THE SIGNIFICANCE OF UNCONFORMITIES IN THE DEVELOPMENT OF WITWATERSRAND GOLD AND URANIUM PLACERS

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ABSTRACT

Most of the economic gold and uranium placers are developed on low angle disconformities in the Central Rand Group and concentrations of gold and uranium are usually at their optimum on unconformity surfaces. Examples include the Kimberley Reef and South Reef of the East Rand, the Main Reef Leader of the Central Rand, the Carbon Leader of the Carletonville goldfield, the Vaal Reef of the Klerksdorp goldfield and the Basal/Steyn placers of the Welkom goldfield.

The individual goldfields represent fluvial fans which are composed of a large number of tectonogenetic sedimentary packages separated by unconformities. The tectonic responses between cycles of sedimentation produced unconformities and tectonically controlled cyclic sedimentation is one of the key factors culminating in the preparation and deposition of auriferous placers within the Witwatersrand succession.

Unconformities, which represent breaks in sedimentation, result in the preconditioning of palaeosurfaces and the redistribution of sediments and heavy minerals on them. Winnowing of sands produced heavy mineral residual accumulations on erosion surfaces which were generally preserved by small-pebble lags or algal mats. Reworking of units truncated by the unconformities provided additional gold, uranium and heavy minerals to unconformity surfaces.

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INTRODUCTION

The Witwatersrand basin ranks as one of the richest mining fields the world has ever known. It has been estimated that, of all gold mined in all parts of the world, over the whole span of recorded history, about 55% has come from the auriferous placers of the Witwatersrand Supergroup (Pretorius, 1974).

The full succession of the Witwatersrand Supergroup is not preserved in any one locality due to depositional onlapping or erosional removal. A composite lithostratigraphic column is therefore not representative of the goldfields which are located over a distance of some 480 km along the arcuate, outer rim of the Witwatersrand basin. Accordingly, an account of the stratigraphy of the Supergroup is dealt with on the basis of individual goldfields with emphasis placed on cycles of sedimentation and the unconformity - related exploitable placers within the succession.

The individual goldfields represent fluvial fans which are composed of a large number of fining-upwards cycles of sedimentation with boundaries between cycles usually represented by unconformities of varying magnitude. The planes of inter-cycle unconformity are of considerable economic importance, since all exploitable placers occur on, or immediately adjacent to, the unconformities. The majority of unconformities represent surfaces of erosion initiated in response to tectonism during, or between, cycles of sedimentation.

The nature of the footwall contacts of the various reefs is important in understanding the distribution of the gold, uranium and heavy minerals on the unconformity surfaces. A detailed account is therefore given of the palaeosurfaces of erosion which underly the economically significant placers and the factors responsible for the preparation of these surfaces, are stressed. The palaeosurfaces bear erosional etches which are channel forms that make local angular unconformities with the footwall. The configuration of these channel forms dictates to a large extent the continuity and payshoot trends of the auriferous/uraniferous placers. Braided-etched intraformational erosion surfaces are economically attractive due to their relatively large area and continuity of conglomerate sheets deposited on them, examples of which are afforded by the Basal/Steyn placers of the Welkom goldfield and the Main Reef Leader of the Central Rand. In contrast, the "B" placer of the Welkom goldfield is economically of secondary importance compared with the Basal and Steyn placers because, although it is distributed over an area of 400 km^2, it is confined to shallow interconnected channelways which cover less than 35% of the palaeosurface.

Unconformities are significant as they result in the preconditioning of palaeosurfaces and allow the settling, concentration and winnowing of heavy minerals on erosion surfaces. The distribution pattern of gold is largely the result of different hydrodynamic conditions which prevailed during the deposition of the placer and the gold content essentially expresses a hydraulic energy-level fabric, controlled regionally by the geographic situation on the palaeosurface and locally by the detailed shapes of the footwall surface. An account is given of the trapping agencies and mechanisms responsible for the concentration and preservation of heavy minerals on unconformity surfaces.

The final chapter deals with the economic implications of the control exercised by unconformities in the development of gold and uranium placers.

NATURE AND TYPES OF UNCONFORMITIES

An unconformity is defined by Dunbar and Rodgers (1957) as a "temporal break in a stratigraphic sequence resulting from a change in regimen that caused deposition to cease for a considerable period of time". Unconformities normally imply uplift and erosion, with the loss of some previously formed record, and are structurally significant because they are clues to tectonic activity. Longwell and Flint (1962) emphasize that an unconformity is not a simple geometric feature, but a relationship, and state that "the contact between two uncomformable rock masses is properly called the surface of unconformity". According to Holmes (1965) , "every unconformity is an erosion surface of one kind or another, representing a lapse of time during which denudation exceeded deposition at that place". The time interval concerned in the break in the continuity of the geological record is called a hiatus.

Barrel (1917) introduced the term diastem with the intention of distinguishing between major breaks in the sedimentary record (unconformities) and minor interruptions of a brief duration (diastems). Dunbar and Rodgers (1957) drew a clear distinction between unconformities and diastems : the latter are "smaller breaks resulting from normal changes that occur without any basic change in the general regimen".

Structural relations between unconformable units fall into one of the four types illustrated in Fig. 1. Dunbar and Rodgers proposed the term nonconformity in which stratified rocks are unconformable with non-stratified, either igneous or metamorphic. An angular unconformity (see also Fig. 3) is a surface of erosion separating tilted or folded strata from essentially horizontal overlying undisturbed strata. If an unconformity is interpreted as angular, deformation of the beds below the surface of unconformity is implied. Grabau (1905) proposed the term disconformity for that type of unconformable relation "in which no folding of the older set of strata is involved" and is the relationship in which the strata both above and below the surface of unconformity are essentially parallel. Dunbar and Rodgers restricted the term disconformity to imply an erosion surface of appreciable relief between parallel strata and introduced the term paraconformity in which beds are parallel and the contact is a simple bedding plane. They may be caused by a change in environment where no deposition occurred, and the hiatus may, for instance, be inferred because of an abrupt faunal change.

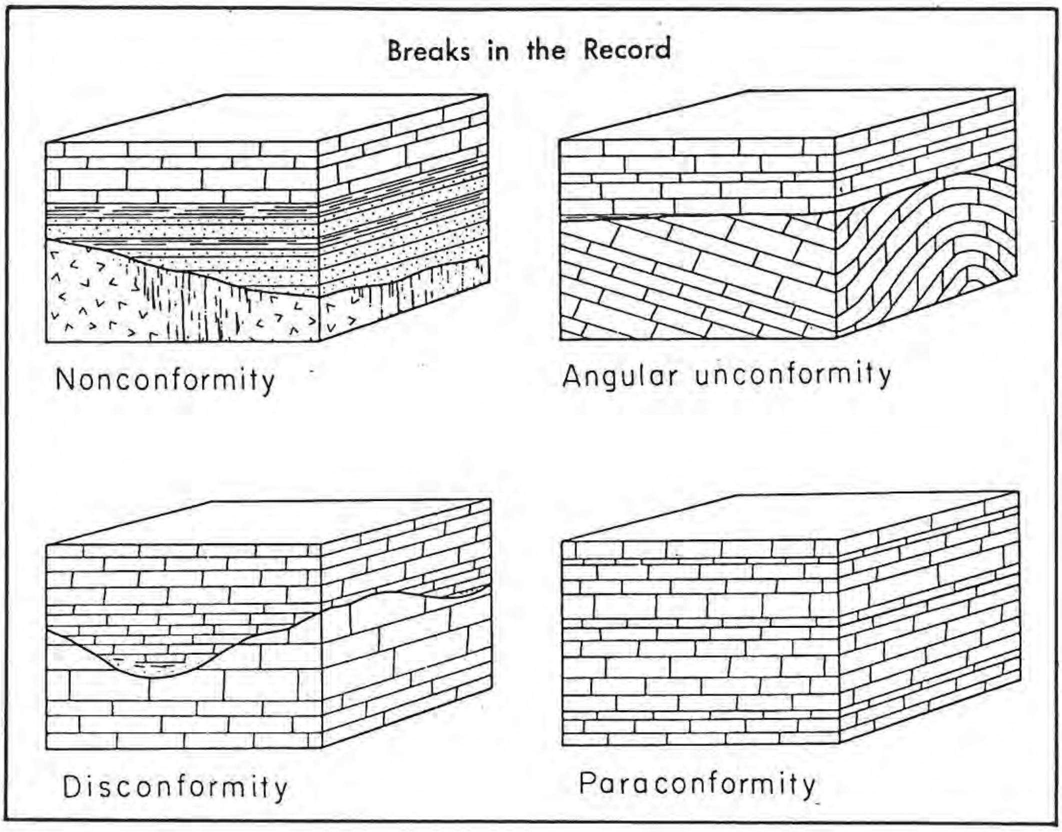


Fig. 1. The four types for unconformity. (Dunbar and Rodgers, 1957).

Billings (1947) distinguishes <u>local unconformities</u> from disconformities and these are local relationships formed on surfaces of erosion that may be preserved by burial. For example, at times of flood within a braided stream environment, deep channels may be scoured out, and as the flood subsides the channel may be filled by sediments. An unconformity of local extent is illustrated in Fig. 2 where conglomerates, that have occupied a channel, truncate the bedding of the shale.

Longwell and Flint (1962) compiled Fig. 3 in order to illustrate the meaning of unconformities; B emphasizes the dynamic relationship between erosion and contemporanous deposition.

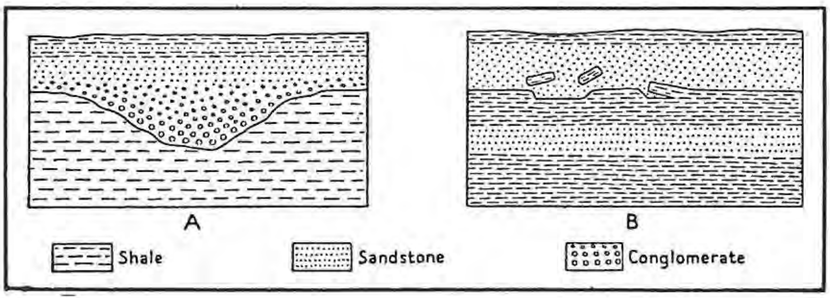


Fig. 2. Channelling and local unconformity. A. Channel cut into shale has been filled by conglomerate. B. Fragments of shale deposited in overlying sandstone. (From Billings, 1947).

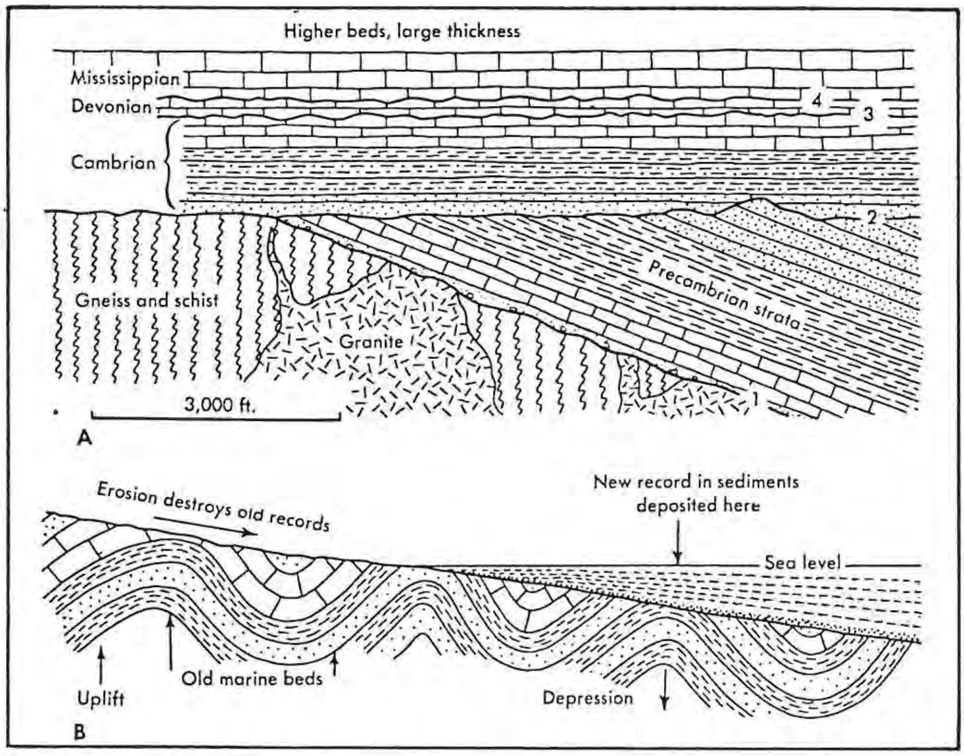


Fig. 3. Meaning of unconformities. A. The sedimentary record in the Grand Canyon has large gaps. Angular unconformities indicated at (1) and (2) represent large-scale crustal movements followed by long intervals of erosion. Surfaces of erosion indicated at (3) and (4), nearly parallel to the sedimentary layers, record broad upwarping followed by erosion and renewed deposition. B. While erosion destroys or prevents formation of a record in some areas, sediments build up to write a new record elsewhere. (From Longwell and Flint, 1962).

Recognition of offlap and onlap relationships associated with major unconformities are often the key to unraveling stratigraphic complexities. The effects of transgression and regression affected both the vertical and lateral relationships of sedimentary bodies and Fig. 4 illustrates typical relationships. Units A to E reflect regression and resulting offlap relationships; units F to I represent transgression and onlap relationships. At point 1, the regressive strata are truncated and the overlapping transgressive beds rest upon them with angular unconformity. At point 2 no evidence of the unconformity exists, and it is apparent that the regressive strata were not exposed to erosion. At point 3, all physical criteria of regression and transgression are lacking; however, by application of palaeontological data, an interpretation would be possible.

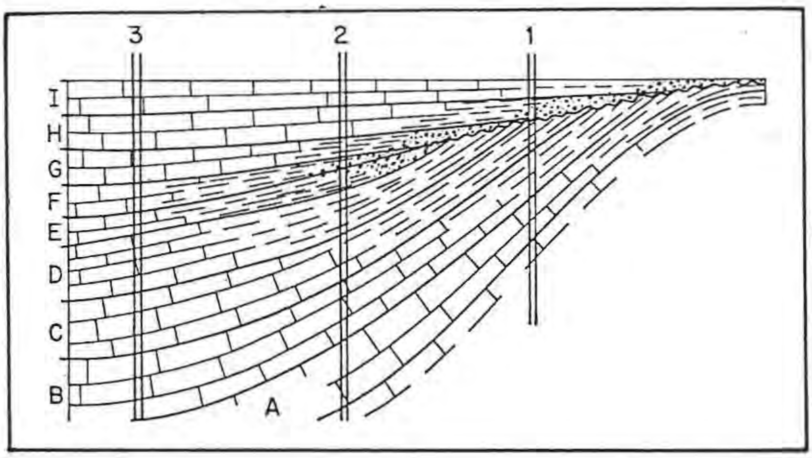


Fig. 4. Offlap and onlap relationships. Units A to E illustrate regression and offlap; units F to I represent transgression and onlap; unit H onlaps unit G, but both overstep units A to E. (From Krumbein and Sloss, 1963).

Criteria for Recognition and Evaluation

Recognising an unconformity is only the first step toward understanding it. The more important objective is to determine the magnitude of the hiatus (Blackwelder, 1909). According to Krumbein and Sloss (1963), criteria for recognising unconformities falls into three classes:

Sedimentary Criteria:

The more important ones include the presence of a basal conglomerate, residual chert, buried soil profiles (palaeosols), and zones of glauconite, phosphatised pebbles, or manganiferous zones.

Palaeontological Criteria:

Abrupt changes in faunal assemblages, gaps in evolutionary development, and the occurrence of bone and tooth conglomerates represent generally accepted criteria. One of the most decisive criteria of an unconformity is an abrupt phylogenetic change from one fossil assemblage to another in a vertical succession of rocks.

Structural Criteria:

Discordance of dip above and below a contact is the definitive criterion of an angular unconformity. An undulatory surface of contact which cuts across bedding planes of underlying formation marks a discontinuity caused by emergence and erosion. Truncation of dykes at a surface of contact marks subaerial unconformities caused by erosion. Relative complexity of faults above and below a surface of contact may indicate an erosional disconformity.

Dunbar and Rodgers (1957) consider the following criteria in recognition and evaluation of unconformities and the hiatus thereof:

Nonconformity:

They consider that a major hiatus is indicated where unmetamorphosed sedimentary rocks rest nonconformably on lower plutonic or metamorphosed rocks.

Angular Discordance:

Angular discordance is one of the most obvious marks of a hiatus since it normally implies that the older beds were deformed and then truncated by erosion before the younger beds were laid down. The angle of discordance does not indicate the relative importance of the hiatus as a time break. Furthermore, in orogenic zones, penecontemporaneous folding, uplift, erosion and deposition are characteristic responses to progressive deformation of the crust. As is shown in Fig. 5, the angles of discordance varies widely according to the position on the folds.

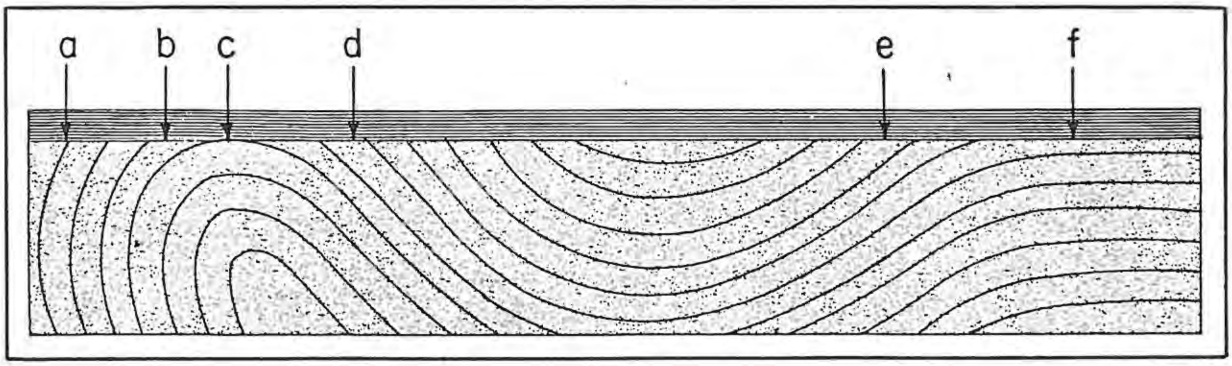


Fig. 5. Diagram of an angular unconformity between folded and non-folded beds, showing variation in the angular discordance according to position on the folds. (From Dunbar and Rodgers, 1957).

Erosional Relief at the Contact:

Where the surface of the unconformity cuts across beds, it is evident that uplift and erosion have occurred during the hiatus. Large reliefs make the unconformity impressive, but is a poor criterion of its temporal value.

Abrupt Lithological Changes:

Abrupt lithological change implies a change in regimen and may indicate a hiatus. A pronounced and abrupt change in lithology should be considered a warning of a possible hiatus but not proof that one exists.

Evidence of an old Erosion Surface:

One of the most satisfactory criteria for unconformity is evidence of an erosion surface between two formations. Such evidence may be in the physical form of the surface, such as pronounced irregularities; the abrupt truncation of structural features such as joints, faults, or dykes in the lower bed; the presence of pebbles from the beds below in the basal layer above, or the development of palaeosols/regoliths on the old surface.

Palaeontological Evidence:

Perhaps the most decisive criterion of an unconformity is an abrupt change from one fossil assemblage to another in vertical succession of the rocks. The relative importance of a hiatus is immediately evident if the beds above and below bear fossils by which they can be assigned their proper position in the geological column. In most instances this is the final and the only criterion that gives quantitative results for large unconformities. However this argument would not apply to pre-Phanerozoic rocks.

Unconformities associated with Witwatersrand Gold and Uranium Placers

Most of the economic gold and uranium-bearing placers are developed on low angle disconformities in the Central Rand Group and concentration of gold and uranium is usually at its optimum on unconformity surfaces. Surfaces of unconformity are found below most of the payable conglomerate sheets of the Witwatersrand basin. Examples include the Kimberley Reef and the "composite" or South Reef of the East Rand, the Main Reef Leader of the Central Rand, the Carbon Leader of the Carletonville goldfield, the Vaal Reef of the Klerksdorp goldfield and the Basal/Steyn placers of the Welkom goldfield. The Ventersdorp Conglomerate Formation comprises economically significant placers at the base of the Ventersdorp Supergroup. These are associated with prominent angular unconformities that truncate the already lithified Witwatersrand Supergroup strata.

Economic concentrations of gold and uranium are not restricted to conglomerates. Wherever winnowing of sands occurred there was potential for the residual concentration of heavy minerals on erosion surfaces. Consequently, thin concentrations of gold and other heavy minerals do occur on bedding planes which represent breaks in sedimentation, without any pebbles necessarily being present.

Unconformity surfaces covered by auriferous/uraniferous conglomerates have been classified by Button and Adams (1981) on the basis of the scale of the unconformity, the time break they represent and the character of the rock types overlying the conglomerate. A major subdivision is made on the basis of the scale of the unconformity and the time break it represents:

Type 1 Fundamental Unconformities/Nonconformities
Type 2 Intraformational Unconformities/Disconformities.

Type 1 : Fundamental Unconformities/Nonconformities

These unconformities can usually be traced over areas ranging from 10^4 to 10^5 km^2 with geological evidence suggesting a hiatus of 10^6 to 10^8 years. An example is the angular unconformity separating the Central and West Rand Groups in the East Rand (Button and Tyler, 1979). An important control on the localisation of conglomerates along fundamental unconformities is the palaeotopographical configuration of the erosion surface which is controlled largely by differential erosion and attitude of the beds below an unconformity. Where the angular difference across the unconformity is small, a single stratigraphical unit can be expected to suboutcrop beneath the unconformity over a relatively large area. Widespread conglomerate sheets are frequently developed on these fairly flat erosion surfaces and an example is afforded by the "Main Reef Leader", which was deposited on the unconformity surface between the Central and West Rand Groups in the East Rand (Fig. 6). This was one of the largest single placer sheets ever mined with a lateral continuity in excess of 400 km^2 (Pretorius, 1974). Mason (pers. comm., 1982) emphasises that the MRL of the East Rand is not the same as the MRL of the Central Rand. Differential erosion across steeply inclined beds has resulted in unconformity surfaces of considerable relief, varying from a few metres to a few hundred metres. An example of this situation is in the West Rand where the Black Reef conglomerates, which rest unconformably on inclined beds (Fig. 6), are largely restricted to palaeovalleys located over softer Witwatersrand formations (Papenfus, 1964).

Type 2 : Intraformational Unconformities/Disconformities

These unconformities usually have an areal extent of 10^2 to 10^3 km^2 and a hiatus of about 10^3 to 10^5 years (Button and Adams, 1981). The conglomerates are located on erosion surfaces cut across Witwatersrand sediments which were in a weakly lithified state at time of erosion with the result that effects of differential erosion are minimal. They are exceptionally important in the Witwatersrand basin as the major uranium-producing conglomerates rest on such surfaces (Button and Adams, 1981). The angular differences between beds above and below the intraformational unconformities are usually inconspicuous, but may be locally very obvious, and in the Central Rand, Cousins (1965), has shown that the Main Reef Leader conglomerate sheet truncates its footwall at a rate equivalent to 8 m/km. In the Vaal Reef of the Klerksdorp goldfield, the truncation occurs at 8,2 m/km (Minter, 1976). Locally, more dramatic unconformities have been noted as for example in the Welkom goldfield where angular discordances as high as 90 degrees are developed within the Central Rand Group (Olivier, 1965). These unconformities were probably formed by repeated upward movements of the western margin of the Witwatersrand basin along the north to south-trending Border Fault zone.

The term "erosion etching" is used to denote gentle channel erosion, usually no more than 1 to 2 m in depth, on a plane of an intraformational unconformity. Braided-etched intraformational erosion surfaces are economically attractive due to the relatively large area and continuity of conglomerate sheets deposited on them. Excellent examples are afforded by the Vaal and Basal/Steyn placers (Minter, 1978), the Carbon Leader and the Main Reef Leader (Central Rand).

Some intraformational unconformities are ornamented by deeper and narrower braided scour channels. The conglomerates developed along these surfaces are frequently restricted to channels and do not form laterally continuous sheets. The "B" Reef of the Welkom goldfield is developed over an area of about 400 km^2 and Minter (1978) estimated that conglomerate-filled channels occupy less than 35 percent of the erosion surface. The channels are from 1 to 200 m in width, and are up to 2 m in depth (Fig. 6).

A second criterion applied to the classification of unconformities is the character of the rock type directly overlying the conglomerate developed on the unconformity. Table 1, a classification of unconformities associated with Witwatersrand gold and uranium deposits, is modified after Button and Adams (1981).

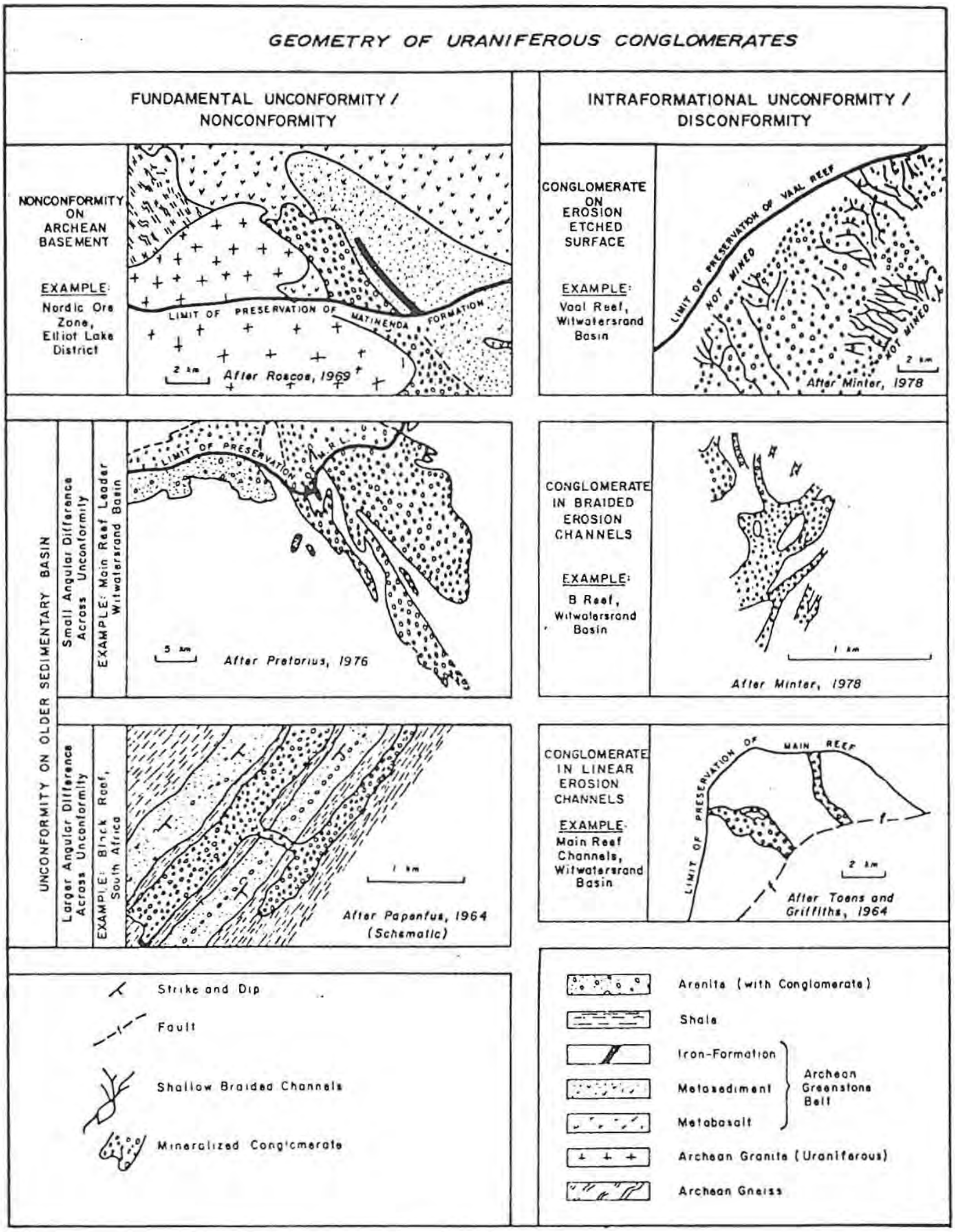


Fig. 6. Schematic diagram showing the typical plan-view shapes of uraniferous conglomerates developed on fundamental and intraformational unconformities. (From Button and Adams, 1981).

TYPE	SUBTYPE		EXAMPLE	REFERENCE
Fundamental Unconformity	Im	Overlain by Fluvial sediments	Black Reef Quartzites in East Rand goldfields	Papenfus, 1964
	Iv	Overlain by volcanic rocks	Ventersdorp Formation, Carletonville goldfield	Minter, 1978
Intraformational Unconformity	IIf	Overlain by fluvial sediments	Basal/Steyn conglomerate, Welkom goldfield	Minter, 1978
	IIm	Overlain by marine sediments	Vaal Reef in Klerksdorp goldfield Kimberley Reef of East Rand	Minter, 1976 Armstrong, 1968

Table 1 : Classification of unconformities associated with Witwatersrand gold and uranium deposits. (After Button and Adams, 1981).

Origin of Unconformities

The origin of unconformities can be sought in the tectonic framework of sedimentation which is defined by Krumbein and Sloss (1963) "as the combination of subsiding, stable, and rising tectonic elements in sedimentary source and depositional areas". The majority of unconformities represent surfaces of erosion initiated in response to tectonism during, or between, cycles of sedimentation.

Although the majority of unconformities represent a greater or lesser degree of erosion and stripping of older rocks, a true surface of unconformity can be formed by a pause in deposition alone. The conditions for unconformity without significant erosion are met in areas that have reached an equilibrium state, in which neither deposition or erosion takes place. In this state, the area is said to have achieved depositional base level, a condition which persists until the equilibrium is upset by uplift (resulting in erosion) or by subsidence (initiating renewed sedimentation and the establishment of a surface of unconformity without erosion). While equilibrium prevails, the sediments that reach the area affected are transported by the available agencies to adjacent areas where depositional interfacies are below depositional base level and are thus capable of accomodating and preserving additional sediment. The phenomenon of sedimentary transport across areas of nondeposition is known as sedimentary by-passing and is a fundamental process in the formation of obscure disconformities (Krumbein and Sloss, 1963).

Non-economic marine unconformities are relatively common in highly mobile depositional basins in which the sedimentary fill is dominated by turbidily current deposits. Each successive turbidity current represents a time of rapid sedimentation followed by a time of virtual nondeposition. The resulting sedimentary succession is therefore broken by numerous, minor local unconformities, each marking a nondepositional episode between sedimentary pulses.

Stratigraphical correlation, specifically in the Witwatersrand basin, must take account of the relative interplay between tectonism, erosion and cycles of sedimentation leading to the formation of unconformities in the sedimentary succession.

SETTING OF WITWATERSRAND BASIN

Form and Tectonic Evolution of Depository

The Witwatersrand basin (2,8 to 2,5 Ma) occupies a synclinal warp within the Kaapvaal Craton of the South African Shield (Minter, 1978). The basin is oval with a 350 km northeast to southwest trending long axis and a 200 km northwest to southeast trending short axis and covers an area of about 39 000 km^2. The Archaean granitic basement has been reactivated causing major domal structures and infolding of the Witwatersrand strata. The outcrop pattern of the strata and basement granite domes are shown in Fig. 7.

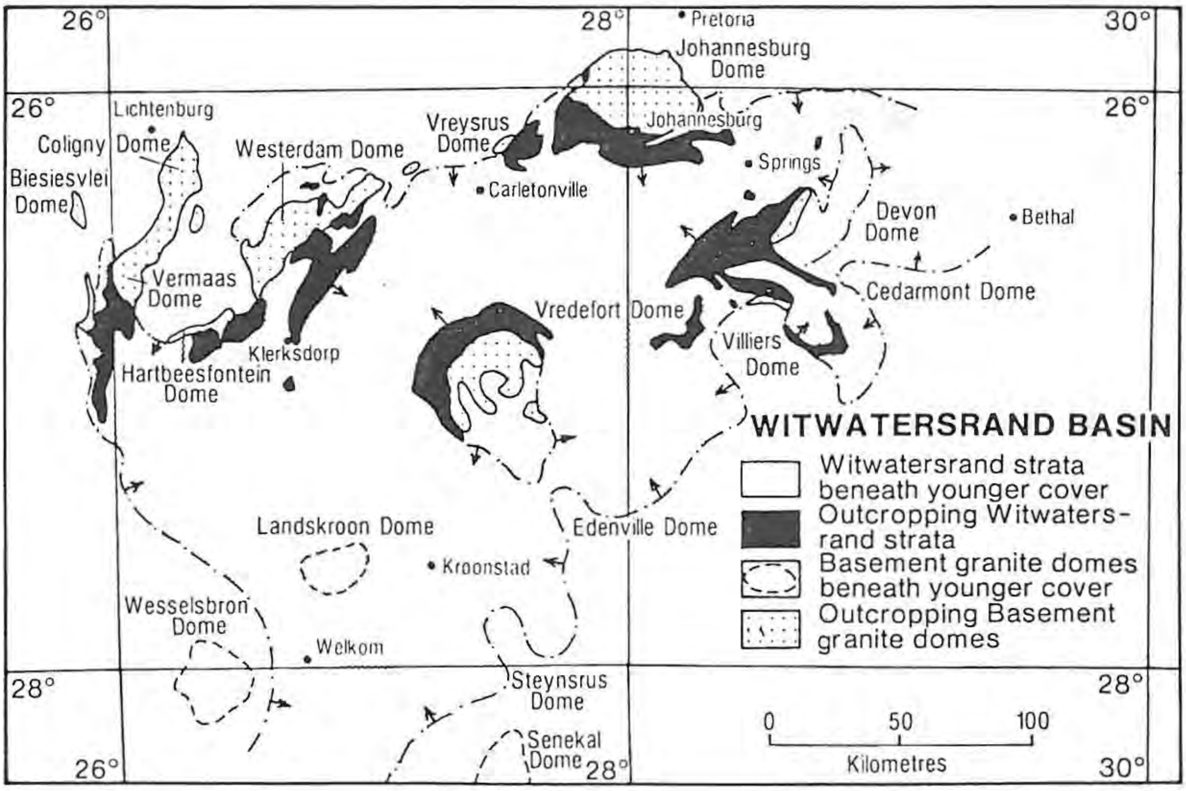


Fig. 7. The outcrop pattern of Witwatersrand strata and basement granite domes. The position of the outcrop and sub-outcrop of the base of the Witwatersrand Sequence has been determined by surface mapping, by magnetometric and gravimetric geophysical surveys, and by coredrilling. (From Pretorius, 1974).

The tectonic evolution of the Witwatersrand basin has been a matter of considerable debate. Brock and Pretorius (1964) visualised it as a structurally closed basin with an origin related to synclinal downwarping between peripherally rising granite domes. The broad tectonosedimentary characteristics of the Witwatersrand basin has been documented by Pretorius (1974). The structural setting envisaged was an intermontane, intracratonic, yoked basin with a fault-bounded, active, northwestern edge and a gently downwarping, passive southeastern boundary (Fig. 8). In addition to the asymmetrical shape, the basin is characterised by a mirror-image stratigraphy in which a basal volcanic and coarse clastic group and a lower coarse clastic and fine clastic group have their counterparts, in reverse sequence, in a terminal volcanic and coarse clastic group and an upper coarse clastic and fine clastic group. The repetition takes place about a pivotal fine clastic and non-clastic group which is located more-or-less in the centre of the complete succession. The shape of the basin is a factor in favouring the prevalence of offlap conditions, on a broad scale, on the short side of the depository and of onlap conditions on the long side. The distribution of the goldfields is intimately related to the pattern of interference folding that produced structural depressions and culminations, the latter in the form of domes of basement granite. The goldfields are all located around the rim of the basin in downwarps between the domes (Fig. 9), and take the form of fluvial fans, or fan deltas, which preferentially developed on the north-western edge of the basin. Uplifting of the source-area along the basin-edge was a continuous process in the mechanism of sedimentation,

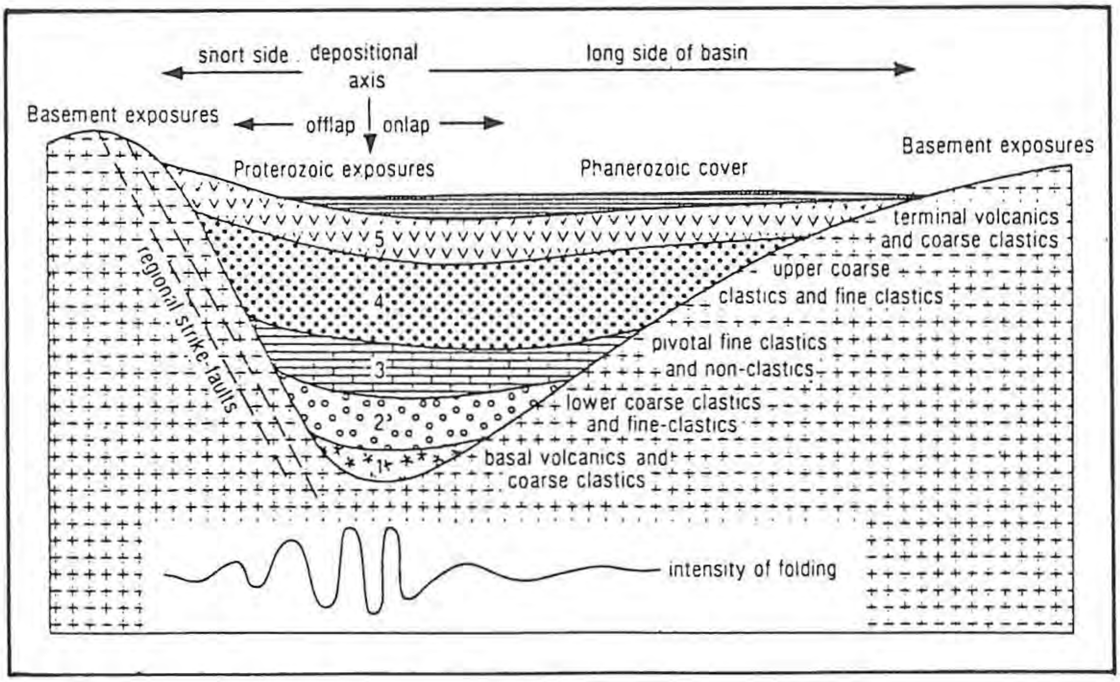


Fig. 8. Schematic section across Witwatersrand basin. (From Pretorius, 1981).

with the result that the fanhead sections of early fans were subjected to elevation, erosion, and reworking into later fans. This repeated reworking resulted in the development of economic concentrations of gold and/or uranium horizons which straddle planes of unconformity separating cycles of sedimentation. The original source of the mineralisation took the form of gold-silver vein quartz deposits in a host of ultramafic and mafic rocks of the Archaean greenstone belts, while the uranium came from the younger granites which enveloped the belts. In response to tectonic activity, gold was eroded from the rocks and concentrated in the basin by sedimentary processes.

