEATRIX REEF

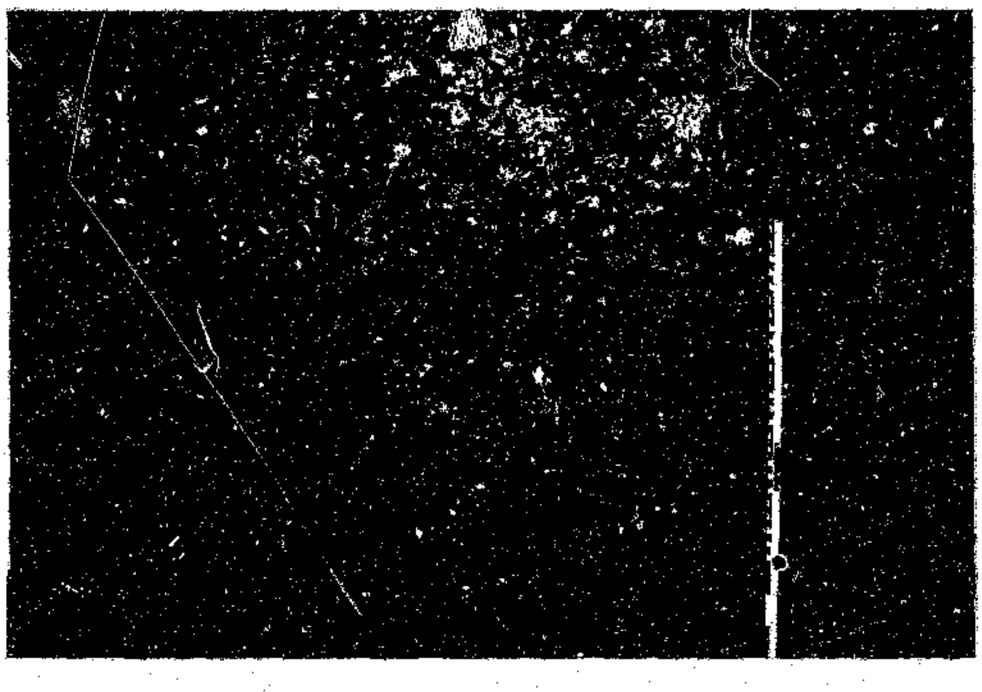

FIGURE 23: PLANAR CROSSBEDDING IN THE BEATRIX REEF. NOTE THE REACTIVATION SURFACES

The oligomictic facies (Beatrix Reef) can be further subdivided into a number of subfacies based on the sedimentary structures present within the conglomerate and pebbly arenite beds, although sedimentary structures are not always obvious in the conglomerate facies. Sedimentary structures in conglomerates are shown by one or more of the following

- changes in clast size or composition
- changes in sorting
- changes in fabric

(After Harms et al., 1982)

They thus become more obvious with variations in the conglomerate and arenite matrix content. Although strongly bimodal in grain size distribution it is assumed that the conglomerate clasts and arenite matrix were deposited together from the same flows at different velocities. This can be shown graphically, as has been done by Harms et al., (1982), comparing the criteria for suspension of sand and rolling of pebbles and cobbles on a bed. Applied shear stress must be sufficient to generate turbulent eddies that overcome settling velocity and prevent grains from settling to the bed, and great enough to overcome the rolling resistance of clasts (Harms et al., 1982). These critical shear stresses are dependant on the grain size of the arenite and the size of the pebbles and the grain sizes of the two modes can thus be related for the same critical shear stress.

Plots of the largest pebble size and the largest matrix sand grain size for four Beatrix Reef conglomerate samples are shown on Figure 24 and confirm that the conglomerate clasts and arenites were transported simultaneously and were probably deposited from the sa e flows at different velocities. The slight mismatch between the data points and the curve is probably due to rounding off the values for clast and grain sizes. This relationship and diagram may however not be valid at very high sedimentation rates or transport rates (Harms et al., 1982).

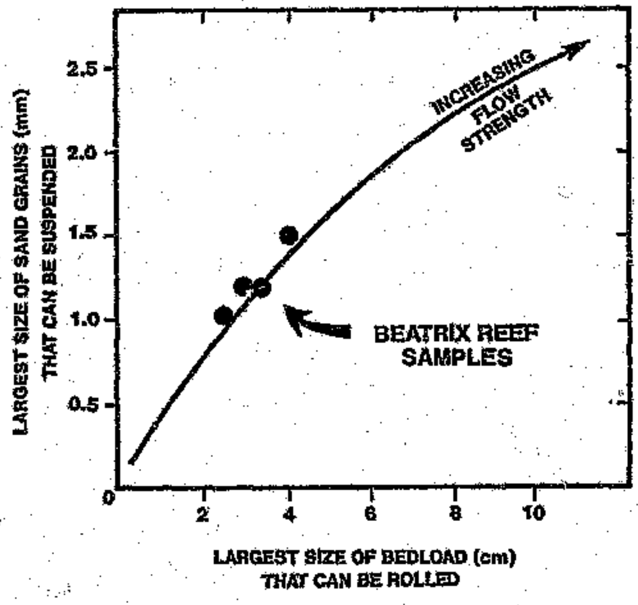

FIGURE 24: CURVE RELATING SIZE OF CLASTS AND SAND GRAINS TRANSPORTED BY THE SAME FLOW

(AFTER HARMS ET.AL.,1982)

In the well-packed, clast-supported, oligomictic conglomerates sedimentary structures are not apparent and the conglomerates are best described as massive (Fig. 19a). Massive conglomerate arises from the accumulation of clasts rolling along the bed into bar forms. Lenses or lenticular beds of massive conglomerate frequently define the remnants of pronounced bar shapes.

The most common sedimentary structure in the oligomictic conglomerate facies (Beatrix Reef) is stratification which is enhanced by changes in clast packing density, and particularly by variations in the detrital pyrite content of the arenite matrix. Both horizontal and inclined stratification are common (Fig. 20). In the horizontally stratified conglomerates the "beds" vary in thickness from a few centimetres to a few tens of centimetres and may be laterally persistent over horizontal distances exceeding 5 m. Inclined stratification varies in angle from a few degrees to close to the angle of repose and is more commonly termed crossbedding. Whereas conglomerates with horizontal stratification suggest deposition by the rolling of clasts along the bed, inclined stratification close to the angle of repose results from avalanching down the downstream faces of gravel bars or dunes. Low angle inclined stratification is more difficult to explain and may reflect local scouring and filling on the bed, or lateral accretion of bar surfaces (Smith, 1974; Hein and Walker, 1977).
Rust (1972), Gustavson (1974) and Boothroyd and Ashley (1975) suggest that migrating longitudinal bars form poorly defined horizontal gravel beds with an imbricate fabric. Smith (1974) has also noted that in fluvial gravels the bedding is predominantly massive, but low angle inclination is fairly common from the migration of bars with low riffle margins. Initial lag formation in these conglomerates is by the rolling of clasts along the bed. If fluid discharge and sediment rate remains high after initial lag formation, then bars tend to

grow downstream faster than aggrading vertically hence no foresets develop and low angle, inclined stratification predominates (Hein and Walker, 1977). Only in decreasing flow is there rapid vertical aggradation and the development of steeper foresets.

3.3.4 TROUGH CROSSBEDDED PEBBLY ARENITE FACIES

In the oligomictic conglomerate (Beatrix Reef) where the arenite matrix increases and conglomerates become more matrix supported, crossbedding becomes more prevalent. The dominant structure is large-scale trough crossbedding in sets about 15 cm thick. Foresets are usually marked by varying concentrations of detrital pyrite (Fig. 21). Crossbedding of this type becomes more noticeable and prevalent as the arenite content of the reef increases, and is particularly marked in the pebbly quartz-arenite interbeds. In these interbeds the crossbed sets are usually smaller and trough crossbed sets in the arenites are about 5 cm thick. (Fig. 22).

Trough crossbedding forms by the accretionary migration of large, lunate ripples (Southard, 1971) and indicates unidirectional flow with significant velocity and depth (Southard, 1971 and Harms et al., 1975). A rule of thumb suggested by Harms et al.(1975) is that the minimum water depth of trough crossbedding is approximately twice the thickness of individual sets. Water depths envisaged for the Beatrix Reef are thus in the order of at least 30 cm deep. Trough crossbedding forms in most shallow water settings and is thus not environmentally diagnostic.

3.3.5 PLANAR CROSSBEDDED PEBBLY ARENITE FACIES

Planar crossbedding is not as common as trough crossbedding but has been observed in the pebbly quartz arenites where it occurs in sets about 5 cm thick, or in slightly larger sets 8 - 10 cm thick. Reactivation surfaces are fairly common in the planar crossbed sets (Fig. 23).

Planar crossbedding forms as a result of the accretionary migration of straight crested ripples or sand waves (Allen, 1963). Again by applying the rule of thumb suggested by Harms et al. (1975) the water depth for the formation of the planar crossbeds observed in the Beatrix Reef is of the order of at least 20 cm deep.

Reactivation surfaces form during periods of slack water or partial erosion of deposited sediment when, during a later rise in stage they are again covered by new deposits of a similar type or bedform (Smith, 1980). De Vries Klein (1970 and 1975) states that reactivation surfaces are characteristic of tidal deposits because such sedimentary structures in this environment are controlled by the simple reversal of tidal currents involving bedload transport, or time velocity asymmetry of these currents. However Collinson (1970) and Smith (1980) have documented reactivation surfaces formed in fluvial environments by the resumption of flow following slack stage.

3.3.6 PALAEOCURRENT INDICATORS

As was discussed previously there is marked, small scale relief on the basal contact of the reef (Figs. 11a and 11b).

This relief results from the erosional scouring of channels into the unconformity surface and therefore provides a trend for palaeocurrent directions. Measurement of the low point orientation of these scours where three dimensional or multiple exposures permit, show a fairly high degree of variance, but a roughly north-south trend dominates (Fig. 25a).

The palaeocurrent transport direction measured from palaeocurrent indicators such as crossbedding shows a predominantly north-northeast to south-southwest transport direction (Fig. 25b). This palaeocurrent transport direction coincides with the north-south channel trends shown by the channel scours (fig. 25a).

3.3.7 OLIGOMICTIC CONGLOMERATE FACIES (BEATRIX REEF) ISOPACHS

The Beatrix Reef varies from a thin, single pebble lag (Fig. 26) to thick sequences of conglomerate and arenite (Figs. 27 and 19b). Much of the variation in thickness can be ascribed to erosional scouring into the unconformity surface at the base of the reef (Figs. 15 and 16). These variations in thickness are a good indication of channel orientations.

An isopach plan of the Beatrix Reef thickness in the 40 exploration boreholes drilled from surface in the Beatrix Mine and immediately surrounding areas (Fig. 28) shows that most of the reef intersected is between 20 to 80 cm in thickness. Areas of thicker reef (over 50 cm) define roughly north-south trending zones (channels?) along the western and central parts of the Mine (Fig. 28). Considering the fairly rapid variations in reef thickness due to the considerable relief of the

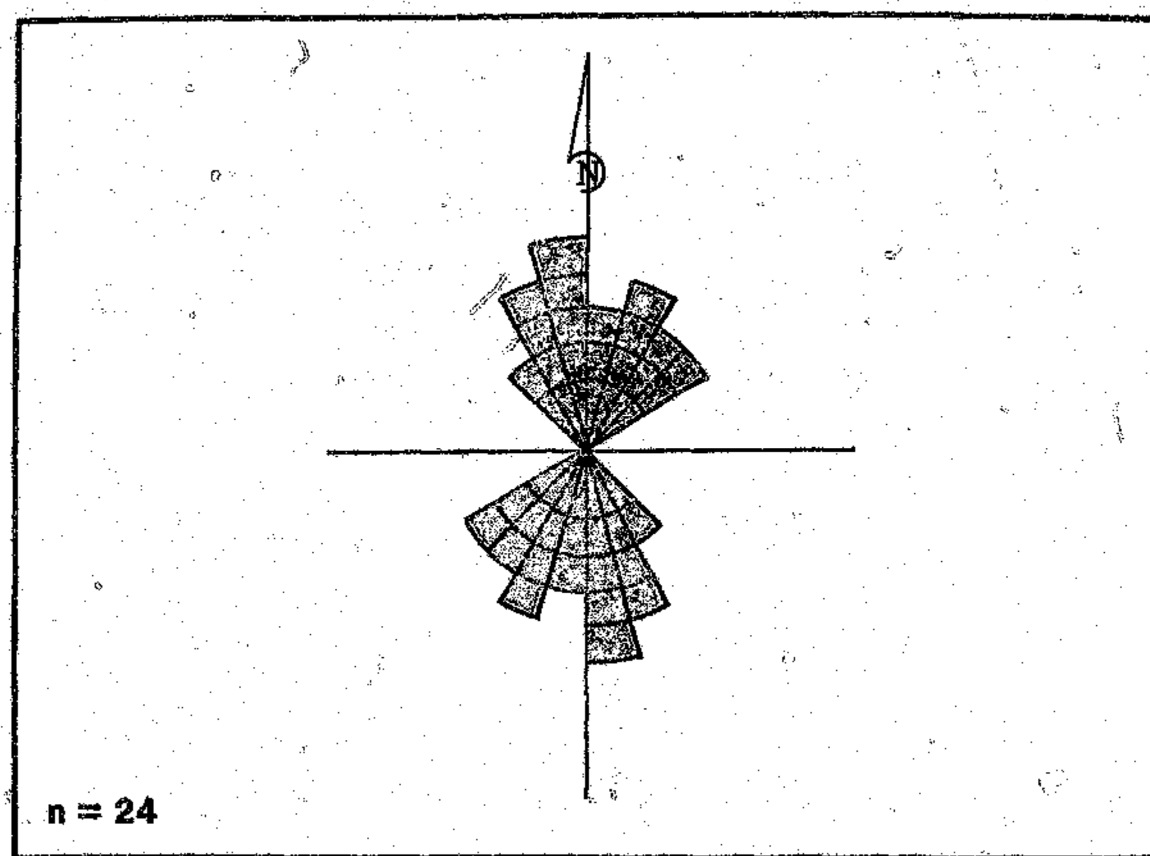

FIGURE 25a: ROSE DIAGRAM OF THE ORIENTATION OF BEATRIX REEF CHANNEL SCOURS

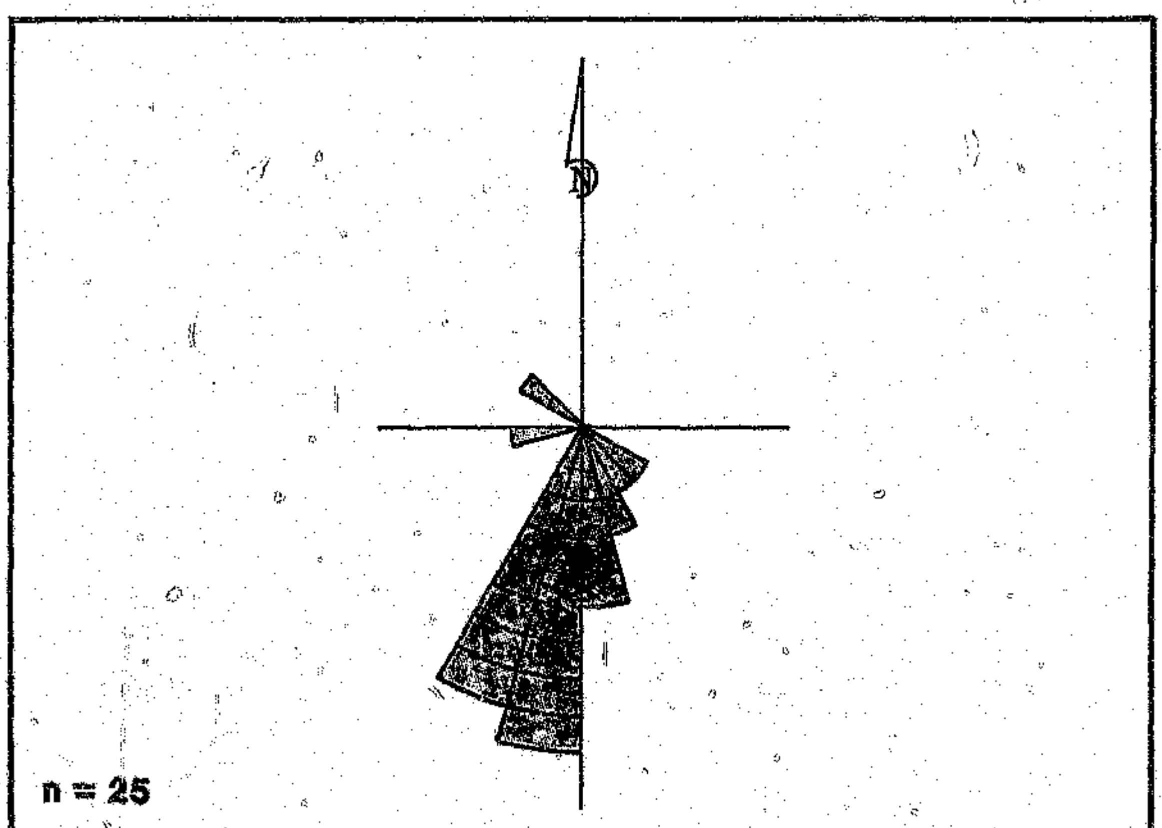

FIGURE 25b: ROSE DIAGRAM OF BEATRIX REEF TROUGH CROSSBEDDING AZIMUTHS

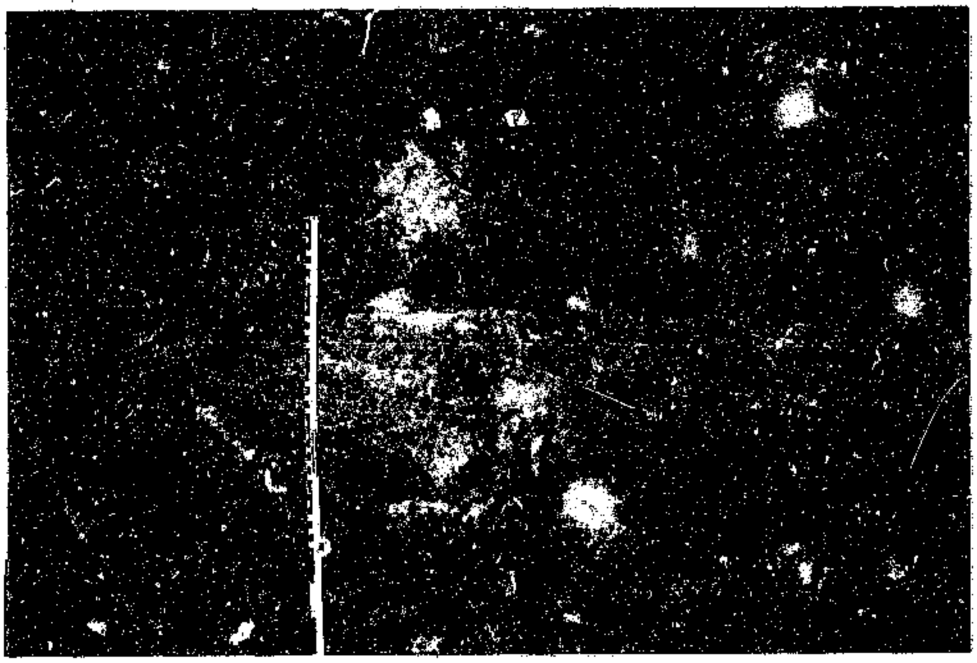

FIGURE 26: ROSEDALE MEMBER ARENITES ON VIRGINIA FORMATION, THE BEATRIX REEF HAVING BEEN TRUNCATED

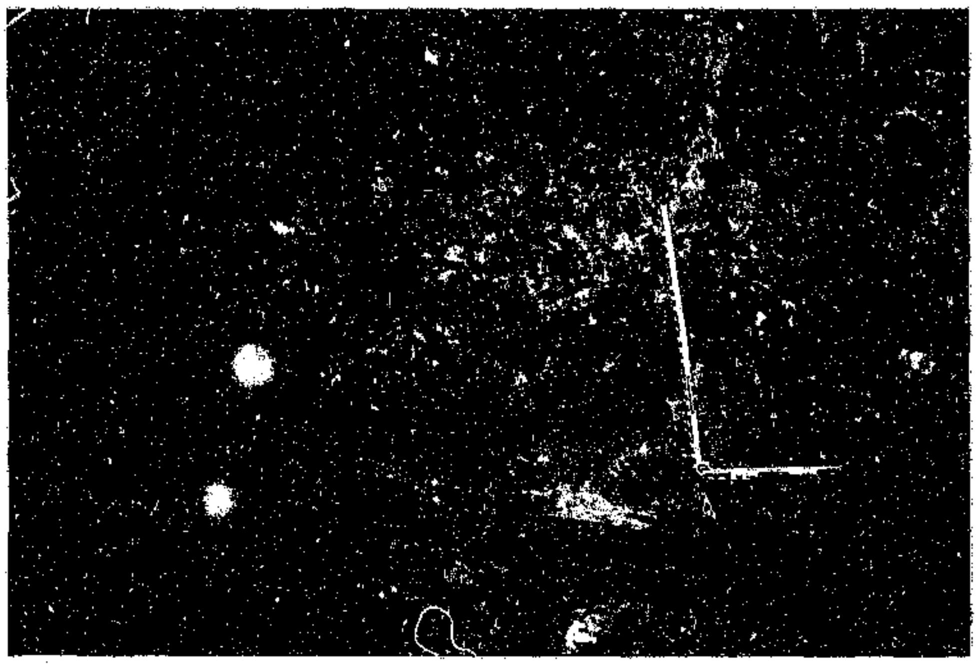

FIGURE 27: THICK BEATRIX REEF SHOWING MULTIPLE SCOUR AND FILL AND QUARTZ ARENITE INTERBEDS

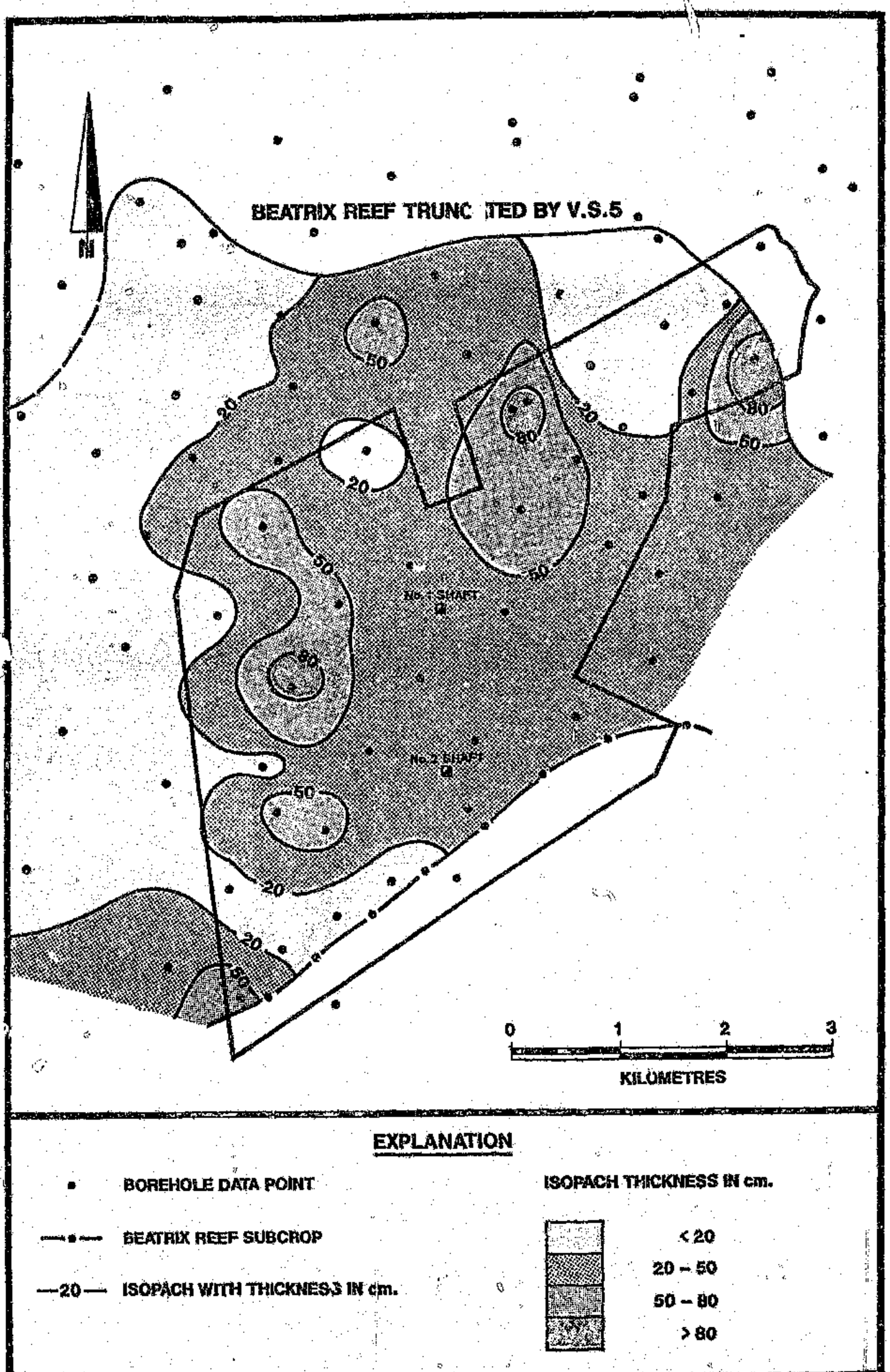

FIGURE 28: BEATRIX REEF ISOPACHS FROM SURFACE EXPLORATION BOREHOLES

unconformity surface, the spacing of surface exploration boreholes (750 m) is too infrequent to provide any meaningful channel orientation trends.

Beatrix Reef thickness measurements recorded by the sampling department on Beatrix Mine during their routine sampling of the orebody were contoured to produce isopach maps which better define the reef channels. Samples are taken on an approximately 6 m by 6 m square grid and afford an excellent coverage of the reef exposed during mining operations. The assay plan plots of this grid sampling were reduced to the more manageable scale of 1:1000 and then hand contoured in 20 cm reef thickness intervals. These 1:1000 contoured plots were then further reduced and combined to produce the isopach plan shown as Figure 29.

For clarity in presentation only the 20 cm and 80 cm isopach lines defining three reef thickness intervals are shown in Figure 29. The isopach trends show well defined areas of reef thicker than 80 cm with a pronounced north-south orientation (Fig. 29). Areas of reef less than 20 cm thick form irregular, elongate areas between these zones of thick reef. These trends confirm the broad trends defined from the surface exploration borehole reef isopach plan.

3.3.8 CONGLOMERATE CLAST MORPHOLOGY AND SIZE VARIATION

a. Clast Size Variations

Conglomerates are best described in terms of the following characteristics of the clasts and clast arrangement......

- sorting and size distribution

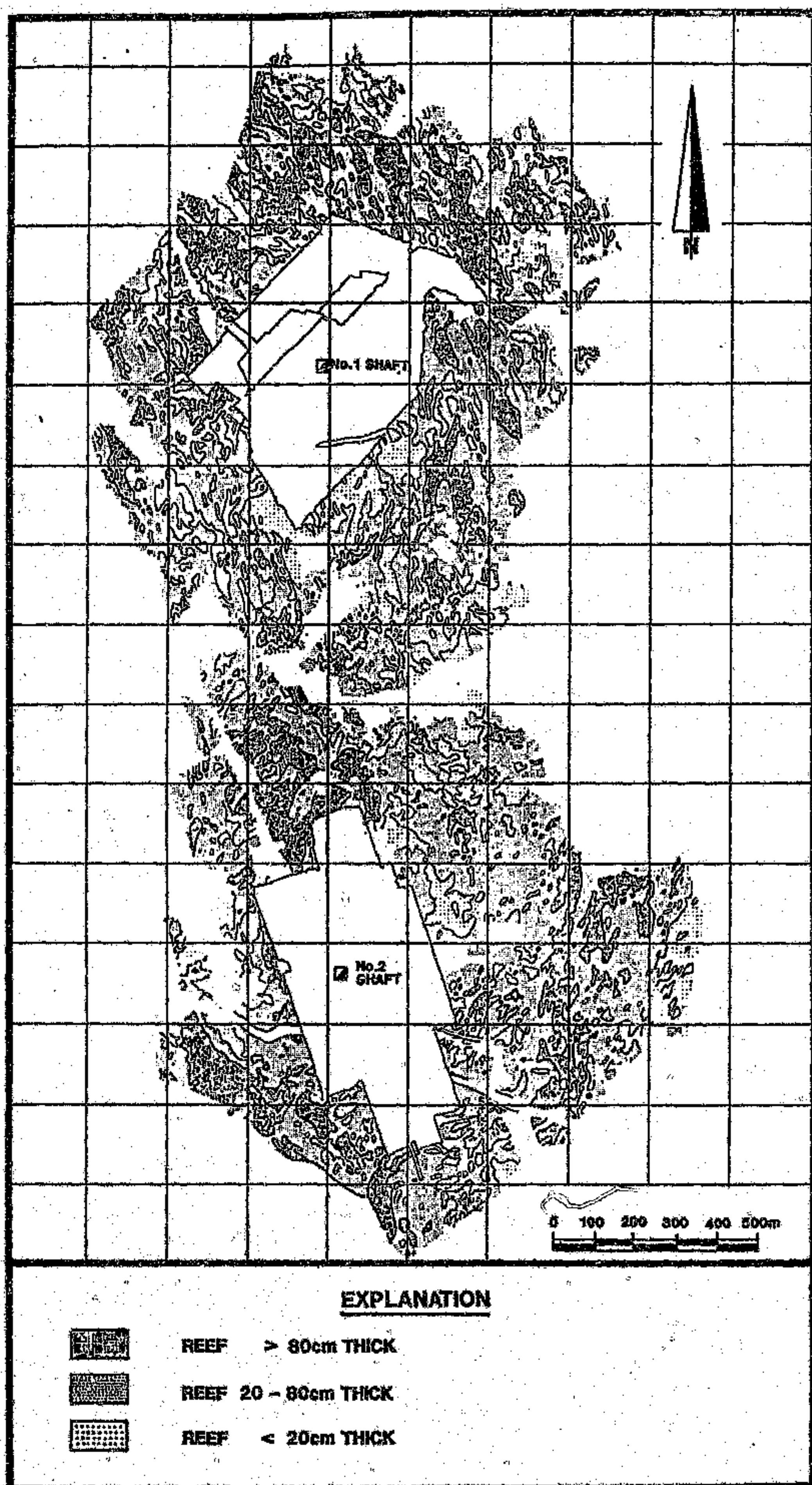

FIGURE 29: BEATRIX REEF ISOPACHS FROM UNDERGROUND SAMPLING

- fabric
- stratification
- grading (After Harms et al., 1982)

The average largest quartz clast size measured from reef intersections in each of the surface exploration boreholes was plotted and contoured in an attempt to ascertain the average largest clast size in the reef and any regional variations in clast size (Fig. 30). The average largest quartz clast size for each intersection was determined as the arithmetic average of the long axis of the 15 largest clasts visible on the split sample surface of the borehole core. Clast sizes in individual intersections from deflections of the same borehole were averaged to provide a single average largest clast size for each borehole. The average size of the 15 largest quartz clasts varies from 17 mm to 35 mm with most clasts between 20 - 30 mm. (Fig. 30). From Figure 30 it is apparent that only broad, regional trends in the average largest clast size can be ascertained. There appears to be an overall decrease of the average largest clast size towards the south (Fig. 30), but this is partly masked by an area of larger clasts in the western part of Beatrix Mine, which corresponds with the area of thicker reef deduced from the isopach plans (Figs. 30 and 28). Considering the spacing of the surface exploration boreholes (750 m) the trends defined for the variation in clast size in Figure 30 are a rough guide only.

