SEDIMENTOLOGICAL CONTROL OF GOLD AND URANINITE MINERALISATION IN THE WHITE REEF OF THE WEST RAND

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ABSTRACT

The primary objective of the study was to determine the controls of mineralisation in the White Reef, which occurs at the base of the Bird Reef Stage of the Upper Witwatersrand System on the West Rand. It is a quartzite with scattered pebbles and occasional 'banket' conglomerates. The average gold content at 317 gm-cm per tonne is low, but uranium grade is amongst the highest on the Witwatersrand.

In 1963 the author demonstrated that some sedimentological properties of the Livingstone Reef are qualitatively related to gold content. More intensive studies have since confirmed the sedimentological control of gold mineralisation. For instance, Pretorius (1974 a, 1975) recognises a general fluvial fan geometry for the Witwatersrand reefs. However, other factors, such as variations in environments, mechanisms of deposition and behaviour of the heavy minerals require further clarification; these form the main subject matter of this study.

A pilot study established interrelationships between sedimentary features and ore grade. Follow-up work revealed systematic downslope changes. The reef was sampled on a systematic grid over the four West Rand mines. All pebbles were measured over complete reef sections. Measurements include 526 of reef thickness, 1 312 of crossbedding, 45 of ripplemarks, 2 of sandwaves, 63 801 of pebble size and sorting, 63 761 for packing, 1 200 of fabric, 33 987 of composition and 1 162 of shape and sphericity. Very large numbers of gold and uranium values, reef elevations and thicknesses were compiled from records.

The area investigated formed a subsiding part of a basin edge between granitic buttresses. Primary structures include the north-south Randfontein trough in the west, which controlled sedimentation from the Main Reef Stage onwards and the smaller north-east trending Witpoortjie trough. Additional control was exercised later by north-east and north-west trending depressions. The major West Rand syncline running north-west, and the basin north of the Witpoortjie fault, are post-depositional features. The White Reef is comparable in geometry and sedimentological features to the Basal Reef (Sims, 1969) and generally conforms to the model of Pretorius (1975). The subsiding Randfontein trough controlled the direction of major payshoots, whilst smaller paystreaks formed along braided channels.

The paleo-environment for the White Reef was that of a braided fluvial fan conforming to the model of Eynon and Walker (1974) for braided rivers. The distribution of depositional facies is related to fan geometry. The avalanched, unsorted pebbly sands of the upper central midfan diverted

sedimentation outwards to form two main lobes of better sorted reefs, with closely packed pebbles over floor highs.

Comparison between properties of other Witwatersrand reefs and those of the White Reef indicates that all are sub-facies of a general depositional fan. A quantitative predictive model for the identification of fan position, facies type and sub-environments can therefore be constructed.

Correlation coefficients between traction properties and metal content decrease systematically downslope, indicating a change of deposition dominantly from traction to that from suspension loads.

Stepwise regression relates the metal - sediment properties as follows: y (gold) = -33,5962 + 2,32798x_1 + 0,86630x_2, with x_1 representing pebble size and x_2 packing. This mathematical model suffered a 12 per cent decrease in prediction accuracy (from a correlation coefficient of 0,76 - 0,67) over a distance of 1 700 feet upslope of the pilot study area on the lower midfan.

Heavy mineral concentration over floor highs occurred in the basal main lobe gravels of the lower midfan to central fanbase. At the pilot study locality, values over floor highs exceed those over lows by 1,3 for pebble size, 3,6 for packing and 4,7 for gold content.

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DESIGN AND HISTCRY OF RESEARCH

Research results obtained by the author indicated that gold values in the Livingstone Reefs on the West Rand are generally related to changes in robustness of the conglomerate (Steyn 1963). This suggested that genetic relationships may exist between yet undefined aspects of the traction load and the mineralisation. This opened a new field of research largely neglected up to that stage as only observations of a general nature were available. In 1963 it was therefore decided to initiate a comprehensive and quantitative macroscopic study mainly concerned with traction load behaviour. Bed load and matrix metal characteristics were to be investigated simultaneously in order to gain insight into the following:

(a) the modes of conglomerate deposition,

(b) the traction load - precious metals relationships and its implications on the manner of heavy mineral transportation and deposition, and,

(c) the determination of such relationships which have applications in the field of economic geology.

The research was encouraged and partly financed by General Mining and Finance Corporation Ltd. who was beset with the problem of the location of economic zones in the White Reef on the West Rand Consolidated Mines (Pty.) Ltd in areas where the gold and uranium grade were both variable and unpredictable.

In order to determine the relative importance of the parameters best correlated with metal content, a pilot investigation was done underground at a suitable locality on the White Reef where the variation in metal grade was marked. Statistical analyses of the results obtained showed certain traction properties to be correlative with the metal grade, but it was realised that the correlations established may have a local validity only. Consequently, additional investigations were conducted at localities elsewhere in order to determine if the relationships were generally valid. This was found to be so, even though a degree of variability was revealed. Correlations were however sufficiently meaningful to proceed with a regional investigation of relevant parameters.

Analysis of the pilot study data made it clear that the local scatter of sedimentary properties was considerable and that insensitive or random sampling could yield results not capable of revealing subtle sub-regional trends. The relationships established in the pilot investigation were therefore utilised to devise a new non-random method of sampling based on the geological processes involved and which statistical analysis showed to yield reliable representative samples.

Thereafter, the regional study was commenced with the systematic measurement of key traction properties on a grid basis. Compilations of these measures were then compared with dispersal patterns of metal content which were compiled from mining sampling and evaluation records. On the basis of results obtained and relationships established, trends of best mineralisation were predicted by extrapolation. The findings were submitted as a detailed report to West Rand Consolidated Mines in 1965 and part of the sedimentological conclusions was briefly presented as a talk to the Geological Society of South Africa (Steyn, 1965). Ten years have since passed and it is therefore possible to evaluate the degree of success obtained with the predictions made.

Data processing was continued at intermittent intervals on a part-time basis. Statistical treatment of results was expanded to include the structural framework as the latter was found to influence the sedimentation closely. During the lengthy period that separated the initiation and completion of this study many other important and comprehensive sedimentological contributions have emerged, e.g. some of the more closely related studies are that of Viljoen (1963), Pretorius (1964 a, b), Brock and Pretorius (1964), Winter (1965), Armstrong (1965), Knowles (1966), Pretorius (1966), Hodgson (1967), Sims (1969), Minter (1972) and Pretorius (1974 a, b, 1975). These works and others increased the knowledge of the processes of the sedimentation of the Witwatersrand conglomerates to today's advanced and sophisticated level. Even at this rate, aspects of the sedimentary processes that determined the deposition of Witwatersrand ore bodies remain to be revealed.

The results and conclusions presented here provide data on a new process of heavy mineral concentration never before so thoroughly investigated, in addition to adding further understanding and new detail concerning the sedimentation processes and environments related to gold and uranium mineralisation. The present study differs from those previously done by examining in great detail the traction load and its relevance to mineralisation and in this context an unparalleled set of data is presented and analysed.

Acknowledgements

The project was initially suggested by Dr P.D. Toens and Dr N.L. Wilson, then employed as consulting geologists of General Mining and Finance Corporation (Pty.) Limited, and the investigation was made possible by a grant from the corporation and a research scholarship at the Economic Geology Research Unit of the University of the Witwatersrand. The author wishes to express his gratitude for this assistance.

The Johannesburg Consolidated Investment Company Limited, General Mining and Finance Corporation (Pty.) Limited, and Goldfields of South Africa Limited kindly made available for study all information concerning gold and uranium assay values on the mines under their control on the West Rand.

The management of the four mines concerned, especially some senior members of the production staffs, went to great lengths to re-open large sections of the mine workings already closed down. Without this assistance, systematic grid sampling of sedimentary properties would not have been possible. Special thanks are due to the following officials for their assistance: Mr S.W. de Wet, Mine Overseer on Luipaardsvlei Estates; Mr N.H.B. van der Riet, Mine Overseer on West Rand Consolidated; and Mr J.I.B. Raubenheimer, Mine Overseer and Mr J.H. Howard, Acting Underground Manager on Randfontein Estates. For the purpose of the pilot study, the management of West Rand Consolidated went to the expense of mining a stope on the White Reef. Messrs D.H. Holt, Section Underground Manager, and B.A. Thomas, Underground Manager, are thanked for organising the mining aspect of this operation.

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SELECTION OF PARAMETERS, SAMPLING PROCEDURES AND ANALYTICAL METHODS

1. COMPILED DATA

SURFACE GEOLOGY

The surface geology of the area studied is shown on map 1, p. 224, which is based on that of Mellor (1913). The outcrops are mainly of quartzites and secondly of lavas. The quartzites and conglomerates of the Upper Witwatersrand System crop out along the rim of the West Rand syncline. The decomposed conglomerates of the Bird Reefs, including that of the White Reef, are only occasionally exposed (map 2, p. 225). The Ventersdorp lavas crop out in the south-central part of the area against the Witpoortjie fault. The Black Reef Series of the Transvaal System, which unconformably overlies the Witwatersrand and Ventersdorp Systems, covers much of the western part of the area. The Witpoortjie fault forms the boundary of the area on the south-east.

The curved outline of the West Rand syncline is reflected by the dip and strike of the conglomerates of the Upper Witwatersrand in outcrop. These are inclined towards the synclinal trough at angles ranging from near 90^{o} in the west to a few degrees in the east. Structural dip to the north-west is shown, immediately north of the Witpoortjie fault, by a small outcrop of Kimberley Reef.

UNDERGROUND STRUCTURAL GEOLOGY

Structure contour maps of the White Reef horizon were available for certain sections of West Rand Consolidated and Randfontein Estates Mines. These were reduced by pantograph to a uniform scale of 1 : 10 000. For other parts of Randfontein Estates, elevation contour maps were compiled by the author by means of conventional methods. In certain parts of West Rand Consolidated and the whole of Luipaardsvlei Mine exposures of the White Reef are so few and far between that reliable elevation contours could not be established. This problem was overcome by integrating data from existing structure plans for the underlying Monarch Reef horizon with isopach thicknesses for the strata between the Monarch and White Reefs, obtained from an isopach plan prepared by Toens and Griffiths (1964). For East Champ d'Or Mine the main faults were transferred from existing mine structure plans of the White Reef on a scale of 1 : 1 000. The compiled structural data are shown on map 3, p. 226.

An attempt was made to determine the attitude of the much fragmented White Reef stratum prior to major faulting, intrusion and overturned folding on the western flank of the syncline. The faults were resolved by adjusting smaller displaced blocks to the level of the larger relatively undisturbed adjacent ones. The strike of the smaller displaced units are usually unaffected by faulting. Elevation contours were therefore extended across these, parallel to existing contour lines, with compensation for different dip gradients where present. The generalised, smoothed-out structural pattern so obtained shows only the larger anticlinal and synclinal trends (map 4, p. 227). This process does not remove post Witwatersrand folding, but rather allows it to be seen more clearly. Local anticlinal and synclinal warping are shown by the mild deflection of the elevation contours. The axis of the major fold is denoted by the lowermost elevations along the trough. To check the reliability of these structural trends a second reconstructed structural map was prepared by the same method at the elevation of the Main Reef horizon (map 5, p. 228).

FOOTWALL ISOPACH DATA

Isopach data provide information on sedimentation trends and the response of sedimentation to structural movement. An isopach map of the footwall sediments immediately below the White Reef could not be compiled due to the lack of continuous marker beds. The White Reef is at the base of the Bird Reef Stage and is underlain by the quartzites of the Livingstone Reef Stage; these have an average thickness of 830 feet and extend down to the top of the Livingstone Reefs conglomerates, which are on average about 60 feet thick. An isopach map is available for the area where the latter are best developed (Steyn, 1963; map 5). The Livingstone Reefs are underlain by the Main Reef Stage, which consists of quartzites, with several gold-bearing conglomerates (map 1, p. 224). An isochore map of the Main to South Reef interval is included to illustrate the effect of structure on pre-White Reef sedimentation (map 6, p. 229; Toens and Griffiths, 1964).

WHITE REEF SAMPLING DATA

Dispersal patterns for gold and uranium, and the variability in the thickness of the White Reef conglomerate, were established from mines sampling data. The distribution maps for gold and uranium concentrations were designed to serve two purposes; the first was to indicate the regional trends of mineralisation and the second to provide an ore reserve value map. With the latter purpose in mind, it was decided to compile average value maps and to process them further with moving average techniques only if the trends were not sufficiently clear. However, after the average values were contoured, it was found that the trends were clear enough to make further processing unnecessary. The use of computer based polynomial trend surfaces was considered in the final stage of data presentation, but this was rejected for the same reasons as for the moving average techniques and because of time and cost considerations.

The area studied was covered by a 500 feet square grid system, and average values were compiled for each of the blocks containing sampled exposures. The choice of block size is considered critical. If the blocks are too large, values are considerably displaced from their points of occurrence; also, small mineable areas with higher values could easily be lost in larger areas with poor values and thus reduce the economic value of the maps. On the other hand, if the blocks are too small, there are too many blocks containing no information whatsoever, and contouring becomes difficult. It is considered that the best indication of the most suitable grid size is the smallest size of the minor pay-streaks. Existing mine value plans indicated that these had minimum dimensions of 200 to 300 feet. Since blocks 250 feet square would have left too many open spaces without values, it was decided to use a larger, 500 feet square grid system.

CHOICE OF UNIT FOR THE EXPRESSION OF GOLD AND URANIUM CONCENTRATIONS

As all the data available for processing was expressed in imperial units it was decided to produce maps using these units. In expressing gold and uranium values the alternatives were to use inch/dwts, gold and inch/ lbs U_3O_8, or dwts/ton gold and lbs/ton U_3O_8. Dr. D.C. Krige (personal communication) pointed out that accurate dwts/ton gold and lbs/ton uranium maps can only be obtained by pre-compiling inch/dwts gold, inch/lbs U_3O_8, as well as channel thickness maps, and then converting these to dwts/ton and lbs/ton. As inch/dwts gold and inch/lbs U_3O_8 are normally used for judging payability in mining practice (alternatively dwts/ton over a fixed stope width), it was decided to compile inch/dwts gold and inch/lbs U_3O_8 maps first, and to use dwts/ton and lbs/ton distributions instead only if these were not satisfactory. A large amount of information on mineralisation was available in the form of detailed stope-sampling records. However, since the processing of these would have taken many months, alternative sources of information had to be found. The procedures described below were adopted at the different mines for the compilation of maps 7, 8 and 9.

PROCESSING OF DATA

Randfontein Estates

A full sequence of ore reserve plans was available dating back to the first development on the White Reef. These had been combined on a single map, which was covered by irregularly shaped ore reserve blocks of different values. In some cases as many as 20 different value areas were included in a 500 feet square block. The averaging of the ore reserve blocks was done as follows. A plastic transparent overlay was placed over each of the 500 feet square blocks. The plastic overlay was marked with a grid system, so that the 500 feet squares were subdivided into 100 smaller squares, each five feet square. The areas of the irregularly shaped ore reserve blocks were now represented by a number of small units of equal size. By multiplying a value by the number of unit areas representative of that value, and by repeating the operation for ore reserve blocks of different values, the ore reserve areas were weighted according to their values and sizes to obtain an average for the 500 feet square blocks. The actual averaging was compiled arithmetically on an electric calculator. A different procedure had to be used to record conglomerate thicknesses, as the ore reserve plans did not yield any information in this respect. It was necessary to refer to the original development sampling records, which give the actual conglomerate thicknesses for sample sections taken at five feet intervals. From these the average values for blocks approximately 600 feet square were obtained, as mining raises were developed at intervals of 600 feet. Very often it was necessary to locate the map positions of sample records by plotting the co-ordinates of survey pegs, whose numbers formed part of the sample records. A complicating factor arose in connection with conglomerate thicknesses due to the method used in mine sampling. Samples of the White Reef were taken over a minimum width of three inches by the mine samplers even where the conglomerate itself was thinner. Therefore lesser minimum widths of the conglomerate could not be recorded on map 7, p. 230. In some areas extensive borehole sampling results were available. Where several boreholes were close to each other, average values were calculated. Single borehole results are also indicated.

West Rand Consolidated

Ore reserve maps cover only a very small portion of the partially developed ground and of the mine. Where a sufficient number of ore reserve blocks had been laid out, the procedure described previously was used. Over the remaining, large, unevaluated tracts of the mine, development assay plans were available which gave the value of a development section in terms of gold dwt/ton and uranium lbs/ton calculated over the channel width. These values were averaged over 500 by 500 feet blocks. Three or more development exposures per block were considered to be sufficiently representative to give a reasonable average value for that block, provided they were spaced fairly widely apart. Less than three exposures per block were not considered representative unless the exposures were unusually large, and the averages derived from them were classified as less reliable.

In the north-central part of West Rand Consolidated Mine a disparity was found between ore reserve block values and the much higher values based on stope sampling after some mining had taken place. In this area the values used for the stoped areas were based on the averages of the more numerous stope sampling results.

Luipaardsvlei

Development on the White Reef itself was mostly restricted to the northern, shallow levels of the mine. Intersections of the White Reef at greater depths were usually incidental and relatively small. Nevertheless a considerable number of small exposures of White Reef are present over virtually the whole mine lease area. Exposure sampling records had to be examined individually, and very often considerable difficulty was experienced in correlating a White Reef sampling record with its exact sampling position on the plan. The method used on West Rand Consolidated for averaging development sampling results was applied here as well. Due to the limited and small intersections a much higher percentage of average block values had to be classified as less reliable.

East Champ d'Or

A high density of development exposures is available on this mine, as well as a limited number of stope exposures and numerous borehole intersections. The averaging of this information was also done on a grid system, making use of the methods previously described.

CONTOURING PROCEDURES

Normal contouring procedures such as described by Krumbein and Sloss (1963) were used. Contour lines between 'reliable' average values were considered as well defined and are indicated by solid lines; those based on 'less reliable' averages were classed as uncertain and are indicated by broken lines, while contours between points based on scanty information and extrapolations across areas with no information were considered speculative and are indicated by dotted lines.

HANGINGWALL ISOPACH DATA

Map 11, p. 234, shows the isochores of the White - Monarch Reefs interval after correction of dip (Toens and Griffiths, 1964). This allows the paleo-surface at the time following the deposition of the White Reef to be reconstructed. It shows a southward thickening of sediments and an east-west paleostrike. The iso-thickness lines curve gently northwards at the centre of the area.

SUMMARY OF COMPILED DATA

The above-mentioned data provide information about structure, apparent paleoslope gradients, geometry of the White Reef, gold and uranium distribution. However, these properties do not represent all the aspects investigated. The data compiled are summarised in the following table no. 1, p. 9.

2. MEASURED DATA

PILOT STUDY

PURPOSE

To unravel the processes that produced the White Reef and its gold and uranium concentrations, it was necessary to make a field or underground study of this sedimentary deposit. A pilot study was first carried out to determine whether some properties of the conglomerate could be quantita-

TABLE 1

SUMMARY OF COMPILED DATA

TYPE OF DATA	ABUNDANCE OF DATA	TREATMENT	MAP NO.
Elevations - Main Reef	Very large*	Contouring of average values	5
- White Reef	Very large	"	3 & 4
Thicknesses - Main/South Reef	Unknown*	"	6
- White Reef	Averages compiled for 511 blocks of 500 ft. sq.	"	7
- White/ Monarch Reef	Unknown*	"	11
Gold content - White Reef	Averages compiled for 513 blocks of 500 ft. sq.	"	8
Uranium content - White Reef	Averages compiled for 554 blocks of 500 ft. sq.	"	9
Gold-uranium ratio - White Reef	Averages compiled for 420 blocks of 500 ft. sq.	Contour of moving averages	10

* Compiled by Toens and Griffiths (1964)

tively related to the grade of mineralisation. These could then, as a follow-up stage, be investigated over a wider area to locate areas favourable for further exploration. The more specific objectives of the pilot study were as follows:

(a) To determine whether any of the sedimentological properties of the gold- and uranium-bearing conglomerate could be quantitatively related to the grade of mineralisation;

(b) To investigate in detail the factors controlling conglomerate deposition as well as the conditions responsible for variations in conglomerate development;

(c) To determine, if possible, some of the basic principles controlling gold and uranium mineralisation;

(d) To explain the extreme local variations in gold-uranium mineralisation in the White Reef indicated by sampling results; and

(e) To deduce from the above the most suitable and rapid methods for the regional study of gravel deposition and controls of mineralisation.

CHOICE OF PROPERTIES AND TECHNIQUES

The study of the White Reef was done with straightforward field techniques suitable for routine underground measurements by mine geologists without the use of expensive or complicated instruments. The parameters selected had therefore to be suitable for direct macroscopic and relatively straightforward measurement. The properties also had to reflect the basic sedimentological processes that formed the White Reef conglomerate and which were responsible for its mineralisation.

Steyn (1963) showed, in a general sense, that correlations exist between macroscopic textural grain properties and precious metal content of the Livingstone gold-bearing conglomerate. It was therefore decided to examine the nature and meaning of these relationships quantitatively, systematically, and in detail. It was felt that these correlations have not been fully examined nor been fully understood and that a detailed investigation would add to the understanding of gravel and related heavy mineral deposition.

Selected external properties

Thickness and geometry The geometry and thickness of the White Reef were selected for study. These are, on a local scale, both related to the undulating topography of the pre-White Reef floor, which could have had an important bearing on the nature of the overlying gravel.

Selected internal properties

The internal parameters of the conglomerate selected for measurement were the size, packing and sorting properties of the coarser particles of the grain population, namely the pebble fraction. The grain sizes can reflect the size of detritus supplied and the current velocities and transporting ability of the depositional currents, whilst variations in packing and sorting can indicate the degree of particle concentration by sorting processes. Study of these parameters along with other internal features such as crossbedding may provide an insight into the mode of gravel deposition. If the associated detrital gold and uranium minerals were transported along with the sand and pebble particles, information would thus become available on the transportation and depositional conditions of the economic minerals.

Pebble size In previous regional studies over large areas, measurements on pebbles were limited to the recording of maximum pebble sizes (Potter, 1955; Schlee, 1957; Pelletier, 1958). For qualitative studies over smaller areas such as those carried out previously on Witwatersrand paleo-gravels, the ten largest pebbles per square foot of exposure proved effective in providing a rapid measure of size variation (Steyn, 1963). To determine the detailed variations in size, sorting and packing required for this study it proved necessary to measure all the grains present over many full-width sections of the gravel. This approach thus entails an intensive study of the factors which affect the distribution, relative packing and sorting of the pebble fraction of the conglomerate and of their relationship with mineralisation and the topography of the floor.

Pettijohn (1957) defines pebbles as grains over 4 mm in diameter. By measuring all the grain sizes over 4 mm (less than 2 mm is considered as sand size, 2 - 4 mm as granule size), it was possible to calculate the mean grain-size of the entire pebble population of the sample section as well as the density of pebble packing and the sorting coefficients.

As a very large number of grain measurements had to be made, (a total of 63 801 eventually) it was decided to make only one size measurement per grain, that of the long axis of the pebble. Prior to the pilot study an investigation of pebble shape (sphericity) was undertaken with the purpose of determining the true average pebble shape. The pebbles were found to be on an average 72,5 per cent spherical, with sphere and dome shapes in the majority (appendix 15, p. 186). The long axis measurement was therefore approximately 27,5 per cent in excess of the nominal grain diameter, which is generally accepted as the best measure of grain-size. According to Pettijohn (op. cit.) two dimensional measurements of grain-sizes generally represent only 75 per cent of the nominal diameter, giving a shortfall of 25 per cent. The sphericity values obtained therefore indicate that the long axis can be considered as a fair approximation of the nominal diameter.

Pebble packing Changes in hydraulic energy, winnowing and sorting during deposition, and variations in relative supply of sand and pebble fractions, would all affect pebble packing. This study of this property is therefore important for determining the mode of gravel deposition. In calculating the density of pebble packing, each long axis measurement was considered to represent the nominal diameter of the pebble and was used as such to calculate the two-dimensional area covered by the pebble. The sum of the total pebble areas was converted to a percentage of the total area covered by the sample strip.

Sorting The nature of the size distribution yields information about the size range of particles available for deposition and also the degree of particle selection operative during the depositional processes. It is an important indicator of selective deposition when processes of concentration of gravels and associated heavy minerals are to be examined.

The application of sorting coefficients has the disadvantage of being heavily dependent on the particle size, and there is a tendency for variations in sorting coefficients to be strongly reflective of the particle size distribution. The White Reef is no exception to this rule, as is also demonstrated by the data provided by the regional study. For visual presentation of the sorting characteristics of the pilot study, histograms of the pebble sizes were found effective for demonstrating variations in sorting.

Crossbedding Crossbedding is a useful vector property indicating direction of paleoslope and paleocurrent. It also provides additional information on the mode of conglomerate deposition, especially where it can be observed that the reef was deposited as a single crossbedded unit. The direction of foreset inclination, the angle of inclination and the thicknesses of crossbeds were measured according to the method described for the regional study.

Gold, uranium and silver contents To obtain a fully representative sampling of the entire conglomerate, samples covering the full thickness of the reef were taken in six inch wide strips at right angles to the bedding. The sedimentological properties of the strips were first studied, and the same rock surface was then groove-sampled to a depth of an inch for analysis of the metal content, which was undertaken by the assay departments of the mines concerned. All the samples were assayed for gold and uranium, and whenever analysis routine allowed, for silver and sulphide content as well. With the seventh and ninth samplings the sample size was doubled, and twelve inch wide samples strips were measured in an attempt to improve the correlations between sediment textural properties and metal concentration which were already evident at that stage but showed wide scatter.

Internal properties not measured

A large number of geological properties can be measured in a conglomerate. These are described in detail by Pretorius (1966). A study of all these would have defined the deposits more adequately and allowed a more comprehensive analysis of the sedimentary processes involved to be made. Due to the regional scope of this investigation, the budget and time limitations, various additional potentially useful studies had to be omitted, such as the analysis of the sand fraction, heavy minerals and other matrix materials. In view of this it was decided to explore more fully the relationship between the economic minerals and the pebble fraction since the results of earlier studies referred to above showed promise for such an approach. The behaviour of the heavy minerals can however be partially deduced from the dispersal patterns of gold and uranium, and the finer matrix constituents such as the clay minerals are considered to be of lesser importance, in the study of gold and uranium mineralisation. The relative abundance of different pebble types was not investigated during the pilot study but was included in the regional study, as it is a useful indication of regional provenance but unlikely to show local variations related to mineralisation.

Shape and roundness of pebbles were not anticipated to show significant local variations and were likewise not measured during the pilot study. Observations on pebble shape in outcrops were however made prior to the pilot study to help in deciding on the best method for measuring pebble size.

Orientation and imbrication of pebbles were, unlike crossbedding, not measured because they were thought to be unrelated to variance of local gold content. Seen in the light of later knowledge, such measurements could have been useful in the analysis of local variations in the mode of deposition. Pebble orientation was however measured as part of the regional study.

Choice of locality

An underground working place was selected in the area of future exploration interest, namely K_6 on the regional locality grid (map 2, p. 225). The site satisfied the following requirements:

(a) There had been a minimum of structural disturbance, so that there was little hydrothermal redistribution of the ore minerals, and

(b) Considerable local variations in gold and uranium contents indicated by previous mine sampling made the site suitable for study of extreme variations in the grade of mineralisation.

Sampling interval

A 150 feet section of the conglomerate exposed on a mine stope face was sampled at five feet intervals. To obtain a three-dimensional sampling, the two-dimensional exposure on the working face was sampled after each of ten consecutive blasts. Each of these initial sampling stations, as well as the consecutive exposures, were surveyed by tape to locate their positions accurately. These were later plotted on the standard 1 : 200 scale for stope plans (fig. 2, p. 201).

Treatment of results

The arithmetic mean and the standard deviations of the grain sizes were calculated on a computer. The full set of results is visually represented on block diagrams, scatter diagrams and histograms (figs. 2 - 10). Statistical analyses were carried out by computer for the pairwise relationships between and within the four sedimentological properties - mean pebble diameter, standard deviation of pebble diameter as a measure of sorting, pebble packing and channel width - and the yields of gold silver and uranium were studied by means of bivariate linear regression. In cases where the relationships were not linear, the regressions were fitted to log transformations of the variables (see appendix 16, p. 187). Curve fitting was done on the computer by regression techniques to determine the nature of the pairwise relationships. In complex cases family regression methods were applied (appendix 4, p. 158). Analysis of variance was utilised to test for homogeny between suspected different populations of the conglomerate (see appendices 3 and 7). Stepwise regression and matrix analyses were finally done in order to determine the relative strengths of interrelationships (appendix 17, p. 189).

SUMMARY OF MEASUREMENTS

The measurements made and their statistical treatment and presentation are summarised in table 2 below.

TABLE 2

SUMMARY OF MEASURED DATA

PILOT STUDY

(224 full width sections of conglomerate studied; Sample interval 5 ft for 10 successive blasts; 1st sampling 50 largest pebbles per six inch wide strip; 2 - 6th sampling all pebbles per six inch wide strip; 7th & 9th sampling all pebbles per twelve inch wide strip; 10th sampling 25 largest pebbles per six inch wide strip; total pebbles measured 12 759)

CONGLOMERATE PROPERTY	SECTIONS MEASURED	STATISTICAL TREATMENT	VISUAL PRESENTATION
Pebble size	126	Variance and regression analyses	B-S-H
Pebble packing	125	"	B-S
Pebble sorting	126	"	B-S-H
Conglomerate thickness	224	"	B-S
Gold content	224	"	B-S-H
Uranium content	146	"	B-S
Silver content	31	"	S

Abbreviations: B - Block diagrams; S - Scatter diagrams
H - Histograms

CHECKS ON PILOT STUDY RESULTS

PURPOSE

It was not known whether the validity of the relationships established at the locality of the pilot study extended over wide areas. The probability existed that the conditions there reflected local hydraulic equilibrium on the paleo-slope. It was therefore decided to conduct control tests at both up- and down-current positions relative to the pilot study locality.

CHOICE OF PROPERTIES AND TECHNIQUES

The same sets of external and internal properties of the conglomerate were measured systematically, and samples were analysed for gold and uranium content. In these two limited tests sampling was limited to two-dimensional reef surfaces only. The correlations obtained from the more restricted data are not as good as those for the three-dimensional pilot study.

Upcurrent area

At the upstream locality at 7^{A}VW18 stope (grid position I_6 - J_6) there are no complicating factors due to narrowness of the reef as experienced in the pilot study area.

Downcurrent area

The 26-0 mine workings on Randfontein Estates (S_7 grid locality) represent the farthest downcurrent facies of the White Reef, 10 000 feet downslope from the pilot study site (grid position K_6, map 2, p. 225); and are situated close to the termination of the economic zone of the reef.

Treatment of results

The results were processed and analysed in the same way as for the pilot study. Apart from statistical analyses (appendices 5 and 6) the relationships were plotted on graphs, scatter diagrams and histograms for visual comparison (figs. 11 - 14).

SUMMARY OF MEASUREMENTS

The measurements carried out at the control sites and their treatment are summarised in table 3 below.

TABLE 3

CHECKS ON PILOT STUDY

SUMMARY OF MEASUREMENTS

LOCALITY	UPCURRENT (7A VW18)	DOWNCURRENT (26-0)
Number of full width conglomerate sections measured	9	8
Width of sampling strips	6 inches	12 inches
Total pebbles measured	1 729	1 073

SUMMARY OF TREATMENT

CONGLOMERATE PROPERTY	STATISTICAL TREATMENT	VISUAL PRESENTATION
Pebble size	Regression correlation	G-S-H
Pebble packing	"	G-S
Pebble sorting	"	G-S
Conglomerate thickness	"	G-S
Gold content	"	G-S
Uranium content	"	G-S
Sulphide content		G
Silver content		G

Abbreviations: G - Graphs
S - Scatter diagrams
H - Histograms

FOOTWALL DATA

The White Reef is the basal unit of the Bird Reef Stage. It is underlain by the quartzites of the Livingstone Reef Stage, which has an average thickness of 830 feet down to the top of the Livingstone Reef conglomerates.

NATURE OF THE FOOTWALL BEDS

The quartzites immediately below the White Reef range from siliceous to argillaceous. A variable number of gritty beds and layers with scattered pebbles are present, but they are laterally discontinuous and therefore difficult to correlate. Locally they pass into robust, well-packed conglomerates for short distances, which are separated by quartzites with pebbly stringers. The footwall sediments were stratigraphically mapped underground with the objective of compiling an isopach map, but this could not be achieved due to the absence of continuous marker beds.

CROSSBEDDING

Description

Two different types of crossbedding - planar and trough - are present. The planar variety is predominant, with the Alpha type (Allen, 1963) being more abundant. These overlie level, non-erosional bases in contrast to the Gamma cross-stratification, which is developed over eroded surfaces. Trough crossbeds or Phi cross-stratification after Allen are only rarely developed, and the troughs are usually not more than three to four feet wide.

Measurement

Areal distribution To ensure an even density of readings, measurements were based on a 1 000 feet square grid pattern covering the area investigated. Measurements were taken at the centre of the squares whenever exposures permitted.

Number of measurements Olson and Potter (1954) show that the variance in orientation between various crossbedded units at any locality is far greater than the variance in a single crossbedded unit. It was therefore decided to sample as many different crossbedded units as possible at every locality. To do this it was necessary to limit readings in a single crossbedded unit to a minimum. In Potter and Olson's regional study, which covered hundreds of square miles, two readings were taken per crossbedded unit at each locality. Since the present study is a more detailed one of paleocurrent variation over a relatively small area (ten miles along strike), it was considered necessary to determine the average current direction in a single unit more accurately. As the underground exposures of sedimentary units are usually small, cross-sets measured in a single crossbedded unit were usually so close together that they showed little variation in orientation. Moreover, it was found that measurements of three different cross-sets at close intervals in the same crossbedded unit yielded nearly the same readings. The standard procedure adopted throughout was to measure the orientations of three individual cross-sets per crossbedded unit. These three readings generally agreed so closely that their arithmetic means did not differ from their vectoral means, and the former were therefore used to indicate the average azimuth directions of the individual units.

<u>Current azimuths</u> The measurement of the smaller cross-sets was done by means of the stratameter developed by G. Armstrong of the Economic Geology Research Unit of the University of the Witwatersrand. Larger crossbedded units and the dip and strike of the strata containing the cross-beds were measured by means of a measuring tape, clino rule and Brunton compass. The thicknesses of the crossbedded units were measured in inches using a tape. Measurement was limited to cases where the type of cross-bedding could be identified. The direction of trough axis of a trough bed was measured only if a cross-section was available for inspection. The external moulds of these troughs can easily be confused with shallow erosion channels or hollows between sandwaves. The stratigraphic position of the crossbedded units in which readings were taken were limited to within five feet downward of the base of the White Reef.

Treatment of data

<u>Current azimuths</u> The crossbedding orientations were untilted by the means of normal untilting procedures such as described by Hargraves (1962), Ramsay (1961) and Potter and Pettijohn (1963). As mentioned previously, the average for the three readings per crossbedded unit was calculated arithmetically. Different symbols were used on map 12, p. 235, to differentiate between orientations in the conglomerate and in the over- and underlying quartzites. Trough crossbedding was also indicated by a different symbol. The local variations in crossbedding orientations were smoothed out to illustrate the regional paleocurrent patterns more clearly by the calculation of moving averages for overlapping blocks of 2 000 by 2 000 feet. The procedure followed is similar to that described by Potter and Pettijohn (1963). The resultants for the 2 000 feet square blocks were obtained by graphic vector addition according to the method illustrated by Steyn (1963, fig. 18). The vector magnitude was expressed as a percentage of the consistency ratio (cf. Curray, 1956). These results are tabulated in appendix 9, p. 177, and plotted on map 13, p. 231. The significance of the resultants was tested by means of the visual Raleigh test described by Curray.

WHITE REEF DATA

PEBBLE SIZE, PACKING AND SORTING

Measurements

<u>Grid sampling</u> The results of the pilot study show that size, density of packing and sorting characteristics of the pebbles of the White Reef are all related to gold, uranium and sulphide content on a local scale. It was therefore thought that a similar correlation could exist on a regional scale. To test this possibility it was necessary to obtain representative samples over a large area. The sampling was systematically done on a

regular sampling grid; this ensured an equal density of measurements over the area investigated. In the south-western corner of West Rand Consolidated measurements were made at closer intervals in order to obtain greater accuracy for this area of special exploration interest. Normal scientific sampling, especially where measurements are to be subjected to statistical analysis, requires random selection to ensure representative results. In the present study, sampling stations were located at the centres of 1 000 by 1 000 feet blocks, thus eliminating personal bias in the selection of the sampling locality.

Representative sampling   Two alternative sampling methods were possible. The first was the choice of a single sample according to a method that would ensure random selection. The second, more comprehensive method was to take a number of measurements or samples and consider their average value to be representative. The latter method seemed to be the best alternative, since the pilot study indicated that local variations could be so marked that a single sampling section randomly selected would not yield parameter values representative of the locality as a whole. The pilot study area, for instance, has an overall average pebble diameter of 9,8 mm for a total of 126 sample sections measured over the width of the reef, with a maximum average of 16,4 mm and a minimum average of 7,8 mm for single sample stations, and a large local variation is thus apparent. The other two parameters also vary considerably; the density of pebble packing has an average value of 27,4 per cent and varies between 7 and 74 per cent. The standard deviation, which can be regarded as a measure of sorting, has an overall average value of 4,9 mm, with a range of 9,7 to 2,2 mm (table 4, p. 20). From the above figures it is obvious that a single random sample will not yield representative values. On the other hand, if more than one or two grain counts covering the complete cross-section of the conglomerate were taken, it would have required considerably more time than was available. The problem was thus to obtain representative values with a less time consuming method than that of group sampling. A normal distribution (fig. 3b, p. 203) indicates that statistical analyses can be applied.