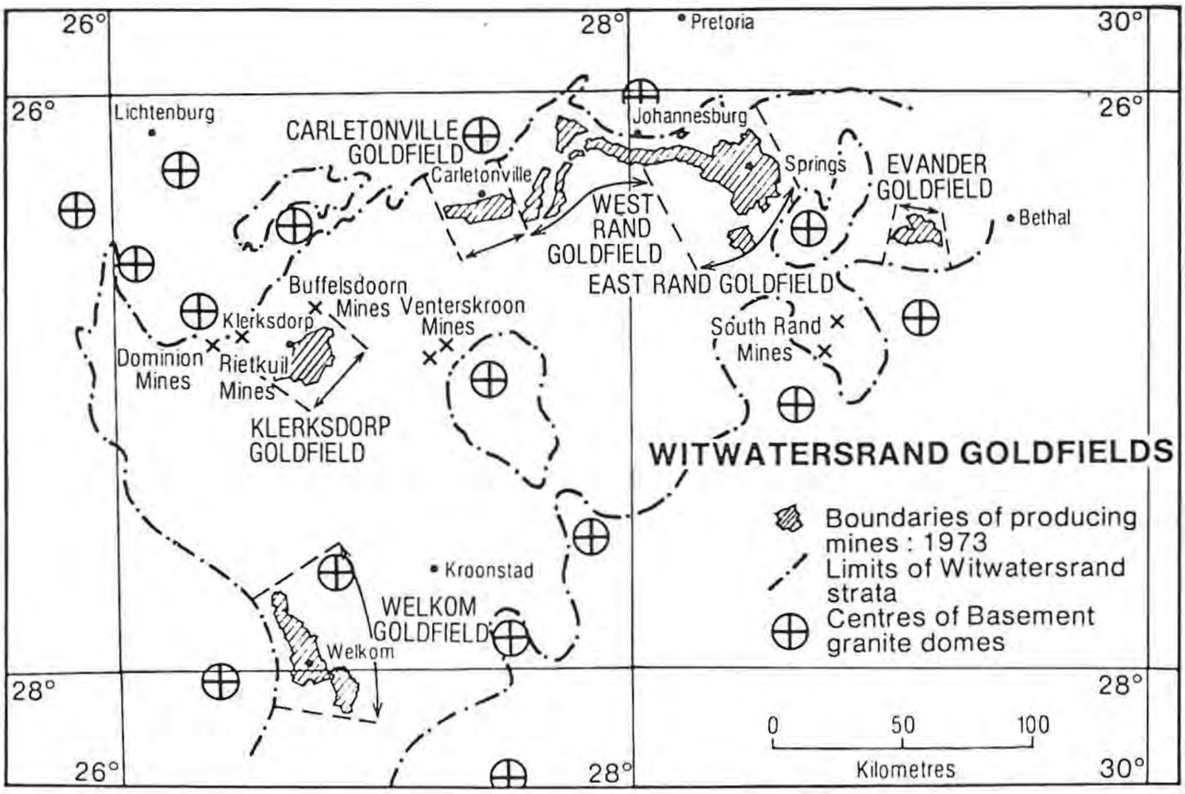


Fig. 9. The location of the major goldfields and the minor mineralised areas in the Witwatersrand basin. The boundaries of current mining activities within each goldfield are shown, as well as the locations of the goldfields in synclinal downwarps between basement granite domes. (From Pretorius, 1974).

An alternative to this fault-controlled model is suggested by recent studies (Minter, 1976, 1978) which indicate that the geometry of the sedimentary units, unconformities, and palaeocurrent patterns of the basin can be accounted for by epeirogenic tilting and warping, followed by basin closure as a result of diapiric granite doming. An opposing view was presented by van Biljon (1977), who attempted to explain the evolution of the Witwatersrand basin by early Precambrian plate movements. He believes the basin presents a marginal embayment in the continental edges of two colliding Archaean mini-continents.

Depositional Environment

The individual goldfields represent fluvial fans that developed at the entry-points of major river systems debouching into a closed intracratonic basin. The six fans so far discovered constitute the Evander, East Rand, West Rand, Carletonville, Klerksdorp and Welkom goldfields and were mostly restricted to the northwestern margin of the depository.

A fluvial fan, a conceptual model of which is depicted in Fig. 10, was built up in a series of pulses of sedimentation that were laid down on the interface between fluvial and lacustrine environments (Pretorius, 1974). The river system was constrained between structural domes, and the fan formed immediately below the point where the river debouched over the elevated ground between the domes. Pretorius (1981) recognises three facies :

(1) a fanhead facies, characterised by the coarsest clastics and lower gold and uranium concentrations;
(2) a midfan facies of well-developed pebble conglomerates with relatively high concentration of heavy minerals; and
(3) a fanbase facies of fine-grained sediments and low percentage of conglomerate, in which lesser amounts of gold and uranium are concentrated.

The apex of the fan was located along the tectonically unstable basin-edge where repeated uplift of the source-area took place along longitudinal faults. The fanheads of earlier fans were thus uplifted and reworked into later fans, while the midfan and fanbase sections were structurally depressed and thereby preserved. Cannibalisation was an integral process in the formation of auriferous fans and promoted the concentration of heavy minerals into residual lag accumulations.

According to Pretorius (1974), a typical fluvial fan comprised two main lobes in which were located a large number of braided stream channels, thicker and coarser clastics, and higher concentrations of detrital gold and uranium. The material that was laid down between the lobes took the form of sands, silts and muds. Conditions under these lower-energy regimes at times provided the optimum environment for the growth of algae or lichens, which took the form of thin algal mats.

The arenaceous sediments comprising each fan are typically cross-bedded. Planar, tangential, and trough-crossbedding occurs in various parts of the fan, indicating the different energy-levels which prevailed at the time of transportation and deposition of the sand.

Repeated diapir-like upward movement of the domes has contributed to the reworking of the sediments flanking the domes. According to Pretorius (1981) "the intimate relation between tectonics, sedimentation, and reworking, leading to economic concentrations of gold and uranium, is the key factor in the formation of a Witwatersrand goldfield".

The placers appear to be braided-stream deposits that were produced by a complex pattern of shifting bars and channels on fan-deltas (Smith & Minter, 1979). The preservation potential of placers in proximal environments along the upwarping edge of the Witwatersrand basin was low because of tectonic instability.

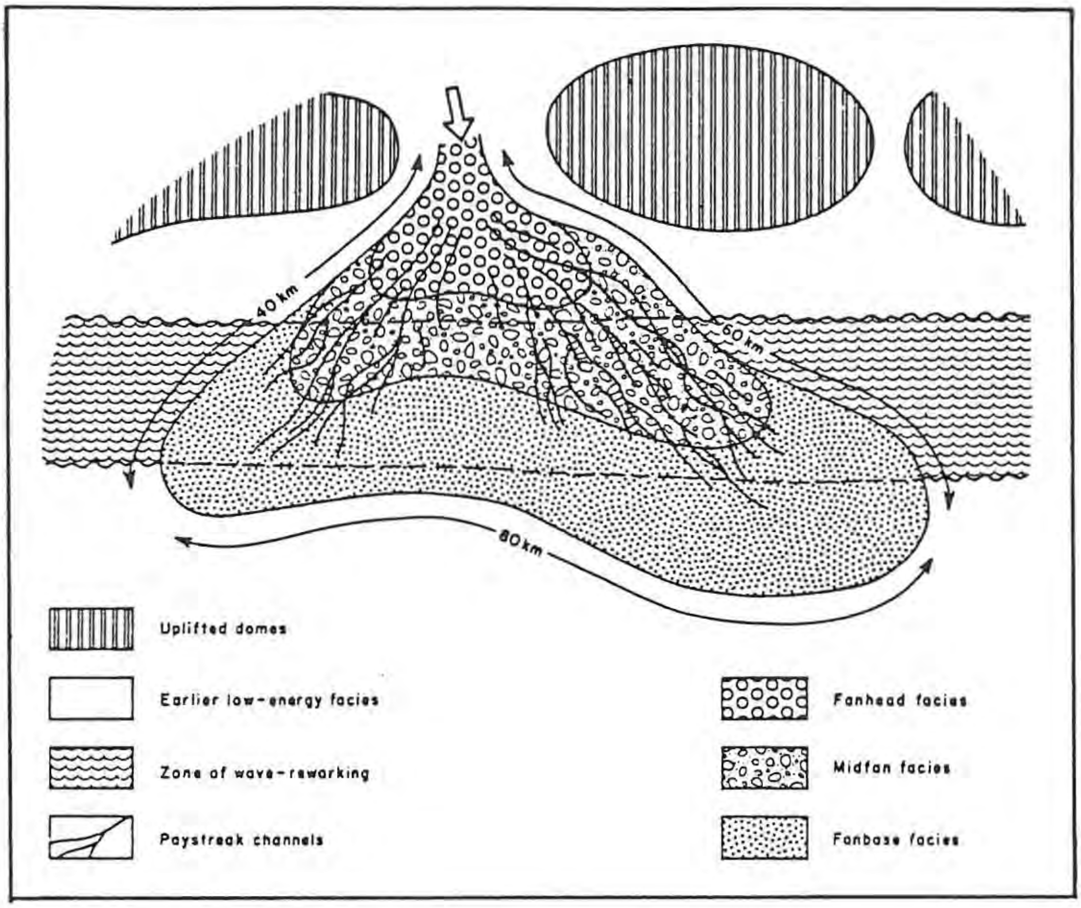


Fig. 10. Conceptual model of a typical prograding fluvial fan in the Witwatersrand basin, showing the location of the fanhead, midfan, and fanbase facies and the zone of reworking by wave-action in transgressive depository-waters. (From Pretorius, 1981).

STRATIGRAPHY OF THE WITWATERSRAND SUPERGROUP

Succession and Thicknesses

The Witwatersrand succession comprises approximately 14 000 m of clastic sediments and volcanics and is divided into a predominantly argillaceous lower division (West Rand Group), and an arenaceous upper division (Central Rand Group). The sediments consist mainly of quartzites (metamorphosed sandstones), shales and conglomerates. Pretorius (1981) has compiled a composite stratigraphical column of the Supergroup showing the maximum thicknesses :

Klipriviersberg Group : 2 500 m - basalts, andesites, conglomerates, quartzites.
Central Rand Group : 3 500 m - conglomerate, sub-greywacke, feldspathic quartzite, siltstone, shale, volcanics.
Jeppe Group : 1 500 m - conglomerate, feldspathic quartzite, siltstone, shale, ferruginous shale, calcareous shale, volcanics.
West Rand Group : 5 500 m - conglomerate, sub-greywacke, subarkose, orthoquartzite, siltstone, shale, ferruginous shale, banded ironstone.
Dominion Group : 1 500 m - andesite, quartz porphyry, rhyolite, tuff, conglomerate, feldspathic quartzite, shaly quartzite.

Pretorius (1974) also presented Table 2 showing thicknesses and ratios of Witwatersrand sequences from type areas of development.

The ratio of volcanics : sediments is a pointer to the general order of infilling in the Witwatersrand basin. The basin had an initial period of high crustal instability during which time only limited quantities of sediments were mixed with the volcanics. The middle stages of basin development were almost devoid of volcanic activity, and lacustrine sedimentation dominated the scene. The terminal phase of the

Group	Total metres	Volcanics metres	Quartzites metres	Shales metres	Sand:Shale Ratio	Volcanics:Sediments Ratio
Klipriviersberg	3 050	2 740	130	180	0.7	8.8
Kimberley-Elsburg	1 670	0	1 640	30	54.7	0.0
Main-Bird	1 490	300	1 010	180	5.6	0.3
Jeppestown	1 380	420	410	550	0.8	0.4
Government	1 970	0	1 240	730	1.7	0.0
Hospital Hill	1 620	0	610	1 010	0.6	0.0
Dominion	2 720	2 650	60	10	6.0	37.9
Klipriviersberg	3 050	2 740	130	180	0.7	8.8
Upper Witwatersrand	3 160	300	2 650	210	12.6	0.1
Lower Witwatersrand	4 970	420	2 260	2 290	1.0	0.1
Dominion	2 720	2 650	60	10	6.0	37.9
Witwatersrand	13 900	6 110	5 100	2 690	1.9	0.8

Table 2. Composite stratigraphical thicknesses and ratios of Witwatersrand sequence from type areas of development. (From Pretorius, 1974).

depository was marked by a recurrence of crustal instability and associated volcanism and sedimentation during this period was minimal. The relatively low overall percentage of fine-grained sediments is an indicator of the generally high level of energy that prevailed in the basin during the whole period of its formation. Higher-energy sediments are generally more abundant on the northwestern, shorter side of the basin, where conditions of offlap prevailed (Pretorius, 1981).

The Dominion Group (Fig 11) is believed to represent a protobasinal phase of the greater Witwatersrand basin (Tankard et al., 1982), and is preserved over an area covering approximately 15 000 km^2 in the western Orange Free State and the southwestern Transvaal. Sediments and lavas of this group rest nonconformably on Archaean basement complex 3,0 Ma to 2,7 Ma in age (Hunter, 1974). Extensive weathering of the granitic palaeosurface is evidenced by palaeosols (Button and Adams, 1981) and deposition of sediments derived from these granitic palaeosols took place dominantly in shallow braided streams that followed dendritic drainage systems. At the base of the Rhenoster-

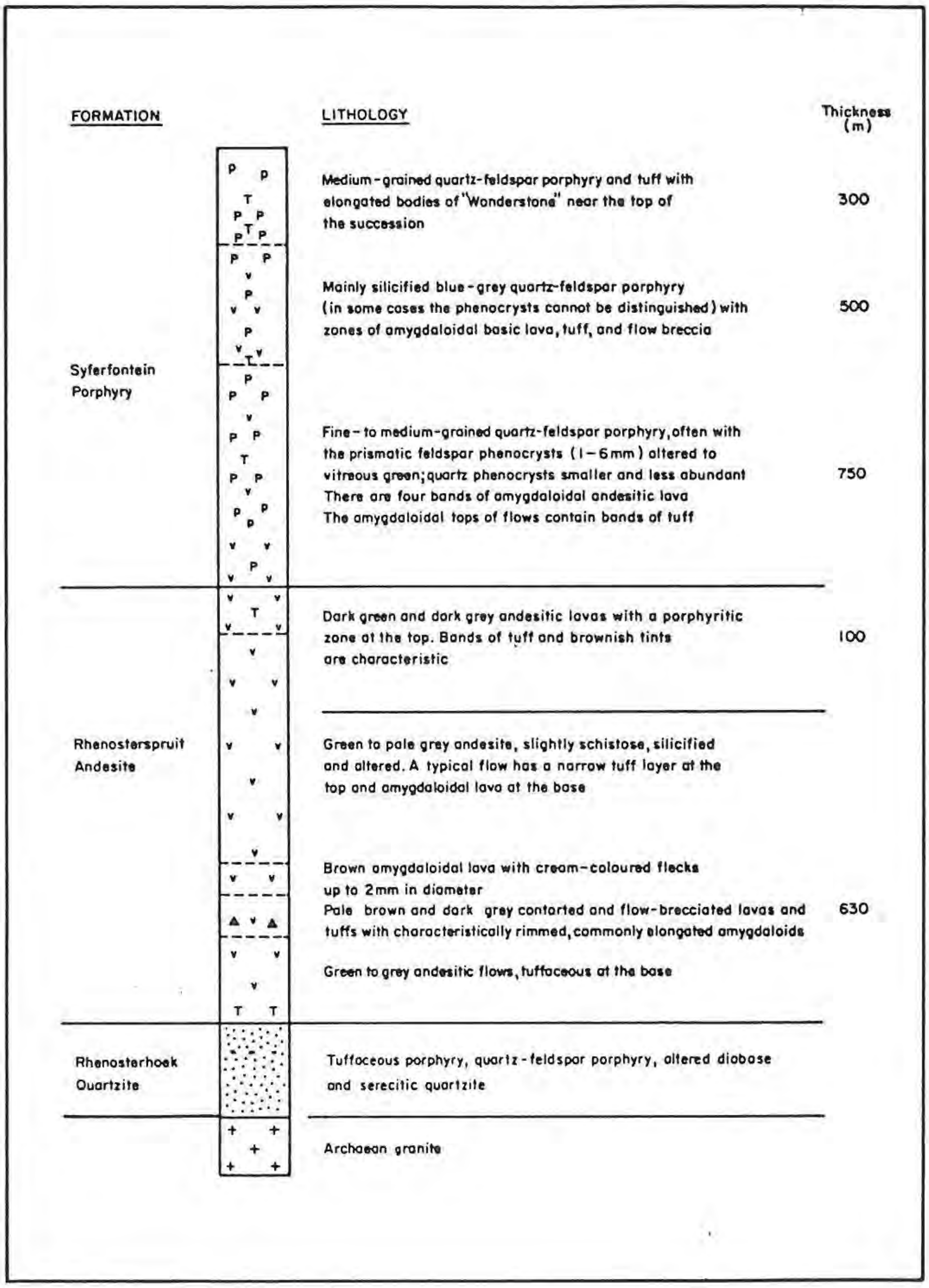


Fig. 11. Lithostratigraphic column of the Dominion Group. (After P.M. Strydom). (SACS, 1980).

hoek Quartzite Formation, single-pebble layers and multiple sheetlike gravels accumulated in channels. These basal placers, up to 3 metres in thickness, were deposited on the nonconformity and confined by the palaeorelief to areas between basement highs. The basal placers were originally mined for their gold content in 1888 and for their uranium content from 1953 to 1963. About 18 metres higher in the valley-fill sequence, small-pebble conglomerates in a zone up to 4 metres thick, were deposited on an intraformational discontinuity surface. The gold and silver contents are very low but densely packed pebble beds as thin as 30 cm are enriched in uraninite towards the top of the zone.

The apparently conformable overlying Rhenosterspruit Andesite Formation comprises a succession of green and grey andesitic lavas with subordinate tuffs. Around Ottosdal the lower part of the lava contains intercalated bands of sediments up to 40 metres thick. A further 1 550 metres of acid lava with subordinate layers of tuff, andesitic lava, volcanic breccia, and quartz-feldspar porphyry lava constitute the Syferfontein Porphyry Formation. No sediments are present in these upper volcanics.

The West Rand Group, formerly known as the Lower Division of the Witwatersrand System, occupies a roughly oval area 42 000 km^2 in extent (Fig. 12). West Rand Group sediments unconformably overly the Dominion Group and elsewhere nonconformably overlap the Archaean basement complex. The sediments vary in thickness from 830 m in the Evander area to 7 500 m northwest of Krugersdorp. The sequence contains shales and sandstones in equal proportions and 250 m of volcanic rocks (Crown Formation). The unifying lithologies are the alternating quartzites and shales of the Hospital Hill, the Government, and the Jeppestown Subgroups.

The Central Rand Group, formerly known as the Upper Division, comprises the Johannesburg Subgroup, Booysens Shale Formation, and Turffontein Subgroup, and consists predominantly of coarse-grained subgreywacke with less than 10 percent conglomerate and quartz arenite. Depositional isopachs of the sediments are shown in Fig. 14, and are preserved in an area of 9 750 km^2 above the West Rand Group. The two divisions of the Witwatersrand Supergroup are separated by an angular unconformity in the eastern part of the basin.

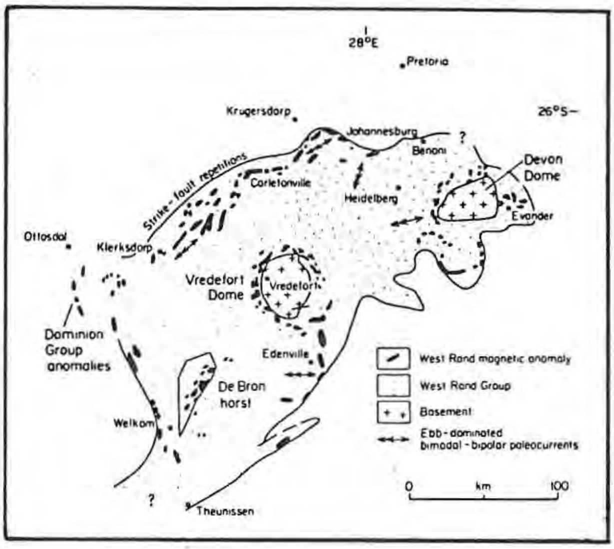


Fig. 12. Map showing the distribution of the West Rand Group based on outcrop and magnetic anomalies and showing regional palaeocurrent trends. (From Tankard et al., 1982).

Cyclicity of Sedimentation

Sharpe (1949) stressed the cyclic nature of the sedimentation throughout the whole of the Witwatersrand succession. He recognised primary oscillations on a regional scale and secondary ones on a local scale, and attributed these to regional movements of uplift and subsidence, which progressively decreased in intensity stratigraphically upwards, so that, by the end of the Witwatersrand times, conditions had become almost static. He attributed the increase in arenaceous sedimentation towards the top of the Witwatersrand Supergroup to the decreasing magnitude of a primary oscillation cycle, and the alternations of shale and quartzite groups to secondary oscillatory cycles. This idea is presented in graphical form in Fig. 13.

Sharpe emphasized the point that payable reefs such as Main Reef, Bird Reef and Kimberley Reef, represented initial deposits formed on disconformable erosion surfaces, after a considerable break in sedimentation. He also pioneered the concept of correlating cycles of sedimentation within the Witwatersrand basin. The correlation of the "beds" in the Witwatersrand has led to gross misinterpretations of the stratigraphy. But if a bed or unit is ultimately related to an unconformity

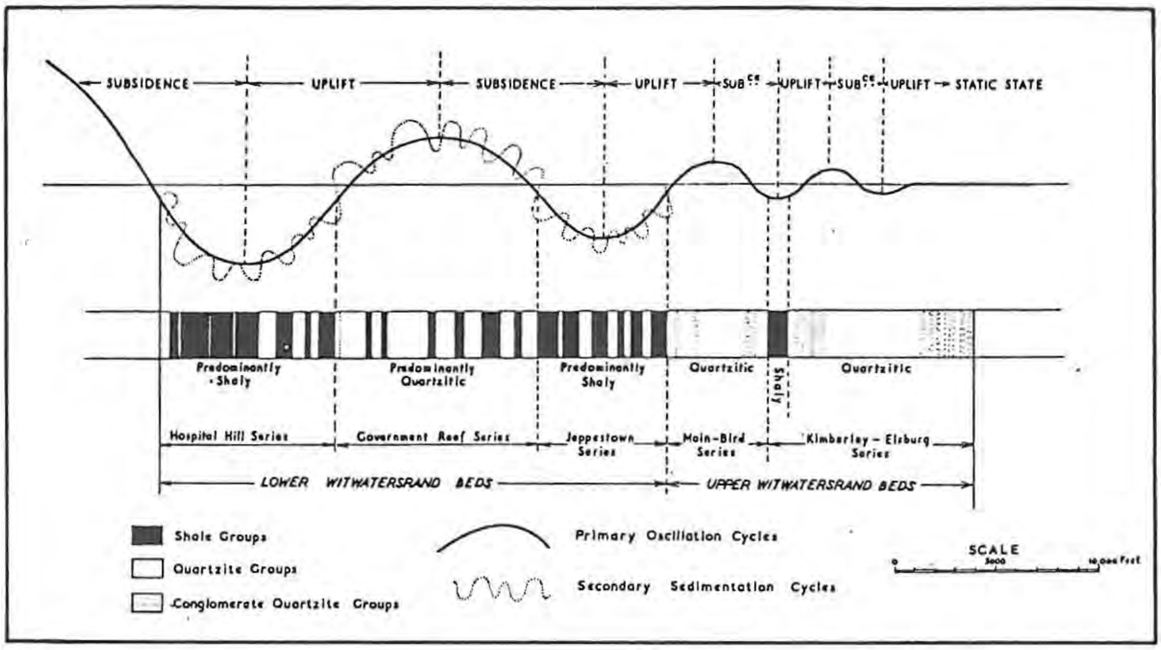


Fig. 13. Diagrammatic representation of sedimentation cycles during the Witwatersrand period. (From Sharpe, 1949).

surface e.g. MRL/Carbon Leader, then it is legitimate to correlate the base of the bed i.e. the unconformity.

Cousins (1965) has suggested that the Main Conglomerate Formation in the East and West Rand goldfields exhibits four cycles of sedimentation, each with a gold-bearing conglomerate at the base. Between this basal conglomerate and its footwall there is a discontinuity of varying intensity. These cycles he calls successively the Main Reef, Carbon Leader, Main Reef Leader and South Reef cycles. The theme of cyclicity and unconformity-related exploitable reefs has been developed by Pretorius (1974, 1981).

The fluvial fans are composed of a large number of cycles of sedimentation with the boundaries between cycles usually represented by unconformities of varying magnitude. The cycles of sedimentation, which show fining-upward sequences, vary in thickness between 30 and 600 m, averaging 250 metres (Pretorius, 1981). Each cycle started with a high energy pulse of sedimentation resulting in pebble lags or gravel bars accumulating on scour surfaces. These were overlain by trough-crossbedded quartzites, which grade upwards into sub-greywackes and siltstones. The base of a cycle is thus marked by a regression, and the remainder of the cycle by transgressive conditions. The tectonic responses between cycles produced an unconformity, the sediments below which were laid down at the end of a transgression and the sediments above the unconformity at the beginning of a regression. The end-phase sediments were frequently sub-aerially exposed and scoured by erosional processes that were dominant between cycles of sedimentation. The planes of inter-cycle unconformity are of considerable economic importance, since all exploitable reefs occur on, or immediately adjacent to, the unconformities (Pretorius, 1974). The Central Rand Group comprises numerous tectonogenetic sedimentary packages separated by unconformities and the gold and uranium now exploited occurs in five forms (Pretorius, 1974):

(i) in the matrix of the conglomerates but more specially on basal surfaces related to basal gravel pulses;

(ii) in heavily pyritic sands which usually fill erosion channels, the gold, uranium, and pyritic particles lying on the foresets of the crossbedded sands;

(iii) on sand along the planes of unconformity that separate two cycles of sedimentation;

(iv) on mud along the planes of unconformity that separate succeeding cycles of sedimentation; and

(v) in carbon seams that are developed on, or immediately adjacent to, planes of unconformity.

The three last-mentioned types of reef were formed in the terminal stages of one cycle of sedimentation, and the first-mentioned two in the initial stages of a succeeding cycle. Gold and uranium are closely associated with conglomerate horizons which mark the beginning of many cycles of erosion in the Central Rand Group. The conglomerates, deposited on unconformity surfaces, are therefore the main exploration targets. In a number of instances, the energy-level of the succeeding cycle was not high enough to bring in gravels, and only sand and silt washed over the unconformity, so that mineralised bands can occur along the interface between sand and sand, or mud and sand, without any conglomerates being present in the immediate vicinity. Tectonically controlled cyclic sedimentation is one of the key factors culminating in the preparation and deposition of auriferous placers within the Witwatersrand succession.

Stratigraphy and Lithology of the Witwatersrand Goldfields

The preserved portion of the Witwatersrand basin in the Transvaal and Orange Free State forms an arc which is concave to the southeast. The outer rim of the arc is of the order of 480 km long and the width is 180 km (Pretorius, 1981). Six goldfields have been discovered along the outer rim, and the possibility exists that more fields might be present under a cover of younger Proterozoic and Phanerozoic rocks. The position of the goldfields, the arcuate nature of the basin, and the depositional isopachs of the Central Rand Group are shown in Fig. 14.

By far the greater proportion of well-mineralised rudites occur in the Central Rand Group and a correlation of the stratigraphical columns of the major goldfields, showing the principal placers, is presented in Fig. 15. An account of the stratigraphy of the various goldfields follows and emphasis is placed on cycles of sedimentation and the unconformity-related exploitable placers within the succession.

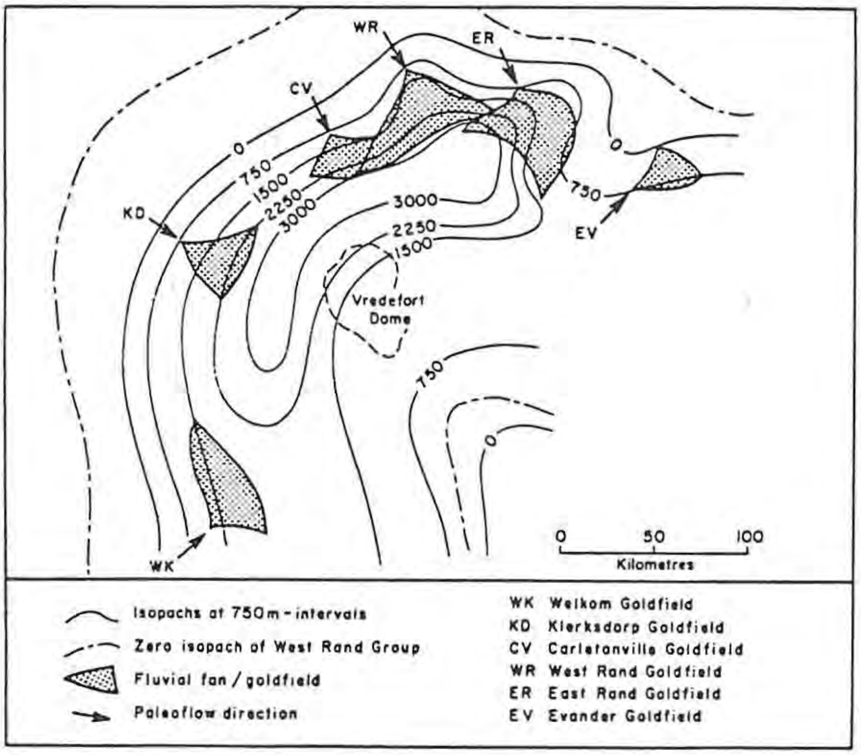


Fig. 14. Geometry of the Witwatersrand basin, as revealed by depositional isopachs of the Central Rand Group. The asymmetry of the basin is shown by the distances between the zero isopachs and the depositional axis. Six fluvial fans, hosting the major goldfields, are all located on the short, shrinking side of the depository. (From Pretorius, 1981).

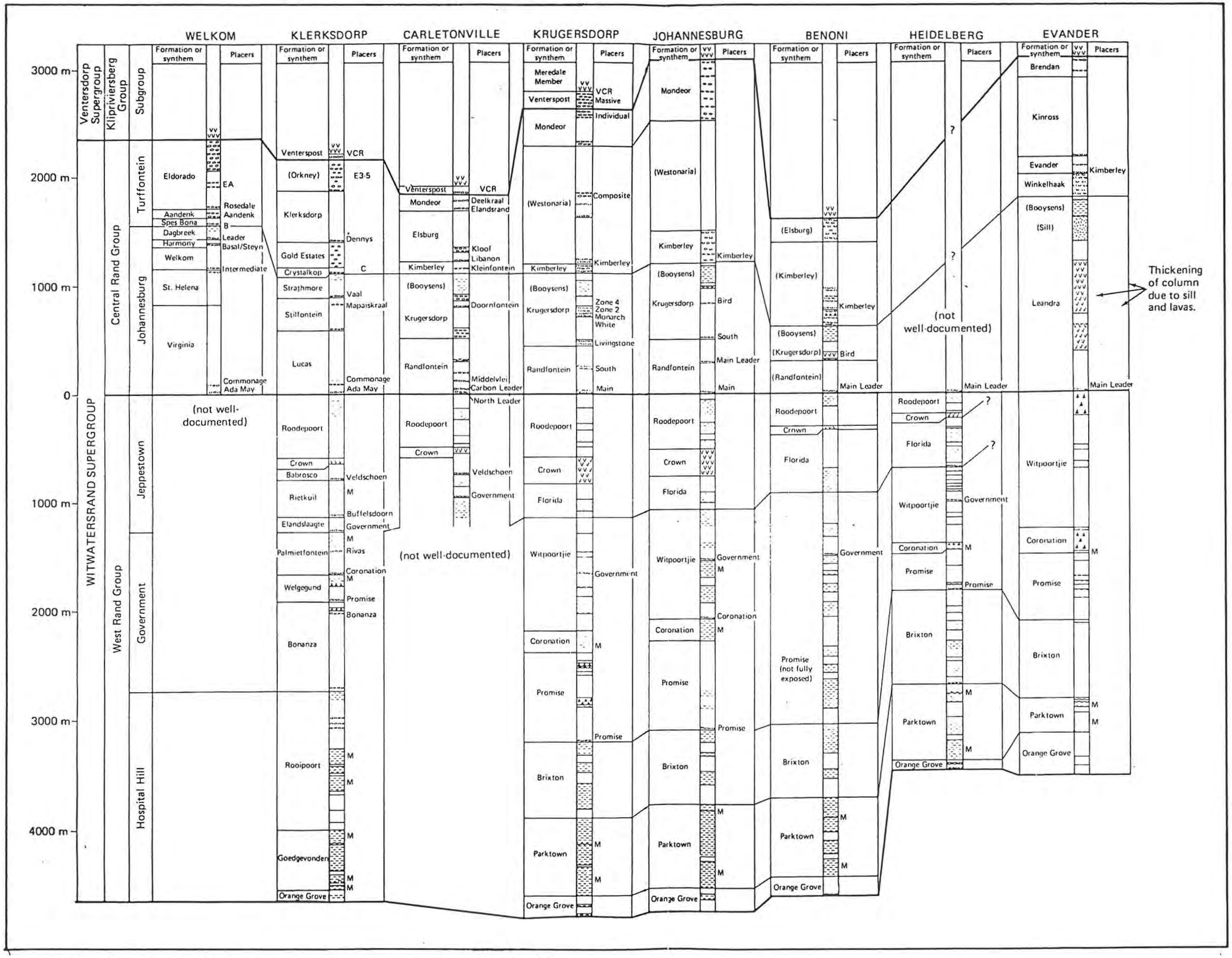


Fig. 15. Correlation of the stratigraphical columns of the major goldfields, showing the principal placers. (From Tankard et al., 1982).

The Evander Goldfield

Four mines, Winkelhaak, Kinross, Bracken and Leslie constitute the Evander goldfield which is located on the southern edge of a northerly dipping, arcuate sedimentary basin some 120 km ESE of Johannesburg. The Witwatersrand Supergroup attains a total thickness of about 1 500 m in the Evander basin. The succession dips moderately northward and is successively overlain by the Ventersdorp lavas and beds of the Transvaal Supergroup. The only gold producing horizon is the Kimberley Reef which was deposited on an angular unconformity surface located towards the base of the Turffontein Subgroup. Various unconformities and marker horizons occur throughout the succession.

Sediments of the West Rand Group, which attain a maximum thickness of 750 m, were deposited on a nonconformity surface eroded on Archaean basement. A notable feature of this Group in the Evander basin is the absence of the Jeppestown Subgroup. The Hospital Hill and Government Subgroups consist of a sequence of alternating arenites and argillites and the Government Subgroup contains siliceous siltstones and greywackes that may represent debris flows. Certain of the argillites are magnetic such as the "Contorted Bed" and "West Rand Shales", and constitute marker horizons.

The Central Rand Group attains a maximum thickness of 750 m and is subdivided into the Johannesburg and Turffontein Subgroups (Fig. 16). The regional dip of the strata averages 25° northward but local variations are frequent. The lithology and stratigraphy of the Central Rand Group in the Evander basin are summarised as follows (after Tweedie, 1981):

Speckled Contact Zone	Light-grey to black, gritty quartzite with scattered small-pebble conglomerates.
Scattered Reef Zone	Subargillaceous, yellow-grey quartzite interbedded with medium- to large-pebble conglomerates.

Drab Quartzite	Medium- to coarse-grained, gritty, argillaceous quartzite, with occasional grit bands, greenish-grey in colour.
Intermediate Quartzite	Crossbedded, subsiliceous to subargillaceous, greenish-grey quartzite with basal vein quartz conglomerate. (Intermediate Reef).
Hangingwall Quartzite (H.W.1)	Subsiliceous, medium-grained, yellow-grey quartzite with abundant chert-speckling. The quartz-rich Leader Reef occurs at the base of this unit.
Hangingwall Quartzite (H.W.2)	Medium-grained, subargillaceous quartzite with numerous sericitic partings, yellow-grey in colour.
Kimberley Reef	Oligomictic, mature conglomerate resting on a well-defined angular unconformity.
Middle Kimberley Quartzite (M.K.1)	Yellow-green, medium-grained, argillaceous, pebbly quartzite.
Middle Kimberley Quartzite (M.K.2)	Yellow-green, argillaceous quartzite with interbedded conglomerates.
Middle Kimberley Quartzite (M.K.3)	Lithologically identical to the M.K.1 quartzite.
Lower Kimberley Quartzite (L.K.1)	Grey, fine-grained, siliceous quartzite with a chert-rich, basal small-pebble conglomerate (L.K.1 Reef).
Kimberley Shale	Black, fine-grained, calcareous argillite.

Main-Bird Quartzite (M.B.Q.1)	Grey, fine-grained, siliceous quartzite with black chert-speckling.
Bird Amygdaloid (B.A.1)	Sequence of superimposed andesitic lava flows.
Main-Bird Quartzite (M.B.Q.2)	Composite sequence of medium-grained, subsiliceous and subargillaceous quartzites with occasional grit/pebble bands.
Bird Amygdaloid (B.A.2)	Lithologically identical to B.A.1.
Main-Bird Quartzite (M.B.Q.3)	Composite sequence of subsiliceous and subargillaceous quartzites, grey-green in colour, with occasional pebble bands.
Main Reef	Thin, non-auriferous, grit to small-pebble conglomerate.