Attempts were made to further constrain the clast size variations by the measurement of average Beatrix Reef clast

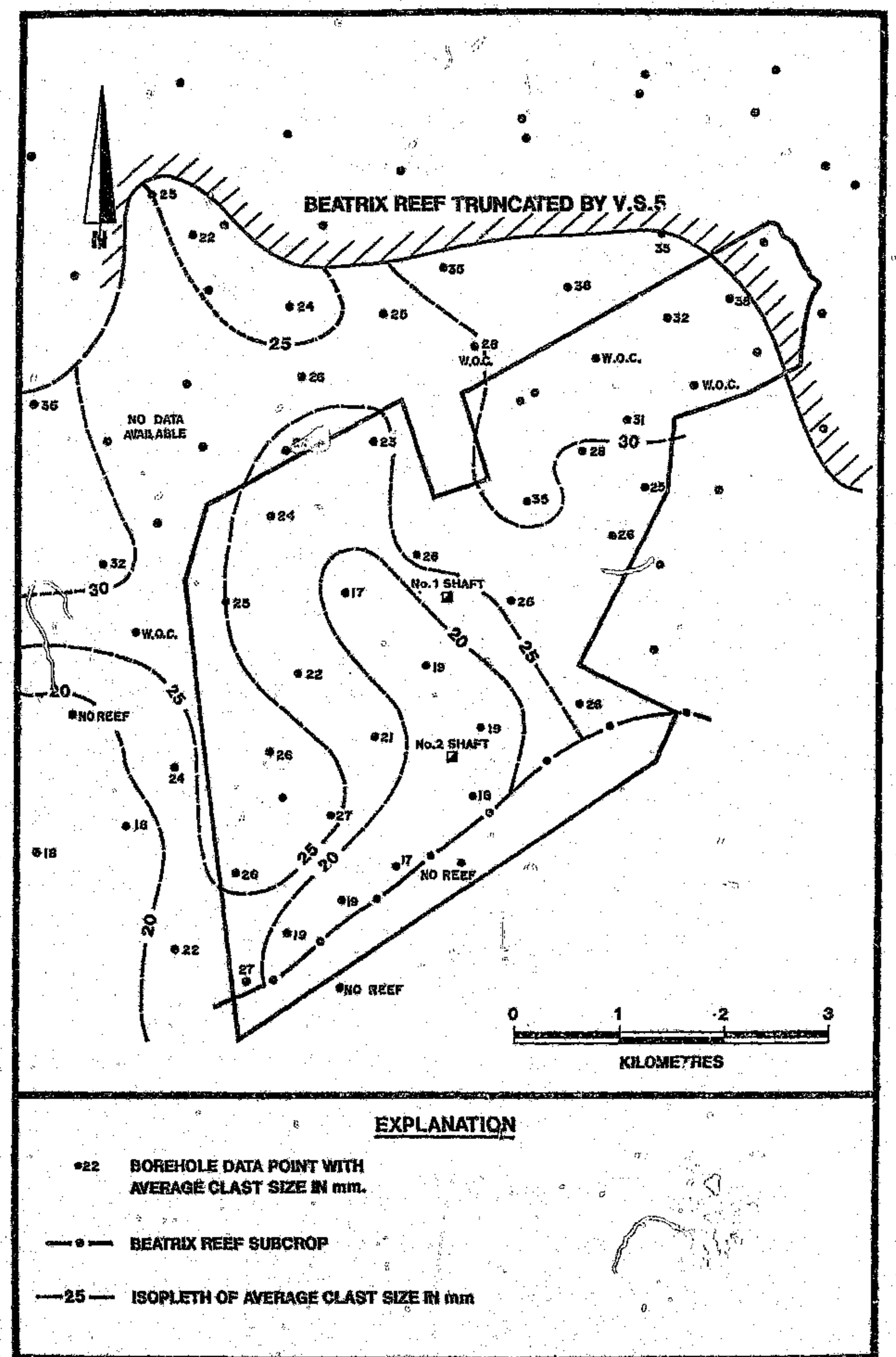

FIGURE 30: AVERAGE LARGEST CLAST SIZE IN BEATRIX REEF IN SURFACE BOREHOLES

sizes in the underground prospect boreholes. To date some 600 boreholes have been drilled from the underground development on Beatrix Mine for routine evaluation and prospecting. Pebble counts were carried out on 230 reef intersections from the underground boreholes. The location of the boreholes used gives a random scatter of data points providing good coverage of the area of the current underground workings on Beatrix Mine (Fig 31). The lithology and the long axis of each clast longer than 4 mm was recorded in half phi class intervals. The average clast size for the intersection was then calculated from the total of the sum of the frequency of observations in each class interval, divided by the total number of observations. Observations in each class interval are assigned a size value equivalent to the midpoint of that interval. The average clast sizes were then contoured using the SURFER program on a personal computer (Fig. 31). The average oligomictic conglomerate facies (Beatrix Reef) clast size as measured in the underground boreholes varies from 9 mm to 24 mm, and a southerly decrease in clast size is apparent (Fig. 31). An area of slightly larger clasts still occurs in the western part of the Mine workings where a strong north-south isopleth trend is evident (Fig. 31).

Average clast sizes measured in the underground borehole intersections are generally smaller than those measured in the surface borehole intersections or in underground exposures. This is due to the smaller diameter of the borehole core used for the measurements. Underground borehole core is only 32 mm in diameter therefore only rarely are the larger clasts

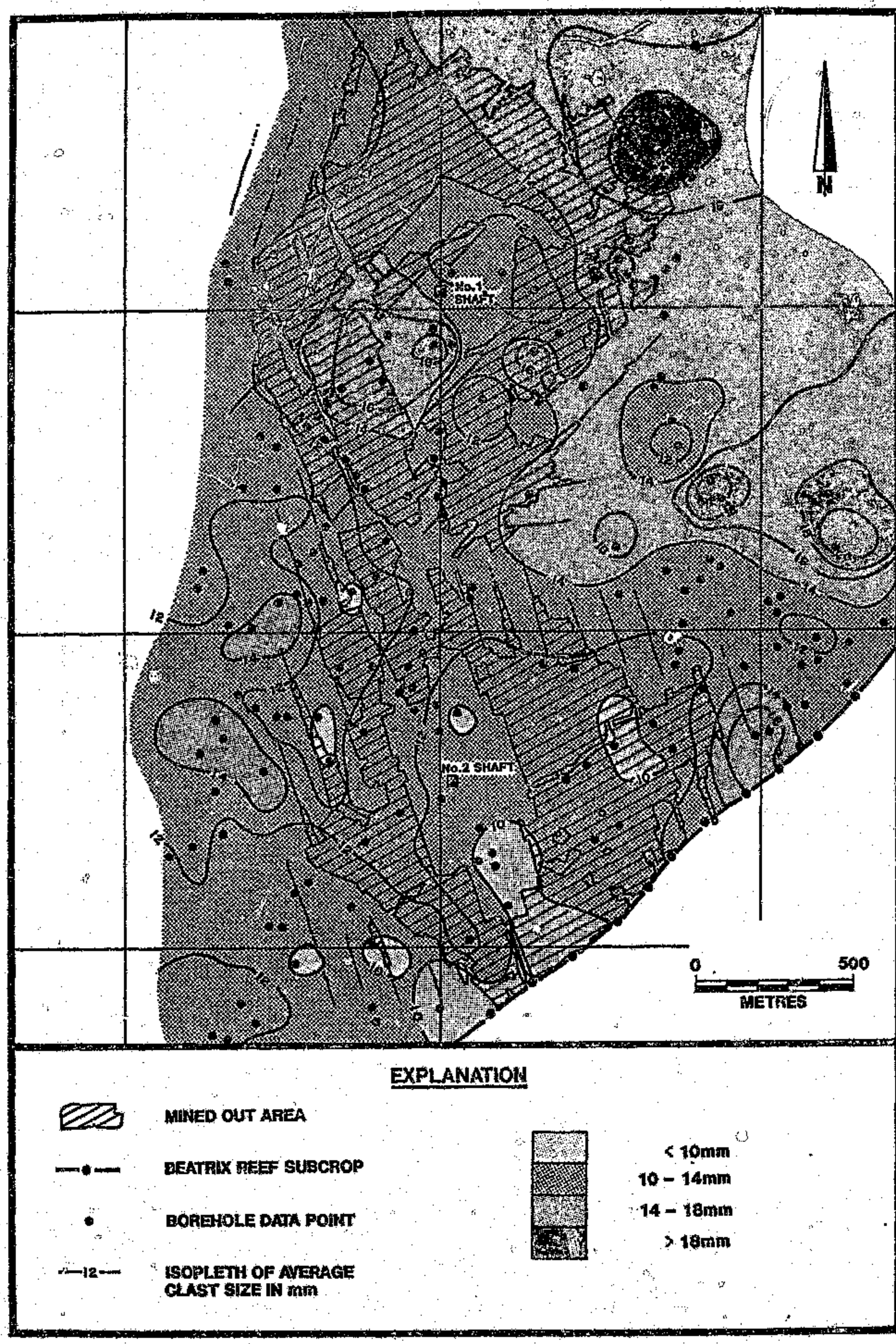

FIGURE 31: AVERAGE BEATRIX REEF CLAST SIZE IN UNDERGROUND BOREHOLES

(greater than 30 mm) intersected such that they can be measured.

The average oligomictic conglomerate facies clast size was also measured at a number of localities in the underground mine workings (Fig. 32). Measurements were made by measuring the long axis exposed on the broken surface, of every clast longer than 4 mm within a narrow band (35 mm wide) over the whole width of the reef. The long axis of larger clasts only partly included within the measuring band were also measured. In areas of thin reef the band within which measurements was done was widened to ensure a population of at least one hundred measurements at each locality.

Clasts vary in size with the largest clast measured being 150 mm. The average clast size from all measured sections is 18 mm. A slight decrease in the average clast size in a southerly direction is still apparent (Fig. 32).

b. Clast Morphology

In areas where the reef is overlain by black shale and siltstone, or in areas where the matrix comprises very high concentrations of detrital pyrite, it was possible to remove individual clasts from the conglomerate in spite of the generally high degree of lithification of the reef. Barrett (1980) considers pebble shape to comprise three related properties : form, roundness and surface texture. Form indices such as maximum projection sphericity (Sneed and Folk, 1958), coefficient of flatness (Luttig, 1962) and oblate-prolate index (Dobkins and Folk, 1970) are thought to be useful diagnostic

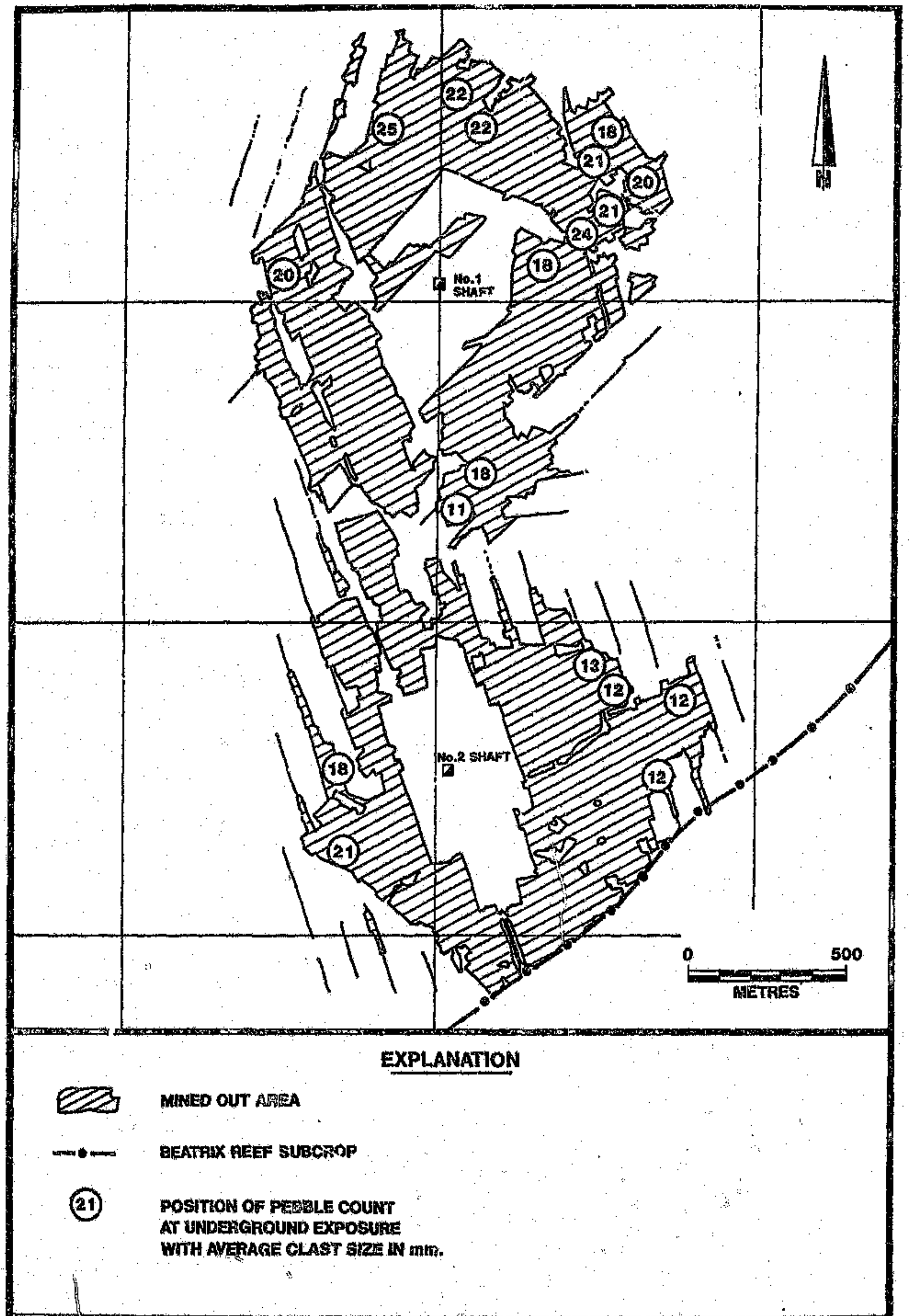

FIGURE 32: AVERAGE BEATRIX REEF CLAST SIZE FROM MEASUREMENTS IN THE UNDERGROUND WORKINGS

environmental indicators and have been tested in studies of modern gravels by Dobkins and Folk (1970) and Stratten (1974). Thamm (1987) has used clast form indices as palaeoenvironment indicators on gravels from the Nardouw Formation (Cape Supergroup). These studies have however been questioned by Reddering and Illenberger (1988) who point out that shape sorting as described by Hobday and Banks (1971), Dobkins and Folk (1970) and Orford (1975) appears to be a more important control on the shape distribution of clasts on beaches. Flat clasts are concentrated on the intertidal part of the beach where they are segregated from their more spherical counterparts which are concentrated in the subtidal zone. (Hobday and Banks, 1971 and Orford, 1975).

Studies by Els (1988) of the Middelvlei Conglomerates appear to be the first studies incorporating clast form indices for the conglomerates of the Witwatersrand Supergroup.

The clasts removed from the Beatrix Reef are generally well-rounded with smooth surfaces (Fig. 33), and there is little evidence of the commonly described reaction between quartz clasts and the phyllosilicate matrix. (eg. Els, 1988, Verrezen, 1987 and Law et al.,1989).

The three form indices most commonly used by previous workers

- maximum projection sphericity (Sneed and Folk, 1958)
- coefficient of flatness (Luttig, 1962)
- oblate-prolate index (Dobkins and Folk, 1970)

were calculated from the principal axes measurements of 169 clasts collected from various exposures of the oligomictic

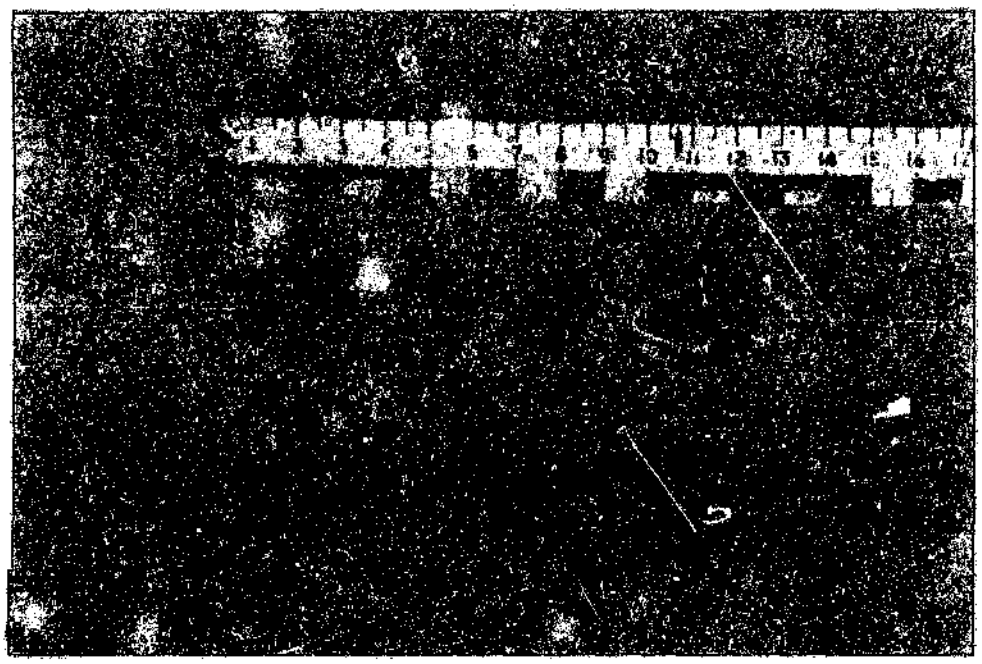

FIGURE 33: WELL ROUNDED QUARTZ CLASTS EXTRACTED FROM THE BEATRIX REEF AND USED FOR MORPHOLOGY MEASUREMENTS

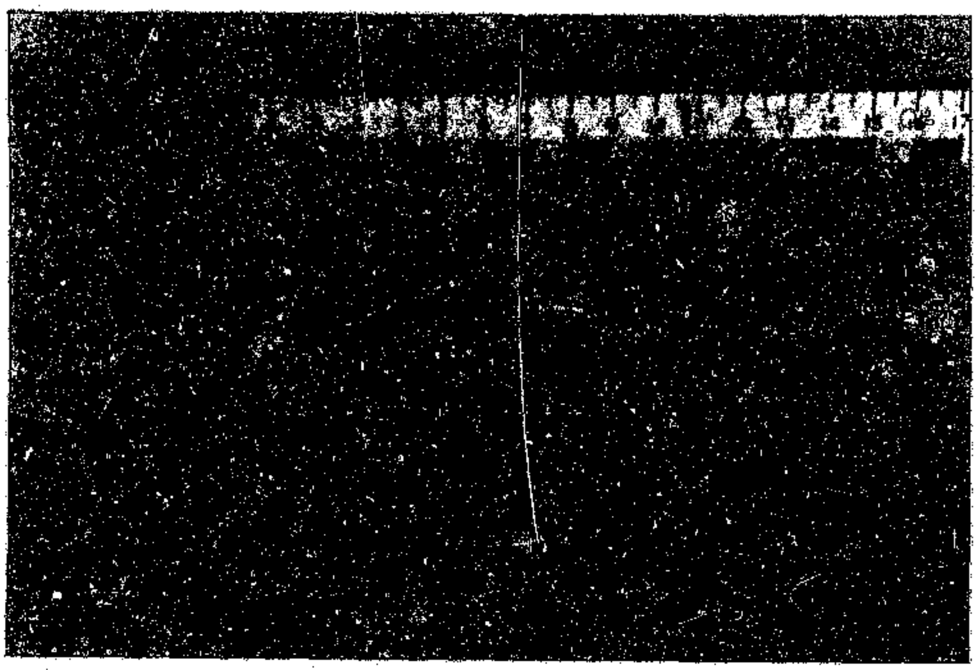

FIGURE 34: QUARTZ CLASTS BROKEN PRIOR TO DEPOSITION IN THE REEF. NOTE THE ROUNDING OF THE BREAK EDGES.

conglomerate facies (Beatrix Reef) in the underground workings. Clasts were selected for which the three principal axes could be determined unambiguously and accurately and these axes were measured using a simple vernier caliper. Of the selected clasts some 27 % still displayed facets due to pre-depositional breaks. These pre-depositional breaks appear as facets on the normal, rounded clast shape and have had the break edges partially rounded prior to deposition (Fig. 34). In extreme cases the clast may take on the appearance of being a rounded "dreikanter".

As a control, 19 quartzite pebbles collected from a gravel beach near Plettenberg Bay were also measured and their form indices calculated to check the discrimination of the method. The average form indices determined from the Beatrix Reef clasts are summarised below.

Co-efficient of Flatness (Luttig,1962)	:	54.51
Sphericity (Sneed and Folk, 1958)	:	0.72
Oblate-Prolate Index (Dobkins and Folk, 1970)	:	17.31

These form indices are significantly greater than the lower limits determined by previous workers (Dobkins and Folk, 1970 and Stratten, 1974) to differentiate between fluvial and beach pebbles in modern gravels. The indices for co-efficient of flatness and sphericity are very close to the averages for South African river quartz pebbles (53.6 and 0.72 respectively) determined by Stratten (1974) (Fig. 35). Some 10 % clasts measured have sphericity and co-efficient of flatness indices below the lower limits suggested by Stratten (1974) for fluvial

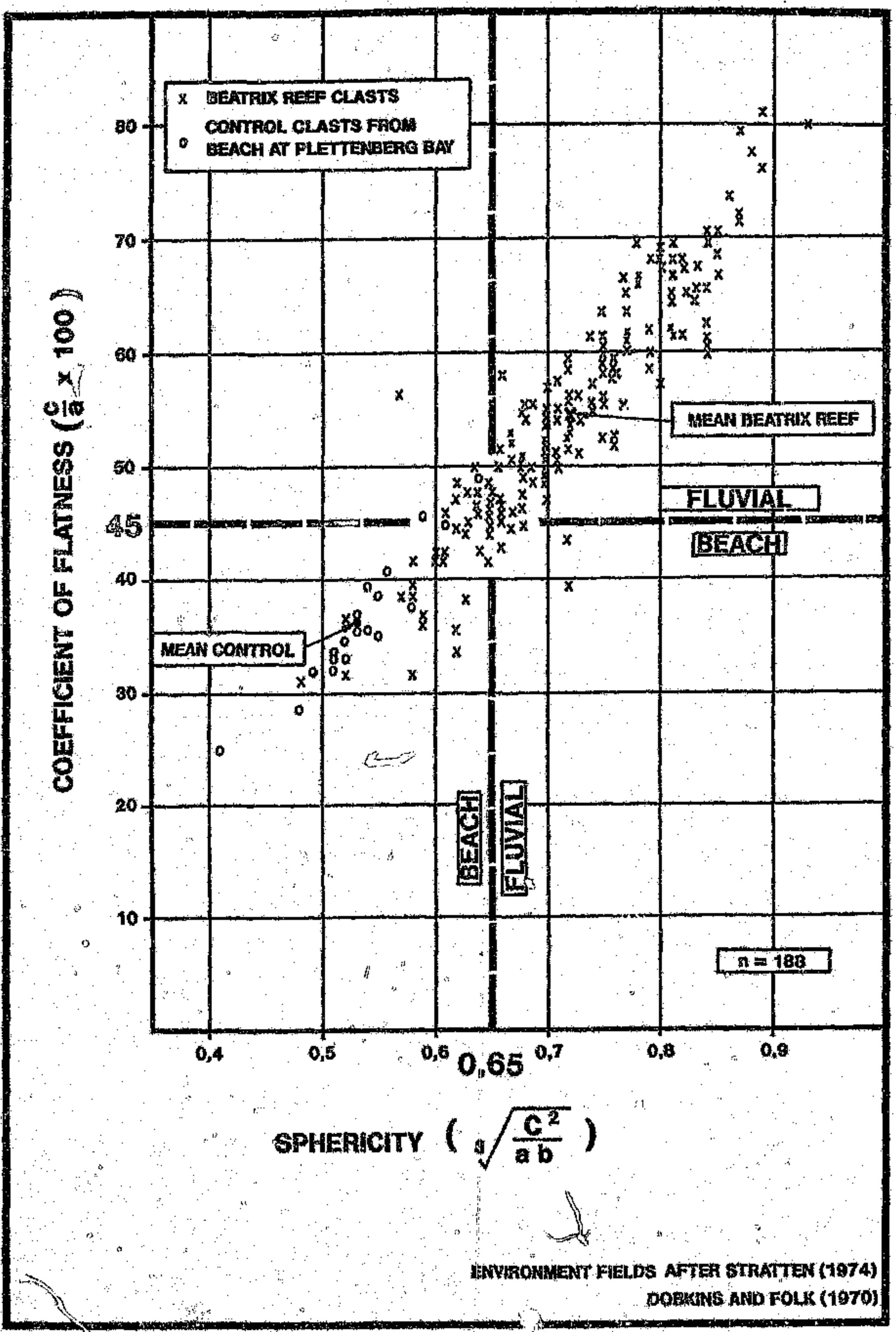

FIGURE 35: SPHERICITY vs COEFFICIENT OF FLATNESS FOR BEATRIX REEF CLASTS

pebbles and have indices characteristic of beach pebbles (Fig. 35).

c. Fabric

The term fabric refers to the arrangement in a rock of its various components, and includes packing and the orientation of clastic particles in sedimentary rocks (Harms et al., 1982). Where the clasts are of asymmetric form, a well-developed orientation of clasts strongly suggests that individual clasts have moved freely with respect to each other, and have assumed an orientation (imbrication) imposed by characteristics of the flow.

Imbrication is not very common or obvious in the Beatrix Reef conglomerates, but has been observed in a number of locations, particularly in the thinner reefs where the reef is only a few pebble diameters thick. The clast orientation is usually with the long axis (a-axis) transverse to the flow and the intermediate axis (b-axis) imbricate dipping upstream. This can be coded, as suggested by Harms et al., (1982), as a(t)b(i). The oligomictic conglomerate clasts are generally well-rounded and their shape probably accounts for the scarcity of an imbricate fabric.

The a(t)b(i) fabric is characteristically the result of clasts rolling on the bed and has been observed in many river gravels (Rust, 1972). A fabric with the long axis (a-axis) parallel to the flow and imbricate dipping upstream, coded as a(p)a(i) by Harms et al., (1982), is much less common and has only been documented in clast supported, "deep water, turbidite-like" conglomerates (Walker, 1975). Rust (1972) has also noted that smaller size and increased concentration of pebbles reduces the degree of preferred orientation. With clast sizes less than 2 cm and stream velocities slightly higher, clasts are no longer rolling but leave the bed as saltating grains and an orientation with a-axis parallel to flow could develop (Rust, 1972). Conglomerates without a preferred clast orientation imply transport and depositional processes in which the clasts are less free to move relative to each other, and hence are unable to respond individually to fluid stresses.

3.3.9 BED LENTICULARITY AND PEBBLE SEGREGATION

Clifton (1973) has suggested that two aspects of bedding may permit visual discrimination between wave-worked and alluvial gravel. Pebbles in wave-worked gravels tend to be better segregated into discrete beds and bedding in wave-worked gravels tends to be more laterally regular, or less lenticular than in fluvial gravels (Clifton, 1973). The two aspects that could be quantified to allow the discrimination were the pebble segregation factor and lenticularity index defined by Clifton (1973) as follows :

pebble segregation factor = $| 50 - m |$

where m is the midpoint of a semi-quantitative class of pebble concentration expressed as a percentage.

lenticularity index = $(T_{max} - T_{min}) / 1$

where T_{max} = maximum bed thickness in a 5 metre section

T_{min} = minimum bed thickness in a 5 metre section

l = lateral extent of the bed in the 5 metre section

Pebble segregation and bed lenticularity were measured over a number of five metre stretches of the Beatrix Reef in underground exposures as per the methods described by Clifton (1973). The results are plotted on the pebble segregation factor versus lenticularity index diagram (Fig. 36) with the environment fields as defined by Clifton (1973).

The conglomerate beds all plot within the alluvial field defined by Clifton (1973), but the arenite interbeds give spurious pebble segregation factors as the conglomerate fraction of the interbeds is generally very low (less than 10%) and the pebble segregation factors are accordingly very high.