Statistical analyses of the results of the pilot study indicate that the textural and metal properties of conglomerate populations vary with floor relief. Analysis of variance by means of F-tests show that the three groups of samples representative of high (0 - 4,9 inches reef width), intermediate (5 - 9,9 inches reef width) and low floor relief (reef thicker than ten inches) do not represent a homogeneous population (appendix 3, p. 155). The analysis reveals large differences in standard deviation between groups for the two metal properties, especially the uranium content. However, with the sample numbers being approximately equal, the analysis of variance for differences between groups is less sensitive to those differences. Further, because of the very high levels of confidence for F, it is believed that a true difference between populations is indicated (Sceffe. H. - The analysis of variance, Chapter 10, 1959). The differences for the sediment properties are nevertheless stronger than for the metals. The variability in textural and metal properties are therefore to a large extent related to changes in the floor topography. T-tests indicate that there is no significant difference between averages for the values measured at mean reef width and the grand means calculated for the overall number of samples (appendix 7,

TABLE 4

METAL AND CONGLOMERATE POPULATIONS RELATED TO VARIABLE FLOOR TOPOGRAPHY PILOT STUDY AREA

POPULATIONS	MEAN CONGLOMERATE AND METAL PROPERTIES					
	Channel Width (inches)	Pebble Size (mm)	Pebble Packing (per cent)	Sorting (St Dev) (mm)	Gold (dwts /ton)	Uranium (ounces /ton)
High floor	0 - 4,9	11,4	41	5,5	27	155
Intermediate floor	5 - 9,9	9,5	26	4,8	9	52
Low floor	9,9 +	9,0	19	4,6	7	45
GRAND MEANS - $\bar{X}$	7,6	9,8	27	4,9	13	79
Individual sections at average reef widths (x)	7,5 7,5 7,5 7,5 7,5 7,5	9,1 10,4 9,2 10,2 9,1 9,1	21 26 22 31 23 28	4,1 5,5 4,3 5,1 4,5 4,2	7 4 3 -- 6 5	*
Maximum deviations of x from $\bar{X}$	0,1	0,7	6	0,8	10	63
Maximum deviations of non-average sections from $\bar{X}$	12,4	6,6	47	4,0	88	679

* No uranium values

p. 168). It is therefore possible to gain representative samples of conglomerate properties by measurements at average floor topography, i.e. at average reef widths. A close correlation exists between the values for individual reef sections at near-average width and the overall averages as is demonstrated by table 4, p. 20 . Whilst this is true for the sedimentation properties it is statistically invalid for the gold and uranium due to the large variations although the same trend is present.

A very significant saving in sediment sampling effort can therefore be achieved while still obtaining fairly accurate representative values of conglomerate properties, since measurements on single reef sections are representative of larger sampling areas. In the regional sampling, therefore, the average channel width at any locality was first determined, and a reef section with a width as close as possible to the average was then selected for measuring.

Grain-sampling procedures Sampling localities were selected on the above basis, and textural properties were measured over the full thickness of the conglomerate at the centres of 1 000 feet square blocks wherever exposures permitted. All the grains over 4 mm in diameter (long axis) were measured along strips across the full width of the conglomerate with standard surface areas of one square foot. The widths of the strips thus varied inversely with the thicknesses of the conglomerate. To cope with the problem of grains lying across the boundary of the strips, all those on the left were disregarded, while all those on the right were counted.

In cases of abnormal reef thickness the width of the sampling area can become so small that unsatisfactory results, especially with regard to pebble packing densities, are obtained (too many boundary cases). To obviate this a minimum sample width of six inches was used, so that thicker conglomerate sections are represented by larger sampling areas.

The same set of grain-size measurements was used for the calculations of mean pebble size, density of pebble packing, and sorting coefficients. The pebble types were identified when the grain sizes were measured, and the relative amounts of the various types were converted to percentages.

Treatment of results The arithmetic means and standard deviations of the grain sizes were calculated by computer. The results are tabulated (appendix 8, p. 171). Regression correlation analysis was done to define the nature of the relationship between pebble size and standard deviation (appendix 4H, p. 162). The latter property was utilised as a parameter to investigate sorting. Average value distribution contour maps were compiled both for mean pebble size (map 14, p. 237) and mean standard deviation (map 15, p. 239).

In calculating the density of pebble packing, each long axis measurement was considered to approximate the nominal diameter of the pebble and was used as such to calculate the two-dimensional area covered by the pebble. The sum of the total pebble areas was converted to a percentage of the total area covered by the sample strip. This was done by computer. The pebble packing percentages are tabulated in appendix 8, p.171. A contoured distribution map of pebble packing percentages was prepared (map 16, p. 241).

PEBBLE FABRIC

General fabric characteristics of gravels

The two most important aspects of pebble orientation are the direction of inclination with respect to the paleoslope (up or down) and the angle of inclination. Cailleux (1945), cited in Pettijohn (1957), studied the inclination of pebbles in formations ranging in age from Paleozoic to Recent. He found that imbrication is very common and that it is somewhat variable in direction in marine formations, whereas the inclination is notably uniform is river deposits. The mean upstream inclination in fluvial deposits is 15 - 30°, whereas marine deposits show pebble inclinations of only 2 - 12°. He also found that flat pebbles exhibit lower angles of inclination and that pebbles in contact with others are better orientated that isolated ones. According to Pettijohn (op. cit.) the majority of fragments on sub-aerial talus slopes and in esker gravels dip in the same direction as the bed itself. In deltaic gravels, on the other hand, the pebbles are generally inclined upstream in a direction opposite to the initial dip of the beds. This up-current imbrication was also found by Krumbein (1942) in the gravel deposits of the San Gabriel and Arroyo Seco canyons. Twenhofel (1950) states that disc-shaped pebbles deposited on beaches tend to imbricate seaward.

From the foregoing it seems that there are important differences between marine and fluvial pebble orientation; marine pebbles are imbricated seaward at low angles, while fluvial gravels contain pebbles inclined at greater angles in the upslope direction. However, according to Twenhofel (1961) exceptions are numerous. Potter and Pettijohn (1963) draw attention to apparent downstream imbrication which may result from failure to recognise crossbedding. They point out that few if any regional studies have been made of fabric in ancient conglomerates.

Measurement

Orientation measurements of pebbles are usually made on loose ones. In the case of the White Reef conglomerate only two-dimensional exposures of pebbles were available for study in the underground workings. As pebble orientations can be used to examine depositional and environmental conditions it was decided to carry out a limited number of systematic measurements on two-dimensional exposures, as an experiment. This was done at a late stage of the field investigation after earlier investigations indicated that three different facies of the conglomerate were present. Pebble orientations on two-dimensional exposures were therefore made at four widely separated localities for each of the three facies of the conglomerate. Fabric measurements were made only after the paleo-current directions had been determined from crossbedding measurements. Underground measuring stations were selected where two exposures, approximately at right angles to each other, were available, and where one of them was orientated roughly in the local paleo-current direction. On each rock surface fifty pebbles were selected with a definite flat or elongated shape (long axis = 3 x short axis). The angle of deviation from the bedding of the conglomerate was measured, as well as the direction of pebble inclination.

Treatment

The orientations of the pebbles were analysed with reference to the paleocurrent direction. The respective percentages of pebbles which dip up- and downcurrent were calculated. The average angles of the grain inclinations in these two directions were then determined. The process was repeated for pebble inclinations exposed at right-angles to the current direction. The results are tabulated in appendices 12, 13 and 14. The orientations are visually presented on map 17, p. 242.

PEBBLE SHAPE AND SPHERICITY

Definitions

Shape The method chosen to express shape is that of Zingg (1935), explained by Krumbein and Sloss (1963). He shows that, if the ratio of the intermediate to the maximum intercept ($^{b}/a$) of a particle is plotted against that of the shortest to the intermediate intercept ($^{c}/b$), the particle may be classified according to its shape. Zingg's classification involves four different shape classes (Krumbein and Sloss, 1963, figs. 4 - 8).

Sphericity Operational sphericity has been described by Wadell (1933) as the ratio ($^{d}/a$) of the nominal diameter (d) to the maximum intercept (a) of the particle. The operational sphericity can be related to Zingg's classification of shape in terms of particle intercepts. The relationship is shown in figs. 4 - 8 of Krumbein and Sloss (op. cit.) and can be used to deduce sphericity values from the shape data.

Measurement

Pebble shape and sphericity measurements were conducted, as pebble shape is of importance when selecting methods of measuring the pebble size and packing. These preceded the measurements in the pilot stope, where pebble packing was one of the textural properties investigated. The determination of the three-dimensional shape of the pebbles (+ 4 mm long diameter) was done on pebbles removed from weathered rock close to the surface. Pebbles were obtainable at only one surface locality, but they could not be parted from the silicified matrix without damage. At four widely spaced mine workings the matrix of the conglomerate was found to be sufficiently decomposed near the surface to provide unbroken pebbles. After cleaning, the axes of the pebbles were measured according to the method suggested by Krumbein (1941) and amplified by Pettijohn (1957). The maximum (a), intermediate (b) and minimum (c) intercept lengths were recorded.

Treatment

Ratios of axes lengths ($^{b}/a$, $^{c}/b$) of pebbles were plotted according to the

Zingg Shape Indices as per Pettijohn (1957) to determine shape and sphericity distributions.

Figs 16 a - f, p. 169, and appendix 15, p. 186 illustrate the pebble shapes according to Zingg's classification. The related operational sphericity values are also shown. According to Folk (1961) variation of shape with size is nearly always present in the sense that the coarser grains are usually more spherical than the finer ones. For this reason only pebbles in similar size classes are compared for the three localities where measurements were made (appendix 15). Map 17, p. 242 shows the positions of the three localities and the average sphericity values obtained.

TWO-DIMENSIONAL SPHERICITY

Two-dimensional sphericities were measured as a limited experiment at fourteen widely separated rock surfaces underground. Maximum (x) and minimum (y) intercepts were measured for fifty pebbles at each locality without knowledge of their true dimensions or orientations. The averages of the x/y ratios are shown on map 17.

COMPOSITION OF PEBBLES

Description

The pebbles in the conglomerate represent a large variety of rock types; these are summarised in the following table no. 5, p. 25.

Measurement

It was found that the major rock components and the miscellaneous types listed in table 5 could be distinguished on the rock surfaces underground. The pebbles measured for size were therefore identified at 145 pebble localities with regard to type and counted. The differentiation between the quartzite, chert and quartz rock types was controlled by means of regular microscopic examination.

Treatment

The counts were tabulated and converted into relative percentages, which are plotted on map 18, p. 243. The quartz percentages were divided into two groups - the first consisting of the milky white quartz, and the second of all the other colours. The relative percentages of the quartzite component, which exhibits the greatest variability, were contoured.

TABLE 5

ROCK TYPES REPRESENTED BY CONGLOMERATE PEBBLES

MAJOR ROCK TYPES	SUB-VARIETIES
Quartzite	Light-grey, fine-grained quartzite Grey, medium-grained glassy quartzite Dark quartzite
Chert (subrounded to angular)	Grey, black, green or buff varieties
Quartz	Milky white quartz (Light-grey, translucent quartz (Grey quartz (Black quartz
Miscellaneous (mostly sediments)	Green, black and buff schist Grey, coarse-grained lava Blue-shot grit Grey-white clay Brown shale

CROSSBEDDING

Description

Planar crossbedding greatly predominates over the trough type. The thicker conglomerates often contain abundant crossbeds. Sometimes scattered-pebble, cross-stratified conglomerate makes up the entire reef, which is then often poorly mineralised. In such cases either the full width of the conglomerate consists of a single crossbedded unit, or several cross-stratified sub-units are present. Layers of pebbles frequently cover the inclined foresets, with the pebbles lying flat on the inclined slopes. In areas of narrower reef crossbedded conglomerate is less abundant. Pebbly or more often pyritic stringers are present as foresets.

Measurement

The azimuth directions and dips of foreset beds, thicknesses of crossbedded units and strikes and dips of the surrounding strata were measured and recorded.

Treatment

Tilt correction of foreset azimuths, graphic vectoral addition for compilation of moving averages, consistency ratios for 2 000 feet squares, and tabulation (appendix 10, p. 179) were carried out. The resultant vectors and the consistency ratios presented on map 19, p. 244, reflect the dispersal currents which deposited the White Reef.

HANGINGWALL DATA

The White Reef is overlain by a homogeneous succession of medium-grained grey or greenish-grey quartzites, which extend up to the base of the Monarch Reef. The isopachs of this interval are shown on map 11, p. 234. Sedimentary structures such as crossbedding, sandwaves and ripplemarks are present and were measured in the quartzites directly overlying the White Reef. Planar cross-stratification, developed on a small scale, is by far the most abundant but trough crossbedding is rare. Sandwaves are very scarce and ripplemarks are occasionally present.

CROSSBEDDING

Measurement

The azimuth directions and dips of foreset beds of the crossbeds were measured along with the orientation of the surrounding strata. The trough directions of the Phi cross-stratification were measured where cross-sections were available to identify the trough crossbeds.

Treatment

As mentioned before, tilt correction of foreset azimuths, graphic vector addition for compilation of moving averages and consistency ratios for 2 000 feet squares, and tabulation (appendix 11, p. 181) were done. The resultant vectors and the consistency ratios are shown on map 20, p. 245, and indicate the dispersal pattern of the quartzites immediately overlying the White Reef.

RIPPLEMARKS AND SANDWAVES

The axial directions of ripplemarks and sandwaves were measured with a Brunton compass. The symmetry of the ripplemarks was studied by means of plasticine moulds, and the wavelengths and amplitudes were measured as well. Three readings were averaged arithmetically and were considered sufficient to reflect the average axis orientation of a set of ripples. These are plotted on map 12, p. 235.

SUMMARY OF MEASURED DATA

The measured data are summarised and their treatment and presentation indicated in table 6, p. 27.

TABLE 6

SUMMARY OF MEASURED DATA

Column Headings:

- P - Pilot Study
- C - Checks on Pilot Study Results
- W.R - White Reef Measurements
- H.W - Hangingwall Measurements
- F.W - Footwall Measurements
- Ts - Total Measuring Stations
- Ti - Total Individual Measurements

Abbreviations:

- Av. con. - Averages contoured
- Mov. av. - Moving average
- Or. plot. - Orientation plotted
- Reg. cor. - Regression correlation
- Av. - Averaged
- Av. va. map - Average value map
- St. dev. - Standard deviation

PROPERTY	DATA							TREATMENT	PRESENTATION
	P	C	W.R	H.W	F.W	Ts	Ti		
Thickness	224	17	285			526	526	Av. con.	Isopach
Crossbeds	10		94	180	160	435	1 312	Mov. av.	Vector map
Ripplemarks				15		15	45	Or. plot.	
Sandwaves				2		2	2	Or. plot	
Pebble size	126	17	285			428	63 801	Av. con.; Reg. cor.	Size map
Pebble packing	125	17	285			427	63 761	Av. con.; Reg. cor.	Percentage map
Pebble sorting	126	17	285			428	63 801	Av. con.; Reg. cor.	St. dev. map
Pebble fabric			12			12	1 200	Av.	Orientation map
Pebble composition			145			145	33 987	Av. con.	Isopleth map
Pebble shape and sphericity			6			6	462	Av.	Av. va. map
Two-dimensional sphericity			14			14	700	Av. con.	Av. va. map
Gold content	224	17				241		Av. con.	Av. va. map
Uranium content	146	17				163		Av. con.	Av. va. map
Silver content	31					31		Av.	Graphic
Sulphide content		9				9		Av.	Graphic

ANALYSIS

1. STRUCTURE

FOLDING

DESCRIPTION

North of the Witpoortjie fault, the White Reef reflects an asymmetrical structural basin with a steeper western flank, which is slightly overturned. The original form has been considerably altered as a result of displacement along faults and dykes. Due to this fragmentation, and the incompleteness of data in the south-east, the exact shape of the basin is hard to define in this direction (map 3, p. 226). The main elements of the reconstituted structure, prior to fragmentation, are shown at the levels of the White and Main Reefs (maps 4 and 5) and on surface (map 1, p. 224).

The major fold is the West Rand syncline plunging to the south-east (maps 1 and 5). It is important to note that it is reflected at the level of the White Reef only by the wider outer shallow rim (map 4, p. 228). The interior of the syncline, at the level of the White Reef is folded into a prominent basin, which will be called the Randfontein trough, situated against the western flank of the major syncline. It's axis is orientated north - south but, where it is positioned close to the Witpoortjie fault in the south, it changes to a south-westerly direction (map 4). This change in direction of the Randfontein trough is caused by its merger with the north-easterly Witpoortjie trough (see map 6, p. 229). The West Rand syncline, orientated to the north-west similarly changes orientation into a north-easterly fold where it abuts against the western rim at the level of the Main Reef (map 5, p. 228). In the northern section, the basin is complicated by steep dips associated with overturning and major reversed faulting, the effects of which could not entirely be removed by the reconstitution of the White and Main Reef structural surfaces (see Plate II, cross section GH, Toens and Griffiths, 1964, for these faults). Apart from the Randfontein depression, various smaller order anticlines and synclines, or rather swells and depressions, are present. Most of the smaller features, orientated in north-eastern and north-western directions, are reflected at both sub-surface structural levels (maps 4 and 5), whilst very minor ones are revealed by isopach lows in areas where data are adequate (map 7, p. 230). The fold trends, present at various stratigraphic levels, combine to form an orderly geometric pattern (map 22, p. 247). It is noteworthy that the surface Witpoortjie syncline, orientated to the north-east and situated against the Witpoortjie fault (map 1) is also present at the two sub-surface levels, except in the central Deep Shaft area where exposures are sparse (maps 4 and 5).

INTERPRETATION

The isopach thicknesses of the South - Main Reef interval (map 6) show a symmetrical pattern of sediment infill towards the central area, indicative of an early active broad West Rand depositional trough. The close similarity of the isopach and structural patterns reveals that the outer rim framework and the Randfontein and Witpoortjie troughs have been largely retained by the present day West Rand syncline at White Reef level (maps 4 and 6). The Randfontein and Witpoortjie depressions were present as early subsidence features and cannot correctly be termed as synclines in the early stages, as they were related to a process of basining not necessarily caused by compression. The western flank was the steepest in South - Main Reef times, in accordance with the present day steeper western limb and it is flanked by the linear Randfontein trough which extends northwards (map 6). The isopach pattern also shows the slighter, shallow Witpoortjie depression extending north-eastwards towards the mine boundary between West Rand Consolidated and Luipaardsvlei Estates. The depression is also visible at both Main and White Reef levels, but only where exposures are adequate. There is, however, no isopach evidence of an early strong north-west depression coindicent with the axis of the main West Rand syncline, as expressed at the level of the Main Reef and by the outer rim at White Reef level (maps 4 and 5). This fold must therefore have been developed at a later stage.

Indications of the continued activity of the general north-eastern 'fold', or more correctly subsidence system, are present at the level of the Livingstone Reefs zone which is generally about 800 feet below the White Reef horizon. The syncline, orientated to the north-east and positioned at the boundary of the West Rand Consolidated and Randfontein Estates (A_6, map 5, p. 228), coincides in position at its northern end with the main entry point of the Livingstone Reefs sediments. Here, the highest gold concentrations and highest conglomerate percentages occur. The major isopach channel for the Livingstone Reefs, which contains the main payshoots, coincides in position with the upper section of the syncline (maps 3 - 7, Steyn, 1963) and reflects the influence of the Randfontein trough on Livingstone Reefs mineralisation. The sedimentological data of the Livingstone Reefs do not, however, extend far enough laterally to cover the other structural elements discussed here. Steyn (1963, fig. 16) compiled a π-diagram plot of dip and strikes obtained from mine plans of the economic area of the Livingstone Reefs and determined a plunge of 22^o in the 186^o direction of the axial fold of the Randfontein inner basin and not the wider West Rand syncline. The Randfontein trough thus represents the axial base of the larger West Rand subsidence during the South - Main Reef period of sedimentation. Southwards it bends into the north-easterly Witpoortjie trough which suggests that the latter is another primary structure parallel to the axis of the Main basin. An early system of north-easterly tensional troughs was thus active. A local closed basin developed at the confluence of these two troughs during the interval that separated the South and Main Reefs (map 6, p. 229).

Limited post-depositional folding is related to the uplift of the Witpoortjie horst which uptilted the sediments immediately against its northern edge.

This steepened the southern flank of the adjacent, north-easterly directed Witpoortjie trough and also the southern rim of the Randfontein basin, developed at the level of the White Reef.

The major phase of folding related to the formation of the West Rand syncline, is post-depositional as is shown by the various sections illustrated in Plate II, Toens and Griffiths, 1964, which do not reflect marked basining for Main - Kimberly Reef interval, or even for the V.C.R. The folding accentuated the early dips of the flanks of the West Rand trough, expecially that of the western flank. Previous investigators, e.g. Roering (1968), postulate that the movement probably took place in response to north-south compression. It is not clear, however, how such north-south compression failed to deform the major syncline and how it provided the mechanism to steepen the flanks of the north-south orientated interior Randfontein basin. The curved surface of the Witpoortjie fault does not factually prove the north-south compression, as non-linear faults are by nor means exceptional.

Mellor (1917), Pretorius (1964) and Roering (1968) saw the main mechanism as that of relatively incompetent Witwatersrand sediments moving into the depression between adjacent granite buttresses. The isopach and paleocurrent data, to be presented later, clearly illustrate that the West Rand depression was in fact subsiding from early depositional times, and that the flanks were rising. The steep dip of the western limb of the syncline is superimposed on a rapidly thinning Main Reef Stage, indicative of such basining (map 6, p. 229). The thinning was still in evidence during White Reef times (map 7, p. 230) and immediately thereafter (map 20, p. 245), but less so during the following White- Monarch Reefs interval (map 11, p. 234). It is evident that the Randfontein trough was actively subsiding adjacent to the western limb, and that its early position is reflected by the present day structural basin, best visible at the level of the White Reef (map 4, p. 227). The marginal Randfontein trough is suspected to be analogous with that described in detail for the Loraine Mine in the O.F.S. by Olivier (1963). He showed that a direct relationship exists between sedimentation and contemporaneous folding and local overthrusting. The Loraine trough has a similar, very steep, western marginal limb and a relatively flat area from the fold axis eastwards.

At a later stage the mechanism was not so much the sinking of the depositional area, but rather the strong uplift of the surrounding denuded granitic source areas and eroded synclinal flank sediments which was most likely due to isostatic response to load reduction. This uplift did not terminate at the end of Witwatersrand deposition but continued, in response to later erosion, to deform and fracture the brittle sediments after lithification. Pretorius (1974 a) is also of the opinion that post-depositional regional structures in the Witwatersrand basin are due to the continued activity of the earlier faulting and folding. The basining eventually phased into fold compression which steepened the dips on the west flank and formed the reverse faults.

In summary, the fold history is that of a large subsiding trough containing fixed sub-component areas of subsidence, which exhibited variable activity at different stratigraphic levels (map 22, p. 247). The main NNW-SSE and north-easterly trends of subsidence of Main - South Reef times were maintained in the White Reef period, however they switched to a north-east subsidence in the White - Monarch period. However, minor subsidence trends with constant north-east and north-west directions were active throughout.

FAULTING AND INTRUSIVES

DESCRIPTION

The main displacement on the West Rand is the Witpoortjie fault, which defines the southern limit of the area investigated. This structure generally strikes north-east on Randfontein Estates. Further eastwards it veers more towards the east, and on East Champ d'Or it trends nearly east-west.

The other faults of the West Rand can be divided into two sets; the most important set has an average north-east trend, while the other runs approximately north-west.

The north-east set includes virtually all the larger faults whose orientations seem to be related to that of the major Witpoortjie fault. They appear to subtend small, but almost constant, angles with the latter regardless of changes in trend of the major structure. In the western part of the Randfontein Estates and in West Rand Consolidated (map 3, p. 226), the faults strike predominantly north-north-east. Eastwards, along the boundary between West Rand Consolidated and Luipaardsvlei Estates, the average trend is north-east, while near the East Champ d'Or it changes to east-north-east.

The north-east trending faults are not only related to one another by virtue of a common attitude in relation to the Witpoortjie fault, but also have larger displacements than the second set of faults. With the exception of the faults on the steep western limb of the basin, they are all of normal type, associated with relatively large 'losses' of ground. Vertical displacements on the larger ones range from 600 to 1 200 feet, with horizontal displacements as great as 1 500 feet. Reverse faults are only found on the western flank of the basin and trend north-north-east.

The north-west set are also normal faults, but have relatively small vertical and horizontal displacements, which rarely exceed 200 feet in either direction. Some of them laterally displace the major north-east faults, notably those occupied by dykes just north of Monarch Shaft (map 3, p. 226) and immediately to the south of West Shaft on Luipaardsvlei Estates.

The dykes which cut the beds of the Upper Witwatersrand, are related to the faults described above, and thus fall into two groups aligned north-west and north-east respectively. The largest ones follow major north-east faults, with occasional offshoots along cross-fractures, and occupy the middle sections of the faults, where maximum displacement occurs. Thus, the two largest dykes on West Rand Consolidated are restricted to the middle sections of normal faults and die out laterally or split up into a number of smaller dykes where the displacements become small. The dykes associated with the north-west faults are either offshoots from larger, north-east trending dykes, or form independent intrusions.

Interpretation

The sinking of the depositional area during sedimentation and the associated uplift along the eroded basin edges caused normal faults to develop parallel to the basin edges. Roering (1968) postulated that the earliest event was the development of strike faults. These faults are best visible at the level of the White Reef on Randfontein Estates and West Rand Consolidated and involve both sets of faults mentioned. Some of these faults seem to displace the lower beds to a larger extent indicating their possible early initiation (Plate II, Toens and Griffiths, 1964). The earlier basin edge strike faults are complicated by later, similarly orientated displacements.

The major displacements, like the Witpoortjie fault, the dyke-filled fault passing through South Shaft on West Rand Consolidated and the other large faults between them, are curved in outcrop orientation and strike roughly north-east, indicating that they were formed sufficiently early to be bent by the late stages of folding which accentuated the major West Rand subsidence. They may be contemporaneous with some of the later strike faults which developed along the edge of the basin.

During the late phase of the tensional state, dykes were emplaced mainly along the north-north-east faults, according to Pegg (1950). This was possibly preceded by the east-west compression, which led to the steepening of dip on the west flank, as well as reverse faulting (Mellor, 1913; Toens and Griffiths, 1964; Roering, 1968). The last structural event was the development of north-west trending faults, which displaced the earlier faults of Witpoortjie age and are best represented on West Rand Consolidated (Toens and Griffiths, 1964; Roering, 1968).

2. FOOTWALL GEOLOGY

The purpose of the study is to analyse the processes of sedimentation and mineralisation control of the White Reef conglomerate. It is nevertheless relevant to define, in a general sense, the shape, sedimentation trends and structural evolution of the underlying beds in order to establish the geometry and tectonic setting of the surface that received the White Reef conglomerate. The information available about the footwall is limited and restricted to certain stratigraphic levels, but is nevertheless adequate for this purpose.

MAIN REEF STAGE

SOUTH-MAIN REEF INTERVAL

An isopach plan (map 6, p. 229) for the South-Main Reef interval was compiled by Toens and Griffiths (1964). It can be compared to the reconstructed structural map at the level of the Main Reef (map 5, p. 228).

Description

The outer framework of the isopach and structural patterns are generally similar. The very slight north-south 'Randfontein' depression is present on the isopach map adjacent to the western rim, and so is the elongated, faint 'Witpoortjie' depression extending from east of S.V. Shaft (Randfontein Estates) north-eastwards over the common mine boundary between West Rand Consolidated and Luipaardsvlei Estates.

Interpretation

The isopachs indicate that the West Rand area was an early trough that subsided during the South-Main Reef period. The early geometry of the trough is similar to the overall form of the present day area except for the later developed West Rand syncline. Early features have been accentuated at higher stratigraphic levels. The local Randfontein subsidence orientated north-south adjacent to the western rim, formed the bottom of the wider West Rand trough, and adjusted its terminal ends to early existing minor NE-SW trends of weakness. The western flank of the trough was at that early time, already rising faster than the eastern limb indicating that the asymmetry was an early feature. The shallow Witpoortjie depression, extending north-eastwards is seen at both marker bed levels mentioned. It is a minor linear subsidence which probably developed as a local basin in early Main Reef Stage times (map 6).

POST MAIN REEF

Only two large erosion channels cut into the Main Reef horizon (Plate II, Toens and Griffiths, 1964). In its upper reaches, the larger channel is situated high up the western rim of the major West Rand syncline in the area of its axial position, and is orientated to the south-east. The second, smaller channel is also related, in its higher rim position at the common mine boundary between West Rand Consolidated and Luipaardsvlei, to the north-east trending Witpoortjie syncline. These two instances indicate possible subsidence control of post Main Reef streams which was, however, not retained lower down the flatter flanks of the West Rand trough.

LIVINGSTONE REEF STAGE

THE LIVINGSTONE REEFS

Indications of the continued activity of the north-eastern trend of subsidence are present at the level of the Livingstone Reefs zone, which forms the base of the Livingstone Reef Stage and is generally situated about 800 feet below the White Reef horizon. The small syncline, orientated to the north-east and situated at the northern boundary of West Rand Consolidated and Randfontein Estates (map 5, p. 228), coincides in position at its northern end with the main point of entry of the Livingstone Reef sediments. Here the highest gold concentrations and conglomerate percentages occur. The major isopach channel which contains the main payshoots, coincides with the upper section of the syncline (maps 3 - 7, Steyn, 1963). The sedimentological data of the Livingstone Reefs do not, however, extend far enough laterally to cover the other main elements of the sub-regional structure. It is significant that the best developed and highest pay Livingstone Reefs are related to the upper end of the north-south Randfontein trough which was previously active as early as Main-South Reef times.

The Footwall Beds of the White Reef

The White Reef, as the basal unit of the Bird Reef Stage, is underlain by the upper quartzites of the Livingstone Reef Stage.

Lithology

The quartzites below the White Reef range from siliceous to argillaceous. A variable number of gritty beds and layers with scattered pebbles are present, and also some lenticular conglomerates. These are laterally discontinuous and could not be correlated successfully for the purpose of the construction of an isopach map. The increase of coarser sediments upwards indicates the absence of a marked unconformity directly below the White Reef, and also suggests that the genetic base of the Bird Reef Stage should be taken at the base of the zone of footwall grits and conglomerates. The upward coarsening of sediments also indicates that regression, or an increased uplift in the northern source areas, had already begun prior to the White Reef conglomeratic pulse.

Paleocurrent Patterns

The trends of sedimentation are clearly shown by the azimuth directions of planar crossbedding foresets and this compensates for the lack of isopach data for the immediate foorwall beds (map 13, p. 236).

Description The paleocurrent pattern, based on moving averages of crossbedding vectors, illustrates two major trends, one on either side of the axial position of the West Rand syncline (map 13). On the east flank of the main syncline the flow direction (arithmetic mean of vectors 167^o, standard deviation 35^o, fig. 18, p. 218) was sub-parallel to the 132^o strike direction of the eastern limb of the fold shown on fig. 20 (p. 219). The offset angle is 35^o directed inwards, convergent towards the trough axis. On the west flank the general flow direction (arithmetic mean 182^o, standard deviation 42^o, fig. 19, p. 218) is similarly offset basinwards by an angle of 18^o from the 220^o strike direction of the western limb (fig. 20, p. 219). The combination of these two major paleocurrent trends results in an overall sedimentation direction towards the south-south-east (arithmetic mean 176^o, standard deviation 42^o) which closely approaches the axial plunge direction of 186^o of the north-south Randfontein fold as determined by Steyn (1963, fig. 16) using a π-diagram plot of dip and strikes obtained from mine plans.

The differences between the two flow trends are more effectively illustrated by rose diagrams. The sedimentation of the eastern flank is homogeneously directed to the south-east, with the major mode in the 150 - 170^o direction which is representative of 27 per cent of the azimuth directions (fig. 18). The paleocurrents associated with the western flank have the major mode in the 190 - 210^o direction, and are also representative of 27 per cent of the vector directions (fig. 19). In the latter case, the deviation from the arithmetic mean direction by the major mode, the presence of a minor mode and the larger standard deviation all indicate greater heterogenity related to a lower paleogradient. The existence of these two main modes, as also demonstrated by the rose diagram of fig. 20, is probably not real but a reflection of the distribution of data points measured mainly along the flanks of the West Rand syncline.

The overall pattern contains several noteworthy local deviations from the general fan pattern. On Luipaardsvlei a small fanlike dispersal pattern radiates southwards away from A_{24}; it is also reflected by scalar properties (map 15, p. 239). The second feature is the small group of azimuth directions around E_{10} directed to the south-east. The third minor subcomponent is the symmetrical flow orientated directly southwards at the extreme ends of both synclinal limbs. Lastly, there are the deviations towards the south-west at I_{27}.

Interpretation The apex position of the azimuth spread indicates that the main point(s) of sediment entry is located north of the central outcrops on West Rand Consolidated (map 13, p. 236). It is offset by a small degree from the axial position of the main syncline, as it is situated just to the north-east of the outcrop of the synclinal axis. Fig. 20 is an attempt to illustrate the offset relationship.

The northerly position of the entry points indicates that the main point of debouchment was in that direction. The proximity of the main entry points to the apex position of the West Rand syncline indicates subsidence control of the major inflowing streams. With flow trends on both limbs of the syncline symmetrically diverging towards the trough centre and with the flow directed down it in the lower reaches, it appears that the overall sedimentation was contained and directed by the depositional trough. Whilst the source area north of the eastern limb was in a stage of active uplift, the western limb was dormant as far as sediment supply was concerned. It was nevertheless prominent enough to act as a barrier preventing significant flow to the south-west. The source uplift, north of the eastern limb, was responsible for the main entry point(s) being positioned north-eastwards and offset of the axial position of the syncline, and for the smaller entry point or channel head, being further east. The geometry of the flow pattern, nevertheless, followed that of the tectonic framework due to this uplift in the north and the sinking of the trough. The change, from an initial fanlike dispersal pattern, to a direct north-to-south flow at both ends of the synclinal limbs, possibly suggests the terminal position of the channelling effect of the West Rand trough, and a transition to general north-to-south sedimentation into the larger Witwatersrand basin beyond the confines of the trough. The relevant data at these two positions are, however, too limited to make this anything but a suggestion.

3. THE WHITE REEF

EXTERNAL GEOMETRY

DESCRIPTION

Two major areas, one with a relatively thin and another with a thicker conglomerate, can be defined.

South-Western Area with Thin Conglomerate

An area of generally thin conglomerate extends over the south-western corner of West Rand Consolidated and the whole of Randfontein Estates with the exception of the north-eastern corner of the latter mine area (map 7, p. 230). The zone with the thin reef trends mainly south-southeast, and is linked to a second smaller zone of narrow reef extending to the north-east over N_8 - M_9. Local areas with relatively thicker reef (+ 11 inches) are centered on R_5, at O_{6-7}, extending eastwards and at L_7 - K_7, extending northwards.

North-Eastern Area with Thicker Conglomerate

The remainder of the area studied, is covered by relatively thicker reef.

West Rand Consolidated The boundary between the major areas containing thick and thin conglomerates occurs in the south-western section of the mine, where exposures are limited; it runs between Monarch and Deep Shafts and extends to the south-east. To the north-east of this line, the reef thickens, and two distinct elongated zones with thicker reef are present. In the centre of the mine an elongated zone with thicker reef extends to the south from B_{11} near the outcrop. It contains the main payshoot for gold (map 8, p. 231). The second zone, located further east, also starts at the outcrop (B_{15}, map 7, p. 230) and extends to the south-southeast. A small patch of thicker reef is also indicated by the thirty inch contour at B_{9-10}.

Luipaardsvlei Estates Intersections of the reef are reasonably well spaced and distributed, but are not numerous enough to yield truly representative values (map 7). The pattern of thickness variation is thus less reliable than that at the other mines and is further complicated by the two major faults which cross the central area. On Luipaardsvlei Estates the reef is generally thicker than elsewhere and locally attains a thickness of seventy-two inches. In the central portion of the mine, aroung F_{23}, there is a large area of relatively thick reef (plus thirty inches on map 7). Three elongated areas of thicker reef extend from this central part of the mine to the outcrops at B_{20}, C_{25} and F_{28}.

East Champ d'Or A well-defined broad zone of thick reef stretches from just east of Tudor Shaft at G_{29}, south-eastwards to the Witpoortjie fault at I_{31} and covers most of the mine area. Its central area with the thickest, large pebbled reef contained fairly high gold mineralisation and was mined (maps 2, 7, 8 and 14).

INTERPRETATION

On a regional scale the shape and thickness of a sedimentary body is controlled by tectonics. According to Sloss (1962) external source sedimentation tends to strongly reflect conditions in the source uplifts while the rate of subsidence of the depositional area is a minor factor. The isopachs of maps 6 and 11 show that in the West Rand trough, marked subsidence underlies the thicker quartzites so that the structural pattern is imprinted on that of sedimentation.

In a shorter time span there is less time for structural adjustment. With a coarse thin gravel rapidly deposited on a fan by braided stream action, the external control could be strong. This is effectively demonstrated for the White Reef by the general increase in thicknesses and sediment coarsening towards the north-eastern outcrops (maps 7, 14, 15 and 16). The external source is the major control for reef thickness variation. The strong source uplift to the north-east caused the greater part of the sediment load to spill southwards over the eastern rim of the trough in initial disarray, with the position of the apex high on the paleoslope (map 19, p. 244). Lower down, the trough asserted control of the direction of sedimentation, indicating that subsidence is the second order control factor, as the thicknesses around the rim also generally increase basinwards.