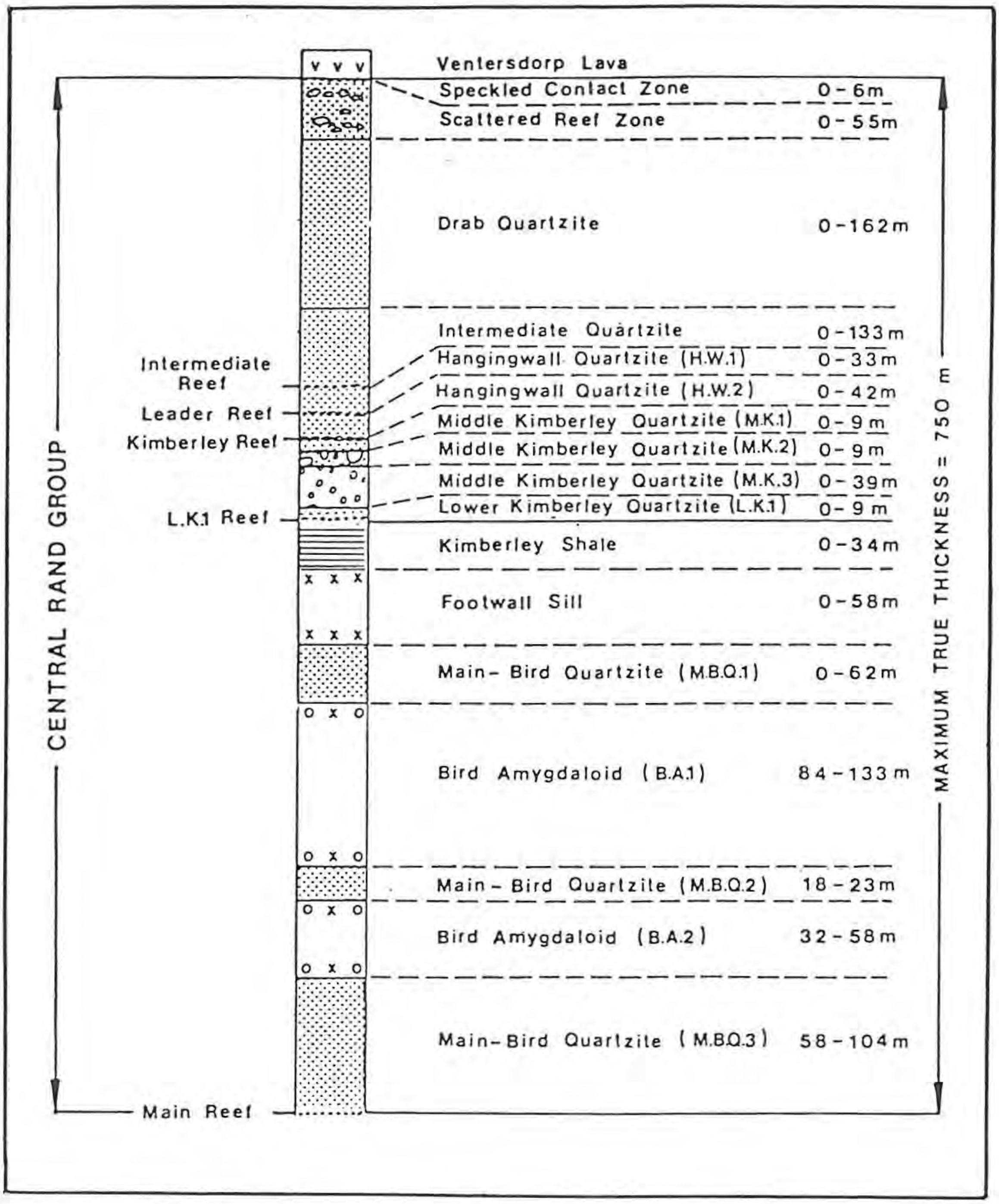


Fig. 16. Generalised geological column of Central Rand Group in the Evander Basin. (From Tweedie, 1981).

The East Rand Goldfield

The best developed and most extensively mined fluvial fan in the Witwatersrand basin is that of the East Rand. Fig. 17 illustrates the main components of this fan which had an apex located in a synclinal downwarp between two granite domes. According to Pretorius (1974) two main lobes were formed, the eastern lobe constituting the East Rand goldfield, and the western lobe forming part of the Central Rand goldfield. The palaeocurrent direction of the western lobe in Fig. 17 is

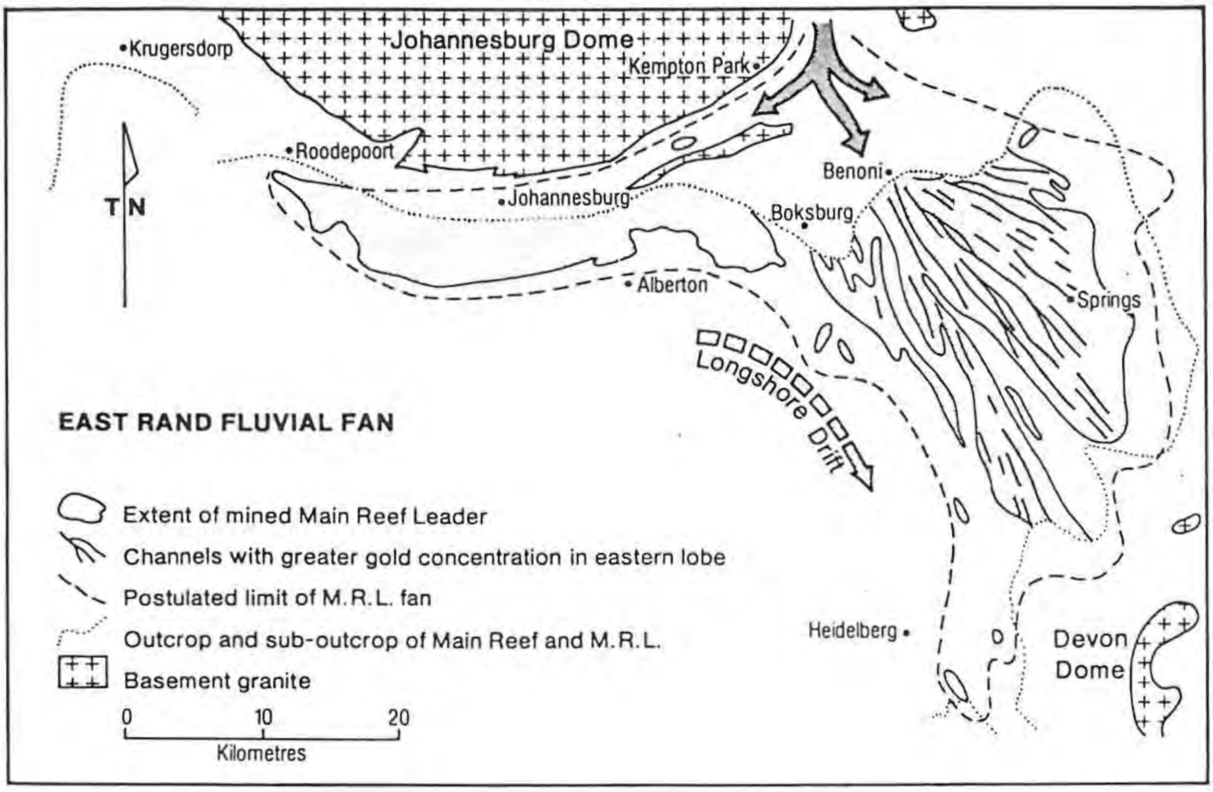


Fig. 17. The main components of a typical fluvial fan in which optimum mineralization is found. The western lobe forms part of the Central Rand goldfield and the eastern lobe the whole of the East Rand goldfield. The original fan covered at least 1 300 km^2. (From Pretorius, 1974).

questionable as a Mineral Exploration Study Group from Rhodes University (1981), engaged in a sedimentological project on the Central Rand, unequivocally established northwest to southeast channel and payshoot trends, similar to those indicated by Reinecke (1927). The locations of the mines constituting the East Rand goldfield are shown in Fig. 18.

The thickness of the Witwatersrand succession is greatest in the northwestern and western parts of the basin, in the vicinity of Brakpan and Van Dyk, and shows a thinning in an easterly direction. Variations in the thickness of the succession can be attributed to erosion or

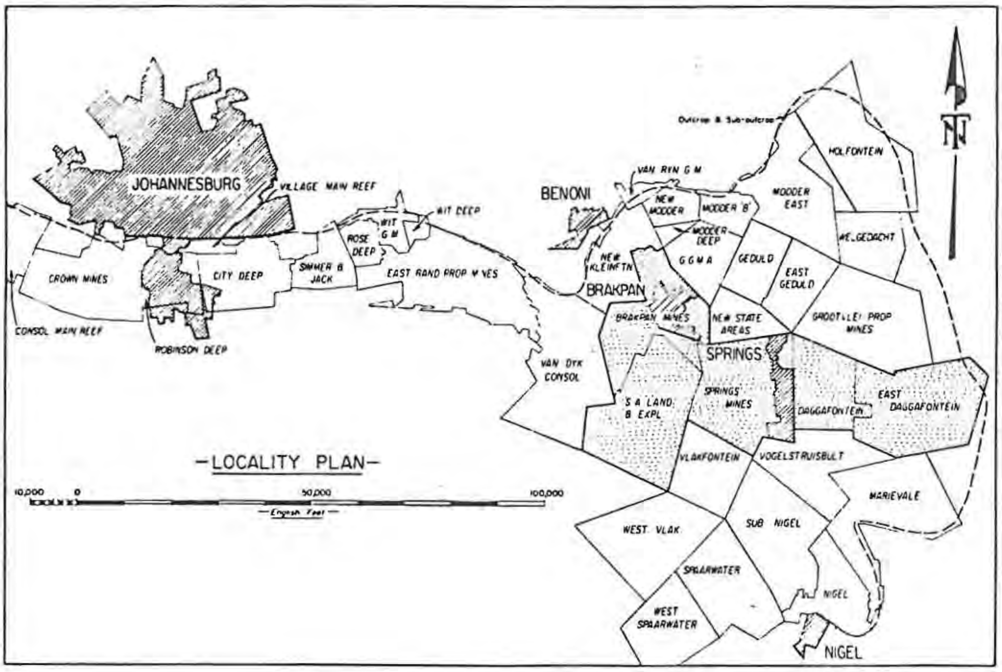


Fig. 18 Locality plan of mines constituting the East Rand goldfield. (From Antrobus and Whiteside, 1964).

nondeposition between pulses of sedimentation. Two geological columns, one near the centre of the East Rand basin and the other near the eastern margin, were presented by Antrobus and Whiteside (1964) to illustrate the progressive eastward thinning of the succession (Fig. 19).

The West Rand Group varies in thickness from 2 750 m to 4 570 m and consists of alternating shales and quartzite horizons, the former predominating. The Hospital Hill Subgroup rests with a clear unconformity on the Archaean basement. The Government Subgroup hosts the Government Reef placer which consists of a quartz and chert pebble conglomerate, usually about 30 cm thick, resting on shale. It has been prospected at several localities in and around Benoni but gold values are negligible.

The Jeppestown Subgroup, consisting of alternating quartzites and shales and an amydaloidal lava horizon, has been divided by Antrobus (1964) as follows:

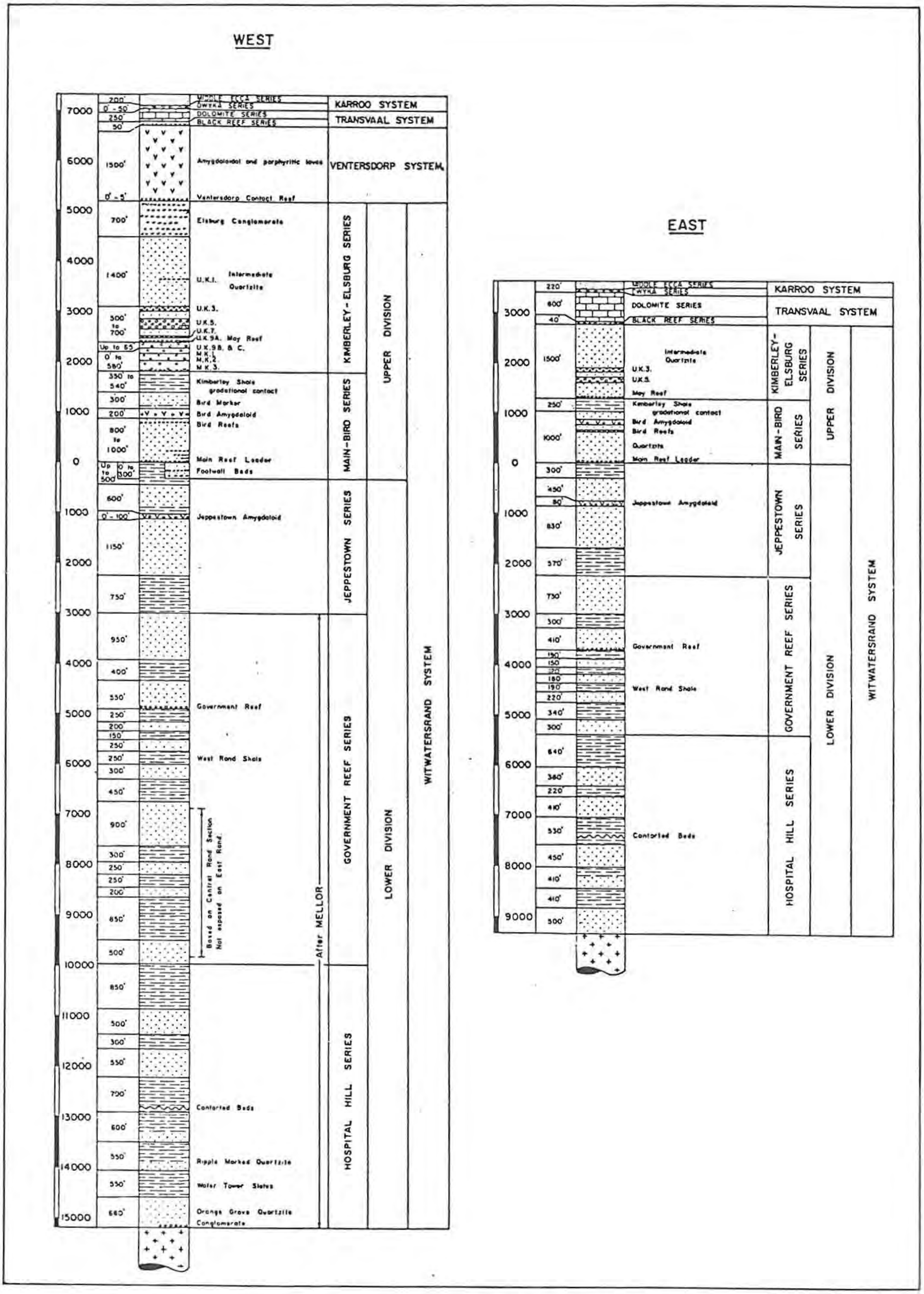


Fig. 19. Geological columns of East Rand goldfield. (From Antrobus and Whiteside, 1964).

A. Upper Jeppestown Shales and Quartzites (Roodepoort Formation)

(i) Grey arenaceous shales - 46 m
(ii) Grey to black shales - 122 m
(iii) Quartzites and shales - 137 m

B. Jeppestown Amygdaloid (Crown Formation) - 6 to 60 m

C. Lower Jeppestown Quartzites and Shales (Florida Quartzites)

(i) Quartzites - 70 m
(ii) Shales - 64 m

The grey arenaceous shales are present in the western and southwest part of the basin with a maximum thickness of 46 m, but thin eastwards by virtue of erosion by the South Reef unconformity surface, which cuts progressively into the underlying succession.

The Central Rand Group consists of the Turffontein Subgroup (Kimberley - Elsburg Series), the Booysens Shale Formation (Kimberley Shale), and the Johannesburg Subgroup (Main - Bird Series).

The Johannesburg Subgroup extends from the top of the Roodepoort Formation to the base of the Booysens Shale Formation and consists predominantly of quartzite. Narrow conglomerate horizons are concentrated at the top and bottom of the subgroup and a lava flow occurs towards the top of the succession. The Footwall Beds, in the form of channel deposits or layered succession, consist of arenaceous and chloritoid shales, "puddingstones", shale-pebble conglomerates, quartz-pebble conglomerates and quartzites of all kinds, including auriferous pyritic quartzites (Antrobus, 1964). Their origin is obscure and there is debate as to whether they are an integral part of the Jeppestown Subgroup, or whether they should more properly be included in the Johannesburg Subgroup.

The Main Conglomerate Formation, also referred to as the Main Bird Reef Zone, includes the North Reef, Main Reef Leader and South Reef. The "Main Reef Leader" constitutes the main orebody of the East Rand and is variously referred to as the Main Reef, the Nigel Reef or Main Reef

Leader. The concensus of opinion is that it is a composite reef incorporating through overlap all the reefs of the Main Conglomerate Formation as developed on ERPM and consequently more properly called the South Reef (Antrobus, 1964). He adds, however, that southwards, some of the Hangingwall Leaders have overlapped and incorporated the older reefs, in which case the term "South Reef" would itself be a misnomer. The South Reef shows a marked transgressive relationship with underlying beds and on ERPM it transgresses all the lower beds until it reaches horizons in the footwall of the North Reef. The transgression was first studied by Mellor (1915) who, on the evidence then available, decided that the single economic reef of the East Rand basin was the Main Reef Leader. Cousins (1965) is of the opinion that the evidence clearly shows that the so-called "Main Reef Leader" of the East Rand is the transgressing South Reef.

The Hangingwall Leaders, which consist of irregular large and small-pebble conglomerates, grit bands and "carbon" seams occur up to 60 m above the Main Reef Leader. According to Jones (1936), some of the top-most Hangingwall Leaders are to be correlated with the Livingstone Reefs, but throughout the greater part of the East Rand the Livingstone Reefs are not identifiable. The Bird Conglomerate Formation varies in thickness from 9 to 60 m and consists of rather poorly developed small-pebble conglomerates interbedded with clean, gritty quartzites.

Several of the reefs are auriferous, but not in economic quantities (Antrobus, 1964). The Bird Amygdaloid, a sheet of amygdaloidal lava present throughout the East Rand, varies in thickness from 30 to 75 m. The Bird Amygadoidal Marker occurs 3 to 5 m above the top of the amygdaloid and is 3 to 10 m thick, consisting of easily recognisable, chloritoid quartzitic shale.

The Booysens Shale Formation (Kimberley Shale), present throughout practically the whole area, varies in thickness from 90 to 135 m, and forms a useful marker. The dark grey shales are interbedded with fine-grained quartzitic shales.

The Turffontein Subgroup is divided into the Mondeor Conglomerate, Elsburg Quartzite and Kimberley Conglomerate Formations. The divisions used for the Kimberley Conglomerate Formation are those proposed by

Sharp (1942-1945), namely, the Middle Kimberley and the Upper Kimberley. These are further divided, in ascending succession, into the zones M.K.3 to M.K.1, and U.K.9 to U.K.1, respectively.

The M.K.3 zone contains greenish quartzites with scattered angular cherts and occasional rounded quartz pebbles. An inconsistent pebble bed, containing quartz, chert, and yellow shale pebbles, occurs at the base. The M.K.2 zone consists of well-developed conglomerates and interbedded quartzites and is variable in thickness due to folding and erosion prior to deposition of the M.K.1 and U.K.9 beds (Antrobus, 1964). The M.K.1 beds consist of chloritoid shale, shale, quartzites, conglomerates and "puddingstones". Channel deposits are common and the succession shows considerable local variation both in lithology and thickness. Gold values are erratic, and isolated payable values have been encountered.

The Upper Kimberley (U.K.9 to 1) consists of alternating conglomerate and quartzite horizons, the odd numbers being conglomerates and the even numbers being quartzites. The U.K.9 zone contains payable auriferous reefs, and the following divisions are accepted for the East Rand. The U.K.9C Reefs consist of one to three narrow conglomerate bands resting unconformably on the underlying rocks, and are characterised by the presence of large, well-rounded, quartz pebbles, angular shaly inclusions, and boulders of various footwall rock-types. The U.K.9B Reef consists of interbedded conglomerates and quartzites; the conglomerates are usually massive, up to 5 m thick, and contain isolated gold concentrations which are seldom payable.

The U.K.9A Reef, also known as the May Reef or Kimberley Reef, is the economically most important of the U.K.9 zone, and is a highly pyritic (pyrite content 2-3%), small-pebble conglomerate. The pebbles are predominantly of quartz except in the eastern parts where chert pebbles are of local significance.

There is an unconformable relationship between the U.K.9A and the beds below. According to Armstrong (1968) this placer was deposited on an erosional surface dipping consistently towards the east-southeast. The general attitude of the erosional plane is considered to have been due to regional tectonics, such as relative uplift in the northwestern margin of the present East Rand basin. Relatively small-scale folding, as shown by eroded footwall anticlines, took place prior to the deposition of the U.K.9A Reef. De Jager (1957) clearly demonstrates the relation between eroded footwall anticlines and the distribution of the U.K.9A Reef, where the reef was occasionally deposited as a veneer of lag gravel on the crests of truncated anticlines, more frequently on the flanks of these features and largely in the palaeo-synclines. Local palaeo-topographic features have therefore produced placer trends at variance to the general dip of the depositional (unconformity) surface.

The U.K.9A Marker is a fine-grained, glassy quartzite often displaying a greenish tinge. The remaining odd-numbered zones of the Upper Kimberley, namely the U.K.7 to U.K.1, contain generally well-developed conglomerate horizons, interbedded with subordinate quartzite. The even-numbered zones (U.K.8 to U.K.2) consist dominantly of coarse-grained quartzites, with occasional scattered-pebble horizons.

The Elsburg Quartzite Formation (Intermediate Quartzite), comprising medium-grained quartzite, attains a maximum thickness of 430 m. Near the top there are a few thin beds of impersistent grits and small-pebble conglomerates, and thin beds of argillaceous quartzite and shale are developed near the base of the formation. The rocks of the Mondeor Conglomerate Formation (Elsburg Conglomerate) have been removed by pre-Transvaal erosion throughout most of the area and are preserved only in the southwestern parts. The formation is about 215 m thick and consists of numerous beds interbedded with quartzite. Some of the conglomerates are auriferous but no payable beds have been found (Antrobus, 1964).

The Central Rand Goldfield

The Central Rand is contained within an east-west distance of 46 km, from the Roodepoort Fault in the west, through Johannesburg, to the Boksburg "Gap" in the east (Pretorius, 1964). Historically the area is of major significance since exploitable auriferous conglomerates were first discovered in this section.

The stratigraphical column of the Central Rand (Fig. 20) is essentially similar to that of the East Rand goldfield and will therefore not

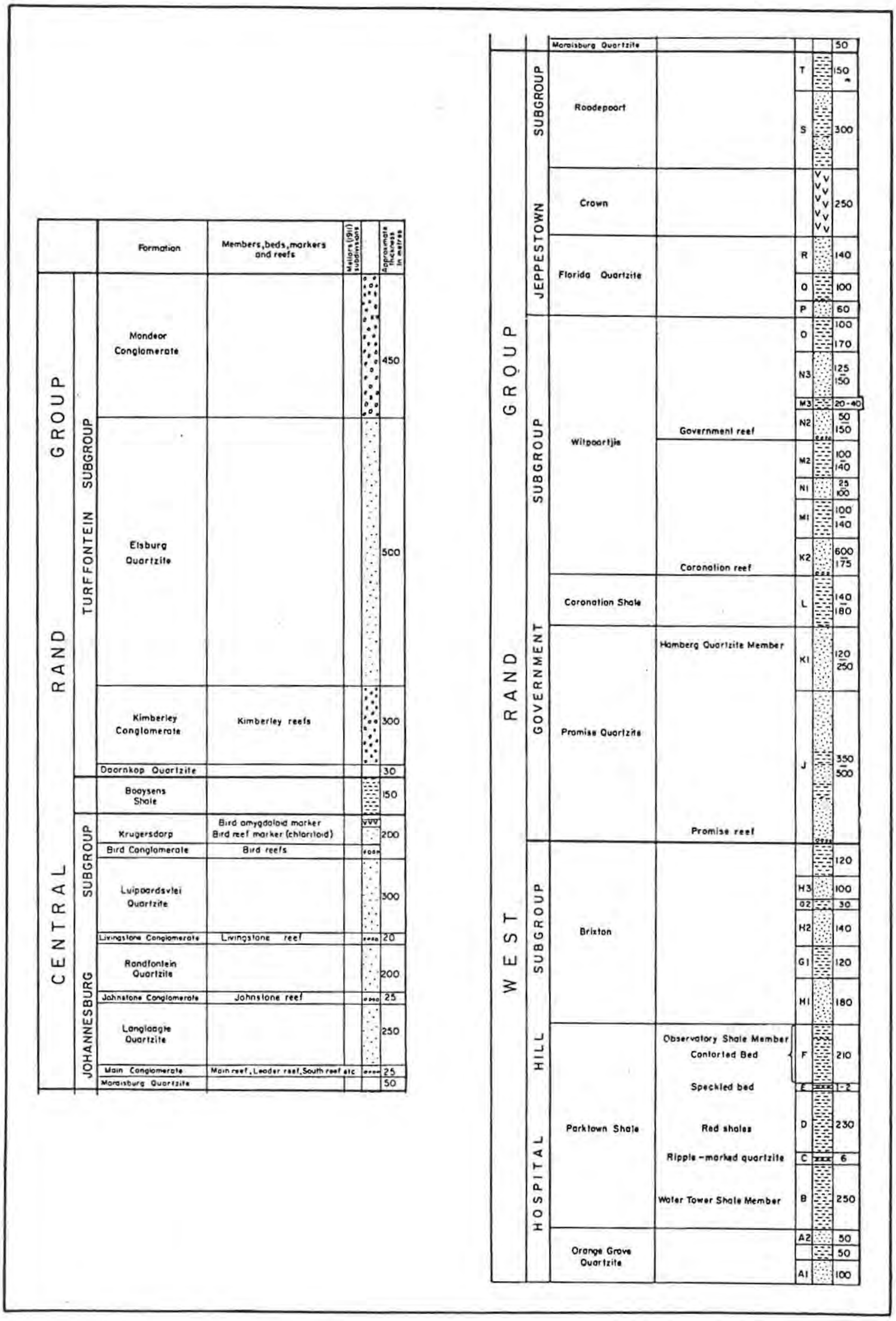


Fig. 20. Stratigraphic column of Witwatersrand Supergroup, Central Rand goldfield. (From SACS, 1980).

be described further. Attention will instead be drawn to the various placer horizons within the succession.

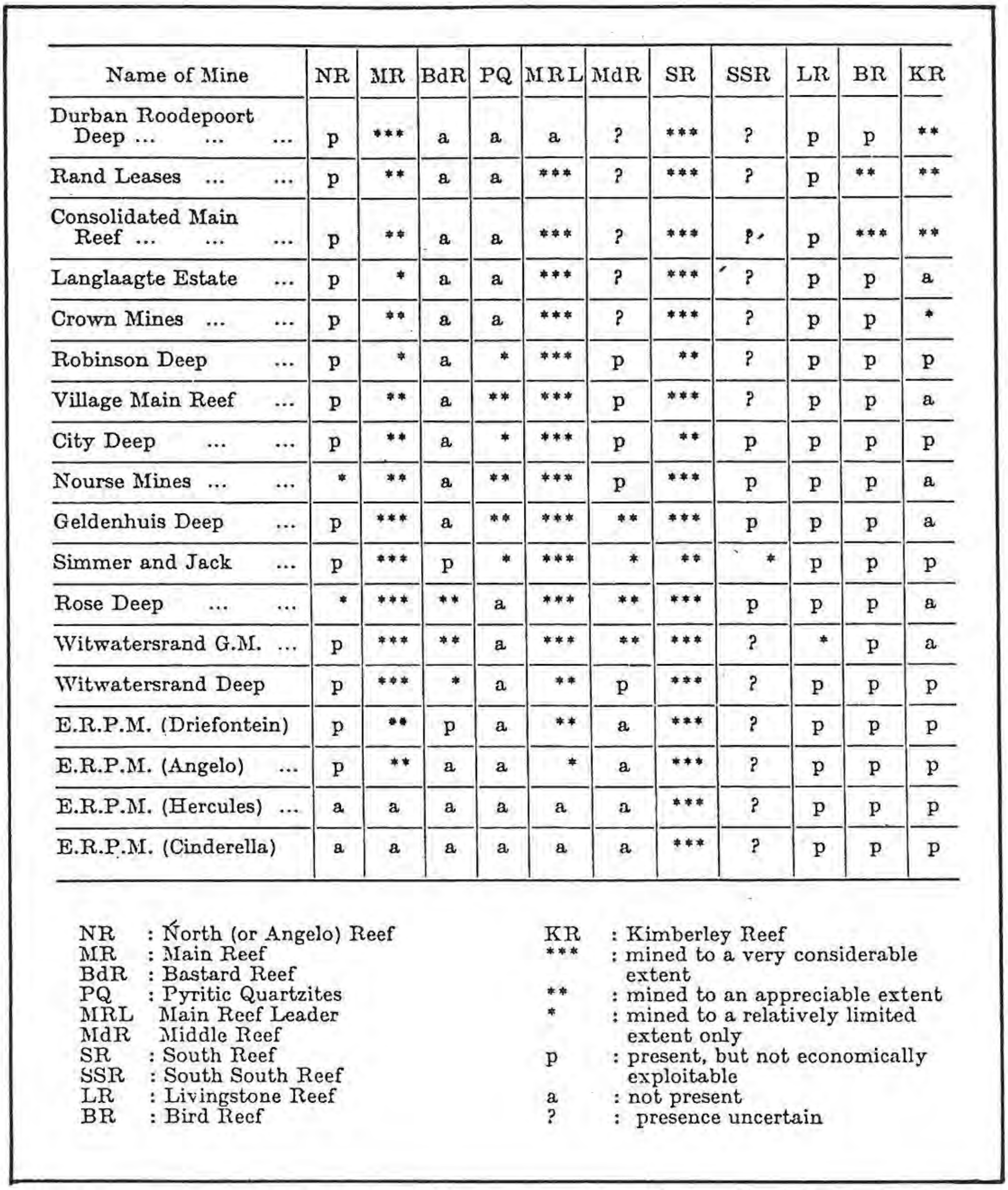
Pretorius (1964) compiled Table 3 which indicates the relative economic importance of the various reefs which have contributed to the gold output in the Central Rand. The Promise Reef, attaining a maximum thickness of 60 cm, occurs at the base of the Promise Quartzite Formation, and was described by Mellor (1917) as having predominantly small pebbles, with a few of up to 5 cm in diameter. Gold values have not proved to be economic in any portion of the Central Rand.

The Government Reef lies on a 150 m thick shale horizon near the top of the Witpoortjie Formation and varies in thickness from a thin pebble lag up to 65 cm. The pebbles are well-rounded and consist mainly of white quartz up to 5 cm in diameter but gold concentrations are negligible.

The Main Conglomerate Formation (Fig. 20 and 48), comprising the North Reef, Main Reef, Main Reef Leader and South Reef, is host to the economically most important placers in the Central Rand goldfield. Variations in the average channel widths of these placers, from west to east along strike, is given in Table 4. The North Reef consists of a small-pebble conglomerate and is of negligible economic importance. The Main Reef is the most strongly developed placer in the Main Conglomerate Formation but is poorer in gold values than either the Main Reef Leader or South Reef. In the eastern portion the reef generally consists of three or four conglomerate horizons interbedded with quartzites and on ERPM it is truncated by the South Reef.

The Main Reef Leader constitutes the main orebody and according to Mason (pers. comm., 1982) is an entity that defines the Central Rand goldfield. This placer was deposited on a major unconformity surface which was etched with grooves/channels orientated northwest to southeast. The MRL is truncated by the South Reef near the common boundary between the old Witwatersrand Mine and ERPM.

The South Reef, a zone of interbedded conglomerates and quartzites, generally some 1,2 to 1,5 m thick, but which may attain a maximum thickness of 9 m, has been one of the major sources of gold won from the



Name of Mine	NR	MR	BdR	PQ	MRL	MdR	SR	SSR	LR	BR	KR
Durban Roodepoort Deep	p	***	a	a	a	?	***	?	p	p	**
Rand Leases	p	**	a	a	***	?	***	?	p	**	**
Consolidated Main Reef	p	**	a	a	***	?	***	?	p	***	**
Langlaagte Estate ...	p	*	a	a	***	?	***	?	p	p	a
Crown Mines	p	**	a	a	***	?	***	?	p	p	*
Robinson Deep ...	p	*	a	*	***	p	**	?	p	p	p
Village Main Reef ...	p	**	a	**	***	p	***	?	p	p	a
City Deep	p	**	a	*	***	p	**	p	p	p	p
Nourse Mines	*	**	a	**	***	p	***	p	p	p	a
Geldenhuis Deep ...	p	***	a	**	***	**	***	p	p	p	a
Simmer and Jack ...	p	***	p	*	***	*	**	*	p	p	p
Rose Deep	*	***	**	a	***	**	***	p	p	p	a
Witwatersrand G.M. ...	p	***	**	a	***	**	***	?	*	p	a
Witwatersrand Deep	p	***	*	a	**	p	***	?	p	p	p
E.R.P.M. (Driefontein)	p	**	p	a	**	a	***	?	p	p	p
E.R.P.M. (Angelo) ...	p	**	a	a	*	a	***	?	p	p	p
E.R.P.M. (Hercules) ...	a	a	a	a	a	a	***	?	p	p	p
E.R.P.M. (Cinderella)	a	a	a	a	a	a	***	?	p	p	p

NR : North (or Angelo) Reef
MR : Main Reef
BdR : Bastard Reef
PQ : Pyritic Quartzites
MRL Main Reef Leader
MdR Middle Reef
SR : South Reef
SSR : South South Reef
LR : Livingstone Reef
BR : Bird Reef

KR : Kimberley Reef
*** : mined to a very considerable extent
** : mined to an appreciable extent
* : mined to a relatively limited extent only
p : present, but not economically exploitable
a : not present
? : presence uncertain

Table 3. Variations in relative economic importance of reefs present in Central Rand Group, Central Rand goldfield. (From Pretorius, 1964).

Central Rand. Where the South Reef is a single band of conglomerate, a condition found on the eastern portion of the Central Rand, gold may be spread throughout the reef (Cousins, 1965). In other areas, where the reef is split into a number of bands, it is the bottom conglomerate, the South Reef Leader, which contains most of the gold. The South Reef Leader is generally a single-pebble, basal lag deposit resting on a prominant unconformity surface. Uranium values are low, but very high

Name of Mine	M.R. (in.)	M.R.L. (in.)	S.R. (in.)
Durban Roodepoort Deep	20	0	5
Rand Leases	35	10	15
Consolidated Main Reef	40	15	20
Crown Mines	45	15	25
Robinson Deep	90	50	60
Village Main Reef	115	60	55
City Deep	80	20	65
Nourse Mine	50	20	50
Geldenhuis Deep	145	15	85
Simmer and Jack	85	20	85
Rose Deep	50	10	80
Witwatersrand G.M.	60	5	55
Witwatersrand Deep	60	5	50
E.R.P.M. (Driefontein Section)	60	5	50
E.R.P.M. (Angelo Section)	40	5	45
E.R.P.M. (Hercules Section)	0	0	40
E.R.P.M. (Cinderella Section)	0	0	35

Table 4. Variations in average channel widths of Main Reef, Main Reef Leader and South Reef, from west to east along strike of Central Rand. (From Pretorius, 1964).

gold values may occur and visible gold is a frequent occurrence. Gold values on the South Reef diminish sharply at approximately the 1 500 m depth contour, although characteristic reef is found below this level. The placer extends into the West Rand and shows a marked transgressive relationship with the underlying beds in the East Rand.

The only mining of the Livingstone Reef on the Central Rand was carried out in the very early days on the old Livingstone Mine which was subsequently to become part of the Witwatersrand Mine (Pretorius, 1964). Here the reef consists of a succession of narrow pebbly bands (Mellor, 1921), and westwards the placer deteriorates into a grit, less than 15 cm thick, containing very little pyrite and negligible amounts of gold (Jones, 1936).

The Bird Reef consists of one of three to six conglomerate bands interbedded with quartzites (Jones, 1936). Most of the bands are discontinuous and lenticular and only one has a high enough gold content to warrant exploitation. This placer is of economic importance only in the western portion of the Central Rand and its average thickness from mine to mine is given in Table 5.

The Kimberley Reefs group of conglomerates are distributed over a zone of between 150 and 275 m of coarse-grained quartzites and grits. As many as 17 individual reef bands occur, varying in width from 45 cm to 3,3 m (Jones, 1936). Individual bands are lenticular and do not persist for any great distance along strike (Mellor, 1921). As with

	N.R. (in.)	B.R. (in.)	K.R. (in.)
Durban Roodepoort Deep ...	15	30	70
Rand Leases	20	50	60
Consolidated Main Reef ...	30	55	55
Crown Mines	35	45	50
Robinson Deep	40	25	45
City Deep	35	20	40

Table 5. Variations in average channel widths of North Reef, Bird Reef (exploited horizon) and Kimberley Reef (exploited horizon), from west to east along strike of western portion of Central Rand. (From Pretorius, 1964).

the Bird Reef, the Kimberley Reef has proved payable only in the western section of the Central Rand, and in places two separate conglomerate horizons have been worked, of which the more important occurs immediately above a narrow bed of shale, about midway in the Kimberley Conglomerate Formation (Pretorius, 1964). The variations in the average channel widths of the reef exploited west of Johannesburg are given in Table 5.

The West Rand Goldfield

The West Rand goldfield, about 35 km west of Johannesburg, comprises the following mines : Randfontein Estates, West Rand Consolidated, Luipaards Vlei Estate, East Champ d'Or and South Roodepoort. The Main and the South Reefs have been the principal sources of gold in the West Rand and, with the exception of a relatively small area in the centre of Randfontein Estates, are payable throughout the area. The discussion of the succession will therefore be confined to the Main Conglomerate Formation and its footwall beds.

During a detailed investigation into the correlation of reefs of the Main Conglomerate Formation (Main Reef Zone) in the West Rand (Cousins, 1965), it became apparent that the persistent gold-bearing conglomerates of this zone are associated with disconformites. These disconformities are not confined to the Main Conglomerate Formation, but occur in the Kimberley Conglomerate, Elsburg Quartzite and Mondeor Conglomerate Formations.