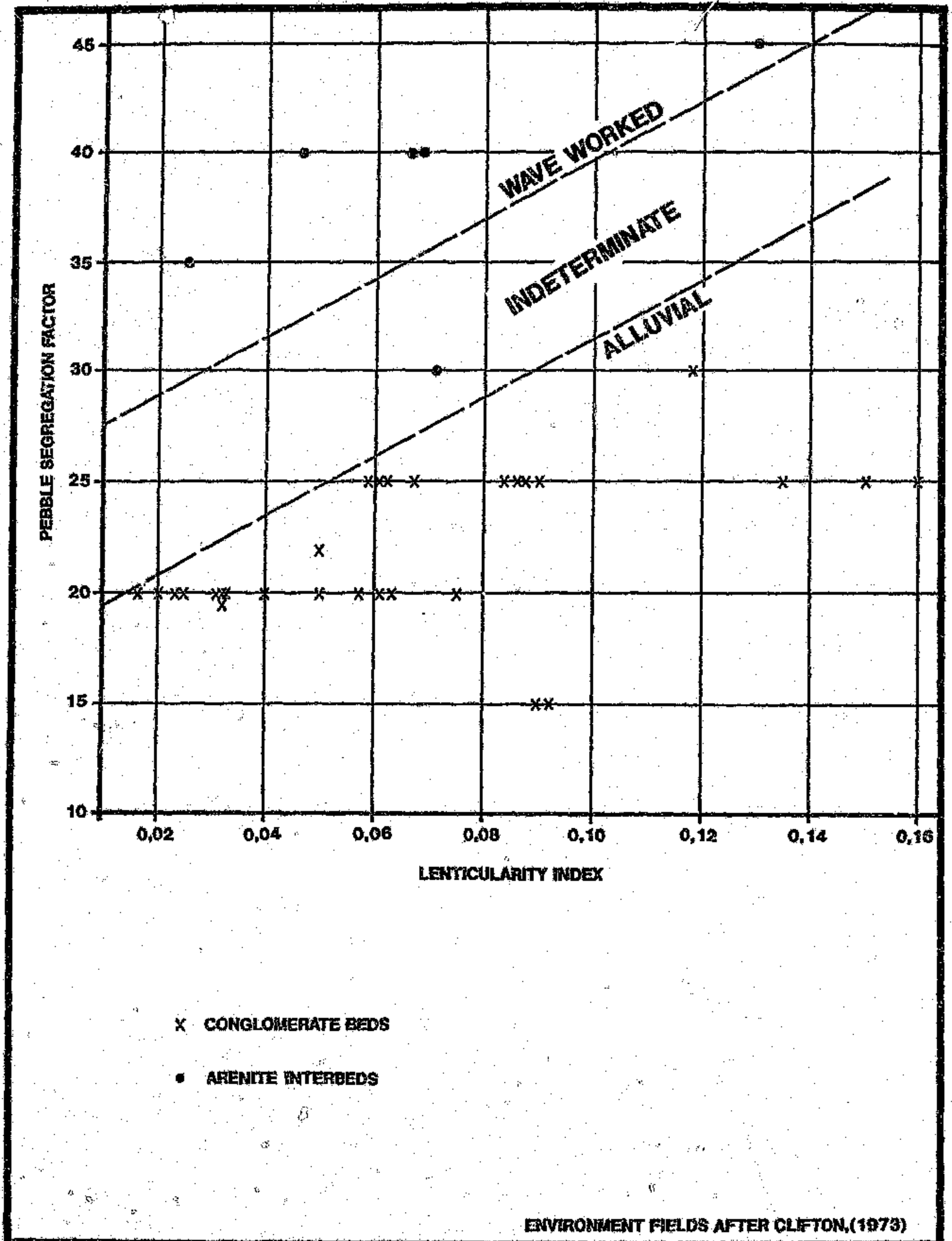

FIGURE 36: PEBBLE SEGREGATION FACTOR vs LENTICULARITY INDEX

3.4 FACIES OF THE ROSEDALE MEMBER HANGINGWALL

3.4.1 INTRODUCTION

The Rosedale Member (V.S. 4a) is the lowermost member of the Eldorado Formation and directly overlies the Beatrix Reef (Fig. 8). The contact with the Beatrix Reef is disconformable, but is locally unconformable where the coarser grained facies of the Rosedale Member have eroded into and removed parts of the Beatrix Reef.

Based on sedimentary structures and lithologies, four distinct sedimentary facies are recognised in the Rosedale Member viz.

polymictic conglomerate facies
trough crossbedded arenite facies
planar crossbedded arenite facies
heterolithic facies

The heterolithic facies is so named as it comprises rapid alternations of mud, silt and fine-grained arenite and sedimentary structures vary rapidly from horizontal lamination and plane bedding to ripple marking and small scale crossbedding.

3.4.2 THE CONTACT WITH THE BEATRIX REEF

It is known that in areas to the north of Beatrix Mine the Rosedale Member unconformably overlies the Aandenk Formation and has also truncated the Aandenk Formation and unconformably overlies the St Helena or Virginia Formations of the footwall successions. In these areas Beatrix Reef is either not developed or has also been removed through erosion and is represented by the unconformity at the base of the Rosedale Member. On Beatrix Mine the contact of the Rosedale Member with the Beatrix Reef is disconformable.

The lower part of the Rosedale Member is highly channeled although, due to the lack of sufficient underground exposure, it is not possible to fully document these channels or produce isopach maps of individual channels or units. Detailed mapping, at regular intervals, of a selected area to the northeast of Beatrix Mine's No. 1 Shaft has shown the channeled nature of the basal parts of the Rosedale Member and its relationship to the facies of the Beatrix Reef. In this study area the base of the Rosedale Member has a discrete, well defined, north south trending channel which has truncated and removed the Beatrix Reef (Figs. 37 and 38). The channel is a composite unit about 6 - 8 m wide and just over a metre in total depth. Scour surfaces within the channel show that it is a composite unit comprising at least four scour and fill episodes. The channel is filled with trough crossbedded quartz and lithic arenites and pebbly arenites. Conglomerates only occur as rare bar forms close to the banks of the channel and as lag layers a few pebble diameters thick on the scour surfaces.

Where the upper contact of the Beatrix Reef has been preserved below the finer grained facies of the Rosedale Member, such as the black shale and fine-grained lithic arenite, it occurs as a remarkably flat, planar surface conformably overlain by the fine-grained sediments (Fig. 39).

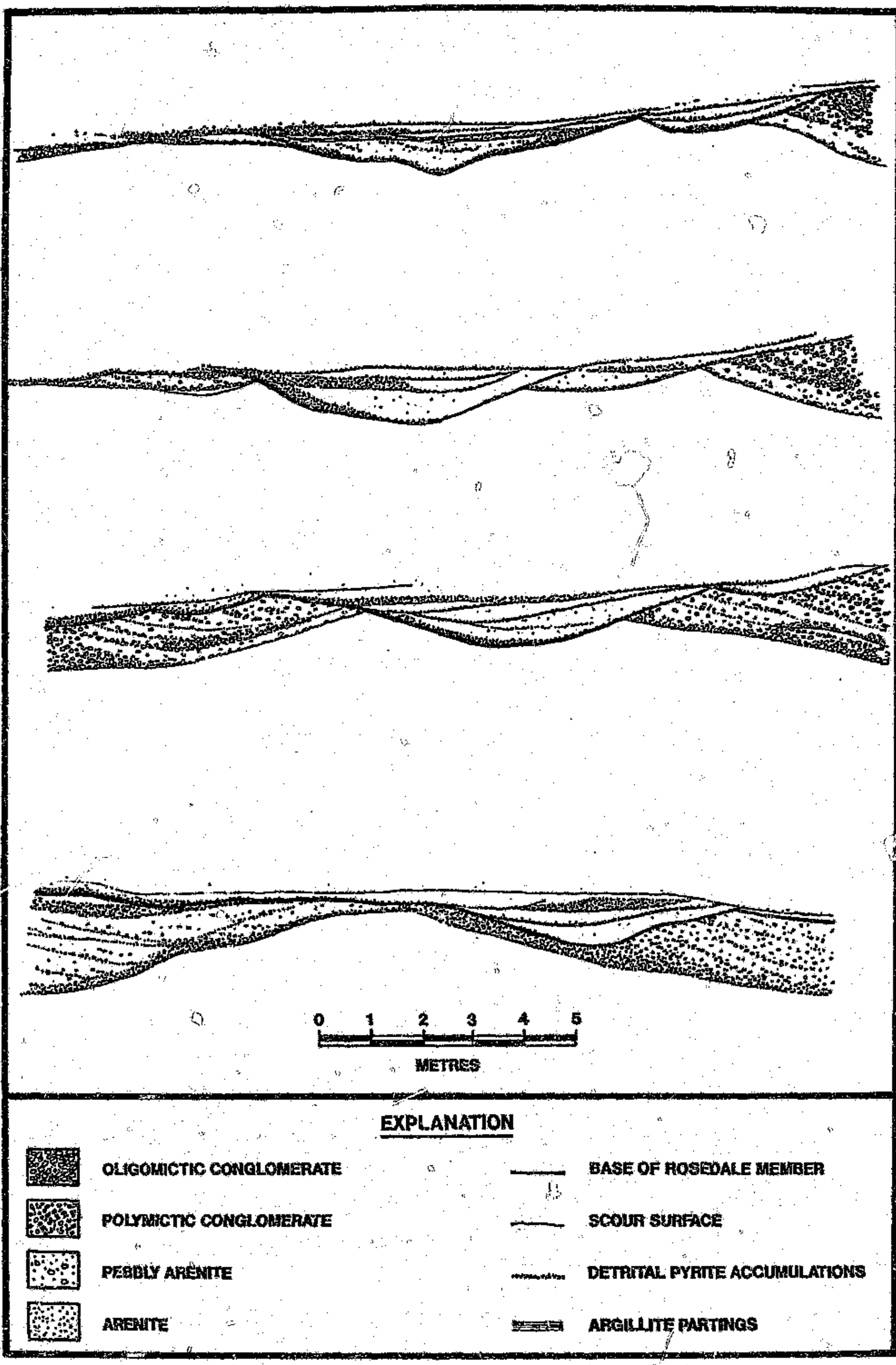

FIGURE 37: THE BASE OF THE ROSEDALE MEMBER IN 16B61 STOPE

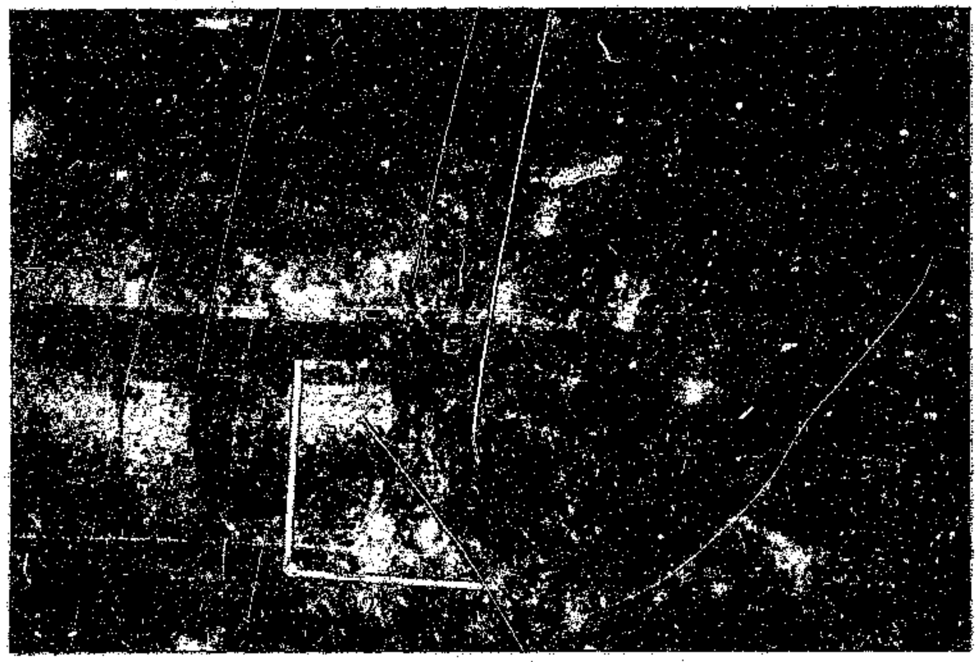

FIGURE 38: A DEEPLY INCISED CHANNEL AT THE BASE OF THE ROSEDALE MEMBER SCOURING INTO THE BEATRIX REEF

FIGURE 39: FINE GRAINED LITHOLOGIES OF THE ROSEDALE MEMBER CONFORMABLY OVERLYING THE BEATRIX REEF

3.4.3 THE POLYMICTIC CONGLOMERATE FACIES

The polymictic conglomerate facies is, as the name implies, characterised by a polymictic clast assemblage (Fig. 40). The clasts are noticably smaller and less well-rounded than within the oligomictic conglomerate facies of the Beatrix Reef. The clasts consist of quartz, chert, quartzite, silicified shale (yellow and grey) and other rock fragments such as acidic igneous rocks. Rock types other than quartz or chert form up to 30% of the clast population. The average clast size in the pebble counts done in underground exposures at No. 1 shaft is 12 mm. The matrix of the polymictic conglomerates consists of lithic arenite in which chert and silicified shale grains impart a distinct speckling.

The polymictic conglomerate facies is very similar to the V.S. 5 conglomerate which occurs at the base of the Rosedale Member in areas to the north and northeast of the Mine (Fig. 41), and probably represents southerly channel extensions of the coarser phases (V.S. 5) of the Rosedale Member. The V.S. 5 conglomerate per se does not occur on Beatrix Mine.

On Beatrix Mine the polymictic conglomerate facies tends to be confined to discrete channels up to 100 m wide and over 1 m deep, and is more prevalent in the northern parts of the Mine.

The conglomerates are generally trough crossbedded in sets 10 - 15 cm thick, although some low angle, inclined stratification occurs in parts. Horizontal stratification such as observed in the oligomictic conglomerate facies does not occur in the polymictic conglomerates. The crossbedding results from the accretionary migration of large, lunate ripples

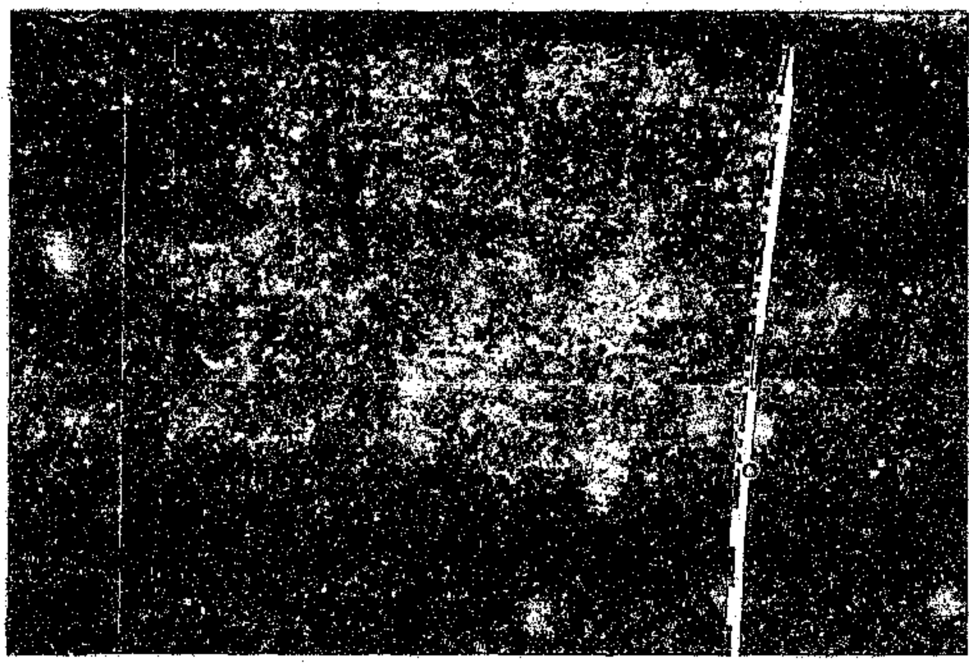

FIGURE 40a: POLYMICTIC FACIES REEF. NOTE THE SMALL CLAST SIZE AND ABUNDANT ROCK FRAGMENTS.

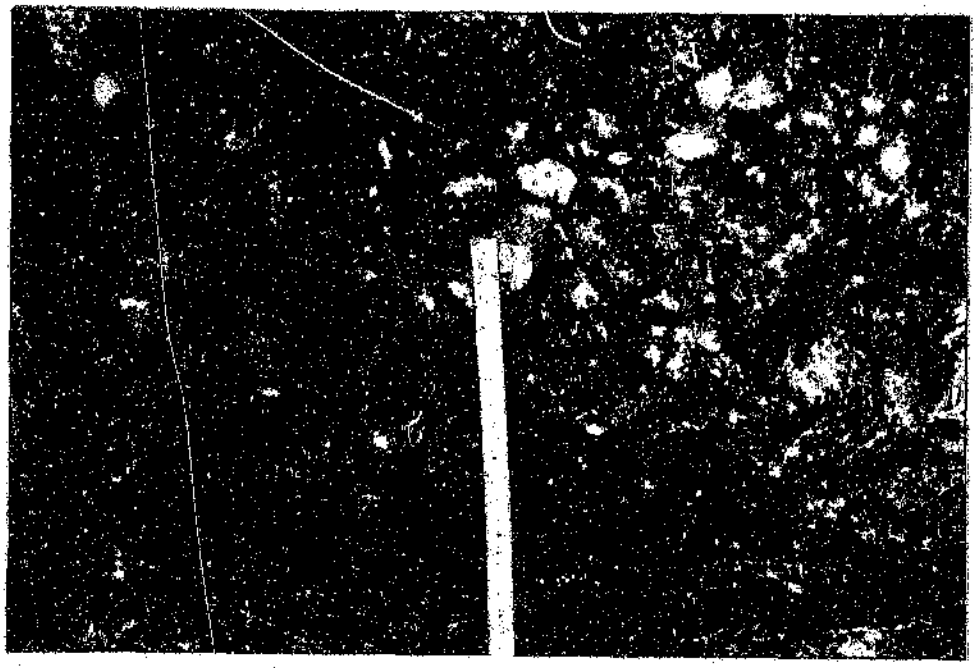

FIGURE 40b: ROSEDALE MEMBER LAG CONGLOMERATE UNCONFORMABLY OVERLYING "A" FACIES REEF. CLASTS IN THE LAG CONGLOMERATE ARE SCAVANGED FROM THE REEF.

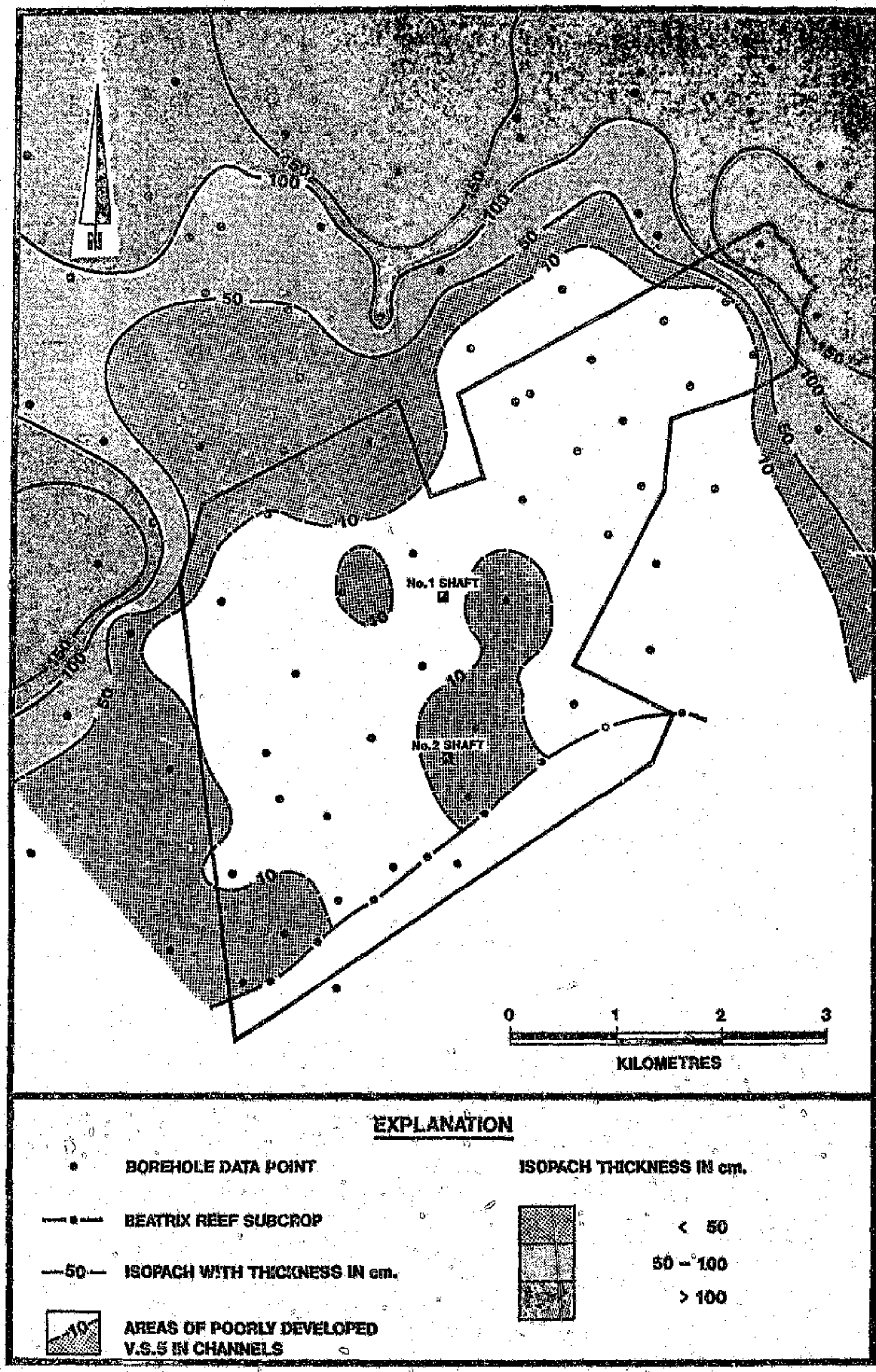

FIGURE 41: DISTRIBUTION AND ISOPACHS OF THE V.S.5 CONGLOMERATE

(Southard, 1971), or the accretionary migration of gravel bars with low riffle margins (Smith, 1974). The minimum water depths envisaged for this deposition are in the order of half a metre deep (using the rule of Harms et al., 1975).

The polymictic conglomerate facies also occurs as thin, lag conglomerate layers up to 5 cm thick at the base of crossbedded arenite units (Fig. 40b). In these cases it is obvious from the clast morphology and composition that the clasts have been scavanged from the underlying Beatrix Reef during scouring into the top of the reef by the Rosedale Member. Deposition of these lag conglomerates would be by rolling clasts along the bed.

3.4.4 THE TROUGH CROSSBEDDED ARENITE FACIES

The most common facies in the Rosedale Member consists of 5 to 15 cm thick sets of trough crossbedded arenite. The trough shaped scours are frequently preserved on the hangingwall of the stopes where it is seen that these scours are up to 40 cm wide and 5 cm deep. The orientation of these scours, and the cusp lines between scours, give a good indication of the palaeocurrent trend and are generally orientated north-south.

The arenites are fine to medium grained and contain up to 10 % black argillaceous material in the matrix. Foresets are frequently defined by variations in the argillite content, and lithic-fragment granules may accumulate on foreset toes.

The trough crossbedding forms by the accretionary migration of large, lunate ripples (Southard, 1971) and indicates unidirectional flow with significant velocity and depth (Southard, 1971 and Harms et al., 1975).

3.4.5 THE PLANAR CROSSBEDDED ARENITE FACIES

Planar crossbedding is also fairly common in the Rosedale Member arenites, occurring in sets about 15 cm thick (Fig. 42), and having a maximum thickness of 50 cm. Changes in the foreset dip angle within some crossbed sets suggest reactivation surfaces.

Planar crossbedding forms by the accretionary migration of straight crested ripples or sandwaves (Allen, 1963). The minimum inferred water depth for the deposition of the planar crossbed sets observed in the lower parts of the Rosedale Member is in the order of half a metre (using the rule of Harms et al., 1975). Comments regarding the reactivation surfaces and their origin are the same as those mentioned in the planar crossbedded pebbly arenite facies of the Beatrix Reef.

3.4.6 HETEROLITHIC FACIES ASSOCIATION

Within the fine-grained sediments at the base of the Rosedale Member overlying the Beatrix Reef, horizontal lamination is extremely common. Sets are only a few millimetres thick (Fig. 43) and consist of alternating black argillite and fine arenite. The upper surfaces of the sets are frequently ripple marked, but ripple lamination is rare. The mixed supply of argillite and fine-grained arenite results in lenticular and wavy bedding with isolated and connected, ripple-marked arenite lenses in the black argillite (Fig. 44). In addition loading of this unit has produced load structures, particularly ball and pillow structures and convolute bedding (Fig. 45).

A number of surface sedimentary structures are preserved on

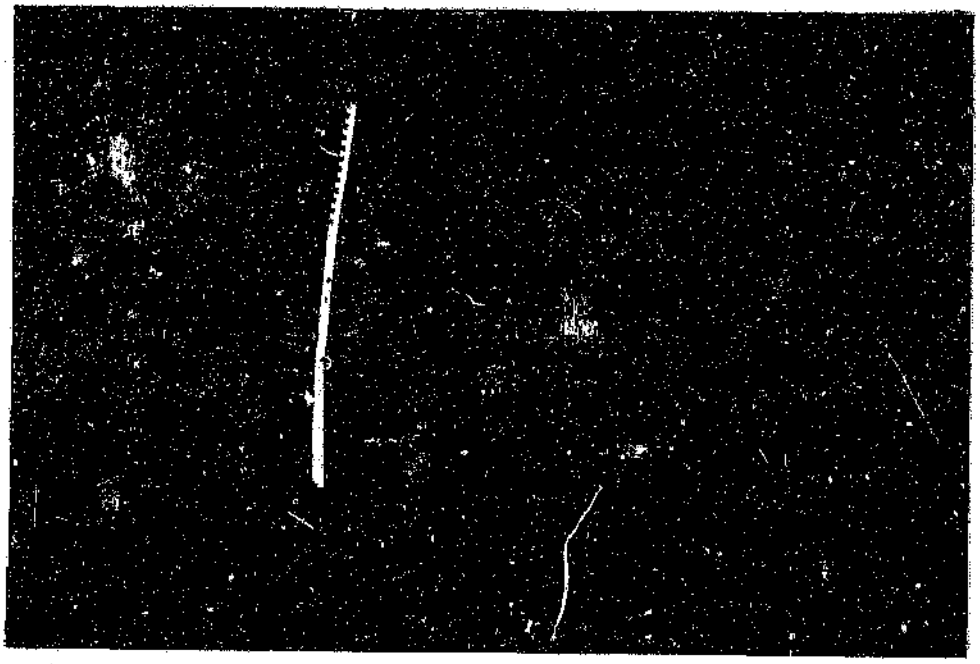

FIGURE 42: PLANAR CROSSBEDDING IN ROSEDALE MEMBER ARENITES OVERLYING THE REEF. NOTE THE REACTIVATION SURFACE TO THE LEFT OF THE SCALE RULE.