Smaller subsidences were also active although their effects were very slight. They can be recognised by the coincidence of thicker reef with known positions of depressions, e.g. the minor payshoot extending south-west at D_{16} (maps 4, 5, 6, 7 and 8). These very mild structural flexures can also be deduced from the isopachs. This is clearly visible on Randfontein Estates (map 7, p. 230). This marked geometrical pattern of isopach linears cannot logically be explained by means of differential erosion, as the two directions are anomalous with that of the paleocurrents (map 19, p. 244). As the directions are aligned along with that of the known structural fold directions, they are interpreted as very mild flexures active during sedimentation. Such detailed interpretation can be accurately determined for the area of the Randfontein facies only where data points are dense. There is, however, no valid reason to disbelieve that the pattern is not present over the remainder of the West Rand. Using the known NE and NW directions as a guide, similarly aligned isopach lows can be interpreted as possible structural lows on the other mines. The positions of these have, however, not been delineated on map 7 as their interpretation is somewhat speculative. The very low vertical and horizontal amplitudes, and the right-angled interference pattern are by no means unique, and are comparable with that observed by Sims (1972) occurring below the Basal Reef in the O.F.S. Goldfields where horizontal amplitudes of several hundred feet and low vertical amplitudes were present, reaching down to a few feet at the level of the Lower Reef.

There is also the north-south Randfontein trough which is a marginal feature, related to the western rim of the major West Rand trough (map 4, p. 227). There is therefore no need to try and reconcile its different orientation with that of the NW and NE folds, which have been recognised elsewhere to be of regional and even basinal distribution, according to Pretorius (1964). In areas where reef thicknesses are adequately exposed along the fold axis, e.g. E_8 - G_8, M_8 and S_7 - T_6 the reef is somewhat thicker. There is, therefore, no proof that this fold was not active, as was the case in South-Main reef times (maps 4, 6 and 7).

Uneven erosional scouring of the pre-White floor is common at many localities as a low order determinant of the shape of the conglomerate body (e.g. fig. 2). The erosional force of a coarse bedload can be considerable. The elongation directions of several zones with thicker reef, i.e. over E_{20} and H_{30}, and possibly also those at D_{11} - G_{10} and D_{15}, are coincident with the local paleocurrent directions of the reef (maps 7 and 19). Most of these zones also contain larger pebbles (map 14, p. 237) and apparently represent larger stream channels which were scoured out of the underlying floor sediments by rapid flowing abrasive currents.

VECTOR PROPERTIES

The azimuth directions of the inclinations of crossbedding foresets in the reef at ninety-nine measuring stations are shown on map 12 (p. 235). A moving average technique was utilised to smooth out the scatter, in order to obtain the general paleocurrent pattern shown on map 19.

DESCRIPTION

The moving average pattern illustrates three component trends. On West Rand Consolidated, west of B_{15}, the paleoflow is almost homogeneously towards the south-west with the main mode in the 210 - 230° direction (map 23 A, p. 248). This tendency extends downslope onto the north-eastern part of Randfontein Estates over M_8 and M_{12} (map 19). Over the remainder of the latter mine, deposition was directed towards the south-east, swinging slightly more eastwards east of 32 Shaft. The two main modes shown on map 23 at B for this area, when viewed in the light of the limited number of measuring stations, is part of a general tendency towards the south-east with a marked degree of scatter present. Over the remainder of the area, east of B_{16}, the paleocurrent azimuths are generally directed towards the south-south-east, with the main component in the 150 - 170° segment (map 23 C). However, the trend at the centre of Luipaardsvlei Mine is more directly southwards (map 19). The rose diagram D on map 23 which combines all the measurements, is somewhat misleading as the directions of the larger percentage segments reflect the greater amount of readings taken on West Rand Consolidated Mines. For an overall interpretation, it is necessary to view the relative fit of the three separate components.

INTERPRETATION

Combination of vector and scalar properties of the White Reef indicate that the main entry points of sediment supply were situated to the north beyond the eastern limb of the West Rand trough (maps 10, 14, 16, 17 and 19). The local current trend over the western section of Randfontein Estates, is directed towards the south-east and does not therefore exclude the possibility of another entry point west of 32 and 2N Shafts. The paleocurrents show a progressive change in azimuth directions down the paleoslope and it is possible that the currents did swing gradually from a northerly entry first towards the south-west and then south-eastwards in a broad meanderlike curve. This is confirmed by patterns of various scalar properties which exhibit similar gradual changes of direction (maps 8, 9, 14 and 16). The ratio of gold to uranium which successfully locates the northern entry points fails to support a western entry lower down the western limb (map 10), but the probability of a minor entry point situated directly south of 32 Shaft is supported by some scalar properties (maps 9, 14 and 16). It is therefore concluded that the main influx of gravel deposited along the western limb moved in from the north and followed a broad curve to the south-west which changed lower down the paleoslope to the south-east.

The overall pattern of azimuth spread on the three northerly mines, forms a fan diverging southwards away from the central northern entry point. The previously described trend, orientated towards the south-west on West Rand Consolidated, is seen as a segment of this pronounced fan-out. It is probably due to the main entry being off-centre, east of the trough axis and resulting from inflow into the north-south Randfontein trough (map 4). With this exception, the direction of sedimentation is largely in harmony with that of the footwall beds, being contained and directed by the main north to south plunging subsidence (maps 4, 23 D).

It is noteworthy that the detail of the White Reef flow pattern differs somewhat from that of the immediate footwall sediments. The strong sedimentation of the footwall beds towards the south, lower down the western flank, had given way to White Reef currents directed to the south-east. This change, along with the mentioned likelihood of a minor westward entry point south of 32 Shaft, suggests that the western rim was in White Reef times subjected to stronger, but still minor, uplift. Another difference is that the fan-shaped pattern of the White Reef high up the paleoslope is more pronounced than that of the floor quartzites. This means that in White Reef times the depositional fan regressed further into the main basin.

There is some evidence that the upslope paleocurrents were influenced by local topographic variations of the floor, e.g. E_{20}, H_{30}, D_{11} - G_{10}, G_{15} (see p. 38). Comparisons, however, are hampered by the limited paleocurrent data. Lower down the slope, e.g. to the south-west of Monarch Shaft, the variations of floor topography are too slight to affect a strong chanelling of flow. There, the flow is generally more uniformly controlled by the orientation of the paleoslope.

The structural control of paleocurrents can, in the light of the above, be clearly defined. The base of the large West Rand subsidence was located along the Randfontein trough which guided continued main stream sedimentation along its course. Upslope on the depositional fan, minor north-easterly and north-westerly subsidences did influence the direction of depositional currents. Lower downslope, the relief effects related to subsidences were too minor to deviate the paleocurrents and there was not enough strong current-driven scouring to keep low floor areas open (maps 8, 9, 14, 15 and 16).

COMPOSITION OF PEBBLES

The pebbles in the conglomerate represent a large variety of rock types; these are summarised in table 5 (p. 25) and are classified, for comparative purposes, into the main types, shown in table 7 below.

DESCRIPTION OF PEBBLE DISTRIBUTION

On the basis of the areal distribution of pebble types present, the conglomerate can be divided into three facies (table 7 and map 18, p. 243). The Randfontein and Luipaardsvlei facies possess virtually identical pebble compositions and strong sedimentological evidence will be presented at a later stage to argue a single deposition. They will be referred to separately, however, due to the differences in mineralisation and depositional energy related to their different locations.

The main difference between the facies is that the West Rand conglomerate contains almost no pebbles of quartzite, which is the second most abundant rock type in the other two facies. It also contains almost twice as many chert and milky white quartz pebbles. Coloured quartz constitutes the major pebble type in all the conglomerates but it is more abundant in the West Rand facies than elsewhere. The Randfontein and Luipaardsvlei pebble

TABLE 7

LATERAL VARIATION IN PEBBLE LITHOLOGY

PEBBLE COMPOSITION	RANDFONTEIN FACIES (per cent)	WEST RAND FACIES (per cent)	LUIPAARDSVLEI FACIES (per cent)
Quartzite	33	3	30
Chert	5	8	4
Milky white quartz	10	24	11
Coloured quartz	43	60	50
Miscellaneous	9	5	5
	100	100	100
Number of measuring sections	58	38	49

populations are almost identical in composition except for different amounts of miscellaneous rock type pebbles.

Since it is difficult to distinguish between quartz and quartzite, it is still necessary to determine whether the West Rand pulse is indeed a different phase. There is various evidence to support this conclusion. Firstly, Minter (1972), in an independent study showed an almost identical composition for the White Reef on West Rand Consolidated, see table 8, p. 43 , confirming the identification of components. Secondly, errors arising from the comparison of pebbles from weathered outcrops and those from the subsurface can be excluded, since 99 percent of the fragments examined came from the underground workings. Thirdly, misidentification related to changes with progressive study is unlikely as the Luipaardsvlei phase contains pebbles embedded in a light siliceous matrix while that of the Randfontein pulse is dark and carbon rich. Fourthly, if the lithological aspect is ignored, differences in depositional mechanisms (to be presented later) independently necessitate the defining of the West Rand phase as a separate entity.

Randfontein Facies

The Randfontein facies occurs over the entire Randfontein Estates Mine area and the south-western corner of West Rand Consolidated (map 18, p. 243). Quartzite pebbles, which average 33 per cent and range from 8 to 60 percent, form an important part of the pebble population. As in the case of the other two facies, coloured quartz pebbles are most abundant, constituting 43 per cent of the total pebbles counted. In the eastern part of the area, miscellaneous pebble types are more abundant than elsewhere, averaging 14 per cent in comparison with a mean value of 9 per cent for the area as a whole. In the extreme south-west, at the U_3, V_3 and W_1 grid localities, chert pebbles make up 12 per cent, compared with the overall average of 5 per cent. Sims (1969) noted a similar increase in smaller chert fragments down the slope and ascribed it to the break up of brittle chert.

West Rand Facies

The central part of the West Rand Consolidated Mine area is underlain by the conglomerate of this facies. Pebble counts yielded consistently low quartzite percentages, the overall average being 3 per cent. Coloured quartz pebbles are the most abundant; they form 60 per cent of the overall pebble population and over 70 per cent near the centre of the area.

Three sub-ordinate facies are present close to the northern outcrops. Two small areas around C_8 and B_{17} contain 15 and 16 per cent chert respectively compared with the facies mean of 8 per cent. Over a comparatively large area around B_{11}, white quartz pebbles exceed 50 per cent, although the average for this pebble type is only 24 per cent. Miscellaneous pebble types account for only 5 per cent of the West Rand facies.

Luipaardsvlei Facies

The Luipaardsvlei facies occurs over Luipaardsvlei Estates and East Champ d'Or mines, and over a small section on the eastern margin of West Rand Consolidated mine. Quartzite pebbles are abundant and form, on average, 30 per cent of the pebble population; along an east-west zone running across the centre of Luipaardsvlei, however, the proportion is even higher. Coloured quartz pebbles predominate and constitute, on average, 50 per cent of the population, with the highest values in the south. Milky white quartz pebbles make up on average, 11 per cent of the conglomerate, but over most of East Champ d'Or they exceed 20 per cent. Chert and miscellaneous pebble types each constitute 5 per cent or less.

INTERPRETATION

The presence of different lithological phases, each containing various sub-populations, indicates a limited mixing related to only a moderate distance of transportation.

The compositions of the White Reef pebbles are compared with those of other Witwatersrand reefs in table no. 8 on the following page.

TABLE 8

PEBBLE COMPOSITIONS OF VARIOUS WITWATERSRAND REEFS

	WEST RAND									O.F.S. GOLDFIELDS							KLERKSDORP			
	R	WR	L	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Qz	33	3	30	16	11	3	7	10	11	5	5	2	7	3	1	5	7	3	5	10
Ch	5	8	4	7	6	8	7	6	6	92	23	48	46	45	86	80	17	12	13	8
Q	53	84	61	77	82	85	86	84	83	3	60	50	45	47	10	10	70	85	78	52
Ms	9	5	3	-	-	4	-	-	-	-	12	-	2	5	3	5	6	0	4	30

Qz = quartzite Ch = chert Q = quartz Ms = miscellaneous

WEST RAND

R	=	Randfontein phase	White Reef	(Steyn)
WR	=	West Rand phase		
L	=	Luipaardsvlei phase		
1	=	Zone 2 Reef	Bird Reefs	(Minter, 1972)
2	=	Monarch Reef		
3	=	White Reef		
4	=	South Reef	Main Group	(Minter, 1972)
5	=	Main Reef		
6	=	North Reef		

O.F.S. GOLDFIELDS

7	=	UF-2 Reef	Livingstone Group	(McKinney, 196
8	=	Basal Reef	Bird Group	(Minter, 1972)
9	=	Middle Reef	Bird Group	(McKinney, 1964)
10	=	Leader Reef	Bird Group	
11	=	B Reef	Kimberley Group	
12	=	Lower Reef	Elsburg Group	
13	=	Upper Reef	Elsburg Group	

KLERKSDORP

14	=	Basal Grit	(Minter, 1972)
15	=	Vaal Reef	
16	=	Zandpan Marker	
17	=	Upper MD 4 Grit	

The table shows the White Reef to contain more quartzite pebbles than the other reefs, although the above data of Minter (1972) for the White Reef reflects only the composition of the West Rand facies. However, it is difficult to compare his results as neither the localities or sample populations are known, and lateral variations in Witwatersrand reefs are considerable. This is demonstrated for the White Reef by table 7 (p. 43) and for example, also by Sims (1969) for the 'B' reef in the O.F.S. with white quartz ranging between 14 and 40, quartzite between 12 and 24 and chert between 9 and 27 per cent. Many of the above average values may, therefore, reflect generalisations, especially as the composition of fluvial gravels changes downslope (Plumley, 1948; Schlee, 1957). However, a higher quartzitic content for the West Rand reef sources is also reflected by the stratigraphically proximate Zone 2 Reef (see table 8), and the underlying Livingstone Reefs, which, according to Toens and Griffiths (1964), are mainly composed of quartz pebbles and also a considerable number of quartzite pebbles. It is likely, therefore, that the source areas north of the West Rand differed from those at Klerksdorp and in the O.F.S., by introducing in the upper Main-Bird stage more quartzites and also fewer cherts. Knowles (1966) found boulders and cobbles of quartzite in the V.C.R. at West Driefontein, but these could have been derived, as he pointed out, from the Witwatersrand sediments and there is probably no connection with these earlier quartzites. Further, it is of interest to note that the composition of the stratigraphically correlative White Reef (West Rand phase) is identical to that of the Basal and Vaal Reefs, as was observed by Minter (1972) indicating related source rock types.

The quartz pebbles, being the most durable (Pettijohn, 1957), can be utilised as an index of the distances transported. In this case, the Randfontein and Luipaardsvlei phases represent shorter distances of travel than the other reefs on the West Rand. The gravels of the O.F.S., however, appear to have undergone least transport if judged only on lithology.

PEBBLE SIZE

REGIONAL TREND

Regional variations in mean pebble size are shown on map 14 (p. 237). There is an overall decrease in pebble size from east to west and also southwards. The change towards the west is progressive: the pebbles of the Luipaardsvlei facies have a mean size of 14,3 mm; the West Rand facies an intermediate mean size of 10,66 mm; and the Randfontein facies the smallest average pebble size of 9,94 mm. The t-test analysis shows that the group averages for the last two facies are significantly different (appendix 19, p. 195).

SUB-PATTERNS

Luipaardsvlei Facies

Description The largest mean sizes, exceeding 15 mm, occur in an irregular zone elongated south-eastwards from D_{25}. The direction of elongation coincides with the paleocurrent direction (map 19, p. 244). Westwards, this large pebble zone merges into an elongated zone of small pebbles, having a mean size of 10 mm, with the same directional trend; this latter zone extends southwards from B_{22} to I_{25}. It is bordered, on the west, by an area with larger pebbles, which begins at B_{21} and divides into two smaller branches down the paleoslope. One branch extends south-westwards to E 17, whilst the other continues southwards, east of Turk Shaft. The latter trend is mainly parallel with the crossbedding direction, although both the pebble and the crossbedding trends deviate locally.

Interpretation The direction of elongation of the larger and smaller pebble zones and the crossbedding directions (map 19) form an ill-defined fan-shaped pattern with an upcurrent apex located beyond the reef outcrop line to the north of West Shaft. It appears, therefore, that the conglomerate of this facies was introduced by a separate distributary, situated to the east of the West Rand facies. Variation of pebble size is controlled by the size available and the energy of the transporting currents, which are, in turn, dependent on the gradient and local relief of the depositional slope. Therefore, the pattern of variation can be interpreted in the light of the paleocurrent directions and the changes in the configuration of the depositional surface (map 7, p. 230). It is not possible to assess the variations caused by restrictions in the size of the gravel fragments supplied from the source.

In most instances, larger pebbles are found over floor highs, e.g. zones between C_{23} - E_{28}; at E_{28} they reach a mean of 19,8 mm in a conglomerate only 5 inches thick, while those around D_{18}, F_{22}, H_{21} and H_{27} suggest upgrading of pebble size caused by stream winnowing over exposed floor positions.

Similarly, a decrease in pebble size usually corresponds to lower floor relief. E.g. in the large south-central part of the mine around F_{23} relatively smaller pebbles, 10,2 mm mean size, predominate over low floor topography. The channel with a reef as thick as sixty inches and mean pebble sizes as large as 17,8 mm on East Champ d'Or, is considered to represent a different situation where the coarser materials were concentrated as residual deposits in a relatively deep channel.

West Rand Facies

Description The pebble distribution pattern in this facies is less complicated than that of the Luipaardsvlei facies. In general, the pebbles decrease in size down the paleoslope away from the northern outcrops often in elongated channels. Four areas with larger pebbles occur at B_{10}, C_{12}, B_{15} and C_8. They all extend southwards in the general paleoflow direction. In contrast to the Luipaardsvlei facies, larger mean pebble sizes generally occur along areas of lower floor topography overlain by thicker reef. The outcrop zone stretching southwards from C_8 is an exception to this rule.

Interpretation It is concluded that the majority of big pebble zones coincide with floor depressions overlain by thicker reef elongated in the paleoflow directions. The more robust reef thus represents channel deposits and interfluve areas containing scattered, pebbled quartzites. There are, however, minor exceptions, for instance at F_{13}. The thin reef with larger pebbles southwards of C_8 is associated with the northern extension of the Randfontein facies and is, therefore, considered below.

Randfontein Facies

Description An overall decrease in size persists towards the south and south-east (map 14, p. 237). A major belt with larger pebbles extends SSW from C_8 along the western outcrops of West Rand Consolidated into Randfontein Estates. At the south-western corner of West Rand Consolidated it widens, and the main trend changes direction slightly towards the SSE, as indicated by the 12 mm contour. It is interrupted at O_6, but the larger pebbled zone continues beyond this point as far as T_7.

Three minor elongated belts of larger pebbles are present. At 32 Shaft, one extends southwards from S_4 to V_3; near North-East Shaft another trends south-westwards from M_{11-12}; and at the northern boundary of Randfontein Estates, a third runs south-westwards from L_{8-9} to join the major zone at N_7.

Interpretation Three factors controlled the variations in pebble size. Firstly, there is an overall decrease in pebble size down the paleoslope, at a lower rate than that of the upslope reef phases.

The second factor was the presence of distributary currents - the four belts with larger pebbles, elongated in the paleocurrent direction, are viewed as zones of stronger current flow along directions of distributaries.

The third factor was the presence of floor highs over which coarse pebbles accumulated through winnowing out of the finer pebbles, grits and sands, the largest area being situated at the south-western corner of West Rand Consolidated (map 7, p. 230). In this main stream zone, the low floor, as indicated by thicker reef at O_{6-7}, is responsible for the short break in the major big-pebble belt extending towards the south-east. The localities of low floor relief around L_7 and R_5 similarly contain smaller pebbles. West of North East Shaft, at N_{11-12}, the narrow zone of larger pebbles coincides with an ill-defined area of thinner reef. The positive correlation between larger pebbles and areas of positive floor topography is, however, restricted to zones with stronger current flow generally delineated by robust reef.

CONCLUSIONS

The variation in pebble size of the White Reef was controlled primarily by the gradient of the paleoslope. Secondly, large-pebble zones elongated along the paleocurrent direction, reflect the main distributary directions or currents. Thirdly, in the case of the Randfontein and Luipaardsvlei phases, effective grain sorting took place over floor highs.

The 19,8 to 8,1 mm mean pebble size range of the proximal Luipaardsvlei and West Rand phases of the White Reef is similar to the 18,5 to 10,1 mm range of the underlying Livingstone Reefs, but it must be kept in mind that the latter values reflect only five localities (Steyn, 1963). This suggests either the incorporation of Livingstone Reefs particles or, more probably, similar hydraulic conditions and slope gradients during transportation and deposition, which the author described as fluvial to deltaic for the Livingstone Reefs.

The smaller mean size range of 13,0 to 6,7 mm for the Randfontein phase indicates a lower energy environment, not represented in the Livingstone Reefs. This is the more distal environment containing carbon seam reefs and high uraninite concentrations, as is also the case with the Vaal Reef where Minter (1972) measured a smaller pebble size range of about 10 to 7 mm (overall average for ten largest pebbles = 22 mm). The size ranges of the Vaal Reef reflect a more basinward environment, considered as distal fluvio-deltaic by Minter (op. cit.).

On the south-western side of the Witwatersrand basin, the deposition of the Basal Reef in the vicinity of President Steyn Mine, as described by Sims (1969), is, in many ways, closely comparable to that of the White Reef. These aspects are discussed in later sections. There are, unfortunately, no comparable averages representing all pebble sizes exceeding 4 mm, as he measured the largest 25 pebbles only. He classified the environment of the Basal Reef as fluvial to deltaic. However, Hodgson (1967) found that the mean pebble sizes of the Basal Reef in the Harmony Mine were in the 25 to 10 mm range indicating that this upslope zone of the Basal Reef at this mine reflects more basin edge conditions than the proximal phases of the White Reef. At Loraine at the distal end of the Basal Reef deposit, the pebbles are much smaller, probably 5 to 6 mm average according to Winter (personal communication).

On the basis of the above comparisons of pebble sizes set out against depositional conditions, the White Reef can be provisionally linked to the proximal side of fluvial-deltaic conditions. Later the environment, and also the sub-environments, will be determined quantitatively, utilising all parameters available. The above comparisons illustrate that the different Witwatersrand reefs represent a closely associated range of environments which can be defined to some extent by various parameters, singly, or, more comprehensively, by suites of properties.

PEBBLE PACKING

REGIONAL TREND

Description

The regional trend of pebble packing density (map 16, p. 241) is largely similar to that of the pebble size dispersal pattern (map 14, p. 237). Local changes may be due mainly to differences in interpretation in areas where information is sparse. However, one difference is evident - while the regional pebble size pattern shows that the smallest pebbles occur in the Randfontein facies, the average pebble packing of this facies does not differ from that of the West Rand facies (table 9).

TABLE 9

PEBBLE PACKING VALUES FOR THE WHITE REEF CONGLOMERATE

CONGLOMERATE FACIES	AVERAGE PACKING VALUE (per cent)	NUMBER OF MEASURING STATIONS
Luipaardsvlei	46	60
West Rand	26	73
Randfontein	26	60

These values reflect measurements taken on a systematic grid measured over complete sections of the reef

Interpretation

The mean pebble sizes, related to current velocities, decrease progressively from the east towards the south-west. Pebble packing should likewise decrease downslope. Equal mean packing values for the West Rand and Randfontein phases indicate that current strength is not the only factor involved. It will be demonstrated later that sorting strongly controls packing variations.

The average White Reef packing ot 33 per cent, exceeds the average of 20 per cent for the Vaal Reef (Minter, 1972), supporting the conclusion, based on the pebble size ranges, that the Vaal Reef is, relatively, the more distal deposit The proximal Luipaardsvlei phase of the White Reef, however, exhibits values equal to that of the robust Livingstone Reefs which average 44 per cent for five determinations only (Steyn, 1963). The White

Reef packing may be related to that of the Basal Reef at Harmony Mines, which Hodgson (1967) found for the B_2 phase, to be in excess of 30 per cent which is still loosely pebbled; and averages of 25 per cent and 22 per cent for the B_1 and B_3 reefs, respectively, can be calculated from his data. He states that the B_2 reef phase exhibits uniform packing values of about 30 per cent and the B_3 reef phase packing values of 15 to 30 per cent. These values illustrate, firstly, that packing is, like size, environment-sensitive; secondly that many of the Witwatersrand conglomerates are loosely pebbled, indicative of the simultaneous deposition of pebbles and sand. The general impression that most Witwatersrand reefs are pebble supported bankets thus requires revision as the result of quantitative measurements, more so, if it is kept in mind that packing values change down the slope in the same deposit, which in the case of the White Reef range from 79 per cent upslope to 4 per cent downslope. According to Allen (1965) alluvial fans are typically of gravel grade with silt and sand grades usually subordinate. This implies that only the Witwatersrand conglomerates representing alluvial fans or rivers with high gradients, would be uniformly pebble supported or 'banket' type.

SUB-PATTERNS

Luipaardsvlei Facies

Description Elongated areas of loose and tighter pebble packing converge northwards towards B_{24} (map 16, p. 241) and form an ill-defined fan-shaped pattern somewhat similar to that of the paleocurrents (map 19, p. 244). The fan shape is best shown by the sorting parameter (map 15, p. 239). The pattern is masked, to a large extent, by a curved east-west zone of reef, with closer pebble packing running through E_{19}, D_{21}, E_{27} and H_{29}, and corresponding to one with higher floor topography and thinner conglomerate. In the south-central part of Luipaardsvlei Mine the conglomerate is thicker (map 7, p. 230) and contains more loosely packed pebbles. A curved belt with low packing values runs through the mine from B_{24} to I_{24}. In the central area of loosely packed reef, there occur a few minor cases of higher pebble packing not corresponding with thinner reef (e.g. H_{22} and F_{22}).

Interpretation The ill-defined fan-shaped pattern of pebble packing weakly resembles that of the crossbedding azimuths' orientation, in that the elongated areas with variable packing densities converge northwards towards B_{24} (map 16, p. 241). Variations related to the uneven floor topography complicate the influx pattern. Floor highs, like the curved area along E_{19} - D_{21} - E_{27} - H_{29}, are overlain by narrow reef containing more densely packed pebbles. These reflect a higher energy regime in which sorting was more effective than elsewhere. The more thorough sorting over floor highs thus dominates the overall pattern.

In general, the well-packed conglomerate of the Luipaardsvlei facies was subjected to much transport turbulence, which removed a large amount of sand and fine-grained materials. The winnowing, or reworking, must have been relatively continuous throughout transportation, allowing the floor topography to leave its imprint on the overlying gravel.

West Rand Facies

Description   To identify the true pattern, measurements to the east of the 15 - 16 grid boundary, south of the B - C grid boundary (map 16, p. 241) have to be excluded, since the conglomerate there, on the basis of its pebble composition, belongs to the Luipaardsvlei facies (map 18, p. 243). However, it can be seen that the West Rand facies grades eastwards into the Luipaardsvlei type; the quartzite pebble proportion of 10 per cent, taken as the dividing line between the two facies, is an arbitrary figure, and the boundary could have been placed slightly more westwards if a lower quartzite pebble percentage had been chosen. The area of anomalously dense packing in the centre of the mine at F_{13} (map 16) is based on a single value. The extrapolation of this high value over the large area shown on the map may therefore be unjustified. If allowance is made for this, and for the overlapping effect of the adjoining Luipaardsvlei facies, a more reliable pattern is obtained for the West Rand facies.

Closer pebble packing (+ 20 per cent) characterises the upcurrent outcrop area in the centre of the mine, while the pebbles become more scattered down the paleoslope. The high pebble packing at B_{11} grades southwards into a belt of relatively well-packed conglomerate extending down to E_{11}. The floor topography (map 7, p. 230) shows that this reflects a depression containing thicker reef. Another occurrence of high pebble packing density is at C_{15}. Conforming to the pebble size pattern, and occupying a trough in the floor (map 7), it extends south-eastwards to D_{15} and then swings to the south-west into an area for which limited data are available. Over the rest of the area, relatively higher floor topography underlies more loosely packed pebbles.

Interpretation   Closer packing in the upcurrent areas is associated, over the steeper depositional slope, with a higher energy regime, which is accentuated in the restricted distributaries. Lower downslope, more sparsely packed pebbles, dispersed between sandy sediments, reflect the gradual decrease of current velocities. Lag concentrations of heavier particles, resulting in denser pebble packing, were effectively developed only in the two north-south channels running through B_{11} and B_{15}; these were eroded into the footwall and probably acted as main transportation courses. The channels remained open at the time when the flanking areas were already covered by gravel. Outside the channels, gravelly sand was initially deposited under conditions of abundant debris supply, and apparently, little or no reworking took place. As abundant crossbedding is present in the conglomerate outside the channels it appears that this conglomerate was often deposited by means of a series of forward building crossbeds. The latter is, significantly, absent in the channels filled with coarser gravels, suggesting continual resorting. Rapid deposition under conditions of oversupply for the facies is also reflected by the lack of imprint of floor highs on the distribution patterns of the overlying conglomerate. Burial of the paleoslope took place, the uneven topography was drowned, and sedimentation was completed before reworking could set in. The West Rand phase of deposition is associated with advancing bar forms often related to avalanching. It represents a mode of deposition different from that of the other two facies which will be described at a later stage.

Randfontein Facies

Discussion The pattern of pebble packing variation (map 16, p. 241) resembles that of the pebble size distribution (map 14, p. 237).

Interpretation Several important relationships are evident. Firstly, there is a decrease in packing density down the paleoslope. Low down on the slope, south of 2N Shaft, the pebbles are more loosely packed than elsewhere.

A second characteristic is the persistence of good packing along positions of dispersal streams. The areas of well-developed reef, with good packing and larger pebbles, are all, to a varying extent, elongated in the paleocurrent direction, e.g. the major zone along J_5 - M_5 - $Q_{6/7}$ - T_7, its branch along M_8 - N_7, and the two minor elongated zones at S_4 and N_{11-12}. The gentle curve of the major zone of robust reef closely follows the components of the paleocurrent system (map 19, p. 244). It is concluded that the four zones represent the courses of stronger and more continuously flowing distributary streams which were the main factor responsible for denser pebble packing.

A third important characteristic is the relationship between pebble packing and size and the similarity of their distribution patterns (cf. maps 14 and 16). Both patterns on Randfontein Estates generally reflect floor topography (map 7, p. 230) with the maximum values over floor highs in the path of the main current. In such positions increased values are present to some degree even when the floor is relatively low, e.g. at L_7. Their correlation does show some scatter (fig. 6 a) and the correlation co-efficient of 0,72 (appendix 4) reflects a small degree of dissimilar behaviour. Extensive sorting increased pebble packing values strongly without a correspondingly large increase in size, apparently because of the limitations to the size ranges. This is illustrated at S_4, for example, where a packing value of 52 per cent, is more than double that of the surrounding area (23 per cent average); while the pebble size at the same measuring station is 10,9 mm, representing only a 12 per cent increase on the average of 9,7 per cent for the surrounding area (map 14a). The pebble packing is, therefore, more sensitive to winnowing or sorting processes, and it thus produces a more variable pattern than pebble size.

The fourth notable feature is the closer packing over elevated floor areas. E.g. the reef thickness and packing variations are virtually identical (maps 7 and 16). A study of these maps shows that nearly all the variations in the packing pattern are, similar to the pebble size pattern, dependent on floor topography. This was brought about by a common response to different energy regimes related to floor topography. This mode of deposition is common to both the Randfontein and Luipaardsvlei phases. The winnowing which took place under conditions of sheet deposition will be explained in detail at a later stage.

PEBBLE SORTING

INTRODUCTION

The present study deals extensively with the effects of sorting on the dispersal and concentration of the constituents of a gravel. The standard deviation was employed as a measure of sorting. Sorting effects are, nevertheless, also well expressed by variations in pebble size and packing, and changes in the relative concentration of metals.

SORTING COEFFICIENTS

The sorting of a sediment is often expressed in terms of the standard deviation of its grain sizes, e.g. Friedman (1962). Standard deviations were, therefore, calculated for each pebble-count population as was done by Steyn (1963) and Armstrong (1965) for other Witwatersrand conglomerates. As the minimum grain size measured was 4 mm, the conclusions reached are applicable only to the pebble size range. Map 15 (p. 239) shows the regional variations in standard deviation for the pebble size distribution. The pattern obtained is identical to that of the dispersal of pebble sizes (map 14, p. 237) if allowances are made for differences in data distribution and contouring. The relationship between pebble sizes and related standard deviations is also shown on fig. 6 c. The scatter diagram and related regression correlation (appendix 16) reflects a direct linear relationship between pebble size and standard deviation. The high correlation value of 0,91 shows that a variation in pebble size will be closely reflected by pebble sorting values. This confirms that the sorting of the pebbles of the conglomerate is almost completely dependent on the pebble sizes present. The standard deviation measure as an independent indicator of environments is not considered effective under these circumstances.

According to Folk (1961) sorting is dependent on, amongst other factors, the size range of material supplied, the type of deposition and the current characteristics. He also believes that in every environment sorting would be strongly dependent on grain size, and suggests that scatter diagrams, such as fig. 6 c, are the best means of evaluating the relationship. It is possible to consider all three of these factors for the White Reef. Firstly, it was shown above that the sorting of the White Reef pebbles is highly dependent on available grain sizes. Secondly, the variations in sorting relative to floor topography is statistically significant (appendix 3, p. 155) and this implies that current fluctuations, related to floor elevation, also constituted an important local factor.

Thirdly, Folk (op. cit.) considers that the type of deposition is important; in the Randfontein phase 'beanspreading', by currents continuously working over thin sheets of grains yields better sorting than the 'city-dump' type of deposition, in which sediments are laid down as an advancing series of crossbeds and then rapidly buried.

PEBBLE SHAPE AND SPHERICITY

DESCRIPTION

Figs. 16 a - f (p. 216) and table 10 illustrate the shapes of outcrop pebbles measured according to Zingg's classification (p. 23). The related operational values are also shown. According to Folk (1961), variation of shape with size is nearly always present in the sense that the coarser grains are usually more spherical than the finer ones. For this reason, only pebbles in similar size classes are compared for the three localities where measurements were made. Map 17 (p. 242) shows the areal variations in the two- and three-dimensional sphericity values.

TABLE 10

PEBBLE SHAPE AND SPHERICITIES AT OUTCROPS OF THE WHITE REEF ON THE WEST RAND

Locality	Pebble size range	Pebble Shapes (per cent)				Average sphericity	No. of pebbles measured
		Disc	Spheroid	Blade	Roller		
B_{10}	32 - 64 mm	31	50	2	17	0,74	62
B_{15}		25	6	25	44	0,59	16
C_{26}		28	65	3	4	0,74	53
B_{10}	16 - 32 mm	27	54	3	16	0,77	84
B_{15}		43	32	6	19	0,72	180
C_{26}		26	67	3	4	0,79	67

INTERPRETATION

Sphericity in Relation to Size

In view of the finding by Folk (1961), that the coarser pebbles are usually more spherical than the finer ones, it was surprising to obtain the opposite result. This is reflected by both the percentage of spheroids and the average sphericities (table 10). A t-test shows that the average sphericities for the two size classes are significantly different at locality C_{26} (appendix 20). This would then also be the case at B_{10} and B_{15} where the differences in sphericities at these points are equal to or larger than those at C_{26}. It is difficult to explain this anomaly by means of sedimentary processes.

Pebble Shape

Localities B_{10} and B_{15} are situated relatively close together, at the northern outcrop of the West Rand conglomerate facies (map 17, p. 242). C_{26} is located farther eastwards, on the outcrop of the Luipaardsvlei facies. One would, therefore, expect to see closer similarities between B_{10} and B_{15} than between either of these and C_{26}. However, this is not the case; at B_{10} and C_{26}, 50 per cent or more of the pebbles are spheroidal for both pebble size ranges. At B_{15}, on the other hand, the majority of the larger pebbles (32 to 64 mm) are of a roller shape, whilst the smaller pebbles (16 to 32 mm) are disc shaped. If the larger pebbles from B_{15} are excluded, it is seen that 75 per cent or more of the pebbles at all three localities are either spheroidal or disc shaped. Roller and especially blade shaped pebbles are subordinate. In table 11 where all the values for the White Reef are proportionately averaged according to group counts, the above shape characteristics are compared with those determined for the Livingstone Reefs on the West Rand by Steyn (1963). The shapes are largely similar and the sphericities virtually identical; in both cases, disc shaped and spheroidal pebbles predominate and include at least 75 per cent of all pebbles measured. Blade shaped pebbles are subordinate, making up 5 per cent of the sample populations in both cases. Roller shapes are relatively common and account for the remaining 15 to 20 per cent.

TABLE 11

COMPARISON OF PEBBLE SHAPES OF THE WHITE AND LIVINGSTONE REEFS OF THE WEST RAND

Stratigraphic Position	Pebble Shapes (per cent)				Average Sphericity
	Disc	Spheroid	Blade	Roller	
White Reef	34	46	5	15	0,74
Livingstone Reefs	24	51	5	20	0,75

From the above table, it is evident that the pebble shape characteristics of some conglomerates of the Main Bird Series on the West Rand are closely comparable. Not enough data are available to assess the full implications of this similarity, though it evidently points to a similar history of erosion, a comparable provenance, and perhaps, even more specifically, an equivalent abrasion history. It is possible that some of the conclusions, previously drawn for the Livingstone Reefs with regard to distance of source area and of transportation, may be applicable to the White Reef, especially if the almost equivalent average sphericities are noted (table 11). There is, of course, the alternative possibility that several cycles of reworking could have caused these similarities. This raises the question as to whether higher sphericities are associated with better mineralisation, as seems to be suggested by the greater abundance of spheroidal pebbles and slightly higher sphericity values of the Livingstone Reefs as compared with the White Reef with its lower gold content. The information available is considered in the sections dealing with mineralisation.

Operational Sphericity

Operational sphericities, as defined on p. 23 , were measured on pebbles extracted from the weathered outcrops and are shown in table 10 (p. 53). The overall average for all pebbles measured is 0,74 (table 11). Variations between the different localities and size classes fall within the 0,72 - 0,79 range (table 10) if the low value of 0,59 for locality B_{15} is excluded.