A geological section through the Main Conglomerate Formation at Randfontein Estates gold mine is presented in Fig. 21. The upper

(Jeppestown) shales of the Roodepoort Formation grade gradually upward from fine to coarser-grained sediments. Above the massive shale, argillaceous quartzite, with shale bands, are found for some 15 m. The shale bands first becomes subordinate and then absent, while the argillaceous quartzite grades slowly upwards into cleaner, less argillaceous and coarser-grained quartzite.

Above these quartzites, the zone of the <u>Boulder Marker</u>, described by Roberts and Kransdorff (1939), occurs. The peculiar "boulders" do not seem to be true sedimentary boulders or cobbles (Cousins, 1965) and Roberts and Kransdorff believed that they might be replacements or concretions of cherty material. The Boulder Marker is overlain by the <u>Square Pebble Quartzite</u>, a greenish, somewhat dirty, quartzite in which

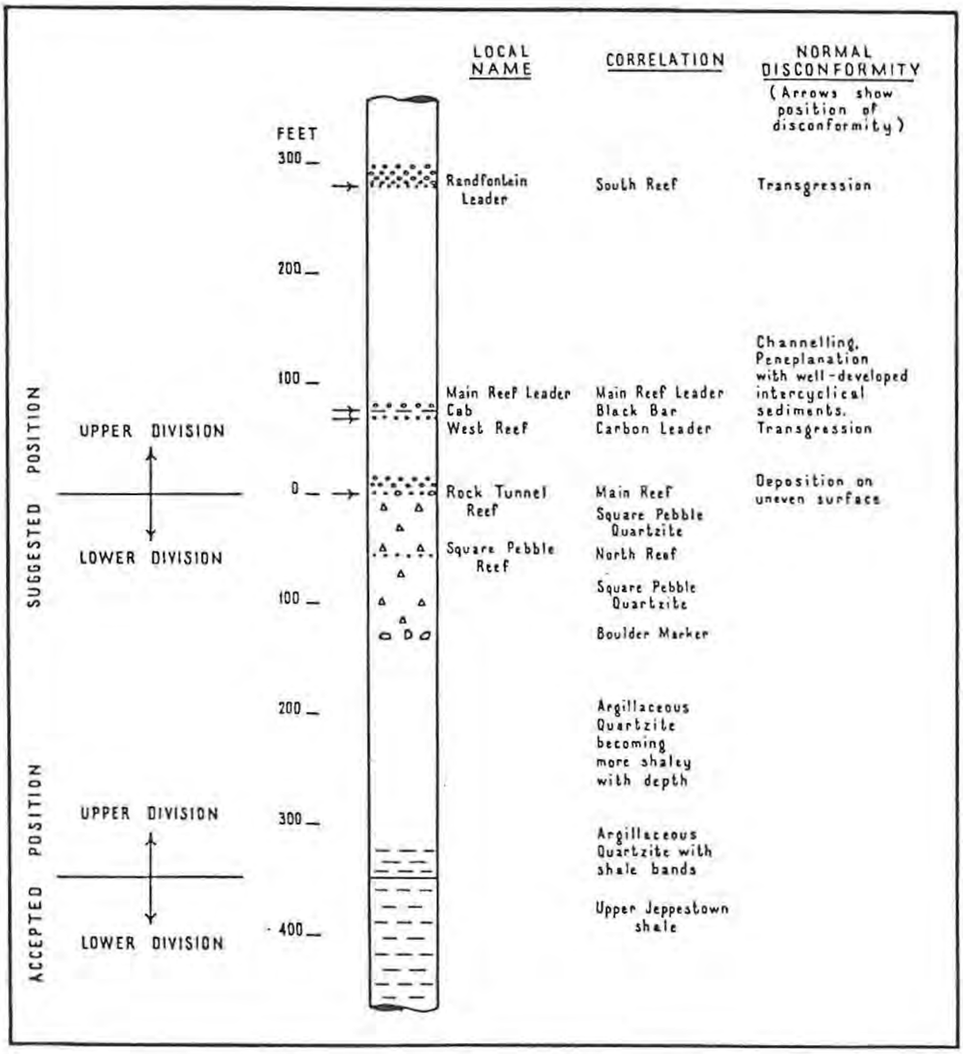


Fig. 21. Geological column through Main Conglomerate Formation, Randfontein Estates. (From Cousins, 1965).

sub-angular to angular chert pebbles, usually about 1 cm in size, are irregularly scattered.

Near the top of the Square Pebble Quartzite lies the North Reef which is a compact small-pebble conglomerate, varying in thickness from 2 cm to over 60 cm (Cousins, 1965). The conglomerate contains a high proportion of chert pebbles, both rounded and angular, and rounded pebbles of quartz. The pyrite content is low and gold values occur but are almost invariably unpayable. At Randfontein Estate the reef in the same stratigraphical position and with the same lithological characteristics is known as the "Square Pebble Reef" (Cousins, 1965). The Square Pebble Quartzite continues up to the immediate footwall of the Main Reef.

The Main Reef normally consists of a thick body of interbedded quartzites and conglomerates, averaging between 35 cm and 1,5 m in thickness, but reaching 6 m in some localities (Toens and Griffiths, 1964). The lowest conglomerate horizon of the reef, which varies from a wide body down to a thin pebble lag, shows characteristics suggestive of a basal conglomerate, deposited on a very undulating palaeosurface. Cousins (1965) correlates the Rock Tunnel Reef of Randfontein Estates with the Main Reef. Gold payability is high in the East Champ d'Or, Luipaardsvlei Estate and West Rand Consolidated mines where extensive areas on the Main Reef have been mined. Its uranium content is very low, even in the gold-rich areas.

Erosion channel complexes are present on Randfontein Estates and Luipaards Vlei mines. The most conspicuous channel on Randfontein Estates strikes in a southeasterly direction and is up to 500 m wide attaining a depth of 45 m (Toens and Griffiths, 1964). The channel-fill is composed of shaly quartzites overlain in places by crossbedded pyritic quartzites. An Luipaards Vlei an erosion channel attains a width of about 320 cm and a depth of between 4 and 17 m. The channel-fill is composed of poorly sorted lenticular bodies of conglomerate and gold values are negligible.

The Carbon Leader is a small-pebble conglomerate with a chert matrix and a high pyrite content, varying in width from about 3 cm to over 1 m. The lower contact is frequently a uranium-bearing carbon seam, which may exceed 1 cm in thickness. High gold values are associated with thick development of the carbon seam and visible gold may be present in the carbon. According to Cousins (1965), the West Reef of Randfontein Estates is equivalent to the Carbon Leader, as suggested by Roberts and Kransdorff (1940).

The Black Bar or "Cab" as it is known on Randfontein Estates, is a massive shale of black to dark olive-green colour which may grade into an argillaceous quartzite. It is characterised by a plentiful development of chloritoid and although widespread and very persistent, its thickness may vary from over 3 m to less than 1 m over short distances and may be absent over wide areas. Cousins (1965) considers that the Black Bar is a widespread inter-cyclical sediment deposited on a disconformity in the break between the Carbon Leader and Main Reef Leader cycles.

The Main Reef Leader degenerates from being a highly payable auriferous placer on the Central Rand to a pyritic grit with only rare pebbles and a negligible gold content on the West Rand. The MRL is very discontinuous and over the areas it cannot be recognised the Main Reef has a much higher gold content. Cousins (1965) believes that the MRL transgressed rapidly downwards, eliminating the West Reef and the quartzites of the Main Reef cycle, to lie on a partly reworked Main Reef which has now acquired the gold associated with the deposition of the Main Reef Leader conglomerate.

The South Reef is present throughout the West Rand and is generally payable but shows a decrease in gold content towards the central portion of Randfontein Estates (Toens and Griffiths, 1964). The reef on West Rand Consolidated usually consists of a number of small-pebble conglomerate horizons, varying from less than 1 cm to 1,5 m in thickness. The South Reef Leader, a basal lag deposited on a disconformity surface, carries most of the gold. In several localities the South Reef Leader (Basal Band) is very poorly developed and may be represented by a narrow stringer of carbon along which phenomenal gold values may occur (Toens and Griffiths, 1964). Gold is usually visible in these high-grade areas.

The Carletonville Goldfield

The Carletonville goldfield is located along the northwestern rim of the Witwatersrand basin approximately 65 km southwest of Johannesburg (Fig. 22). A generalised lithostratigraphical column of this area is presented in Fig. 23.

The Witwatersrand Supergroup attains a maximum thickness of 5 155 m (Krapez, 1979); 1 909 m for the West Rand Group and 3 246 m for the Central Rand Group. The Ventersdorp Conglomerate Formation, represented by the Ventersdorp Contact Reef, rests on an angular unconformity surface truncating the Witwatersrand Supergroup beds.

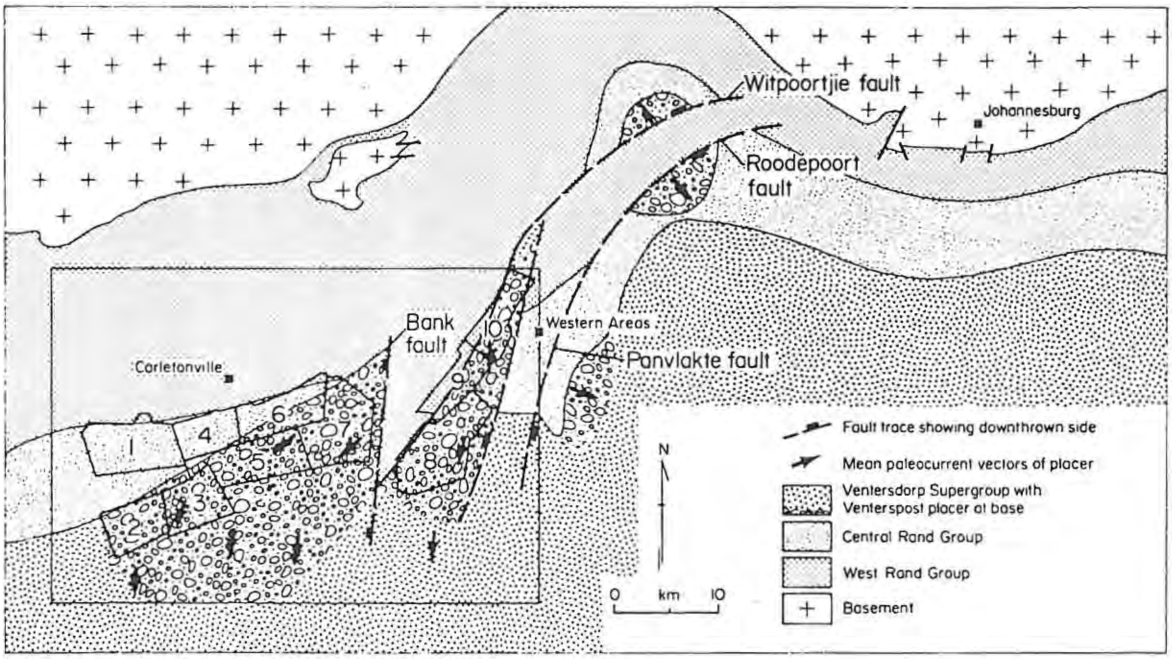


Fig. 22. Suboutcrop map of the Witwatersrand and Ventersdorp Supergroups below the Transvaal Supergroup. Ventersdorp placers at the base of the Ventersdorp Supergroup are confined to grabens. Gold mine properties shown are : (1) Doornfontein, (2) Deelkraal, (3) Elandsrand, (4) Blyvooruitzicht, (5) Western Deep Levels, (6) West Driefontein, (7) East Driefontein, (8) Kloof, (9) Libanon, (10) Venterspost. (From Tankard et al, 1982).

The West Rand Group consists dominantly of argillaceous sediments with interbedded coarse to fine-grained pure and impure sandstones. Several thin conglomerate horizons occur but none are auriferous. The only volcanic horizon is the Crown Lava Formation, which is a dark green amygdaloid.

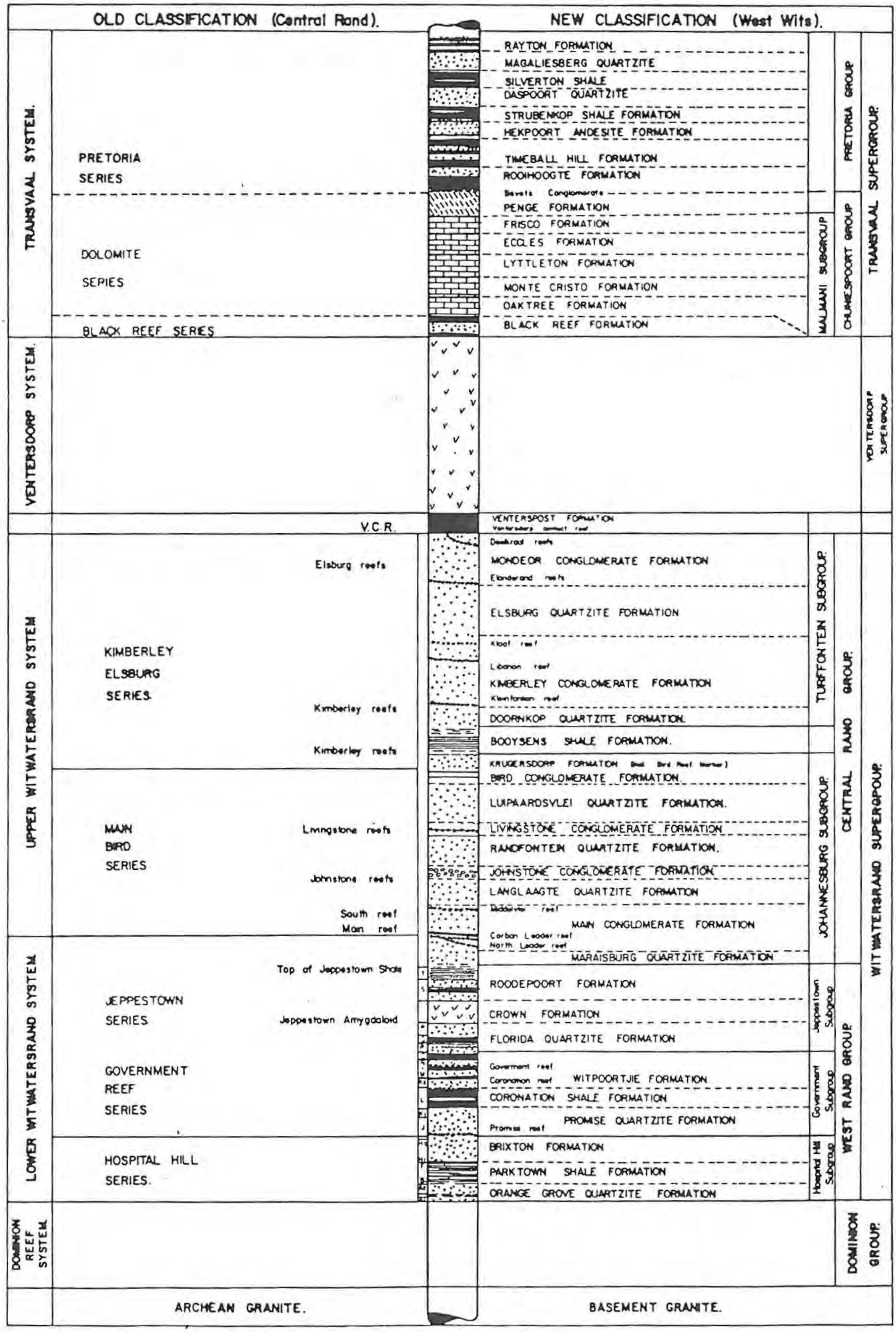


Fig. 23. Lithostratigraphical column for Carletonville area. (From Goldfields, Internal Company Report).

The base of the Central Rand Group is a transitional zone from shales to argillaceous sandstone. The Carbon Leader Zone, comprising the Rice Pebble Band, the Carbon Leader and the North Leader Reef, lies unconformably above the Square Pebble Quartzite (Fig. 24).

Several cycles of sedimentation occur which usually consist of medium to small-pebble conglomeratic basal lags overlain by trough and planar-crossbedded quartzites. The end of a depositional pulse may be marked by a thin massive silt layer. The North Leader Reef was

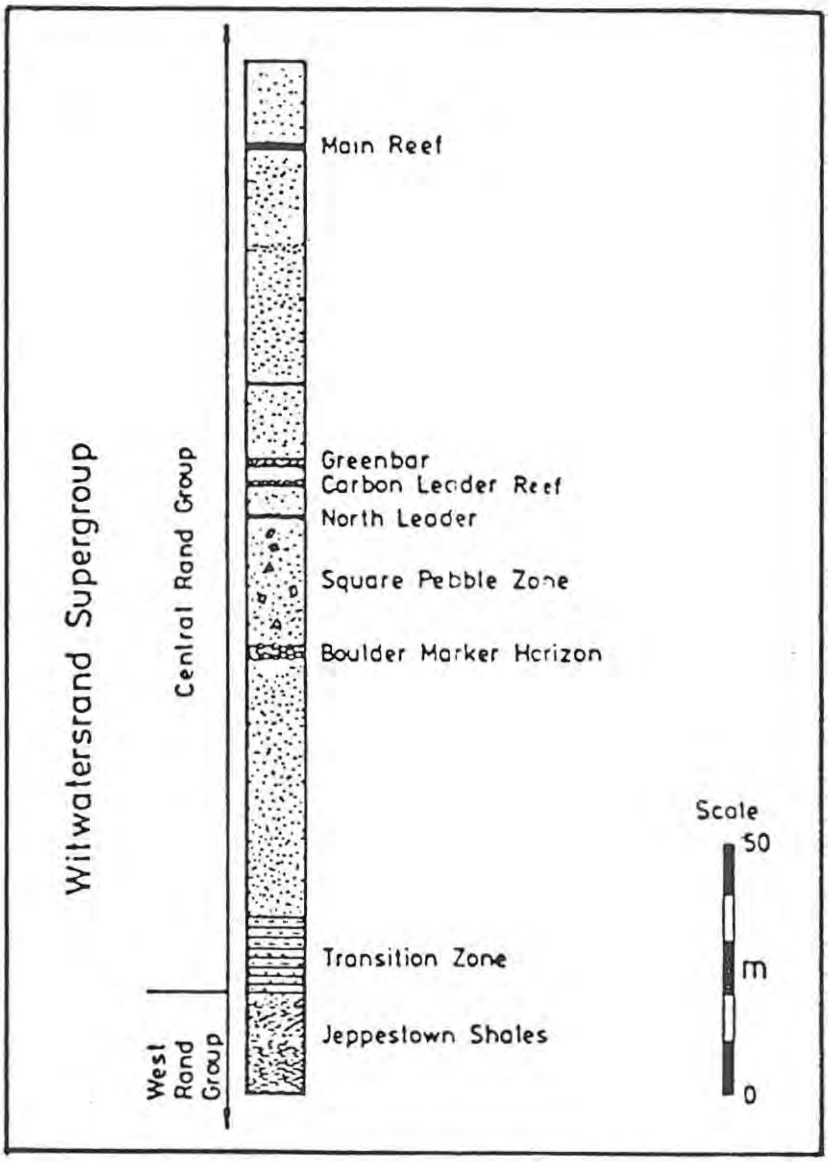


Fig. 24. Stratigraphical division of the lower part of the Central Rand Group. (From Nami, 1981).

sporadically deposited on an erosion surface cut across the Square Pebble Quartzite and thus in places the Carbon Leader unconformably overlies the Square Pebble Quartzite. The Carbon Leader placer is the principal gold producing horizon of the Carletonville goldfield and is extensively mined in the Blyvooruitzicht, West Driefontein, Doornfontein and Western Deep Levels gold mines. The Rice Pebble Marker is a 2-10 cm thick sporadically developed clast supported grit conformably overlain by the chloritoid-bearing siltstone of the Green Bar.

The deposition of the hangingwall Carbon Leader quartzites was followed by an erosional period during which several large channel complexes were formed (Dales, 1980). The effect of channelling was to eliminate the Carbon Leader over large areas. On West Driefontein, the main channel complex eliminates some 15% of the Carbon Leader Reef, and occurs in a broad 2 200m wide zone trending in a northwest to southeast direction, situated in the eastern section of West Driefontein. An erosion channel complex, trending in a similar direction, is present on Doornfontein, and is approximately 1 900 m in width. Some small-pebble conglomerate bands within the channel-fill sediments are auriferous but their lenticular shape and erratic distribution will preclude their exploitation.

The Main Reef (Middelvlei Reef) occurs about 60 m above the Carbon Leader (Fig. 24) and consists of one or more beds of large-pebble conglomerates. The overall thickness of the reef is variable, ranging from 0,3 - 1,5 m but in parts of Venterspost it may attain 7,5 m. The remainder of the Johannesburg Subgroup consists of coarse to medium grained sandstone with abundant conglomerate horizons. Above the Johannesburg Subgroup is the Booysens Shale Formation, comprising shales, mudstones and siltstones.

The overlying Turffontein Subgroup contains several conglomerate horizons, many of which are auriferous. The Deelkraal Reef Zone occurs within the Mondeor Conglomerate Formation and contains two major conglomerate zones which were deposited on intraformational disconformities. The upper zone is known as the Deelkraal Reef and the lower zone has been named the Elandsrand Reef. Several pulses of uplift, erosion and subsequent aggradation occurred during the deposition of these placers (du Toit, 1981). The general cycle seems to be, firstly a period of uplift and footwall incision, followed by a period of rather rapid deposition, resulting in the formation of pebbly quartzites and matrix-supported conglomerates. A period of erosion and scouring followed with the development of scour surfaces and the formation of pebble lags. Further more pronounced footwall incision followed with the development of major channels which were subsequently filled by massive pebble-supported gravels, with waning flow resulting in upward-fining sequences.

The Ventersdorp Conglomerate Formation, at the top of the succession, is conformable with the overlying Ventersdorp volcanics and is therefore considered to be the basal conglomerate of the Ventersdorp Supergroup (Krapez, 1979). The Ventersdorp placers, generated by the uplift, reworking and redeposition of Witwatersrand placers, were deposited in graben structures on pronounced angular unconformity surfaces. The magnitude and nature of the pre-Ventersdorp erosion and folding are the most important structural features of the Carletonville goldfield. The Witwatersrand Supergroup was apparently folded into a series of plunging anticlines and synclines with general north to south trending fold axes. The amount of pre-Ventersdorp erosion is considerable as the unconformity cuts down from near the top of the Mondeor Conglomerate Formation to the Crown Formation, a thickness of 2 300 m. Maximum erosion and the position of the fold axis of the major anticline are centred on or around East Driefontein (Krapez, 1979).

The Klerksdorp Goldfield

The West Rand Group is subdivided into three subgroups, the Hospital Hill, Government and Jeppestown within each of which three formations are identified (Fig. 25). It is only in the Klerksdorp area that this group hosts economic gold and uranium deposits, confined to the lower part of the Jeppestown Subgroup.

The Hospital Hill Subgroup attains a maximum thickness of 900 m and is characterised by lower and upper formations, consisting of quartz arenites and an argillaceous unit with minor arkoses and channel sediments. The Orange Grove Formation nonconformably overlies the volcanic rocks of the Dominion Group and comprises two quartz arenite units, with interbedded mudstones, arranged in a fining-upward

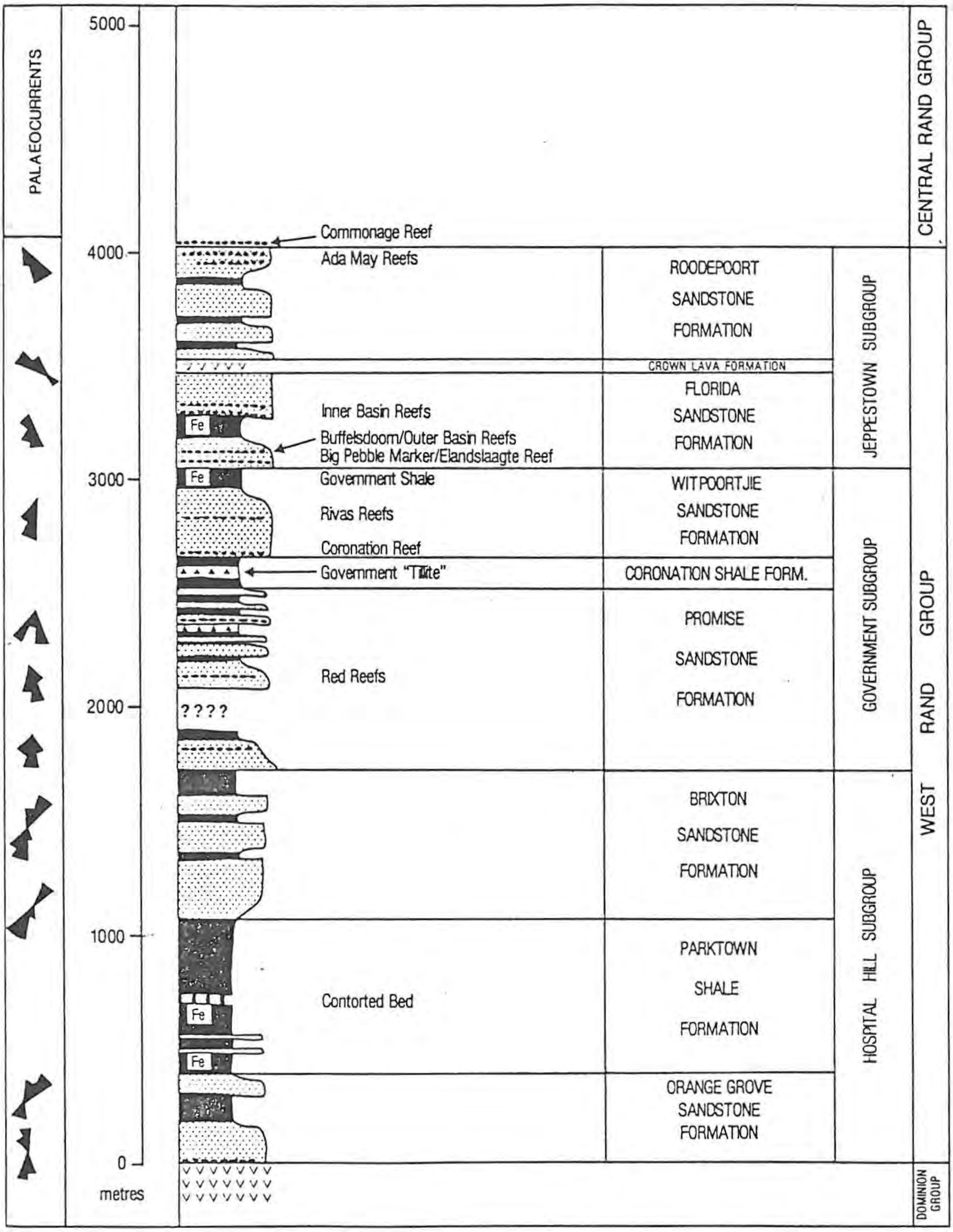


Fig. 25. Stratigraphy, textural trends, and generalised palaeocurrents of the West Rand Group in the Klerksdorp area. (From Watchorn, 1980).

sequence. The quartz arenites are fine-to-medium grained, with an irregular basal conglomerate composed of quartz clasts in a quartzose matrix. The interbedded argillites are up to 50 m thick and comprise interlaminated siltstones and mudstones, with minor erosively-based sandstone laminae.

Varying proportions of mudstones and siltstones comprise the bulk of the Parktown Formation, which attains a maximum thickness of 650 m. Intercalated sandstones are generally arkosic, within which small-scale (50 - 100 cm) fining-upward cycles are evident (Watchorn, 1980). A number of magnetic horizons are developed in the Parktown Formation, of which two are regionally significant. The lower of these occurs 50 - 60 m above the Orange Grove Formation and is correlated with the Water Tower Slates on the Witwatersrand. The Contorted Bed is the upper magnetic horizon which is immediately overlain by a series of magnetic mudstones.

The base of the 500 m thick Brixton Formation is taken as the first sandstone unit above the Contorted Bed. The sequence is only fully developed in the area north of Klerksdorp, where it comprises three superimposed cycles which coarsen-upwards. These cycles have interlaminated mudstones and siltstones at the base, succeeded by medium-grained quartz arenites. Occasional thin (20 - 30 cm) conglomerates occur at the base of minor upward-fining sequences within the sandstones. According to Watchorn (1980), the Brixton Formation marks the beginning of a major regressive phase during the evolution of the West Rand Basin.

The Government Subgroup is distinguished from the Hospital Hill by the relative increase in the proportion of coarse clastics, their immaturity, and the frequency of interbedded conglomerates (Watchorn, 1980). The sequence comprises two formations dominated by sandstones, separated by an argillaceous unit. The base of the 800 m thick Promise Sandstone Formation occurs at the top of an upward-fining cycle, which has a lower graditional contact with the Brixton Formation. The sandstone is an immature coarse-grained arkose, within which thin (15 -20 cm) small-pebble conglomerates overlie shallow scours. The middle Promise Formation consists of trough-crossbedded sandstones containing numerous small-pebble conglomerates (Red Reefs). The sequence of the upper Promise Formation consists of three or four sandstone horizons, separated by argillaceous units. The sandstones have sharp erosive bases and grade upwards into the overlying mudstones and siltstones. The Promise Reef is developed on an erosion surface at the base of one of these units.

The dominantly-argillaceous Coronation Shale Formation attains a maximum thickness of 140 m and hosts a consistent diamictite marker horizon. The succession consists of interlaminated siltstones and mudstones, with minor fine sandstone laminae.

The 400 m thick Witpoortjie Formation comprises a lower sandstone member with numerous interbedded small-pebble conglomerates, upward-fining to the Government Shale. At the base, the Coronation Reef, consisting of immature conglomerates, directly overlies mudstones.

The Jeppestown Subgroup comprises two predominantly arenaceous formations, separated by a thin volcanic unit. The Florida Formation attains a maximum thickness of 400 m and consists of upper and lower sandstone members, separated by an intervening argillite. The lower sandstone unconformably overlies the Government Shale and hosts three conglomerate horizons which have been exploited, or extensively prospected, for gold and uranium. These are the Government Reef, the Big Pebble Marker and the Buffelsdoorn Reef (Fig. 26). The Government Reef is erratically distributed on the basal unformity surface. The upper Florida sandstone is a very coarse arkosic arenite with a number of conglomerates near the base (Veldskoen Reef).

The conglomerate horizons are variable in thickness, ranging between 20 cm and 5 m, and are composed essentially of vein-quartz pebbles.

The Crown Lava Formation, formerly known as the Jeppestown Amygdaloid, is one of the most reliable and persistent markers in the West Rand Group, and has a thickness of about 50 cm. It is predominantly a greyish-green aphanitic rock, with prominant amygdales.

The Roodepoort Sandstone Formation, up to 500 m thick, is composed predominantly of arenaceous sediments arranged in one upward-coarsening and three upward-fining cycles. The three lower sandstone members all

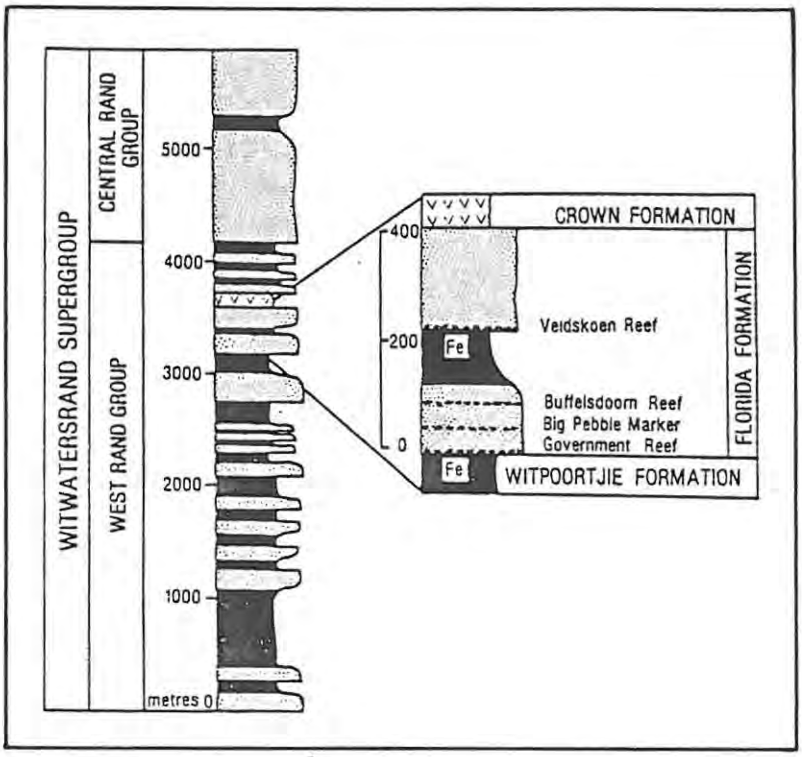


Fig. 26. The stratigraphical setting of the Florida Formation in the Klerksdorp region of the Witwatersrand basin. (From Watchorn, 1981).

grade upwards into siltstones, mudstones, and fine-grained sandstones, representing transgressive cycles. The upper contact of the Jeppestown has been conventially placed at the Ada May Reef, which forms a 10 - 20 m thick zone of immature conglomerates. However, Watchorn (1980), proposed that a more suitable and readily-identifiable contact is the discontinuity beneath the Coronation Reef.

The Central Rand Group hosts a number of significant placers (Fig. 27). Wilson et al. (1964) reviewed previous work and established a numerical Main-Bird nomenclature in order of borehole intersections from the surface. The column is composed of siliceous and argillaceous quartzites, pebbly quartzites and relatively minor conglomerate and shaly strata. Subdivisions are based on angular unconformities, disconformities and subtle lithological changes.

The Commonage Formation, about 570 m thick, consists of coarse to medium-grained argillaceous quartzites containing occasional bands of

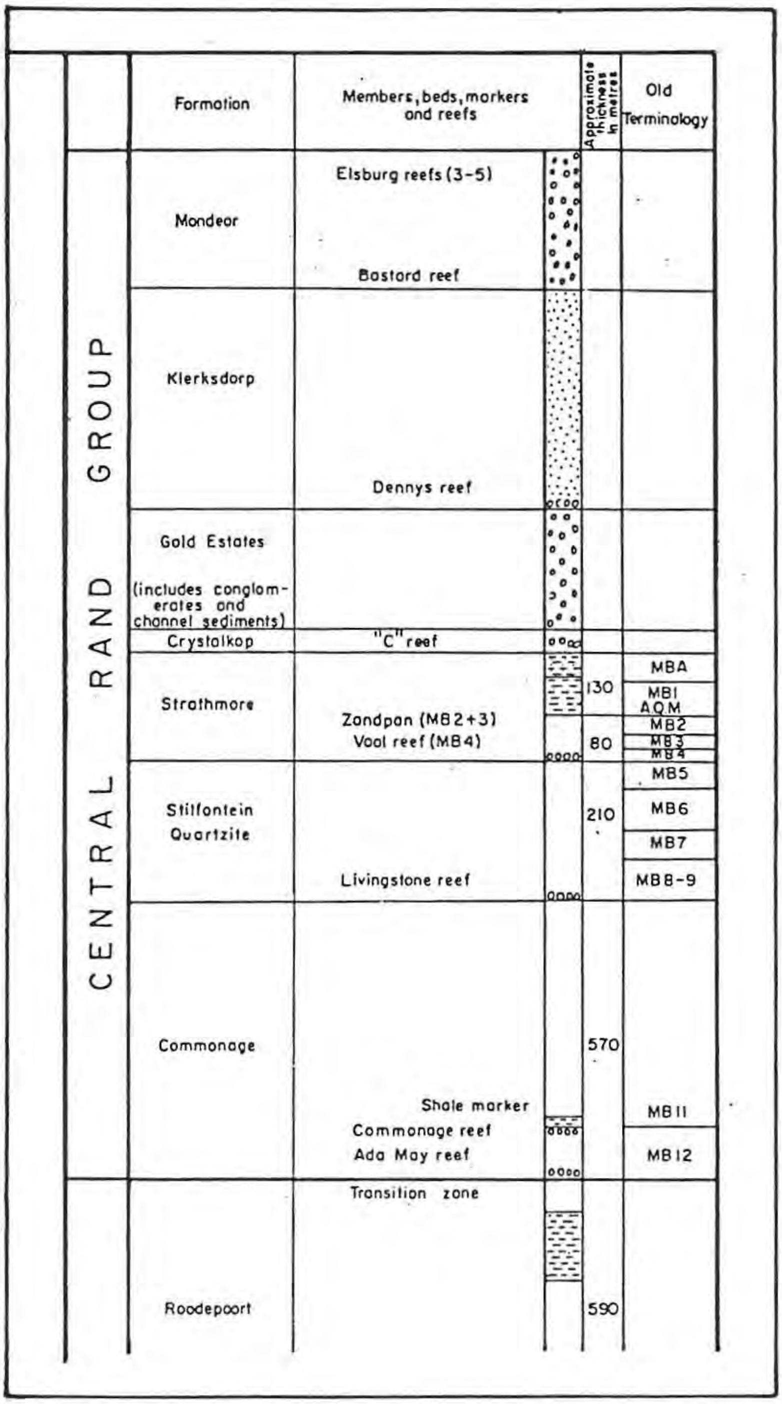


Fig. 27. Stratigraphical column of Central Rand Group in Klerksdorp area. (From SACS, 1980).

grit and small-pebble conglomerate horizons. The Ada May and Commonage placers, which contain erratic gold and uranium values, have only been mined on New Klerksdorp Gold Estates (Wilson et al., 1964). The Ada May Reef varies from a well-mineralised big-pebble conglomerate, up to 1,5 m thick on Townlands, to a carbon seam or grit in the rest of the area. The Commonage Reef occurs at the top of a number of bands of conglomerate and where it was worked on Townlands it varied in thickness from a thin pebble lag to three bands over 6 m thick.

The Stilfontein Formation consists essentially of siliceous and argillaceous quartzites, and up to 15 conglomerate horizons. These occur towards the base of the Livingstone Reef and contain negligible amounts of gold and vary in thickness from 30 cm to 1,20 m. The Strathmore Formation (Bird Reef Stage), hosts the Vaal Reef placer, the major gold and uranium-bearing orebody in the Klerksdorp goldfield. This placer has an average thickness of 30 cm and rests upon a prominant and regular angular unconformity surface (Minter, 1976). The quartzitic Strathmore Formation is up to 250 m thick and shows a fining-upward sequence with shaly quartzite, black shale and argillaceous quartzite found towards the top of the formation.