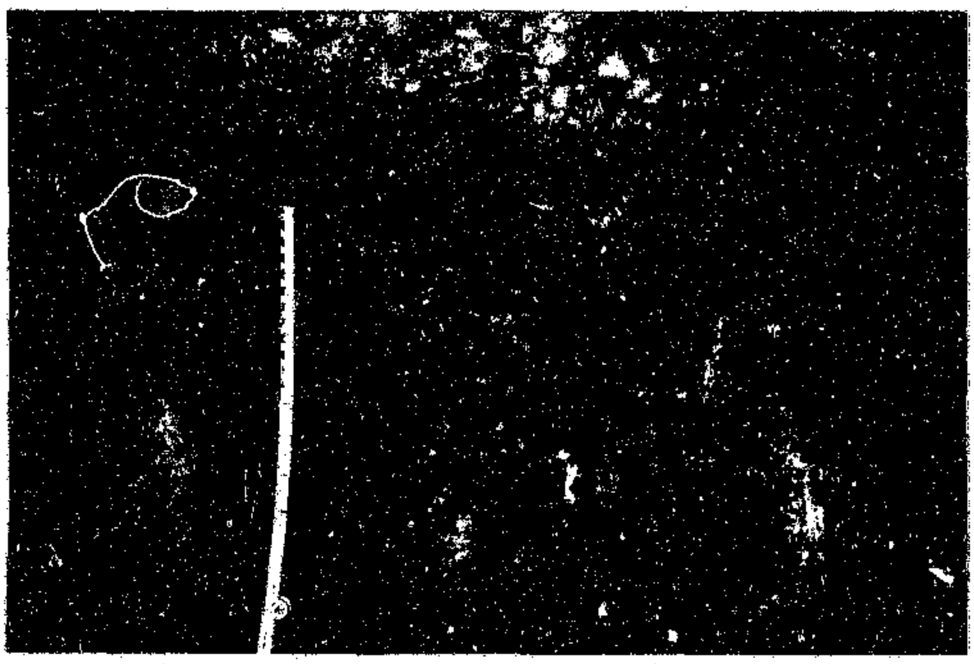

FIGURE 43: HORIZONTALLY LAMINATED AND RIPPLE MARKED ARENITE AND ARGILLITE AT THE BASE OF THE ROSEDALE MEMBER

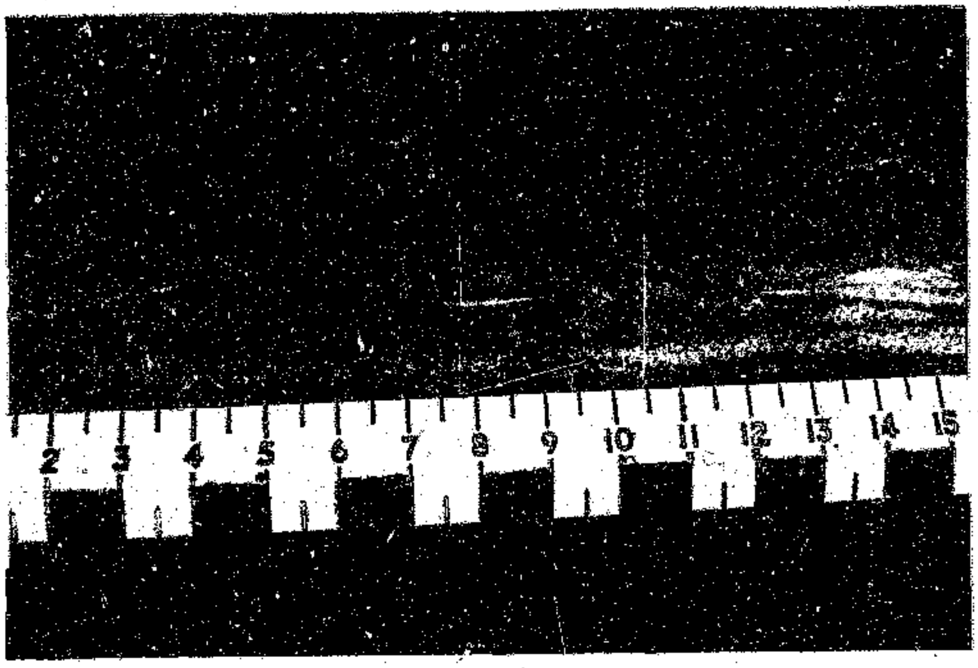

FIGURE 44: INTERBEDDED ARENITE AND ARGILLITE DISPLAYING LENTICULAR AND WAVY BEDDING

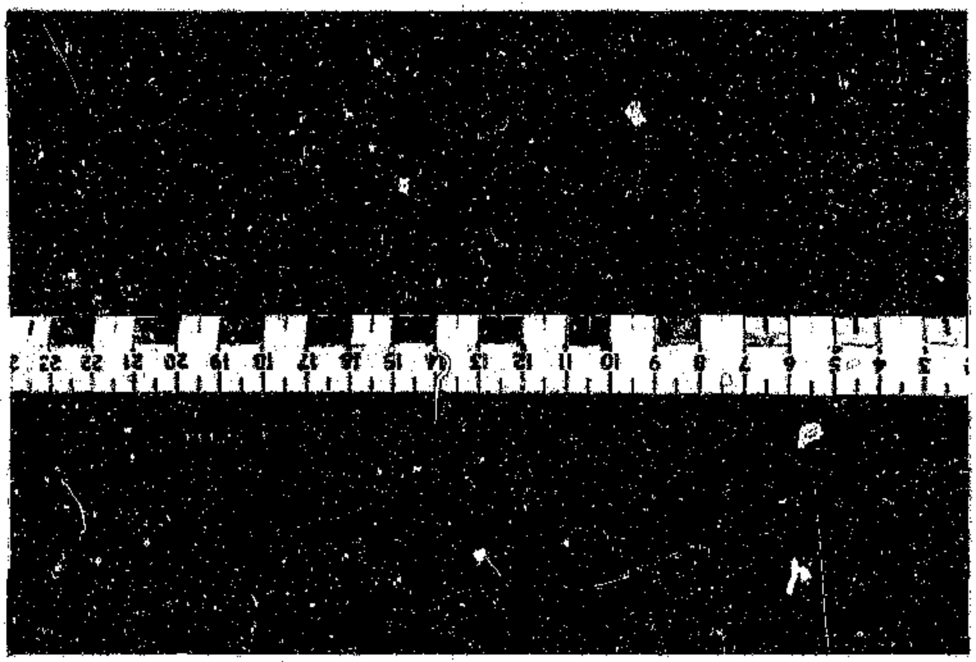

FIGURE 45: BALL AND PILLOW LOAD STRUCTURES FROM THE INTERBEDDED ARENITE AND ARGILLITE UNIT AT THE BASE OF THE ROSEDALE MEMBER

the bedding planes of the heterolithic facies. The most common of these are as follows

- symmetrical and asymmetrical ripple marks
- interference ripple marks and ladderback ripples
- mudcracks
- raindrop imprints or rinzel marks
- obstacle marks or current crescents

Ripple marks are particulary common and occur as casts wherever a black argillite parting is exposed on the hangingwall of the stope. Symmetrical ripple marks are the most common and have a wavelength of 1 - 3 cm and an amplitude of half a centimetre (Figs. 46 and 47). Ripple crests are straight or partly bifurcating, and in spite of a fairly high degree of variance, are most commonly oriented east - west (Fig. 48a). This ripple crest orientation is consistent throughout the Mine. In parts the ripple marks may be asymmetrical with fairly definate stoss and lee sides. Measurement of the indicated palaeocurrent direction from the ripple asymmetry suggests a bimodal direction with a north to south trend dominant (Fig. 48b). This bimodality may result from oscillation asymmetry under the influence of current flow in the two, different indicated directions, but is more likely a result of the difficulty in unambiguously determining the stoss and lee sides of ripples that are essentially symmetrical.

Occasionally in the larger ripples (wavelength 3 cm) secondary, smaller ripple crests are developed in the troughs of the ripples (Fig. 47). Interference ripples, formed from the interference of ripple trains of different orientation, occur

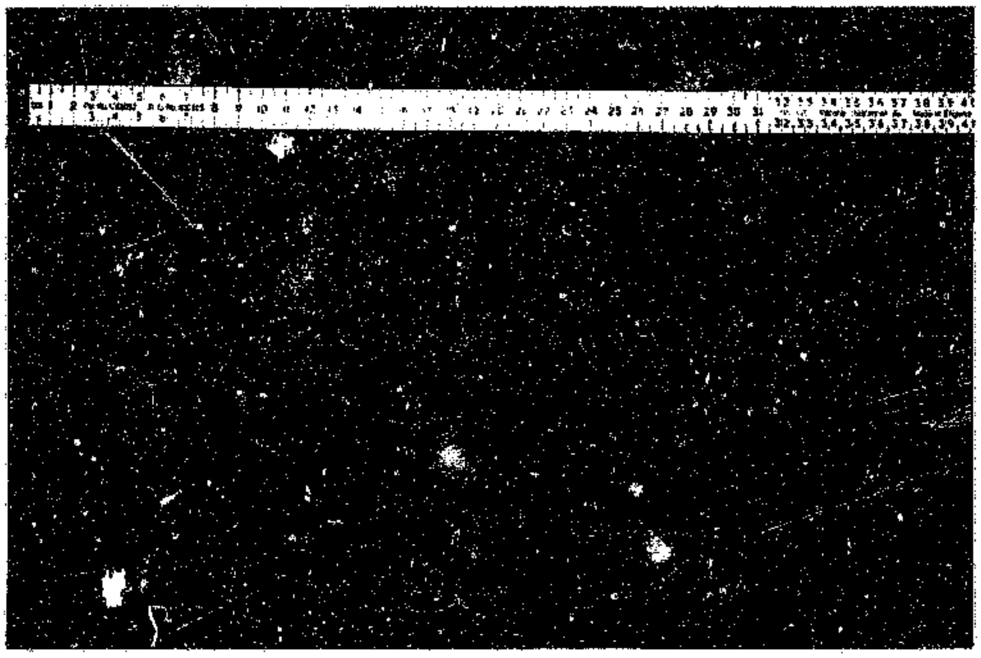

FIGURE 46: SYMMETRIC, OSCILLATION RIPPLE MARKS FROM THE LOWER PARTS OF THE ROSEDALE MEMBER

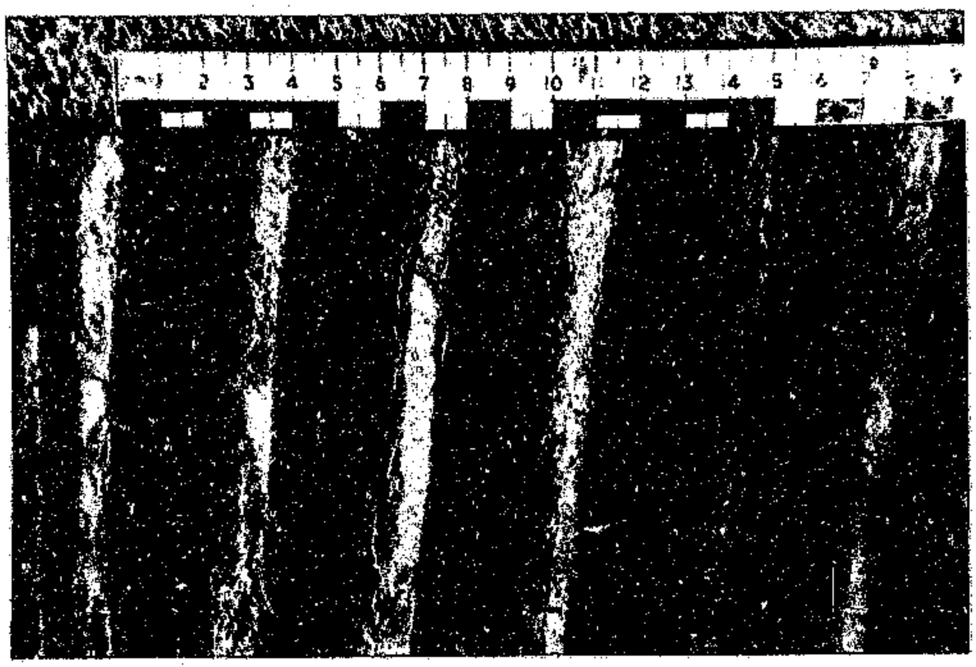

FIGURE 47: SYMMETRIC RIPPLE MARKS WITH SMALLER CRESTS IN THE TROUGHS OF THE LARGER RIPPLE TRAIN

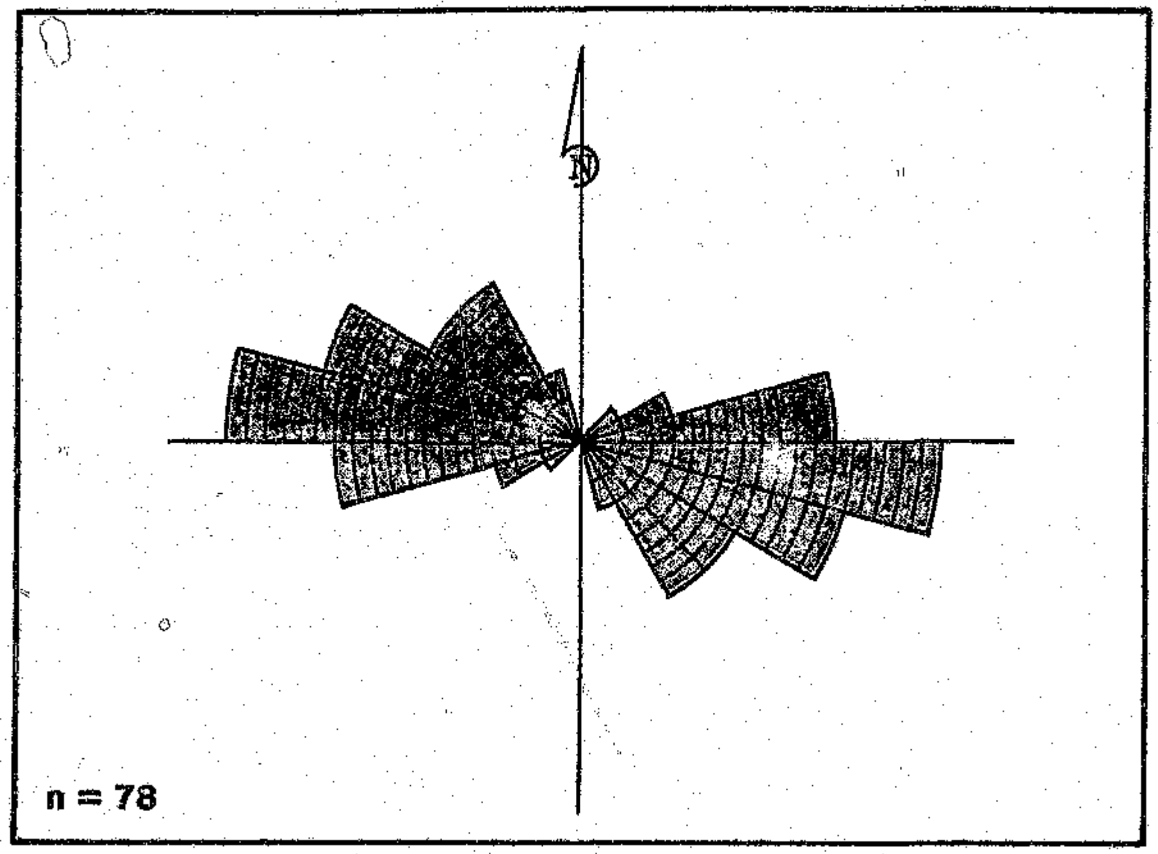

FIGURE 48a: ROSE DIAGRAM OF V.S.4a WAVE RIPPLE CREST ORIENTATIONS

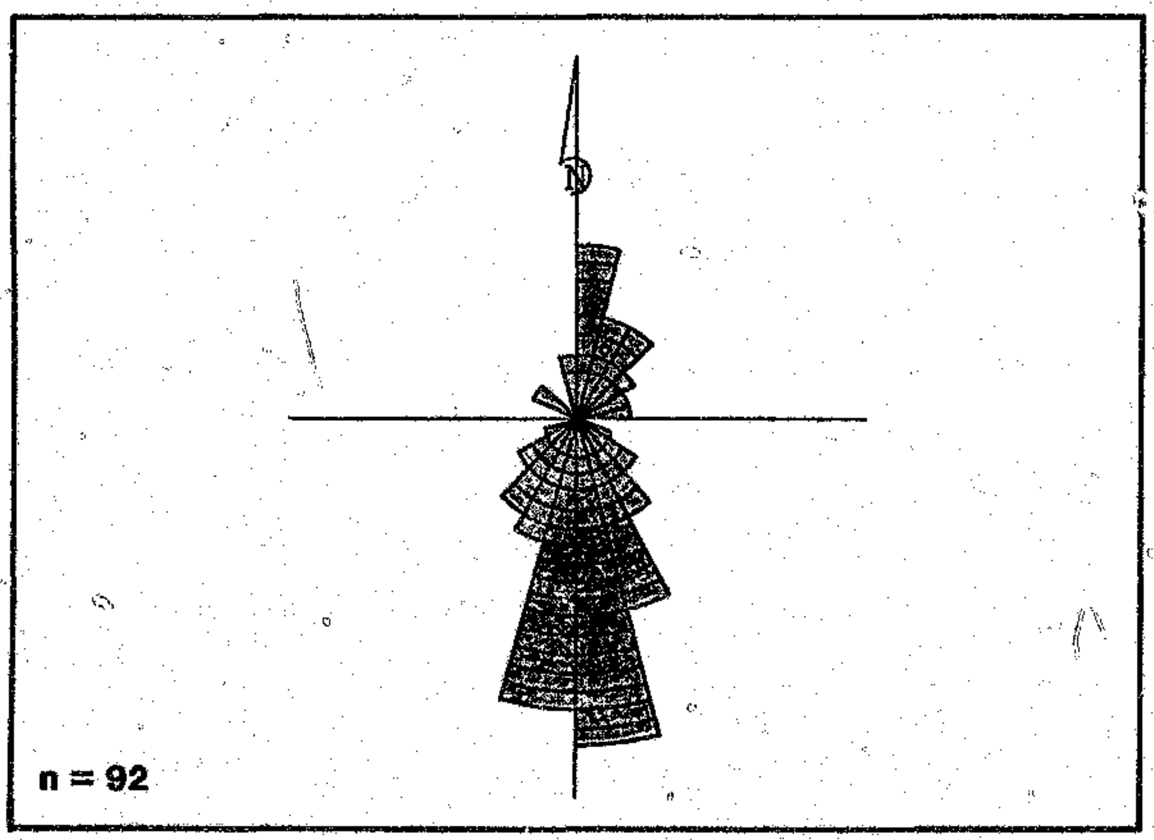

FIGURE 48b: ROSE DIAGRAM OF V.S.4a ASYMMETRIC RIPPLE CURRENT AZIMUTHS

in parts, but are usually isolated occurrences confined to small areas. Ladder-back ripples, a special class of interference ripple, have been noted in the No. 1 Shaft area. The ladder-back ripples comprise a primary set of ripples with a wavelength of 20 cm which are remarkably flat topped and have an amplitude of 1,5 cm. In the troughs of this primary ripple set, at right angles to their trend, is a set of smaller ripples with a wavelength of 2 cm (Fig. 49).

Mudcracks have also been noted on the argillite partings throughout the Mine (Fig. 50). The mudcracks form a pronounced polygonal pattern with polygons in the order of 10 - 30 cm in size. In places the mudcracks occur on ripple marked surfaces, in which case the ripple troughs have influenced the orientation of the cracks. Where seen in section the mudcracks have a poorly defined "V" cross-section and extend to less than 2 cm into the substrate.

Other marks that occur on the argillite partings consist of irregular, partly connected depressions and narrow ridges less than 1 mm in size. These are inferred to be raindrop imprints or wrinkle marks (rinzel marks). Wrinkle marks are produced on sediment surfaces that are partly cohesive. If such a sediment surface is covered by only a very thin film of water (up to 1 cm), and if a strong wind blows over it, the surface develops wrinkles (Reineck and Singh, 1975). Wrinkle marks are a good indicator of intermittent emergence of the sediment surface.

The majority of the ripple marks preserved in the heterolithic facies at the base of the Rosedale Member are

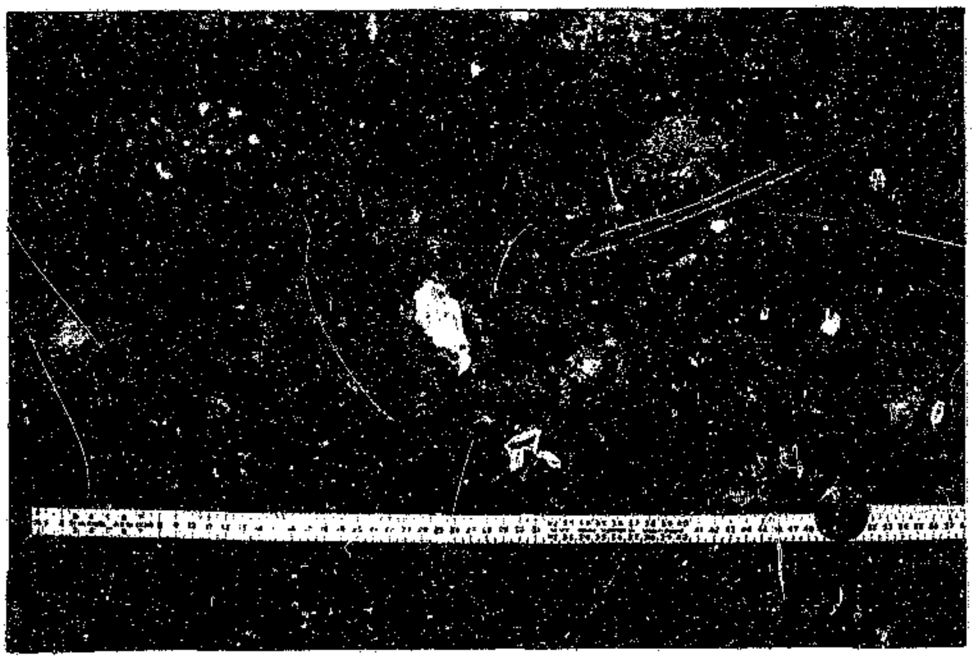

FIGURE 49: LADDER – BACK RIPPLE MARKS FROM THE LOWER PARTS OF THE ROSEDALE MEMBER

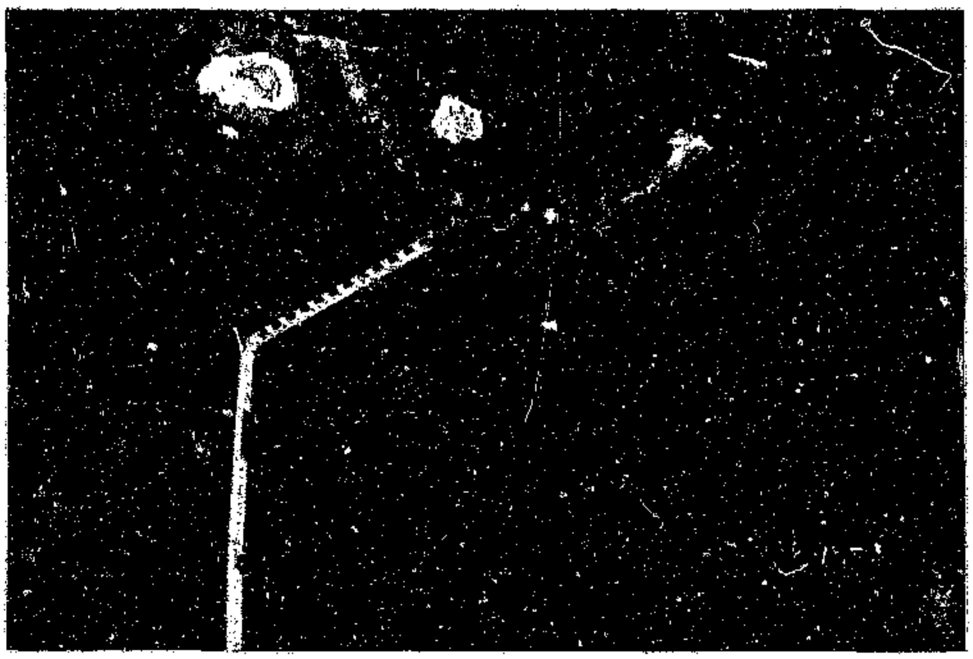

FIGURE 50: MUDCRACK IMPRESSIONS IN THE ARGILLITES AT THE BASE OF THE ROSEDALE MEMBER

symmetrical, or wave ripples (Fig. 46). Symmetrical ripple marks are formed by the regular oscillation of the water body across a sediment substrate. The ripple indices and short wavelength suggest deposition and formation in shallow water (Komar, 1974, Allen, 1981 and Diem, 1985). The presence of wave ripples interbedded with the horizontal lamination in fine-grained sediment (less than 0,25 mm grain size), indicates maximum flow velocities of 60 - 80 cm/sec (Allen, 1970). Such symmetrical, oscillation ripple marks are frequently documented from shallow marine settings (Clifton and Dingler, 1984; Diem, 1985), but also occur in lacustrine or abandoned fluvial channel settings. The frequent occurrence of secondary, smaller ripple crests in the troughs of the larger ripples (Fig. 47) indicates shallowing water during deposition.

Interference ripple marks, and particularly ladder-back ripples, are formed when the oscillation direction during falling water stage is different to the transport direction during the deposition of the original ripple train. Conditions for the formation of ladder-back ripples are often encountered in tidal environments where ebb and flow direction and strength are different.

The ripple mark characteristics all suggest deposition in very shallow water, a supposition supported by the occurrence of mudcracks (Fig. 50), frequently on the rippled surfaces. Other sedimentary structures which attest to periods of subaerial exposure are the raindrop imprints and wrinkle marks.

In spite of the abundance of ripple marking in the argillites and fine-grained arenites, ripple lamination is rare. McKee

(1965), in his experiments on ripple lamination, noted that it does not necessarily occur in areas of ripple marking. An essential factor in forming appreciable deposits of ripple laminated sand is the introduction of an abundance of sediment into an area of ripple movement (McKee, 1965). Ripple lamination is thus commonly observed on river flood plains where bank overflow introduces abundant sediment (McKee, 1965). Large areas of ripple marking without ripple lamination occur frequently on tidal flats because of the lack of sediment supply and the constant redistribution by ebb and flow.

The convolute bedding and ball and pillow structures (Fig. 45) point to rapid sedimentation and gravitational instability (Potter and Pettijohn, 1963) but are not diagnostic of any particular environment, having been described from deep water turbidites, marginal marine (tidalites) and fluvial settings. Lenticular and flaser bedding have been described by Reineck and Wunderlich (1968) and forms by the regular alternation of two types of bedding. Lenticular bedding (Fig.44) is produced when incomplete sand ripples are formed on a muddy substrate and preserved as a result of the deposition of the next mud layer (Reineck and Wunderlich, 1968), and are thus produced under conditions more favourable for the deposition of mud. From the mode of formation requiring periods of wave or current action alternating with periods of slack water, the preferred environments for the formation of lenticular bedding are thus intertidal and subtidal zones (Reineck and Wunderlich, 1968).

3.4.7 PALAEOCURRENT INDICATORS IN THE ROSEDALE MEMBER

The orientation of the trough shaped scours, and the cusp lines between the scours, provide an indication of the palaeocurrent trend, and show a predominantly north-south orientation (Fig. 51a). Palaeocurrent measurements from trough and planar crossbedding in the Rosedale Member arenites confirm a north to south palaeocurrent direction (Fig. 51b).

A north to south palaeocurrent direction is further supported by the orientation of ripple mark crestlines and the current azimuths deduced from the asymmetrical ripple marks (Figs. 48a and 48b).

3.5 FACIES ASSOCIATIONS OF THE ELDORADO FORMATION

3.5.1 ROSEDALE MEMBER

Much of the description of the facies has been confined to the lowermost metre of the Rosedale Member as this is all that is usually exposed during underground stoping operations on Beatrix Mine. From the detailed logging of exploration borehole cores on the Mine lease, and areas to the northwest of the Mine, regional variations in the lithology and facies sequences of the Rosedale Member and the Eldorado Formation become apparent.

From the mixed polymictic conglomerate, trough crossbedded arenite, and heterolithic facies at its base the Rosedale Member coarsens upward to polymictic conglomerate and granulestone and coarse-grained, trough crossbedded arenites. The sediments then become finer grained and form a sequence of

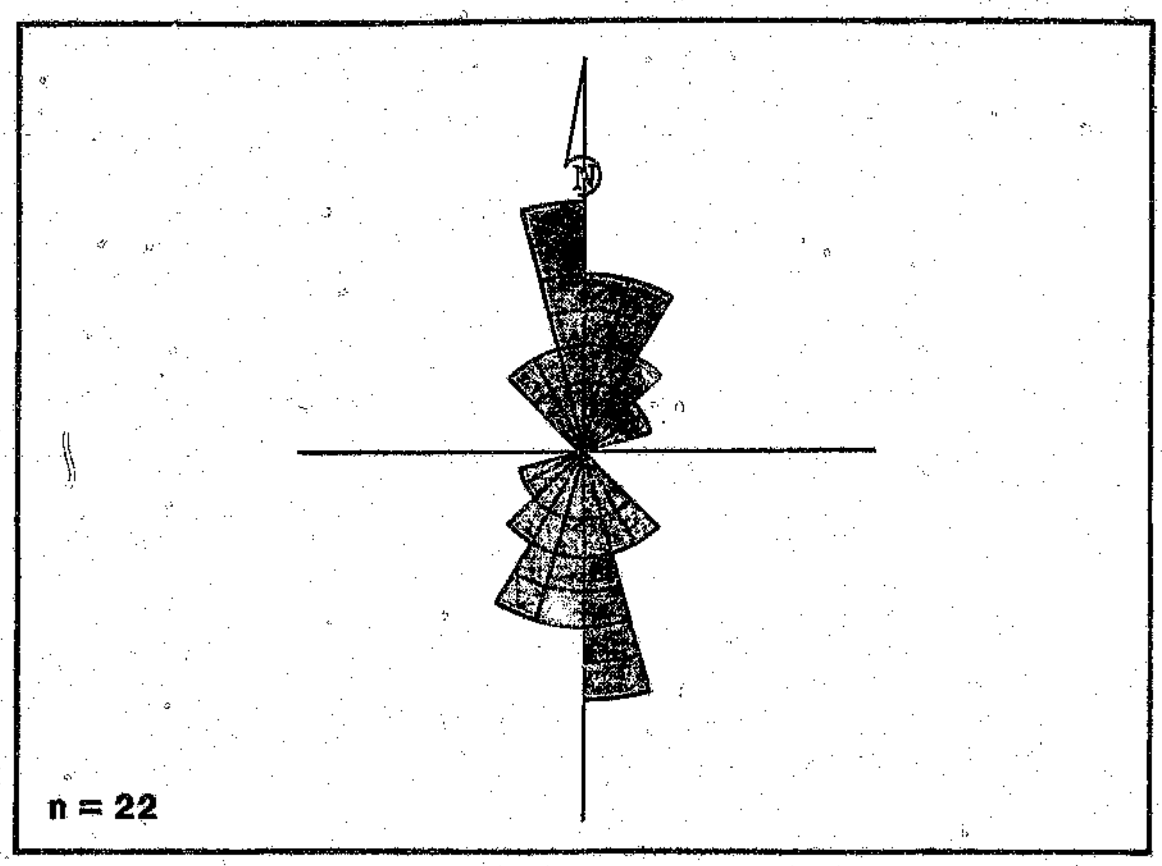

FIGURE 51a: ROSE DIAGRAM OF ROSEDALE MEMBER TROUGH AXES TRENDS

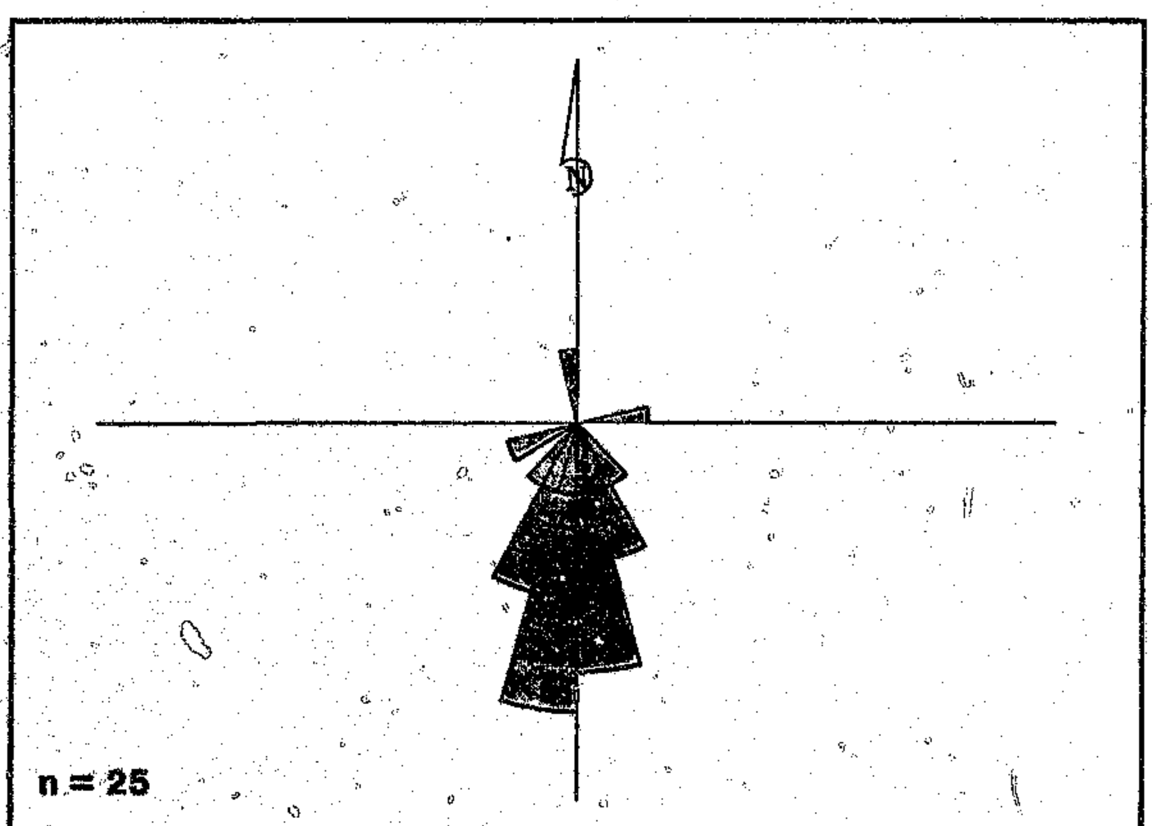

FIGURE 51b: ROSE DIAGRAM OF ROSEDALE MEMBER CROSSBEDDING AZIMUTHS

crossbedded lithic arenites overlain by a 2-3 m thick sequence of ripple-marked and horizontally-laminated fine-grained lithic arenite and black argillite. This unit occurs at a distance of 25 m above the Beatrix Reef and marks the top of the Rosedale Member (Fig. 52). This fine-grained mudrock is regionally persistant and is used as a useful stratigraphic marker. Average clast sizes of the Rosedale Member conglomerates (V.S. 5), measured as the average of the 15 largest clasts in the borehole intersection, vary from 50 mm at Oryx Mine to about 8 mm in the Beatrix Mine area (Fig. 53). Similar changes in clast size in the conglomerates of the Uitkyk Member are also apparent but have not been documented in detail in this study.