The variations between the three sample localities can be examined in relation to the different conglomerate facies present. On the basis of pebble composition, the B_{10} and B_{15} localities represent the West Rand conglomerate facies, whereas the C_{26} conglomerate belongs to the Luipaardsvlei facies. The combined results for the first two give an average of 0,73 for the West Rand pebble population compared with 0,77 for the single locality of the Luipaardsvlei pebble population samples. The better sphericity of the latter could possibly be related to larger pebble size, as is usually the case. Statistical analysis shows that the averages are not significantly different for localities B_{10} and C_{26} for the -32 mm size class (appendix 21).

Two-Dimensional Sphericity

As explained before (p. 24), the two-dimensional sphericity values are based on measurements of randomly orientated two-dimensional exposures of conglomerate underground. Measurements were made at a limited number (14) of localities on an experimental basis.

The regional variation of the average values plotted on map 17 (p. 242) follows a distinct pattern, which becomes meaningful if the two-dimensional sphericities of the different conglomerate facies are viewed separately. Ten of the 14 stations fall inside the boundaries of the West Rand conglomerate facies and their average values show a clear pattern of increasing values downdip in the paleocurrent direction, inferred from other parameters. The two iso-contours are roughly parallel to the strike of the depositional paleoslope, and the two-dimensional sphericity measurements may therefore be a quick way to define the trend of this slope. A broad bulge of poorer sphericities extends down the paleoslope into the centre of West Rand Consolidated Mine area and reflects stronger paleocurrents. The rapid increase in the values down the paleoslope of the West Rand facies suggests that two-dimensional sphericity is a sensitive measure of energy decrease in the transporting current. It is ascribed to the different rate of transport of differently shaped grains, with the more spheroidal pebbles being moved farther down the depositional slope (Folk, 1961).

The relationship between the two-dimensional random sphericity and the standard operational sphericity is not clear, as different relationships were obtained at positions B_{10} and B_{15} (map 17). The operational sphericities at B_{10} average 0,74 and 0,77 respectively for the larger and smaller size classes (table 10, p. 53). An average two-dimensional sphericity value of 0,58 was obtained close by at B_{11}, and for sphericities of about 0,75, the two-dimensional sphericities appear to be about 0,17 lower. This ratio is valid when the 0,72 value at B_{15} (16 to 32 mm class) is compared with the two-dimensional value of 0,58 at C_{14}, but in the 32 to 64 mm class the two measures are virtually alike. It can be expected that the differences will increase progressively with lower operational sphericities.

Only four stations were measured over the area underlain by the Randfontein facies, and conclusions can, therefore, only be of a very tentative nature. One value of 0,69 at H_7, close to the ill-defined northern border with the West Rand facies (map 17, p. 242), is anomalous, and may belong to the West Rand facies which has an identical value of 0,69 at I_{11}. Two other values of 0,56 at K_5 and 0,59 at J_6, are located well inside the Randfontein facies boundary, on the upcurrent side. A single value of 0,66 is shown near the extreme south-western corner of Randfontein Estates at the U_3 locality. A maximum sphericity increase of 0,10, therefore, seems to take place over a distance of 11 000 feet between the up- and downcurrent localities. It is smaller than the increase of approximately 0,11, calculated over a distance of 7 000 feet on West Rand Consolidated. The higher rate of increase in the West Rand facies is related to a greater energy decrease down the paleoslope.

In general, it can be concluded that two-dimensional sphericity gives a meaningful pattern of increasing sphericity in the downcurrent direction due to differential transportation of differently shaped grains, with more spheroidal pebbles moving further down the paleoslope. These results seem to justify a wider application in future studies as the method is simple and rapid.

PEBBLE FABRIC

DESCRIPTION

The localities at which measurements were made, as well as their average orientations, are shown on map 17. This graphic presentation, along with the summary of results (table 12, p. 59), shows different responses for each of the three facies of the conglomerate but with marked similarities between the Randfontein and Luipaardsvlei types. The results obtained for each facies at different localities are remarkably similar, so that the average fabric characteristics of a facies can be readily deduced. These results are recorded in appendices 12 - 14 (pp 183 - 185).

INTERPRETATION

The Luipaardsvlei Facies

The majority of the pebbles (68 per cent) dip upslope against the direction of the paleocurrent (table 12, p. 59). This is usual for environments which are non-marine such as fluvial or deltaic. The high degree of uniformity in orientation (appendix 12) is indicative of a river environment. The relatively high average inclination of 17^{o} (table 12) in the upstream direction also falls within the 15 - 30^{o} range for fluvial deposits as indicated by Cailleux (1945). Similar upcurrent pebble inclinations occur in the Kimberley 9A Reef on the East Rand, which Armstrong (1965) defined as being of fluvial origin; and in the Ventersdorp Contact reef on West Driefontein, which Knowles (1966) interpreted as an alluvial fan condition.

A small number of pebbles are inclined downstream (28 per cent); this is not considered to be related to marine deposition but rather to pebbles lying on the inclined foresets of crossbedding formed under fluvial conditions. The angle of inclination, in the upcurrent direction, is less than that measured by Knowles and Armstrong, who found inclinations in the 25 - 30^{o} class. The downcurrent angles of inclination (average 18^{o}) exceed the 2 - 12^{o} characteristic of marine gravels (Cailleux, 1945). This illustrates further that those characteristics of pebble orientation in the White Reef which, at first, appear to be marine in type, are not.

The significance of pebble imbrication measurement results on rock surfaces orientated at right angles to the paleocurrent is equally clear (appendix 12, table 12). An almost equal number of pebbles are inclined west and east. Pebble orientations along the paleostrike direction, therefore, do not show any preferential trend.

The West Rand Facies

In contrast to the other two facies, the majority of pebbles in the West Rand facies, 66 per cent, dip downstream (appendix 13, p. 184) at an average angle of 14^{o} (table 12, p. 59). The imbrication direction is similar to that on subaerial talus slopes and in marine gravels, which contain pebbles inclined in the downslope direction (Pettijohn, 1957; Twenhofel, 1950). However, a marine origin cannot be postulated for this facies on the basis of pebble fabric, as it was deposited in a comparable position on the paleoslope to the Luipaardsvlei facies, which shows only fluvial influences. A marine beach environment is also unlikely, since the Randfontein facies, which occupies a lower position on the paleoslope, appears to have been deposited in a fluvial environment. The downslope inclination of pebbles (average 14^o) of the West Rand facies is also outside the range of $2 - 12^o$ for marine gravels recorded by Cailleux (1945).

The explanation for the dominant downslope inclination lies in the mode of deposition of the gravel. Evidence of abundant and undisturbed cross-bedding in the conglomerate is provided by analysis of measurements of this type of sedimentary structure - 39 per cent of all the crossbedding recorded over the area covered by the facies was measured in the conglomerate itself (map 12, p. 235). In contrast, the corresponding figures for the Luipaardsvlei and Randfontein facies are only 21 and 9 per cent respectively. It is, therefore, concluded that the downslope inclination of the pebbles in the West Rand facies is related to their position on the inclined foresets of crossbedding. Sims (1969) observed similar pebble alignments on the plane of foresets developed in the southern massive phase of the Basal Reef on President Steyn and there should, therefore, be similarities in the mode of reef formation, even though the pebble inclinations in the Basal Reef are higher ($10 - 24^o$).

The relatively low pebble inclinations along both the paleoslope and paleo-strike directions as compared with the Luipaardsvlei facies is linked with an increase in the proportion of apparently flat-lying pebbles in these directions. An almost equal number of pebbles are inclined in opposite directions along the paleostrike, indicating a uniform response to the paleocurrent. This is to be expected with the current force acting at right angles; and it provides further proof that the paleocurrent directions, deduced from crossbedding measurements, are correct.

The Randfontein Facies

The majority of the pebbles (54 per cent average, table 12, p. 59) are inclined upslope similar to those of the Luipaardsvlei facies, but at steeper angles (average 20^o). This indicates a similar mode of deposition. The individual pebbles attained positions of maximum stability with an upslope inclination consistent with that observed in fluvial sediments.

Fewer pebbles (54 per cent) are imbricated upstream as compared with the Luipaardsvlei facies (68 per cent) due to the increase in the number of pebbles lying horizontally. Parallel to the paleostrike, more pebbles are horizontal (33 per cent) than in the Luipaardsvlei facies (7 per cent); these changes may be due to lower energy conditions, which are reflected by the smaller pebbles. Along the paleostrike, an equal number of pebbles are inclined in opposite directions, which demonstrates that preferred orientation is limited to the paleocurrent direction.

CONCLUSIONS

The pebble orientations of the Luipaardsvlei - Randfontein phases are characteristic of fluvial and river environments with most pebbles inclined $15 - 30^o$ upcurrent. In the West Rand facies, the majority of pebbles are inclined downslope due to deposition on inclined crossbedding foresets under conditions of rapid dump-type deposition.

The low proportion of flat-lying pebbles of the Luipaardsvlei conglomerate facies can possibly be considered, together with the larger pebble sizes and the closer packing, as an indication of high current velocities and turbulence.

The relative abundance of flat-lying pebbles in the Randfontein facies, together with frequent horizontal bedding, is probably related to sheet deposition of the thin layer of small pebbled gravel. The two styles of pebble orientations which can both be associated with a fluvial environment, are also found in other Witwatersrand conglomerates.

TABLE 12

COMPARISON OF THE PEBBLE FABRIC OF THE THREE FACIES OF THE WHITE REEF CONGLOMERATE

Pebble inclination in paleocurrent direction	L	W	R	Pebble inclination along paleostrike direction	L	W	R
Flat pebbles (p.c.)	6	8	16	Flat pebbles (p.c.)	7	27	33
Dipping upcurrent (p.c.)	68	26	54	Dipping west (p.c.)	48	37	32
Dipping down-current (p.c.)	28	66	30	Dipping east (p.c.)	44	36	35
Av. dip, up-current	17^{o}	12^{o}	20^{o}	Av. dip, west	11^{o}	9^{o}	12^{o}
Av. dip, down-current	18^{o}	14^{o}	13^{o}	Av. dip, east	15^{o}	12^{o}	11^{o}

L = Luipaardsvlei facies
W = West Rand facies
R = Randfontein facies

p.c. = per cent

PILOT STUDY OF SEDIMENTARY AND MINERALISATION PROPERTIES

PURPOSE

The pilot study preceded the regional study and was undertaken in order to:

(a) Determine whether any of the macroscopic sedimentological properties of the gold- and uranium-bearing conglomerate could be quantitatively related to the grade of mineralisation. The study did not include any microscopic or matrix studies as was explained on p. 12.

(b) Investigate in detail the local factors controlling conglomerate deposition;

(c) Determine, if possible, some of the basic principles controlling gold and uranium mineralisation;

(d) Explain the extreme local variations in gold-uranium mineralisation in the White Reef indicated by sampling results; and

(e) Deduce, from the above, the most suitable and least time-consuming methods for the regional study of gravel deposition and controls of mineralisation.

PRESENTATION OF RESULTS

The results of the pilot study are graphically represented in fig. 2 (p. 201). The plan section on top of each diagram represents the horizontal area covered by ten successive blasts, whereas the vertical section illustrates the conglomerate thickness as it would be seen on the stope face before the first blast. The vertical scale is exaggerated. Each point indicates a sampling position and represents an average value obtained from samples taken over the full thickness of the conglomerate for a cross-section six inches wide. The 7th and 9th samplings represent twelve inch wide sections of reef.

INTERPRETATION

Effects of Variation in Reef Thickness

Floor Topography The thickness of the conglomerate (fig. 2a) varies considerably - from a parting to twenty inches. The upper surface is generally smooth, while the bottom contact is undulating, indicating that the floor was uneven or scoured. Hollows in the floor are marked by thicker reef, whereas floor highs are overlain by narrower reef.

The conglomerate on the left hand side of the pilot area is very thin, decreasing to less than 25 mm and in some places to a mere parting where there are no pebbles. It thickens towards the centre of the area, over an original floor low covered by conglomerate over ten inches thick. To the right of the central hollow, a floor high is overlain by conglomerate thinner than ten inches. Farther towards the right, a second, narrow elongated depression lies between the two ten inch contour lines. This is bordered on the right by reef less than five inches thick, indicating another floor high.

The truncation of gritty lamellae in the footwall quartzites by the conglomerate on the sides of the hollows suggests that the uneven floor resulted from pre-White Reef scouring, which seems generally to have been of a shallow nature and seldom produced deep gullies extending into the floor. Sharp erosional features are present, but are rare. The scouring did not cut down more than a foot or two, apparently, since deeper gullies were not found. The floor sediments were already compacted and firm before this limited erosion took place. Some isolated, small-scale post-White Reef erosional features are also found and indicate that minor erosional phases occurred after the reef was deposited.

<u>Pebble Sizes</u> Fig. 2a illustrates the lateral variation in average pebble sizes (cf. table 4, p. 20). Analysis of variance shows significant differences in mean pebble size between areas of high and low floor topography at the 99 per cent level (appendix 3, p. 155). Smaller pebbles occur in the areas of thick conglomerate covering floor lows. The largest mean pebble sizes are found on the left side of fig. 2a, over the floor high. On top of the rise, however, where the reef is less than two inches thick, a decrease in mean pebble size occurs. It appears, therefore, that for reef thicknesses exceeding two inches the mean pebble size is inversely proportional to conglomerate thickness and is dependent on floor topography.

Fig. 4b (p. 204) further investigates the relationship between reef thickness and pebble size. The data were tested by family regression; the correlation with a coefficient of 0,60 is best expressed by a parabolic curve $y = 12,49 - 0,55\ x + 0,02\ x^2$ (appendix 4, p. 158). It could be useful, at this stage, to define the significance of the correlation coefficient (r). According to Weatherburn (1961) ' the variables are usually described as uncorrelated when r is zero. ... The magnitude of r may be taken as a measure of the degree to which the association between the variables approaches a linear functional relationship'. A marked amount of scatter is present in fig, 4b and the curve satisfies only 39 per cent of the data. With an increase in conglomerate thickness the mean pebble size decreases. The gradient at the base of the regression curve flattens out, suggesting that a constant mean pebble size will be reached above a certain reef thickness, which is about twelve inches in this case. On the other hand, the mean pebble size increases rapidly as the reef narrows, until a thickness of about two inches is reached. Below this, mean pebble sizes are erratic, but show a general decrease in size, as is illustrated by fig. 2a (p. 201); the largest individual means associated with two inch wide reef are no longer present. This variation of size with topography is due to a process of winnowing which is most efficient for floor elevation differences of between two and twelve inches. The process will be fully discussed later, in the synthesis section.

Pebble Packing Fig. 2b (p. 201) illustrates the lateral variation in pebble packing. The two hollows inside the ten inch contour show the lowest packing percentages whilst the floor highs reflect relatively higher packing. The most pronounced floor high on the left side of fig. 2b shows a systematic increase in the pebble packing as the reef thins, with maximum values exceeding 50 per cent. Variations in packing are thus similar to that of the mean pebble sizes. Analyses of variance yield significant differences at the 99 per cent level for packing values over areas of high and low floor (appendix 3, p. 155). Packing is, like size, inversely related to conglomerate thickness (fig. 4c, p. 204). The degree of correlation -0,72, and the relationship is best reflected by the logarithmic curve $y = 52,73-13,83 \ln x$, which satisfies 61 per cent of the data (appendix 4, p.158). However, it should be noted that, contrary to the behaviour of the mean pebble size, no decrease in packing is found for reef thicknesses of less than two inches. It is suspected that the packing is inaccurate at very narrow reef widths.

Gold Concentrations Fig. 2d (p. 201) illustrates the lateral variation in gold values. In both areas of thickest reef covering floor lows, the gold values are generally less than 10 dwts/ton. The central and right-hand rises of medium height, are overlain by small scattered areas with relatively higher gold values (20 - 30 dwts/ton) separated by areas with lower values. On the flank of the high left-hand hump, there is a progressive increase in gold concentration as the reef narrows, with values of over 30 dwts/ton being attained. On the top of the rise, however, the gold values decrease where the reef thins to less than about two inches. This pattern is comparable with that of the mean pebble size distribution shown in fig. 2a. Gold content and reef thickness have a correlation coefficient of 0,52, and the nature of the correlation curve is best expressed by a power equation of $y = 28,4\ x^{-0,64}$ which fits only 37 per cent of the data (appendix 4).

The scatter diagram of fig. 4a (p. 204) illustrates the above conclusion that the gold content increases as the reef thins and reaches maximum values at a conglomerate thickness of about two inches. The individual data points on the figure indicate lower gold values for reef thicknesses below two inches. Though gold content decreases as the reef thickens, the rate of decrease becomes progressively smaller, so that the regression curve straightens out to a large extent at the base. This implies that the gold concentration will not decrease appreciably if the reef thickens beyond a certain value; a lower limit of about 6 dwts/ton is reached at a reef thickness of sixteen inches. Statistical analysis supports the concept of significant differences in gold content being related to varying floor topography to the extent of 99 per cent (appendix 3).

Uranium Content Fig. 2e (p. 201) shows that the uranium distribution pattern is mainly similar to that of the gold, pebble packing and pebble size. A slight difference occurs over the central low area where the gold pattern shows more consistently low values than the uranium pattern. Variance analysis supports the unequal distribution of uranium relative to floor topography to the extent of 99 per cent (appendix 3, p. 159).

Sorting Characteristics   Fig. 2c (p. 201) illustrates the distribution of pebble sizes relative to floor heights. The areas on top of the humps, inside the five inch thickness contours, are treated as separate pebble populations. Samples falling inside the ten inch contours have been grouped together to represent populations over floor lows. Comparison shows that the humps are deficient in smaller pebble sizes. Fig. 3 a (p. 202) of pebble sizes expressed as weight frequency percentages shows that the hollows, in comparison, contain 7 per cent more pebbles in the three smallest size classes than the rises. Larger standard deviation values are obtained over the humps, as is shown in table 13 below. This is due to the high degree of dependency of standard deviation on size. Even if sorting is much better in the thin reef, it will be still reflected by high standard deviation values.

TABLE 13

GRAIN SIZE CHARACTERISTICS - PILOT STUDY AREA

	Left Hump	Left Hollow	Right Hollow	Right Hump
Number of grains measured	940	2 571	1 075	341
Mean pebble size (mm)	11,30	9,08	8,78	10,14
Standard deviation (mm)	5,52	4,69	4,45	5,05

Analysis of variance confirms that standard deviation, as a measure of sorting, vary significantly with regards to floor topography (appendix 3).

Sedimentary Structures in the Conglomerate   Crossbedding structures are sometimes found in the thicker portions of the conglomerate (fig. 2a, p. 201). This shows that sediment reworking was restricted after the infilling of the hollows, as such structures would have been destroyed. No crossbedding was observed in the narrower reef sections. This indicates that deposition of foresets did not occur over highs or that subsequent reworking destroyed such inclined beds. Later, it will be seen that sheet deposition formed the thin reef. The crossbedding directions indicate that local current flow was influenced by the alignment of the floor depressions.

Relationship between Sedimentary Properties

Figures 5 (p. 205) and 6 (p. 206 and 207) illustrate the relationships between size and packing, size and sorting, and packing and sorting of the conglomerate.

Size and Packing Fig. 5a shows that an increase in size is accompanied by closer packing, with a positive correlation at a 95 per cent confidence level (appendix 16, p. 187). Regression correlation yields a correlation coefficient of 0,54. The line of best fit for the data illustrated in fig. 5a is a parabolic curve $y = -207,31 + 39,45x - 1,56x^2$, with a data fit coefficient of 0,41 (appendix 4D, p. 161). For reef thinner than three inches an erratic relationship exists, which is similar to the behaviour of other sedimentological and metal properties. This phenomenon is discussed in detail in the synthesis section. The regional study of this aspect covers conglomerate thicknesses in excess of three inches, see fig. 6a (p. 206). The deviations from the uniform correlation curve are predictably smaller than those of the narrow reef of fig. 5a. Consequently, the degree of correlation is larger, being 0,72 (appendix 4, p. 158) and is confirmed by a correlation at the 95 per cent confidence interval (see statistical appendix 16, notations 1 and 3). The pebbles are, thus, more closely packed where the average size is larger, with the important difference that for thicker reef there is no change as is the case in reef narrower than three inches. The increase of packing with size is interpreted as being caused by increasing environmental current velocities and, secondly, by a persistence in flow, causing removal of the small, less stable grains.

Size and Sorting Figures 5b (p. 205) and 6c (p. 207) illustrate that, for reef thicker than three inches, standard deviation values are dependent on the mean size to the extent of 0,84 and 0,91 for the pilot and regional areas respectively (appendix 4). The relationship becomes erratic, with large deviations from the mean correlation trend, where the conglomerate is is less than three inches thick (fig. 5b) and the correlation decreases to 0,66.

Sorting and Packing An increase in the standard deviation (poorer sorting) accompanies better packing for reef thicker than three inches, as is demonstrated by regression correlation coefficients of 0,57 for the pilot study data and confirmed by the value 0,61, for the regional area (appendix 16). To a large extent, this correlation is due to the control of sorting by size. Yet, as the correlation between standard deviation and packing is lower than that between standard deviation and size, factors other than size must also be involved. The association between closer packing and poorer sorting is probably related to higher current rates removing a part of the finer grain population of the traction carpet, with a consequent sediment coarsening and higher pebble packing. The result is poorer sorting, i.e. larger standard deviation, as there is the residual population of small grains whilst some larger grains are added. This association between poorer sorting and the coarsening of a gravel is illustrated by Folk (1961). As the winnowing out of the finer grains progress to near completion, the wide range of grain sizes present narrow to a more homogeneous population of larger grains, with a return to better sorting. Such a situation is perhaps illustrated in figs. 9c (p. 209) and 12c (p. 212) where the highest gold values seem to be related to a return to smaller standard deviation values, even though the associated average pebble size is at its maximum (fig. 9a).

The occurrence of larger and closer packed pebble zones over higher floor topography in the White Reef can be compared with similar phenomena, firstly the Ostler lenses of Martini and Ostler (1973), which are small dunes, mounds or small transverse pebble bars observed at the downstream end of braid islands, bars and point bars of alluvial channels. Ostler lenses are described as being part of the openwork gravel family. They fine upwards, and the mounds tend to be smaller than one metre in width and length and twenty to forty centimetres in thickness. Openwork and fining upward aspects are virtually absent in the White Reef, and the largest hump in the White Reef pilot study area exceeds a length of fifteen metres. There are, therefore, no grounds for classifying these features as Ostler lenses. The White Reef might possibly have more in common with the humped gravels, observed in bars in braided rivers by Eynon and Walker (1974). This facet will be discussed in a synthesis section dealing with depositional environments.

Relationship between Ore Minerals

Gold - Uranium The relationship between gold and uranium content for the samples taken in the pilot study area is shown in fig. 7 (p. 208). Statistical tests yield a local correlation value of 0,96 (appendix 17, p. 189) which decreases, on a regional scale, to a value of 0,70 (appendix 16, p. 187). The implications of the changing amount of gold deposited relative to uranium down the depositional slope are later discussed in detail.

Silver - Gold Figure 8 (p. 208) shows a generally sympathetic relationship between the gold and silver content of individual samples. There is a 95 per cent confidence level for this correlation (appendix 16). The curve is not linear, and samples with low gold values contain relatively more silver than those richer in gold, causing the silver contained in gold to vary between 16 and 30 per cent. This could be caused by the method of determining silver content in samples poor in gold, since silver is added as a part of the analysis procedure. The large local variation does not favour correlation of the silver content of the White Reef with that of other reefs, which show variations of only a few per cent between various reef horizons (Pretorius, 1974a, table 27).

Sulphide Minerals Figure 11 (p. 211) at the 7^{A}VW18 locality illustrates that the sulphide minerals (mainly pyrite and pyrrhotite) show variation patterns different from those of the other metals. This could be due to the introduction of pyrrhotite as an epigenetic mineral.

Relationship between Conglomerate Texture and Metal Distributions

As a sympathetic relationshp exists between gold and uranium, the relationships discussed below apply to both ores.

Pebble Size Figure 2 (p. 201) shows that mean pebble size and gold content vary sympathetically. Figures 9a (p. 209) and 12a (p. 212) yield further information about the nature of this relationship. In both cases a parabolic curve provides the best fit for the data (appendices 4, p. 163 and 5, p. 165). At the pilot study locality (grid position K_6), although interpretation is complicated by somewhat irregular results for reef below three inches thick, a relatively high correlation coefficient of 0,77 is obtained for twenty three samples taken over one foot wide sampling strips. Analysis of data, related to reef thicknesses in excess of three inches only, do not yield an improved correlation (appendix 4). Although the conglomerate at 7^AVW18 stope (grid position K_6) is fairly uniform in thickness and there are no complications due to the reef being narrower than three inches, the lower correlation coefficient of 0,56 (appendix 5) indicates a greater scatter. This correlation improves to 0,69 if gold is correlated with the larger pebbles only (appendix 18, p. 194). The tendency for an almost constantly low gold value (fig. 9a) to be associated with smaller pebble sizes is confirmed by fig. 4a (p. 204). It seems that a minimum gold value exists, which, in the pilot study area, amounts to about 6 dwts/ton.

With increasing pebble diameter, gold values rise sharply, and the extrapolated gradients of the curve in fig. 9a (p. 209) would be similar to those of fig. 12a (p. 212) with the gradient value approaching infinity. Lower down the paleoslope, conditions change, and the transition to new relationships, as is suggested by fig. 14, p. 214 (grid position S_7), will be discussed separately. The behaviour of the curves where pebble sizes are large is such that a limit to the size of the pebbles will be reached as the gold content increases. Beyond this limit, an increase in the gold content will, evidently, not be associated with an increase in pebble size. This limit is estimated at a mean pebble size of about fifteen millimetres in the pilot study area. The almost constant gold values at the lower ends of the curves, which reflect the hollows (fig. 2), are considered to approximate the original gold content of the gravel at the time of deposition, without any enrichment due to winnowing.

Pebble Packing Reef with closer packing contains higher concentrations of gold and uranium (fig. 2). This relationship extends beyond the limits of the pilot study area to 7^AVW18 at the I_6 control locality with a high correlation of 0,86 (fig. 12b, p. 212; appendix 5, p. 165). For the related data of fig. 12b, a parabolic curve provides the excellent fit coefficient of 0,97 (appendix 5). Deviations from the mean trend are apparently small in areas with moderate variations in floor elevation such as 7^AVW18. At the pilot study locality, situated lower downslope, the general packing-gold correlation is 0,74 (appendix 17, p. 189). For reefs narrower than three inches in the pilot study area, the exceedingly low correlation coefficient of 0,09 is obtained (fig. 9b, p. 209 ; appendix 4, p. 159). This may be related partly to faulty packing measurements at narrow thicknesses. This value was improved to 0,50 by excluding values associated with reef thinner than three inches (appendix 4, p. 159). The flattening at the base of the correlation curves (figs. 9b, p. 209 ; 12b, p. 212) suggests that gold values will not continue to decline with lower packing, but that a minimum gold value may exist, as was suggested previously. A progressive increase in packing values is accompanied by a rapid increase in gold content for values above about 25 per cent, as is indicated by the curve of fig. 12b. The above results show packing to be the characteristic of conglomerates most strongly and consistently linked to high gold concentrations.

Sorting The standard deviation of pebble size is dependent on the pebble size to the extent of 0,66 (appendix 17, p. 189).

It follows, therefore, that sorting would, like size, be related to gold content (figs. 9c, p. 209; 12c, p. 212; and 14c, p. 214). The degree of correlation between standard deviation and gold is 0,30, which is weaker than the 0,41 for the relationship between size and gold and the 0,74 between packing and gold (appendix 17). Lower standard deviation values are consistently associated with poorer gold values and higher standard deviations are accompanied by a moderate increase in gold content. The highest gold values in figs. 9c, 12c and 14c are associated with just below maximum standard deviations and represent samples taken over floor highs. As the samples with highest gold values are also relatively more deficient in small pebbles (figs. 10, p. 210; 13, p. 213), they probably represent the most advanced stage of winnowing. Sufficient removal of small grains reverses the tendency towards poorer sorting, and the remaining pebble populations approach homogeneity resulting in better sorting.

A comparison between the histograms of the pebble populations and their associated gold values in order to assess kurtosis (fig. 13) indicates that relatively high gold values are related to leptokurtic or excessively peaked probability curves. Marked skewness seems to be related to lower gold concentrations. Negative skewness is associated with higher gold values than positive skewness.

Relationship between Specific Pebble Sizes and Gold Content The histograms of fig. 10 (p. 210) show that higher gold values are associated mainly with the larger pebble size classes of the distribution. With decreasing gold values the frequency percentages of the pebble size classes above 16 mm, drop sharply. In histograms 17 and 18 there are relatively few grains left in the classes larger than 16 mm, while the gold concentrations have also decreased to the low value of 2 - 3 dwts/ton. However, it must be stressed that this relationship will change in upcurrent, and even more so, in downcurrent areas, where the initial size of the gold particles and the energy conditions of the depositional environment were different. The affinity between gold and large pebbles suggests that, in the pilot study area on the paleoslope (K_6 grid position), much of the gold, like the pebble constituents of the gravel, was transported by traction over the depositional floor. Traction comprises saltation and floor creep, i.e. jump-sliding and rolling. It is fairly certain that the pebbles moved in contact with the floor, but it is possible that the smaller gold particles moved mainly by saltation. Another possibility is that winnowing removed the smaller pebbles and many of the finer particles leaving the heavier gold grains, some of which had settled out of suspension, and the larger pebbles, It should be kept in mind that the White Reef is a loose pebbled quartzite and not an openwork pebble supported 'banket' type of conglomerate conducive to second phase infiltration of finer particles.

CHECKS ON THE PILOT STUDY

Less detailed tests were carried out at other localities to determine whether the relationships established in the pilot study were of wider application. The results are illustrated in figs. 11, 12, 13 and 14 (pp 211 - 214).

UPSTREAM AREAS

At the upstream locality (7^AVW18 stope, grid position I_6 - J_6, map 2) there are no complicating effects due to narrow reef. Relationships similar to those of the pilot study area can be deduced from the results (figs. 11, 12 and 13); an important difference is that the degrees of correlation between traction properties and gold, that are obtained (appendix 5, p. 164) are comparatively higher than those of the pilot study area; see table 14 below. It is interesting that the size - gold correlation can be further increased from 0,56 to 0,69 by exclusion of the smaller pebble size ranges (appendix 18, p. 194).

At this stage, the nature of correlation coefficients should be explained. Correlation coefficients vary from nil for a random distribution to one (or minus one) when all data points on a scatter diagram fall in a straight line. According to Snedecor (1956) judgements concerning the value of a correlation should be made with regard to similar correlations encountered in the same field of research, sometimes with little reference to the theoretical limit of $\pm$ 1. Appendices 22 (p. 198) and 23 (p. 199) provide a good illustration of the link between correlation coefficients and significance tests and show that even a low correlation can be significant.

DOWNCURRENT AREAS

Fig. 14 (p. 214) represents the farthest downcurrent facies of the White Reef at grid locality S_7, which is 10 000 feet downslope relative to the pilot study site at grid position K_6 on map 2 (p. 225) and close to the termination of the economic zone. The most significant change is that there is far less local variation in the conglomerate textural properties. The mean pebble sizes, in particular, tend to be uniform. Some of the relationships established in the pilot area can still be seen, but important differences have developed. The highest gold values, and the higher mean pebble sizes and packing densities, still occur in narrow reef, but the sorting values appear to be rather erratic. It is evident that both the pebble and metal properties are still related to the floor topography but the relationship between metal and pebble properties is diminishing. It is clearly indicated by the correlation coefficients calculated between pebble and metal properties (appendix 6, p. 166) which are all lower than those of the upslope positions (table 14).

TABLE 14

COMPARISON OF CORRELATION COEFFICIENTS RELATING SEDIMENTARY AND METAL PROPERTIES FOR THE UPCURRENT, PILOT STUDY AND DOWNCURRENT AREAS

Properties	Upcurrent	Pilot Study (mid current)	Downcurrent	Average
Size - Gold	0,56	0,41	0,29	0,42
Packing - Gold	0,86	0,74	0,51	0,70
Sorting - Gold	0,26	0,30	0,02	0,19
Average	0,56	0,48	0,27	
Data appendix no.	5	16	6	

The slighter variation in textural properties and the decreasing correlation coefficients downslope, indicate a progressive weakening of the traction load to metal concentration interaction. It points to a change-over from traction to suspension transport for the majority of the economic heavy minerals. Still farther downcurrent the dominant mode of gold transportation would have changed to suspension or even solution. The factors controlling these conditions fall outside the scope of this traction study. Such conditions could speculatively be related to pH, salinity, water temperature, abundance of organic matter and other factors related to suspension and solution precipitation.

COMBINATION OF UP- AND DOWNCURRENT EFFECTS

Further measurements were made in order to obtain results covering the full length of the available paleoslope (fig. 17, p. 217), which provides additional evidence about the behaviour of the gold (and uranium) particles. At the furthermost upcurrent position (5W4 at D_{12} close to the fanhead) the correlation curve for gold - size is almost linear, indicative of an unchanging relationship. This is best explained by the possibility that most gold particles were deposited with the traction load. This possibility although contrary to many currently held ideas, would also explain the correlation between higher gold values and larger pebbles (figs. 10, p. 210, 13, p. 213 ; appendix 18, p. 194) and the poorer correlation between gold and traction properties farther downstream (table 14, p. 69).

Intermediate positions on the depositional fan are represented by mine workings 10VW22 (J_6 on grid) and 7A VW18 (I_6 on grid). The correlation curves for these are now different, having changed to a completely parabolic shape (fig. 17, p. 217). The decreasing energy conditions lower down the slope provide an explanation. The lower segments of the parabolic curves could represent gold particles transported by creep and saltation. The upper portions of the curves, with an almost vertical gradient, are approaching a state where gold content increases while pebble size remains constant, suggesting that the two parameters are no longer interrelated. Under these conditions most of the gold was deposited out of suspension. It is, therefore, suggested that at intermediate positions on the fan, many of the original gold particles were finer than those deposited farther upcurrent. The variable grain size of Witwatersrand gold particles is well substantiated by the numerous measurements which have been made. The data has been recently reviewed by Pretorius (1974 a) and Feather and Koen (1975) and indicate significant size ranges on either side of 0,07 mm which is accepted as the transition between traction and suspension.

Farthest downcurrent on the paleoslope, at 24 - 3N stope (N_8), even the lower sections of the curve are becoming steep. A more advanced condition is represented, with the highest gold contents apparently not related to pebble sizes (top of curve - N_8). There is less gold in the traction load section (bottom of curve), and most of it was carried in suspension.

Two further conditions, not clearly demonstrated by fig. 17, may have existed. The first relates to the occurrence of thucholite and fly-speck carbon. These forms of radio-active carbon become relatively abundant in the down-fan environment of the Randfontein facies where uraninite and gold have been recovered from thucholite. The thucholite is considered to represent organic carbon with a composition similar to coal (Snyman, 1965). This type of deposit would have required a low energy aqueous environment covering the fan-base for periods of sufficient duration to grow mats which, today, are represented in the White Reef by columnar carbon reaching a thickness of 50 mm and by 'fly-speck' carbon grains. More recently Hallbauer and Van Warmelo (1974), using optical and scanning electron microscopy, were able to identify biological structures retained by the fossil carbon. They found that the carbon most commonly occurs as vertical finger-like columns, resembling moss. The evidence present led Hallbauer and Van Warmelo to postulate that the columnar carbon is the fossil remains of fungus-algae similar to a modern lichen. They also suggest that the fly-speck carbon is the reproductive mode, which resembles spores. It is pointed out by Feather and Koen (1975), in a recent review of the mineralogy of the Witwatersrand reefs, that the upper surface of the lichen colonies would have been capable of concentrating the associated heavy minerals, by a process resembling gravity concentration on a corduroy table. In addition, the carbon could have absorbed mineral salts from solution. The carbon, as seams and loose grains, therefore, did play a role in the concentration of gold and uranium.

The second condition applies to the fanhead environment which extends northwards beyond locality 5W4. At 5W4 (D_{12} on grid) the gold content and pebble distribution are in equilibrium, and the gold and pebbles may have been co-transported. Farther upcurrent, where there is an increase in the size of the pebbles but not in that of the gold particles, the equilibrium may disappear, as the size range of the gold particles, supplied from the source area, was mainly restricted, as is indicated by the rarity of gold nuggets in the Witwatersrand reefs.

GOLD MINERALISATION

DESCRIPTION OF THE REGIONAL TREND

A definite regional trend in gold mineralisation is shown on map 8 (p. 231) Mineralisation increases towards the west and south, away from the Luipaardsvlei facies, which contains the least gold, averaging about 50 inch-dwts. The West Rand phase has an overall grade of about 70 inch-dwts, while the Randfontein facies is the richest, and averages 90 inch-dwts. High mineralisation is restricted and irregularly distributed, the White Reef containing more than 100 inch-dwts over only 30 per cent of the area studied.

The main area of high mineralisation (+ 100 inch-dwts) takes the form of a broad, curved zone beginning at the central outcrop of West Rand Consolidated (map 8). It extends down-dip, in the paleocurrent direction (map 19, p. 244), coinciding with the major trend of robust conglomerate down to G_{10} (map 14, p. 237). A poorly investigated low-value gap separates this payshoot of the West Rand phase from the principal payshoot of the Randfontein facies. The northern end of the main Randfontein payshoot has not yet been fully exposed, but the northern point is at G_7. The two payshoots thus appear to be slightly offset. The lower pay zone extends SSW over the south-western corner of West Rand Consolidated Mines, thereafter curving gently SSE to T_8, close to the eastern border of Randfontein Estates G.M. Co. Ltd. The main shoot is generally about 3 000 feet wide and, over its length of 15 000 feet, reflects a strong paleocurrent flow represented by a robust conglomerate (maps 14, 15 and 16). Apart from these two major payshoots, which can be linked together along a broad curve, only minor areas of higher minerlisation are present. These will be described in the section dealing with the sub-patterns.

INTERPRETATION OF THE REGIONAL TREND

Most of the variablility in the gold values of the three facies is due to the differences in grade of the influxing gravels. There is no evidence that gold was uniformly distributed in the source rocks, which, on the evidence of pebble types, came from a heterogeneous metamorphic and granitic terrain. Moreover, differential transportation along the feeder rivers would have led to further segregation.