The Crystalkop Formation, a sandy distal sequence containing a basal placer known as the Crystalkop placer, is truncated by the Gold Estate angular unconformity in the southern end of the goldfield. The Gold Estates Formation hosts coarse proximal placer deposits that were deposited on a prominant angular unconformity surface at the base of the formation. These placers contain erratic gold concentrations that were exploited by the New Klerksdorp Gold Estate Mine.

The Elsburg Formation, about 275 m thick, is composed of medium to coarse-grained siliceous quartzites hosting 6 to 7 conglomerate horizons (Orkney placers). These gold-bearing proximal deposits, comprising a multi-pulse gravel succession, are best developed in the western part of the goldfield. The sub-economic Elsburg No. 5 Reef placer occurs about 200 m above the base of the Elsburg Formation (Fig. 28), comprising a multiple sequence of braided channel sediments resting on scour surfaces. It has been mined at Orkney in conjunction with the Ventersdorp placers. The Elsburg Formation is truncated to the west and north by a major angular unconformity at the base of the Ventersdorp Supergroup.

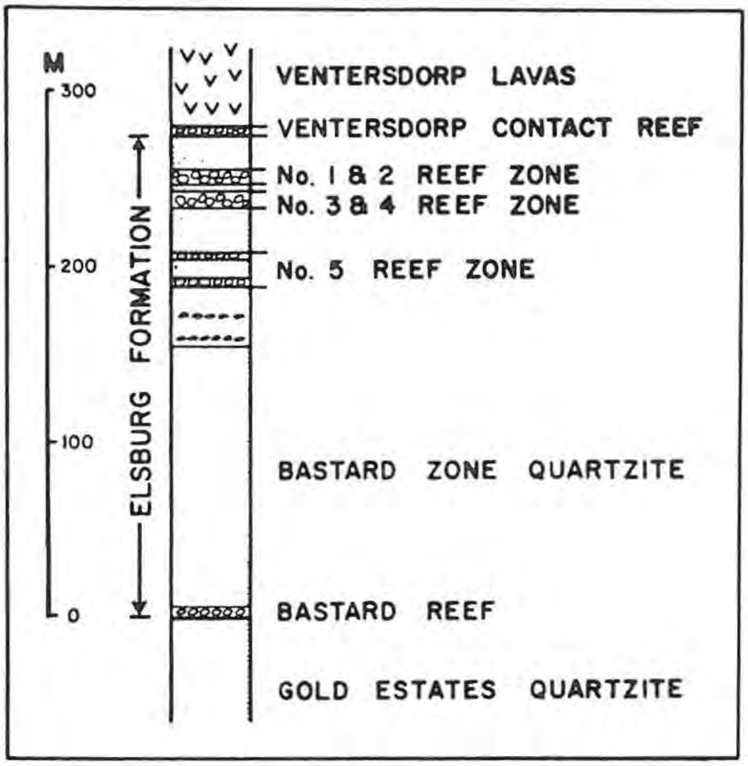


Fig. 28. Schematic stratigraphical column, showing position of the Elsburg No. 5 Reef Zone in the Klerksdorp Goldfield. (From Smith and Minter, 1979).

The Welkom Goldfield

It became evident during literature searches that little up-to-date published information is available for the stratigraphy of the Welkom area. Detailed stratigraphical columns are available in company reports but cannot be incorporated in this report due to their confidential nature. A schematic stratigraphical column of the Central Rand Group is presented in Fig. 29.

The Johannesburg Subgroup hosts a number of exploitable placers, most of which are associated with planes of unconformities. A placer stratigraphically equivalent to the Ada May placer of the Klerksdorp goldfield is present at the base of the Virginia Formation near the transitional contact with the Jeppestown Shale. It is unevenly distributed and appears to represent the initial progradation of alluvial fans in the area (Tankard et al., 1982).

The Welkom Formation is a distal fluvial fan sequence composed of a thin uranium-bearing conglomerate at the base (Intermediate placer) and some 300 m of quartz arenites. The coarse-grained sediment is arranged in trough-crossbedded sets with cosets that are between one and two metres thick.

The Basal Reef, which is the major gold and uranium orebody in the Welkom goldfield, rests disconformably on a scour surface at the top of the formation. This reef is composed of the laterally coalescing Basal and Steyn placers that were deposited on practically the same palaeosurface (Minter, 1978).

The sub-economic Leader Reef rests on an angular unconformity 20 m above the Basal and Steyn placers (Fig.30), and is generally mined because of its close proximity to the Basal Reef. The Dagbreek Formation is a transgressive fining-upward sequence from a basal conglomerate unit to a very fine-grained argillaceous quartzite and shale unit.

The Aandenk Formation consists of 90 m of coarse-grained fluvial sediment containing a number of gravel units. The "B" Reef placer lies at the base of this formation and represents a regression over the underlying Dagbreek Formation (Minter, 1978).

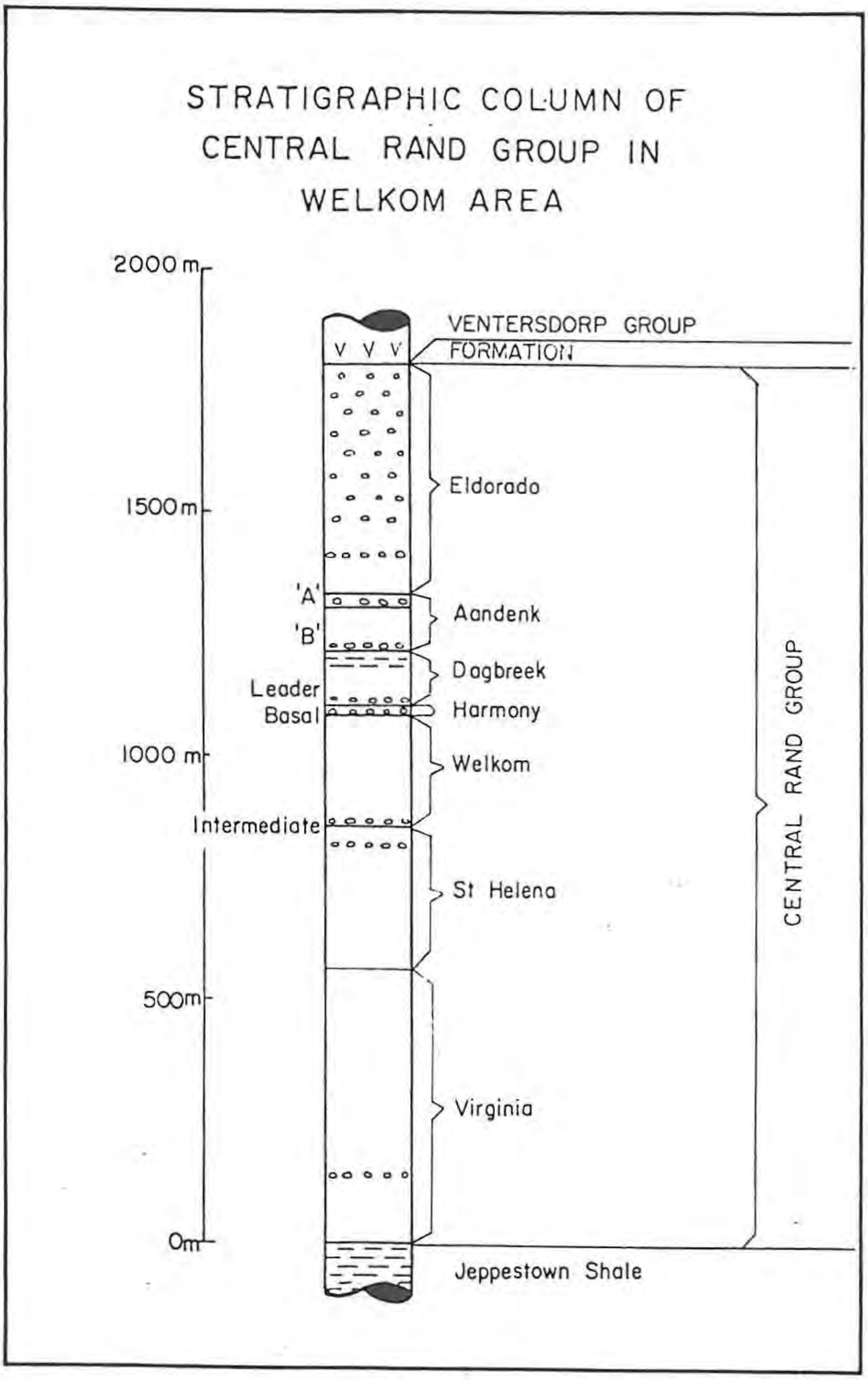


Fig. 29 Schematic geological column of Central Rand Group, Welkom area. (From Minter and Kingsley, 1980).

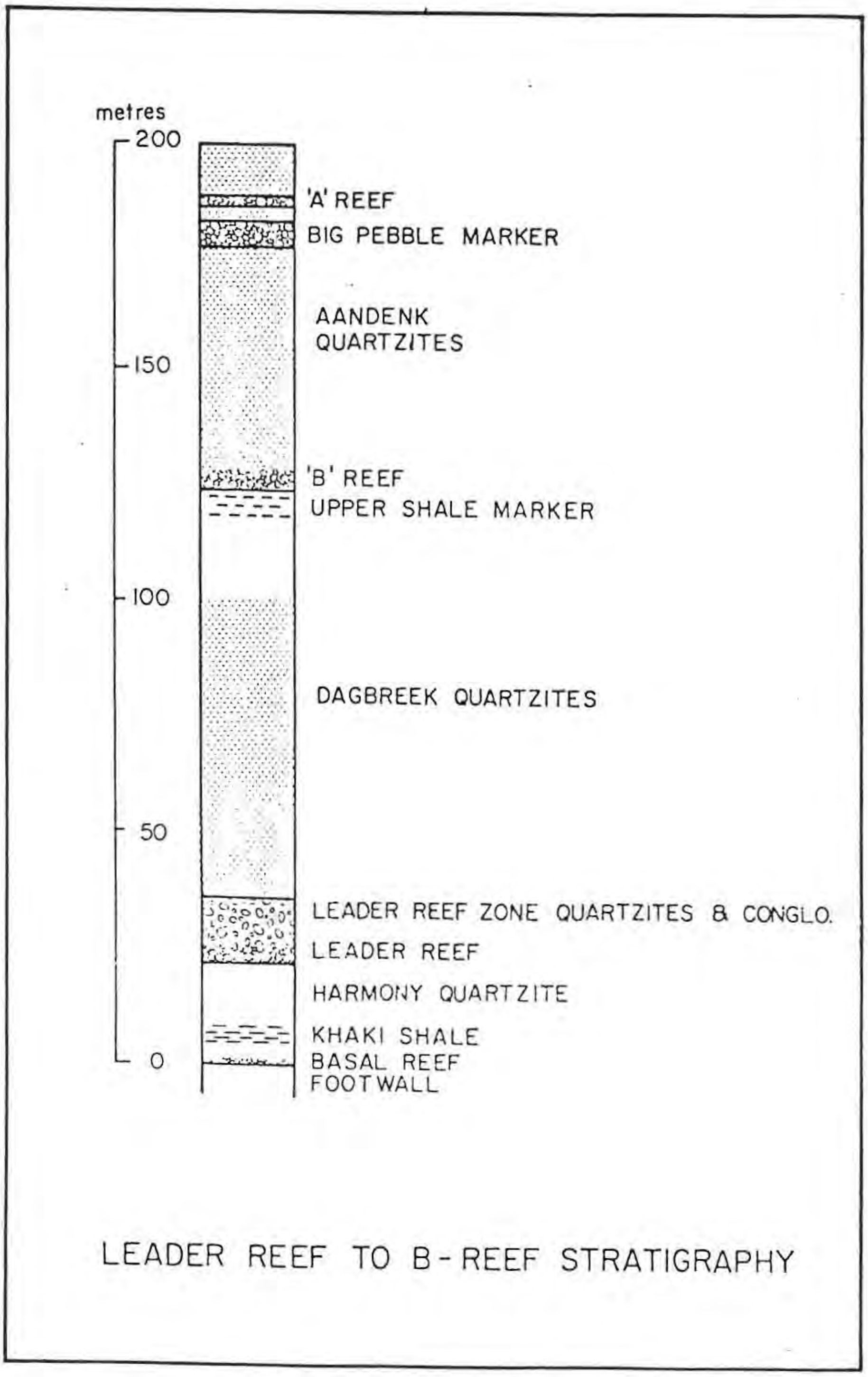


Fig. 30. Schematic stratigraphical column, showing position of the Leader Reef. (From Minter and Kingsley, 1980).

WITWATERSRAND PLACER DEPOSITS

In essence, the placer model envisaged by Pretorius (1974) and Minter (1975), describes the dispersal of sediments from eroding auriferous provenance areas down dendritic systems of tributary channels into braided belts. Placer deposits are by their nature very erratic and unpredictable and this is a reflection of their mode of development and the processes related to the type of sedimentary systems and environments that they occur in.

Types of Placers

Minter (1975) recognised the following types of Witwatersrand placers:

Alluvial-Fan Placers

Preserved gold-bearing alluvial-fan deposits appear to be confined to the Ventersdorp Conglomerate Formation, which was shed off reworked Witwatersrand Supergroup horsts and deposited into structurally controlled yoked basins.

Fluvial-fan Placers

The Livingstone Reefs described by Steyn (1963) at West Rand Consolidated on the West Rand have a fluvial-fan geometry. As many as twelve gold-bearing conglomerate layers are interbedded with quartzites to form a clastic cone of sediment, which is over 30 m thick at its proximal end and thins laterally and downslope to about 15 m. The reefs that have been mined are pebble-supported conglomerates with detrital heavy minerals dispersed throughout their matrix.

Proximal Braided-Belt Placers

The regressive, proximal-facies, placer accumulations were deposited in relatively high-energy conditions on channel scour-surfaces averaging 50 to 200 cm in depth with a channel index as much as 500. The channels, as in the "B" Reef of the Welkom goldfield, were eroded into the underlying footwall sediments, and separated by minor interchannel topographic elevations. The channels, defined by their fill of more mature sediment, have well-defined edges. They are either filled with large pebble-supported conglomerate containing detrital heavy minerals throughout the matrix or with mature pebbly quartzite, in which detrital heavy minerals are less well concentrated. In shallow channels only thin lags occur overlain by argillaceous quartzite. These lags may contain very high concentrations of detrital heavy minerals.

Distal Braided-Belt Placers

These transgressive placers, of considerable economic importance, formed on extensive unconformity surfaces that were virtually flat. Braided streams in a more distal position anastomosed to form an apparent sheet of placer sediment, for example, the Vaal Reef of the Klerksdorp goldfield. The channelways are still evident, however, and attain a maximum depth of 100 cm but generally are less than 50 cm and have a channel index as much as 3 000. The placer sediment in this more distal environment is no longer a pebble-supported conglomerate reef but a pebbly quartzite carbon-seam type of reef. The preservation of detrital heavy mineral concentration was not dependent on physical protection by pebble layers but, in the prevailing lower-energy environment, the heavy minerals were deposited on sedimentary partings in the reef, usually the bottom contact.

In very distal environments the reef unit becomes a thin sand layer with occasional grits or small pebbles and a thin detrital layer of heavy mineral concentrates. The reef unit is erratically distributed, possibly taking the form of pods and ribbons in deltaic-shaped areas.

Sedimentological Aspects

Facies

The facies recognised in Witwatersrand placers are essentially a scour surface; a pebble lag; horizontally layered conglomerates; planar-crossbedded pebbly quartzite; trough-crossbedded quartzite;

planar-crossbedded quartzite; horizontally bedded quartzite; and thin mud drapes (Minter, 1978).

The coarse-grained sediment facies in the placers comprise : crudely bedded conglomerates forming sheets and longitudinal bars; trough-crossbedded conglomerates in the form of channels; and rare tabular sets of planar-crossbedded conglomerates and pebbly quartzites, representing transverse bars. Conglomerate-filled depressions, lags and bars are pebble-supported and planar-crossbedded units are usually matrix-supported.

The sandy facies include trough-crossbedded quartzites, horizontally bedded quartzites, and rare solitary sets of planar-crossbedded quartzites. A very fine-grained facies is represented by shaly mud drapes and clasts.

The vertical sequence of these placer sediment facies begins with a scour surface and is generally followed by a pebble lag which grades normally into trough-crossbedded quartzite. Multiple scour surfaces are common and the internal geometry is lenslike. Proximal locations may be distinguished from distal locations by means of the sizes of clasts and heavy minerals, changes in the vertical sequence, and by mineral ratio changes. Distal locations are marked by a decrease in pebbles, a sandy facies, and predominant mud drapes and mud clasts.

Lithology

The most striking features of the Witwatersrand placers is their lithological and mineralogical maturity. They are composed of coarse-grained quartz arenites and mainly oligomictic conglomerates in contrast to the bounding lithologies which are more argillaceous and polymictic. The mineralised conglomerates consist of about 80 percent pebbles (by weight), which are predominantly represented by durable rock-types such as vein-quartz and chert. Polymictic conglomerates carry clasts of quartzite, shale, lava, and schist, in addition to the quartz and chert. The matrices of the conglomerates consist primarily of quartz, sericite and chlorite, together with a large suite of heavy minerals. More than 70 ore minerals have been recorded; the more significant of these include, pyrite, pyrrhotite, chalcopyrite, galena, sphalerite, arsenopyrite, molybdenite, cobaltite, rutile, leucoxene, ilmenite, zircon, chromite, osmiridium, uraninite, thucholite, brannerite, and gold. Pyrite constitutes up to 15 percent of the matrix and occurs in three forms, one of which is clearly detrital, another an apparently in situ development from sulphidic muds in interchannel areas, and the third a recrystallisation product of metamorphism (Pretorius, 1981). The gold particles range in size between 5 and 100 microns and the uraninite between 15 and 250 microns.

Distribution and Concentrations of Heavy Minerals

The distribution of heavy minerals within a particular placer horizon is ultimately governed by the local hydraulic processes which operate at the times of deposition. Smith and Minter (1979) have classified the areal concentrations of heavy minerals in fluvial systems into four categories which broadly correspond to spatial scales at which the hydraulic sorting processes operate :

Large scale concentrations occur on a regional scale in response to some optimal combination of average size of available heavy minerals and the long-term characteristics of the fluvial environment. Width scales range from hundreds of metres to kilometres.

Intermediate scale concentrations arise from processes associated with major topographic elements within channel systems, for example, channel bends, braid bars, or channel junctions. Distribution scales are in the order of metres to tens of metres along widths or lengths.

Small scale concentrations and sorting processes occur at bedform level, and typical examples include heavy mineral rich laminae in crossbeds and in horizontal strata. Linear scales commonly range from centimetres to tens of centimetres.

Very small scale concentrations result from processes operating at the millimetre scale, for example, cluster of grains within laminae or within voids between larger grains. Heavy detrital particles of gold and hydraulically equivalent-sized particles of uraninite and pyrite were concentrated and preserved, particularly as lag accumulations on scour surfaces within pebble-supported conglomerate and trough-crossbedded pebbly quartz arenite facies.

All the significant placer accumulations of gold and uranium were deposited in shallow braided streams. The stream channels had low sinuosity and their depths generally did not exceed two metres. Reworking, under either regressive or transgressive conditions, of the gravels and sands led to the generation of well-mineralised conglomerates. Openwork gravel bars were formed, and the heavy minerals were introduced by subsequent pulses of sand-influx, the arenites migrating in dunes over the gravels. During the periods of non-deposition, at the ends of pulses and cycles of sediment-inflow, winnowing of pebbly sands removed the fine, lighter material and left behind lag-gravels with heavy minerals, mainly pyrite, gold and uraninite. The significance of unconformities becomes apparent; they represent breaks in sedimentation and allow settling, concentration and winnowing of heavy minerals on erosion surfaces. Unconformities result in the preconditioning of palaeosurfaces and the redistribution of sediments and heavy minerals on them.

Heavy minerals are generally hydraulically equivalent to the sand-sized fractions of the trough-crossbedded pebbly quartzites and are found concentrated on the tangential toes of foresets and merge along the scoured base of each set. The scour and fill mechanisms appear to have reworked the sediments as the train of sand dunes migrated downstream. When the migration of sediments dominated and preservation was low, only the bottom well-mineralised part of each set was preserved. Winnowing of sands over a long period of time produced heavy mineral residual accumulations on erosion surfaces which were generally preserved by small-pebble accumulations or by algal mats. In low-energy environments in the distal parts of the fans, algal mats grew, and fine-grained gold and uraninite particles, which passed beyond the gravel traps, were arrested in the mats, where substantial concentrations build up, to form the so-called Carbon Leaders. Biochemical reworking led to further concentrations of these minerals which were fixed in place by the algae. Inasmuch as carbon has obviously assisted in fixing both gold and uranium carried by formation waters, it is important to attempt to understand the control by the unconformities on the development of the algal-bacterial colonies.

It is widely appreciated that unconformities are favourable for the occurrence of placer deposits, formed by specific gravity sorting of dense stable mineral species. A study of Witwatersrand literature has added two extra dimensions to this observation. Firstly, angular unconformities are deflation surfaces, where large volumes of unconsolidated sediments were erosively removed. The heavy minerals contained in these sediments were contributed to the surface of unconformity. Secondly, during the erosive interval, Witwatersrand braided fan surfaces stood above the base-level of deposition. Consequently, these surfaces were not surfaces of permanent deposition for a considerable period of time. Large volumes of coarse clastic detritus moved across them, leaving behind no trace other than a lag of heavy and economically important minerals.

Unconformity - Related Gold and Uranium Placer Deposits

Stratigraphically the economically important placers occur as: regressive deposits on unconformities at the base of sedimentary units; transgressive deposits on angular unconformities at the base of sedimentary units; or as terminal deposits on disconformities at the top of sedimentary units (Minter, 1978). Reworking, under either regressive or transgressive conditions, of the gravels and sands led to the generation of well-mineralised placers.

The Basal and Steyn Placers

The Basal and Steyn placers (Welkom goldfield) rest disconformably on a scour surface at the top of the quartzitic Welkom Formation of which they represent a regressive terminal phase (Minter, 1978). Channels up to 4 m deep and over 500 m wide, that branch and join in braided patterns, have been filled by mature placer sediment which has overlapped between the deepest channels to form an extensive thin sheet of sediment. The channel distribution pattern has been interpreted from an integration of detailed moving-average trends of thicknesses and gold and uranium content with palaeocurrent vectors (Fig. 31A). Along the palaeostrike marked by the 40 mm maximum pebble-size isopleth, major channel scours are preserved. Multiple scour surfaces with asssociated lag gravels are evident in Fig. 32A with the last scour overlapping on

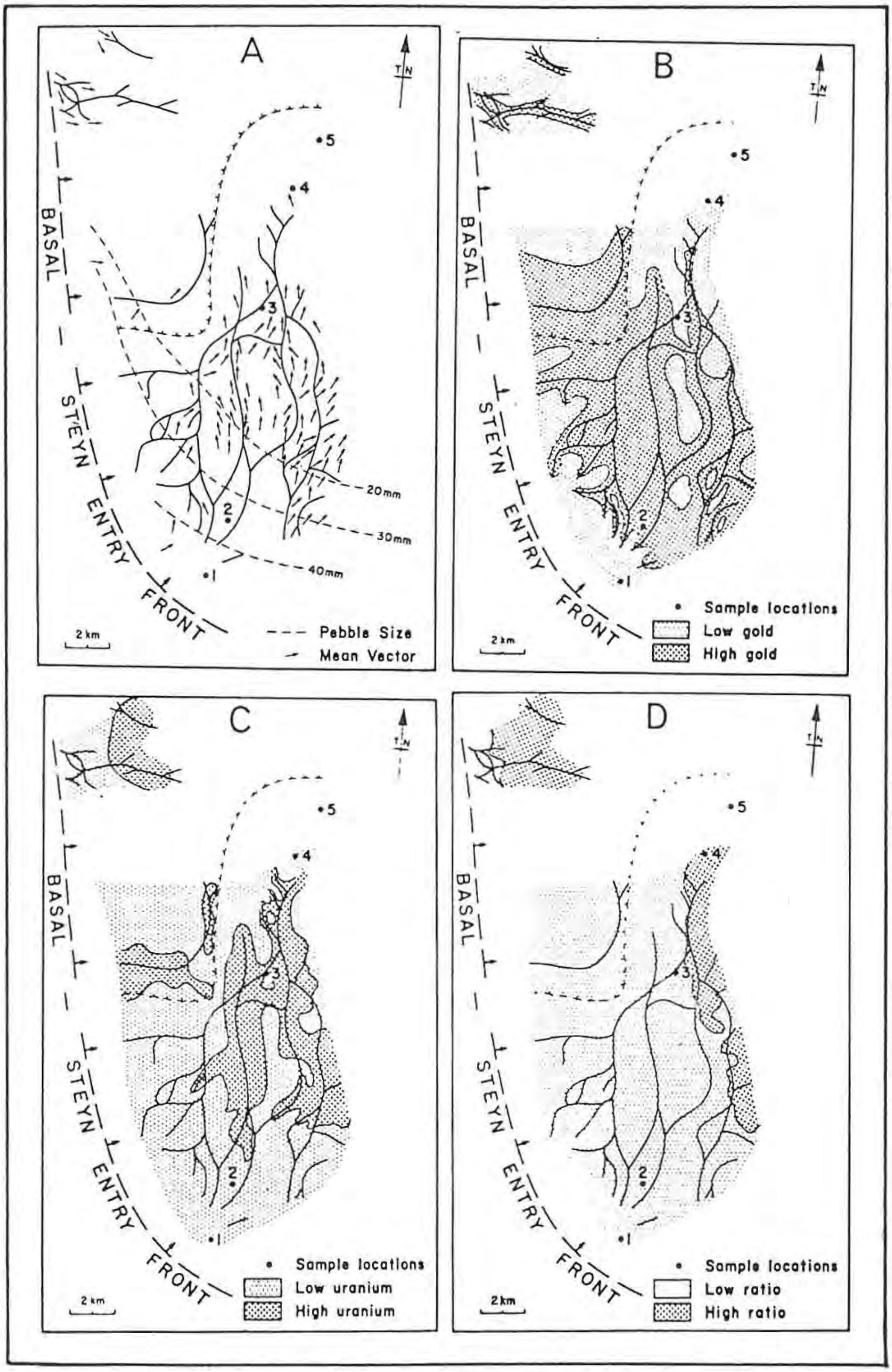


Fig. 31. Basal and Steyn placer deposits showing : A, palaeocurrent plan; B, location and distribution pattern of the high gold content facies; C, location and distribution of high uranium content facies; D, a mineralogical ratio change down the palaeoslope, expressed by the ratio of uranium to gold. (From Minter, 1978).

to similar but older adjacent channels.

In the proximal parts of the Steyn placer, near location 2 (Fig. 31A) where deep channels containing large-pebble conglomerates occur, gold and uranium are concentrated in the pebble-supported gravels and in pebble lags on scour surfaces (Fig. 32A, B). The winnowed tops of gravel bars are also sites of heavy mineral concentration.

Twenty kilometres further down the palaeoslope, the Steyn placer is essentially a quartz arenite unit which was built by shallow sandbars and dunes. Thin yellow mud veneers less than 1 mm thick occur on bedform surfaces and mark periods of fine sediment settling between periods of sand transport. Small pebbles lie at the base of trough sets and form thin lag veneers on scour surfaces and in particular on the scalloped scoured base of the placer unit. In the more distal parts of the Steyn placer, channelled bedforms are not prominent, the discontinuity is subtly scalloped, and the placer sediment is essentially a sandbody. Younger channelling is evident and multiple depositional surfaces within the sediment are marked by yellow mud drapes (Fig. 33A). The scour surfaces marking the bottom of the channels were often well-mineralised by the migration of overlying trough-crossbedded dunes (Fig. 33A, B).

The detailed trend surface pattern of gold content described by flow lines conform with the palaeocurrent data (Fig. 31A, B). The high gold content facies, marked by contour re-entrants up the palaeoslope along a curved palaeostrike lying between locations 1 and 2, terminates about 10 km down the palaeoslope. The distribution of uranium content indicates a similar hydraulically controlled pattern of distribution with the contour re-entrants upslope and terminal tongues further down the palaeoslope. Although gold and uranium distributions are sympathetic, the commencement of the high uranium content facies is displaced 2 km downslope from commencement of the gold facies area. This relative displacement is further illustrated by the ratio of uranium to gold content shown in Fig. 31D.

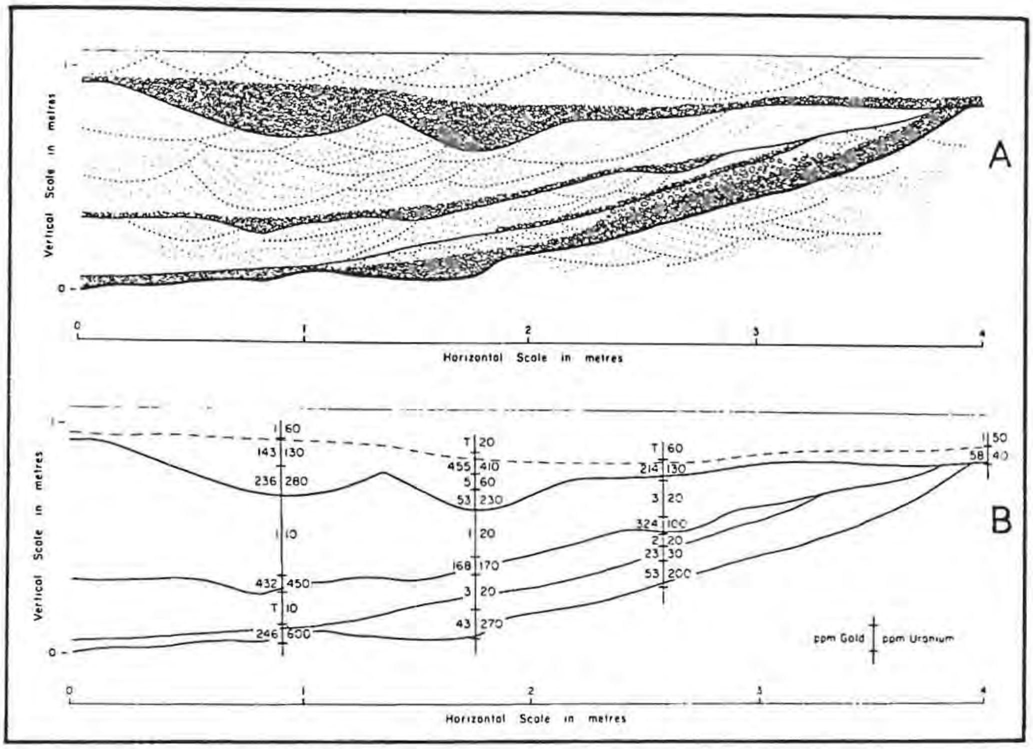


Fig. 32. Edge of a Steyn placer channelway showing : A, multiple scour surfaces within the channel with associated lag gravels and intercalated trough-crossbedded quartz arenite; B, gold and uranium concentrations related to the channel sediments. (From Minter, 1978).

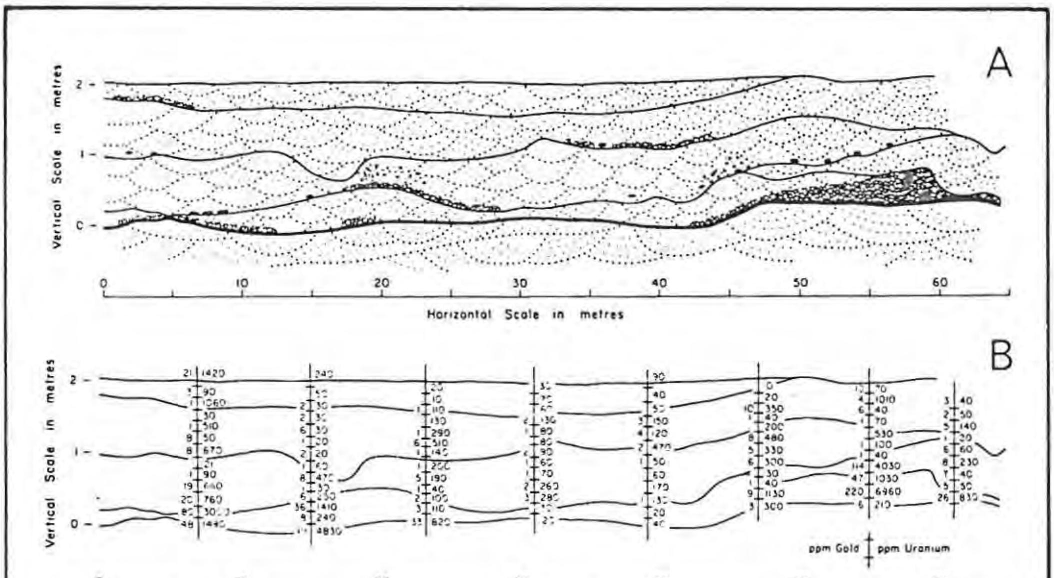


Fig. 33. A. very distal Steyn placer sediment composed of trough-crossbedded quartz arenite resting on a well-defined disconformity. Younger channelling, which has partly removed and reworked the placer, is distinguished by scour surfaces, yellow mud drapes and mud clasts. B. Scour surfaces, and coarser sediment accumulations are associated with higher gold and uranium concentrations. Samples with trace amounts of gold have been left blank. (From Minter, 1978).

The Leader Reef Placer

The Leader Reef covers an area of approximately 400 km^2 and was deposited on an unconformity surface at the base of Dagbreek Formation, and consists of roughly equal proportions of interbedded sandstone and conglomerate. The sandstones are predominantly quartzitic and trough-crossbedded, though planar-crossbedding and planar stratification are also common. Detrital pyrite is abundant in both the sandstones and conglomerates occurring most characteristically as (1) matrix in well-sorted conglomerates, (2) concentrations along scour surfaces, and (3) concentrations in crossbed troughs and foresets, and in laminae of planar stratification.

Channel-and-bar forms are characteristic of the Leader Reef, and Smith and Minter (1979) examined in detail a particularly well-developed channel at Welkom No. 3 Shaft to see if gold concentrations could be related to depositional processes inferred from sedimentary structures. Gold concentrations are higher on the left side of the channel (facing current) than the right (Fig. 34). Both sides consist of conglomerates along the base overlain by interbedded sandstones and conglomerate. The sandstones on the left side are composed of mainly planar-crossbeds with foresets dipping towards the channel bank and were probably deposited by transverse sand bars. Such bank-hugger transverse bars migrate towards a bank until the increasingly confined flow becomes too strong to permit further growth (Smith, 1971). At this point, sediment transport over the bar edge is carried away by the swift confined flow rather than being deposited at bar foresets. In the Leader Reef example, gold was trapped by gravel that formed the bed of the turbulent bank-to-bank sluiceway, and an interpretive sketch of the channel is shown in Fig. 35.

Smith and Minter (1979) caution that although the channel form (above) contains relatively high gold concentrations, it should not be assumed that such linear structures will always yield high values, even if they occur in the same placer horizon and were formed under identical hydraulic conditions. The reason for this lies in the basically random nature of local sediment scours in braided systems. Braided streams, with their constantly-shifting flows and bed-relief elements, can be thought of as a complex environment in which heavy minerals may be either locally concentrated or dispersed within the alluvium. Bedload

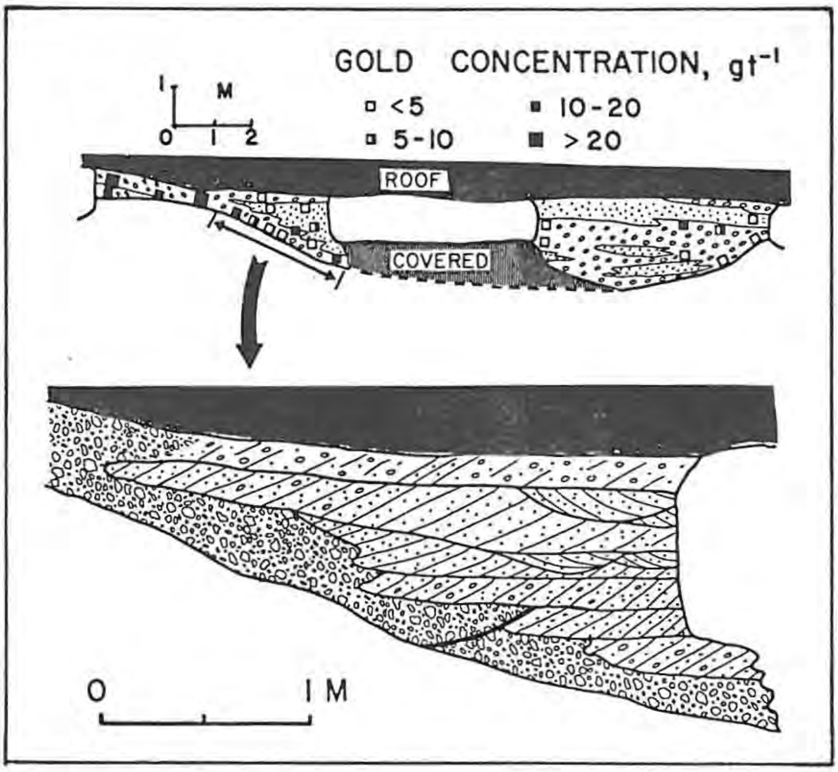


Fig. 34. Channel structure in Leader Reef exposed in adjacent pillars. Top: distribution of gold, showing higher concentrations on left side of channel. Bottom: enlarged portion of left side of channel, showing channel-bed conglomerate overlain by, and inter-fingered with, planar-crossbedded sandstones with bankward-dipping foresets. (From Smith and Minter, 1979).