3.5.2 VAN DEN HEEVERSRUST AND UITKYK MEMBERS

The Van Den Heeversrust Member (coarse-grained lithic arenite) and the Uitkyk Member (conglomeratic) form an overall upward coarsening sequence for the Eldorado Formation. (cf Fig. 8). Rapid grain size variation and facies changes similar to those documented by Kingsley (1987) are apparent in the Eldorado Formation in a northerly and westerly direction. The Eldorado Formation intersected in exploration boreholes in the Oryx Mine area is essentially conglomeratic as opposed to the essentially arenaceous sequences at Beatrix Mine (Fig. 54).

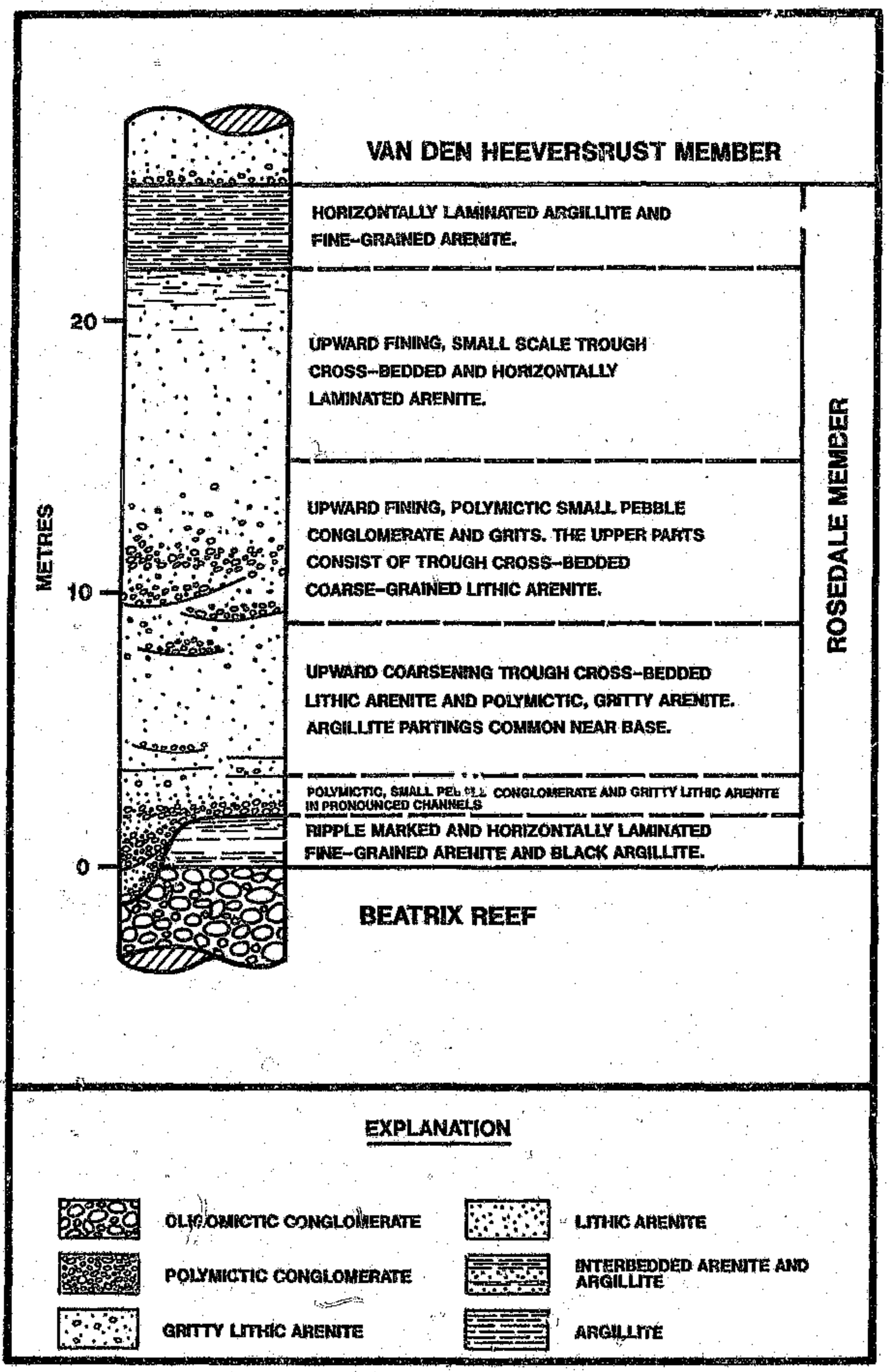

FIGURE 52: LITHOLOGICAL FACIES OF THE ROSEDALE MEMBER IN THE BEATRIX AREA

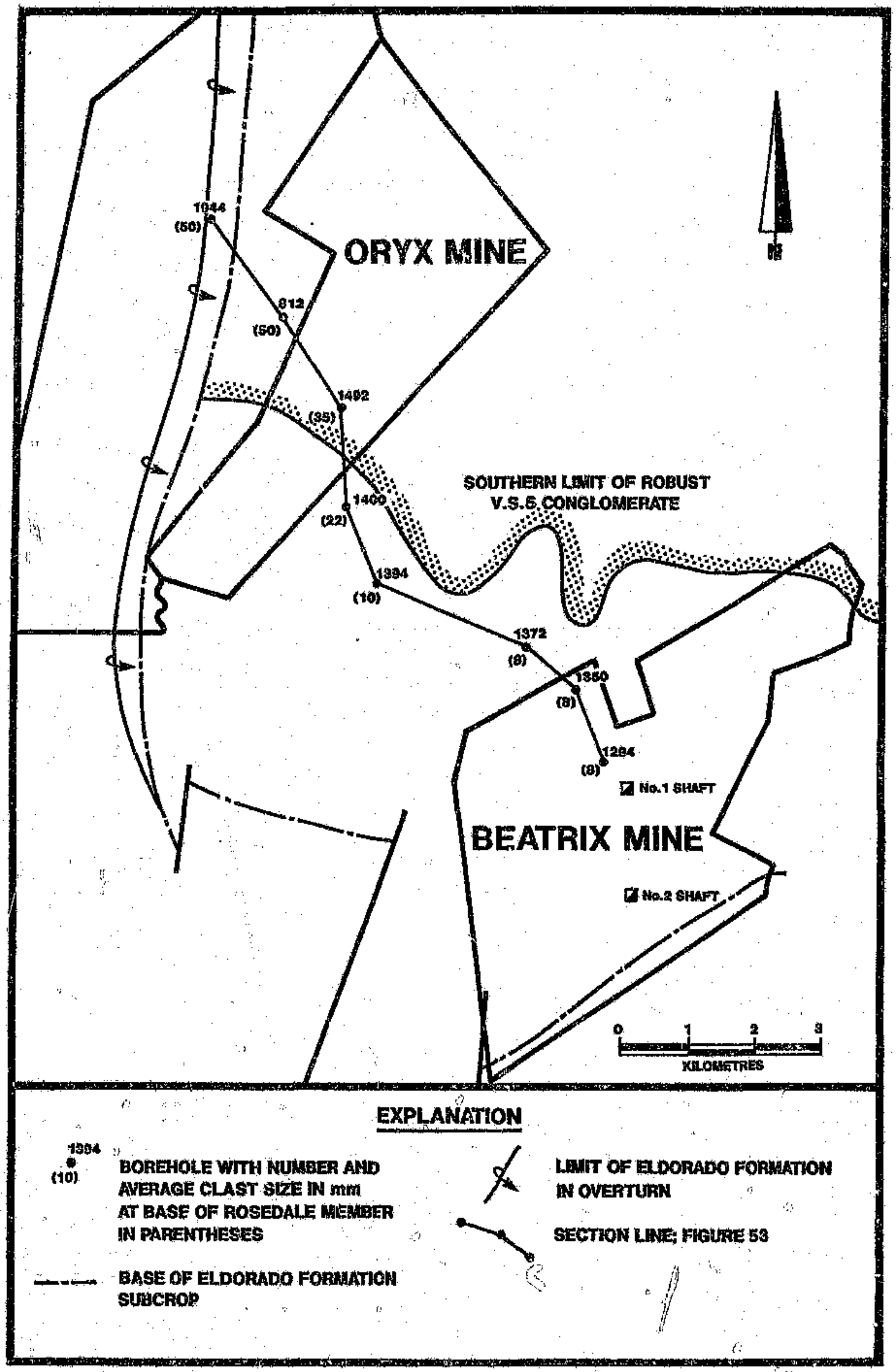

FIGURE 53: AVERAGE ROSEDALE MEMBER CLAST SIZE IN BOREHOLES BETWEEN BEATRIX AND ORYX MINES

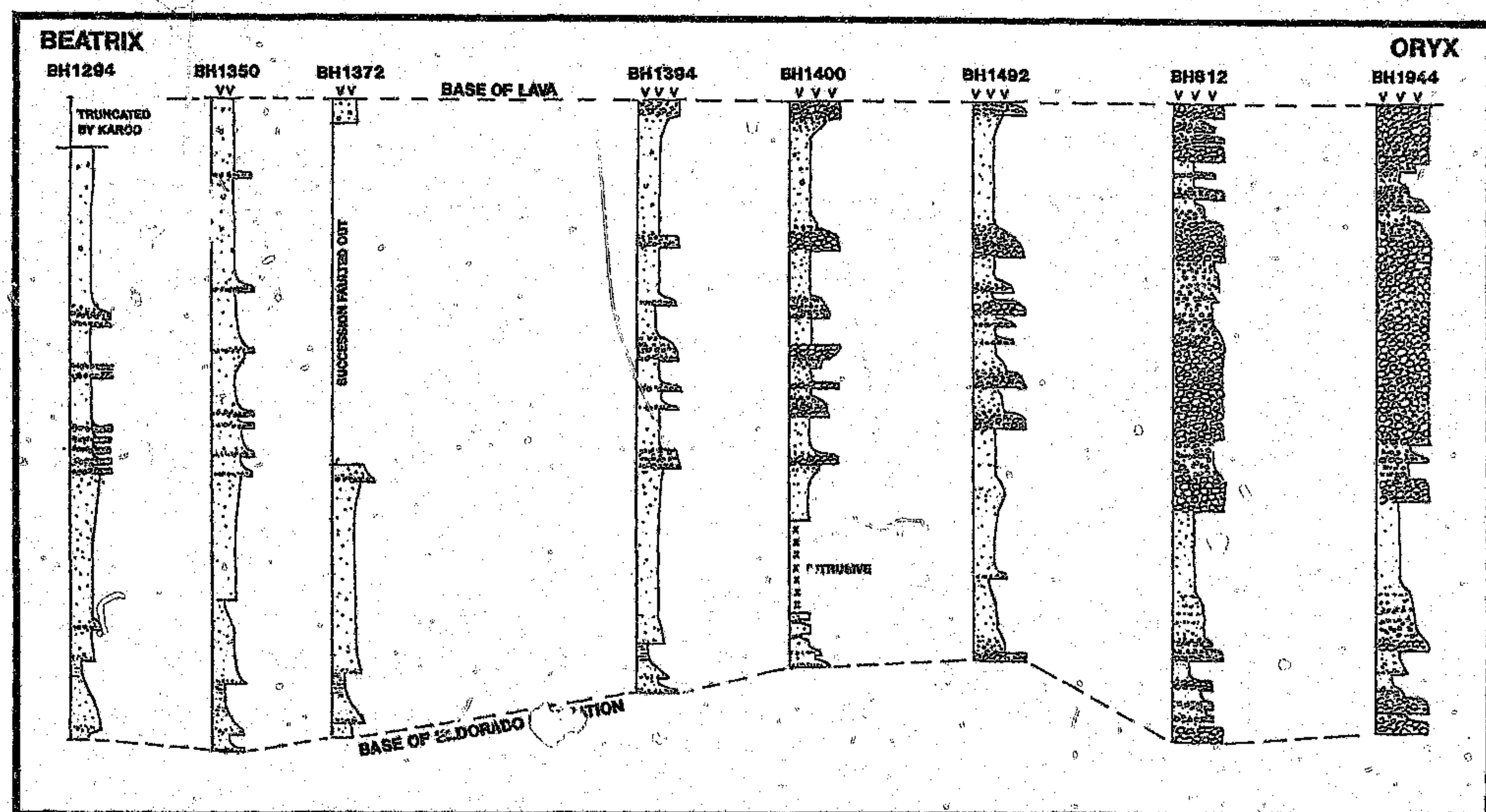

FIGURE 54: LITHOLOGIC CHANGE IN THE ELDORADO FORMATION BETWEEN BEATRIX AND ORYX MINES

4 DEPOSITIONAL MODELS AND PALAEOENVIRONMENTS

4.1 GENERAL PRINCIPLES OF DEPOSITIONAL MODELS

A depositional sedimentary environment can be defined in terms of physical, biological, chemical, or geomorphic variables. Such a place of deposition is characterised by a unique set of physical, biological and chemical processes acting at a specified rate and intensity which impart sufficient imprint on the sediment so that a characteristic deposit (facies) is produced (Pettijohn, 1957). A sedimentary facies is thus the result of deposition in a given environment, and will possess characteristics related to the process of formation within that specific environment.

The presence or absence of individual sedimentary features or facies cannot generally be used as a positive sign in environmental interpretation. Most of the structures or facies can occur in several environments. It is generally the spectrum of sedimentary structures and their presence in certain combinations that provide direct clues in environmental interpretation. Certain associations of sedimentary structures and sequence of facies associations are typical for specific environments (Reineck and Singh, 1975).

The study of present-day depositional environments has provided vast information, on the basis of which depositional models can be constructed. However, such models should be considered no more than "models", because many variations in deposits of similar environments are possible (Reineck and Singh, 1975).

In the study of ancient sedimentary rocks the probable palaeoenvironment of deposition can thus be determined once the processes of formation of individual facies and sedimentary structures are ascertained, and the sequence of facies and structures are compared with depositional models determined from the study of present-day depositional environments.

4.2 THE UNCONFORMITY SURFACE AT THE BASE OF THE BEATRIX REEF

The very close association of the Beatrix Reef with an unconformity surface suggests that, as with the majority of Witwatersrand palaeoplacers, the angular unconformity surface is important in the genesis of the reef. An angular relationship of about 2 degrees has been mapped out using isopachs of the upper unit (L.F.1 zone) of the Virginia Formation to quantify the degree of truncation of the footwall beds (Fig. 10). Remnants of the Aandenk Formation unconformably overlying the Virginia Formation are preserved below the unconformity at the base of the Beatrix Reef in the northern parts of the mine. This is evidence that the truncation of the Virginia Formation is also due to erosion during the formation of an unconformity at the base of the Aandenk Formation. The correlation of placers of the Aandenk and Spes Bona Formations in the area south of the Sand River is problematical (cf. Section 2.4) because of the partial truncation of the Spes Bona Formation by Aandenk unconformities (at the bases of the Aandenk Channel and Aandenk Formation). In view of the relief of the Aandenk Channel unconformity (Winter, 1964b) and its basin-wide correlation (Tankard et al., 1982 and Minter et al.,

1986) it is probably this unconformity that extends southwards to the Beatrix Mine area and is responsible for much of the truncation of the footwall succession prior to the erosion forming the unconformity at the base of the Beatrix Reef.

The data from Beatrix Mine show the morphology of the unconformity surface at the base of the Beatrix Reef as a flat, extensive surface resulting from the combined effects of periods of erosional truncation prior to the deposition of both the Aandenk Formation and the Beatrix Reef. The isopachs of the L.F.1 unit of the Virginia Formation (Fig. 10) trend northwest southeast and are slightly curved depicting a broad synformal structure. Minor irregularities due to channeling at the base of the reef are also evident. Bed relief indices are fairly high and show that in spite of being a regionally flat surface, the unconformity surface shows considerable, local relief (Figs. 11a and 11b). This information suggests that the unconformity surface formed as a result of erosion due to a shift in the base level. The extent of the unconformity surface and the degree of truncation of the underlying strata suggests that tectonic uplift was the cause of this base level change (Shanmugan, 1988), as eustatic sea level changes generally don't occour over such large ranges as to cause such angular discordance (Curray, 1964; Swift, 1968 and Blatt et al., 1972). Unconformities cut by major marine transgressions, such as described by Clifton (1981) for the Miocene, shoreline deposits of the Caliente Range, tend to be planar and show little, if any, local relief (Shanmugan, 1988). Typically they are overlain by a thin, laterally continuous basal conglomerate which fines upward to siltstone and fine-grained sandstones of the offshore facies (Clifton, 1981).

A change in the angular relationship between the unconformity surface and the footwall strata is not evident in the relatively small area of Beatrix Mine, but an "upturn" structure similar to that documented by Stanistreet et al. (1986) in the Johannesburg Goldfield occurs at this unconformity surface further to the west on Oryx Mine and has been documented in the Welkom Goldfield and Loraine Mine (Winter, 1964a and Minter et al., 1986). On Oryx Mine the angular discordance between the unconformity surface and the footwall strata increases in a westerly and southwesterly direction, as does the degree of truncation of the footwall beds, suggesting that the area of uplift and the basin margin lay to the west.

4.3 RELATIONSHIP BETWEEN THE ELDORADO FORMATION AND THE BEATRIX REEF

The marked unconformity at the base of the Beatrix Reef, and the amount of truncation of older units (72[illegible]f combined St Helena, Welkom, Harmony and Dagbreek Formations) at this level suggests that depositional models inferred for the footwall units cannot be related in any way to those of the Beatrix Reef, i.e. the Virginia Formation merely formed the substrate upon which the reef was deposited. For this reason, depositional models of the Virginia Formation are not reviewed in the interpretation of the palaeoenvironment of the Beatrix

Reef sediments.

The Eldorado Formation disconformably overlies the Beatrix Reef. The two units of strata (Formations) have the same palaeosurface orientation but are separated by an uneven erosional (?) surface reflecting a variable temporal break (Shanmugan, 1988). In addition there is a significant difference in the lithologies and facies associations between the Beatrix Reef and the overlying Rosedale Member of the Eldorado Formation which can only partially be explained by the normal facies variations resulting from a channelled morphology. The variations more likely confirm the disconformable relationship between the Beatrix Reef and the Eldorado Formation.

In areas to the north of Beatrix Mine the Eldorado Formation overlies the Aandenk or Virginia Formations unconformably and the Beatrix Reef is not developed. In these northern areas an angular relationship of about two degrees exists at this unconformity, truncating successively older units towards the south. On Beatrix Mine the Aandenk Formation is only present in the northern parts of the mine as remnants below the unconformity at the base of the Beatrix Reef, or below the unconformity at the base of the Eldorado Formation where the Beatrix Reef is not developed or preserved. Throughout the rest of the mine the Eldorado Formation disconformably overlies the Beatrix Reef.

4.4 DEPOSITIONAL MODELS FOR THE BEATRIX REEF

The Beatrix Reef is not unique or significantly different from other Witwatersrand palaeoplacers and the interpretation of the palaeoenvironmental conditions or depositional models responsible for the formation of the sedimentary structures and placer mineral accumulations in the Beatrix Reef are very similar to those proposed for many other Witwatersrand reefs (eg. Minter, 1976 and 1987, Buck and Minter, 1985 and Verrezen, 1987). The depositional model inferred for the Beatrix Reef can thus serve as a model for Central Rand Group placer formation.

The most significant feature of the Beatrix Reef, or in fact any of the Witwatersrand reefs, is that in spite of a high bed relief index and fairly abrupt changes in thickness, the reef is essentially a thin gravel sheet overlying an unconformity of regional extent, and is succeeded (disconformably) by a largely arenaceous sequence. Depositional models for the Beatrix Reef are thus based on the sequence of facies within the conglomerate and interbedded arenite between the unconformity surface at the base of the reef and the disconformable base of the Eldorado Formation.

Modern conglomerates accumulate in a fairly limited number of environments viz.

- alluvial fans
- braided streams
- shorelines or shallow marine settings
- deep sea submarine fans
- glacial outwash or moraines

Numerous workers (Walker, 1979; Miall, 1978; Harms et al., 1975; Harms et al., 1982; and many others) have [illegible] that various combinations of descriptive features such [illegible] thology, composition, sedimentary structures, geometry and palaeocurrents, or the arrangement of these in vertical and lateral facies sequences, suggest different depositional processes or environments.

Some of the factors proposed by various workers to differentiate gravels and their environments of deposition are shown below

- clast shape sorting on beaches (Orford, 1975; Hobday and Banks, 1971)
- bed continuity and clast segregation (Clifton, 1973)
- size and sorting of clasts (Emery, 1955)
- clast roundness (Sames, 1966)
- clast fabric or imbrication (Harms et al., 1975)
- sediment maturity
- fossils or trace fossils
- characteristics of the associated sands

Many of these proposals rely on variations in the sorting and size distribution of clasts in the conglomerate as being environmentally diagnostic.

The most common association of features in conglomerates used as environmental indicators is shown diagrammatically below (after Harms et al., 1982), although this is by no means intended to show all possible types.

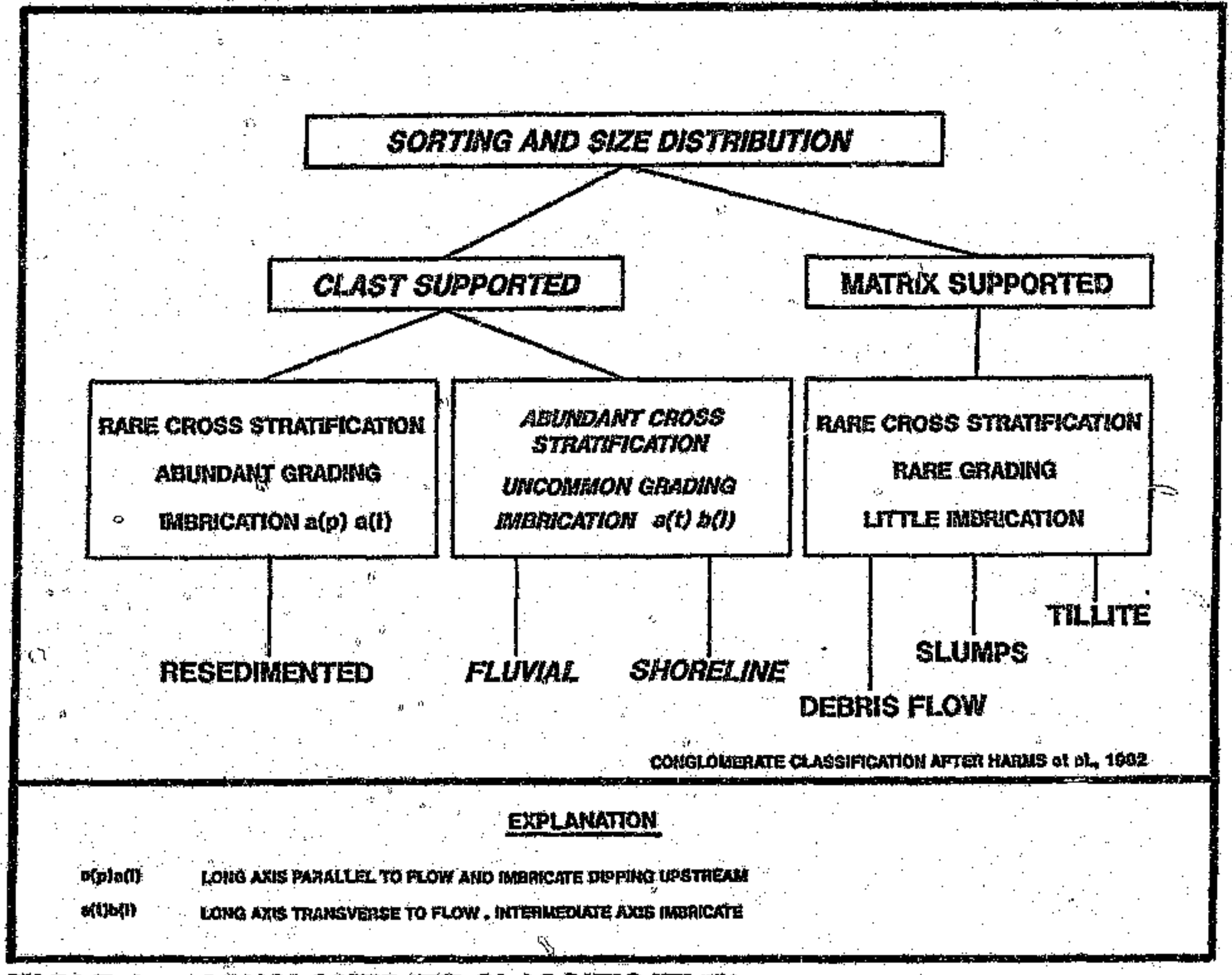

TABLE 1 : CONGLOMERATE CLASSIFICATION

Characteristics of the Beatrix Reef conglomerates such as the clast-supported gravels, well-developed crossbedding, lack of grading and the occassional imbrication thus classify the Beatrix Reef conglomerates as having been deposited in either a braided fluvial or a shallow marine shoreline environment (Table 1).

Morphometric studies on clasts extracted from the Beatrix Reef have shown that the average clast shape occurs in the field of those generally found in fluvial environments (Dobkins and Folk, 1970 and Stratten, 1974). However Hobday and Banks (1971) have pointed out that prolate-spheroid shaped clasts may occur in the subtidal zones of coarse-grained shoreline deposits, whereas oblate, "disc-shaped" clasts are only indicative of the intertidal swash zone of such deposits.

A definate stratified fabric is apparent in nearly all the Beatrix Reef conglomerate (Figs. 19 and 20) and varies from horizontal or low angle planar lamination to trough cross-bedding and some planar crossbedding. Massive, apparently unstratified gravels are also fairly common.

The crossbedding types are indicative of the accretionary migration of large bedforms (lunate and straight crested ripples and bars) in unidirectional flow with significant velocity and at depths of at least half a metre (Southard, 1971, Harms et al., 1975). Crossbedding forms in most shallow-water environments and is thus not diagnostic of either a braided fluvial or shallow marine shoreface depositional model for the Beatrix Reef conglomerates.

Rust (1972), Gustavson (1974) and Boothroyd and Ashley (1975) suggest that migrating longitudinal bars in fluvial environments form poorly defined horizontal gravel beds with an a(t)b(i) preferred fabric. Smith (1974) has also noted that in fluvial gravels the bedding is predominantly massive, but low angle inclination is fairly common from the migration of bars with low riffle margins. High angle planar crossbedding occurs at the margins of bars but is uncommon and is mostly confined to finer-grained gravels (Smith, 1974). The main bar types (after Smith, 1974) that occur in unidirectional flows are

- longitudinal

- transverse
- diagonal
- point bar

Usually only remnants of the bars remain due to their complex history of formation (Smith, 1974).

Hein and Walker (1977) have reported major differences in the gravel stratification between the upstream and downstream reaches of the Kicking Horse River. The upstream reach is characterised by diffuse gravel sheets consisting of the coarsest bedload as a lag pavement. In the downstream reaches there is some bar formation and migration. If fluid discharge and sediment rate remains high after initial lag formation, then bars tend to grow downstream faster than aggrading vertically hence no foresets develop and low angle, inclined stratification predominates. Only in decreasing flow is there rapid vertical aggradation and the development of steeper foresets (Hein and Walker, 1977).

Although the remnants of bar forms can occassionally be seen in the Beatrix Reef conglomerates, the usual two dimensional exposure and the fact that only remnants of bars remain because of their complex history of formation, mean that no detailed work was possible on the most common bar types or variations in bar types or stratification types down the palaeocurrent trend at Beatrix Mine.

In coarse-grained nearshore deposits the unusual or "storm event" deposit tends to have greater potential for preservation and is therefore usually diagnostic of the depositional model (De Celles, 1987, Leithold and Bourgeois, 1984). De Celles

(1987) in his study of coarse-grained nearshore, Tertiary deposits of the San Emigdio Range in southern California has described crossbedded conglomeratic sequences very similar to the Beatrix Reef conglomerates. However, these nearshore conglomerates are overlain by well sorted, swash-zone sands and pebbly sands in which low angle, clino-stratification, small-scale trough crossbedding and hummocky cross-stratification are common. Massari and Parea (1988) in their descriptions of the progradational gravel beach sequences of the Southern Alps and Apenninic chain comment on the characteristic low-angle, hummocky and clinostratified sands and the clinostratified, well-sorted, clast-supported gravels. Shape sorting and imbrication of the gravel clasts is characteristic (Massari and Parea, 1988). Bourgeois (1980) has also noted the predominance of hummocky cross-stratification in the nearshore deposits of the Cape Sebastian Sandstone and Harms et al., (1982) suggest that hummocky cross-stratification may be typical and characteristic of nearshore/shoreface deposits depicting the preservation of storm events.

The lack of hummocky cross-stratification or low angle, clino-stratification (swash) in the Beatrix Reef mitigates against deposition in, or preservation of, the intertidal swash-zone of a shoreface environment.

The facies sequences and associations typical of braided fluvial depositional models have been reviewed in detail by Miall (1973, 1977 and 1978).