The upslope gravels belong to the Luipaardsvlei and West Rand phases which contain less gold than the more distal Randfontein type. It is, therefore, possible that the two northern phases reflect poorly mineralised source rocks. It is more likely that a large quantity of gold lagged along the rivers during transportation and enriched the Randfontein pulse, which is shown by later analysis to be a late phase of deposition. An important third factor is the higher energy regimes which were operative during the deposition of the northern gravels. High current velocities may have restricted deposition there to sparse coarser gold particles, as was postulated previously. Finally, the regional distribution of gold is also affected by the mode of gravel deposition, the highest grades of the Randfontein phase were upgraded by winnnowing during beanspreading deposition.

DESCRIPTION OF LUIPAARDSVLEI FACIES

The facies is of low grade and the mineralisation is erratic (map 8, p. 231). Isolated small areas of higher grade (+ 100 inch-dwts) are randomly distributed; there are ten such zones together comprising less than a tenth of the facies area. The richer patches cover about one and a half 1 000 feet square units and are located at D_{16}, D_{20}, G_{19}, G_{23}, G_{26}, J_{19}, I_{27} and I_{31}. Most of these occur in the southern part of the facies, and some are poorly elongated in the paleocurrent direction (map 19, p. 244)

A weak tendency of the values to increase down the paleoslope is shown by the average values calculated for successive 1 000 feet wide east-west strips, using the regional reference grid. The value of the inch-dwt contour line passing through the centre of each unit block on map 8 was taken to represent the block, and the following north to south variations were obtained: B = 35, C = 35, D = 50, E = 35, F = 40, G = 55, H = 50 and I = 50. Areas with faulting or for which no information is available were excluded from this estimate.

Small, almost barren areas with less than 25 inch-dwts form about 20 per cent of the facies; they are located at the C_{22}, D_{18}, D_{24}, D_{26}, F_{25}, F_{27}, H_{25} and I_{21} grid positions. The areas are nearly equal in size, each covering about two 1 000 feet square unit blocks. The lowest gold values are found in larger, elongated zones of low mineralisation, which are sub-parallel to the paleocurrent direction (e.g. that along B_{19} - E_{19} - G_{20} - I_{21}, B_{22} - D_{22}, G_{22} - I_{22}, C_{26} - G_{27} - H_{27}).

The relationship between gold mineralisation and pebble composition is best shown by plotting the most variable lithology type against gold content, see table 15 below.

TABLE 15

RELATIONSHIP BETWEEN PEBBLE LITHOLOGY AND GOLD MINERALISATION

LUIPAARDSVLEI FACIES						
Quartzite (per cent)	10 - 20	20 - 30	30 - 40	40 - 50		
Average gold, inch-dwts	40	51	65	33		
No. of pebble counts	4	22	16	4		
WEST RAND FACIES						
Quartzite (per cent)	0 - 2	2 - 4	4 - 6	6 - 8		
Average gold, inch-dwts	68	79	77	59		
No. of pebble counts	15	14	4	2		
RANDFONTEIN FACIES						
Quartzite (per cent)	0 - 10	10 - 20	20 - 30	30 - 40	40 - 50	50 - 60
Average gold, inch-dwts	23	69	95	85	124	200
No. of pebble counts	1	7	14	23	12	1

INTERPRETATION OF LUIPAARDSVLEI FACIES

The overall gold content increases downcurrent, and both high- and low-grade areas tend to be elongated in the paleocurrent direction.

Faulting

No definite relationship exists between faulting and mineralisation.

Paleoslope Effects

The slight progressive increase in gold content down the paleoslope is probably due to an increasingly higher metal content in the gravels deposited farther downslope.

Gravel Composition

A paired t-test of the data of table 14 shows that there is no direct correlation between average gold value and proportion of quartzite pebbles in the Luipaardsvlei facies, and the correlation coefficient is as low as 0,06 (appendix 22, p. 198).

Paleocurrents and Floor Topography

The larger zones with higher mineralisation tend to correspond to areas of negative floor topography extending northwards towards the entry points (map 7, p. 230). Due to scarcity of information, however, the mineralisation trends in this facies are ill-defined and their interpretation remains rather speculative.

Also elongated northwards towards the entry points are zones of low mineralisation such as those running along B_{19} - E_{19}, C_{22} - E_{22}, C_{24} - G_{24}, C_{26} - G_{27} and H_{29} - I_{30} (map 8, p. 231). It seems that current flow in these zones was impeded by early blockage, by stream shifting, braiding or by the partial barriers formed by higher floor topography which deflected much of the flow. A possible explanation for the distribution of gold is that much of the gravel came in along the feeder channels, and that, while the pebble and sand particles were readily spread out and redistributed over the floor highs, most of the gold lagged in the channel positions and was not easily dispersed. This aspect of sorting is better dealt with in the next section. Some of the floor lows with higher mineralisation correspond in direction to the structural grain and paleocurrents, both orientated towards the north-west, and could, perhaps, represent synclinal depressions active during deposition, e.g. along H_{30} (map 7). Other lows are obliquely orientated to the structural grain, but lie almost directly in the paleocurrent direction, e.g. C_{25} - D_{25} suggesting possible footwall scour channels directed approximately north-south. It thus seems that subsidences orientated in the direction of the paleocurrent may have been utilised as dispersal channels, otherwise scour channels developed as dispersal chutes.

Sorting

Reworking effects on mineralisation can be investigated by comparing the calculated average pebble size values (map 14, p. 237), the standard deviation of pebble sizes (map 15, p. 239) and the average pebble-packing percentages (map 16, p. 241) with the gold trends (map 8, p. 231). The latter values do not constitute reliable quantitative information, as the mineralised zones are not clearly defined and it depends on chance whether the zones and conglomerate measuring stations coincide. Nevertheless, it seems that pebble-packing values for high- and low-grade mineralisation positions are identical, both averaging 50 per cent. The pebble size averages are also almost identical, 15,5 mm for the high-grade and 14,1 for the low-grade areas, i.e. a difference of 10 per cent. This difference is, however, too small to be of statistical significance. Sorting, in terms of standard deviation, can be correlated with pebble size to the high degree of 0,91 (appendix 4, p. 158). Consequently, a similar degree of coincidence of sorting with gold distribution can be expected.

DESCRIPTION OF THE WEST RAND FACIES

The major feature is the payshoot situated in the centre of the mine and extending SSW from C_{12} (map 8). In its upper reaches, average values exceed 200 inch-dwts. The exposed length of the shoot is about 5 000 feet, and values diminish downcurrent. A second minor area of better mineralisation extends south-westwards from D_{16}. Two small patches of +100 inch-dwt values occur at B_9 and B_{10}. Low gold mineralisation is found in the area around B_{14}, B_{16}, D_9 and D_{12}. An elongated area with low values borders the main payshoot on the western side. Another zone of poor values along D_{14} - E_{13} is crossed by the main dyke.

INTERPRETATION OF WEST RAND FACIES

The two elongated payshoots mark channels filled by thicker reef (map 7, p. 230) containing larger, more closely packed pebbles which have undergone more sorting than the reef elsewhere (maps 14, 15 and 16). The channels are seen as larger dispersal chutes which supplied areas lower down the paleoslope. Extensive transportation resulted in the accumulation of heavy traction particles, including gold and uranium, as lag deposits. The two small areas at B_9 and B_{10} also coincide with floor depressions and more robust reef, containing larger and better sorted pebbles (maps 14 and 15), but there is no clear-cut relationship between gold content and pebble packing (map 16).

CONCLUSIONS

The factors that apparently controlled gold mineralisation in the West Rand facies, in order of decreasing importance, are as follows:

Original Gold Grade

The conglomerate contains an average gold content of about 70 inch-dwts.

Dispersal Channels

All areas of comparatively higher mineralisation correspond to well-developed conglomerate occupying dispersal channels marked by floor depressions. A progressive concentration of heavier particles of gold, uraninite and other heavy minerals, together with pebbles, produced lag deposits along the channels, while lighter particles were more readily moved downstream. Sorting was restricted to the dispersal channels; over the rest of the facies the gravels were deposited mainly by avalanche sedimentation.

Paleoslope Effects

The gold content decreases down the paleoslope. This is apparently related to the decrease in current velocities, or, alternatively, to the fact that the gold supply in the transported load had been exhausted by removal further upslope.

Gravel Lithology

A paired t-test of gold mineralisation and pebble composition of the data of table 15 (p. 73) shows a positive relationship between percentages of quartzite pebbles and gold (appendix 22, p. 198)

Floor Topography

There is a negative correlation between floor highs and gold distribution as opposed to the positive correlation found in the pilot study which is situated in an area of sheet flood deposition.

Structure

The minor payshoot, extending to the north-east over D_{16}, covers an area of repeated floor sagging (maps 4, 5, 6 and 22). The major zone of mineralisation along C_{12} - G_{10} has a parallel orientation and is also a thicker reef and could therefore possibly be related genetically to synclinal development, even though the reconstituted structure shows a mild anticline close by (map 4, p. 227). Yet, this is difficult to prove since data relating to reef thickness is not of adequate density to allow the deduction of subtle thickness to fold relationships, as was possible for Randfontein Estates (map 7, p. 230).

DESCRIPTION OF THE RANDFONTEIN FACIES

The dominant feature is the large payshoot which, over the south-western corner of West Rand Consolidated, curves gently south-eastwards towards the T_8 grid position adjacent to the Witpoortjie fault (map 8, p. 231). The payshoot is reasonably well outlined by the 100 inch-dwt contour lines. It is generally 3 000 feet wide and about 15 000 feet long. Gold concentrations reach maximum values at L_5 and at S_8. Minor paystreaks extend over L_9 - M_8 - N_8, and southwards over M_{11}. Small, isolated higher values are found at M_{10}, P_8, and O_{10}. Slightly higher values, not shown by the contours, extend southwards over S_4 - T_4 - U_4, but are better illustrated by the uranium dispersal pattern (map 9, p. 232).

INTERPRETATION OF THE RANDFONTEIN FACIES

The dominant control of gold mineralisation was provided by the interaction of strong current flow in confined areas (distributary streams) and the variations in floor topography. These two factors were both influenced by the position of structural subsidence, as will be discussed later.

Distributary Streams

The main payshoot curves along the paleocurrent path (map 19, p. 244) and generally corresponds with better developed conglomerate (maps 14, 15 and 16). The payshoot is seen as a central dispersal area of strong flow, in which large and heavy sediment grains gradually accumulated. Higher concentrations of gold and especially uranium occur along the inner bend of the curve (e.g. at R_7, map 9), where river placers usually show concentrations of heavy minerals due to decreases in water velocity. Two minor dispersal channels with more robust reef appear to be present along M_{11} - P_{10} and S_4 - T_4 (maps 14, 15 and 16). They contain higher values of gold and even higher values of uranium (maps 8 and 9).

Floor Topography

Better exposure to water turbulence over floor highs led to more effective sorting which resulted in the formation of robust conglomerate. Within the main payshoot the best grades are shown by the conglomerates over the highs. Outside the main stream, and its subsidiaries, higher gold mineralisation is not limited to areas of high floor indicating the effective sorting is linked to areas of strong flow. Gold-distribution and reef-thickness variation patterns (maps 7 and 8) show broad similarities along the main payshoot, and that poor gold mineralisation is usually related to floor lows. The large area of narrowest reef, in the south-western corner of West Rand Consolidated, contains the highest gold values. The payshoot is interrupted at O_6, where the floor topography is at its lowest (map 7, p. 230). Far down the paleoslope, at S_8 - T_7, the area of maximum gold values covers the highest floor in that locality. The rich zones at Q_{6-7} and L_9 - N_8 are also narrow reef floor types.

A topographic low at L_7 separates the main and minor payshoots; the boundaries of the south-eastern part of the main shoot, beyond O_6, coincide with the termination of the elevated floor area. Smaller patches of poor mineralisation at R_7, O_7, L_4, M_8 and J_6 overlie lower floor (map 7, p. 230).

Some small scale anomalies are also present in the sense that better gold values and relatively high floor topography do not always coincide, e.g. the floor high at N_4 (map 8, p. 231) is covered by poorer values and the low at S_7 (west side), is overlain by the relatively high values of the main payshoot. These anomalies are minor and do not invalidate the main conclusions set out above. In fact, on the basis of the pebble size, sorting and packing patterns most of these anomalies can be explained in terms of fluctuating current strengths; at N_4 the floor high with low mineralisation values, is overlain by a conglomerate with relatively small sorting, packing and pebble size values indicative of locally lower energy outside the centre of the main channel. At S_7 the low topography is not reflected by smaller pebble size or packing values, and there is no indication, therefore, that there was a decrease in local environmental energy for this part of the centre of the main current.

The lack of correlation between floor effects and gold values, which cannot be explained in terms of conglomerate properties, becomes of relative importance only in the far upcurrent area of the facies, for instance at I_5 and J_6, where high gold values occur in thicker reef, and at K_4, J_5 and I_6, where low gold values occur in narrow reef (maps 7 and 8). These positions are related to the boundary of the Randfontein Facies where deposition was changing northwards into the avalanching deposition of the adjacent West Rand facies.

Gravel Composition

The paired t-test of appendix 22 (p. 198) shows a very high degree of correlation (0, 93) between quartzite pebble abundance and higher gold. However, this factor is apparently of lesser importance than the distribution channel and topography control of gold distribution.

The variable proportion of quartzite pebbles over the Randfontein facies area indicates that reworking has not completely homogenised the constituents of the gravel (map 18, p. 243). It is possible, therefore, that correlation between gold and pebble type reflects a variable mineralisation of the load transported. If this is so, a large amount of the gold particles and higher amounts of quartzite pebbles must have been co-transported by traction. Since such co-transportation is more likely over restricted distances, this possibility is supported by the fact that the quartzite fragments are part of the immature of 'soft' section of the bedload which would have disappeared with prolonged transportation. At a later stage it will be explained that the 'immature' Randfontein gravels bypassed the more mature lithological phase of the West Rand.

Structure

The Randfontein trough formed the axis of the West Rand subsiding fold during Main-Bird times (maps, 4, 6; fig. 20). The major pay areas are associated with the trough in that they are not more than 3 000 feet distant from the axis at any place along its length of about 15 000 feet (map 22, p. 247). It appears that the stream which built the main payshoots was confined by a broad valley formed by this trough.

Grade of Gravel

The moderate gold content of the original gravel limited the economic potential. The initial grade is reflected by the values present outside the payshoots and paystreaks. In the main payshoot, original values were nearly doubled due to reconcentration processes. It is possible that the poor grade of the upslope gravels is due to unfavourably high velocities which swept most gold grains downslope to positions where deposition exceeded transport.

SUMMARY OF CONTROLLING FACTORS

The relative importance of the factors which affected mineralisation in the three facies of the conglomerate are summarised in table 16 below. These reflect the properties that primarily determined the grade of gold and are not listed in order of decreasing correlation with gold content.

TABLE 16

RELATIVE IMPORTANCE OF FACTORS WHICH AFFECTED GOLD MINERALISATION

	Luipaardsvlei Facies	West Rand Facies	Randfontein Facies
FIRST ORDER	Low gravel grade, velocity controlled Lag concentrations along distributaries	Moderate gravel grade, velocity controlled Lag concentrations along structurally controlled distributary channels	Higher gravel grade, velocity controlled Lag concentrations along main stream which is fold controlled
SECOND ORDER		Variable gravel composition	Strong concentrations over floor highs, velocity controlled Variable gravel composition

COMPARISON OF MINERALISATION CONTROLS FOR WITWATERSRAND REEFS

The controls are compared below with those determined for other reefs studied recently (table 17). Various common controls are present. The grade of mineralisation of the source materials is of first order importance for the proximal reefs, and less so for more distal facies, e.g. Vaal Reef and Kimberley 9A. Another common first order control is the synclinal guidance of major payshoots, excellently illustrated by the Vaal (Minter, 1972) and White Reefs. It is possible that not all cases of fold control have yet been determined or exploited as an exploration tool.

TABLE 17

MINERALISATION CONTROLS FOR VARIOUS WITWATERSRAND REEFS

Factors:
1. Grade of provenance materials
2. Payshoot controls by large syncline
3. Accumulations along distributary channels
4. Paleoslope control
5. Local floor shape, erosional or small folds
6. Carbon mats
7. Reworking of footwall beds
8. Diastrophism (degradation/aggradation)
9. Lithology control

Reefs	White	Livingstone	V.C.R.	Basal	Vaal	Kimberley 9A
Mega controls	1 2 3	1 2 3	1 2 3 7	3	1 2 3 5	2 7
Medium controls	4 5	4	5	4 5 8		
Local controls	5 6 9	7		5 6 7	6 7	

This also applies to the delineation of distributary channels which are the most common control, being often positioned by synclinal axes. The channel concentrations are, therefore, the most fundamental control and it can be anticipated that this would apply to the general fluvial mode of deposition.

The influence of the paleoslope gradient, i.e. strong increase or decrease of mineralisation downslope, is a feature related to proximal or relatively small basin edge fans, e.g. White and Basal Reefs (Winter, personal communication). The effect is less marked in extensive fan deposits like the Kimberley reefs of the East Rand or the more distally deposited Vaal Reef at Klerksdorp, or where only a portion of the fan, away from the entry points, has been studied.

The local shape of the floor is normally of a lower order control, but in the distal environments it becomes of medium order importance, e.g. White Reef (Randfontein facies), or even a primary control, e.g. the Vaal Reef (Minter, 1972).

The importance of pebble lithology as a controlling factor is rather unusual, possibly due to the limited data for this aspect in other reefs. It may be a feature of gravels transported over short distances.

The factor that varies most in its relative importance is that of reworking of footwall reefs, or recycling. It is, however, of primary importance for post-Witwatersrand deposits, e.g. V.C.R., and also the Kimberley 9A deposits (Armstrong, 1965).

The development of carbon seams is seen as a minor control factor for the reefs of table 17 and is only related to distal environments. The degradation-aggradation reef type as defined by De Kock (1964) is of primary importance for reefs accumulated as erosional conglomerates, e.g. the Carbon Leader on the Far West Rand. It is poorly represented in the above comparison, but, according to Sims (1969), it is of intermediate significance for the Basal Reef.

URANIUM MINERALISATION

The distribution pattern of uranium (map 9, p. 232) largely reflects that of gold (map 8, p. 231). There are some subordinate but systematic regional differences. The correlation between conglomerate properties and gold mineralisation, already established, apply largely to uranium as well. Details will therefore be omitted except where the differences between gold and uranium mineralisation patterns occur.

DISCUSSION OF THE LUIPAARDSVLEI FACIES

The relationship between the largest areas of better uranium mineralisation and thicker reef is distinct (e.g. around D_{20-21}, G_{25-26} and F_{26}), and suggests the concentration of uranium along channels covering low floor topography (map 7, p. 230). The correlation between uranium and robust reef is less definite (maps 14, 15 and 16). Comparison is difficult because of sparse uranium values and speculative value contours.

Variations in lithology as indicated by pebble compositions are significantly reflected by the uranium distribution pattern (table 18, below; appendix 23, p. 199). There is a tendency towards better mineralisation lower down the paleoslope. There are minor instances where small areas of better mineralisation occur in relatively thin reef, e.g. B_{21}, D_{22}, G_{19}, G_{22} and J_{19} (map 7, p. 230).

TABLE 18

PEBBLE COMPOSITION RELATIVE TO URANINITE MINERALISATION

LUIPAARDSVLEI FACIES						
Quartzite (per cent)	0 - 10	10 - 20	20 - 30	30 - 40	40 - 50	50 - 60
Average uraninite (inch-lbs)	-	6,4	5,1	8,8	6,5	-
No. of pebble counts	-	5	18	11	2	-
WEST RAND FACIES						
Quartzite (per cent)	0 - 2	2 - 4	4 - 6	6 - 8	8 - 10	
Average uraninite (inch-lbs)	4,9	11,6	11,8	10,5	-	
No. of pebble counts	15	11	11	2	-	
RANDFONTEIN FACIES						
Quartzite (per cent)	0 - 10	10 - 20	20 - 30	30 - 40	40 - 50	50 - 60
Average uraninite (inch-lbs)	20	33	40	46	54	55
No. of pebble counts	1	7	14	24	11	1

INTERPRETATION OF THE LUIPAARDSVLEI FACIES

The factors that apparently controlled uranium can be summarised in order of decreasing importance:

Original Uranium Content

The overall concentration of uranium-bearing minerals is low and is generally less than 10 inch-pounds. Mineralisation varies inversely with the energy state at the time of deposition. High on the paleoslope and nearest to the entry points, where high-energy conditions prevailed, the transport of heavy minerals exceeded their deposition and uranium values are poor, in spite of the presence of better developed conglomerate. Lower down the slope the grade improves due to drop-out caused by lower current velocities, or to an improvement in the grade of material supplied.

Accumulation along Dispersal Channels

As in the case of gold more uraninite was deposited along the zones of lowest floor topography.

Sorting Processes

Winnowing produced better concentrated gravels over floor highs, it did not, however, bring about a similar upgrading of the uranium minerals. This is in contrast to the situation in the other phases of the reef where high energy regimes caused continued sorting and concentrated both uraninite and gold in robust reef. The reason for this anomaly lies in the very high energy conditions of the Luipaardsvlei phase, which only permitted settling of heavy minerals along sheltered floor lows.

DESCRIPTION OF THE WEST RAND FACIES

The overall uranium distribution pattern is similar to that of gold (maps 8 and 9) except that, in general, the uraninite content increases down the paleoslope whilst the gold content decreases.

INTERPRETATION OF THE WEST RAND FACIES

Mode of Deposition

The progressive increase in uranium content down the paleoslope, again, proves that a relatively low energy environment is more suitable for its concentration. In the White Reef, this environment is defined by the presence of pebbles generally less than 10 mm in size (maps 9 and 14). The main payshoot which reflects a transport channel, provides an important exception. This is due to the continuous sorting and concentration of heavy particles, which did not take place in the adjacent areas. The overall increase in mineralisation down the paleoslope is related to the specific gravity of heavy minerals, particle size and depositional factors. The West Rand facies was rapidly deposited, often by means of avalanching, whilst, farther downslope, sheet flood deposition was operative. The change to the latter process resulted in an increased degree of winnowing and a related increase in uranium content.

Grain Size

There is an area of relatively low uranium mineralisation at E_{10-11}, which separates the northern payshoot from the general area of higher mineralisation in the south and is indicated by the 10 inch-lb contour line (map 9, p. 232). It can be speculated that this point approximately indicates the depositional boundary between two sub-populations of uraninite and gold particles (map 8, p. 231), with coarser particles associated with more robust reef in the north, and finer particles, reflecting a lower energy environment, in the south. If this is so, there was a distinct difference between the mineralisation controls; in the channels corresponding with low floor topography, the coarse uraninite and gold particles of the upper West Rand and Luipaardsvlei facies were deposited, while finer, more mobile heavy mineral particles were winnowed by currents and concentrated in algal mats and over floor highs in the lower West Rand and Randfontein facies.

Carbon Seams

The significance of thucholite, which is an uranium-rich carbonaceous substance of organic origin, comparable to a thin coal (Snyman, 1965), must be considered. It is usually found near the upper contact of the White Reef conglomerate in the Randfontein facies and sometimes attains a thickness of two inches, but is absent over most of the other two facies. Feather and Koen (1975) suggest that the upper surface of the lichen mats was capable of trapping heavy minerals, and that the carbon was capable of absorbing mineral salts from solution. Reimer (1975) went so far as to suggest that most gold and uranium were deposited from solution under strong organic influences.

In the White Reef, thucholite only contains a portion of the total amount or uraninite, which is indicated by sampling to be scattered throughout the whole of the conglomerate, whilst the carbon is mostly present as thin layers usually close to the top of the conglomerate. The thucholite is, thus, not of primary significance in controlling the distribution of uranium, as best mineralisation is associated with zones of robust lag conglomerates. The presence of thin seams of carbon does indicate, however, that the southern section of the West Rand facies was frequently covered by water for sufficient periods for carbon seams to accumulate. Quiet, swampy sub-aqueous conditions, intermittant between flood periods which provided the coarse sediments, are thus indicated.

Gravel Lithology

A paired t-test (appendix 23, p. 199) comparing uranium and pebble lithology as set out in table 17 (p. 80) indicates a positive association between uranium ore and quartzite. The implications have been discussed previously (p. 78). The increase in quartzite pebbles, both downdip and in the central payshoot, indicates a progressive increase in quartzite in the gravels deposited downslope, which may have bypassed through this channel to feed the Randfontein phase.

DESCRIPTION OF THE RANDFONTEIN FACIES

The highest values of uranium occur lower down the paleoslope than those of gold. The major payshoot is, in the downcurrent reaches, better defined by uranium than by gold values. Upcurrent, the reverse is true. The asymmetric distribution of uranium across the width of the channel is quite clear - the highest values occur on the inside of the curve, at R_7 (map 9). The high uranium content downchannel is consistent and reaches peak values of over 110 inch-lbs at T_7; the upchannel values, on the other hand, are lower, more erratic and rarely exceed 70 inch-lbs.

The minor payshoot over L_9 - M_8 is well defined by the 40 inch-lbs contour line, and also its link with the main channel. The two remaining small payshoots, over M_{11} - N_{11} and S_4 - V_5, are both more clearly indicated by the uraninite distribution than by that of gold.

Beyond the western margin of the main payshoot the overall grade of uranium mineralisation increases steadily southwards in the paleocurrent direction to a maximum of 49 inch-lbs uraninite at R_4. Farther on, there is a gradual decrease in values towards the south-east. Towards the extreme south, along the outcrops, there is a pronounced decrease in the uranium grade and at Z_1 the values of less than 10 inch-lbs are comparable with those recorded for the farthest upstream positions of the two other facies.

INTERPRETATION OF THE RANDFONTEIN FACIES

Main Stream Beds

The four areas of comparatively higher uranium mineralisation are all elongated (map 9, p. 232), appear to lie in the paleocurrent direction (map 19, p. 244) and contain better developed conglomerate (maps 14, 15 and 16). These are believed to represent stream beds which accumulated heavier detrital particles.

Floor Highs

In the main channel and in its auxiliary over M_8 better concentrations were often achieved over local floor highs. This type of enrichment is not of primary importance as it is limited to restricted areas of the main distribution channel which contains relatively good mineralisation throughout, even where the floor is low.

Grain Size and Specific Gravity Effects

Uranium grade increases progressively downslope. The uranium-rich lower section of the main stream area is well demarcated by pebble size. The pebbles are smaller than those in the zones of lower mineralisation farther upcurrent, indicating that the current upslope was too turbulent to permit most of the relatively small uraninite grains to settle. The best uranium mineralisation downstream in excess of 70 inch-lbs, is coupled to a mean pebble size of 10 - 11 mm representing the velocities most conducive to maximum uranium particle drop-out (map 14, p. 237). The size of the uranium particles is unfortunately not known.

Gravel Composition

In table 18 the distribution of quartzite pebbles relative to uranium mineralisation is shown. The values were obtained from maps 9 (p. 232) and 18 (p. 243) by utilising the average uranium grade in the unit block containing the corresponding pebble count station.

The results, as quantified by statistical tests (appendix 23, p. 199), show that an increasing proportion of quartzite pebbles is accompanied by richer uranium mineralisation.

Organic Carbon

The Randfontein facies, deposited under low-energy conditions, contains most thucholite and also most uranium. Yet, it seems that the uranium is mostly concentrated in the robust conglomerate and is not restricted to thucholite; mine sampling records prove that the uranium is distributed throughout the total conglomerate thickness. In the West Rand payshoot at C_{12} (map 9, p. 232) it can be seen that a relatively high concentration of uranium was evident even where no thucholite was present. It, therefore, appears that organic carbon was not the major control for uranium ores.

Structure

The first order control for uranium was the north-south Randfontein trough which guided the main stream forming the major payshoot.

Original Uranium Grade

The original grade of the gravels is, perhaps, best reflected by values existing outside the payshoots, namely 10 - 40 inch-lbs. The supply of uraninite reached its peak during deposition of the Randfontein facies. Even in the distributary streams the original uraninite content was the most important factor in determining the eventual grade. Where little reworking took place the grade was hardly changed, but under the most favourable conditions of reworking it was approximately doubled.

SUMMARY OF FACTORS CONTROLLING MINERALISATION

The factors that determined grade and distribution of uranium in the Randfontein facies are listed in table 19 below and are compared with those of the other two facies.

TABLE 19

RELATIVE IMPORTANCE OF FACTORS WHICH AFFECTED URANINITE MINERALISATION

	Luipaardsvlei Facies	West Rand Facies	Randfontein Facies
MAIN CONTROLS	Unfavourable high velocities Accumulation in dispersal channels	Medium velocities Accumulation in dispersal channels	Favourable low velocities Accumulation in dispersal channels. The main payshoot being fold controlled
SECONDARY FACTORS	Gravel composition	Gravel composition	Accumulation over floor highs. Gravel composition
MINOR FACTORS		Organic carbon	Organic carbon

DISTRIBUTION OF GOLD RELATIVE TO URANIUM

DESCRIPTION

Gold and uraninite contents vary sympathetically over practically the whole area. This is well illustrated by the regional distribution patterns and the more detailed results of the pilot and follow-up studies.

There are significant differences between gold and uranium distribution patterns in the West Rand and Randfontein facies (maps 8 and 9). The maximum concentration of gold occurs relatively high up on the paleoslope at C_{12} and L_5, and there is a general decrease in gold content down the slope, except for the small high-grade areas at Q_7 and S_8 in the south. On the other hand, the uranium content in these two facies steadily increases down the paleoslope to reach a peak at S_7 in the main channel of the Randfontein facies. The progressive increase in uranium relative to gold down the slope is shown by the iso-ratio contours of map 10 (p. 233).

Comparable ratios are present in the Luipaardsvlei and West Rand facies, with maximum ratio values exceeding 16:1 in both cases. The calculated overall average ratio value of 10:1 for the Luipaardsvlei facies is slightly higher than the 9:1 of the West Rand facies, whilst that of the Randfontein facies is as low as 2,4:1.

DISCUSSION

The iso-ratio contours, away from the entry points and distribution channels, generally parallel the strike of the depositional surface. This suggests that the attitude of the paleoslope, plus the direction and relative strength of the paleocurrents were mainly responsible for the differential distribution of gold and uraninite. The heavier gold particles were apparently deposited at a faster rate with progressive decrease in current velocity than the lighter uraninite grains in the same size ranges. However, variations in the competency of the currents were present and consistent stronger flow carried more gold down the main distributary channels, which results in the iso-value contours bending southwards along the stream channels. Other factors, like grain size distributions, grain shape variations, and entrapment or uranium in carbon, probably also affected the relative distribution of the two minerals. Their effect appears minor, as the overall pattern is linked mainly to paleoslope and dispersal channel control. It is of interest, however, that the highest ratios occur at B_{11} and D_{27} together with maximum pebble sizes (map 14, p. 237). This suggests that, under the conditions of maximum current velocity at the entry points, the uraninite settled only with difficulty.

CONCLUSIONS

The gold-uranium ratio map reflects the dominant control of depositional slope, current strength and flow directions on the relative accumulation of the two metals. It also confirms that gold was deposited in relatively greater abundance on the upper parts of the paleoslope, while, downslope, the position was almost completely reversed. However, these were relatively long-distance effects and are therefore not noticeable over small areas, where good correlations between gold and uranium prevail up to the extent of 0,97 (appendix 17, p. 139). The regional systematic differences and good local correlations are best explained by the fact that gold and uraninite were both transported as detrital grains; the faster drop out of gold, high on the paleoslope, being due to its higher specific gravity; the local correlation is indicative of largely similar effects of local transportation on sorting conditions. Other factors probably also affected the relative dispersal of gold and uranium but they cannot be assessed on the basis of the data available and their importance seems to be minor. The uraninite grain sizes were not stable in the highest energy zones and the highest ratios thus indicate the approximate positions of the entry points of the West Rand and Luipaardsvlei facies.

The Au/U ratios of the White Reef can be compared with those of other reefs. Minter (1972) illustrated that during the deposition of the Main-Bird period, the amount of gold decreased, whilst the uranium increased, so that the ratio of Au/U diminishes progressively. He suggested that the source rocks supplied an increasing amount of uranium relative to gold, or alternatively that these minerals were selectively transported into the depository. The third, and, according to him, more feasible, explanation is that selective deposition took place and that the Main, North and Livingstone Reefs are representative of more proximal environments whilst the overlying Bird reefs are more distal deposits. Pretorius (1974 a) shows that the Main, South, Livingstone, Vaal, Basal and White Reefs generally fall into the same Au/U category, with the White Reef being the richest in uranium. He presents ratios for the Zone 2 and Monarch Reefs of the overlying upper Bird Reefs illustrating that they form an uranium rich class of their own.

The Au/U distribution pattern for the White Reef supports Minter's contention that distal lower energy environments favour higher uranium concentration. Yet, the White Reef which is the more proximal deposit has a significantly lower Au/U ratio of 1:4 (table 17, Pretorius, 1974 a) than the Vaal Reef. This illustrates that environment is not the major factor controlling the change. It seems that the richer uranium deposits of the later reefs are related to the incorporation into the conglomerate of more uranium-bearing granitic source materials in preference to the gold producing ultramafic and mafic rocks of the greenstone belts of the source area, which were being depleted by erosion. The change in ratios is, therefore, interpreted as being related to a progressive change in source rock type. This also explains why the West Rand depositional area generally contains lower gold values than the other entry points to the Witwatersrand basin.

4. HANGINGWALL GEOLOGY

THE IMMEDIATE HANGINGWALL QUARTZITES

LITHOLOGY

Description

The first few feet of quartzites deposited directly on top of the White Reef vary in character depending on the paleoslope position. Over the area of the northerly mines, the covering quartzites are of medium grain and impure with a fair amount of argillaceous matrix. Scattered small pebble conglomerates and gritty stringers are present. Crossbedding is relatively abundant.

Farther downslope, over the extent of Randfontein Mines, the quartzite decrease in grain size from the medium - fine range, to only fine. The matrix between the grains is mainly devoid of argillaceous material and the overlying eight to twenty-four inches of quartzite usually have a blue 'bar' appearance. Only very occasionally are pebbly grits found or a gradual downward transition from overlying grit into the White Reef proper observed.

Interpretation

The hangingwall quartzite becomes finer grained down the slope of the fan and loses much of the matrix argillaceous material. This improved sorting can be related to a change of depositional environment, still in the fluvial range, or, alternatively, to the introduction of wave sorting processes lapping onto the fan-base, out of the main basin.

VECTORAL PROPERTIES

Description

Crossbedding azimuth directions spread southwards in a fanlike form (map 20, p. 245). Minor deviations in the pattern are present in the southern section of Randfontein Estates, close to the apex position of the West Rand fold, and also between West and Turk shafts on Luipaardsvlei Estates.

Interpretation

The fan pattern and largely unimodal flow, indicate shallow water deposition. The variable lithology, with argillaceous, gritty and conglomeratic materials present in the upfan section, shows the fan to be of fluvial origin.

Mainly northerly sources and entry points are indicated. All minor deviations from the overall fan pattern are inherited from earlier periods. Firstly, there is the uplift in the west opposite the southern end of the western flank of the main fold. This uplift had only a mild effect during the pre-White Reef period, deviating the paleocurrents slightly towards the south-east in the vicinity of 2N and 32 shafts (map 13, p. 236). Thereafter, the uplift increased and directed the White Reef paleocurrents, on the Randfontein Mine, more to the south-east (map 19, p. 244). In the immediate post-White Reef period, the uplift caused a current trend towards the east, south of 32 Shaft. The uplift beyond the western flank of the Randfontein trough was sufficient during the pre-White to immediate post-White Reef period to cause the main current to deviate from an original south-westerly direction towards the south-east. It is of major importance for mineralisation as it deflected the main payshoot towards the south-east (maps 8 and 9).

The deviation in current direction towards the south-west between West and Turk shafts is, likewise, of earlier origin being inherited from the pre-White Reef period and is related to a minor channel head. The deviation in current directions towards the south-east in the proximity of the apex position of the West Rand syncline, at B_{9-11}, D_{10} and F_{12} reflects a trend already visible in pre-White Reef times (compare map 13, p. 236). It suggests some locally aligned sedimentation along the axis of the West Rand fold and also that the fold was not entirely post-depositional. During White Reef times accentuated source uplift caused unwavering uniform sedimentation away from the northern entries towards the south-west and, temporarily, decreased this weak local deviation (map 19). Another trend that continued unchanged after White Reef times was that of uniformly directed north to south sedimentation at the end of the eastern flank of the main fold (maps 19 and 20). Symmetrical sedimentation response to uplift at both extreme ends of the subsiding area, thus, points to slightly more pronounced rim control in the immediate post-White Reef period.

RIPPLEMARKS AND SANDWAVES

Description

Symmetrical moulds of ripplemarks were measured at D_{13}, E_{10}, R_4, T_6 and V_5. The axes are orientated predominantly north-south (map 12, p. 235). Moulds of symmetrical sandwaves are present at E_{11} and D_{13} with a similar orientation. Asymmetrical ripple moulds at L_4, M_4, N_4, M_5 and N_7 were observed with variable and opposing orientations.

Interpretation

Virtually all fossil current ripples are aqueous. The symmetrical ripple moulds are classified as being of oscillation origin, presumably wave generated. As wave movement dies out rapidly with depth, such oscillation ripples are indicative of a shallow sandy bottom not more than a few tens of feet deep (Pettijohn, 1957). Oscillation ripples have been reported from very deep water, but this is not anticipated here because of the presence of coarse sands and of sandwaves, which reflect a high energy state, more often than not of fluvial origin. The few ripple axes present are mostly orientated parallel to the general paleocurrent direction, as deduced from crossbedding asimuths.