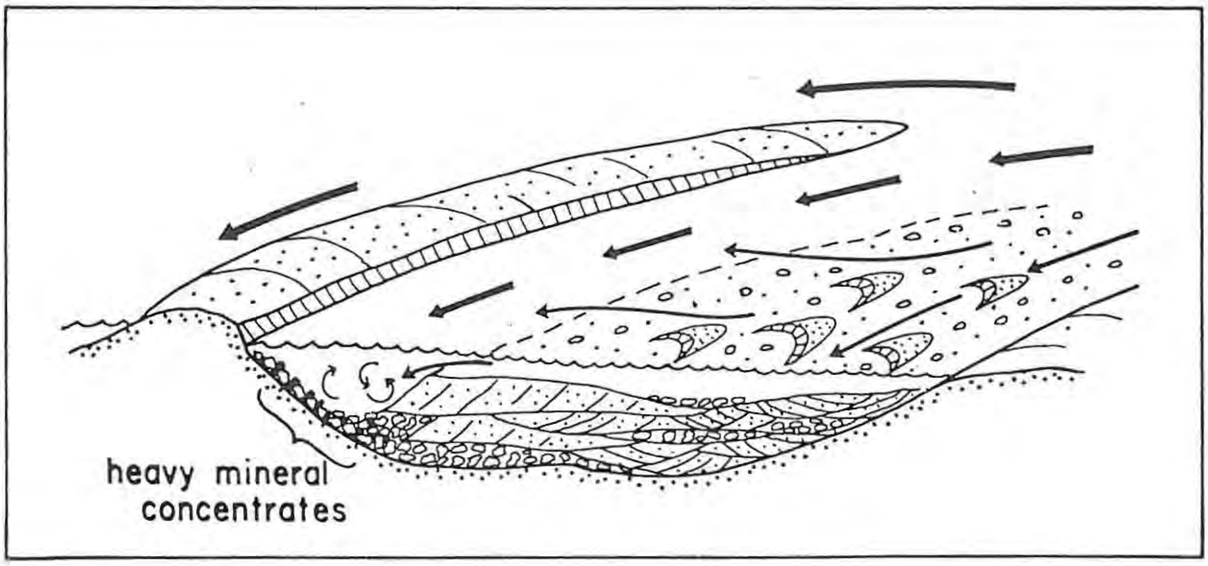


Fig. 35. Interpretive sketch of Leader Reef channel (Fig. 34). Planar-crossbeds are formed by bank-hugger transverse bar enlarging toward bank. Convergent flow becomes increasingly restricted by growing bar margin, reworking channel-bottom sediments and concentrating heavy minerals. (From Smith and Minter, 1979).

erosion and transport in braided streams tend to be sporadic, and, given the fluctuating and transient character of the local hydraulic environment, we can expect to find very uneven distributions of heavy minerals within the braided deposits. To form a local concentration of heavy minerals in braided alluvium, a suitable concentration mechanism and a local point-scour deposit containing heavy minerals are both required.

The "B" Placer

The "B" placer of the Welkom goldfield is economically of secondary importance compared with the Basal and Steyn placers because, although it is distributed over an area of 400 km^2, it is confined to shallow interconnected channelways which cover less than 35% of the palaeosurface (Fig. 36). The placer is essentially a quartz arenite unit and the most prominant facies are scour surfaces overlain by thin pebble lags, low relief pebble bars, pebble-filled depressions, and tabular planar-crossbedded quartzites.

The placer channelways range in width from 1 to 200 m and are up to 2 m deep and their profiles are seldom symmetrical but generally show one steeply-inclined side and an opposite low-angled side. The channel sediments of the "B" placer have not spread sufficiently to produce a sheet of sediment but, together with the associated gold and uranium mineralisation, are confined to channelways (Fig. 37). As a result of this confinement the gold distribution follows a simple drainage pattern and average concentrations are found on the basal contact in thin lags, in pebble-supported conglomerates, and on sedimentary partings within the placer.

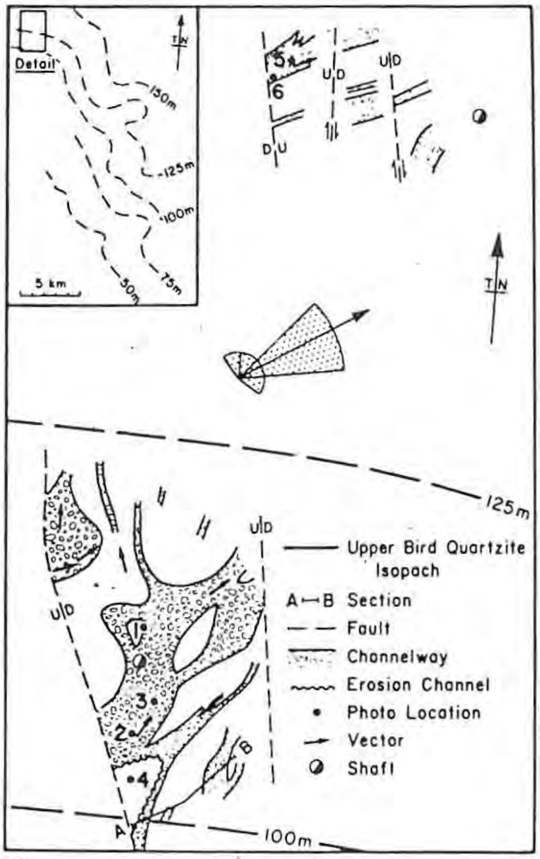


Fig. 36. Details of an area in the northern part of Welkom goldfield showing palaeochannels of the "B" placer superimposed on the Bird Formation isopachs. (From Minter, 1978).

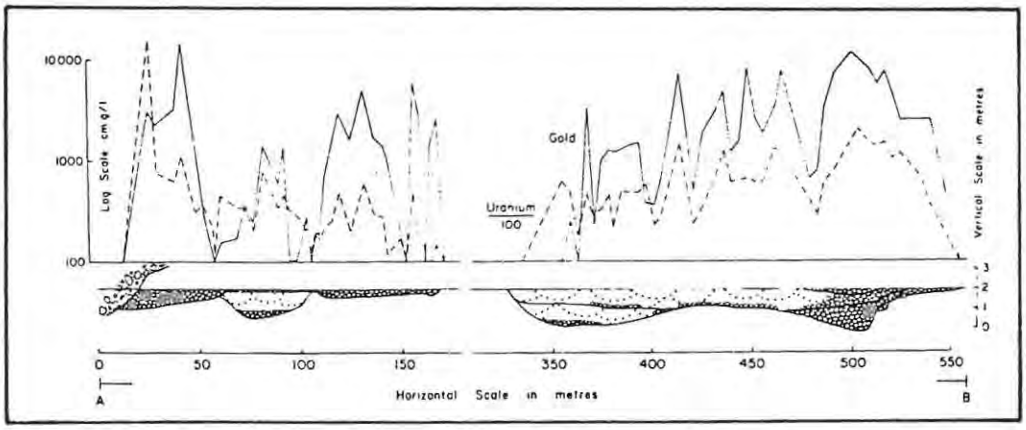


Fig. 37. A section drawn along line A-B, shown on Fig. 36, to illustrate that channel sediment of the "B" placer and associated gold and uranium mineralization are confined to channelways. A younger erosion channel has removed placer sediments to the left of the section. (From Minter, 1978).

The Vaal Reef Placer

The Vaal Reef placer of the Klerksdorp goldfield rests upon a prominant angular unconformity which transgressively truncates an underlying fluvial fan delta (Fig. 38). The nature of the truncation is veiwed by considering the total thickness of MB5 strata between the MB6 formation and the Vaal Reef orebody. Isopach contours of this thickness describe a regular surface striking northeast with increasing hiatus to the northwest (Fig. 39). Gradients read from contour intervals decrease to the southeast from 1 : 120 at Stilfontein to 1 : 360 at Buffelsfontein (Minter, 1976).

The palaeoslope bears erosional etches which are channel forms (Fig. 39) that make local angular unconformities with the footwall of up to 70° but generally of 5° to 15° along the edges. These channels, which are up to 1 m deep but average 30 cm, have a width/depth ratio of between 200 and 1 000, and show a sinuous and braided pattern that represents the final drainage etch on the palaeosurface of truncation. The placer sediment filled and eventually overflowed the

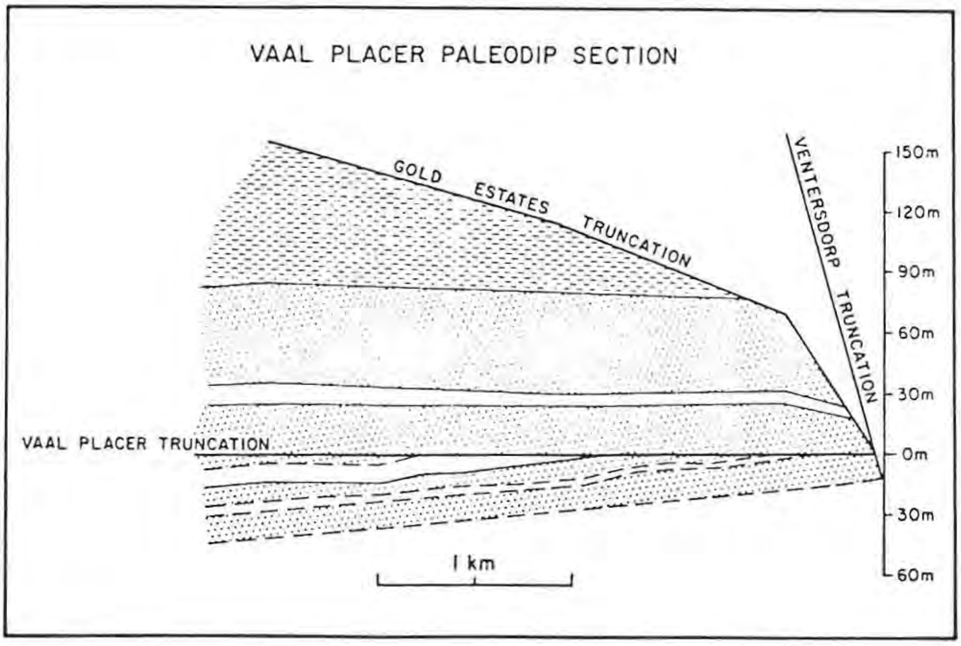


Fig. 38. A section drawn down the palaeoslope of the Vaal placer to illustrate prominant angular unconformities. (From Minter, 1978).

channels to produce a dendroidal sheet of sediment, only a few centimetres thick in places.

The Vaal placer is essentially a pebbly quartz arenite unit, the most prominant facies being scour surfaces overlain by thin pebbly lags, and trough-crossbedded quartzites. These may be repeated in the vertical sequence within deeper channels, grading normally upwards. However, an inverse grading is sometimes evident at the top of the placer unit where reworking of the surface has produced a winnowed pebbly concentrate. The pebble-supported conglomerate facies is not common; the average pebble packing density is 23%.

Essentially, the sediment of the Vaal placer was a pebbly sand that was transported over a regionally flat truncated surface of consolidated sand and deposited in shallow channels and on interchannel flats. The placer was buried by coarse sands that were transported by longshore currents which flowed parallel to the truncated surface isopachs (Minter, 1978).

The moving-average trend surface of the thickness of the Vaal placer has been generalised in Fig. 40A. to illustrate the relationship between thicker placer and channels. The patterns of gold and uranium contents (Fig. 40B, C) illustrate broad correlations with channels of thicker placer sediment.

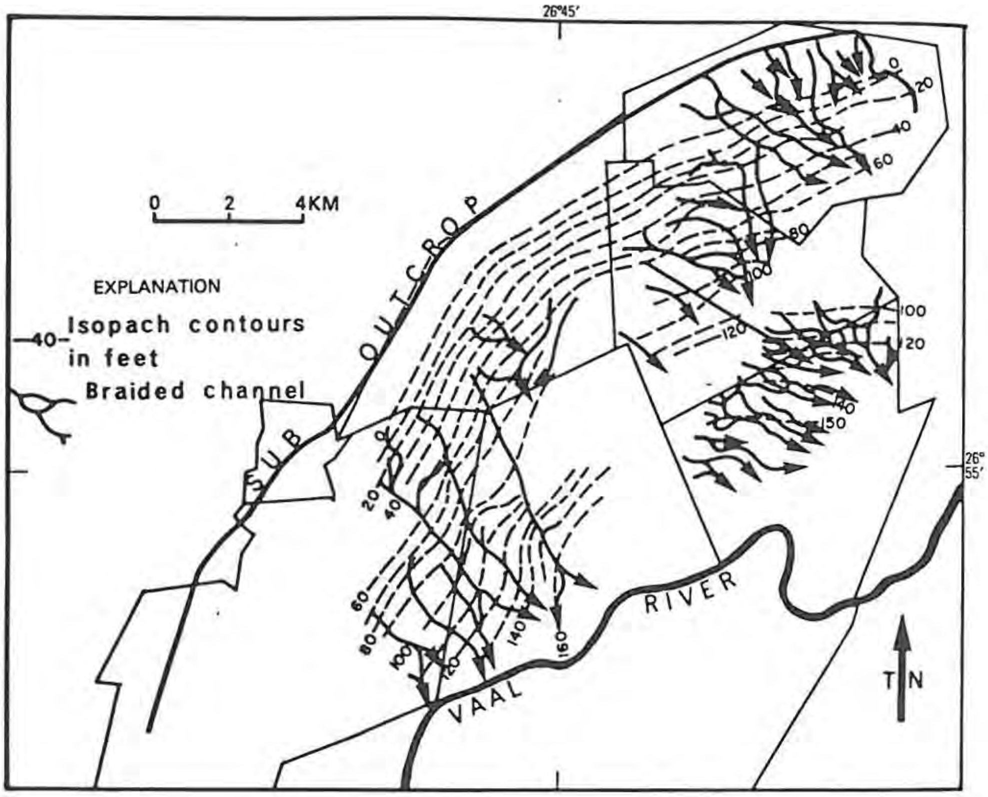


Fig. 39. Isopach plan of the truncated MB5 quartzite, which underlies the Vaal Reef unconformably. The strike of isopachs reflects a synclinal axis. Final erosional etches on the palaeosurface are evident as a braided channel pattern. (From Minter, 1975).

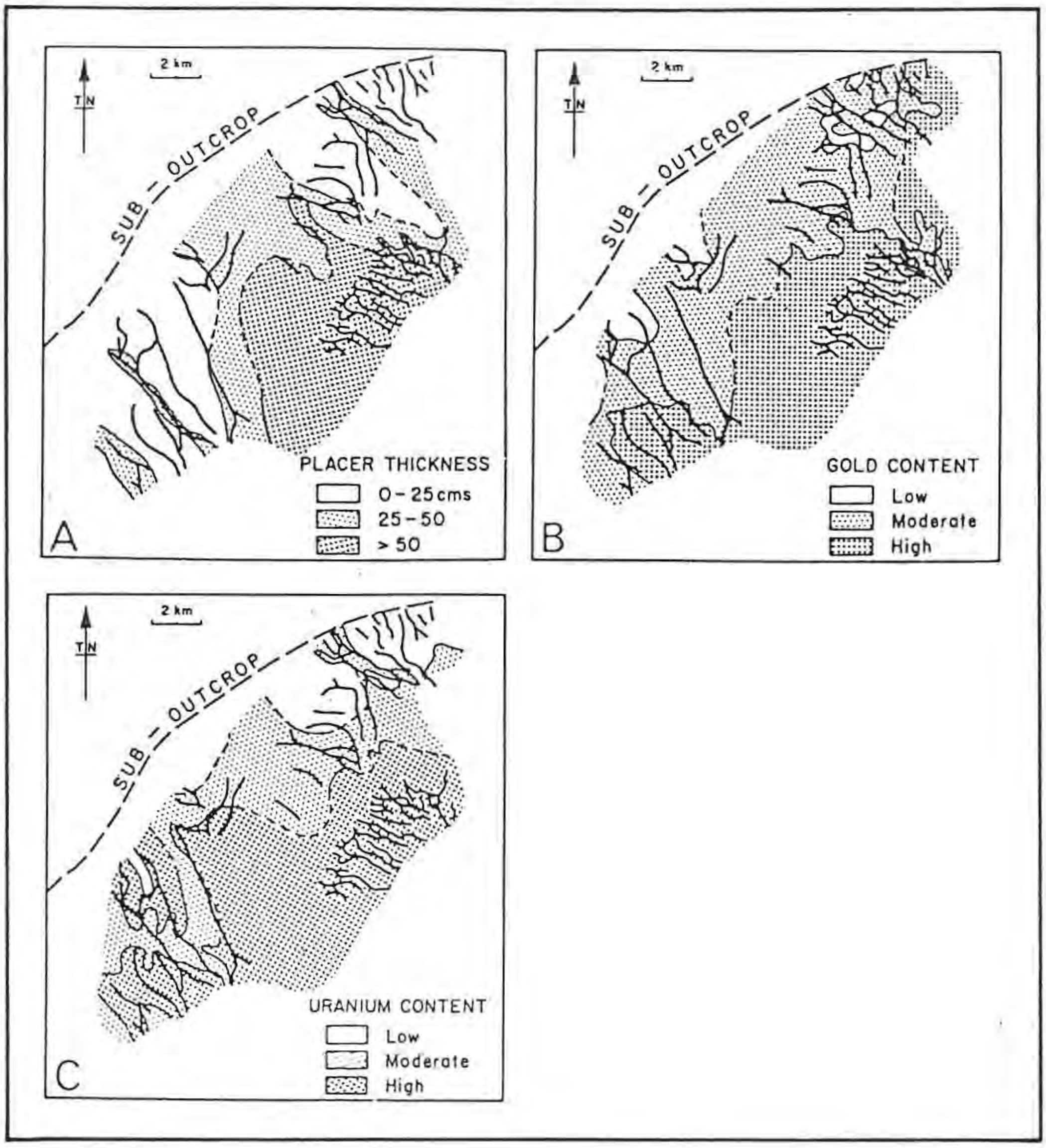


Fig. 40. Generalised moving-average distribution pattern of thickness (A), gold content (B), and uranium content (C), in the Vaal placer related to the palaeoslope and channel patterns. (From Minter, 1978).

The Elsburg Reef No. 5 Placer

The Elsburg Reef No 5 placer of the Klerksdorp goldfield rests on an erosion surface planed across underlying quartzite. Smith and Minter (1979) conducted a study on this placer to investigate the relationship between mineralisation and sedimentary features. The Elsburg Reef, within the study section at the Vaal Reefs West No 6 Shaft, Orkney, consists of roughly equal proportions of interbedded sandstone and conglomerate. The conglomerates are mineralogically mature, comprising mostly quartz and chert pebbles in sandy matrices, and texturally range from well-sorted and clast-supported to poorly-sorted and matrix-supported. Most are internally massive, though some display large-scale planar-crossbedding. Sandstones are predominantly quartzitic and trough-crossbedded, though planar-crossbedding and planar stratification are also common.

Smith and Minter are of the opinion that the Elsburg unit occupied a relatively proximal position on a fluvial fan and that it was deposited by shallow, transient braided streams. The local thickness-distribution of the basal conglomerate of the Elsburg study unit is shown in Fig. 41. Although isopachs cannot distinguish topographic highs (bars) from lows (channels), the pattern shown suggests bar-and-channel topography, particularly in view of the unimodal palaeocurrent trend which approximately parallels the isopach trends. The most striking relief features is a prominant gravel bar form in the southeast row of pillars. The bar is succeeded by a sandstone unit composed of a single planar-crossbed and a series of trough-crossbeds, all indicating unimodal palaeocurrents slightly oblique to the bar trend. Several distinct pyrite-rich bands occur within the bar; these are interpreted

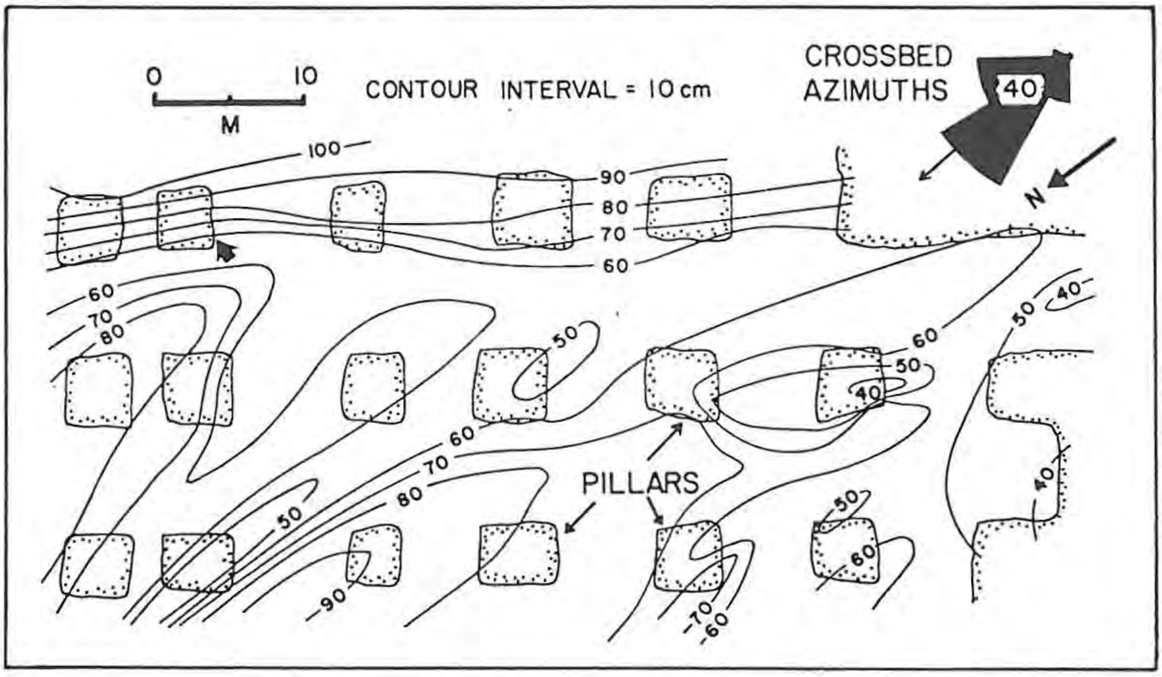


Fig. 41. Map showing isopachs of the Elsburg No. 5 Reef basal conglomerate bed examined in Vaal Reefs West No. 6 Shaft, Orkney. Note general alignment of isopach trends with paleocurrents (crossbed azimuths), suggesting channel-and-bar topography. (From Smith and Minter, 1979).

as scour-surfaces upon which pyrite was concentrated between successive events of gravel deposition. Samples of the gravel bar and overlying sandstone reveals that the highest gold concentrations occur with the pyrite-rich bands on scour-surfaces (Fig. 42). Uranium values likewise tend to be greater in pyrite bands, although their distribution is somewhat more sporadic. The significance of local unconformities, usually scour surfaces, in the concentration of gold and uranium, is apparent.

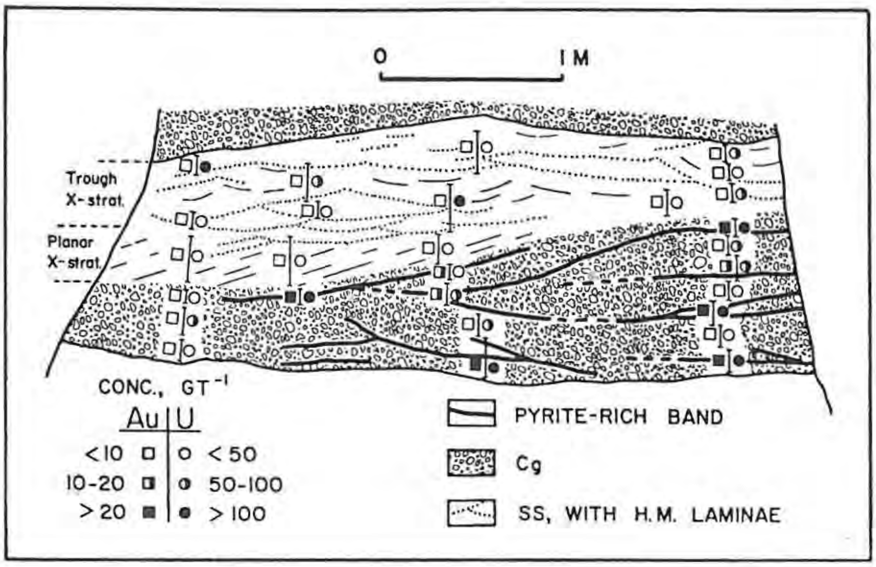


Fig. 42. Cross-section of gravel bar and overlying sandstones, showing pyrite-rich and other heavy mineral bands and distribution of gold and uranium concentrations. Position of pillar indicated by arrow in Fig. 41. (From Smith and Minter, 1979).

The Carbon Leader Zone

The Carbon Leader Zone in the Carletonville area rests on an unconformity and consists of several upward-fining sequences. These sequences usually consist of medium to small laterally impersistent conglomeratic basal lags overlain by trough and planar-crossbedded quartzites.

The North Leader placer, a basal pebble lag, marks the base of the Carbon Leader Zone and unconformably overlies the Square Pebble Quartzite (Fig. 24). It is a thin (2 - 10 cm) polymictic veneer containing mostly vein quartz and chert pebbles, overlain by a clean crossbedded quartzite. The North Leader has not been mined although interesting gold values do occur.

The type area of the Carbon Leader placer is considered as being confined to the area lying approximately 2 km on either side of the common Blyvooruitzicht - West Driefontein boundary. In its typical development the placer deposit consists of a thin sheet-like conglomerate with an underlying, friable layer of carbonaceous material which often shows a columnar texture, with interstitial visible gold flakes. The thickness of the conglomerate is normally about 10 cm and seldom exceeds 30 cm.

A detailed sedimentological study of the Carbon Leader placer at the Blyvooruitzicht No. 2 Shaft pillar (5 - 22 Drive) was undertaken by Nami (1981). The aim of the study was to establish the relationship between sedimentological features and the distribution patterns of gold, and so permit identification of processes responsible for the concentration of gold in such distal placer deposits. The Carbon Leader at the site of investigation is approximately 65 m below the Main Reef and 60 m above the Jeppestown Shales. It dips at an angle of approximately 20° to the south and is truncated in the north by the Black Reef Formation of the Transvaal Supergroup.

Nami has distinguished two sedimentary sub-facies in the Carbon Leader placer :

(1) sub-facies A, a single sheet-like conglomerate, and
(2) sub-facies B, lenticular shaped conglomerate/quartzite.

The conglomerate of sub-facies A, with an average thickness of 7 cm, is of a sand-supported type and pebbles are enclosed in a fine- to medium-grained quartzite matrix. Normally thin sericitic/chloritic shale up to 4 cm thick occurs between the conglomerate and footwall quartzite. Sub-facies B, varying in thickness from 6 to 20 cm, consists of several conglomerate bands alternating with quartzite. The conglomerates are poorly sorted, both pebble and sand-supported; are lenticular in shape not exceeding 8 m in lateral extension, and are overlain by planar or trough-crossbedded quartzite. The quartzite in turn is overlain by another conglomerate band with an erosive base.

Generally the majority of the carbonaceous matter is associated with sub-facies A and occurs in the following forms :

(1) at the base of the conglomerate bands,
(2) on the reactivation surfaces and around the pebbles, and
(3) as "fly speck" carbon.

At the base of the conglomerates the carbonaceous matter occurs as single or multiple layers of columnar carbonaceous matter with filamentous structures perpendicular to the bedding plane, and several layers not exceeding 3 mm in thickness are also present on reactivation surfaces within the conglomerates.

Nami is of the opinion that a number of features exhibited by sub-facies B strongly suggests that it is the result of stream-channel deposition, which took place in the initial stage of Carbon Leader formation. Following partial erosion of the underlying strata, sedimentation occurred by accumulation of the coarse bed load fraction of the stream as a channel lag. Streams, with varied flow discharges, erosional and depositional phases, were responsible for the formation of multi-storied conglomerate/quartzite channel deposits.

In contrast, sub-facies A has a planar base and the lack of evidence of channel downcutting is probably indicative of deposition in the form of sheet flood rather than channellised flow. During this stage the sediment-laden water, rather than being in channels, followed an unconfined course.

The origin of the carbonaceous matter and its position within the depositional setting implies that the low energy and inactive areas had favourable conditions for colonization of algal mats. The environment in which carbonaceous matter occurs is similar to that of algal mats in modern fluvial environments which occur mainly on margins of active channels and in abandoned channels (Button, 1979).

Relationships between the two sub-facies recognised from the Carbon Leader Reef are given as a generalised block diagram in Fig. 43.

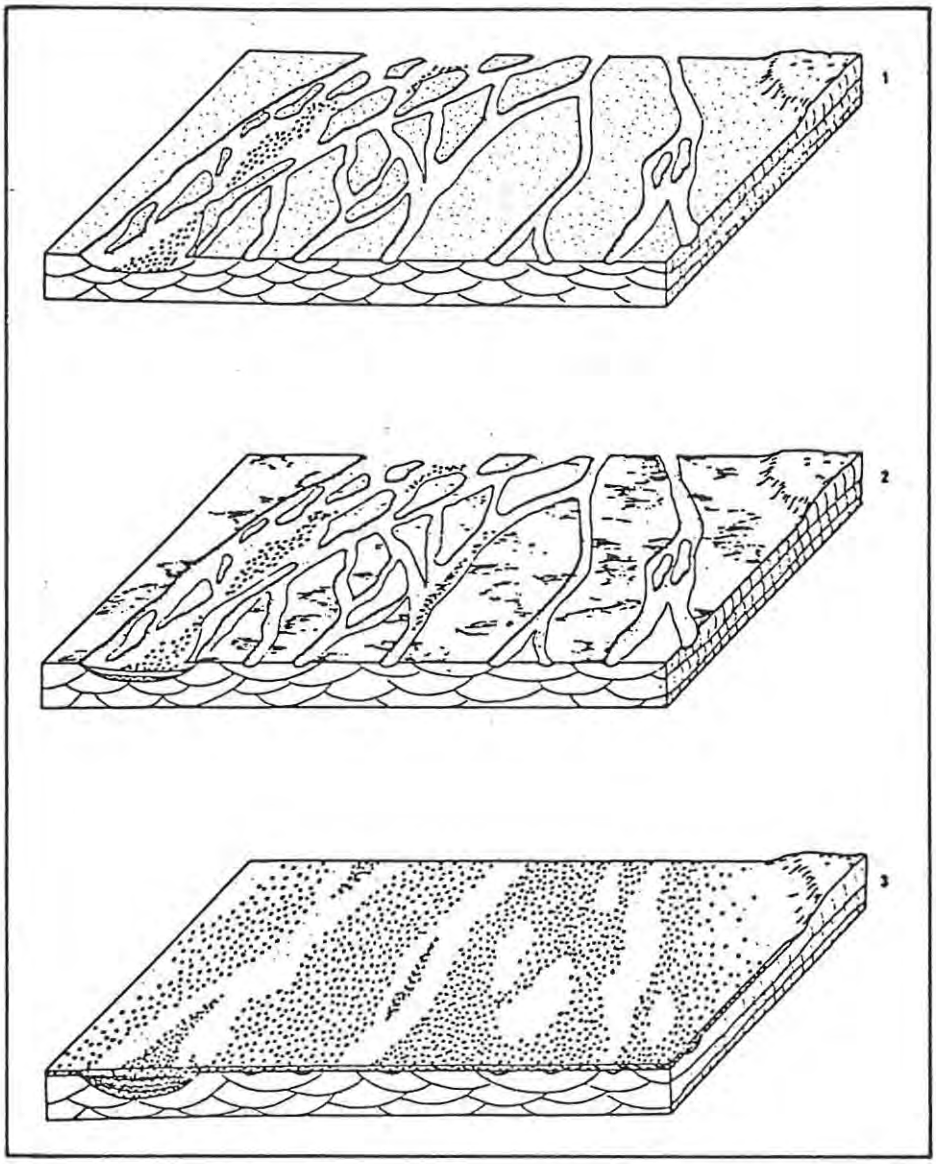


Fig. 43. Generalised block diagram, illustrating the development of Carbon Leader Reef in the study area. (From Nami, 1981).

During the deposition of the Carbon Leader Reef the different topographic levels of the palaeosurface played a major role. In the first stage the highest fluvial activity was concentrated in the low-lying areas which were either part of the existing relief of the palaeosurface or produced by channel incision. In these areas the channels responded to a single rejuvenation event resulting in the formation of multi-storey conglomerates/quartzites. While the fluvial activity was taking place in low-lying areas the higher levels were receiving sediments during flood events and conditions were generally suitable for growth of primitive algae. In later stages the sheet flood produced sub-facies A and post-depositional flows gave rise to some degree of erosional and depositional modification.

The transporting medium of sub-facies B could transport sand and pebbles separately and was able to produce downcutting and cross-bedding. In sub-facies A there was a measure of incompatability between erosional and depositional processes and the transporting medium did not segregate the course and fine material.

The presence of gold is confined to the conglomerate zones, and as Fig. 44 shows, between 65-95% of the gold is situated at the base sub-facies A, where it is associated mainly with carbonaceous matter. The gold occurs either in the form of detrital grains in the upper part or as filaments within the fossil plants. In the case of sub-facies B, where the carbonaceous matter is absent, gold is in the matrix of the conglomerate together with other heavy minerals and the concentrations are either in the bottom band or in the well-packed middle conglomerate band.

There is a marked difference in the distribution pattern of gold within the two sub-facies and in sub-facies A the pattern is relatively uniform with high mean gold values, whereas in sub-facies B the pattern is irregular and the mean gold value is low.

According to Nami the foregoing analysis of the Carbon Leader Reef demonstrates that the observed distribution pattern of gold in the study-area is the result of different hydrodynamic conditions which prevailed during the deposition of the placer. During the initial stage a high rate of flow was concentrated in the channels and the gold particles being small in size were probably transported in suspension. Although the conditions were not suitable for the concentration of gold, the presence of open-framework pebbles could have acted as a trap for the gold particles. The resulting channel sediments generally have low gold content, but erratic high values will occur.

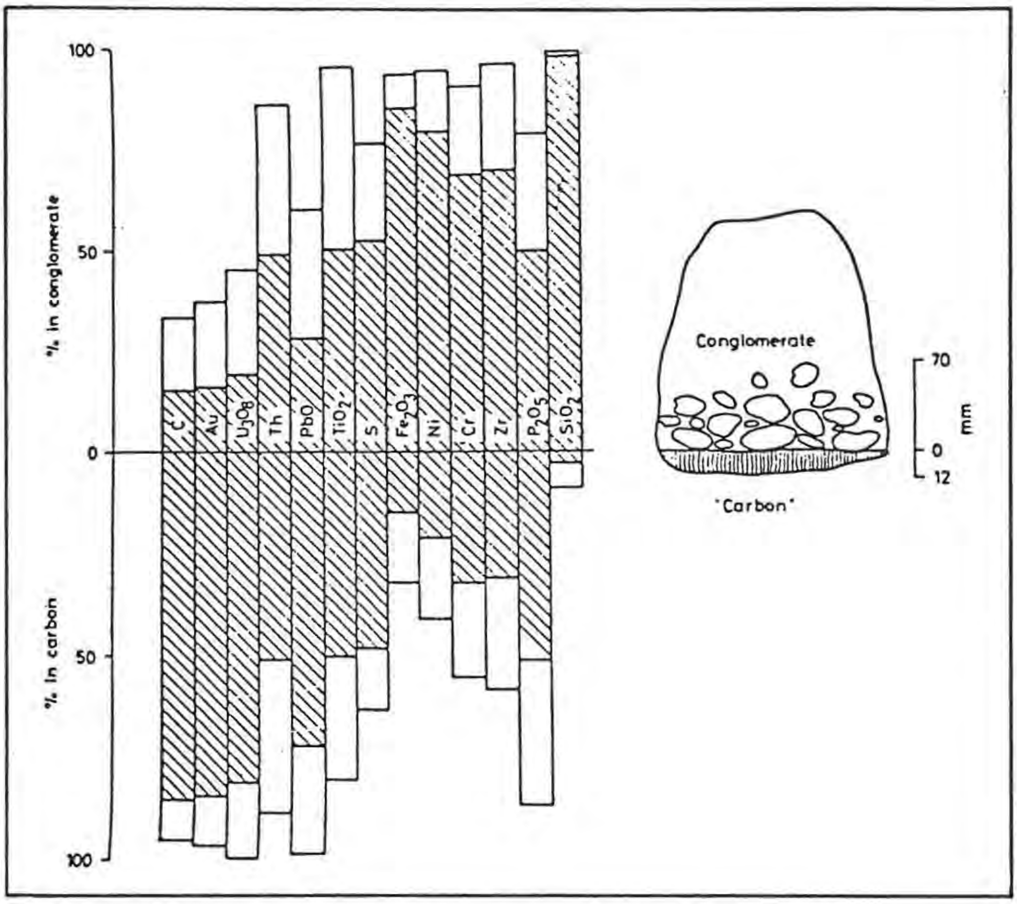


Fig. 44. Concentration of the selected elements within carbonaceous matter and overlying conglomerate band. (From Nami, 1981).

The area between the stream channels was periodically covered by unconfined flow where conditions were suitable for the growth of primitive plants. Large amounts of gold were concentrated in these areas due to the presence of mass vegetation which trapped the gold particles, in a similar manner to the corduroy tables in metallurgical practice (Hallbauer, 1975).

The Deelkraal Reef Zone

The Deelkraal Reef Zone consists of a multiple zone of large to medium polymictic pebble conglomerates, highly variable both in vertical and lateral extent. Three broadly defined sedimentary cycles, named A-type, B-type, and C-type have been recognised from the base upwards (Fig. 45).

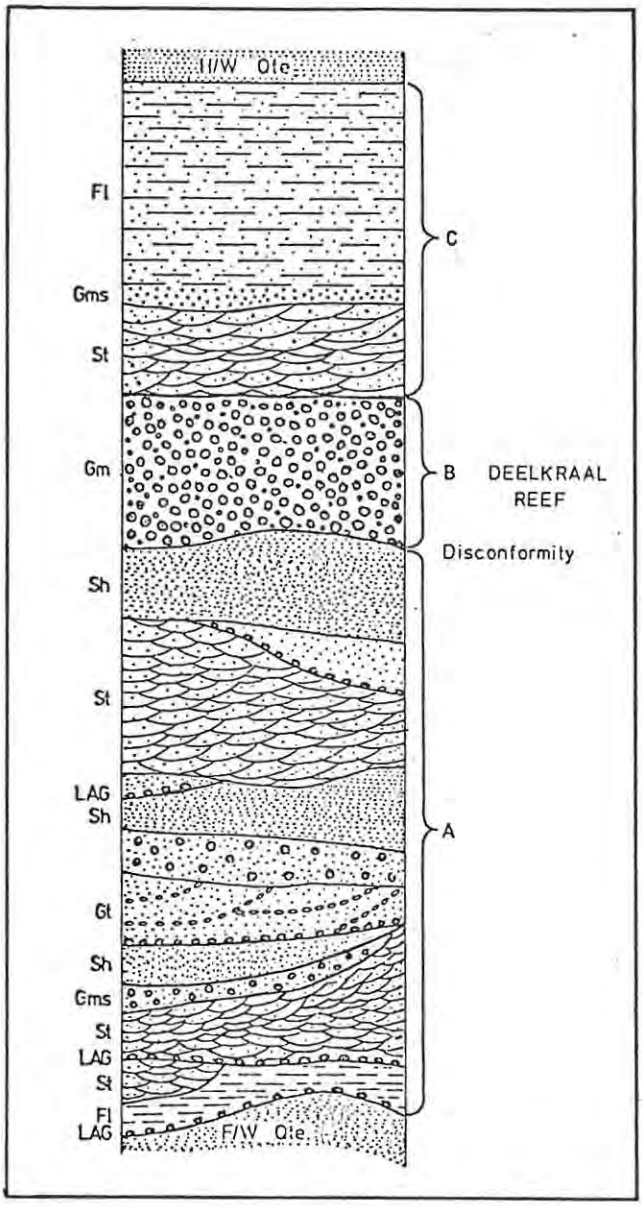


Fig. 45. Profile of Deelkraal Reef Zone showing sedimentary cycles. (After du Toit, 1981).