The most common facies sequence in the Beatrix Reef conglomerates and arenites consists of a marked scour surface overlain by massive or horizontal/low angle cross-stratified gravels and trough cross-stratified gravels. These in turn are overlain by trough crossbedded and/or planar crossbedded pebbly sands and gravels. Sequences may rarely be capped by trough crossbedded sands. Finer grained facies are not developed in the Beatrix Reef. The facies sequence typical of the Beatrix Reef can be summarised as

Scour --- Gm --- Gh --- Gt/Gp --- St

(using the facies descriptive terms after Miall, 1978 modified after Miall, 1977)

This facies association sequence is typical of the Scott type to Donjek type braided stream facies sequences documented by Miall (1977) and Miall (1978) as characteristic of these types of braided stream.

The Scott or Donjek type braided stream models however form conglomerate dominated sedimentary sequences tens of metres thick, a geometry not observed in the Beatrix Reef which is a sheet-like deposit 1-3 m thick. Also, the well-sorted nature of the Beatrix Reef conglomerate and the clean, quartz arenite matrix is indicative of significant and prolonged periods of reworking which are not evident in Miall's (1978) Scott or Donjek models.

Brierley's (1989) detailed study of the facies associations in various planform facies models of the Squamish River in British Columbia have also questioned the applicability of such facies "type sequences" in the characterisation of fluvial deposits.

The Squamish River may perhaps be viewed as intermediary between Miall's (1978) Scott and Donjek models, but Markov analysis by Brierly (1989) predicted many, alternative sedimentary facies sequences to the "type sequences" thereby negating the apparent simplicity of facies models (Brierly, 1989). The inapplicability of the simplified, sedimentary facies sequences and associations in the characterisation of fluvial depositional environments has also been noted by Miall (1987), suggesting that such facies sequence characterisation is not valid.

Characteristics of the Beatrix Reef conglomerates and the observed facies sequence associations however have been described more commonly from braided fluvial sequences rather than the shallow marine shoreline models proposed by other workers (eg. Walker, 1979; Leithold and Bourgeois, 1984; Bourgeois and Leithold, 1984; Clifton and Dingler, 1984). A fluvial setting is reinforced by unidirectional palaeoflow (Fig. 25) associated with longitudinal barforms. The braided, fluvial facies sequences and the extensive, sheet-like geometry are characteristic of the coarse-grained braid-delta model of McPherson et al., (1987). The braid-delta model implies deposition down a braid-plain and into a standing body of water (lacustrine or marine) (McPherson et al., 1987).

The thin, sheet-like geometry of the Beatrix Reef implies deposition in a low aggradation rate system in which frequent reworking generates a mature conglomeratic layer of limited vertical extent. Witwatersrand placer formation by the fluvial degradation of previously deposited alluvial sequences has been

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The thin, sheet-like geometry of the Beatrix Reef implies deposition in a low aggradation rate system in which frequent reworking generates a mature conglomeratic layer of limited vertical extent. Witwatersrand placer formation by the fluvial degradation of previously deposited alluvial sequences has been described by Buck and Minter (1985) and Minter (1987), and is the model most favoured to explain the formation of the Beatrix Reef. The depositional model for the Beatrix Reef as being a placer deposit formed by fluvial degradation, in a coarse-grained braid-delta, of previously deposited sequences may be typical of most Central Rand Group placers. The deposit formed during a transgressive cycle in response to uplift and erosional degradation. The change to the finer-grained, heterolithic facies sequence disconformably overlying the Beatrix Reef, suggests that the fluvial degradation cycle culminated in a transgression of the standing body of water (lacustrine or marine) across the braid-plain.

Marine depositional environments are frequently described from the lower parts of the Witwatersrand Supergroup (eg. Eriksson et al., 1981) and have more recently been proposed as the formative process for palaeoplacers in the upper parts (Central Rand Group) of the Witwatersrand (Verrezen, 1987 and Bailey et al., 1990). Shallow, marginal marine depositional models overlying transgressive, placer forming episodes are described in many of the Central Rand Group reefs (eg. Main Reef Leader - Button, 1979, Vaal Reef - Minter, 1976 and Verrezen, 1987, Kimberley Reefs - Armstrong, 1966 and Bailey et al., 1990). A marginal marine transgression across the braid-plain as the culmination to the Beatrix Reef placer forming event would therefore not be unique, but would need to be substantiated by further evidence.

4.5 DEPOSITIONAL MODELS FOR THE ROSEDALE MEMBER AND THE ELDORADO FORMATION

Two dominant sedimentary facies sequences are evident in the Rosedale Member at the base of the Eldorado Formation. The first sequence comprises an upward-coarsening succession of finer-grained facies disconformably overlying the Beatrix Reef. The second sequence comprises an upward-fining succession of coarser-grained facies overlying marked scour surfaces eroded into the finer-grained facies or the Beatrix Reef. Above the Rosedale Member the Eldorado Formation forms an overall upward-coarsening sequence of arenites and conglomerates.

Within the finer-grained sequence the most common association of sedimentary facies comprises the heterolithic facies disconformably overlying the Beatrix Reef, and in turn overlain by the trough crossbedded arenite facies. This facies association can be summarised as follows

Fl --- Sh/Sr --- St

(using the facies codes of Miall, 1978)

The sedimentary structures within these facies (lenticular bedding, wave ripples and mudcracks) attest to deposition during alternating periods of wave or current action and slack water in a shallow to very shallow water environment with periodic subaerial exposure (Komar, 1974, Allen, 1981, Diem, 1985). Deposits of this type have most frequently been described from shallow, marginal marine (tidal-flat) environments (eg. Reineck and Wunderlich, 1968, DeVries Klein, 1970 and 1975, Clifton and Dingler, 1984, Diem, 1985).

Similar facies sequences and sedimentary structures are also documented within the fine-grained sediments of abandoned channels and overbank deposition in braided fluvial environments (Williams and Rust, 1969, Boothroyd and Ashley, 1975, Allen, 1981).

The heterolithic facies sequence disconformably overlies the Beatrix Reef with a sharp, planar contact and occurs throughout the mine area. It also occurs overlying the Beatrix Reef in borehole intersections to the north and west of the mine suggesting a distribution covering over 20 sq km. The thin, sheet-like geometry of the finer grained facies, the upward coarsening, and the ripple marking with a lack of ripple lamination (McKee, 1965) are inadequately explained by an abandoned, braided fluvial channel model. The tidal environment is thus the preferred model for these sediments at the base of the Rosedale Member.

The coarser grained facies sequence at the base of the Eldorado Formation (Rosedale Member) rests on an erosional scour surface. This scour surface, or diastem, may truncate the finer-grained facies sequence and/or the upper parts of the Beatrix Reef (Fig. 38), and represents a minor break resulting from the expected, random variation in the sediment rate without any basic change in the environment (Shanmugan, 1988). Immediately overlying the scour surface are thin lag conglomerate layers or trough crossbedded, polymictic conglomerate facies. The lag conglomerate contains significant admixtures of large, rounded quartz clasts scavanged from the Beatrix Reef where the top of the reef has been eroded (Fig.

40b). Overlying the conglomerate are trough crossbedded, lithic arenite with granulestone layers and granule accumulations on foreset toes, and some planar crossbedded lithic arenite. The sequence fines upward into small-scale trough crossbedded lithic arenite. This facies sequence association can be summarised as follows

Scour --- Gm/Gt --- St/Sp --- St

(using the facies codes of Miall, 1978)

The immaturity and poorer sorting of the Rosedale Member lithologies supports the facies association sequence in suggesting a braided fluvial depositional model. The sequence of facies summarised above are similar to Miall's (1978) Donjek-type braided stream model and indicate progradation of a fluvial environment across the braid-plain during a regressive cycle.

Vertically, above the Rosedale Member, the Eldorado Formation comprises a thick sequence (120 m of Van Den Heeversrust Member) dominated by trough crossbedded lithic arenite facies and planar crossbedded lithic arenites with minor, trough crossbedded and massive conglomerate facies. These coarsen upward to the Uitkyk Member (200 m) in which the conglomerate facies becomes more prevalent (Figs. 8 and 53).

Towards the west on Oryx Mine, the Eldorado Formation is dominated by massive, polymictic conglomerate facies (Fig. 53) with a facies sequence association similar to the Scott-type braided fluvial model (Miall, 1978). Poorly-sorted, matrix-supported gravels representing debris flow deposits also occur in the Eldorado Formation in the Oryx area. The change from debris-flow and Scott-type braided fluvial deposits at Oryx Mine to Donjek-type sequences at Beatrix (Fig. 53) may reflect within fan proximal-distal variations as suggested by Rust (1978), with the upward coarsening change reflecting progradation of the alluvial fan.

Similar lithologic facies variations are described by Andrews-Speed (1986) for the progradation from distal braided stream facies to more proximal fan facies in the Proterozoic aged Mporokoso Basin in northern Zambia, and is also described in the alluvial fan models of Chevren (1984).

The interpreted depositional model (this study) of the Eldorado Formation as a prograding, braided fluvial system on an alluvial fan or fan-fed braid-delta supports the findings of Kingsley's (1987) depositional model for the Eldorado Formation in the Welkom Goldfield north of the Sand River.

5. MINERALISATION AND ITS CONTROLS IN THE BEATRIX AREA

5.1 MINERALISATION AND ITS RELATIONSHIP TO SEDIMENTARY FEATURES IN THE BEATRIX REEF

Concentrations of rounded, heavy mineral grains are common within the Beatrix Reef. The heavy mineral grains occur as discrete accumulations a few millimetres thick, concentrated along certain bedding and scour surfaces within the arenites and conglomerates (Fig. 55 and cf also Figs. 20, 21, 22 and 23). Heavy mineral grains also occur as a dominant constituent of the matrix in the better packed conglomerate beds (Fig. 56). Pyrite is the most common heavy mineral accounting for over 85% of the heavy mineral suite, although gold is naturally the most economically significant. Other heavy minerals noted in the Beatrix Reef are chromite, ilmenite, leucoxene, zircon, uraninite and brannerite, galena and other Fe and Cu sulphides. Pyrite (85 %) and uraninite and brannerite (which together comprise some 10 - 13 % of the heavy mineral suite) are the dominant ore minerals and the other heavy minerals (including gold) together comprise less than two percent of the ore. The suite of heavy minerals in the Beatrix Reef is similar to that found in normal Witwatersrand type placers (Feather and Koen, 1975), but Potgieter (1979) and Minter et al. (1988) have commented on the virtual lack of uraninite in favour of brannerite and suggest that the heavy mineral suite is derived from the weathering of older placers with the alteration of uraninite to brannerite. They cite the presence of fragmental and apparently abraded pyrite, of a form normally found as

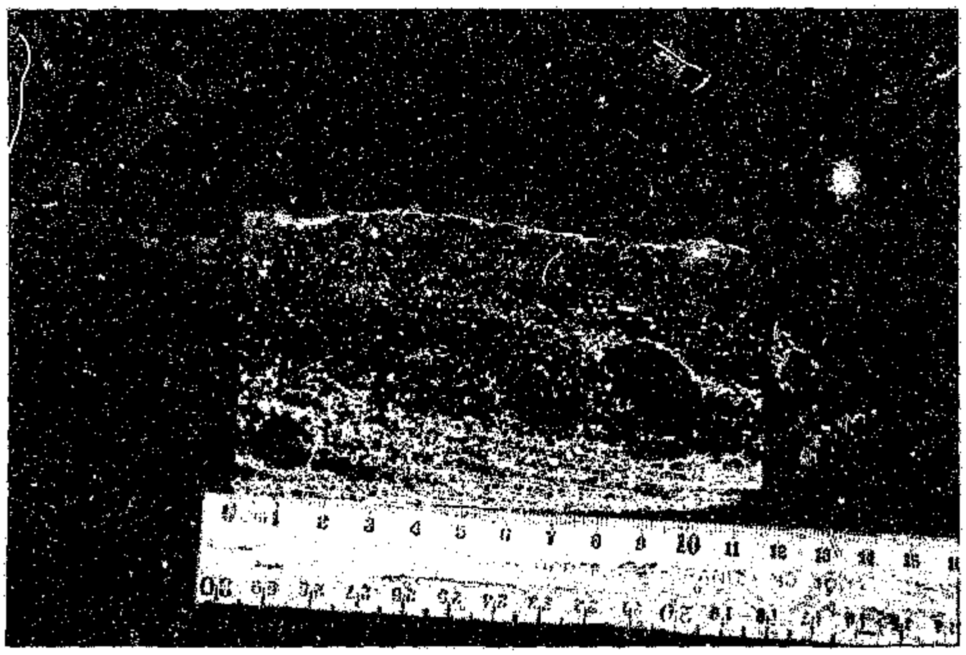

FIGURE 55: PYRITE GRAINS CONCENTRATED ON THE TOES OF FORESETS IN CROSSBEDDED, PEBBLY ARENITE.

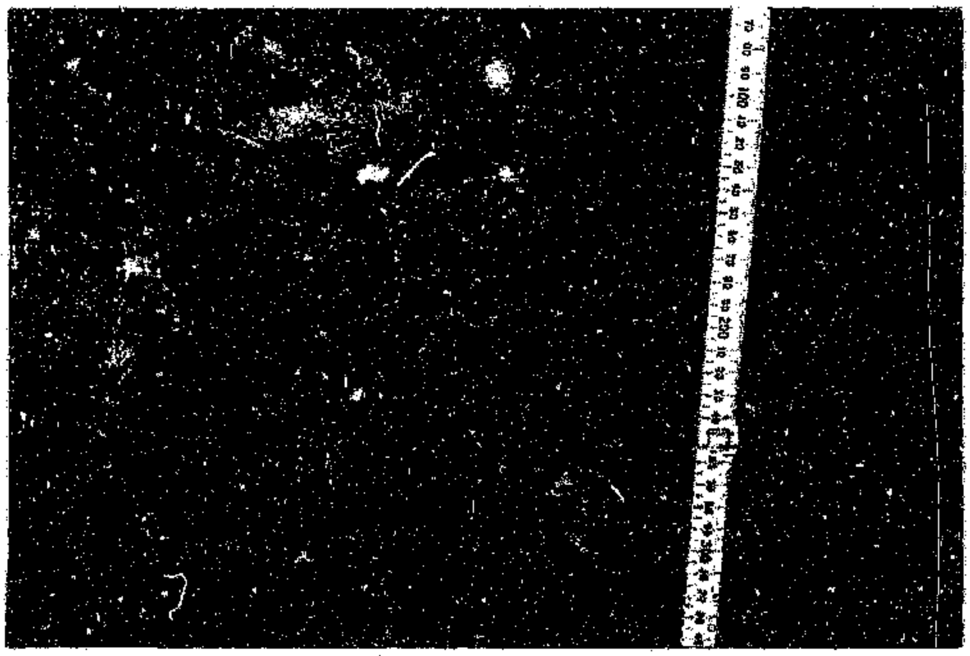

FIGURE 56: PYRITE GRAINS AS THE DOMINANT CONSTITUENT IN THE MATRIX OF THE BEATRIX REEF CONGLOMERATE.

secondary authigenic pyrite in Witwatersrand ores, as further support for an origin from underlying placers (Minter et al., 1988).

The pyrite occurs chiefly in three forms with a fourth form occuring rarely.

- Compact pyrite occurs as compact, rounded grains varying from 0.5 to 15 mm in size (Fig. 57). This form is the well known "buckshot" pyrite of Witwatersrand ores and is considered to be detrital in origin (Saager, 1970, Koppel and Saager, 1974, Maclean and Fleet, 1989).

- Concretionary pyrite occurs as rounded grains but is highly porous (Fig. 58). This form is the well known porous "mudball" pyrite (Saager, 1970).

- Recrystallised pyrite is common and occurs as compact authigenic anhedral pyrite, or as idiomorphic overgrowths on detrital pyrite (Fig. 59). Much of this pyrite probably formed by recrystallisation during diagenesis and metamorphism. (Feather and Koen, 1975).

- Pseudomorphic pyrite is rare and is formed by the pyritisation of former iron minerals but retaining the structural features of the original rock or mineral (Potgieter, 1979).

The compact pyrite occurs in varying concentrations on many bedding surfaces (Figs. 55 and 20, 21, 22 and 23), and accentuates sedimentary structures.

secondary authigenic pyrite in Witwatersrand ores, as further support for an origin from underlying placers (Minter et al., 1988).

The pyrite occurs chiefly in three forms with a fourth form occuring rarely.

- Compact pyrite occurs as compact, rounded grains varying from 0.5 to 15 mm in size (Fig. 57). This form is the well known "buckshot" pyrite of Witwatersrand ores and is considered to be detrital in origin (Saager, 1970, Koppel and Saager, 1974, Maclean and Fleet, 1989).

- Concretionary pyrite occurs as rounded grains but is highly porous (Fig. 58). This form is the well known porous "mudball" pyrite (Saager, 1970).

- Recrystallised pyrite is common and occurs as compact authigenic anhedral pyrite, or as idiomorphic overgrowths on detrital pyrite (Fig. 59). Much of this pyrite probably formed by recrystallisation during diagenesis and metamorphism. (Feather and Koen, 1975).

- Pseudomorphic pyrite is rare and is formed by the pyritisation of former iron minerals but retaining the structural features of the original rock or mineral (Potgieter, 1979).

The compact pyrite occurs in varying concentrations on many bedding surfaces (Figs. 55 and 20, 21, 22 and 23), and accentuates sedimentary structures.

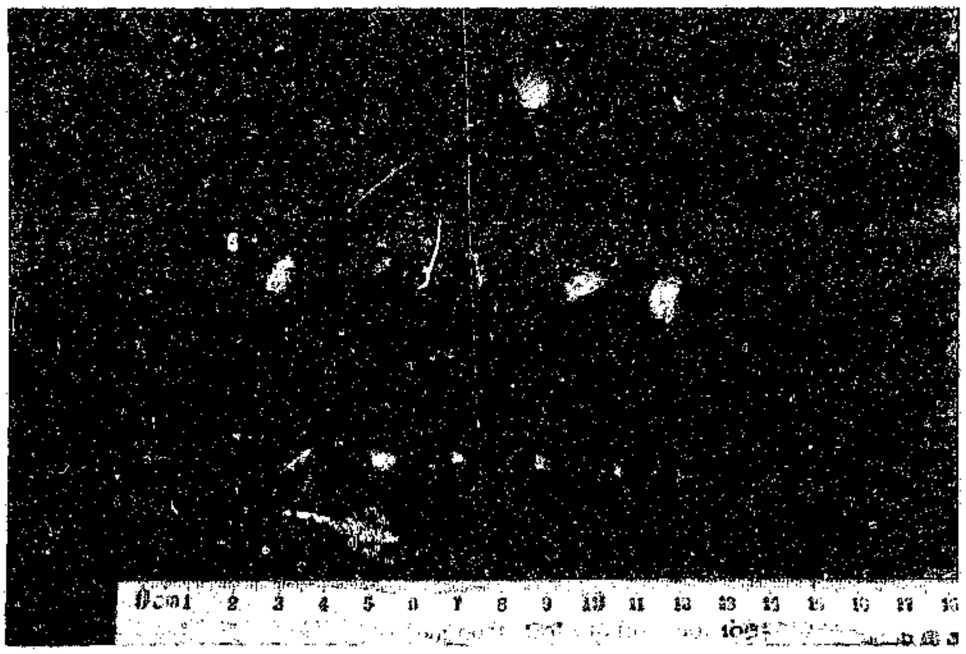

FIGURE 57a: COMPACT, ROUNDED PYRITE GRAINS. NOTE HOW PRE-DEPOSITIONAL BREAKS ON GRAINS IN THE TOP ROW HAVE BEEN ROUNDED.

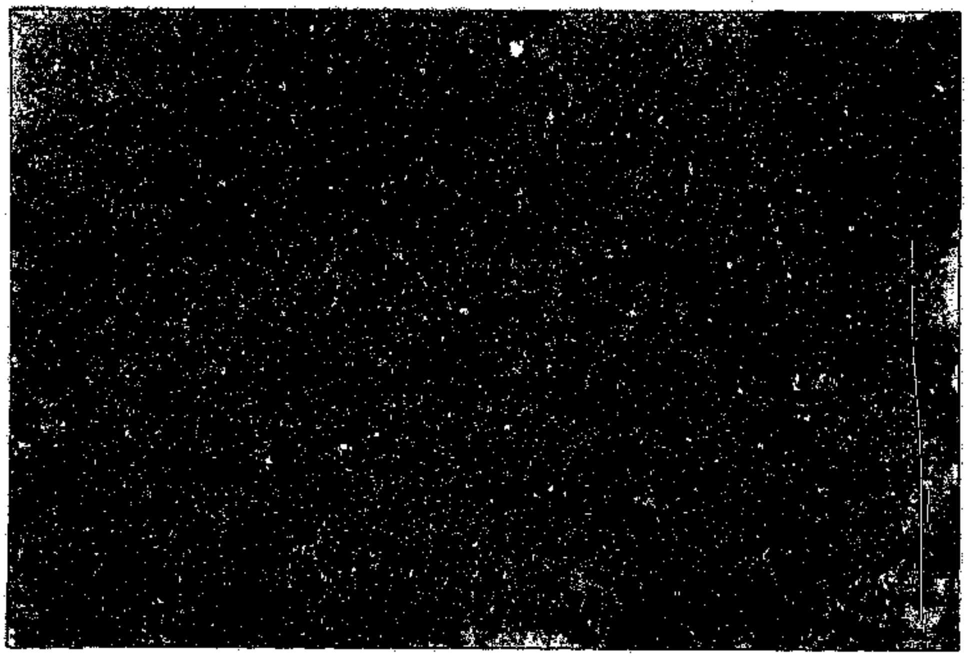

FIGURE 57b: PHOTOMICROGRAPH OF ROUNDED PYRITE GRAIN (X 100)

FIGURE 57: COMPACT, ROUNDED PYRITE GRAINS

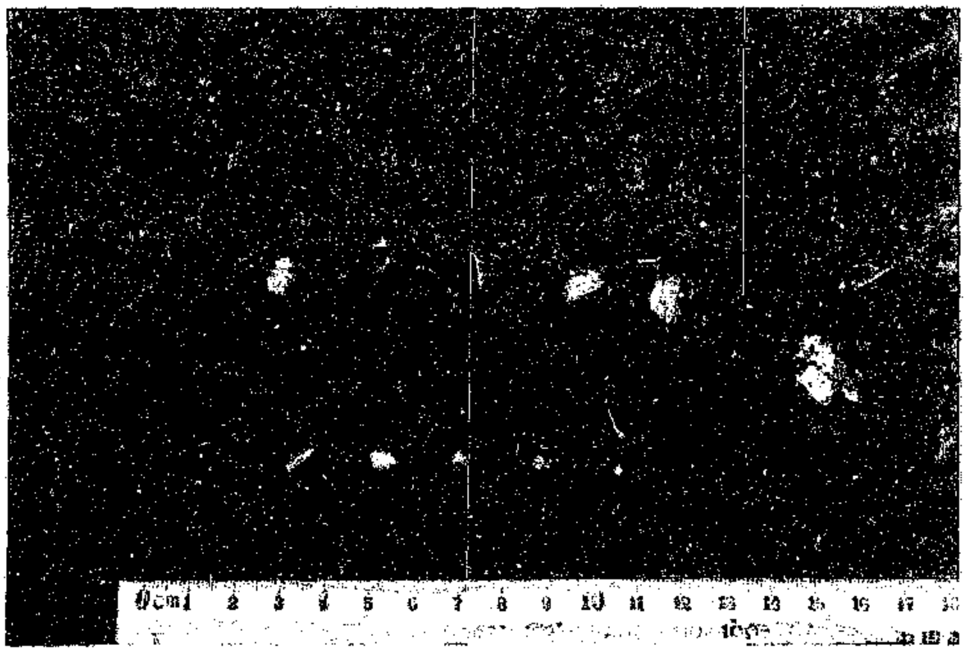

FIGURE 57a: COMPACT, ROUNDED PYRITE GRAINS. NOTE HOW PRE-DEPOSITIONAL BREAKS ON GRAINS IN THE TOP ROW HAVE BEEN ROUNDED.

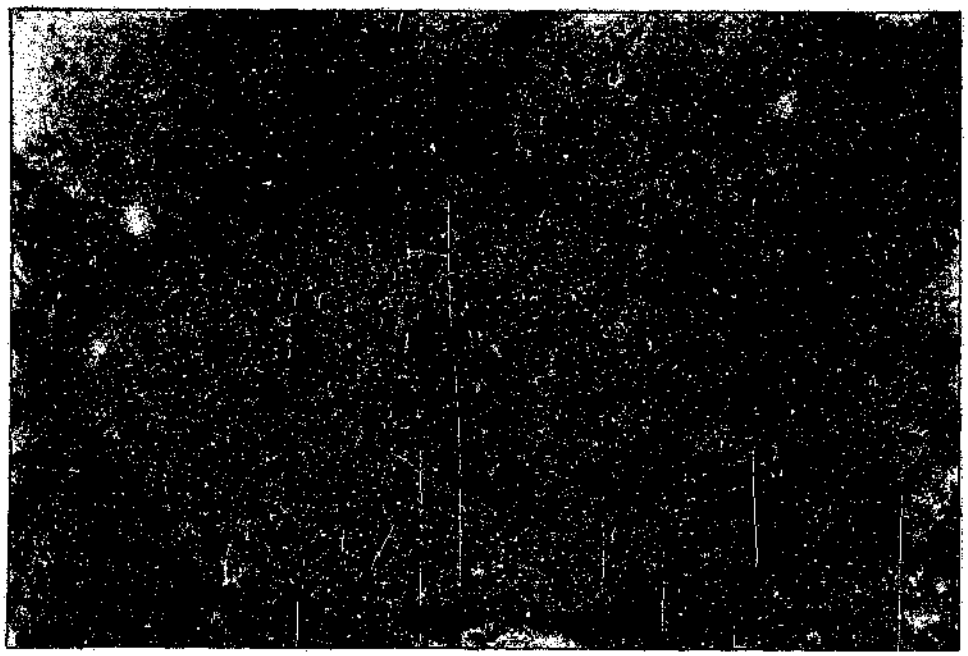

FIGURE 57b: PHOTOMICROGRAPH OF ROUNDED PYRITE GRAIN (X 100)

FIGURE 57: COMPACT, ROUNDED PYRITE GRAINS

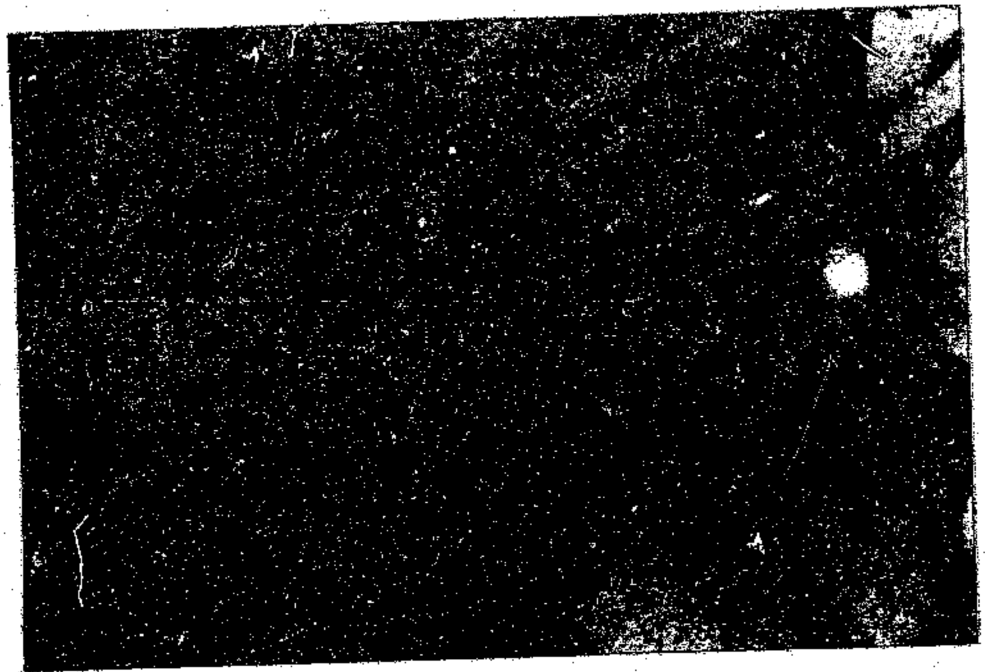

FIGURE 58: POROUS "MUDBALL" PYRITE (X 100)

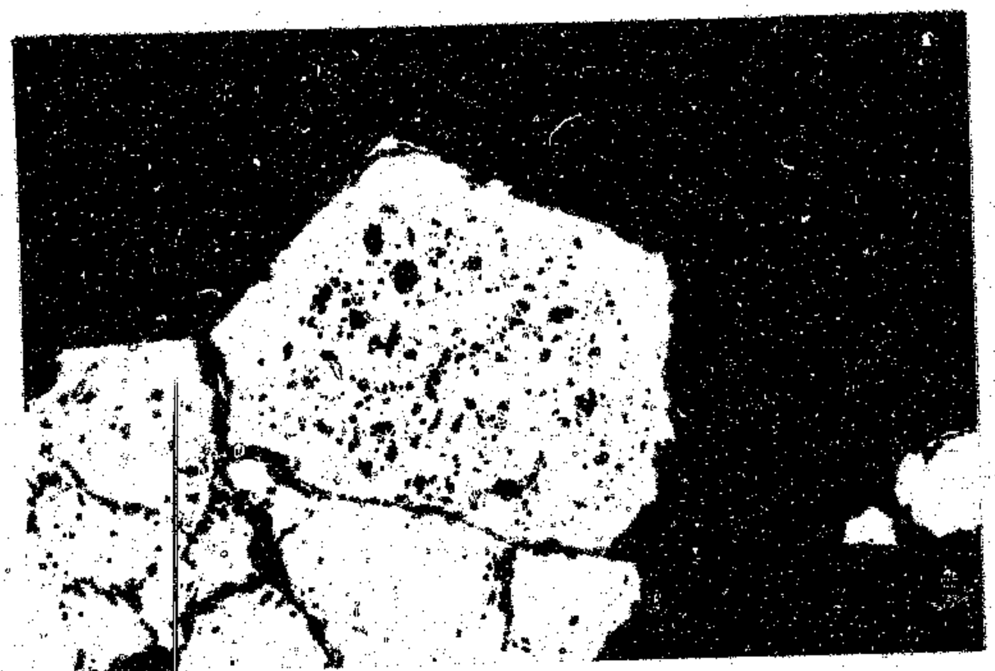

FIGURE 59: AUTHIGENIC PYRITE AS AN OVERGROWTH ON A ROUND, POROUS(?) PYRITE GRAIN (X 50)

Other sulphides such as pyrrhotite, pentlandite and chalcopyrite invariably occur as fine-grained exsolution blebs within the compact pyrite grains, and are rarely observed as discrete grains.