The assymetrical moulds of ripples located to the north and east of 2N Shaft are orientated in all directions, even to the north. They reflect local small scale deviations and reversals in current flow, coinciding to some extent with crossbedding azimuths close by, which are inclined up-slope to the north at S_4, S_5 and T_5 (map 12, p. 235). These contrast with the overall uniform deposition to the south found in these hangingwall quartzites and the earlier beds studied. As the reversals are situated low on the paleoslope, it is possible that, here, for the first time, evidence of a tidal reversal out of the main basin, lapping onto the depositional fan, can be seen. The later sorting action may also have been responsible for cleaning and sorting these hangingwall quartzites, lower down the fan (see p. 90).

INTERVAL BETWEEN THE WHITE AND MONARCH REEFS

LITHOLOGY AND GEOMETRY

The White Reef is overlain by a homogeneous succession of medium-grained grey or greenish-grey quartzites, which extend up to the base of the Monarch Reef. The quartzites thicken from about 75 feet on East Champ d'Or to 150 feet or more in the south of the Randfontein Estates (map 11, p. 234). A small pebble conglomerate, known as the Middle Reef, occurs 10 to 50 feet below the Monarch Reef and contains payable uraninite at East Champ d'Or.

INTERPRETATION

The thickness of the unit is comparable to that of the interval between the South and Main reefs (map 6, p. 229). Unlike the geometry of the latter, the shape of the West Rand syncline is not reflected by the thickness pattern. The thinning towards the eastern and, especially, towards the western rim is much reduced indicating a decrease in the rate of subsidence of the area during this stage of sedimentation. In the centre, a slight subsidence is revealed by minor deflections of the isopach lines. It seems to be associated in position and its north-easterly orientation, with the depression shown more clearly by the isopachs of the South - Main Reefs interval. The early depression may, therefore, have remained active up to Monarch Reef times.

The main feature is the increase in thickness southwards down the paleoslope, away from the northerly source area, as deduced from crossbedding directions (map 20, p. 245).

SYNTHESIS

1. FOLD DEVELOPMENT

The isopachs of the interval separating the Main and South reefs reflect an early broad West Rand subsidence (map 6, p. 229). The lowest section lies along the north-to-south plunging Randfontein trough which generally guided sedimentation southwards. At its southern end the trough is deflected south-westwards into the shallower north-easterly trending Witpoortjie trough, and it is possible that a small basin developed at this position during Main to South reef times. The Witpoortjie trough parallels the main Witwatersrand basin, emphasizing a common origin related to a single regional NW-SE tensional field. The rim framework for the later developed West Rand syncline was already visible, as is shown by the isopach form at the outer rim. The lack of a marked trend of subsidence towards the south-east points to the later development of the major fold. The main syncline, which developed later out of the early subsidence, owes its existence to the unchanging control by the flanking granite buttresses of structure and dependent sedimentation.

The entry point for the Livingstone Reefs is located in the north in the vicinity of A_7 (map 4, p. 227), beyond the outcrops of the White Reef, where the Randfontein trough depressed the apex of the adjoining east and western rims of the West Rand depression. The south-westerly orientation of the major Livingstone Reefs isopach channel (map 5, Steyn, 1973) reflects the continuing existence of the north-easterly orientated subsidence pattern during the period of the Livingstone Reef Stage. The north-eastern direction reflects that of the proximal rigid western rim granite buttress which later strongly deflected the updip end of the West Rand synclinal axis in that direction (map 5, p. 228).

During the deposition of the uppermost quartzites of the Livingstone Reef Stage, the continued control of sedimentation by the Randfontein trough is reflected by the paleocurrent vectors (fig. 20, p. 219). The local deviation of crossbedding directions towards the south-east at E_{10} (map 13, p. 236) concur with the axis direction of the West Rand syncline (map 4) which may thus have already been initiated as a minor feature.

The primary control of the shape of the White Reef conglomerate was the external supply factor caused by rapid uplift. This is demonstrated by the increase in reef thickness towards the northern entry points. The second order control was the overall central subsidence as reflected by lesser reef thicknesses towards the rim (map 7, p. 230). The main control of the paleocurrents, the Randfontein trough (map 23D, p. 248), was unchanged and the major payshoots are associated with its axial position (map 22, p. 247). A low order control of sedimentation is shown by slight flexures, revealed by reef thicknesses, orientated to the north-east and north-west suggesting the introduction of north-westerly and north-easterly directed folding (map 7). Mild local uplift beyond the steeper rising western rim caused local current deviations towards the south-east (map 19, p. 244).

A second stage of tectonic activity is, thus, demonstrated at the initiation of the Bird Reef Stage, consisting of minor warping towards the north-east and north-west. The position in time of the second phase equals that established for the Klerksdorp area which affected the time equivalent Vaal Reef (Minter, 1972).

In the immediate post-White Reef period, the fact that the Randfontein trough was still subsiding is shown by the paleocurrent trend (map 20, p. 245). Interesting deviations to the general flow pattern are, firstly, the local vector directions towards the east, south of 32 Shaft, possibly related to the mentioned local uplift beyond the western rim. Secondly, the re-appearance of some crossbedding directions orientated to the south-east along the axis direction of the West Rand syncline. This subtle trend could have been suppressed in White Reef times by rapid source uplift causing strong flow to the south-west across minor depressions (see p. 91).

The isopachs of the interval that separates the White and Monarch reefs (map 11, p. 234) suggest an overall lower rate of subsidence, and a north-eastern axis of maximum thickening in accordance with earlier subsidence trends. The main feature is the dominant east-west paleoslope and the increase in thickness towards the main basin.

The orientation of the zones of metal concentration of the remainder of the Bird Reefs (Toens and Griffiths, fig. 5, 1964) indicates the continued control of mineralisation during the Bird Reef Stage by the Randfontein trough. The latter structure thus influenced sedimentation throughout the Main-Bird Series.

The third or major phase of folding which formed the West Rand syncline is post-depositional as basining was not marked in the interval separating the Main and Kimberley reefs, or even the V.C.R. (see sections in Plate II, Toens and Griffiths, 1964). The main phase of basining is clearly related to the period following the formation of the Witpoortjie horst. The drag associated with the horst uplifted the southern flank of the basin, present at the level of the White Reef (map 4, p. 227).

An important aspect of the tectonic development, not discussed so far, is the existence of normal faults which must have parallelled the basin edge and which assisted in the uplift of the source area, as is normally the case in yoked basins.

2. FOOTWALL DEPOSITION

The vector structures of the White Reef footwall show a fanlike pattern of sedimentation (map 13, p. 236), with a mean paleocurrent direction coincident with that of the Randfontein trough, towards the south (fig. 20, p. 219). The fanhead is offset and positioned to the east of the apex of the triangular area of subsidence. This is due to the entry point being on the eastern rim.

The litho-facies changes of the footwall beds permit the identification of the paleo-environment. Quartzite predominates ranging from siliceous to argillaceous. Varying numbers of gritty beds, discontinuous layers of small scattered pebbles and occasional lensic conglomerates, indicate fluvial deposition. The increase of coarser sediments upwards, towards the White Reef, points to the absence of a marked unconformity below it and a persistent change towards coarser sedimentation in the depositional environment, i.e. towards more proximal fluvial conditions. This shows that the base of the Bird Reef Stage is situated genetically at the base of the transition zone, where upward coarsening begins.

The pattern of the sediment vectors, likewise, assist in the recognition of the paleo-environment. The bimodiality reflected by the distribution in fig. 20 (p. 219) is illustrated by figs. 18 and 19, as due to bias in sampling related to data distribution. The pattern is seen as unimodal indicative of shallow water. Some current deviations are present, especially on the west, which, lower down the paleoslope, are associated with smaller flow consistancy ratios, indicative of a flatter paleoslope (map 13, p. 236). The immediate footwall beds are mainly considered to be proximal fluvial deposits.

3. FOOTWALL EROSION

The White Reef is underlain by a mildly undulating scoured surface, smooth and well abraded, with sharply incised gulleys, of which only one example was observed. It reflects a firm and relatively compacted surface at the time of erosion, and, thus, also a small break in deposition. No residual debris, accumulated from the erosion, was observed at the position between the erosional interface and the base of the White Reef. This probably resulted from continued wash and downslope transport by the scour currents.

Erosional channels were cut into the floor beds (map 21, p. 246). Their orientation mostly reflect that of the pre-White Reef paleocurrent system, revealing that the break in deposition was not lengthy enough for a new channel system to develop. The only marked deviation occurs at the centre of West Rand Consolidated. Here the footwall beds, deposited towards the south-east, were scoured towards the south-west. The latter direction may have developed due to the entry point fan moving southwards in response to stronger uplift of the northern source beyond the east rim, in the period of weathering and erosion before the deposition of White Reef gravel was initiated. Under the shallow water conditions that prevailed, the consolidated footwall was probably exposed to sub-aerial conditions, such as that of a large deltaic sand flat, which were possibly due to temporary transgression. The relatively high bed-relief index (B.R.I.) of the floor topography, calculated as 5,2 for fig. 2, according to the method of Smith (1970, fig. 22), suggests proximal fluvial erosion and this interpretation which discards the complexity of temporary and rapid sea-level movement, is preferred.

The channels merge, meander and criss-cross on the paleoslope. Their orientations are mostly to the north-west and north-east conforming to the two systems of minor fold warping (map 21, p. 246). They may, therefore have been controlled by low order features of the existing tectonic framework. The channels reached lengths as great as ten thousand feet, but their extent is difficult to determine with accuracy because of divergence, convergence and criss-crossing. Widths of several thousands of feet are common and maximum incision reached a depth of about five feet in the upslope area of strong abrasive flow. Low down the paleoslope the reduced velocities of erosional streams is reflected in mininal channel depths measurable only in inches. The channel indices vary from about 100 to 1 500, which is similar to those of the Basal Reef (B_1 phase) at Harmony Mine, which Hodgson (1967) found to vary between 286 and 1 800.

4. PROVENANCE MATERIALS

The rock types of the source areas can be partially deduced from the detrital fragments. Moderate to advanced mechanical abrasion is indicated by the sphericity values (table 10, p. 53), and by the resistant nature of the pebble types (table 7, p. 41). The relative proportions of the lithologies represented in the Luipaardsvlei and Randfontein phases and to a large extent also in the West Rand facies, is directly related to resistance to transportation, with abundant quartz, less quartzite and least chert present in accordance with the resistance gradings of Pettijohn (1957). The relative percentages thus reflect the break-up during transportation and not relative rock abundances at the source. Coarser fragments of softer and brittle rocks were greatly reduced or lost during transportation. The rock types that survived weathering and transport indicate mainly metamorphic and igneous terrain.

Quartz pebbles are about four times more durable than quartzite according to Pettijohn (1957). Their relative abundance can thus be utilised as an index to the distance of transport, on condition that both types are derived from a mutual source and that the relative percentage resulted from selective break-up during transportation, which seems to be the case for the Luipaardsvlei and Randfontein phases. The ratios of quartzite to quartz in the Luipaardsvlei and Randfontein facies are both relatively high, being 1:1,6 and 1:2 respectively indicating that maximum abrasion was not achieved and that the distance of transportation must have been moderate. This is largely in agreement with the conclusion by Pretorius (1974 a, b) which suggested a short linear fluvial transport for Witwatersrand Reefs. The almost identical pebble lithologies reflect a common source for these two conglomerate phases, which, apart for areal differences, form a single deposit, as will be explained later. The origin for the quartzite pebbles could be any of the older sedimentary systems, with some contributions from the underlying reefs of the Witwatersrand System. The percentage of quartzite pebbles is high when compared to other Witwatersrand reefs, but so are those of the Zone 2 and Monarch Reefs (table 8, p. 43), and also of the Livingstone Reefs, which according to Toens and Griffiths (1964) contain considerable amounts of quartzite pebbles. This indicates that transportation during the deposition of the Livingstone and Bird Reefs was not of sufficient distance to reduce the quartzite which is normally classified with the immature load. Restricted mixing is, likewise, indicated by the presence of sub-populations of pebble types in the various facies.

The abundant quartz of various types was probably derived from the migmatite, gneiss and ultra-metamorphic rocks of the Transvaal belt of metamorphism and granitization of the Archaean Complex. The presence of heavy minerals, such as gold, suggests that mafics and ultra-mafics were present as source rocks. Pretorius (1974 b) illustrates that the nature of the heavy minerals in the Witwatersrand reefs is an indicator of the composition of the source rocks from which the mineralisation was drawn. He shows that the diagnostic minerals can be placed in at least two groups. The platinoids, chromite, diamonds, cobalt and nickel sulphides were probably originally present in ultra-mafic rocks. The uraninite, zircon, cassiterite, garnet, and quartz were probably drawn from granitic members of the pre-Witwatersrand basement.

As basic and ultra-basic rocks are not chemically resistant to intensive weathering, their absence as pebble types can be expected. Their breakdown would have been facilitated by the humid climate which seems to be indicated by the absence of feldspar which should have been washed in from the granitic sources in abundance. According to Pretorius (1974 a) the rock equivalents of the Swaziland sequence were originally present towards the north-west of the Witwatersrand basin. He postulates that rocks situated at the base of the Fig Tree Group and top section of the Onverwacht Group were responsible for Main -Bird Group sources; and also that the coarse clastic sediments were originally felspathic quartzites, derived from the mafic and felsic volcanics of the Upper Onverwacht Group and from the ever-increasing volumes of granite that were eroded as more and more of the greenstone belt was stripped away.

The quartzite-quartz ratio of 1:28 for the West Rand facies, with less quartzite than chert indicates either a different source area from the other combined phase or much more transportation and related disintegration of quartzite. The two-dimensional pebble sphericity average values for the Randfontein and West Rand facies shown on map 17 (p. 242) are both 0,63 indicative of a comparable transportation history. The West Rand facies is thus seen as having been derived from the same general source area but with lesser outcrops of quartzite available, or, alternatively, incorporating more constituents from lower reefs.

Naturally, to the possible source rocks, eroded rim equivalents of underlying Witwatersrand conglomerates must also be added. This is suggested by the pebble-shape characteristics of the White Reef which, in the main, reflect those of the underlying Livingstone Reefs, whereas pebble sphericity measurements also yield identical results (table 11, p. 54). This could have been brought about by similar source rocks and abrasion history. Alternatively, it is possible that detritus from underlying reefs was incorporated into the White Reef as a result of basin-edge uplift and erosion. Applying Sternberg's law, as set out in Pettijohn (1962); Steyn (1963) calculated that, for the upper and middle zones of the Livingstone Reefs, the apex of the alluviating delta was situated approximately four miles and six miles, respectively, to the north of present-day outcrops. The same assumptions and formulae can be applied to the White Reef, substituting the appropriate pebble sizes and pebble-size decrease gradients indicated on map 14 (p. 237). Such calculations indicate that the apex of the alluviating delta was, for the Randfontein facies, approximately two miles beyond the present-day outcrops. For the coarser gravels of the West Rand and Luipaardsvlei phases the distances become less than a mile. These figures are based on various assumptions which are questionable, and yield only an estimate of the order of distance involved. They do suggest, however, that the studied portion of the White Reef was deposited close to an apex position of a depositional fan, and also that the earlier fan of the Livingstone Reefs did persist further northwards, about four miles beyond that of the White Reef, making erosion and inclusion of Livingstone fanhead and upstream materials a definite possibility. The shorter distances illustrate also the regression of the apices of successive fans, from the basin edge towards the centre of the Main basin which was shrinking progressively with time.

This possibility of the inclusion of materials from the underlying reef horizon necessitates an explanation for the large, disc-shaped pebbles characteristic of the upslope section of the Livingstone Reefs which are mostly absent in the White Reef, and also the absence in the Livingstone Reefs of high concentrations of uraninite which are present mainly in the southern low energy facies of the White Reef. These differences can be explained by the selective transportation of pebble types and by the generally lower energy environment which prevailed during the deposition of the uranium rich Randfontein facies of the White Reef, but which was absent for the Livingstone Reefs. There is, therefore, a strong case for the incorporation of Livingstone Reefs materials. The degree of recycling at the basin edge was limited, however, as extensive reworking would have changed the indications of a moderate distance of transportation. The relatively poor gold content can, thus, be explained by sparse source mineralisation, poor build-up of concentrations before transport and deposition, plus limited basin edge recycling.

5. THE GEOMETRY OF THE WHITE REEF DEPOSITIONAL FAN

The paleocurrents of the White Reef form a fan spreading southwards. The updip extrapolation of vectors from various positions, diverges at a point about three quarters of a mile north of the boundary between West Rand Consolidated and Luipaardsvlei Estates. Calculations, based on Sternberg's law (Pettijohn, 1962), indicate that the apex of the depositional fan was situated about two miles north of the northern end of the Randfontein facies. For the higher upslope gravels of the other two phases of the conglomerate the distance is somewhat less than a mile. These four separate reconstructions coincide to locate the apex with accuracy as shown on fig. 21 (p. 220). The latter diagram represents a generalised model of the White Reef fan.

The fanhead and, also the fanbase, except for the basal south-western section, are eroded. At the lower end of the fanhead, the river system splits into three sub-systems. The central one is relatively minor and it is probable that the upper midfan section became choked with debris during initial deposition, forcing the main channels to develop towards the outer flanks. A short distance down the slope, the sub-systems further subdivide into a braided stream pattern. The smaller channels separate, cross and rejoin, often following the directions of north-west and north-east folding, e.g. the Witpoortjie subsidence. The two outer main channels remained reasonably coherent. The eastern main stream beds formed the coarser conglomerate and the western one the major economic zone. The major current on the west side followed a gentle curve down the valley pre-determined by the north to south plunging Randfontein trough. The preserved section of the fanbase covers the low lying trough area and contains the carbon rich Randfontein phase. It can confidently be concluded that the latter area was covered by a shallow lake which provided the conditions that were necessary for the repetitive development of algal mats during periods when fluvial turbulence was much reduced. The colonies of lichen thrived in what was otherwise a high velocity environment characterised by pebbly sand deposition. The periods of quiescence reached a maximum time equivalent of two inches of thucholite growth and were possibly seasonal as is shown by the presence of many repetitive thin carbon seams. Sediment starved conditions are reflected by the carbon seams enclosing the pebbles and coarse sands which formed the depositional surface.

The mode of gravel deposition is related to the fan geometry. The West Rand lithological facies occupies the upper midfan section, situated off centre towards the west. It was formed, under conditions of oversupply, mostly by the avalanche of gravels without sorting, except in the distributaries. This early deposit apparently blocked the central midfan section and diverted sedimentation symmetrically sideways. Both the Randfontein and Luipaardsvlei main lobe facies were subjected to extensive winnowing under conditions of relatively lean supply. This is convincingly demonstrated by the development of closely packed clog gravels over floor highs, in the main current areas.

The distribution of gold and uranium is likewise related to the fan geometry. The low gold content (Au+) at the top of the midfan section decreases upslope suggesting even lower mineralisation in the eroded fanhead section. Most gold (A+++) is contained on the lower midfan to upper fanbase area, and then decreases downslope to reach intermediate values on the central fanbase (A++). The uranium distribution is similar to that of gold but reaches peak concentrations farther downslope, in the central part of the fanbase area, at a position where the two main structural depressions merge (fig. 21, map 22). This suggests a very slight basining at this position during the relatively short period of White Reef deposition, weakly repeating the stronger basining developed over the longer period that separated Main and South reef deposition (map 6, p. 229).

The White Reef can be compared with other fans, notably with the general conceptual model devised for fluvial fans of Witwatersrand goldfields by Pretorius (1975). The similarity to the model is striking and differences are related to factors peculiar to the West Rand structural framework. The overall agreement certainly substantiates the validity of the general model: the fanhead was likewise uplifted and eroded, possibly reworked into later fans; the supplying rivers flowed equally short distances before dispersing through a braided-stream pattern; the midfan and fanbase sections were structurally depressed and preserved; two similar main lobes developed containing braided channels, represented by the two outer subsidiary main channels of the White Reef; the metal distributions are similar and the distal facies contain algal mats. Whilst Pretorius does not offer an explanation for the development of two main lobes, it is readily explained by the mode of deposition of the White Reef. The West Rand phase was rapidly dumped on the central midfan area, forcing major channels to develop on either side around the obstacle. Pretorius favours the development of asymmetrical fans caused by clockwise movement of currents which prograded the eastern lobe. There is no real indication of a clockwise current flow in the White Reef paleocurrent pattern. Major fault uplift and subsequent erosion destroyed the south-eastern segment of the fanbase of the White Reef and consequently the asymmetry cannot be effectively studied. However, the eastern lobe does contain coarser conglomerates due to a stronger transporting current but the western lobe, although being less robust, contains most of the mineralisation. The asymmetric aspect is firstly related to the structural framework also demonstrated by the patterns of the Livingstone Reefs sedimentation (Steyn 1963, map 7) and by the overlying Monarch Reefs (Toens and Griffiths, 1964, fig. 5). These all show an asymmetry with higher mineralisation in the western lobe due to north-south control of the main channel by the Randfontein trough. Secondly, the coarser conglomerate of the eastern lobe may have been caused by the initial dumping of the West Rand phase off-centre towards the west on the central upper midfan (fig. 21, p. 220) forcing the development of a stronger major distributary towards the east.

The Livingstone Reefs fan demonstrates a different variation in mineralisation with highest gold grades being contained in the fanhead area. It illustrates a deviation from the general model of Pretorius and that of the White Reef where the gold was usually of too fine a grain to settle in the fanhead facies. This difference could be due to the fluvial-deltaic environment postulated for the Livingstone Reefs. However, seen in retrospect it is the view of the writer that earlier conclusions about reef environments require revision in the light of the more quantitative criteria now available for evaluation. In this connection, the general finding by Pretorius (1974 a, b) that the Witwatersrand reefs are fluvial fans, varying in their environmental conditions to fluvial-deltaic, requires serious attention.

The White Reef fan also closely resembles the reconstructed model for the south-westerly part of the Basal Reef depository (Sims, 1969, fig. 38) which contains various aspects of the more important features incorporated by Pretorius (op. cit) in his later more comprehensive model, e.g. the asymmetry of the lobes and the distal carbon seam facies. The proximate pebble mill facies of Sims is seen as the equivalent of the upper midfan avalanche facies of the White Reef; his midfan composite reefs compare with the lower midfan facies of the White Reef, whilst the distal carbon seam facies equals the fanbase facies of the White Reef. The Basal and White Reef fans are both asymmetric with the eastern lobe more strongly developed and this substantiates the argument of Pretorius for clockwise current movement in the main Witwatersrand basin. This current movement is not displayed by the paleoflow pattern of the White Reef, which was positioned outside the main water body of the parent basin. The clockwise current effect can, however, possibly be detected in the crossbedding directions of the overlying quartzites at the toe of the fanbase.

The much larger East Rand, Main Reef Leader fan as described by Pretorius (1974 b), conforms in its general characteristics with the White Reef fan which is incompletely preserved due to the Witpoortjie faulting. One noteworthy common feature of these two fans is the poorly developed reefs on the central midfan situated below the fanhead, another is that mineralisation in the western lobe is apparently of a higher grade.

6. TIME RELATIONSHIPS OF THE CONGLOMERATE PHASES

The West Rand phase was previously referred to as the initial pulse of sedimentation, rapidly dumped, off-centre, in the upper midfan area. The obstruction caused a diversion of the main channels towards the outer sides of the fan. Alternative sequences of events should also be considered. The systematic decrease, over the fan, of average pebble size and reef thicknesses south-westwards, could be related to a waning of depositional energy while deposition switched gradually from east to south-west. The Luipaardsvlei conglomerate could then represent the initial high-energy phase following uplift in the source area, the West Rand the intermediate pulse, and the Randfontein type the final low-energy stage. Heavy minerals, accumulated as lag deposits in the rivers above the fanhead, would be progressively released to enrich the deposit as sedimentation shifted westwards. This explanation of events, however plausible, lacks an acceptable reason for the initial shift of sedimentation towards the east, at a stage when the central midfan area was available and empty.

Another possibility is the simultaneous deposition of the West Rand and Luipaardsvlei facies at adjacent and level positions on the midfan. It is not favoured, as only a single entry point is indicated by the paleocurrent pattern and the different pebble assemblages point to non-simultaneous deposition. A fourth alternative is that a single Randfontein-Luipaardsvlei gravel covered the entire fan area, that erosion followed, with later deposition of the quartzite deficient West Rand facies. Various arguments disfavour such a sequence of events. The lithofacies, scalar and vectorial trends do not reflect an abrupt cut-off of time lines at the boundaries of the West Rand phase; secondly the related sphericities suggest uniform, uninterrupted transportation and deposition. It is also unlikely that the Randfontein facies represents a smaller pebbled washed-out variant of the West Rand gravels as the marked differences in pebble assemblage would then be unexplained.

In conclusion, the deposition of the West Rand pulse, followed by the simultaneous sedimentation of the Luipaardsvlei and Randfontein phases affords the most simple and logical sequence of events. It simplifies source area events to initial erosion of quartz-rich metamorphic and igneous rocks, followed by erosional incision into sediments containing quartzites, or incorporation of quartzite pebbles from earlier conglomerates. The initial blockage of the central upfan area on the west side, diverted stronger flow and transport of larger fragments eastwards, forming the robust conglomerates of the Luipaardsvlei facies. Partial obstruction on the upper central midfan area towards the west, reduced the velocity of the main stream that developed the smaller pebbled lobe of gravel. Flow persisted, however, throughout the total White Reef period to upgrade mineralisation by shifting lag accumulations of heavy mineral build-up in the river system above the fan. The Randfontein phase bypassed the West Rand gravels through the larger of the western distributaries indicated on the model. This resulted in channel lag enrichment in the area of the West Rand facies, upgrading it to an overall gold and uranium content intermediate between that of the other two facies. This possibility is supported by a slight increase in quartzite pebble percentages, so typical of the Randfontein facies, in the main channel of West Rand (map 18, p. 243)

7. MODES OF CONGLOMERATE DEPOSITION

INTRODUCTION

The White Reef is a pebbly quartzite and not a pebble supported conglomerate. The degrees of pebble packing, which were extensively and quantitatively determined (map 16, p. 241) seldom reach the high values of about 67 per cent (Plumley, 1948) required to form pebble supported conglomerates of the banket type. There are some exceptions present, notably in upper midfan positions of the eastern lobe. Deposition generally took place out of a single phase of transportation of pebbles, sand and coarser heavy minerals which all moved as bedload, including saltation. The silt, clay and finer heavy minerals moved mainly in suspension.

Whilst the overall facies can be classified mainly as a scattered pebbled sand, the fanbase phase on Randfontein Estates can be grouped with carbon seam types of reefs because of the presence of thucholite layers which reach a maximum thickness of two inches at the south-western corner of West Rand Consolidated. In essence, the overall grouping does not change from that of a scattered pebbled sand and the Randfontein type reflects only a finer particled, more distal phase.

Two main opposing modes of conglomerate deposition developed in response to different fan geometry positions, the interplay of variable rates of sediment supply, and current regime. These caused fundamental dissimilarities to develop in the scalar and vectorial properties of the conglomerate, mineralisation and robustness changes related to floor topography.

CENTRAL MIDFAN FACIES

The West Rand conglomerate is typified by an abundantly crossbedded, loose pebbled pebbly quartzite outside the distributaries. The interfluve areas of high floor level, reflect the smallest average pebble size, packing and sorting values. This is in contrast to the other two main lobe phases where floor highs are systematically covered by the most robust reef. A maximum of 55 per cent for the pebble packing indicates that the gravel was not typically pebble supported even though minor instances of open-work gravels occur in the channels where lag conglomerates developed. The major modes of deposition were thick avalanche crossbedding or thinner, coarsening upwards, pebbly crossbedding. The former is clearly illustrated by the pebble fabric. A majority of pebbles (66 per cent, table 12, p. 59) dip downslope, reflecting pebble imbrication on inclined foresets.

The deposition of reef in crossbedded form is reflected by the relative abundance of reef foresets measured in this facies. With 54, 60 and 87 measuring localities investigated for the West Rand, Luipaardsvlei and Randfontein phases respectively, relative abundances of 1,4 : 0,5 : 0,3 reef crossbeds were measured per unit area. Note that the Randfontein and Luipaardsvlei values are comparable even though they reflect opposing extremes in reef widths. Related in origin to the abundance of crossbedding is the upward coarsening which is characteristic of the White Reef, and best developed in the West Rand facies. These represent bars formed in braided streams (Allen, 1965). Braided channels are, likewise, reflected on the reconstructed model (fig. 21, p. 220) by patterns of larger pebbled and better mineralised reef, and vectors. Allen (op. cit.) describes braided stream deposits and quotes Leopold and Wolman (1957) who record the construction of a gravel bar by the progressive addition of foresets at its downstream end.

Avalanche reef deposition is not restricted to the White Reef. A similar downcurrent dip of pebble alignment is recorded for the massive reef phase of the Basal Reef on President Steyn, and a correlative mode and environment of deposition can be interpreted, especially as the respective fan geometry positions are identical (compare Sims, 1969, figs. 37 and 38). The central midfan pulse of the White Reef compares closely with this zone of the Basal Reef which is described as an entry point shore line facies of a fluvial deltaic fan. It contains polymictic reefs characterised by rapid pebble size reduction, and is deficient in U_3O_8 with gold being erratic. Similar to the West Rand facies, this phase of Basal Reef has, in many instances, the best mineralisation at the top or mid sections of the reef. The lower central midfan pulse can be equated to the multiple late-channel type of the Basal Reef, which from Sims' description, appears to develop reverse grading similar to that recorded for the midfan of the White Reef.

MAIN LOBE FACIES

The main lobe or major channel facies, situated on the periphery of the outer fan and reaching down onto the fanbase, is represented by the Randfontein and Luipaardsvlei phases. They are characterised by typical fluvial grain fabric (table 12, p. 59), with pebbles dipping upslope at relatively high angles and by extensive sorting which resulted in relatively high packing and sorting values in the high current velocity regime of the Luipaardsvlei lobe. The most diagnostic feature is the gravel clusters developed over zones of elevated floor, even where they represent interfluve areas between stream channels. These developed in response to winnowing and are accompanied by coarse horizontal bedding.

Due to their respective positions on the depositional fan, there are important differences between the two lobe facies. The eastern phase, situated on the midfan, was exposed to higher velocity sheetflow over a wide area and almost all rises underlie traction clogs. The western, less robust lobe is situated lower downfan and developed the pebble clusters mainly in the major and auxilliary channels, indicative of strong flow being restricted to limited channel zones. There are large areas of high floor elevation, outside the main stream, overlain by poorly developed conglomerates.

It is important to note that the boundaries between the two modes of deposition are not abrupt since they are related to a gradual decrease in the rate of sediment supply to different positions on the fan. The two main lobe phases have different mineralisations which are discussed in the next section.

The downfan sections of the White and Basal Reefs are comparable. Unfortunately, the greatest part of the West Rand fanbase has been eroded. Sufficient exposures remain, however, on Randfontein Estates for a worthwhile comparison. In both instances the reefs are narrow, carbon seam, single reef types containing the maximum concentration of U_3O_8. Differences are also present. The Randfontein phase of the White Reef is characterised by higher metal concentrations over areas of elevated floor. This is not conspicuous in the Basal Reef, although Sims (1969) mentions the presence of 'perched' surfaces of concentration, an aspect which, obviously, requires quantitative re-examination when viewed in the light of the White Reef data. In the case of the Basal Reef distal phase, increasingly more mineralisation is associated with the lower surface, than for the White Reef. Due to a lack of comparable data of a quantitative nature for size, standard deviation and packing properties relative to mineralisation, and keeping in mind that heavy particle size ranges may have differed, it is not possible to make a closer comparison between details of mineralisation and mode of deposition.

8. PROCESS OF HEAVY PARTICLE CONCENTRATION OVER FLOOR RISES

INTRODUCTION

It has been repeatedly demonstrated that heavy detrital particles, represented by pebbles, gold and uraninite grains, are concentrated in positions of high footwall. And, also, that their relative concentrations vary according to the elevation of the footwall. This process of heavy mineral accumulation has not been recorded in the literature, and, as it is the more important mode of deposition of the White Reef, it calls for a detailed explanation. Although this discussion deals primarily with conglomerate deposition, the related aspects of mineralisation are included so that repetition in the following section dealing with mineralisation, may be avoided. Humps of gravels are described in similar braided environments elsewhere and it is, thus, possible that this process is a regular sub-component of the depositional environment.

SETTING

The setting is an environment of major streams of the main lobes extending over the midfan onto the central fanbase. The essential requirement, for the process to operate efficiently, is continuous sheet flow of sufficient strength and duration to allow extensive winnowing. Conditions of limited sediment inwash or balanced rates of influx and deposition, are indicated.

Different responses in mineralisation were obtained on opposite sides of the fan. In the western Randfontein lobe, pebble and metal properties vary sympathetically with regard to changes in the floor topography. This implies that the pebbles and the coarser gold and uraninite grains were co-transported, deposited and concentrated in a single phase of bedload deposition.

In the eastern Luipaardsvlei lobe, well developed reef overlies floor rises, but in contrast, slightly better mineralisation occurs in floor lows. In the eastern lobe, winnowing by vigorous currents doubled the pebble packing and increased average pebble sizes to one and a half times those of the western lobe. The initial depositional phase of the Luipaardsvlei gravel, very low in gold content because of high velocities unsuitable for settling of gold particles, formed dense clusters of conglomerates over floor highs. The channels remained open and bypassed later gravels to the downslope positions. Decreasing stream velocities failed to upgrade pebble size and packing to values exceeding those on floor highs, but prevailed for a sufficient period for a slightly higher grade of gold to accumulate along the distributary streams.

THE PROCESS

Lower channel areas are overlain by scattered pebble reef, whilst larger, closer packed pebbles cover the rises. This differentiation is effective over large differences of the floor, ranging from a few inches on Randfontein Consolidated to as much as five feet on Luipaardsvlei Estates. The optimum topographic range where such sedimentation responses operate is not known. Average values of scalar properties over high floor positions exceed those covering floor lows, by factors of 1,3 for pebble size; 3,6 for packing and 4,7 for gold content in the pilot study area. Sorting increases, as expressed by the standard deviation, are largely similar to those of pebble size as they are, in the pilot locality, size dependent to the extent of 0,84. Therefore, in retrospect, standard deviation is not regarded as an independent or good measure of sorting. Comparative grain counts indicate a relative increase of 23 per cent of the smaller grains, 4 to 12 mm size class, over the hollows in the area of the pilot study. Removal by winnowing of lighter detrital grains over floor highs is thus indicated. Many smaller grains did not maintain stable positions on the humps, due to flow turbulence, but moved into the relatively sheltered hollows or farther downstream. The spaces thus vacated were then filled by heavier and larger grains. The pebble grading over the hollows is often reversed; the upward size increase indicates that, as the hollows filled, increasingly larger numbers of light grains were unstable due to increasing turbulence. Crossbedding structures occur in the reef in the hollows only, indicating that little or no resorting, which would have destroyed such original sedimentary structures, took place. The hollows filled rapidly and caused a levelling of the floor topography but not a cessation of the winnowing over buried highs where traction clogs were firmly established and continued to build upwards. These, according to the principles of physical movement of pebbles and sand (Moss, 1962), would form over the bare firm surfaces of exposed floor highs, and act as traps for coarse grained particles. The properties of the gravels preserved in the hollows, approach those of the influxing pebbly sands; the gold grade, pebble size and packing reach minimum constants in the troughs (figs. 4 a, b, c, p. 204). Yet, even these dispersed concentrates must have exceeded those of the original pebbly sand since much of the sand and silt fractions continued downslope. However, of greater economic importance is the progressive increase in heavy mineral concentrations up the sides of floor highs. Maximum concentrations were reached in the pilot study area in gravel thicknesses of two to three inches. Thereafter, the increase falters and concentrations of heavy particles become erratic or decrease.

Statistical analyses provide further insight into the changes. Changes in floor height are most closely linked to pebble size and packing changes (correlation coefficients of -0,60 and -0,59 respectively - appendix 17, p. 189). As the reef narrows to less than three inches, the values of these properties become erratic and averages decrease (fig. 2, p. 201), except for packing, which was not accurately measured at very narrow widths. The depositional factors that influence size and packing may thus, likewise, have reached maximum competency at the critical gravel thickness, and decreased thereafter. Pebble size is largely determined by the transporting competency of the stream, i.e. the velocity factor, whilst denser packing results from extensive winnowing, i.e. flow persistence.

The crossbedding units measured in the hollow adjacent to the hump (fig. 2 a) are 20 cm thick. According to Allen (1970) the dune height (H) of dune crossbedding (>4 cm high), developed in streams may be expressed as $H = 0,086\ d^{1,19}$, where d = water depth. Substituting H = 20 cm, d becomes 97,5 cm or 37,5 inches. The water cover over the hump was, therefore, about 26 inches. It is unlikely that current velocity and sustained flow would decrease rapidly if the water depth decreased only from 29 to 26 inches. However, between flood periods, the depths could have been much less.

The most likely explanation is that the process of concentration cannot function well without a traction carpet at least two to three inches thick which would constitute an efficient trap for the heavy particles moved mainly by bed load processes and that the accumulating gravel simply did not cover the high floor adequately enough. Should more heavy minerals than the one quarter estimated for this position, have moved in suspension (see next section), there would be little reason for the disruption of concentrations over the floor highs. It seems, however, that this type of mineralisation is closely associated with bedload processes. Unfortunately, only this single instance of very thin reef covering a floor rise was encountered.

Another possibility, not to be disregarded, is the post-White Reef erosion mentioned previously. It eroded the reef to depths of several inches at various localities in the pilot study area. It is readily recognised by the uneven upper reef contact. However, the top surface of the reef is reasonably level over the high. Further, should erosion have removed the pebbles, the heavy matrix minerals would most likely have sunk to the floor and remained, unless compacted chunks of gravel were washed away. It seems less likely, then, that later erosion caused the impoverishment of heavy particles over the area with a gravel cover of less than two inches.

9. PARTICLE MOVEMENT AND DEPOSITION

The principles of particle movement and deposition (Moss 1962, 1963) can be applied to the White Reef conglomerate.