The A-type cycle consists of a multiple series of superimposed coarse sand-filled channel systems defined at their bases by scour surfaces marked by concentrations of pyrite and other heavy minerals. Sporadic gold concentrations and pebble lags are found on the pyritic scour surfaces. Matrix-supported poorly mineralised conglomerates, scattered trough-crossbedded pebble layers and pebble lag deposits occur throughout the predominantly coarse sand sequence.

The base of the B-type cycle (Deelkraal Reef) rests disconformably on the underlying A-type sequence and consists predominantly of massive pebble-supported large to medium pebble conglomerates. Areas of thicker reef, which contain higher gold concentrations, have been interpreted as channel-fill deposits (du Toit, 1981). The lower-grade areas coincide with inter-channel areas occupied by thin conglomerates or pebble veneers.

The C-type cycle consists predominantly of fine-grained impure horizontally bedded siltstones with lesser amounts of trough-crossbedded pebbly sand in its lower portion. Thin lensoid small pebble conglomerates, containing isolated low gold values, occur within the impure horizontally bedded siltstone.

The Ventersdorp Contact Reef (VCR)

The Ventersdorp Contact Reef is a regressive yoked placer that was deposited on an irregular post-Witwatersrand surface characterised by the developement of erosion valleys, scarps and terraces. As a result the VCR shows a rapid lateral variation in thickness and character, with differences in palaeo-topographic levels of up to 25 m occurring between broad sheets of conglomerate.

The angularity between the VCR and the older Witwatersrand beds implies that the latter were tilted and eroded before the VCR was formed. The tilting was confined to the northwestern portion of the Witwatersrand basin and as a result of differential uplift a series of transverse folds were formed which plunged southeasterly in sympathy with the regional dip of the beds. Two major broad anticlines developed; one with its axis in the vicinity of Bank and the other in the vicinity of Potchefstroom. They were flanked by two major broad synclines with axes west of Deelkraal Mine in the Gerhardminnebron area and in the Klerksdorp area, respectively (Fig. 46.). Minor flexures such as the Libanon Anticline and the Kloof Syncline were superimposed on the major folds.

The warping and simultaneous planing of the Witwatersrand beds ceased with the effusion of the Klipriviersberg lava. By that time, the beds occurring in the cores of the anticlines had been planed through

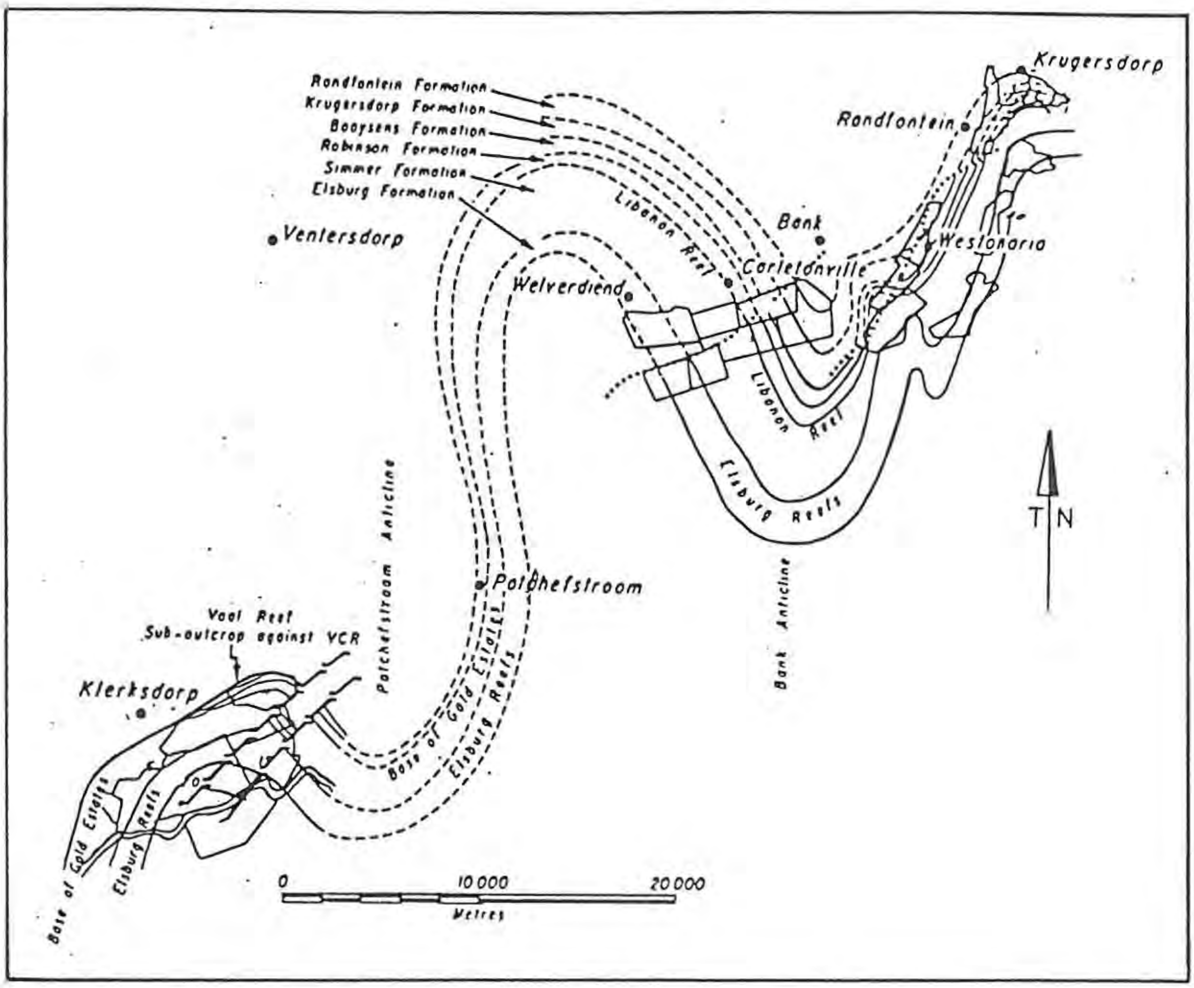


Fig. 46. Plan showing relationship of the VCR to its footwall beds along the northwestern margin of the Witwatersand basin. (From Gold Fields Internal Company Report).

the entire Central Rand Group succession and well into the West Rand Group (East Driefontein Mine), while in the syncline areas (east of Western Areas Mine) even the top Elsburg beds remained intact. The result was a series of sinuous outcrops of Witwatersrand beds trending northeast to southwest, but curving around the noses of the anticlines and synclines (Fig. 46).

On the planed surface of the Witwatersrand beds there remained a veneer of gold-bearing gravels derived from the final stages of erosion of the footwall beds. Within the preserved VCR areas, there are well-defined large payshoot areas separated by barren or near barren tracts. The boundaries of these shoots correlate with suboutcrop zones of the gold-bearing reefs, although offsets, reflecting migration of gold and other heavy minerals, occur.

The VCR shows variation in pebble sizes and irregularity in thickness and conglomerate layers vary from single pebble lags to pebble-supported conglomerates, rarely exceeding 2,5 m in thickness. The clasts vary from pea-size to cobble-size and occasionally boulders up to 50 cm in diameter occur. Light-coloured vein quartz pebbles make up the bulk of the pebble content with subordinate dark quartz, chert and quartzite pebbles. The source of the quartz clasts is considered to be the quartz veins of late Witwatersrand age which are frequently seen to be truncated by the VCR in underground excavations. The dark appearance of the matrix is the result of fine volcanic material which has infiltrated into the conglomerate from above and which has been altered to green chlorite material. Sulphides are always present in the payable areas and are mainly pyrrhotite and pyrite. Buckshot pyrite occurs frequently in high grade areas and attains dimensions of up to 15 mm in diameter.

According to Krapez (1979), who undertook a sedimentological study of the VCR on East Driefontein Gold Mine, the auriferous VCR palaeo-placer consists of several complexly interrelated gravel facies. From interpretations based on underground observations and measurements of scalar properties recorded on photographs, a descriptive framework of gravel characteristics was evolved. Application of this framework to the sediments has resulted in the recognition of five gravel facies. Data derived from these descriptions were used to interpret the depositional process and environment of each facies.

Facies A gravels were formed by torrential flood or debris flow deposits on an alluvial fan and associated sands were formed as plane-beds in the upper flow-regime. Individual conglomerate beds are laterally persistent over hundreds of metres and interbedded with quartzites.

Facies B gravels were deposited by sheetfloods or turbulent streamfloods on the same alluvial fan as facies A. Interbedded quartzites and conglomerates are common and individual beds are persistent over hundreds of metres. The dominant source for facies A and B is considered by Krapez to be the metasedimentary units of the

Witwatersrand Supergroup and Archaean formations although the facies have significantly different clast assemblages.

Facies C gravels were formed by bedload traction processes in a fluvial environment. Four subenvironments have been identified, corresponding to three topographical levels on a braided alluvial plain:

(1) a deep (up to 21 m) incised channel of bare bedrock surfaces and lenticular coarse gravel lags;

(2) a flood plain of coarse gravel lags;

(3) a flood plain of coalesced, longitudinal gravel bars formed during flooding of higher topographic levels; and

(4) isolated islands of bare bedrock or remnant gravel lags.

Source rock terranes for facies C comprised hydrothermal quartz veins in a host of Archaean metamorphic and volcanic rocks.

Facies D gravels and sands formed in a tributary braided stream, consisting of solitary, longitudinal gravel bars and adjacent deep (up to 17 m), inter-bar channels. Thick gravels and thin sands were deposited on the bars, while thick sands and thin gravels formed in the channels. Sand deposition occurred only during low discharge as planebeds, migrating megaripples and accretionary sand wedges. Gravel was transported through the channels during very high discharge and deposited on the bars. The source comprised a mixed terrain of Witwatersrand Supergroup and Archaean metasedimentary rocks and Archaean metamorphics with hydrothermal quartz veins.

Facies E gravels formed as longitudinal channel-fills by the coalescense of a variety of transverse bars, within the confines of the deep, bedrock-walled channel of the braided alluvial plain. The bulk of the gravels were derived by the reworking of facies B and C, while minor amounts of sediment and coarse gold were derived from a primary source of mineralised Archaean basement rocks.

The palaeoenvironment consisted of an alluvial fan prograding from the east and a tributary stream flowing from the west on to an active, braided alluvial plain. The constriction of the alluvial plain was responsible for the incision of the main stream channel and during high discharge, the constriction of the main stream resulted in the overbank deposition of a large proportion of the coarse bedload as gravel bars. During rising floods of a later stage, remnant channel bottom gravels were reworked as gravel bars.

The Ventersdorp Contact Reef on Deelkraal marks the unconformity between lavas of the Klipriviersberg Group and conglomerates and quartzites of the Elsburg Formation. The conglomerate reef is divided into a Green VCR, which is economically exploitable for gold, and a Black VCR, which has a low gold content.

The Green VCR ranges in thickness from a contact, on which no conglomerate is developed, to 3 m of conglomerate reef. The reef has a slightly uneven base, with a well-developed massive basal gravel lying disconformably on 5 to 20 cm of black gritty Witwatersrand quartzite, interpreted by Mullins (1981) as being a pre-VCR weathered surface accumulation (Fig. 47). The character of the Green VCR varies laterally and zones of massive clast-supported conglomerate grade into zones of pebbly sand, lenticular beds of quartzite and thin pebble lags. The more sandy facies contain numerous scour surfaces and may exhibit planar- and trough-crossbedding.

The massive conglomerate zones are better mineralised and contain higher gold values than do the more sandy facies. Within the latter, mineralisation is concentrated along scour surfaces in thin pebble lag deposits and the concentration of gold appears to be controlled by the amount of reworking of the underlying Witwatersrand conglomerates. Sheet flooding on the palaeosurface reworked the sediments thereby winnowing out the lighter material and concentrating the gold and other heavy minerals on the unconformity surface.

The Black VCR, an oligomictic pebble-supported conglomerate, is significantly thicker than the Green VCR, with a mean thickness of 2,07 m and a range from 10 cm to 6,80 m. According to Mullins (1981) the low gold content of the Black VCR may be due to a combination of four factors :

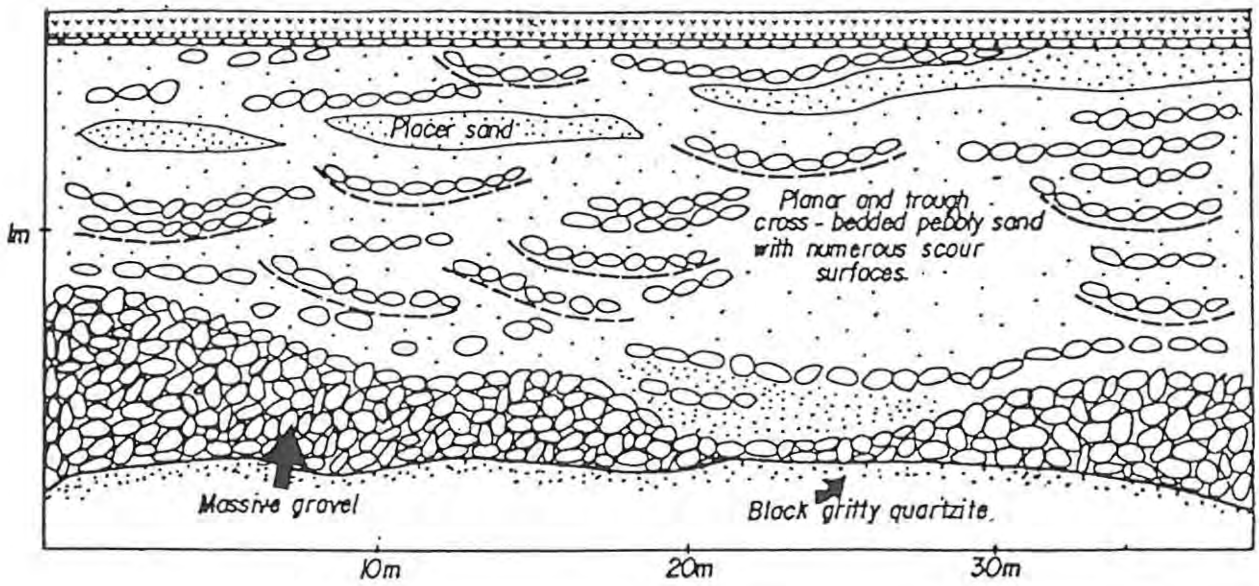


Fig. 47. Massive gravel (Green VCR) on slightly irregular disconformity surface. (From Mullins, 1981).

(1) no significant amounts of gold from the source area;
(2) no reworking of gold from Elsburg sediments;
(3) the relative immaturity of the Black VCR; and
(4) metasomatic dispersion of the gold.

The VCR on Kloof Gold Mine is closely related to Krapez's facies C i.e. it is a clast-supported oligomictic conglomerate whose pebbles consist mostly of vein quartz (Nel, 1982). A fairly uniform sheet of Facies C gravels occurs in the northern portion of the mine, whereas single clast veneers and/or bedrock surfaces predominate in the southern portion.

The VCR at Western Deep Levels has been described by Knowles (1966). The clast assemblage is dominated by vein quartz and the physical characteristics are similar to facies C of East Driefontein except for slightly coarser grain size and better clast sorting. The suggested environmental interpretation was an alluvial fan prograding from a fault scarp in the northeast into an inland sea. Knowles suggested that local folding was responsible for the irregularities of the bedrock surface. Folding influenced depositional style with gravels forming in the structural depressions and lag gravels on the structural culminations.

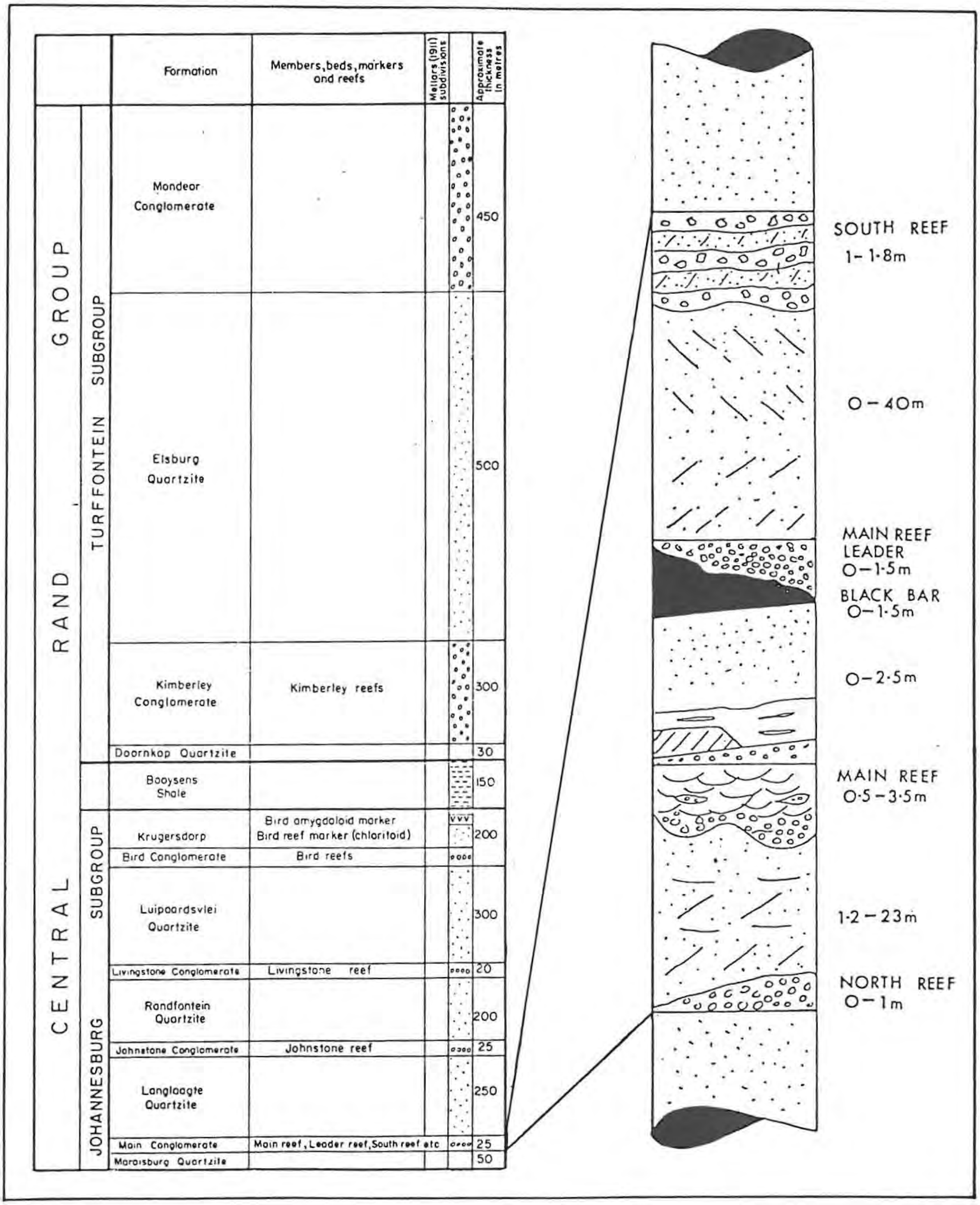
The Main Reef Leader (MRL) - Central Rand

The Main Reef Leader is a thin (0 m - 1,5 m) conglomerate horizon occurring about 65 m above the base of the Central Rand Group (Fig. 48). It occurs in a middle of a sedimentary "package" referred to as the Main Conglomerate Formation which also includes the North Reef, Main Reef and South Reef. The conglomerates are separated mostly by crossbedded quartzites which in places contain scattered pebbles. The one exception to this rule is the "Black Bar", a dark argillaceous horizon which occurs in the immediate footwall of the MRL except where this reef has scoured down through the muddy layer to rest directly on the underlying quartzites. The Black Bar varies from being a fine, black "varved" shale to a dark greyish-green silty/muddy quartzite which may contain scattered pebbles, and is usually very pyritic.

One striking feature of this whole sedimentary package is the amount of pyrite that it contains. This is true not only of the matrix of the reef horizons but also of the intervening quartzites in which the foresets of crossbeds are delineated by pyrite stringers. Indeed the Banded Pyritic Quartzites, lying between the Main Reef and MRL and in erosion channels cutting through the Main Reef (Pretorius, 1969), have been mined for gold in the east-central part of the Central Rand goldfield.

The MRL is an areally extensive sheet of moderately sorted conglomerate present over most of the Central Rand. It can be traced from ERPM in the east, where it suboutcrops against the overlying South Reef, and westwards as far as Randfontein Estates. However, at its western extremity, as shown by Jones (1936), it is reduced to a mere parting plane on which rest some heavy minerals and scattered pebbles. The reef reaches its thickest development in the central part of the goldfield, specifically on Crown Mines, Robinson Deep and City Deep. From here it thins to the east and west and to a lesser extent to the south.

The MRL is truncated by the South Reef on ERPM and the



		Formation	Members, beds, markers and reefs	Mellors (1911) subdivisions	Approximate thickness in metres
CENTRAL RAND GROUP	TURFFONTEIN SUBGROUP	Mondeor Conglomerate			450
		Elsburg Quartzite			500
		Kimberley Conglomerate	Kimberley reefs		300
		Doornkop Quartzite			30
		Booysens Shale			150
	JOHANNESBURG SUBGROUP	Krugersdorp	Bird amygdaloid marker Bird reef marker (chloritoid)		200
		Bird Conglomerate	Bird reefs		
		Luipaardsvlei Quartzite			300
		Livingstone Conglomerate	Livingstone reef		20
		Randfontein Quartzite			200
		Johnstone Conglomerate	Johnstone reef		25
		Langlaagte Quartzite			250
		Main Conglomerate	Main reef, Leader reef, South reef etc		25
		Maraisburg Quartzite			50

Fig. 48. Geological column of Central Rand Group showing details of Main Conglomerate Formation. (From SACS, 1980 and Rhodes Group, 1981).

unconformity on which the "composite" reef of the East Rand lies is related to the base of the South Reef. The South Reef would then assume significance as a major, if not the major producer of the Central/East Rand. According to Mason (pers. comm., 1982) the Main Reef Leader of the Central Rand is an entity that defines the Central Rand goldfield.

The MRL characteristically contains three main facies; scour surfaces, a thin oligomictic conglomerate and a quartzite facies :

(1) Scour surfaces : The most widespread occurrence of this facies is the basal scour which occurs everywhere at the bottom of the reef, but numerous internal scour surfaces are also present in areas of thicker reef.

(2) Oligomictic conglomerate : In many places this makes up the entire thickness of the reef but in areas of thicker reef it usually alternates with the quartzite facies. The matrix of the conglomerate is a dark grey to greenish quartzite and it contains an inordinate amount of pyrite. The pebbles consist mostly of vein quartz, quartzite and chert and are generally well-rounded.

(3) Quartzite : This facies occurs mostly in multi-storied bodies alternating with the conglomeratic facies in channel deposits but also as isolated lenses in areas of relatively thin reef.

The nature of the footwall contact of the MRL and the beds immediately below this contact is important in understanding the MRL itself (Mason, pers. comm., 1982). It has been established that the footwall contact of the MRL is discordant with respect to the footwall beds and Mellor (1915) has described folding in the footwall beds which predate the MRL. A major period of erosion followed this folding and the truncation of the folded beds was accompanied by the incision of erosion channels into the palaeosurface. Further planation and uplift produced a palaeosurface of very low relief which was etched with grooves/channels orientated northwest to southeast. The channels in the MRL are up to 3 m deep but average around 50 cm; they are wide and shallow with width/depth ratios ranging from 40 to over 500.

During the initial stages of sedimentation a high rate of flow was concentrated in the channels and gold particles being small in size were probably transported in suspension. Although the conditions were not suitable for concentration of gold the presence of open-framework gravels could have acted as traps for the particles. The resulting sediments in the channels generally have low gold content, but erratic high values do also occur (Nami, 1981). The placer sediments gradually filled and eventually overflowed the channels to produce a sheet of sediment only a few cm thick; however, in a few places the elevation of these interchannel areas was sufficiently high so that they protruded above the sheet of sediment. Gold was trapped by algal mats in interchannel areas and further enrichment also occurred by the winnowing action of water flowing over the gravels.

The second mineralising event involved sheet floods which washed successive layers of gravels over the subdued palaeosurface. The first pulse of gravel, containing preconcentrated heavy minerals, flooded across the erosion surface. Most of the gold within the early pulses of gravel was concentrated as a lag deposit and trapped by oligomictic conglomerates.

Mason (pers. comm., 1982) regards the preconcentration of heavy minerals in the sediment that gave rise to the sheet-like conglomerate facies as an important step prior to deposition. The preconcentration would be related to an advancing orogenic front to the north of the Witwatersrand basin. A combination of a highly unstable environment with folding of pre-existing sediments, and crumpling of partly consolidated beds, particularly in the upper fan areas, would have created favourable conditions for concentrating heavy minerals.

These placers can therefore be interpreted as a result of large scale tectonic upheavals resulting in the deposition of large volumes of preconcentrated heavy minerals over an extensive palaeosurface.

On Crown Mines, Robinson Deep and City Deep the interchannel areas situated within the major channel complexes appear to be consistently better mineralised than the areas between the channel complexes. These relationships may be explained in terms of hydraulic energy levels and grain size of the gold particles. Minter (1976), in discussing the gold distribution in the Vaal Reef at Stilfontein, said that the gold content essentially expressed a hydraulic energy-level fabric, controlled regionally by the geographic situation on the palaeosurface and locally by detailed shapes of the footwall surface, i.e. the gold is essentially a basal concentrate lying on the unconformity and is not related to any scalar parameters of the reef except the shape of the unconformity. A similar situation appears to be applicable to the Main Reef Leader where zones of higher than average gold content follow the footwall morphology until that morphology changes i.e. the hydraulic energy-level controlled by the footwall shape has changed. Thus the trends follow ridges or channel sides and indicate that the gold was largely hydraulically controlled as detrital particles. Nami (1981) in discussing gold distribution within the Carbon Leader Reef, suggested that the gold is very fine-grained and was thus carried in suspension rather than part of the bedload. Thus the velocity of flow and water turbulence in the channels would have been too great to permit the particles to settle out of suspension; this could only have occurred in quiet, low energy areas, namely the channel edges and inter-channel areas. This situation appears to be applicable to the MRL where gold favours ridges and channel flanks rather than the channels.

The footwall beds of the Main Reef Leader are characterised by a variety of lithotypes and structural attitudes. The Main Reef Leader rests on quartzites, pyritic quartzites, quartzitic grits, scattered-pebble conglomerates, Black Bar and in places it lies directly on the Main Reef conglomerate. The attitude of the Main Reef Leader varies from para-conformable to markedly discordant. One of the best indications of the discordance is the distribution of the Black Bar which is very patchy throughout the Central Rand and on Robinson Deep and City Deep the Black Bar is frequently truncated by the Main Reef Leader on a significant angular unconformity.

There is no doubt that the footwall contact of the Main Reef Leader represents a major break of deposition of the upper Witwatersrand sequence. The tectonic activity responsible for the folding of the footwall beds and subsequent uplift which resulted in their erosion, appears to have been the prelude to one of the most significant mineralising events in the history of the Witwatersrand basin (Mason, pers. comm., 1982).

The South Reef Placer

The South Reef ("Main Reef Leader"), which has made by far the greatest contribution to gold production in the East Rand goldfield (Antrobus and Whiteside, 1964), rests on an angular unconformity truncating folded footwall strata. Reinecke (1930) draws attention to the angular unconformity at the base of the "Main Reef Leader" and to the folding and erosion of footwall shale prior to the deposition of this placer. He states that "in the Geduld and Sub-Nigel mines there are many exposures that show a pronounced angular unconformity between the "Main Reef Leader" and the underlying shale footwall". The discordance between the placer and its footwall beds is illustrated in Fig. 49, and angular discordance of up to 60° has often been observed. According to Cousins (1965) the South Reef affords a striking example of regional transgression as it cuts downwards in the mines from Germiston to

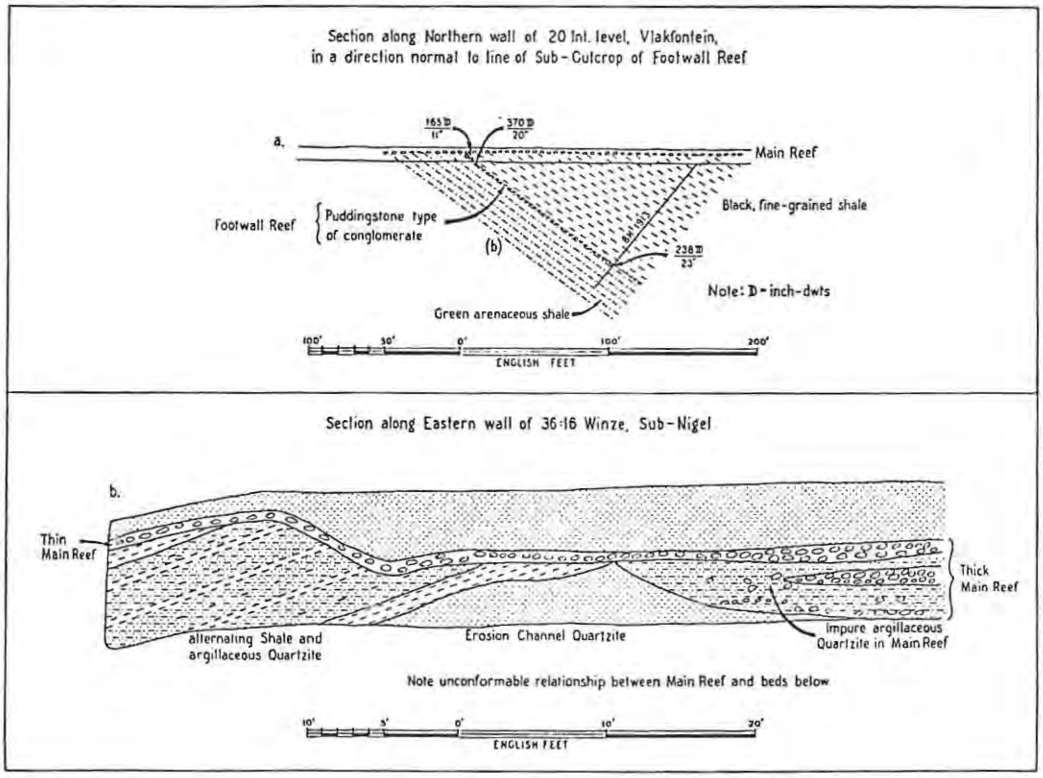


Fig. 49. Angular discordance between the South Reef and footwall beds, Vlakfontein and Sub-Nigel mines. (From de Jager, 1964). Note: it has now been established that the Main Reef is the South Reef.

Boksburg, eliminating in the process all the underlying reefs, until it lies on beds well into the footwall of the North Reef. This transgression continues eastwards until at Droogefontein, at the eastern suboutcrop of the reef, the South Reef lies on beds near the base of the Upper Jeppestown shale, 290 m of strata having been eliminated between Germiston and the eastern suboutcrop (Fig. 50).

The South Reef, a zone of small-pebble conglomerates interbedded with crossbedded quartzite, attains a maximum thickness of 6 m in the northwestern part of the basin. It thins regularly in a southeastern direction to 30 cm or less, becoming sporadic in occurrence and payability (Antrobus, 1964). In contrast to the Kimberley Reef, the uranium content is low and it has never served as an ore for this metal (Antrobus and Whiteside, 1964).

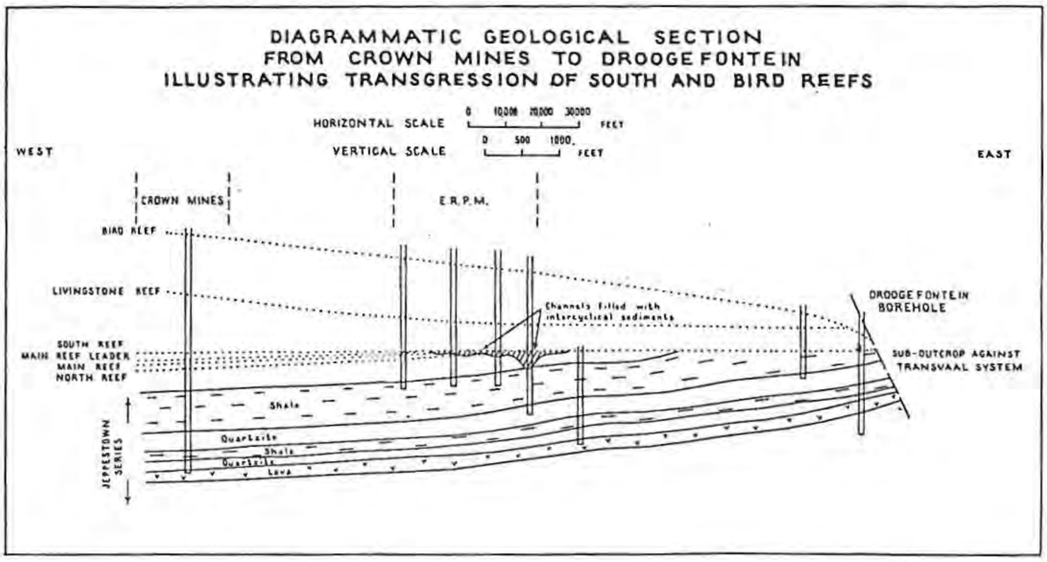


Fig. 50. Diagrammatic geological section from Crown Mines to Droogefontein illustrating transgression of South and Bird Reefs. (From Cousins, 1965).

The trend of the "Main Reef Leader" payshoots was established by Jones (1936) who plotted the stoped areas of "Main Reef Leader" (Fig. 51). The dominant trend is northwest to southeast and thus, combined with the fact that the thickest and coarsest conglomerates are present in the northwest, points strongly to the conclusion that the source of the sediments and gold lay in that direction (Antrobus and Whiteside, 1964).

Pretorius (1974) shows numerous channel forms (Fig. 17) which assumed a braided pattern radiating out from the apex of the East Rand fan. These channels, which contain basal concentrates of gold and heavy minerals, constitute the payshoots which are preferentially mined and in many instances these correspond closely to payshoots established by Reinecke (1927). The interchannel divides have thinner fluvial deposits than the channel scours and may consist of thin pebble veneers, generally poorly mineralised with gold.

The preferentially mineralised channel sediments described above point strongly to the intimate relationship between sedimentary processes and the mineralisation of the conglomerate horizons. The gold and heavy minerals were concentrated to varying degrees in different localities, in response to variations in the hydraulic regime that prevailed on the truncation surface during the deposition of the fluvial sediments.

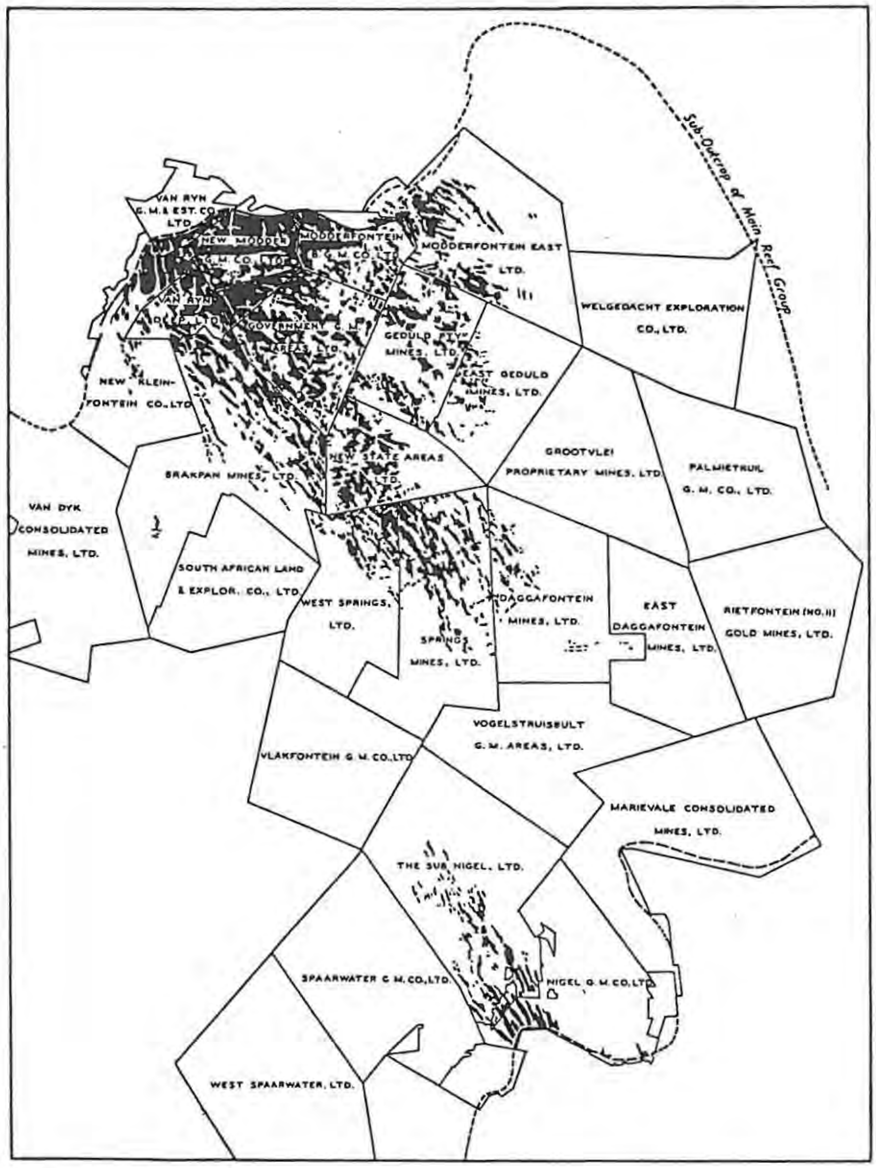


Fig. 51. Stoped areas of "Main Reef Leader" which define payshoot trends. (From Jones, 1936)

The U.K.9 Zone

The base of the U.K.9A Reef of the East Rand goldfield shows a well-marked transgression and the truncation surface on which the placer lies cuts stratigraphically lower eastwards in the same fashion as the South Reef (de Jager, 1964). The angular unconformity at the base of the reef and a truncated pre-U.K.9A fold is illustrated in Fig. 52a. Channels within the M.K.1 (Fig. 52b) were probably cut during the break in sedimentation prior to the deposition of the placer.