Uraninite and brannerite are fairly common and form about 10 % of the heavy mineral suite, with brannerite occuring more frequently than uraninite. The uraninite occurs as subrounded grains about 0,2 mm in diameter and usually contains specks of galena and occasionally chalcopyrite. Brannerite is common as discrete grains and more commonly as the alteration product of uraninite. It also contains specks of galena and chalcopyrite. Irregular, altered encrustations of brannerite could also be uraniferous leucoxene.

Small chloritic nodules are also common in the Beatrix Reef conglomerates. The nodules are roughly spherical and are 1-2 mm in diameter. They are usually concentrated in the conglomerate facies and are thought to be the alteration products of some heavy mineral such as garnets (G. Smits, 1989 pers. comm.).

Gold grains, although a very important constituent of the heavy mineral suite, are not very common. The average size of gold grains in the Beatrix Reef is 32 x 10 microns (Hofmeyr, 1986) although larger grains up to 500 microns long and visible to the unaided eye have been frequently observed. A notable characteristic of the mode of occurence of the gold is its tendency to occur in clusters of grains. Invariably when a grain of gold was observed in polished section other gold grains were noted in the immediate vicinity. Much of the gold (about 70%, Hofmeyr, 1986) is as free grains (Fig. 60a) and only a minor percentage occurs locked up in sulphide (pyrite) grains or in quartz or other silicates. About 5% (Hofmeyr, 1986) of the gold occurs in pyrite grains and this gold is invariably of a much smaller grain size. Where gold occurs included in pyrite, other sulphides such as chalcopyrite and pyrrhotite also occur as exsolutions in the pyrite.

Of the gold occuring in quartz or other silicates a significant amount is associated with chlorite, an association also documented by Law (1990) in his studies.

Carbon, possibly of organic origin, is fairly commonly associated with the conglomerates of the Beatrix Reef. The carbon occurs as scattered, rounded pilules or "flyspeck" at the basal parts of lag conglomerates. In-situ carbon seams are also observed in some places. The seams are up to 5 mm thick, and occur on the unconformity surface at the base of the reef. Thin carbon seams also occur on scour surfaces within the reef, and on the unconformity surface at the base of the Rosedale Member. Carbon in the seams is columnar and fine films or dustings of gold are occassionally visible between the columns.

Gold is frequently associated with the carbon particles (some 15% of gold is directly associated with carbon according to Hofmeyr, 1986) and some 80 % of the carbon particles observed in the study by Hofmeyr (1986) had gold associated with them. The gold is usually as small particles (less than 50 microns) wholly enclosed or attached to the carbon granules (Fig. 60b). This close association results in an increased gold

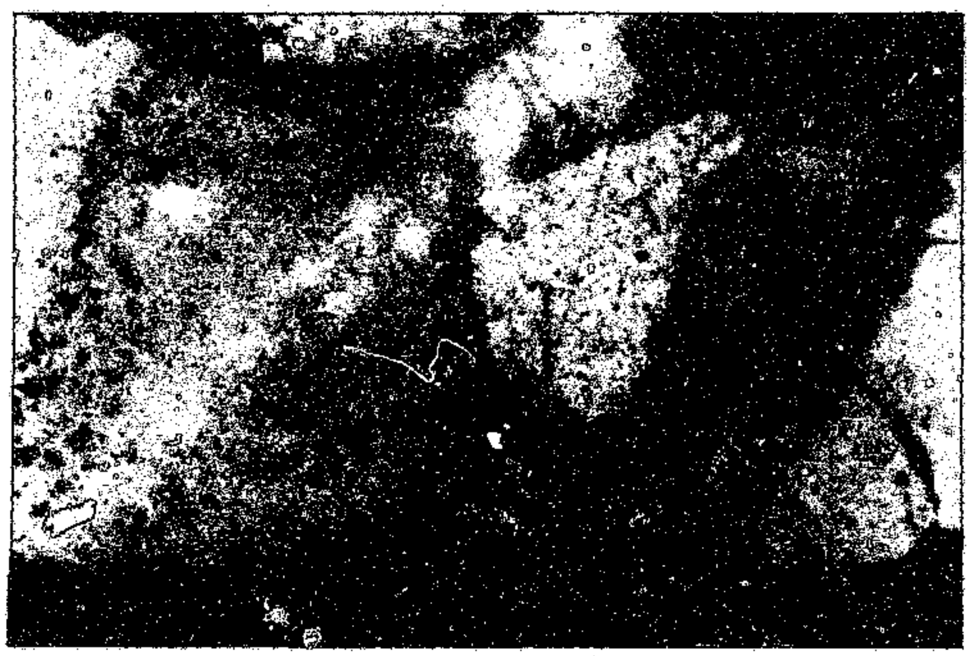

FIGURE 60a: "FREE-MILLING" GOLD GRAIN FROM THE BEATRIX REEF (X 50)

FIGURE 60b: GOLD ASSOCIATED WITH A HYDROCARBON GRANULE (DARK GREY) (X 200)

FIGURE 60: MODES OF OCCURENCE OF GOLD IN THE BEATRIX REEF

concentration in areas of carbon accumulation such as in the lag conglomerates and the carbon seams. Pyrite and other minor sulphides are also commonly included within the carbon granules.

Detailed sedimentological mapping and sampling of sections of the reef show that gold particles are concentrated with the pyrite grains in thin accumulations on bedding surfaces such as foresets (Figs. 61 and 62). These studies also highlight an enhanced concentration of gold along the unconformity surface in association with lag conglomerate, and in areas adjacent to the thickest reef development ie. along the flanks of channels. Gold also shows preferential concentration along the top contact of the reef where there is an enrichment of pyrite at the top of the reef where it is overlain by black shale or fine-grained arenite.

Although the detailed mapping illustrates the small-scale variation in the concentration of pyrite and gold along surfaces related to bedforms, it does not show broader scale lateral variations associated with larger scale sedimentary features such as channels or bars.

An area to the southeast of No. 2 Shaft, Beatrix Mine, was selected for a detailed study of the relationship between broad scale gold concentration variations and Beatrix Reef channel morphology. The area, some 600 m x 500 m in size was selected because the isopach mapping had already shown the existence of a well defined, north-south trending channel system (Fig. 63). Reef thickness, gold concentration and X , Y co-ordinates for

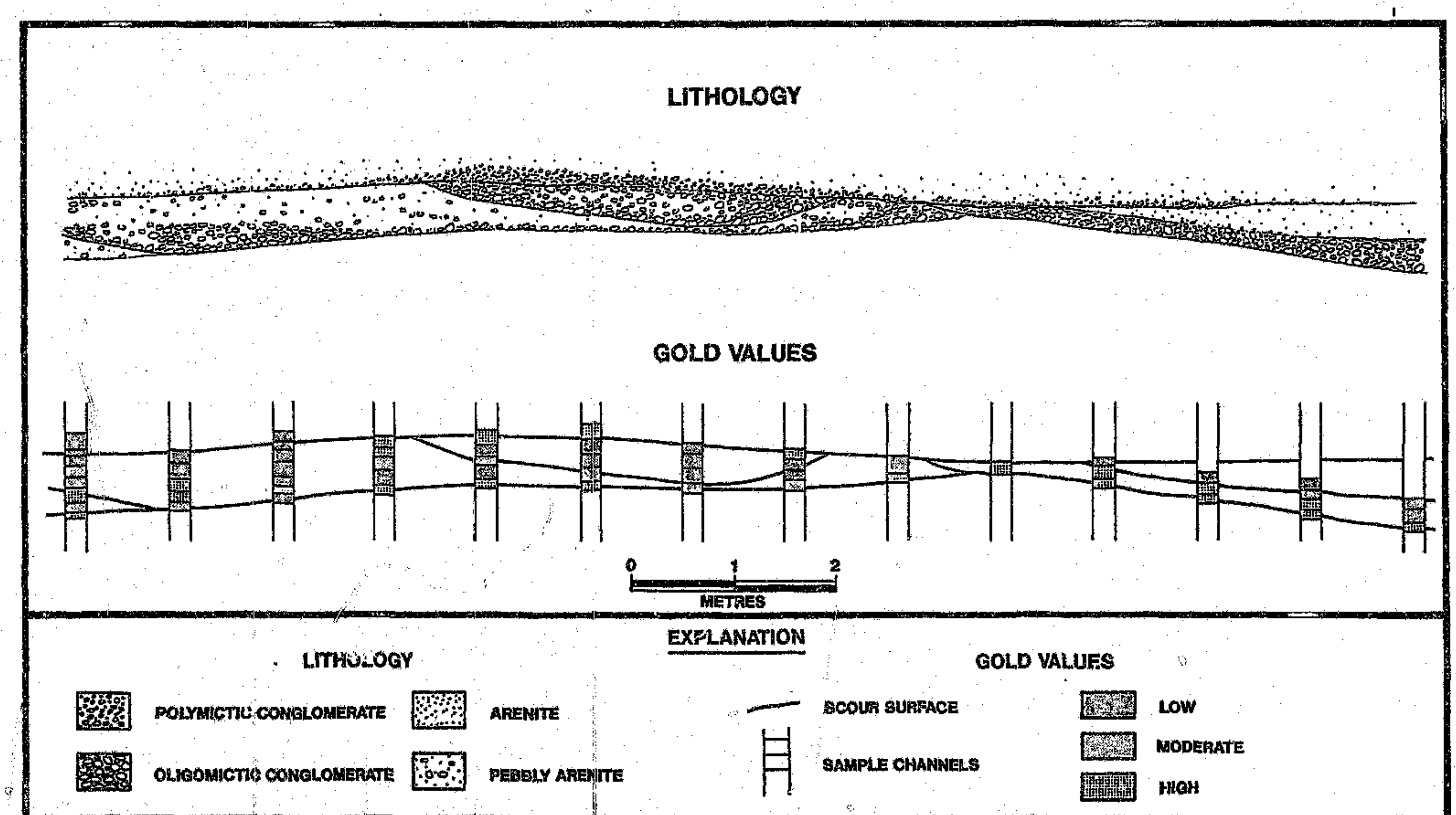

FIGURE 61: GOLD DISTRIBUTION IN THE BEATRIX REEF

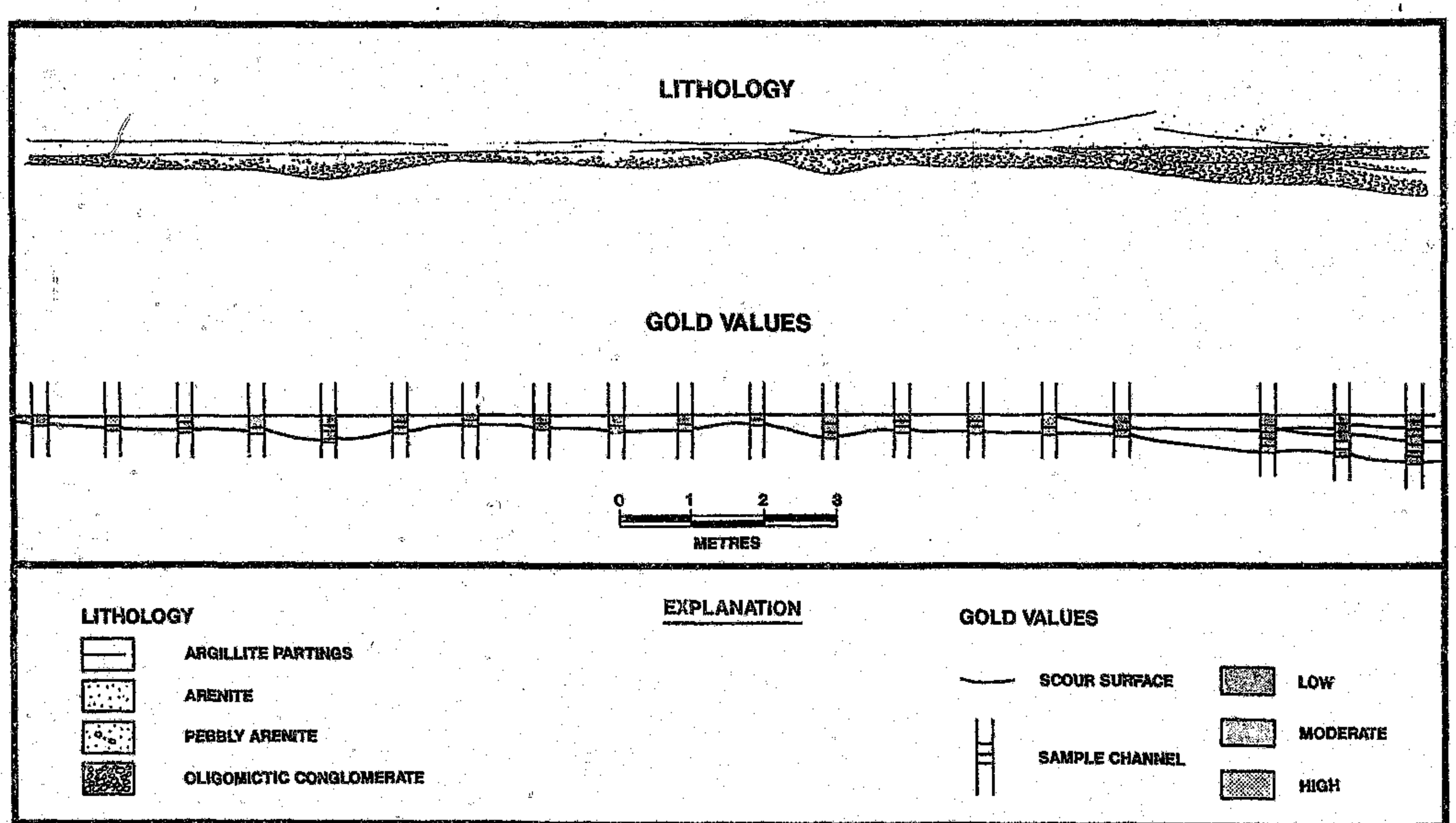

FIGURE 62: GOLD DISTRIBUTION WITHIN THE BEATRIX REEF

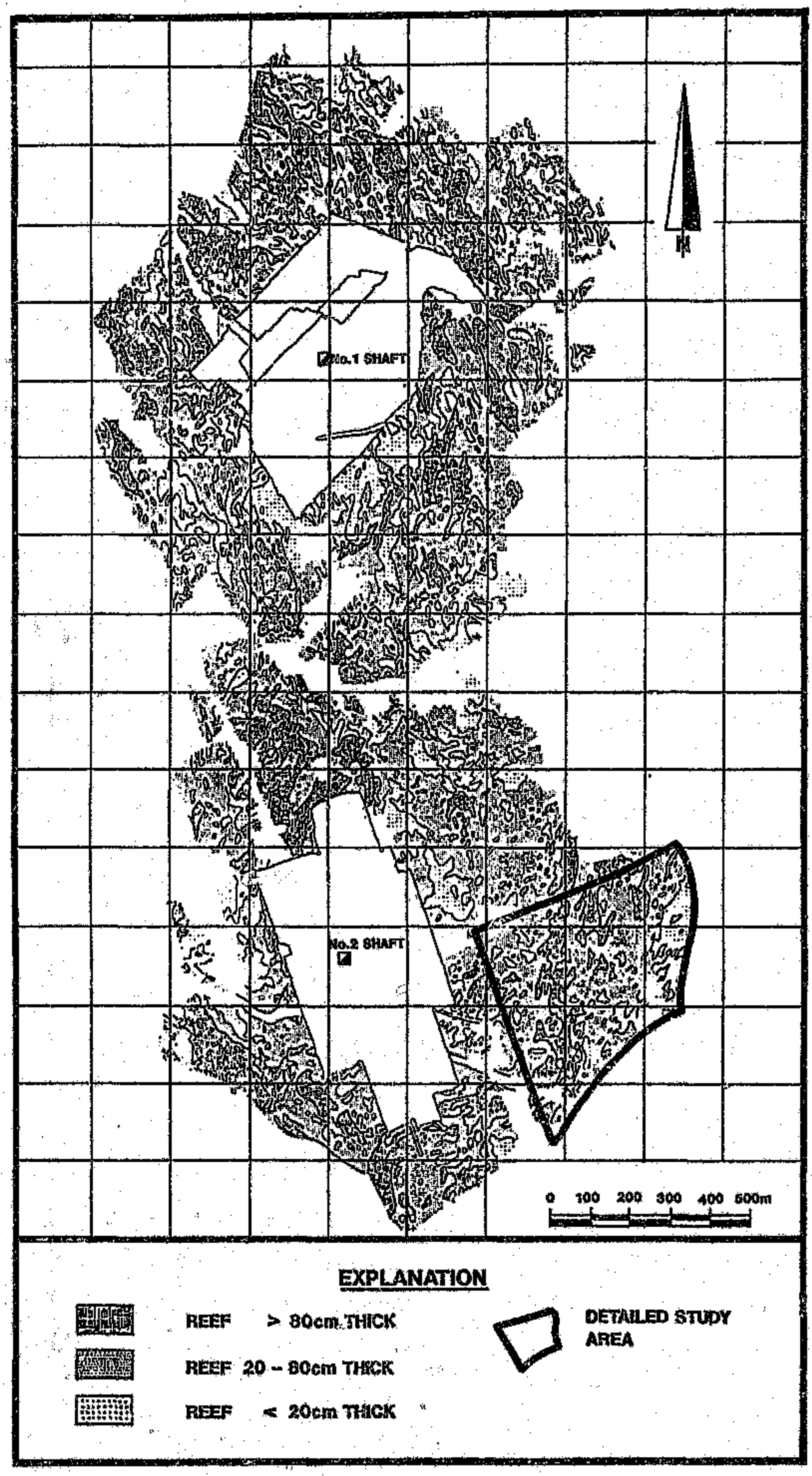

FIGURE 63: ISOPACH PLAN SHOWING THE LOCATION OF THE DETAILED STUDY AREA

each of the routine 6m x 6m grid sampling positions was digitised and stored in a computer database using the VULCAN software. The area was gridded to a regular 3m x 3m grid and isopach maps of reef thickness and gold concentration were compared.

The computer contouring confirmed the well defined north-south trending channel of thicker reef (over 80 cm thick) and the thinner reef (less than 20 cm thick) along the eastern edge of the study area (Fig. 64). The axes of the main channels, taken as areas were the reef exceeds 80 cm in thickness, are also displayed on Figure 64.

On the mine a gold accumulation factor, known as "centimetregrams per ton" (cmg/t) is commonly used to express the level of gold mineralisation in the reef. The gold accumulation factor (cmg/t) is derived from the product of the reef thickness (cm) and the gold concentration (g/t) over the reef width sampled at any sampling point. The contoured plot of the gold accumulation values (Fig. 65) also defines the channel although in this plot a second area of high gold accumulation in the eastern part of the study area is apparent. High gold accumulation values also tend to be slightly offset from the main channel areas, particularly along the eastern channel. A diffuse area of high gold accumulation is apparent near the central part of the area where the channels merge. Small areas of high gold accumulation also occur on the flanks, offset from the areas of very thin reef on the eastern edge of the area. High gold accumulation values are to be expected in areas of channel development because of the influence of the reef

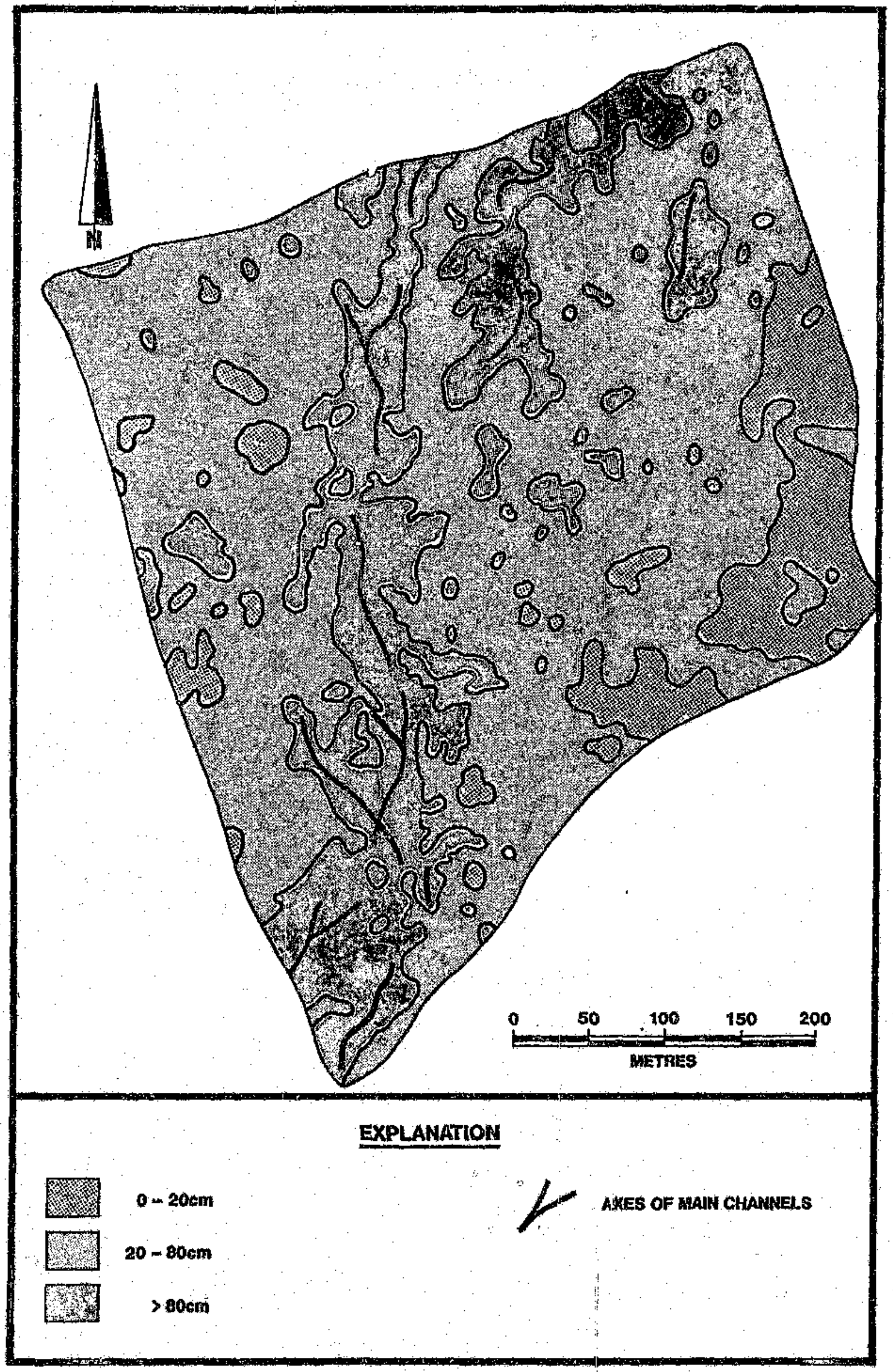

FIGURE 64: BEATRIX REEF ISOPACHS IN THE DETAILED STUDY AREA

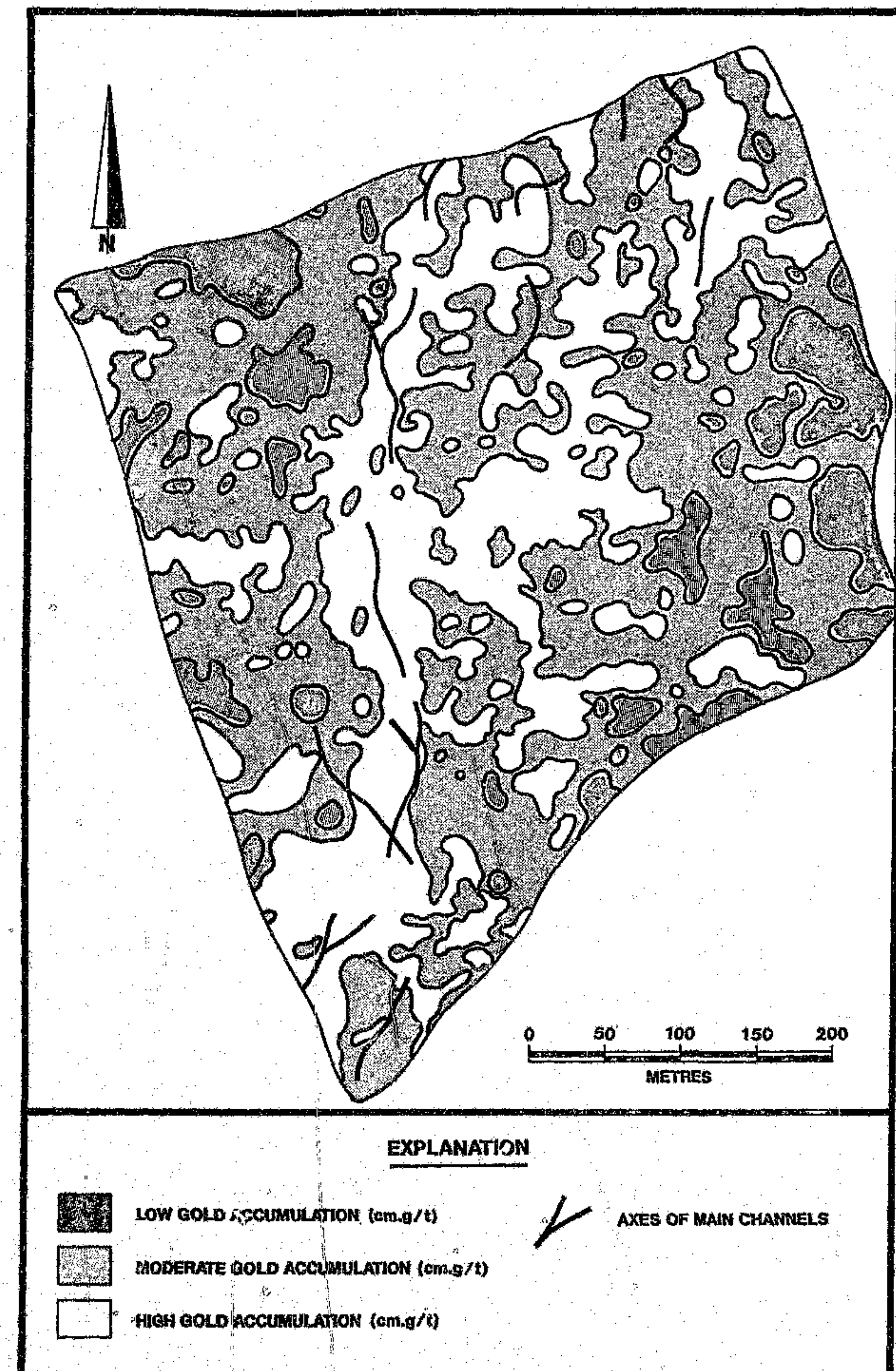

FIGURE 65: GOLD ACCUMULATION IN THE DETAILED STUDY AREA

thickness in the calculation of the cmg/t factor. In order to obtain an unbiased relationship between channel morphology and gold distribution the gold concentration values (g/t) are also contoured (Fig. 66).

Gold concentration shows a very patchy distribution with the bulk of the values in the low to moderate categories. Moderate gold concentrations again fairly closely follow the channel pattern, but are slightly offset from it (Fig. 66). High gold concentrations occur as isolated spots sporadically throughout the study area, but tend to be associated with areas of reef less than 20 cm thick in the southeastern part of the area, and as linear zones along the channels in the central part (Fig. 66).

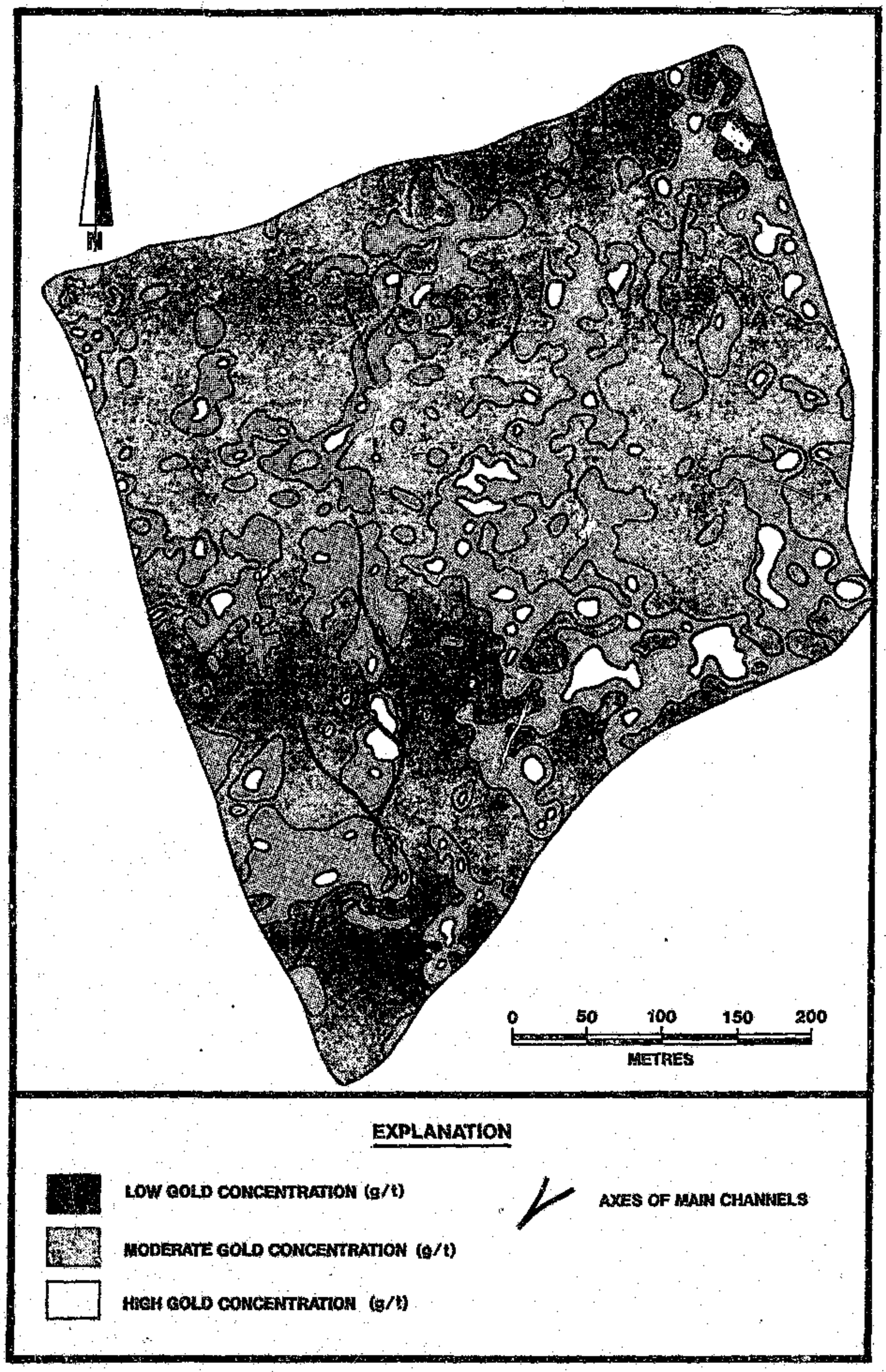

FIGURE 66: GOLD CONCENTRATION IN THE DETAILED STUDY AREA

5.2 MINERALISATION IN THE ROSEDALE MEMBER

Concentrations of heavy minerals are not as well developed in the lower parts of the Rosedale Member as in the Beatrix Reef. Rounded pyrite is again the most abundant component of the heavy mineral suite, but only forms about one percent of the rock. The pyrite grains are generally less than half a millimetre in size and the shape is frequently obscured by authigenic, idiomorphic overgrowths of recrystallised pyrite. The pyrite occurs concentrated on surfaces such as scours and on the toes of foreset laminae or other bedding planes. In general, pyrite is better concentrated with coarser grained sediments, particularly in the polymictic conglomerate facies. In cases where channel scours within the Rosedale Member have scoured into the top of the Beatrix Reef much of the pyrite concentrated at the top of the reef has been removed and is incorporated with the Rosedale Member sediments.