The sediment consisted of three distinct grain populations, termed A, B and C. Saltation particles made up population A and B, while rolling and sliding particles remained to form population C. Population A had a small size range and included the sand and small pebbles. Population B consisted of relatively smaller particles that passed directly from saltation into the interstices of population A. The finer sand particles as well as the heavy minerals were included in population B, since, according to Moss, during current deposition small dense particles preferably enter population B. Population C, which is in the pebble range, was well dispersed and in closely packed traction clogs. With continued influx of sediment, pebbles and sand spread out to overlap onto the floor rises. The firm surface of these offered more frictional resistance to the sliding or rolling pebbles than the sediment-covered surfaces of the adjacent hollows. When the concentration of rolling and sliding particles, especially pebbles, reached a critical value, the halting of one individual caused many to join together on the bed as a 'traction clog' with closely packed pebbles. Sand and finer particles continued to accumulate between the pebbles, and the process was repetitive. In this fashion traction clogs of relatively densely packed pebbles developed over the tops of the humps, and elsewhere, when movement of bedload was impeded.

The coarse sandy fraction, comprising the bulk of the sediment, was transported, as an A population in contact with the floor, by sliding and rolling over similarly sized or smaller particles. However, when it encountered the coarser population C pebbles the mode of transport changed to saltation. The pebbles of the C population moved over the pebbly-sand layer by means of surface creep. For surface creep deposits to grow thicker than a single layer of grains, strong reversed bedding must develop, as rolling and sliding of particles can, obviously, only occur if they are moving over smaller particles. This partly explains the reverse pebble size grading often found in the White Reef.

The heavy minerals and fine sands of population B were usually smaller than the associated coarse sand particles of population A, which formed the bulk of the bed surface during deposition. Before they were deposited, the B particles had to move over a surface of A particles larger than themselves; this would have eliminated surface creep as a mode of progression. Population B usually shows a marked diminution in particle abundance with falling particle size around a diameter of 0,07 mm, a value often quoted as being critical between bedload transportation and suspension. Thus, by elimination, population B must have been associated with saltation, although the possibility that some of its particles were in suspension before deposition cannot be ignored. It is considered that the fine sands and a large number of the heavy-mineral grains behaved as population B particles and that they moved by saltation and sometimes by suspension.

According to Moss (1963), the A population can be removed after deposition by resorting or winnowing, while a B population, consisting of heavy minerals, is being deposited by interstitial sedimentation amongst its particles, which in this case would have been coarse sand and small pebbles. However, no mechanism exists for the removal of population B particles from amongst the sheltering A particles. This would explain the removal of small pebbles and sand grains (population A), as well as the accumulation of heavy minerals (population B) over the floor highs. Rubey (1933) assumes that settling velocity is the important parameter that governs the size relationships of associated minerals of different specific gravity, and deduces hypothetical size distributions for each mineral in such associations; he describes the principle involved as 'hydraulic equivalence'. Rittenhouse (1943) modifies this concept somewhat, making 'hydraulic equivalence' closer to 'equally transportable' in meaning. He also thinks that heavy-mineral concentrations result partly from the selective removal of light minerals from newly arrived material, and partly from the separate deposition of layers of heavy minerals. In the case of the White Reef, the heavy minerals together with finer sand grains were, as B population particles, considered to be 'equally transportable' with the pebbles (C population) and the bulk of the sediment which falls in the coarser class of population A.

The ore minerals of the reef were concentrated by both processes suggested by Rittenhouse (1943), namely the selective removal of lighter grains through extensive resorting over humps and, more so in the major stream beds, and the deposition of separate layers of heavy minerals as population A particles. An excellent example, of the latter process is the bedded pyritic stringers so often found in Witwatersrand conglomerates and quartzites. Gold grains which are concentrated on bedding planes are considered as population A deposits, and many such occurences are described in the literature dealing with the conglomerates of the Witwatersrand. Another factor was responsible for the concentration of the heavy minerals on the floor highs; this was the preferential accumulation of dense particles on bedrock, which offered ultra-stable repose positions for population B particles. During turbulent phases the bedrock would have been most frequently exposed over the elevated areas, and very heavy particles would first have been concentrated between bedrock irregularities and then in the first deposits (often traction clogs) that formed the bedrock.

An explanation for the decreasing concentration of heavy minerals and larger quartzose grains when the gravel layer remained less than two inches thick over floor humps may be that particles of populations A and C were no longer stable. When very thin, the White Reef often consists of a line of scattered pebbles in a quartzite matrix, suggesting that a large part of the pebbles and sand originally deposited had been retransported.

10. HEAVY MINERAL TRANSPORTATION, DEPOSITION AND CONCENTRATION

INTRODUCTION

The main constituents of the White Reef pebbly quartzite were co-deposited. Sand, lesser quantities of pebbles and coarser grades of heavy mineral particles were saltated and bottom rolled, whilst finer heavy mineral fractions moved in suspension and lesser solution along with fine sand, silt and clay. Positions of suspension and bedload transport are interchangeable, depending on the energy state of the transporting system. Increasing velocity lifts bedload particles into suspension whilst deceleration transfers some suspended particles into the bedload. The conditions were different from that of a banket type of conglomerate where the matrix often filters in later. Hydraulic equilibrium relationships in terms of co-transportation existed between grains of various sizes and specific gravity.

HYDRODYNAMIC FACTORS

The relationships previously described between some pebble properties and the metal grades were further analysed by means of a matrix analysis and stepwise regression in order to determine their relative strengths, for the data of the pilot study (appendix 17, p. 189). Packing has the strongest correlation to gold grade with a correlation coefficient of 0,74. This value is significant, seen in the light of the fact that correlation between geological factors seldom approaches unity because of multi-factor responses. Entry of the size factor into the stepwise regression increases the multiple correlation to 0,75. Further additions and deductions established that reef thickness and standard deviation are only capable of increasing this value to 0,76. The stabilised relationship between the metal content and the sedimentological properties can be expressed mathematically by relating gold (y) to size (x_1) and packing (x_2) as follows:

$$y = -33,5962 + 2,32798x_1 + 0,86630x_2$$

(with size = mean of all pebbles > 4 mm, packing = per cent, and gold = dwts/ton)

This relationship is, likewise, locally applicable to uranium, which is correlative to gold to the extent of 0,9615 (appendix 17). The equation expresses the hydrodynamic equilibrium which existed at the K_6 locality on the regional paleoslope. The equation would change systematically up and downslope as metal - packing and metal - size correlations change (see table 14, p. 69). Comparison of computer-predicted gold values with observed values, show, for instance, a 12 per cent prediction loss in the upcurrent direction over a distance of 1 700 feet to I_6 (appendix 17). Although a stabilised correlation value of 0,76 is valid at K_6, higher gold - packing and gold - size correlations obtained at I_6 make it plain that the degree of correlation with traction properties increases upslope as traction becomes dominant (see table 14).

The relationship established means that 76 per cent of the gold content, at the K_6 locality, can be explained by packing and size behaviour effects which are both bedload factors. Processes that improve packing and size, are, thus, responsible for higher metal concentrations. Packing is increased by winnowing and is, thus, an index for stream persistence. It was the most important factor responsible for concentrating gold and uranium as it exceeds the size - gold index by 0,33 (appendix 17). Pebble size generally reflects current strength and is thus a velocity index. It is then postulated that stream velocity and persistence were the critical controls of mineralisation. This is supported by the regional patterns of metal dispersal, with all important payshoots covering main stream beds where velocity and flow persistence were at an optimum.

The floor topography is a valid control factor for mineralisation in the Randfontein payshoot, where the pilot study was conducted. It has a 0,43 correlation with gold (appendix 17). In reality, the exposed floor highs duplicate the highest energy environments of the main streams by presenting optimum exposure conditions. The standard deviation is highly dependent on size (0,66 correlation - appendix 17, p. 189) and so is not a good guide to metal - sorting relationships. Nevertheless, it does still contribute slightly to gold accumulation (0,29 correlation - appendix 17).

With 0,76 of the gold content accounted for by bedload factors, the remaining 0,24 is attributed to suspension and lesser solution transport. The 24 per cent agrees well with Reineck and Singh (1973), who give a suspension population of up to 20 per cent for fluvial sediments. These ratios only reflect conditions at K_6 on the paleoslope. A gradual transition in the mode of transportation of economic minerals down the slope is indicated by the change in pebble gold - size relationships (fig. 17, p. 217). On the upper midfan at D_4 in the West Rand phase, the almost linear curve relating pebble size and gold is interpreted as a homogeneous traction condition. At the midfan and fanbase positions the regression curves reflect two distinct sub-populations of gold particles. The lower segments of the graphs represent gold particles related to a pebble size response, indicative of bedload transport. The upper curves for gold concentrations in excess of about 40 dwts/ton are not related to size. This latter phase moved in suspension and lesser solution, and is important in the lower part of the large payshoot. The progressive decrease in correlation between bedload properties and metal concentration farther downstream is clearly reflected by the correlation coefficients (table 14, p. 69). This is caused by a reduction in current velocities which control size and the related sorting factor. A relatively high correlation coefficient is maintained between gold and packing and winnowing is the traction factor that is still of most importance on the fanbase.

The above demonstrate a transition, from predominantly traction transport of gold particles on the midfan to roughly equal traction and suspension - solution transport in the middle of the fanbase. The lowermost section of the fanbase had not been preserved for study, but the rates of change present indicate that suspension transport would eventually become dominant. Similarly, it is anticipated that at the fan apex, any gold deposited would have dropped out of traction. In the upcurrent position indicated in table 14, it is worth noting that the 0,56 correlation coefficient of gold to size, is increased to 0,69 by correlating gold with percentages of pebbles larger than 12 mm only (appendix 18, p. 194). Thus, upslope, correlation between gold and coarse particle behaviour increases; see also fig. 17.

The introduction here, of quantitative indications that the majority of Witwatersrand gold particles were transported by traction, is new in concept and deviates markedly from earlier conclusions obtained by means of microscopic studies of hydraulic equilibrium which predominately favoured the suspension movement of gold and uraninite, e.g. Koen (1961) and Viljoen (1963). Later, Hiemstra (1968) observed deviations from hydraulic equivalence between uraninite and other heavy minerals, and maintained that the theory of hydraulic equivalence could not explain the relationships he had found. He applied the principles of particle movement developed by Moss (1962, 1963) and suggested that concentration of the heavy minerals could be affected by the selective removal of coarse material consisting predominantly of light minerals. With the progressive change from traction to suspension-solution deposition down the slope, clearly demonstrated here, it is obvious that equilibrium conditions change and that conclusions about transport conditions are valid only for a specific sample locality or sub-environment. A study by microscope, or any method, for that matter, would not be complete without relating sampling localities to the paleo-slope and fan positions, which must be defined in order to make generalised conclusions meaningful. A serious objection to the theory that gold and uraninite were predominantly transported by traction, as stated here, could lie in the small particle sizes of the economic minerals, and unfortunately no size measurements had been made for the White Reef. Hallbauer and Joughin (1973) undertook an analysis of the grain-size frequency distribution of gold particles in eight reefs. Their data (Pretorius, 1974 a, table 31) indicate that only 26 per cent of gold particle sizes are smaller than 0,075 mm. This boundary value approximates the critical 0,07 mm value. It is, thus, possible that roughly one quarter of these gold particles may have been deposited out of suspension. This value compares well with the 24 per cent of the gold population, which could not be coupled with traction processes at the pilot study midfan locality, and it is also related to the 20 per cent suspension population for fluvial sediments of Reineck and Singh (1973). There is, however, abundant evidence that a large number of gold grains were mobilised after deposition and redeposited on pyrite grains, or as thin fibres within carbon. These and, possibly, other changes in original metal grain size make it difficult, if not impossible, to arrive at trustworthy figures for the complete original size range. Other available measurements, representative only of present day economic reefs, seem to reflect a sampling bias towards the richer lower midfan and fanbase positions, i.e. towards smaller metal particle sizes. It is, therefore, not surprising that the average grain sizes of 0,035 mm for gold, 0,065 mm for uraninite, and 0,055 mm for the platinoid particles, quoted by Pretorius (1974 a) from information provided by Coetzee (1966) and de Kock (1964), support more suspension and lesser traction transport, i.e. the equilibrium conditions of the more distal economic reefs. It is, therefore, most important to recognise the transition from predominant traction deposition high on the fluvial fan to the predominance of suspension deposition of heavy minerals low on the fanbase.

The predominant traction transport of gold particles in the White Reef resulted from the conditions that existed on that individual fan segment, which together with the original size range of gold particles, form a specific set of circumstances. It also reflects the deposition of a loose pebble quartzite and not a banket type of pebble supported reef. This mode of gold particle deposition is understandably not applicable to all other fan segments, as is illustrated by Minter (1972) who found that in the Vaal Reef, internal properties like pebble size, packing, percentage of intercalated quartzite and grain composition are not related to gold content. The Vaal Reef is a carbon-seam type of reef, in which gold occurs even where the reef is devoid of pebbles and Minter defined the environment as fluvio-deltaic. It has been judged as a more distal facies than the White Reef (see p. 47) and can be related to a fanbase situation where most of the gold moved in suspension. Minter found, that in the Vaal Reef, the form of the paleosurface affects local gold distribution. Relative anomalies of gold concentrations could be interpolated parallel to paleosurface forms but could not be related directly to the floor topography.

He also found that 50 to 72 per cent of the gold is confined to the basal contact, and that paleosurface rises are poorly mineralised.

Sims (1969), also found that in the Basal Reef the footwall structure appears to have little control over reef development, that gold in the proximal multiple reefs often occurs near the top of the reef, like that of the mid-fan area of the White Reef, but shifts to basal positions in the distal narrow reef facies. He mentions instances of 'perched' narrow Basal and Leader Reefs where well mineralised reef formed on what he describes as elevated surfaces of concentration. The latter may be similar to floor highs in the White Reef. Apart from this aspect there seems to be adequate over-all similarity between the Basal and White Reef fan geometries and environments to suggest that similar study methods may yield comparable results. The degree of correlation will, logically, be dependent on the extent of depositional duplication present in the two fans. Some factors, e.g. reef thickness and mode of conglomerate formation admittedly differ to some degree and so may the environments, which Sims (op. cit.) deduced as fluvial-deltaic for the Basal Reef in contrast to the purely fluvial mode of the White Reef (see next section)

FAN GEOMETRY FACTORS

The role of fan geometry, as far as the distribution of mineralisation is concerned, is clearly illustrated by the conceptual model (fig. 21, p. 220).

The economic potential of the eroded fanhead area appears poor as the sizes and tenor of payshoots and smaller paystreaks decrease up the slope from the midfan. This is related to the high current velocities which swept most gold and uranium particles further downslope. The possibility that a small separate sub-population of coarse gold may have dropped out on the fanhead can not entirely be discarded, as it is suggested by the fan dispersal pattern of Livingstone Reefs gold (Steyn, 1963, map 7). This would have depended on the size of the heavy mineral particles available.

The upper midfan area is characterised by small streaks of mineralisation. Their size and regular spacing suggest a pre-determined control. Their frequent emplacement in straight lines and at intersections of north-east and north-west orientated stream distributaries suggest that geometrical fold patterns may have been the controlling factor. The larger payshoot on West Rand Mine is anomalous as it is much larger in size, but it is related to the main Randfontein trough which maintained overall control of sedimentation.

The fanbase is the optimum position for the accumulation of both gold and uranium. It received, in the payshoots and paystreaks, a grade double that of the gold and uranium deposited on the midfan. Maximum gold phased out early at the midfan-fanbase boundary. Maximum drop-out of uraninite followed 8 000 feet farther downslope at the merger position of the Randfontein and Witpoortjie troughs.

MAIN PAYSHOOTS

Regardless of whether the conglomerates were formed by dumping from avalanching crossbeds or by sheetfloods, the larger payshoots developed along major streambeds. They accumulated residual concentrations of heavy detrital materials, and are accordingly represented by elongated zones of well mineralised robust reef, largely coincidental with the paleocurrent directions. In the two northern facies, the payshoots cover floor depressions related either to scour or synclinal channels. The incompleteness of the data frustrates the accurate location of the depressions which were successfully identified on Randfontein Estates. The orientation of the zones of mineralisation parallel to north-east and north-west fold directions implies possibly such an association. The Randfontein pulse demonstrates that major payshoots at the lower midfan-fanbase positions are not associated with thicker reef filling low topography channels. At this position, lower current velocities seldom scoured into the floor, but concentrated heavy minerals by a relatively gentle winnowing action which removed lighter particles along an axis of fixed strong flow. The main payshoot was controlled by the major north-south Randfontein trough.

ENRICHMENT OVER ELEVATED FLOOR AREAS

In the previous section (p. 106), the control of mineralisation by floor height was discussed. Packing and pebble size are dependent on the underlying floor topography to the degree of -0,59 and -0,60 respectively (appendix 17, p. 189). Gold and uranium have almost equal correlation coefficients (-0,43 and -0,48, respectively) with reef thickness. Pebble and heavy mineral grains are, thus, almost likewise affected in their relative distribution, by the height of the floor. The lesser dependence of the metals on the floor undulations, than both size and packing as revealed by correlation coefficients, reflects the proportion (0,24 for gold) of the heavy minerals which moved with suspension-transport at that paleoslope position.

Current velocity and stream persistence, as factors controlling size and packing, were responsible for upgrading gold and uranium over floor highs. This duplicates main channel mineralisation, where the same factors were important, but here concentration is further aided by the development of traction clogs.

11. ENVIRONMENT OF DEPOSITION

SETTING

The paleogeographic setting is important. To the north, mountainlands were steadily being elevated in isostatic response to prolonged erosion in the source area, indicated by the rivers which were sufficiently steeply graded at times of accelerated uplift to move coarse debris. To the south, the fanbase was lapped in White Reef times by the waters of a lake closely connected to the main Witwatersrand basin.

Abundant evidence, discussed in previous sections, defined the West Rand as a stable and major permanent entry point to the main basin over the many millions of years represented by the Upper Division of the Witwatersrand System. Such prolonged and large scale movement of sediment logically requires a major river system for most of that period and the various associations of the fluvial environment should be closely examined.

According to Reineck and Singh (1973) there are only three specific fluvial sub-environments, namely:

(a) The alluvial fan or piedmont association;

(b) The floodplain association; and

(c) The coastal plain-delta association.

As the White Reef exhibits a fan type of geometry like that of alluvial deposits, this environment can be considered first.

COMPARISON WITH ALLUVIAL FANS

Blissenbach (1954) defines an alluvial fan as a body of detrital sediment built up at a mountain base by a mountain stream. Bull (1964 a, b), who made a detailed investigation of fan deposits in Western Fresno County, California, states that an alluvial fan is a stream deposit whose surface forms a segment of a cone that radiates downslope from the point where the stream channel emerges from a mountainous area. Compound alluvial fans result from lateral coalescence of single fans, according to Blissenbach, and should other properties be in accordance, the three facies of the White Reef may be compared with three coalescing fans. It would thus be similar to a piedmont plain deposit, which, according to Bull, is a broad sloping plain formed by the coalescence of many alluvial fans.

Stream channels on alluvial fans are commonly entrenched into the fanheads, close to the apex and are therefore called 'fanhead trenches' (Bull, 1964 a). Denny (1967) recorded local relief in trenches on the Shadow Mountain fan, ranging from forty feet near the apex to only one or two feet near the toe. Distributary channels eroded in the footwall of the White Reef of the West Rand and Luipaardsvlei facies reach a maximum depth of four feet and are too shallow to be classified as 'trunk channels', but have depths comparable to those developed downslope from the fanhead trenches of alluvial fans where most of the stream channels divide into braided distributary channels one to three feet deep (Bull, 1964 a). The far downslope distributaries on Randfontein Estates, however, show little or no entrenchment, and environmental conditions found beyond the toe of an alluvial fan are indicated here.

According to Bull (1964 a) meandering is the most common pattern of the fanhead trenches whilst braided patterns are characteristic of distributary channels farther downslope. Such braids are present in the White Reef as indicated by the reconstructed model (fig. 21, p. 220) and by the coarsening upward of grain size which can be explained by braiding deposition. The gentle broad curve of the main channel on Randfontein Estates may be compared with a section of a meander but it can equally well be explained as a segment of a normal stream curve.

Most investigators record that the slopes of alluvial fans decrease gradually away from the mountain front, e.g. Blissenbach (1954). Bull (1964 a) found that in Western Fresno County all the fans have distinct breaks in slope which give their profiles a segmented appearance, with the segments steepening towards the mountain front. The White Reef fan can be subdivided for purposes of comparison into a downslope, low gradient Randfontein section and an upslope robust facies related to a steeper paleoslope. There is therefore a similarity to a segmented alluvial fan.

The positional shift in sedimentation on the fan, e.g. from the West Rand facies to the Luipaardsvlei phase, or vice versa, could possibly be related to fanhead trenching and the erosional cut-off of the trunk channel supplying detritus to the earlier fan segment. In the same manner, the Randfontein facies could possibly represent the youngest fan with a gentle slope, deposited from a trunk channel, which may have bypassed along the main payshoot of the West Rand facies. Other equally acceptable explanations for the presence of the various phases of deposition have, however, been presented.

The above illustrate a number of general similarities, mainly of form characteristics, between alluvial fans and the White Reef deposit. There are, however, important textural deviations from that of the alluvial fan environment. If the grain size range of the White Reef is compared with the distribution of maximum pebble sizes along a typical radial profile of an alluvial gravel (Blissenbach, 1954), it becomes obvious that the relatively small pebbled White Reef could only have been deposited at the far end of, or beyond, the fan. Lustig (1965) made a systematic study of variations in pebble size roundness and pebble lithology in the alluvial fans of Deep Springs Valley, California. He found that some of the largest pebble sizes are associated with washes, i.e. channels on the fan, and also that the mean size distribution pattern of fifty pebbles at each measuring station is not in accordance with a uniform decrease in size downfan. In contrast, the relatively even, systematic decrease of the White Reef pebble sizes reflects more uniform, lower energy conditions, farther down the slope, in an environment at the edge or possibly beyond that of an alluvial fan. This is also indicated by the conspicuous absence of larger cobbles and occasional boulders, which were found far downfan by Lustig. The restricted range in pebble sizes present, strongly suggests that the particles of the White Reef were derived from the erosion of previous size sorted gravels, or from an environment more distal than that of an alluvial fan.

In view of the conclusions reached by Allen (1965), the relatively low pebble packing characteristics of the White Reef are opposed to those of typical alluvial fans. He states that alluvial fan deposits are relatively coarse grained and typically of gravel grade, whilst sand and silt grade sediments are usually subordinate. This implies that alluvial fans are generally openwork pebble supported gravels, unlike the pebbly White Reef quartzite. The average sphericity of 0,74 for the White Reef pebbles also exceeds the maximum found for alluvial fans by Blissenbach. Lustig (1965) records an angularity of pebbles on the alluvial fans of Deep Springs Valley, California, which also exceeds that of the White Reef, indicating that the pebbles of the latter were subjected to considerably greater abrasion than would have resulted from a single cycle of erosion and/or transportation of the mountain front nearest to the alluvial fan; this points to longer river transportation and/or reworking far exceeding that associated with a primary mountain-edge alluvial fan.

Somewhat more favourable evidence for an alluvial fan environment for the White Reef is offered by the contrasting composition of gravel types which occur side by side and which may have had their origin in different mountain land sources close by. This could explain the different composition of the West Rand facies, as well as the presence, in all the facies, of pebble sub-populations possibly reflecting shorter transportation distances. It could also offer, amongst others, one explanation for the varying grades of mineralisation of the three facies. Changes in the lateral distribution of pebble compositions of the White Reef are however muted when compared to those in the alluvial fans of the Deep Springs Valley (Lustig 1965). In the latter area pebbles of plutonic rocks vary, from 25 to 100 per cent of the total population within a distance of 1 000 feet. The smaller lateral variation in the White Reef again suggests more advanced mixing than is associated with a primary alluvial fan and again points to an environment of deposition farther downstream.

It is therefore concluded that, although there are various geometrical features present comparable to alluvial fans, there are distinct textural differences apparent which are all related to an environment situated farther downstream at the very end of, or beyond, a typical alluvial fan. Alluvial fan deposits grade into coarse-grained braided river deposits according to Reineck and Singh (1973). The conditions of the White Reef should therefore be closely compared with braided streams. However, first, the alternative two associations of the fluvial environment will be examined.

FLOOD PLAIN ASSOCIATION

According to the mentioned two writers, this is the fluvial sub-environment developed in mature reaches of rivers. In contrast to the alluvial fan association which is mainly bed load deposited, the flood plain association consists of mixed load deposits with both bed load and suspension load deposits well represented. Various sub-components are strongly developed, e.g. the important point bar and channel sequences. The components of these, together with natural levee, crevasse splay, and flood basin deposits are not recognised in the many exposures of the White Reef, even when it is kept in mind that sedimentary differentiation is sometimes not well developed when only channel and flood plain deposits can be recognised in the fluvial deposits. Even the latter, as represented by the repetition of fining-upwards sequences, which is typical of this association, are missing in the conglomerate studied. The absence of all these defining parameters emphasizes that the White Reef is not a flood plain association.

COASTAL PLAIN-DELTA ASSOCIATION

These generally are responsible for the most extensive fluvial deposits, occupying large areas in the lower reaches of rivers and producing thick deposits of fluvial sediments. They grade gradually into upper deltaic plains, coastal sands and tidal flat sediments. Sand is deposited only in the bottom of river channels and the main sediment is silt and clay. It is obvious that this general environment is too low in energy for the gravels of the White Reef.

The above indicate, by a process of elimination, that it is necessary to move upstream to the reaches of the coarse-grained river environments for a closer comparison of key parameters. With reference to the classification of Reineck and Singh (1973) the above data prove the White Reef to be imperfectly associated with the alluvial fan or piedmont association, and only at its most distal phase as the conditions represent those that develop beyond the fan proper. This association is forced by the elimination of the more unsuitable flood plain and coastal plain-delta associations.

BRAIDED OR MEANDER DEPOSITION

Braided stream sediments can be differentiated from meandering stream deposits. Literature on the latter has accumulated rapidly in recent years so that 'upward fining cycles' or alluvial 'cyclothems' are terms well known to sedimentologists. The obvious differences between meander and braided deposits, lie not only in the cyclic or quasi-cyclic natures of meander deposits, but also in their abundance of fine-grained overbank material. Upwarding fining cycles and fine overbank sediments associated with fluvial meanders are not typical of the White Reef. Smith (1970) examines the special hypothetical case where slow subsidence may have permitted the lateral movement of meandering channels to remove virtually all overbank fines and leave only point bar and channel-lag deposits preserved. Could these be distinguished from braided stream deposits? Smith (op. cit.) reached the conclusion that point bars of meandering streams appear to be composed mostly of ripple and dune cross-strata, but that tabular sets of planar cross-strata are not common. The latter conflicts with the environment of the White Reef where planar crossbeds predominate and trough cross-stratification is sparse. On the basis of this, and the absence of fluvial cycles and overbank deposits, the White Reef can not be classified with meander stream sediments. Thus by a further process of elimination it is concluded that the White Reef must be a braided stream deposit as is illustrated in fig. 22 (p. 221). This reasoning can now be tested by further comparison. Smith continued to compare these two types of deposits and found that small-scale variations in grain size and stratification are fewer and less abrupt in point bars than in braided stream deposits. Thin shales and interclays occur more abundantly in braided stream deposits than in the more homogeneous point bars; and here, for the first time, is an explanation for the argillaceous matrix and layering frequently observed in the White Reef conglomerates, even in the higher pay areas. Finally, beds are generally thinner and more irregular in braided stream materials. The obvious gentle curve of the main channel, developed over the length of Randfontein Estates and superficially comparable with a gentle meander, now requires re-classification or clarification. It formed initially as a single gentle stream curve in pre-White Reef time, and remained 'fixed' in position due to locally accelerating uplift on the western flank of the syncline, which prevented the straightening of its course later. It is, therefore, not part of a true 's' shaped meander.

THE BRAIDED STREAM DEPOSITIONAL ENVIRONMENT

According to Smith (1970), braided patterns in streams are mainly created by the accretion of longitudinal bars and dissection of transverse bars. He observed that the distribution of bars in the South Platte River depended on the texture of the bedload, with coarse poorly sorted materials forming transverse bars. Also, that the relative proportion of transverse to longitudinal bars increases downstream, following the river's tendency to fractionate its load into finer sizes downstream. This is accompanied by an increase in the ratio of planar cross-stratification to horizontal stratification and a decrease in cross-channel topographic relief.

The White Reef can be expected to reflect the properties of proximal braided stream deposits, made up predominantly of longitudinal bars, which are defined by Smith (op. cit.) as being essentially accumulations of gravel with varying admixtures of sand and finer materials. Transverse bars are, in contrast, tabular bodies composed predominantly of sand, which grow by the downstream migration of foresets more or less perpendicular to the general current direction. The latter are represented by anomalous crossbedding directions at right angles to the main current direction. These are not found in the White Reef paleocurrent pattern (map 19, p. 244) and it is thus concluded that transverse bars were sparse. According to Smith, the origin of longitudinal bars involves the construction of channel ridges in poorly sorted sediment (Leopold and Wolman, 1957). When a river at any stage becomes unable to move its coarsest load, finer particles become trapped and a ridge begins to build up. By successive entrapments, the ridge, building laterally and vertically, aggrades to a point where it becomes exposed and diverts the flow to both sides. In the later stages of bar evolution, avalanche faces sometimes developed on the downstream margins. These are abundantly exposed in the lower downslope, central areas of West Rand Consolidated and Luipaardsvlei Estates. Longitudinal bars commonly override or merge laterally with each other, resulting in complex bars with a variety of shapes and surface grain-size distribution. Another way in which streams braid is by dissection of transverse bars but this played a minor role in the White Reef deposition.

Longitudinal bars most commonly display a crude horizontal internal stratification, especially in the coarse-grained portions. These are commonly developed in sections of the White Reef, especially in the main payshoot on West Rand Consolidated. When finer sand-size material is abundant, longitudinal bars are usually trough cross-stratified or, occasionally, on downstream margins, planar cross-stratified. Whilst the latter form is easily recognised in the midfan area of the White Reef, trough cross-stratification is only rarely seen.

In summary, a more proximal than distal braided stream environment is assigned to the White Reef, by means of a comparison with the model developed by Smith (1970), through recognition of the particle size population and, secondly, by means of the internal textural characteristics of longitudinal bars and the relative absence of crossbedding patterns associated with the formation of transverse bars.

It should, however, be kept in mind that these two bar types are in reality end members and that many bars represent a complex interfingering of the two types and that the White Reef is a case where the transverse bars are in a relative minority. The model of Smith, is, however, not sufficiently comprehensive to cover all the variations of White Reef sedimentation and does not explain the phenomenon of heavy particle concentration over floor highs or the strong reverse grading of pebble size. It is therefore necessary to examine the sub-components of the White Reef braided fluvial fan environment more closely in order to obtain a complete definition of the depositional environment.

SUB-COMPONENTS OF THE WHITE REEF ENVIRONMENT

The sub-components of the White Reef environment can be recognised by a comparison with the model developed by Eynon and Walker (1974) for bar growth in braided rivers. They studied facies relationships in Pleistocene outwash gravels in Southern Ontario and combined their results with other work to formulate a general comprehensive model which is illustrated in fig. 23 (p. 222).

They define the braided bar as developing around a core consisting of crudely horizontally stratified gravels. Downstream from the core is the bar front facies; consisting of large gravelly foresets, rounded off in many places by reactivation surfaces. Upstream from the core is the bar stoss side facies consisting of several sets of tabular crossbedding arranged in coarsening upward sequences. At right angles to the main current direction is the side channel facies, which consists of trough crossbedded sands. After deposition in the side channel, and growth upstream and downstream from the bar core, the entire system aggraded. Crudely horizontally stratified and imbricated gravel sheets were laid down as a bar top facies.

The outwash gravels studied by the two authors were markedly coarser than the White Reef as cobbles up to 75 cm in diameter were present. Their grain size analysis indicates strongly bimodal distributions, implying that much of the sand in the spaces between pebbles and boulders filtered in after the gravel had been deposited. In contrast, the White Reef pebbly quartzite was mainly deposited as a single sand supported phase. Their Pleistocene model is also characterised by much thicker bars with greater thicknesses developed in all the various facies, than those present in the White Reef and in present-day rivers. Yet, apart from these differences, the sub-facies of their general model can, to a large degree, be recognised in the conglomerate studied. Their Pleistocene bar developed the stoss-side-core-bar front relationship within the short distance of 1 300 feet. It is likely, therefore, that a large number of bars covered the area of the White Reef fan. It will be seen, however, from the following discussion that certain facies, particularly that of the bar core and bar front developed more abundantly or covered larger areas, or were better preserved, in certain geometrical positions of the White Reef fan.

The bar core facies of their model (fig. 23, p. 222) includes a layer of basal gravel, which is continuous containing many topographic 'highs' rising up to four and five metres above the general level of the top of their basal gravel, unit no. 1. These highs were the cores from which the bars in the overlying gravel, unit no. 2, developed. This vertical growth of coarser gravels is similar to the phenomenon of particle concentrations developed over floor highs in the main lobes of the White Reef. The core facies is the coarsest and the overall aspect is one of crude horizontal stratification with imbrication. The pebbles dip upstream at an average of 24^{o}. The pebbles of the main lobes of the White Reef similarly dip upslope at mean angles of 17^{o} and 20^{o}, respectively, for the Luipaardsvlei and Randfontein facies, whilst horizontal stratification over floor highs is conspicuous. The greater part of the main lobe phases of the White Reef can, therefore, confidently be classified as bar core type gravels, and, perhaps, more specifically as basal gravel, except for a thin lag gravel layer present at the top of the reef. The presence of horizontal stratification and the relative absence of cross-stratification in these core gravels suggest that there was no steady advance of bar forms with avalanching on the lee side, but instead, that most of the gravel tended to move in sheet flood form over a system of ephemeral shallow channels and low relief bars, according to Eynon and Walker.

The bar front facies is abundantly developed as thick avalanche crossbedded White Reef in the midfan area, outside the channels of lag conglomerates, especially in the West Rand and to a limited extent in the Luipaardsvlei phases. It forms the major sub-component outside the main lobes and is characterised by poor mineralisation. Similar to the model example, the pebbles of the conglomerate lie on the foresets of large crossbeds and dip downstream. The mean angle of pebble inclination of the outwash gravels is in the 27^{o} - 29^{o} range, whilst the average dip in the White Reef is only 14^{o} (table 12,p. 59). The lower angles are attributed to possibly less sediment influx and lower current velocities.

The side channel facies with its trough crossbeds orientated at right angles to the main current was not clearly detected in the White Reef exposures or reflected in the paleocurrent pattern. This is due to the greater abundance of longitudinal bars relative to transverse bars.

The bar stoss facies consists of tabular units of crossbedded coarse and pebbly sands, arranged in coarsening upward sequences. These occur in the White Reef over wide areas of the upper midfan as well known and conspicuous reverse graded pebble beds often topped by a thin lag gravel. The coarsening upward sequences are interpreted as dunes migrating downslope and climbing on to the stoss side of the bar core. The coarsening upward aspect is related to rising flow conditions. At peak flow, coarse gravel was transported onto and across the bar top, suggesting that the upstream growth of the stoss side was taking place roughly contemporaneously with downstream growth of the bar front.

The bar top facies is represented in the White Reef as thin terminal lag gravels covering large areas of the three facies. As stated earlier, and by Eynon and Walker, it represents, to a large extent, the reworking of underlying core gravels. The crude horizontal stratification and absence of gravelly stratification, suggest that there was no longer a systematic forward advance of bar forms, but that the gravel moved in sheets under shallow water depths. The bar top and basal core gravels are the dominant facies in areas of best mineralisation. This is due to their deposition as lag deposits exposed to conditions of winnowing and sorting, which could not develop in the remaining facies of advancing bar forms since these were often associated with avalanching and rapid burial.

12. A PREDICTIVE MODEL FOR WITWATERSRAND REEF ENVIRONMENTS AND DEPOSITIONAL MODES

The environmental results of the White Reef investigation, combined with conglomerate measurements, can be used as a framework to fit related information gathered about other reefs, notably that by Steyn (1963), De Kock (1964), Armstrong (1966), Knowles (1966), Hodgson (1968), Sims (1969), Minter (1972) and Pretorius (1974 a). This systematic compilation, set out in table 20, provides the basis for a preliminary predictive model for depositional modes and environments of Witwatersrand types of conglomerate (fig. 24, p. 223). The number of predictive parameters is limited to five, with the addition of two extra experimental properties, namely thickness of carbon seams and percentage of gold deposited out of suspension. More refined and comprehensive models, with additional parameters, will doubtlessly be put forward as more data become available. However, the predictive strength of any conceptual model lies in the minimum number of components required for the correct identification of the entirety, which, in this case, is the facies environment. These five properties should be sufficient, and even two or three will give a reasonable indication of the environment and type of deposition.