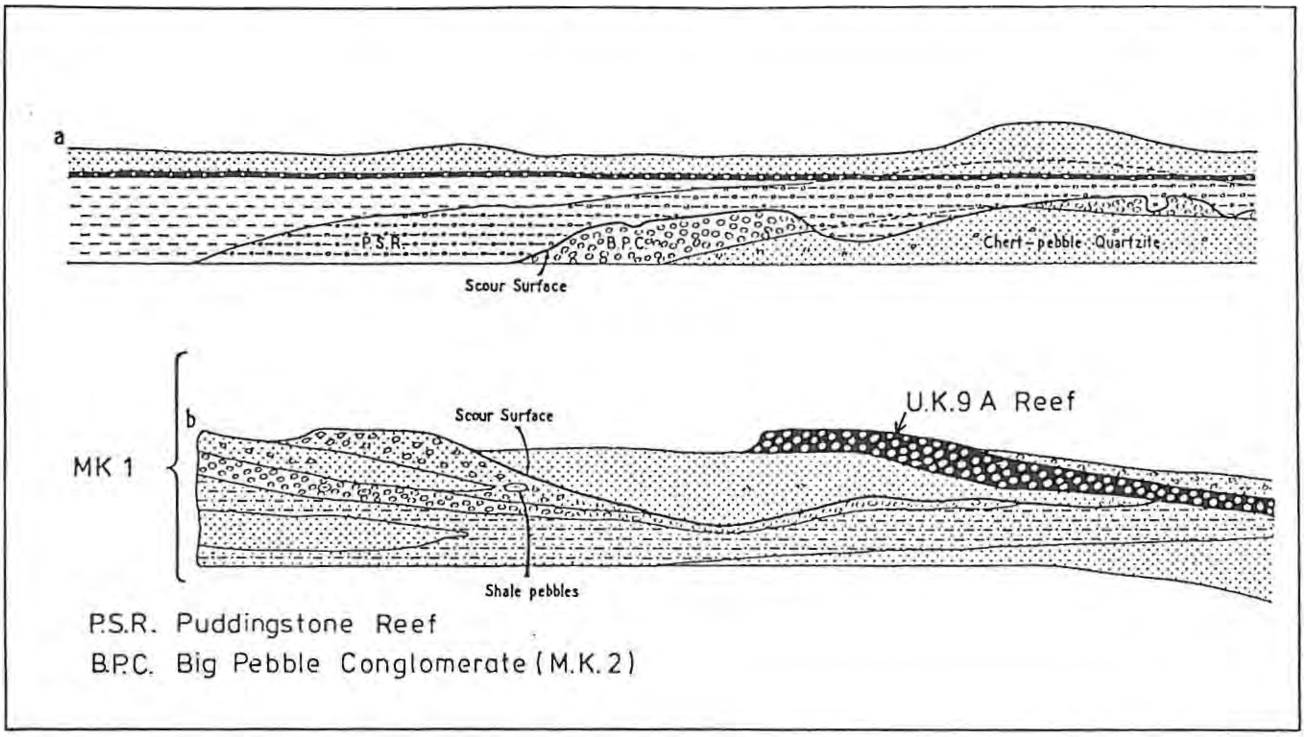


Fig. 52. U.K.9A workings, Vogelstruisbult mine, showing angular unconformity between the U.K.9A Reef and its footwall. (After de Jager, 1964).

According to Antrobus and Whiteside (1964) the payshoots of the U.K.9A Reef are much more irregular than those of the "Main Reef Leader", but otherwise the distribution of the auriferous reefs exhibits many of the features of the "Main Reef Leader". Armstrong (1968) undertook a sedimentological investigation of the U.K.9A Reef with the aim of establishing payshoot trends. The area studied comprises East Daggafontein Mines Limited, Daggafontein Mines Limited, and the north-eastern portion of Springs Mines Limited, and occupies the east-central portion of the East Rand basin. An analysis of crossbedding directions within the U.K.9 zone indicated that the direction of transport (northwest to southeast) and attitude of the depositional surface remained constant during the deposition of the U.K.9B Reefs, the U.K.9A Reef, and the U.K.9A Marker.

On East Daggafontein Mine, the U.K.9A Reef contains significant quantities of chert pebbles where it overlies or is in close proximity to, the suboutcropping footwall beds containing chert pebbles. Armstrong suggests that this points to the origin of the U.K.9A Reef as being derived from the footwall beds, a conclusion also drawn by previous investigators.

An investigation of the underground sampling records on Daggafontein Mine revealed that certain of the U.K.9A Reef footwall conglomerates, particularly the U.K.9B Reef, do contain gold. As these suboutcropping footwall beds show a decrease in thickness and grain size towards the southeast, it is considered that they were derived from a source area situated to the northwest of the goldfield. Armstrong is of the opinion that the U.K.9A Reef gold was derived by erosion and reworking of the footwall reefs, with the U.K.9B Reefs being the chief source of the gold and the coarse fluvial sediments.

Subsequent to the deposition of the M.K.1 sediments over the palaeosurface, relatively rapid uplift of the source area, situated to the northwest of the present East Rand basin, took place. This caused substantial erosion which initiated the truncation of folded structures and the exposure of the Kimberley Shale, M.K.3 and M.K.2 sediments, in addition to the already exposed sediments of the M.K.1 zone. Further uplift and erosion prepared the U.K.9A palaeosurface as a major erosion surface into which braided channels were etched. Then, in the opinion of the writer, a pulse of gold-bearing gravel, preconcentrated with heavy minerals, flooded across the erosion surface and filled and eventually overflowed the channels to produce a veneer of lag gravels over palaeoridges. Further reworking of the footwall beds, specifically the U.K.9B Reefs, and enrichment by winnowing as water flowed over the gravel, produced lag deposits of gold which were concentrated in the braided channels. Thus payshoots, trending generally parallel to the dip of the depositional surface, were produced. Local palaeotopographic features produced placer trends at variance to the general dip of the unconformity surface.

The Kimberley Reef Placer

The Kimberley Reef, comprising a composite distal facies sequence of fluvial channel sediments, covers an area of some 750 km^2 in the Evander basin. This low grade placer attains a maximum thickness of 3,2 m in the southeast of the basin and thins rapidly in a westerly to northwesterly direction.

The reef rests on a well-defined angular unconformity surface which is responsible for a northeast to southwest cutdown of approximately 200 m of footwall sediments over a distance of 20 000 m (Tweedie, 1978). The palaeoslope, formed as a result of tectonic uplift to the southwest of the basin, is regular and essentially planar, although on a local scale relief is high with a maximum amplitude of 3,2 m. Scours and channels of varying orders of magnitude show braided patterns that represent the final etching on the palaeosurface of truncation (Fig. 53). The mean dispersion direction of these channel systems is from southwest to northeast.

The placer sediment filled and eventually overflowed the channels, the interchannel divides having thinner fluvial deposits than the channel scours. The internal geometry of the channel sediments define longitudinal gravel bars and sand bars with pebbly veneers (Tweedie, 1978). Multi-channelling is well-defined in areas of thicker reef, individual channel scours being marked by sericitic mud drapes up to 30 mm thick.

The Kimberley Reef placer is an oligomictic mature conglomerate consisting mainly of vein quartz and chert set in a matrix of essentially quartz and minor proportions of chert, chlorite and sericite. Tweedie (1981) has distinguished the following sub-facies illustrated in Fig. 54:

(1) a thin, conglomerate-filled fluvial scour about 5 cm deep;
(2) thicker clast-supported conglomerate with crossbedded sand lenses;
(3) sand-filled channel with occasional scattered pebbles especially along the upper contact, and
(4) basal lag-gravel lying on a well-defined scour surface, overlain by crossbedded sands.

The correlation between gold-value trends and the axes of the inferred Kimberley Reef channels is good and there is a degree of parallelism between channels, as shown in Fig. 53, and value-trends (Fig. 55). Remnant basal lag gravels, deposited on unconformity surfaces, show the highest gold concentrations. Individual footwall types do not appear to influence either gold distribution or the nature and density of the channels (Tweedie, 1981).

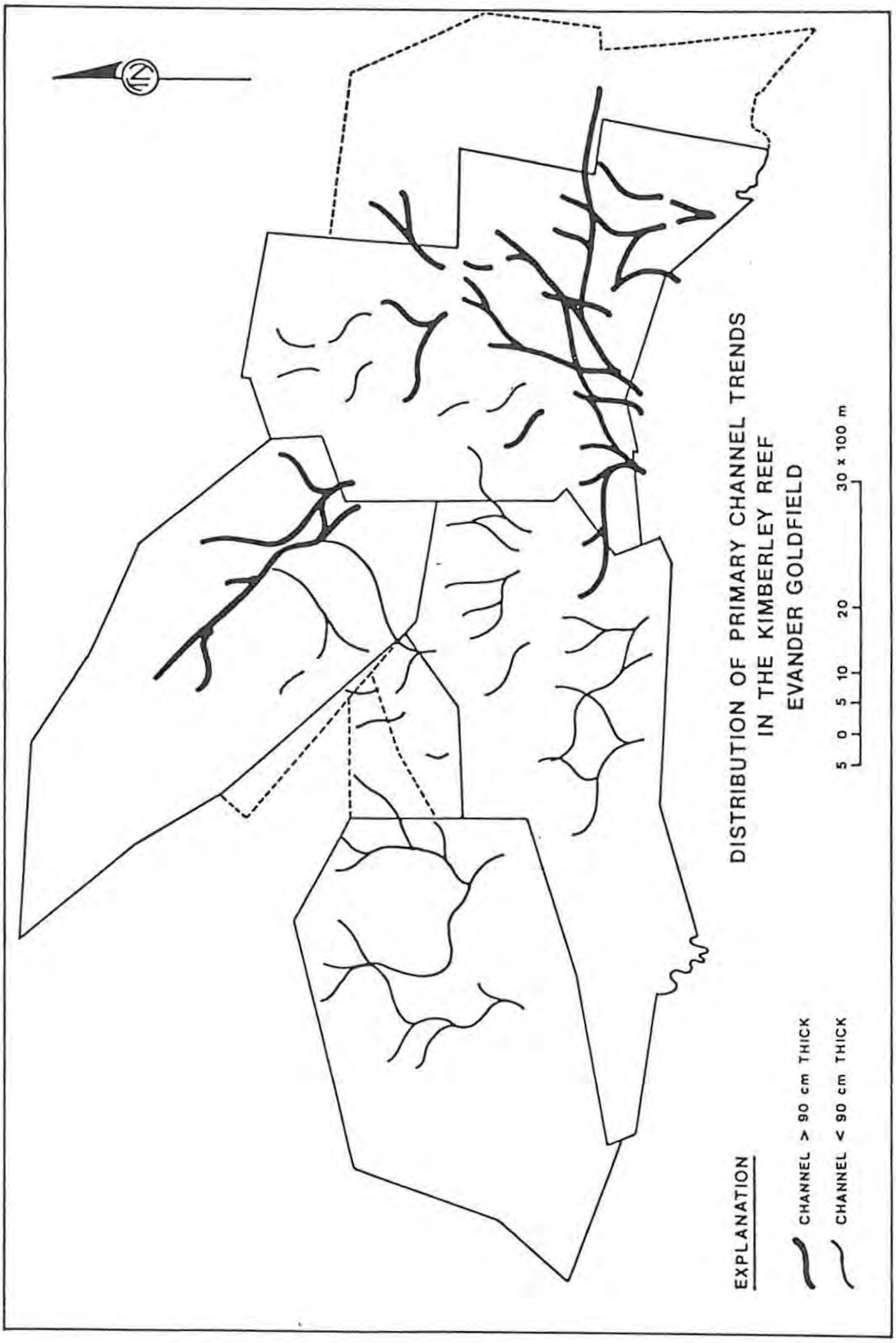


Fig. 53. Distribution of primary channel trends in the Kimberley Reef, Evander goldfield. (From Tweedie, 1981).

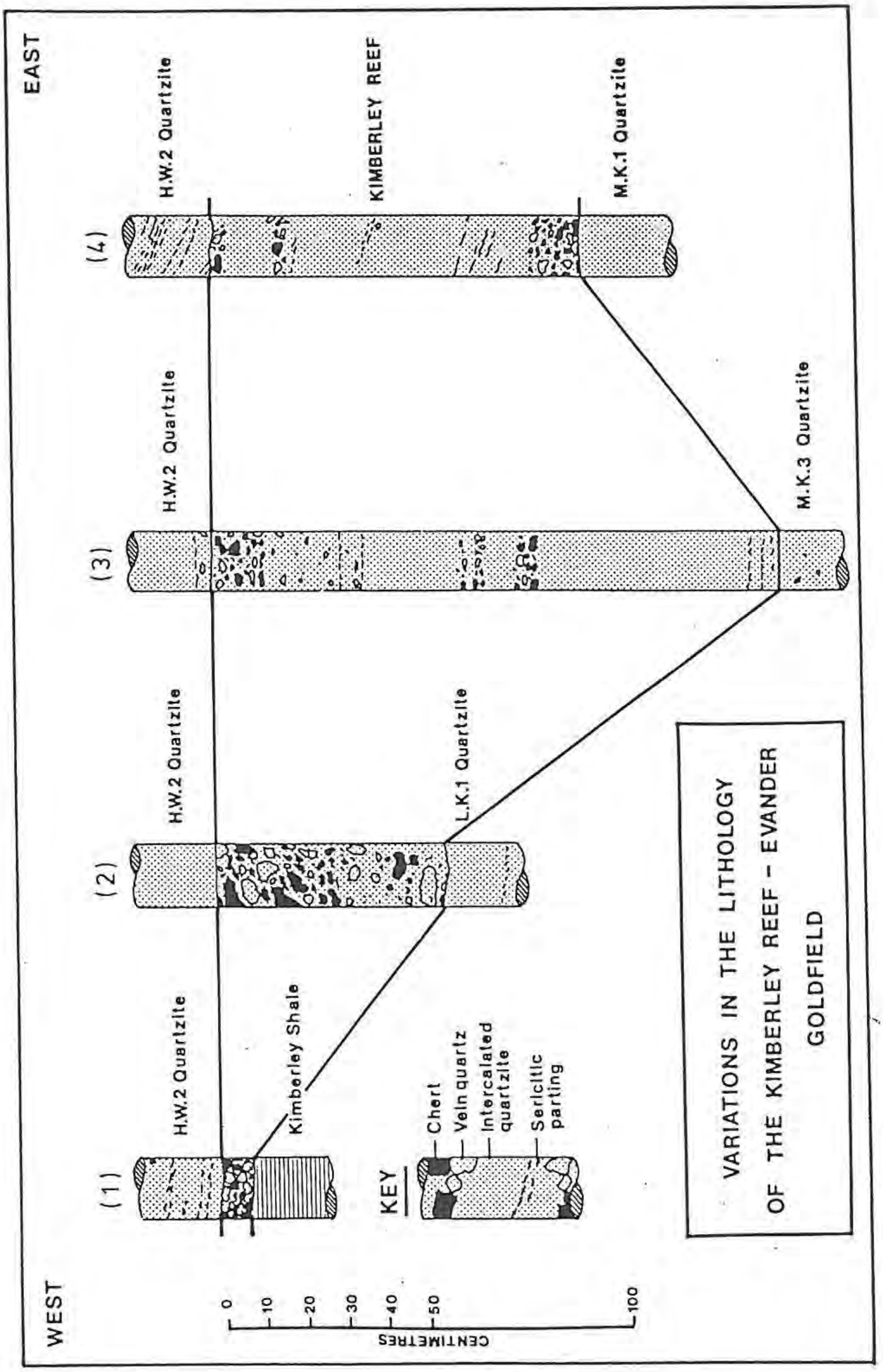


Fig. 54. Variation in the lithology of the Kimberley Reef in Evander goldfield. (From Tweedie, 1981).

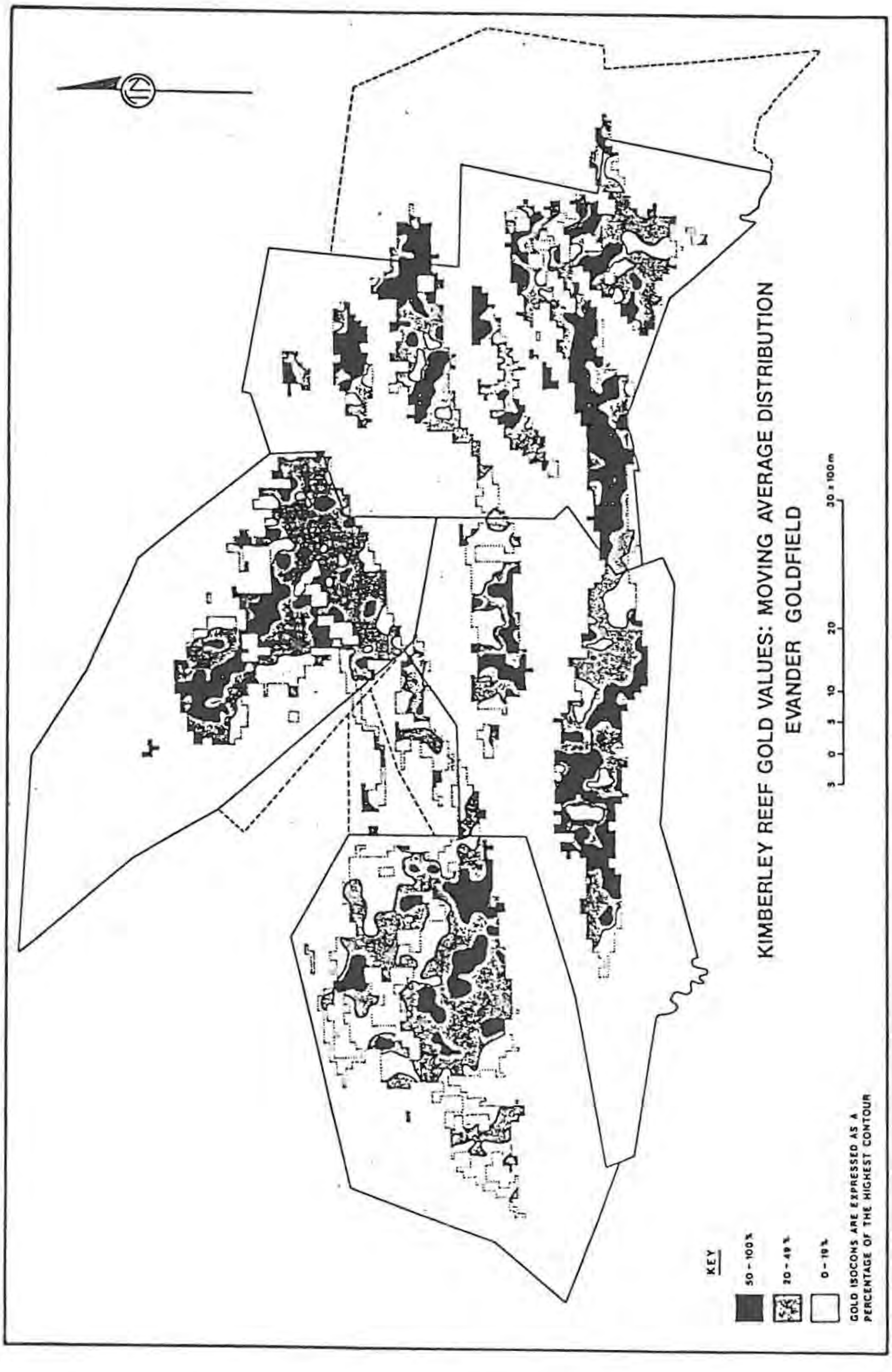


Fig. 55. Kimberley Reef gold values : moving average distribution, Evander goldfield. (From Tweedie, 1981).

Plant Life

During the Proterozoic, plant forms were primitive and the only fossil remains preserved occur as carbonaceous material in the form of granules and thin seams that are rarely up to 5 cm thick. Examination of the material using scanning electron microscope techniques (Hallbauer, 1975) indicated an algal plant form.

The carbonaceous material occurs on bottom scour surfaces; on scour surfaces within the placer unit; sometimes on a thin yellow mud veneer; on the scoured base of trough-crossbedded sets; on the toes of foresets; as detrital granular accumulations occurring on the stoss side of shallow ripples; and on reactivation surfaces in transverse placer sandbars (Minter, 1978). Periods during which little sediment accumulated probably favoured growth and in special circumstances of location resulted in thick carbonaceous seams. Pretorius (1966), was the first to propose that the carbonaceous material was the product of algal mats that existed in quiet times between cycles of sedimentation when the conglomerates were laid down.

The frequent association of gold with carbon is well known, and has led to the common belief that the presence of "carbon" in a reef is a positive proof of its high auriferous content. In many cases this is true, but frequently carbonaceous material has been found to be completely barren (Hallbauer, 1975). The often claimed association of gold and "carbon" is not fully supported by Minter (1978) who found that although high gold and uranium concentrations are associated with the carbonaceous seams, the areal distribution of gold and uranium concentration patterns do not coincide with the abundance of carbonaceous material. Their association appears to be indirect and is probably related to the original spatial coincidence of algal mats and detrital accumulations on surfaces of concentration that were not rapidly buried.

Sharpe (1949) specifies the occurrence of "carbon" in the Central Rand Group beds as follows:

(1) at, or close to, the peneplaned depositional floor of the Main Reef Group of sediments, i.e. Main Reef and Main Reef Leader, Hangingwall Leader;

(2) at, or close to, the peneplaned depositional floor of the U.K.9A Reef;

(3) at, or near, the peneplaned depositional floor of the Transvaal Supergroup - Black Reef;

(4) in channel and lagoonal deposits; and

(5) in less conspicuous amounts in locally payable conglomerates that exist as upper members of minor conglomerates and which may be overlain by quartzitic bars.

Sharpe also suggested that the "carbon" might be the remains of some of the earliest forms of life.

De Kock (1964) states that all the new reefs of any economic importance that have been discovered and are presently exploited have had one feature in common, namely, the intimate association of gold and "carbon". He finds it to be true of the Carbon Leader and the Ventersdorp Contact Reef of the Carletonville goldfield, of the Kimberley Reef of the East Rand, of the Vaal Reef of Klerksdorp, and of the Basal Reef of the Welkom goldfield as well as of the older reefs, the Main Reef Group, and the Bird Reefs.

Carbonaceous material occurs generally in patches on the bottom scour surface of the Steyn and Basal placers and a thick carbonaceous seam at the base of the Steyn placer has entrapped sand grains, pebbles and placer mineral concentrates. In distal locations, the "B" placer contains well-developed seams of "carbon". Abundant visible gold, which is associated with carbonaceous seams in these distal deposits, may have originally been trapped in the algal mats. Seams or granules of carbonaceous material are always present at the base of the Vaal placer, directly on the truncated palaeosurface, and also on other sedimentary surfaces as in the Steyn placer. The carbonaceous material obviously accumulated during or after the major truncation with which the Vaal placer was penecontemporaneous. Black carbonaceous material in seams up to 2 cm thick has been observed in the Ventersdorp Contact Reef in the Klerksdorp goldfield.

According to Button and Tyler (1981) processes on the unconformity may well have played a role in the development of the organic communities. Inasmuch as "carbon" has obviously assisted in fixing both gold and uranium carried by formation waters, it is important to attempt to understand the control by the unconformity on the development of the algal-bacterial colonies.

Synthesis

The synthesis of unconformity-related auriferous/uraniferous placers presented here leans heavily on the models developed by Pretorius (1974, 1981) and Minter (1976, 1978).

A fluvial fan was built up in a series of pulses of sedimentation, which started with progradation during regression, went through aggradation during transgression, and ended with degradation during stillstand. These three stages constituted a single cycle of sedimentation. A new cycle was initiated through tectonic adjustments which led to the formation of numerous unconformities on which winnowing processes concentrated heavy minerals. Cyclic sedimentation, tectonically controlled, is characteristic of the assemblages in which mineralised placers occur, and such cycles resulted in fining-upward sequences, between unconformities.

Uplift and tilting of the palaeoslopes resulted in the increased competency of the streams and permitted erosion and truncation of the footwall lithologies. The major stream systems, which flowed more or less down the downwarp axis, scoured into the palaeosurface to produce channel forms that represent the final drainage etch of the truncation surface. In proximal areas the shallow, low sinuosity channels are up to 4 m deep, but average between 50 and 100 cm further down the palaeoslope. Their channel width/depth indices are between 200 and 1 000. Palaeocurrent measurements obtained from trough-crossbed foresets substantiate a braided pattern of channel flow and indicate unidirectional fluvial transport down palaeoslopes, which are indicated by isopachs of the Central Rand Group or by truncation-surface isopachs measured from underlying strata.

The higher energy level caused progradation and the first pulse of gravel flooded across the erosion surface with pre-concentrated heavy minerals which occupied and eventually overflowed the channels to produce thin sheets of sediment. In some instances, the placers are confined to separate channels that are interconnected in a braided pattern, but generally the placers being mined are thin irregular sheets comprising multiple layers of braided channel sediments. Most of the gold came in with the early pulses and was concentrated as a lag deposit, and further enriched as water flowed over the gravel. The process of channel scour and filling represents the first and main mineralisation event, and the configuration of the erosional etches dictated to a large extent the lateral continuity and payshoot trends of the auriferous/uraniferous placers.

As the energy-levels dropped, transgression took place, with the deposition of finer-grained material, until a state of equilibrium was reached and deposition came to a standstill. Reworking took place under the transgressive conditions, when the depository-waters advanced over the fan and winnowing was effected by wave-action. This end-of-cycle winnowing produced a greater concentration of residual heavy minerals on the erosion surfaces and trapping agencies such as small-pebble lag accumulations and algal mats helped preserve the mineralisation. The unconformity represents a break in sedimentation and is extremely important to allow settling, concentration and winnowing of heavy minerals. Dunes migrating on planes of unconformities often resulted in exceptional concentrations of heavy minerals in the toes of foresets. Reworking of units truncated by the unconformities provided additional gold, uranium and heavy minerals to unconformity surfaces. Continued tectonic adjustments culminated in the prograding sedimentation of the next cycle, thereby producing the unconformable relationships between cycles.

In the Witwatersrand fluvial fans, the optimum sites for higher-grade mineralisation in the conglomerates were situated in the midfan sector, where hydrodynamic conditions were favourable to the settling of the small-sized gold and uraninite particles. Mineralisation occurs not only within the matrices of the conglomerates, but also as residual lag-accumulations on winnowed surfaces, resulting from the reworking of sands in which the heavy minerals were transported into the basin. What is needed is a structure i.e. planar unconformity whereby heavy minerals (including gold), can concentrate on toes of foresets of migrating dunes; such surfaces are often entirely devoid of pebbles. In the lower-energy fan-base facies, gold and uraninite are frequently associated with carbonaceous matter which was derived from algal mats that acted as traps for very fine particles of heavy minerals. Lithologies other than rudites therefore contain economically exploitable amounts of gold and uranium.

The coarse-grained sediment facies observed in the placers comprise: crudely bedded conglomerate forming sheets, longitudinal bars and filling depressions; trough-crossbedded conglomerates in the form of channels; and rare tabular sets of planar-crossbedded conglomerates and pebbly quartzites, representing transverse bars. Conglomerate-filled depressions, lags and bars are pebble-supported and planar-crossbedded units are usually matrix-supported.

The sandy facies include: trough-crossbedded quartzite; horizontally bedded quartzite, both coarse- and fine-grained; and rare solitary sets of planar-crossbedded quartzite. A very fine-grained facies is represented by shaly mud drapes and clasts.

The vertical sequence of these placer sediment facies always begins with a scour surface and is generally followed by a pebble lag which grades normally into trough-crossbedded quartzites. Proximal locations may be distinguished from distal locations by means of: the size of clasts and heavy minerals; changes in the vertical sequence; and by mineral ratio changes.

The typical auriferous and uraniferous conglomerate is oligomictic (vein quartz and chert pebbles) and clast-supported, with pebbles generally well-rounded and well-packed, but not necessarily well-sorted. The matrices of the conglomerates, which consist essentially of quartz, sericite, chlorite and pyrite, are cleaner than the enveloping arenites and show the effects of reworking and winnowing of light and fine material. Pyrite is the most abundant detrital heavy mineral and gold and uraninite are economically the most important. The uranium mineralisation reflects the presence of uraninite and brannerite and concentration of gold and uranium is often at its optimum on unconformities.

Concentrations of heavy minerals are spatially linked to primary sedimentary structures within the placers, particularly with lag accumulations on scour surfaces. These minerals are generally hydraulically equivalent to the sand-sized fraction of the placers and are found concentrated on the toes of the foresets and on the basal scour surfaces of sets. Crossbedding allowing gravity separation at the edge of dunes is essential in identifying potentially important conglomerates. Sand cascading over the dunes faces resulted in the gravity separation and concentration of heavy minerals on foresets of crossbeds. Mineralisation is usually of a higher grade where trough, rather than planar, crossbedding is present in the conglomerate and the adjacent quartzose sediments. Therefore the flow-regime producing trough-crossbedding is considered to be an important element in placer mineral concentration. Abundance ratios of placer minerals appear to change from proximal to distal environments depending on the relative particle size originally supplied from each specific provenance area. The most useful indicator of a proximal or distal environment is the ratio between uranium and gold which becomes progressively larger down many placer palaeoslopes.

ECONOMIC IMPLICATIONS

Exploration

In summing up the course on "Exploration in the Witwatersrand Basin" (Rhodes University, 15-17 March 1982), Pretorius outlined three phases of exploration:

Phase 1

(1) Identify regions with imprints of stretch and piston tectonics.
(2) Employ gravity to identify basement highs and lows.
(3) Employ magnetics to refine configuration of basement.
(4) Establish extent and geometry of sedimentary-volcanic basins.

Phase 2

(5) If basins asymmetrical, identify the short side.
(6) Identify basement domes on margins within short sides.
(7) Establish possible presence of fluvial fans between domes.
(8) Select fans on palaeoslopes downside of axes of elevator controlling domes.

Phase 3

(9) Ascertain degree of completeness of stratigraphical succession.
(10) Identify pivotal lithologies in complete stratigraphical successions.
(11) Establish proximal, intermediate and distal facies in succession above pivotal lithologies.
(12) Establish possible presence of domes and horsts in intermediate and distal facies in upper part of stratigraphy.
(13) Select target areas on palaeoslopes downside of domes and horsts.

During the logging of exploration boreholes careful attention should be paid to the fining-upward sequences of the cycles of sedimentation. The planes of inter-cycle unconformity must be identified as they are of considerable economic significance. It should be appreciated that significant amounts of gold may be concentrated on planar unconformities without pebbles necessarily being present. Sedimentological structures and bedforms, favourable for heavy mineral concentration, should be considered as these factors will determine the confidence limits of borehole values.

The following auriferous/uraniferous placer-types, which are the exploration targets in the Witwatersrand basin, are shown in schematic form in Fig. 56 (Pretorius, pers. comm., 1982).

Type 1	:	Channel-fill placers
Type 2	:	Bar gravel placers
Type 3	:	Pyritic crossbedded quartzites
Type 4	:	Transgressive conglomerates
Type 5	:	Algal mat placers

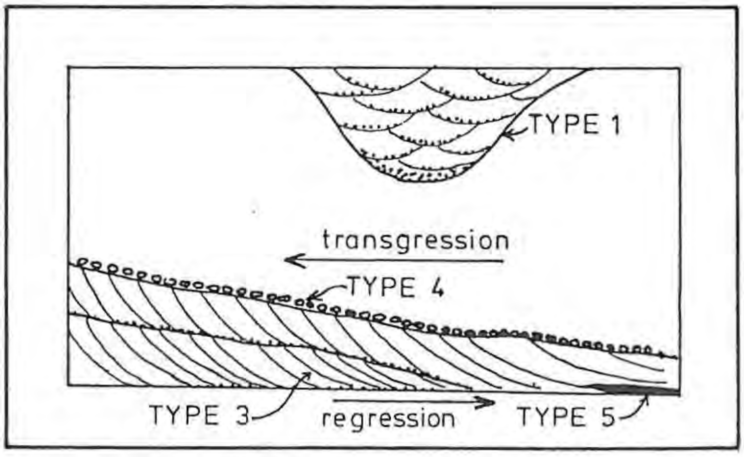


Fig. 56. Schematic diagram showing Witwatersrand gold types. (Pretorius, pers. comm., 1982).

Types 4 and 5 are the most attractive targets although the others cannot be ignored.

The channel-fill placers (type 1) which occupied and were restricted to the channels etched into the palaeosurfaces, have limited lateral continuity and are therefore not economically attractive. During exploration drilling the correlation of these reefs should be treated with extreme caution. The configuration of the erosional channel complexes reflects payshoot trends, a factor to be considered in siting exploration holes. An example of this reef type is afforded by the "B" placer of the Welkom goldfield which is confined to shallow channelways, up to 2 m deep, which cover less than 35% of the palaeosurface.

Placers that have been deposited as gravel bars (type 2) for the most part under regressive conditions in a braided stream environment, are erratically distributed and show limited lateral continuity, and therefore should not be correlated. Bedform erosion and transport in braided streams tends to be sporadic, and, given the fluctuating and transient character of the local hydraulic environment, we can expect to find very uneven distribution of heavy minerals within the braided deposits.

If a bed or unit is ultimately related to an unconformity surface e.g. the transgressive conglomerates (type 4) resting on planar unconformities, then it is legitimate to correlate the base of the bed i.e. the unconformity. These placers are economically attractive because of the consistency of grade/payability and down-dip extension. Although showing relatively uniform mineralisation, distinct payshoot trends parallel to the palaeoslope may be present. Mason (pers. comm., 1982) relates these persistent conglomerate reefs to major basin wide events resulting in the sudden deposition of sediments on to a relatively even erosional palaeosurface. Optimum conditions prevailed on the unconformity surfaces to allow major reworking, winnowing, concentration and settling of heavy minerals. The oligomictic conglomerates and algal mats acted as heavy mineral traps and thereby preserved mineralisation. Examples of this reef type are the Main Reef Leader, Carbon Leader, South Reef and Vaal Reef.

The individual goldfields represent fluvial fans and correlation of adjacent fans has produced gross misinterpretations because sedimentation is taking place at different rates and in different forms in the different fans (Pretorius, pers. comm., 1982).

Evaluation

The tectonosedimentary environment in which the Witwatersrand placers evolved determined the content, distribution and continuity of gold present in the reefs. The appreciation of the different types of gold/uranium placers and their genesis is important in evaluating and establishing confidence limits of borehole values.

The channel-fill placers, bar gravel placers and pyritic crossbedded quartzites (types 1-3) are strongly controlled by fluvial processes and generally have better continuity in the direction of the palaeocurrent flow. Payshoots are present in these placers generally parallel to the palaeocurrent direction and separated by barren to low-pay areas controlled by the irregular braided environment in which they formed. This resulted in impersistent reefs with restricted lateral continuity. Erratic gold distributions determined by bedform processes are found in these placers, and a strong nugget effect was introduced by various bedforms on which heavy minerals preferentially accumulated. The association of placer mineral concentrations with bedforms and palaeochannels parallel to flow makes analysis of these features essential in evaluation and establishing continuity of these reefs. Projections can be extended for greater distances in the direction of palaeoflows rather than transverse to them.

On the other hand gold content within the transgressive placers (type 4) is relatively uniformly distributed. Fine-grained gold, mainly in suspension, was deposited as part of preconcentrated material on to planar unconformities of very low relief, to give rise to rich, laterally persistent reefs. The lateral continuity of the reef types and spheres of influence of the borehole values are summarised as follows :

Type 1 : Restricted continuity; sphere of influence low; correlation of intersected reefs and weighting of borehole values must be treated with extreme caution.

Type 2 : Restricted continuity; sphere of influence low; reefs should not be correlated and little weight should be given to borehole values.

Type 3 : Discontinuously developed pyritic quartzites containing erratic gold concentrations, are restricted in continuity; sphere of influence of borehole values is low.

Type 4 : Extensive lateral continuity; reefs can be correlated over large areas; confidence limits of borehole values are good.

Type 5 : Similar characteristics to type 4; however, carbonaceous material is often ground away in boreholes and therefore difficult to recognise.

The CSIR has developed a computer program based on discriminant analysis (called AID) which uses the parallel between sedimentological features observed in borehole core and gold content. Each sedimentological factor is weighted; in the Carletonville goldfield the carbon content is the factor with the highest loading. This program has been tested on samples of known gold and carbon content and predicted gold values correlate well with assayed gold content. AID is thus used to decide whether a borehole over or under estimates the gold content of an area.

The program could be used to test the continuity of gold/uranium values, with the nature of the footwall contact as the factor of highest loading. These computor techniques can be used as aids in calculating ore reserves; however their limitations should be recognised.

Routine sampling data on many of the gold mines have been stored on a computer data base from which trend surfaces are automatically contoured. Computer programs are used for grain-size and palaeocurrent analysis. Ore reserves in sub-economic areas are selected on the basis of detailed mapping of channel scours, channel sediments and bedforms, and ore-reserve blocks are oriented on the basis of palaeocurrent measurements.

An appreciation of the lognormal distribution of placer mineral content and of the variance caused by the association of heavy minerals with the heterogeneous geometry of the fluvial sediments has enabled one to make better estimates of the mean grades of mineralisation in placers (Minter, 1978).

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