Gold mineralisation is generally poorly developed in the Rosedale Member. Only in places where scour surfaces cut down into the top of the Beatrix Reef are gold concentrations in the Rosedale Member enhanced.

Detailed sampling of the area in 16B61 stope where a pronounced Rosedale Member channel cuts through the Beatrix Reef (shown in Fig. 37), confirms that enhanced gold concentration is present in conglomerate bars close to channel flanks, and in the basal lag conglomerates (Fig. 67), but that gold values in the Rosedale Member are generally low.

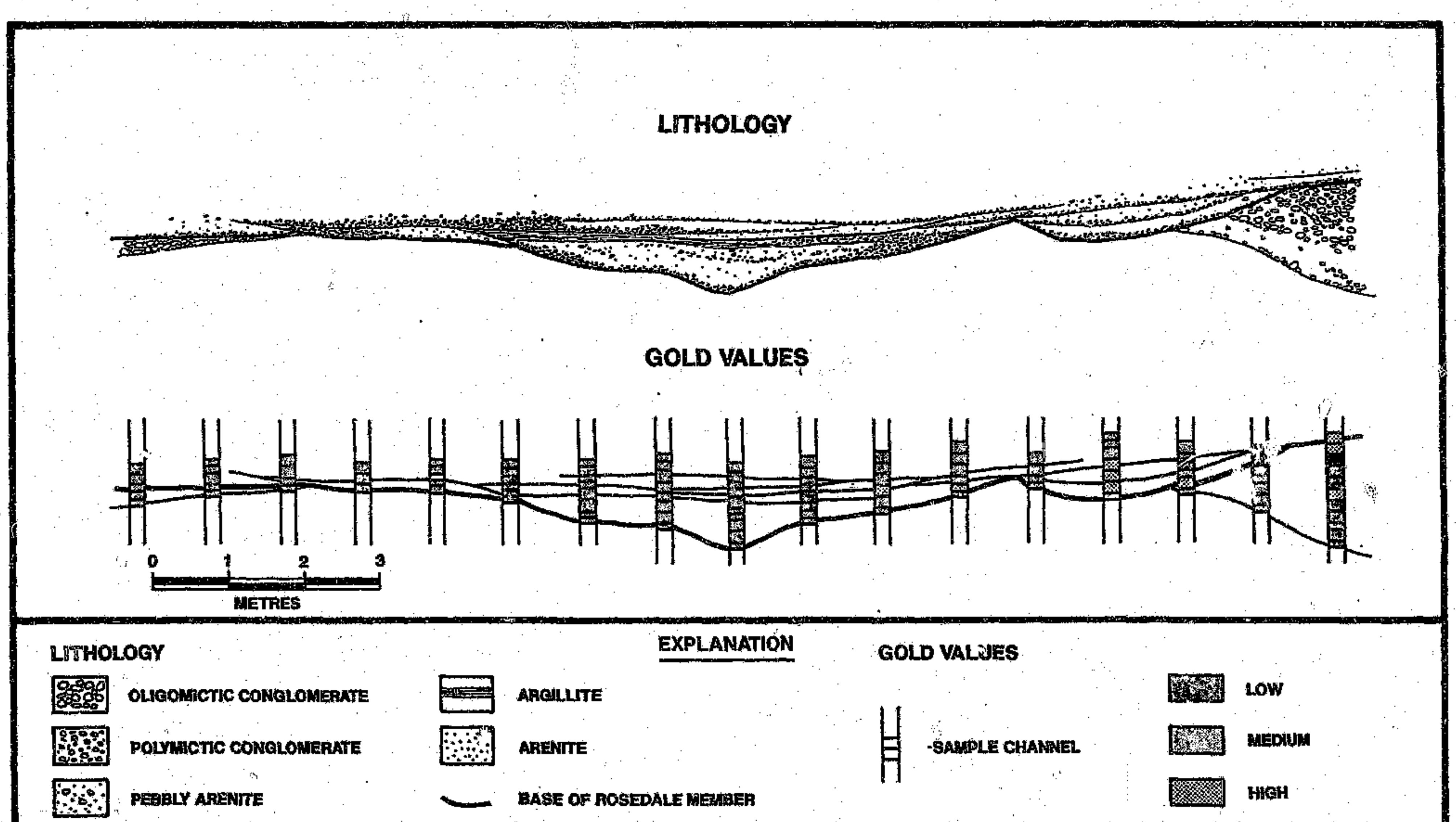

FIGURE 67: DETAILED SAMPLING OF THE BASE OF THE ROSEDALE MEMBER IN 16B61 STOPE

5.3 SEDIMENTARY CONTROLS ON MINERALISATION IN THE BEATRIX REEF

Within the Beatrix Reef heavy minerals most commonly occur as discrete accumulations concentrated along sedimentary and bedding structures such as scour surfaces, crossbed foreset laminae or bedding planes (Figs. 20, 21, 22 and 23). This occurrence as discrete segregations associated with sedimentary structures suggests that heavy minerals were deposited with the sediment and preserved under specific hydraulic conditions. Consideration of the processes responsible for the formation of the sedimentary structures, and the sorting of heavy and light minerals, allows deductions to be made concerning the hydraulic conditions of the depositional environment and the controls on mineral concentration.

Sand transported in suspension in a decelerating stream experiences sorting of heavy from light minerals according to the different settling velocities of the grains (Brady and Jobson, 1973). Sorting of heavy from light minerals will also take place in accelerating or constant flows according to their differing entrainment velocities (Brady and Jobson, 1973). The difference in the fluid lift and frictional drag forces promote entrainment of larger, lighter grains and inhibit the movement of the smaller, heavier grains. Allen (1970b) suggested that the frictional forces experienced by a particle in a flow are a function of the size of that particle in relation to the size and packing of the particles within the bed. This relationship between selective entrainment and particle size was expanded on by Slingerland (1984). The segregation of smaller, heavy minerals from larger, lighter minerals due to selective entrainment is enhanced in the turbulent flow variations encountered across bedforms (McQuivey and Keefer, 1969), or in the convergence zones between banks and bars (Smith and Beukes, 1983). Brady and Jobson (1973) conducted flume experiments to determine the behaviour of heavy minerals in alluvial channels, and found segregations of heavy minerals upon ripples, dunes and upper-flow-regime plane beds at progressively higher flow rates. Heavy mineral accumulations on ripples and dunes occured as thin segregations on the stoss-sides and within topset and foreset laminae (Brady and Jobson, 1973). The stoss-side accumulations comprised ripple-like segregations which migrated slowly towards the crest of the dune or ripple where they accumulated as thick, heavy mineral rich topset laminae (well illustrated in Fig. 55). Foreset accumulations of heavy minerals were widely spaced between light mineral foresets, and resulted from the periodic avalanche of heavy mineral rich topset deposits down the lee-side of the dune. These accumulations were thus confined to the upper parts of the foresets, and thinned rapidly down the foreset (Brady and Jobson, 1973) (cf. Fig. 55).

Strong erosional discordances between bedforms indicate slow sedimentation rates and the rapid migration of bedforms (Allen, 1970b), during which erosion results in the reworking of the tops of bedforms. This reworking allows only the preservation of the bottom parts of the foresets and the heavy mineral rich topset accumulations are thus rarely preserved. This condition for the accumulation of heavy-mineral rich segregations on foresets (Allen, 1970b Brady and Jobson, 1973) has been questioned by Slingerland (1984) who noted that heavy-mineral rich accumulations on the toes of foresets were common and result from two possible sorting mechanisms.

- the reworking of the heavy-mineral rich laminae on the backs of dunes during migration by means of selective entrainment in the trough turbulence zone
- suspension sorting by entrainment off the crest of the dune with various size classes settling to different points in front of the dune, with the heavier grains closer to the lee-face.

The rough surfaces of lag conglomerates produce large variations in the turbulence intensity of stream flow providing ideal conditions for the segregation of heavy minerals (McQuivey and Keefer, 1973). Heavy mineral grains which collect on conglomerate beds, particularly at the toes of migrating ripples or dunes, are effectively shielded from further entrainment by the bed roughness and high frictional resistance created by the pebbles. The concentrations of heavy minerals in horizontally laminated pebbly arenites and on the tops of bedforms represent segregations due to selective entrainment of lighter, larger grains according to differences in entrainment velocity.

From this discussion it is apparent that the most favoured location for the concentration of heavy minerals, and gold, in conglomerates is

- on scour surfaces with pebble lags
- on lag surfaces
- on winnowed surfaces
- on crossbed foresets
- on the tangential toes of foresets
- on planar bedding surfaces

[after Pretorius, (1989) table 9]

The highest concentrations in Witwatersrand reefs will occur

- on the bottom contact = lowest surface of degradation
- on the top contact = winnowed surface

Pretorius (1989) notes that surfaces with kerogen (carbon) are also favoured locations for the concentration of gold in Witwatersrand placers, and a close association of enhanced gold concentration with carbon granules and seams occurs in the Beatrix Reef (Hofmeyr, 1986).

The carbon is considered to be of organic origin, representing the remnants of primitive, algal plants (Hallbauer, 1975 and 1986, Dyer et al., 1988). Gold and heavy mineral grains were physically trapped by the algal mat filiments in a corduroy table-like action (Hallbauer, 1986). Digestive redristribution of gold and uranium by the dissolution of physically trapped particles and their reprecipitation along the filiments of the organism responsible for the formation of the carbonaceous material also occurred (Hallbauer, 1986).

Recent work by Landais et al., (1990) on carbon granules and seams in the Witwatersrand conglomerates suggests that the carbon may be an inorganic hydrocarbon replacing uraninite and the paragenetic sequence between uraninite and hydrocarbon is similar to that of the hinterland granitoids.

Although the mechanisms of segregation of heavy minerals on bedforms and their entrapment in gravels outlined above describe the small-scale variation of heavy mineral (and gold) concentration, they cannot be use.. to predict larger scale variations in mineralisation.

Work by Minter (1970) on the Ventersdorp Contact Reef at South Roodepoort Mine enabled him to correlate broad gold distribution patterns and certain sedimentological parameters and thus draw conclusions regarding the gold distribution and alluvial fan morphology. The best gold mineralisation occurred in the midfan portion of the alluvial fan model defined by the sedimentological parameters (Minter, 1970).

Broad-scale gold distribution patterns are not possible at Beatrix Mine due to the fairly limited extent of the current underground exposure.

The detailed work carried out over the channelled zone on the south-eastern side of No. 2 Shaft (Figs. 64, 65 and 66) gives an indication of the larger scale variation of gold concentration in the Beatrix Reef. The tendency for pyrite and gold to be preferentially concentrated along the flanks of major channel systems has also been noted by Nami (1987) during flume experiments for the Chamber of Mines Research Organisation. This tendency was explained in terms of the hydrodynamic conditions of flow in the channel. Flow velocity in the main channel was too high for the deposition of smaller grain size material, but frictional drag along the flanks of the channel results in local eddy currents and deposition of heavy mineral grains (Nami and James, 1987; Ashworth, 1988). This results in "ribbons" of higher gold value parallel to, but offset from the main channels. (cf Fig. 66).

Mosley and Schumm (1977) and Best (1988) have shown from experimental studies that scours at the confluence of streams and the turbulence at these junctions enhances sediment reworking and promotes the concentration of heavy minerals at these locations. This phenomenon results in local concentrations of heavy minerals on the downstream side of stream tributary junctions (Mosley and Schumm, 1977; Smith and Beukes, 1983). A pattern similar to this is noticeable from the detailed work on the area to the south-east of No. 2 Shaft at Beatrix Mine (Fig. 66).

The pattern of heavy mineral concentration in the Beatrix Reef is thus indicative of concentration from unidirectional flow confined to discrete channels.

5.4 ORIGIN OF THE GOLD

The problem of the source of the abundant gold in the Witwatersrand sediments is as yet inadequately explained in the literature (Pretorius, 1989). The widely held views of Viljoen et al.(1970), Minter (1978) and Pretorius (1981) that the source of the gold, uranium and pyrite in the Witwatersrand is detrital material derived from the erosional denudation, under reducing conditions, of flanking Archaen terrane containing greenstone-hosted gold lodes are being challenged by a revival of the hydrothermal / epigenetic theories for the source of the Witwatersrand gold (Phillips et al., 1987; Law, 1990). Refinements of the detrital source of gold theory come from Hallbauer (1984 and 1986) and Robb and Meyer (1985) who propose hydrothermally altered granites (H.A.G.s) as being the flanking hinterland and the source of the gold and other detrital minerals. Hutchinson and Viljoen (1988) however suggest that the H.A.G.s resulted during the formation of pyritic, auriferous exhalites along the tectonically active northwestern margin of the Witwatersrand basin by shallow marine hydrothermal discharge. Reworking, by fluvio-deltaic processes, of these pyritic exhalites along the regressive margin of the basin formed the mineralised reefs (Hutchinson and Viljoen, 1988).

Pretorius (1989) suggests that there was a pene-contemporaneous relation between tectonic activity, granite emplacement with associated hydrothermal and metasomatic effects, erosion, sedimentation and the introduction of mineralisation during the Central Rand deposition. The degradation of high-level porphyry or epithermal-type gold mineralisation supplied gold and uranium-rich detrital debris which was fluvially reworked on braid-deltas or unconformity surfaces. The fluvial waters possibly contained some dissolved gold and uranium. Hydrothermal fluids, similarly enriched in gold and uranium, impregnated the coarser grained clastics while these were being laid down. Reconstitution of the gold, uranium, sulphides and other matrix material by pervasive, metamorphic fluids took place during later metamorphic events

(Pretorius, 1989). This theory encompasses elements of all the major mineralisation models suggesting that the Witwatersrand mineralisation is more than likely due to a combination of mineralisation processes.

A detailed discussion on the source of the gold mineralisation is beyond the scope of the present study. The close association of detrital heavy minerals and gold with both large- and small-scale sedimentological features, and the lack of any relationship between mineralisation and structural or intrusive events or features supports the hypothesis of mineralisation introduced as detrital material and concentrated by hydrodynamic processes. Reconstitution and possible local remobilisation of minerals during diagenetic or low-grade metamorphic events is likely and would explain many of the mineral characteristics that are favoured in arguments for a hydrothermal origin.

6 SYNTECTONIC BASIN EVOLUTION IN THE BEATRIX MINE AREA

Tectonic movement and folding, syn- and prior to deposition of parts of the Witwatersrand Supergroup has been described from the East Rand basin. In the Evander and Benoni areas the Bird Amygdaloid (Johannesburg Subgroup) lavas thicken in synforms and thin against antiforms indicating that folding took place prior to, or contemporaneous with the extrusion of the lavas (Pretorius, 1964).

In the Welkom Goldfield syntectonic deposition is documented along the western margin of the goldfield where local unconformities within the Eldorado Formation on Loraine Mine indicate periodic uplift along the Western Margin Structure during deposition (Winter, 1964a, Minter et al., 1986).

Basin-wide tectonic movement and deposition is recorded by the Booysens Shale Formation (Upper Shale Marker in the Welkom Goldfield). The shale represents the distal facies equivalents of the formations underlying it and is the product of basin-wide subsidence and transgression (Tankard et al., 1982).

The Central Rand Group in the Welkom Goldfield comprises numerous tectonogenetic sedimentary packages separated by unconformities (Tankard et al., 1982). The packages consist almost entirely of sericitic arenite with minor conglomeratic intervals with placer deposits at the base overlying the unconformity surfaces. Trough crossbedded units reflecting sand dune migration in wide, shallow channels are most common, although accretion of bar margins produced sporadic, planar crossbedded units (Tankard et al., 1982). Channel patterns are generally unconfined and braided, with an almost linear drainage pattern of interconnecting, low-sinuosity channels oriented down the palaeoslope forming a broad braid-plain fan delta. The packages of sediment indicate rapid aggradation of the braid-plain, and repetition of gravel beds in the sequence reflects shifting of the major channels across the the fan with periodic fan-head retrenchment (Tankard et al., 1982). Palaeocurrent information suggests that the sediment transport was mostly towards the east and northeast (Minter et al., 1986).

Uplift along the Western Margin Structure and along the southern basin margin resulted in periodic fluvial degradation and erosion of these previously deposited fluvial packages. This erosion and fluvial degradation resulted in the cutting of unconformity surfaces (with the truncation of much of the Johannesburg Subgroup south of the Sand River), at times with deeply incised fluvial channels such as the Aandenk Channel. Transport directions were still dominantly from west to east (Tankard et al., 1982, Minter et al., 1986). Low aggradation rates during this fluvial degradation result in frequent sediment reworking and the generation of a mature conglomeratic layer of limited vertical extent such as the "B" Reef or Big Pebble Marker. This process is similar to that described by Buck and Minter (1985) and Minter (1987) for placer formation by fluvial degradation of alluvial sequences.

During the later part of Central Rand Group deposition in the area south of the Sand River, and subsequent to the deposition of the Aandenk Formation, renewed tectonic activity, compression, and uplift along the Western Margin Structure led to a further period of fluvial, erosional degradation which cut the unconformity surface at the base of the Beatrix Reef. Erosion to form this unconformity surface truncated the upper formations of the Johannesburg Subgroup, as well as the lower formations of the Turffontein Subgroup, in the Beatrix Mine area.

In the areas south of the Sand River this period of degradation resulted in large tracts of coarse-grained, erosional detritus, including detrital placer minerals, derived from the breakdown of the outcropping Aandenk and Spes Bona Formation placers (Minter et al., 1988).

The association of sedimentary structures and the most common facies sequence in the Beatrix Reef are typical of the Scott type to Donjek type braided stream depositional models of Miall (1977, 1978), but the geometry is best explained in terms of the coarse-grained braid-delta model of McPherson et al. (1987).

Fluvial reworking of the erosional detritus derived from the eroded, underlying formations down a north-south, coarse-grained braid-delta, by low aggradation rate braided streams resulted in reworking and concentration of placer material to form the Beatrix Reef.

Further sourceward uplift causes tilting of the palaeosurface and the previous erosional surface is transgressed.

Alternately, basin subsidence following the cessation of compression and uplift along the Western Margin Structure would

also result in transgression of the previous erosion surface.
The fine-grained, heterolithic facies sequence in the basal part of the Rosedale Member, disconformably overlying the Beatrix Reef, suggests that the erosional cycle and fluvial degradation forming the unconformity surface and the Beatrix Reef culminated in a transgression across the braid-plain in the Beatrix area. The geometry and sedimentary structures in the heterolithic facies indicate that this transgression was shallow, marginal marine (tidalite) or shallow lacustrine (playa lake). Shallow, marginal marine depositional models transgressively overlying placer forming episodes have been described in many of the Central Rand Group placers (eg. Vaal Reef - Minter, 1976 and Verrezen, 1987. Main Reef Leader - Button, 1979. Kimberley Reefs - Armstrong, 1966, and Bailey et al., 1990), and would not be unique to the Beatrix area.

Polymictic conglomerates and trough crossbedded lithic arenites in the distal, fine-grained toes of alluvial fans, disconformably overlying the Beatrix Reef and the heterolithic facies sequence of the Rosedale Member, heralded the onset of Eldorado Formation sedimentation. The dominantly north to south transport direction (Kingsley, 1987 and this study) confirm that subsequent to the erosional episode forming the Beatrix Reef unconformity the palaeoslope had changed and southerly uplift was replaced by subsidence of the southeastern parts of the basin, which was now open to the southeast.

The upward coarsening of the Eldorado Formation from essentially arenitic units to conglomerate dominated sequences illustrates the progradation of the alluvial fans, feeding off the flanking highlands to the west, across the braidplain (Kingsley, 1987). Periodic and continued uplift along the Western Margin Structure throughout the deposition of the Eldorado Formation resulted in local unconformities and placer formation by fluvial degradation episodes within the Eldorado Formation along this western margin of the Welkom Goldfield (Winter, 1964a; Minter et al., 1986).

Regional, basin-wide extension resulted in the outpourings of the Ventersdorp lavas and the curtailment of active, Central Rand Group sedimentation in this part of the Witwatersrand basin. Continued extension during middle-Ventersdorp times led to large scale normal faulting (De Bron, Homestead, Stuirmanspan) and the formation of horst and graben blocks throughout the Welkom Goldfield. Renewed sedimentation from these newly uplifted areas was in the form of local alluvial fans and lacustrinal sediments (Klippan Formation) flanking the horst blocks.

Within the Welkom Goldfields there is no preserved evidence of the later Proterozoic basins or tectonic events until the Dwyka glaciation and Karoo sedimentation.

7. SUMMARY AND CONCLUSIONS

7.1 GEOLOGICAL AND STRATIGRAPHIC SETTING OF THE BEATRIX REEF

Beatrix Mine is the most southerly of the Witwatersrand-type goldmines occurring on the presently known southwestern margin of the Witwatersrand basin some 35 km south of Welkom, and marks the southern limit of the Welkom Goldfield.

In the Welkom Goldfield area south of the Sand River, the Archaen Witwatersrand and Ventersdorp Supergroups are covered by a thick (300 - 500 m) succession of Permo-Triassic aged Karoo Sequence sandstones and shales. All deductions on the geology of the Beatrix Reef and the Witwatersrand rocks are thus based on borehole information or the reef exposed in the underground workings on the Beatrix Mine.

The Beatrix Reef rests on an unconformity surface which, in the area south of the Sand River, subdivides the Central Rand Group into the Johannesburg Subgroup and the overlying Turffontein Subgroup. The reef is not unique or significantly different from any of the other economically exploited reefs in the upper parts of the Witwatersrand Supergroup. Depositional systems inferred for Beatrix Reef sedimentation and placer formation can thus serve as a model for some Central Rand Group placers.

The Central Rand Group in the Beatrix area is represented by the Virginia Formation (Johannesburg Subgroup) and the Eldorado Formation (Turffontein Subgroup), and is about 1000 m thick. In comparison with the Central Rand Group in the Welkom

Goldfield north of the Sand River, just over 1000 m of stratigraphy comprising the St Helena, Welkom, Harmony, Dagbreek, Spes Bona and Aandenk Formations are truncated at the unconformity at the base of the Beatrix Reef. Remnants of the Aandenk Formation below the Beatrix Reef in the northern parts of the mine however suggest that the truncation of a significant part of the underlying Johannesburg Subgroup can be ascribed to erosion documented by the unconformity at the base of the Aandenk Formation.

On Beatrix Mine the Beatrix Reef unconformably overlies the Virginia Formation and is in turn disconformably overlain by the Eldorado Formation. This unconformable relationship and the significant difference in sedimentary facies sequences between the units suggests that the Beatrix Reef should be accorded status as a separate Formation, or at least be recognised as a distinct Member of the Eldorado Formation.

7.2 BEATRIX REEF AND ELDORADO FORMATION SEDIMENTARY FACIES

Oligomictic conglomerates and minor arenites are the dominant components of the Beatrix Reef and, based largely on differences in lithology and the association of bedding and sedimentary structures, a number of facies can be recognised. The main facies of the Beatrix Reef are

- massive, oligomictic conglomerate
- horizontally and low angle inclined stratified conglomerate
- trough crossbedded conglomerate
- planar crossbedded pebbly arenite
- trough crossbedded pebbly arenite

The Beatrix Reef varies from a single pebble, lag layer a few centimetres thick to sequences of interbedded conglomerate and arenite up to 3 m thick. Isopachs of these thickness variations define well-developed north-south trending channels. Palaeocurrent measurements from crossbedding and pebble size variations confirm this trend and indicate a north to south transport direction.

The Rosedale Member disconformably overlies the Beatrix Reef and a number of discrete facies can be recognised from lithological variations and the association of sedimentary structures. The main facies that are recognised are

- polymictic conglomerate
- trough crossbedded arenite
- planar crossbedded arenite
- heterolithic facies

Sedimentary structures preserved within the heterolithic facies include wave ripples, ladder-back ripples, lenticular bedding, convolute bedding, mudcracks and rinzel marks. The Eldorado Formation coarsens upward from a dominantly arenite and argillite sequence in the Rosedale Member at the base to a dominantly polymictic conglomerate sequence in the upper parts of the Uitkyk Member. Palaeocurrent data and grain size variation again indicates a north to south transport direction.

7.3 DEPOSITIONAL MODELS

The extent of the truncation of underlying formations below the Beatrix Reef suggests that tectonic uplift was responsible for erosion and the formation of the unconformity. The Beatrix Reef overlies this unconformity with a pronounced scoured surface which may show local relief up to 2 m. The most common facies sequence is

Scour surface --- Gms --- Gh --- Gt/Gp --- St

and is typical of Miall's (1978) Scott to Donjek type braided stream models. However, the thin, sheet-like geometry of the reef and the maturity of the sediments implies frequent reworking and low aggradation rates. Such features correlate with the coarse-grained, braid-delta model of McPherson et al.(1987).

Two dominant facies sequences are apparent in the basal parts of the Rosedale Member disconformably overlying the reef. The one sequence consists dominantly of fine-grained facies in an upward-coarsening succession indicative of alternating periods of arenite and argillite deposition with the most common facies sequence being;

Fl --- Sh/Sr --- St

The sedimentary structures indicate alternating periods of arenite and argillite deposition (lenticular and convolute bedding) with intermittent subaerial exposure (mudcracks), and is indicative of intertidal deposition in a fine-grained, marginal marine environment, or a shallow lacustrine setting. The other facies sequence in the Rosedale Member comprises lithic arenites and polymictic conglomerate in scour based, upward fining units with the most common facies association being;

Scour surface --- Gm/Gt --- St/Sp --- St

This sequence is again typical of Miall's (1978) braided fluvial (Donjek-type) depositional model. The immaturity of the lithic arenite sediment and the geometry of these sequences confirm deposition in a braid-plain or braided, fluvial fan-delta. The overall upward coarsening of the Eldorado Formation from arenite-dominated to conglomerate-dominated sequences documents progradation of the fan-delta sequence across the braid-plain.

7.4 SYNTECTONIC BASIN EVOLUTION

Within the Welkom Goldfield the Central Rand Group comprises a number of tectonogenetic packages of sediment. These packages consist predominantly of "dirty" arenite with minor, interbedded polymictic conglomerate layers. The lithology and facies associatons of these packages suggest deposition as fluvial sequences in high aggradation rate braided streams on a braid-plain (Tankard et al., 1982). Periodic uplift with concomittent changes in the base level induced erosion and fluvial degradation of the previously deposited sediment packages. Low aggradation rates and frequent reworking during these fluvial degradation cycles led

to placer formation on the unconformities.
The Beatrix Reef is the result of one such period of fluvial degradation where the reworking of detritus derived from the erosion of the truncated, underlying Spes Bona and Aandenk Formations on a north-south oriented, coarse-grained braid-delta, led to placer mineral concentration and the formation of the reef. A transgression at the culmination of this reef-forming cycle is recorded by the fine-grained facies sequence at the base of the Rosedale Member, disconformably overlying the Beatrix Reef. Depositional models suggest a marginal marine (tidalite) or a shallow lacustrine (playa lake) setting after the transgression.

This model for Beatrix Reef formation by fluvial degradation and reworking of detritus derived from previously deposited sequences, in a low aggradation rate, coarse-grained, braid-delta, is probably applicable to many Central Rand Group reefs. Shallow, marginal marine, transgressive depositional models as the culmination of the placer forming cycle have also been described from other Central Rand Group reefs. At Beatrix Mine the regressive cycle following placer formation is recorded by the progradation of the fluvial braid-plain and alluvial fan sequences of the Eldorado Formation across the Beatrix Reef.

7.5 MINERALISATION IN THE BEATRIX REEF

Heavy minerals are an important constituent of the Beatrix Reef placer material. Pyrite is the dominant constituent and comprises 85% of the heavy mineral suite. It occurs mainly as compact, rounded grains (buckshot pyrite), porous, rounded grains ("mudball pyrite") or as authigenic overgrowths on other pyrite grains.

Gold is economically the most important constituent of the heavy mineral suite and occurs mainly as discrete, free-milling grains or associated with carbon material. Minor amounts of gold also occur included within pyrite or within other silicate minerals such as quartz or chlorite. Other heavy minerals within the Beatrix Reef include uraninite and brannerite, chromite, leucoxene and other sulphides such as chalcopyrite and galena but together they comprise only about 10 % of the heavy mineral suite.

The heavy minerals are associated with sedimentary bedding structures and occur as discrete accumulations along foresets or bedding planes. This association is explained in terms of hydrodynamic sorting and the segregation of heavy from light minerals by preferential entrainment. Large-scale variations in heavy mineral concentration also show a correlation with larger scale sedimentary features such as along the flanks of channels or at channel junctions. These features suggest deposition of the heavy minerals in conjunction with the sediment, and sorting and concentration in response to hydrodynamic conditions within the flow system or across bedforms.

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