When the data of the table are compared with the type ranges of the model, it becomes obvious that certain averages do not fit, e.g. the average reef thickness of 50 cm for the Livingstone Reefs, 99 cm and 62 cm for the Monarch and Zone 2, etc. These values are viewed as incomplete, probably representing only the economic section of a reef, or covering a single mine, instead of the entire natural range of that facies. In a similar fashion the unusually wide ranges of Au/U of 10 - 25 for the Basal Reef and 5 - 14 for the Vaal Reef are viewed as the result of combining proximal and more distal phases into a single range. Wide variations can result,

TABLE 20

CLASSIFICATION OF WITWATERSRAND TYPES OF CONGLOMERATES BY PEBBLE PROPERTIES, REEF WIDTHS, Au/U RATIOS, Au PARTICLE SIZES AND ENVIRONMENTS

FAN ENTRY	REEF	PEBBLES					GOLD	THICKNESS		Au/U	ENVIRONMENT
		Size - mm		Packing %		Sorting					
		Grand mean 10 largest pbls	Range of mean sizes	Grand mean	Range of means	Range of means (mm)	Mean particle size (mm)	Grand mean (cm)	Range of means (cm)		
PEBBLE SUPPORTED GRAVEL FACIES.											
FAR WEST RAND	V.C.R		39 - 23				(0,272 at W.R.)	137	352 - 0		Alluvial fan
WEST RAND	MAIN	37,1					0,155	110		11	
LARGE, LOOSE PEBBLED SAND FACIES - PROXIMAL BRAIDED FLUVIAL											
FREE STATE	Proximal Facies: (Harmony) B_1 B_2 B_3		36 - 13 34 - 13 20 - 13	25 +30 22	45 - 0 50 - 0 30 - 15	}		72	179 - 0	10 - 25*	
WEST RAND	White Reef (Luipaards-vlei phase)		18 - 10	46	79 - 15	12,7 - 5,2		89	185 - 13	10	Prox. fluv.
	Livingstone Reefs	35	20 - 10	44	74 - 15	9,4 - 4,2		50*		9	Prox. fluv. (revised)
	West Rand phase (White Reef)		14 - 9	25	55 - 7	9,9 - 3,8		76	170 - 13	9	Prox. fluv. Braided
SMALL LOOSE PEBBLE SAND, CARBON-URANIUM RICH FACIES, DISTAL BRAIDED FLUVIAL-LACUSTRINE											
WEST RAND	W.R. distal Rand. phase		13 - 7	28	57 - 4	6,3 - 1,7		25	91 - 0	2,5	Distal fluv. braided
O.F.S	Basal Reef (all phases)	20					0,277 Welkom	36*		2-9*	Fluv. deltaic
EAST RAND	Kimb. R - 9A		12 - 7					-61*	310 - 0		Fluvial
KLERKS-DORP	Vaal Reef	22	10 - 7	22	49 - 0		0,223	15	102 - 13	5-14*	Fluv. deltaic
WEST RAND	Monarch Zone 2	17,9 20,6					0,338	99* 62*		0,23 0,13	
CARBON RICH SANDS, MINOR NUMBERS OF SMALL PEBBLES, TERMINAL FLUVIAL FAN - LACUSTRINE											
WEST RAND.	South Reef	16,5					0,175	10		7	
FAR WEST RAND	Carbon Leader		± 12*		Hallbauer and	Jounghin- De Kock -	0,200 0,365	8			

* Viewed as representative of an incomplete facies, or several facies combined, or approximate values.

alternatively, from insufficient smoothing or averaging, which, however, was apparently not the case here. The anomalous value ranges require re-definition according to the different reef sub-facies and were, thus, omitted from the model.

It was attempted to expand the model by incorporating the mean gold grain size ranges, as reproduced by Pretorius (1974 a) from information by Hallbauer (1972), Coetzee (1966) and De Kock (1964). Even with the gold particles attached to coarse pyrite and to thucholite omitted, the frequency distributions reflect erratic or incomplete size ranges, unlike that of naturally sorted sediment grain populations. This is probably related to the well documented post-depositional changes in grain size which involved both recrystallization and dissemination, resulting in the formation of minute particles which are unnaturally small for modern day placers, a feature also observed by Pretorius (1974 a). The calculated average gold grain sizes, when plotted for the various reefs do not fall into a meaningful size decrease pattern like the other five sedimentary parameters. This probably reflects non-representative restricted sampling or that the average gold sizes were unrelated to the original energy states of the sub-environments due to the mentioned post-depositional changes. The grand averages for the means of the ten largest pebbles measured per reef were not incorporated into the model as the ranges of the means of all pebble sizes present exceeding 4 mm, are more reliable.

The model shows a systematic progressive downslope decrease in all five properties. The changes reflect lesser slope gradients which caused increasing downcurrent dropout of heavy particles resulting in looser packing, smaller size ranges and thinner reef. The systematic change in energy regime defines similar gradual transitions in environment, all broadly related to the fluvial character. The farthest upslope facies is reflected by the boulder containing Ventersdorp Contact Reef, which is apparently cobble and pebble supported (see photographs, Knowles, 1966) i.e. 'banket-type'. According to Allen (1965), alluvial fans consist of predominantly gravel size particles. The V.C.R. thus seems to be correctly classified by Knowles (1966) as alluvial. The Main Reef on the West Rand is likewise reported to be of a banket-type and, if this is correct, the smaller pebble size and reef thickness support a position downslope of the V.C.R. at the border of the alluvial-fluvial transition, but within the fluvial range. The alluvial phase is representative of the piedmont fans which acted as a source for the adjacent fluvial fans downslope (see fig. 22, p. 221).

The proximal and distal braided fluvial fan environments, as characterised by the White Reef deposits, have been adequately described previously, but it may bear emphasizing that pebble supported phases do not reflect the general situation, but occupy parts of the main distributary streams, and would be most abundant in the extensively sorted more economical reefs, e.g. Main Reef.

The extremely narrow reef of the Carbon Leader, the occasional complete absence of pebbles, which are very small in any case, averaging about 12 mm, plus the thickest carbon seams (De Kock, 1964) position this reef at the very distal end of the fluvial fan environment. It is sufficiently basinward to have participated in the basin edge 'deltaic' or lacustrine conditions of the main water body. The South Reef, with its small pebbles, carbon and narrow reef is closely related.

13. HANGINGWALL EVENTS

THE IMMEDIATELY OVERLYING QUARTZITES

The appearance of the medium grained quartzites directly overlying the White Reef, reflects the waning of the high energy proximal fluvial conditions that prevailed during the deposition of the conglomerate. It therefore represents the initiation of a transgressive phase following White Reef sedimentation.

The sedimentation direction measured in the immediate hangingwall quartzites unchangingly reflects the fanlike, southward distribution of the underlying beds which had all been funnelled down the Randfontein trough (map 20, p. 245). The overall source and supply pattern of materials, therefore, didnot change. The only minor difference is the strong local uplift downslope on the western flank of the trough at 32 Shaft which deflected the paleocurrents to the east.

The rather homogeneous overall flow southwards and the presence of wave-formed symmetrical ripple moulds indicate shallow water. Occasional sandwaves and some trough crossbeds indicate phases of relatively high energy. A fluvial fan environment is indicated over the upper section of the fan. The local switch to the east and north-east of the paleoflow at 32 Shaft could possibly be related to transgression at the lower edges of the fan.

The lithological properties point to a gradually changing environment of deposition down the slope. Medium grained, occasionally argillaceous, quartzites, alternating with some small pebbled conglomerates and grits deposited high on the fan, grade into medium-fine and fine grained sands lower down. Over the basal section of the fan, a siliceous blue 'bar' eight to twenty inches thick covers the White Reef and gritty phases are seldom developed. The coarser northerly phase reflects mainly fluvial sedimentation, whilst at the fanbase the finer grained, siliceous bar sands, containing some local reversed current directions, may be related to temporary transgressions. The environment of the quartzites overlying the White Reef is, then, seen as fluvial-deltaic.

THE STRATA BETWEEN THE WHITE AND MONARCH REEFS

The geometry of the overall West Rand trough (map 6, p. 229) is no longer reflected by the isopachs of the quartzites which separate the White and Monarch Reefs (map 11, p. 234). The thinning towards the outer rim is much reduced due to slower subsidence. Although slight, the north-easterly orientated subsidence, north of the Witpoortjie fault, is visible. The quartzites are generally fine grained indicating that the fluvial-deltaic environment of the post-White Reef period persisted, with transgressive and regressive phases related to finer and coarser intervals respectively.

THE MONARCH REEFS

The deposition of the Monarch and Upper Monarch Reefs, which consist of approximately ten conglomerate bands, all uraniferous, but with less gold, is seen as a repetition of depositional cycles similar in type to the White Reef. The Monarch Reef, for instance, appears to have been deposited on a slightly undulating mud seam footwall, and is also covered by a blue grey siliceous 'bar' (Toens and Griffiths, 1964). This suggests a fluvial deposition for these reefs and a sequence of events similar to that of the White Reef. The positions of the economic metal concentrations of the Monarch, Zone 2 and Zone 4 reefs, as portrayed by Toens and Griffiths (1964, fig. 5), indicate the continued and dominant control of the major payshoots by the Randfontein trough.

14. ECONOMIC APPLICATION

This study was initiated during 1963 to determine the factors controlling mineralisation and to utilise these concepts in the prediction of the unmined areas of best mineralisation on West Rand Consolidated Mines Ltd. Two years of full-time research were concluded in mid 1965 with the compilation of a summary report with recommendations for economic applications. Map 24 (p. 249) was produced at that stage; it shows ten localities, A to J, which were singled out as being of possible superior mineralisation. Four of these, namely A, B, D and E, are of minor potential; three are of intermediate interest, namely C, G and H; and three merit first order consideration, namely F, I and J.

Mining and exploration were discontinued in the White Reef at Randfontein Estates Mines in December, 1964; the following year in East Champ d'Or G.M. Company Limited, and were never initiated on the Luipaardsvlei Estate and G.M. Company Limited. Consequently, the measure of success of these predictions can only be assessed by subsequent results obtained on West Rand Consolidated Mines.

POTENTIAL OF MAIN LOBE AREAS

WESTERN LOBE

The best mineralisation occurs along the Randfontein trough which controlled the major payshoot, which developed along the main stream channel of the western lobe (map 22, p. 247). All mining on West Rand Consolidated had, since 1965, been concentrated in the south-western corner of the mine along the upslope portion of the main streambed. The inset on map 24 shows the extent of mining operations up to the present. The only prediction of first order (F) on West Rand Consolidated has been proved successful and in the 1966 - 1974 period, 1 153 869 tons of ore were extracted, mainly from this area. The future economic potential of the White Reef is predominantly related to the main streambed of the western lobe and its associated auxilliaries, at the lower midfan and especially the central fanbase positions, as depicted on the model (fig. 21, p. 220). The delineation of its boundaries and the detailed internal geometry, which is, in terms of mineralisation, associated with local floor undulations, would be of concern in future exploration. Other zones of predicted higher mineralisation, namely I, J and C form part of the same system of distributaries. The first two are located in the mine which closed down in 1965. Mining at position C, however, recommenced in 1973 even though it was partially exploited at an earlier period; the stoping done during 1974 is indicated on map 24 (p. 249).

EASTERN LOBE

The economic potential of the midfan area of the eastern conglomerate lobe was impaired by the high current velocities which swept the fine grained gold to positions lower downfan. The only mineralisation which merited mining was located at H_{31} (map 24), which is situated in the main lobe far down on the midfan. This indicates that the eastern midfan conditions are, to a marked degree, an extension of those which existed at the fanhead.

POTENTIAL OF THE AUXILLIARY CHANNELS

The mineralised sections of the braided stream channels of the wide midfan area are of secondary interest as both areal extent and the degree of mineralisation are modest. Their probable positions, which include all the known small paystreaks, have been delineated on the plan model. Predicted positions A, B, D and E, which are classified as third order, due to their high midfan position, fall into this category. Position E is of special interest and better mineralisation may extend over a longer distance, as it clearly lies in the Witpoortjie trough (map 22, p. 247). Should additional reef intersections become available, it may be possible, by means of isopach patterns, to identify fully the subtle crossfolds which seem to have pre-determined the localities of these smaller streambeds. The cross-over positions of the synclinal depressions are of special interest as they apparently represent best mineralisation.

Prediction positions G and H, classified as being of second order merit, due to their midfan-fanbase position and their proximity to the main payshoot, are also part of the braided channel pattern. These latter streams did not contain sufficient abrasive strength to cut into the floor. Stronger currents on the lower midfan and fanbase followed neither the scour nor the minor fold channels, which were too small to control the stream flow. The beds of these streams are identified only by the presence of more robust, better mineralised conglomerate, often, best developed over floor highs. Prediction directions are based on the paleocurrent flow vectors and channel intersections.

Application of the mathematical hydraulic equilibrium model

The application of the derived mathematical model $y = -33,5962 + 2,32798\ x_1 + 0,8663\ x_2$, where y = gold dwt/ton, x_1 = mean pebble size (mm) and x_2 = pebble packing per cent (appendix 17, p. 189), for purposes of gold prediction, is limited to the areas immediately surrounding the pilot study area. As a test, it was applied to data for 7^A VW18 stope, which is 1 700 feet away, where size, packing and gold data were available for the same samples. The average gold value predicted, on the basis of sediment properties, was 20 dwt/ton, which was found to be 78 per cent correct, when compared with the sampled gold values, which averaged 26 dwt/ton (appendix 17, 3 - ii). When the equation was applied to the pilot study data, the average predicted gold value of 15,56 dwts, deviated from the average true value of 14,62 dwt/ton by 6,4 per cent (appendix 17, 3 - i).

The model, as it stands, is not comprehensive enough for reliable areal prediction for two reasons. Firstly, it reflects local equilibrium conditions, which changed markedly for positions down and up the paleoslope, in response to velocity and persistence of flow variables (see table 14, p. 69). Secondly, it accounts only for that part of the gold particle population that is controlled by traction transport, and it will, consequently, loose validity downslope. The bedload factors, expressed mathematically, reflect three quarters of the gold grade at the locality of the pilot study, and an estimated half of the gold content lower down at the centre of the fanbase. To arrive at an all inclusive predictive formula, it would be necessary, first, to quantify geologically the measurable responses to suspension-solution transport, and, secondly, to incorporate correction factors for the up and downslope variables affecting both transport processes. This task is outside the objectives of the present traction study, as extensive measurements of the light and heavy matrix particles are required, along with geochemical, environmental and other investigations.

CONCLUSIONS

1. STRUCTURAL FRAMEWORK

The initial position and orientation of the West Rand depression was, like the other entry points to the Witwatersrand basin, pre-determined and guided by immobile flanking buttresses. It was, therefore, an early original structural feature, brought about by the configuration and lithology of the floor. The early shape of the subsidence, as shown by the Main-South Reef isopachs, is reflected, to a large degree, by the structural configuration at the level of the Main Reef. The subsiding Randfontein trough formed the base of the West Rand depression. It received and funnelled sedimentation southwards, throughout the Upper Witwatersrand period. It is situated adjacent to the western rim, in a position similar to that of the fold described by Olivier (1963) for the Loraine area of the O.F.S. It also formed the hinge for asymmetric synclinal development, since the adjacent western rim was being elevated more rapidly as early as the Main-South reef interval. It repeatedly channelled the main streams that deposited the larger payshoots of the Livingstone Reef and Bird Reef Stages.

The shallower north-easterly orientated Witpoortjie trough, situated adjacent to and north of the Witpoortjie fault is another primary axis of subsidence. Its direction, parallel to the axis of the main Witwatersrand basin, points to its participation with the same tensional field. It apparently formed a similar miniature sub-basin in the period separating the South and Main Reefs. This coincides with the highest uraninite mineralisation, attained on the central fanbase of the White Reef at the merger position of the two troughs. The deceleration of currents which led to the drop-out of heavy minerals suggest a continued tendency towards basining. The primary tectonic stage is thus represented by a general West Rand subsidence, with the north-south Randfontein trough as a base, which is deflected downslope, however, into a north-easterly Witpoortjie trough.

A second phase of structural development is reflected by White Reef thicknesses as small scale north-easterly and north-westerly warps. Limited vectorial data suggest that the major West Rand syncline, orientated toward the south-east, was initiated at this stage as part of the mild warping.

A third late phase of post-depositional folding formed the West Rand syncline. The basining, reflected at the level of the White Reef, is related to drag, associated with the uplift of the Witpoortjie horst block.

At various periods during the deposition of the Upper Witwatersrand, the rate of floor subsidence became more pronounced at certain localities, which, apart from the north-south Randfontein trough, set against the western flank, all conform to a north-easterly and north-westerly geometry, and are positioned along pre-existing zones of weakness.

2. DEPOSITION OF THE MAIN-BIRD SERIES

A comparison of conglomerate properties indicates that, on the West Rand, the Main Reef, being stratigraphically the lowermost gravel for which detailed measurements are available, was deposited high upslope under fluvial conditions approaching those of an alluvial fan (table 20, p. 124).

Isopachs of the transgressive quartzite which separates the Main and South Reefs indicate a depositional floor, closely related in geometry to the present day overall structure found at the level of the underlying Main Reef. Decreasing mineralisation, in the Main Reef, towards the south indicates that the source remained constant and was from the northerly entry point, situated between the granite buttresses.

South Reef deposition followed. The smooth pebbled, carbon rich reef with very small gold particles, contained in a reef generally as thin as ten centimetres, identifies it as a distal fanbase or terminal depositional phase on the broad West Rand fluvial fan (table 20). It is overlain by a clean quartzite which was terminated by the progradation of the Johnstone Reefs, whose multi-reef robust character indicates fluvial deposition close to the entry points. The overlying quartzite is variable in character; distal deltaic phases being reflected by siliceous bands whilst fluvial conditions are indicated by crossbedded phases and grit bands. The erosion that followed, marked the end of Main Reef Stage deposition.

The depositional history of the Livingstone Reef Stage, which consists of a basal conglomerate zone and thick overlying quartzite, is similar to that of the Johnstone zone, and typical, for that matter, of several genetical units of the Upper Witwatersrand division. A basal zone of conglomerates moved south over an erosional surface, the robustness (table 20) and multiple layers of thick gravels emphasizing proximal fluvial fan conditions. The overlying transgressive quartzites, variable in character, represent minor transgressions and regressions related to the interchanges of deltaic and fluvial environments. The uppermost quartzites include discontinuous layers of small scattered pebbles and occasional lensic conglomerates which are all related to mainly proximal fluvial conditions. Their paleocurrent pattern shows a fanlike, unimodal shallow water flow, away from the northerly source entry, with the distribution controlled by the Randfontein trough which formed the base of the West Rand subsidence (fig. 20, p. 219).

Deposition of the Bird Reef Stage followed the formation of a scour surface with a relatively high bed-relief index. This was related to proximal fluvial erosion which did not last long enough to develop a channel system different from that of the underlying sediments. The deposition of the Bird Reef Stage with the White Reef as a basal deposit reflects a natural cycle of sedimentation. Initially, several phases of coarse conglomeratic sedimentation repeatedly moved southwards in response to pulsating uplift in the source area. The Bird Reefs display siliceous bars on top of the conglomerates at the fanbase positions, indicative of onlapping deltaic or lacustrine environments. The progressive lowering of the source area is reflected by the phase-over to micaceous quartzites deposited after the Bird Reefs, whilst the approach to a mature stage of erosion in the source area is indicated by the introduction of argillaceous quartzites with bands of shale. The upper shales of the Bird Reef Stage reflect accelerated sinking basinwards coupled with a slow rate of sedimentation.

3. SEDIMENTATION OF THE WHITE REEF

SOURCE AREA

The source area was sufficiently distant for the relative abundance of pebble lithologies to be controlled by their resistance to transportation. The West Rand sub-phase contains little quartzite and has a pebble lithology identical to that of the stratigraphically correlative Basal and Vaal Reefs (table 8, p. 43). The other two sub-facies have abundant quartzite fragments, and it is possible that the source rocks of the West Rand fluvial fan supplied more quartzite detritus during the Main-Bird period than the other entry points of the basin. Alternatively, a more plausible explanation for the overall greater abundance of less durable quartzite pebbles is that there was a shorter distance of abrasive transport. The conglomerates of the O.F.S. goldfield, by comparison, appear to have undergone least transport, if judged on maturity of lithological types alone. Even though the pebble sphericities indicate moderate to advanced mechanical abrasion, short fluvial transport is suggested. Some detritus from the underlying Livingstone Reefs may have been incorporated since the sphericities are nearly identical (table 11, p. 54) and as both reefs contain a high percentage of quartzite pebbles. The association of better mineralisation with more quartzite pebbles, especially in the Randfontein facies, suggests that the eroded material included earlier mineralised, quartzite pebbled conglomerates, possibilities being earlier conglomerates, such as Dominion Reef or rim equivalents of underlying Witwatersrand conglomerates. It also suggests that heavy particles, including pebbles, and heavy minerals were co-transported over the relatively short distance of transportation.

However, most gold mineralisation came from the primary source rocks, with the mafics and ultra-mafics supplying the gold and most uranium coming from the basement granites, according to Pretorius (1974 b). Basin edge recycling was of lesser importance for the White Reef, as is apparently normal for proximal types of reef; see explanation of table 17 (p. 80).

GEOMETRY OF THE DEPOSIT

The geometry of the depositional fan is reconstructed by means of a model (fig. 21, p. 220). The fanhead extended about one mile beyond the outcrops and the main river divided into three major distributaries below the fanhead. The fan is asymmetrical with the eastern channel lobe containing the more robust conglomerate, whilst the western lobe accumulated the best mineralisation. The latter reflects the continued guidance of main channel sedimentation by the Randfontein trough which is the dominant control of mineralisation for the Livingstone and Bird Reefs.

Lower down the midfan, the smaller distributaries braid and recross, and occupy proportionally lesser areas of the fan surface. The distributaries contain the smaller paystreaks, which are often best developed at crossover positions (fig. 21). As the channels frequently have north-west and north-east orientations, it is suspected that they were influenced by similarly orientated fold depressions. The highest concentration of gold occurs at the lower midfan-upper fanbase position and the area of optimum uraninite dropout covered the central fanbase. The distal part of the fanbase has been destroyed by erosion. The fanbase contains carbon seams which have been interpreted by various researchers to present algal mats, or, more precisely, lichens.

The White Reef fan is remarkably similar to that constructed for the Basal Reef of the O.F.S. goldfields (Sims, 1969), it also validates the comprehensive model for general Witwatersrand fluvial fans presented by Pretorius (1975). It is quite obvious that the Witwatersrand Reefs were formed by an orderly system of sedimentation. Part of the system, namely the framework of the depositional fan has been successfully portrayed by both Sims (op. cit and Pretorius (op. cit.). What remains to be done is the closer definition of the changing mode of conglomerate deposition over the wide range of the broad fluvial fan; the sub-environment present; the mineralisation controls and the variable behaviour of heavy minerals over the area of the fan. The latter aspects represent the main interest of this study and contributions in this respect, are summarised below.

MODES OF GRAVEL DEPOSITION

The modes of gravel deposition are related to the fan geometry. The upper central midfan phase represents the initial phase of deposition, dumped under conditions of sediment abundance. Rapid sedimentation, mainly down the front of avalanche faces is shown by abundant large crossbeds and pebbles dipping downslope. Fast burial prevented effective sorting of the pebbly sands and the West Rand phase, therefore, contains low pebble packing percentages, except in the distributary channels. This first pulse blocked the central midfan area and diverted sedimentation symmetrically sideways to form the two main lobe facies, which are situated against the outer periphery of the fan. The equivalent of the central midfan facies is also seen in other similarly positioned conglomerates, e.g. the massive reef phase of the Basal Reef on President Steyn Mine, where a similar downcurrent dip of pebble alignment was recorded by Sims (1969).

Both the Randfontein and Luipaardsvlei main lobe facies were subjected to extensive winnowing and sorting under conditions of lean or balanced sediment inwash. This is convincingly demonstrated by relatively high pebble packing percentages, even for the downslope Randfontein facies, and especially the development of closely packed pebble clusters over areas of rising floor in the strong current areas. The concentrations of heavier particles developed in response to winnowing during prolonged stream flow, and are characterised by frequently uneven horizontal bedding and relative scarcity of crossbeds. In contrast to the upper midfan pulse, the pebbles of the main lobe gravels dip upslope, as is normal for fluvial gravels.

The Randfontein phase of deposition is different from its eastern main lobe equivalent in that it developed as a thin pebbly sand over the low midfan and fanbase. The process of deposition reflects the beanspreading process of Folk (1961), whilst the midfan West Rand and the western section of the Luipaardsvlei facies resembles Folk's city-dump type of deposition. Once again, the downfan phases of the White and Basal Reefs are comparable, being narrow carbon seam reefs containing the highest concentrations of U_3O_8.

ENVIRONMENT OF DEPOSITION

The depositional environment is related to the position of the White Reef fan, which is situated between the northerly source mountains which provided the stream energy to move gravelly loads, and the southerly main water body of the Witwatersrand basin. The West Rand subsidence, stabilised between immobile granite buttresses, provided for at least the duration of the Upper Witwatersrand period, a permanent and major entry point for sediment transported into the main basin. A permanent and large river system was thus required. The environment could then have been that of the fluvial state which Reineck and Singh (1973) defined as covered by the alluvial fan, flood-plain and the delta-plain associations.

The form characteristics of the White Reef fan conforms, to some degree, to alluvial fan conditions. The three lithological phases resemble segments of compounded fans; the depths of stream channels are related to the distal conditions on, or just beyond, alluvial fans. Braiding is a feature of the reef, common also in the alluvial state, downstream of the fanhead trenches. The sub-division of the White Reef into a downslope, thin small pebbled reef, and a thicker upslope robust phase can be compared to the segmentation of alluvial fans of the Western Fresno County, where the fans have distinct breaks in slope.

The textural properties of the White Reef, however, places it beyond the end of an alluvial fan. The pebble sizes are much smaller if compared to the data of Blissenbach (1954) or Allen (1965). The rate of size decrease is much more uniform, in the light of information provided by Lustig (1965). The absence of larger cobbles and boulders and the restricted size range present indicate earlier resorting, partly during deposition of lower reefs, but mostly by selective transportation, probably from alluvial fan sources. Alluvial fans are typically of gravel size (Allen, 1965), i.e. generally openwork and pebble supported. The looser packing of the White Reef represents a pebbly sand and is thus anomalous for this environment. The pebble sphericities exceed the maximum found on alluvial fans, while recorded pebble angularities on alluvial fans exceed those of the White Reef. Longer transportation, more abrasion and reworking is indicated, far exceeding that expected for a primary mountain-edge alluvial fan. Alluvial fan deposits grade into coarse grained braided river deposits, according to Reineck and Singh (1973) and this environment should therefore be closely examined.

The White Reef is classified as a braided fluvial fan deposit and reflects the properties of proximal braided streams made up predominantly of longitudinal bars. These are defined by Smith (1970) as being essentially accumulations of gravel with varying admixtures of sand and finer materials. Longitudinal bars display a crude horizontal internal stratification, especially in the coarse-grained portions. These are commonly developed in sections of the White Reef, as well as avalanche faces sometimes developed on the downstream margins of longitudinal bars.

The sub-facies of the White Reef environment are closely comparable with the model developed by Eynon and Walker (1974) for bar growth in braided rivers (fig. 23, p. 222). Their bar core facies contains a continuous basal conglomerate with many topographic highs, rising four to five metres above the general level of the top of their basal gravel. These highs were the cores from which the bars in the overlying gravel developed. This vertical growth of coarser gravels can be related to the phenomenon of gravel clusters developed vertically over areas of higher floor level in both main lobe facies of the White Reef. The major parts of the main lobe phases can, therefore, be classified as bar core types and more specifically, as basal gravel, except for a thin lag gravel layer present at the top of the reef. The presence of mainly horizontal stratification and relative absence of cross-stratification indicate deposition mainly in sheet flood form.

The bar front facies of Eynon and Walker is abundantly developed as thick avalanche crossbedded White Reef, best observed in the central upper midfan area, outside the channels of the lag conglomerates. Similar to the model example, the pebbles lie on the foresets of large crossbeds and dip downstream. The well documented reverse graded gravels, occuring in wide areas of the upper midfan area of the White Reef, compare with the bar stoss facies of Eynon and Walker. They interpret the coarsening upward sequences as dunes migrating downslope and climbing onto the stoss side of the bar core.

Their bar top facies is present in the White Reef as a thin lag gravel covering large areas of the previously mentioned facies. The crude horizontal stratification indicates that the final gravels moved in sheets under shallow water.

4. A PREDICTIVE MODEL FOR REEF ENVIRONMENTS AND MODES OF DEPOSITION

The data of the White Reef dealing with environmental conditions and with textural measurements of the conglomerate were combined with similar research results obtained over the 1963 - 1974 period from other reefs (table 20, p. 124). This systematic compilation forms the basis for a predictive model designed for the identification of depositional modes and environments of Witwatersrand types of conglomerate (fig. 24, p. 223).

The five parameters used are pebble size, packing and sorting; reef thickness and Au/U ratios. Two extra experimental properties were included, namely thickness of carbon seams and percentage of gold deposited out of suspension. Due to the provisional nature of the latter, as well as the restricted number of measurements available for the other parameters, the model is presented as a preliminary one, until more data become available. An attempt was also made to fit gold particle size into the model, but the mean sizes available do not show the same systematic progressive downslope decrease as the other five properties. This is attributed to incomplete sampling or post-depositional changes in gold size. The model classifies the mean value ranges for the mentioned five properties for the fanhead, upper to midfan, fanbase and distal fanbase positions, along with the facies type and sub-environment.

5. BEHAVIOUR OF THE ECONOMIC HEAVY MINERALS

Direct correlations exist between some traction properties of the conglomerate and the gold and uranium content. These can be expressed mathematically (see appendices 3 - 7, 16 - 18, 22 and 23). Pebble size, packing and sorting (standard deviation) are all related to the gold and uranium content. The correlation coefficients relating these sediment properties to gold, decrease systematically down the paleoslope of the fluvial fan, indicative of a progressive phase change from predominant traction transport of gold particles high on the fluvial fan to mainly suspension transport lower down (table 14, p. 69). These unduplicated results provide new insight into heavy mineral transportation and deposition in Witwatersrand conglomerates. The implications are important as related mineralisation controls change accordingly down the slope. The primary factors for heavy mineral accumulation are the current velocities indexed by the average pebble size, and secondly of greater importance is the persistence of stream flow which caused winnowing, reflected by pebble packing. The latter factor has a correlation coefficient with gold as high as 0,86 for the upcurrent area sampled. Lower downslope, packing loses correlation more slowly than the other traction properties so that a coefficient of 0,51 is still obtained at the middle of the fanbase. Therefore, winnowing (current velocity×persistence) is the consistant process concentrating gold and other heavy minerals, upslope of the central fanbase. Downslope, traction loses importance, with the greater part of the heavy mineral population being moved in suspension.

The relative correlation of the various sedimentary factors to gold, is indicated by statistical analyses. Stepwise regression and matrix analysis show packing to be best linked to gold, with a correlation coefficient of 0,74 for the pilot study area. Addition of the size factor only increases the multiple correlation to 0,75. Further calculations establish that reef thickness (floor height) and standard deviation (sorting) are minor order factors, increasing correlation to 0,76 (appendix 17, p. 189). The stabilised relationship between metal content and the traction properties is expressed mathematically as follows:

$$y = -33,5962 + 2,32798x_1 + 0,86630x_2$$

(with y (gold) = dwt/ton; x_1 = mean size of all pebbles (+ 4 mm) present in a six inch section across the full reef width; and x_2 = mean packing value of same reef area).

This relationship is also locally applicable at the pilot study area to uranium, which is correlative to gold, to the extent of 0,9615. The equation expresses the depositional equilibrium that existed at that specific paleo-slope position. The relationship changes systematically up and downslope, as is indicated by the changing correlation coefficients (table 14, p. 69). Application of the equation for prediction of gold values and comparison with observed values, shows a 12 per cent prediction loss, upslope over a distance of 1 700 feet (appendix 17). To produce a mathematical formula more useful for exploration prediction, this equation, representative of traction transport, must be expanded to include the variables representative of the goid moved by suspension. This undertaking extends beyond the scope of the present study.

A previously unknown process for the accumulation of heavy particles over areas of high floor topography came to light during this investigation. The sedimentological setting for the process is the environment of basal gravel type, situated in the main lobe facies of the fluvial fan, where deposition took place in sheet flood form. At the upper and central midfan position (eastern lobe) the process mainly caused dense pebble clusters to accumulate over areas of high floor relief in a high energy regime, without significantly affecting the distribution of heavy economic minerals, which were only sparsely deposited. Only at the lower midfan and central fan-base (western lobe), where velocities favoured maximum dropout of heavy minerals, were gold and uraninite particles efficiently concentrated in this manner. The accumulations arose from optimum winnowing conditions being reached, due to maximum exposure to currents. This is illustrated by a relative deficiency of 23 per cent of smaller pebbles over the highs (pilot study). Statistical tests indicate that significantly different grain populations were segregated in this manner over highs and lows (appendix 3, p. 155). The average scalar values present over lows are upgraded over highs by factors of 1,3 for pebble size, 3,6 for packing and 4,7 for gold content at the pilot study site. Increasing concentration stops at gravel thicknesses of two to three inches. For narrower reef the process falters and concentrations of both large and small heavy particles become erratic or decrease. The winnowing thus loses efficiency at this critical thickness, possibly due to lack of shielding necessary for the efficient formation of traction clogs. It seems that the process of concentration cannot function well without a minimum thickness of two to three inches of traction carpet being present, which would constitute an efficient trap for the heavy particles which moved mainly by bed load processes. A novel technique for abbreviated sampling was developed from the pilot results, when it was found that single sedimentological samples taken at average floor height, i.e. average reef thickness, were statistically representative of larger areas (table 4, p. 20 ; appendix 7, p. 168).

The mode of gold particle movement, changing from traction, high on the White Reef fan, to suspension, low on the fanbase, was deduced from the changing degrees of correlation existing between definite traction properties and gold content (fig. 17, p. 217; table 14, p. 69). The high degree of traction transported gold and uraninite, found in the upslope area, is, secondly, independently indicated by the positive relationship found between gold and the larger detrital fragments (figs. 10 and 13; appendix 18) and, thirdly, by the affinity between higher metal values and a specific type of pebble (tables 15 and 18). This predominant traction transportation of heavy minerals would apply to the White and other reefs, consisting of similarly deposited pebbly quartzites under related energy conditions. It may or may not be found to be different for upslope positions of the general fluvial fan, where pebble supported 'banket' gravels become prevalent and matrix materials, including Au and U, may have been infiltrated as a separate phase of deposition. Co-transportation could be valid for the alluvial type of environment, postulated for the V.C.R. on the Far West Rand since Knowles (1969) found that the larger pebbled sections of the reef were better mineralised. For distal deposits, situated farther downfan, e.g. the Vaal Reef in the Klerksdorp area, most heavy particles would be moved in suspension and no direct relationship would exist between traction load properties and the Au and U, as was found by Minter (1972).

The behaviour of the larger heavy mineral grains, which did not move by suspension, can be explained according to the principles of particle movement, as set out by Moss (1962, 1963). The heavy mineral particles passed directly from saltation into the interstices of the sand and small pebble ranges. The pebbles, which rolled and slid over the depositional surface, occurred in two ways, either well dispersed or in closely packed traction clogs. The small pebbles and sand can be removed after deposition by winnowing, but, according to Moss, there is no mechanism for the removal of heavy minerals from amongst sheltering pebbles. This explains the affinity between small grained economic heavy minerals and the pebble fraction.

6. MINERALISATION CONTROLS

The definition of the fan geometry is of utmost importance, as it shows the best gold values at the lower midfan position and highest uranium concentrations at the central fanbase (fig. 21, p. 230). The overall mineralisation pattern of the White Reef thus conforms to the general conceptual model for Witwatersrand fluvial fans as constructed by Pretorius (1975).

Economic grades formed as lag conglomerates along main streams and distributary channels by winnowing. Major payshoots developed along larger channels, whilst patchy paystreaks formed along the braided channels, with upgrading at cross-over positions. The better pay areas are identified by more robust conglomerates which are generally elongated and follow the paleocurrent directions, as deduced from crossbedding measurements.

Best mineralisation is found in the basal core and bar top components of the braided bar deposits. These were both formed under sheet flood conditions, favourable for winnowing and resorting. These two depositional forms are easily recognised by the more densely pebbled, coarse horizontally bedded gravels. The rapidly deposited, unsorted, bar stoss and bar front sub-facies are poorly mineralised and are characterised by their scattered pebble and abundantly crossbedded appearance. It is advantageous to map the sub-components of the braided bars in addition to the delineation of the channel positions of stronger bedform flow.

The early structural framework determined the position and orientation of the major payshoots and some of the smaller paystreaks. The West Rand subsidence, defined at its lowest level by the axis of the Randfontein trough, guided the sedimentation of the main stream channels of the western conglomerate lobe of the fan. The main payshoot is never more than 3 000 feet from it over a length of 15 000 feet. The site for optimum uranium values, on the central fanbase, conforms to the merger position of the Randfontein and Witpoortjie trough, where a micro-basin may have developed at a earlier stage (fig. 21; map 6). On the midfan, some paystreaks extend north-east or north-west in accordance with the general fold pattern, present in White Reef times. On the central fanbase, the streams did not adjust their flow directions to conform with the very mild flexures present. The controls of mineralisation were generally determined by the simultaneous interaction of sedimentological and structural processes.

Mineralisation controls of the White Reef can be compared with those of other Witwatersrand types of gold and uranium deposits (table 17, p. 80), in order to relate the controls to the fan geometry, entry point and basin positions. The grade of proximal fluvial reefs, situated on the midfan, and higher upslope, are mainly dependent on the primary concentrations of minerals moved from the source areas. Low grade gold deposits, like the White Reef, develop economic accumulations only along major streambeds and larger distributaries. Moderately graded reefs, such as the Livingstone Reefs, have pay zones extending farther, into the minor braided channels, whilst the better grade Main Reef (West Rand) was economically extracted over most areas of the fan, inclusive of the interfluve positions. This changing pattern of mineralisation to stratigraphic position, plus the sedimentary data (table 20) indicates that the economic horizons of the Main-Bird Series were being deposited progressively farther downslope on the fluvial fan as basin infill continued. The influence of the paleoslope gradient, i.e. strong increase or decrease of mineralisation downslope, is a feature related to proximal or relatively small basin edge fans and can be related to high current velocities which controlled the settling of the heavy minerals. Reworking is of relatively little importance for these proximal deposits.

The reefs, situated at intermediate fan positions on the lower midfan and reaching down to the lower fanbase had different controls, although still retaining important features of the upfan area, e.g. the channel concentration, which is the most widespread and most fundamental control for the full fluvial range. The fold positioning of the major payshoots is now of first order importance, as is illustrated by the moderately distal White Reef (Randfontein phase), the more distal Vaal Reefs at Klerksdorp and the intermediately positioned Kimberley 9A of the East Rand. The grade of the influx sediments is still of primary importance and the presence of carbon mats become of importance. The more distal reefs are developing new controls partly related to the, now dominant, suspension mode of transport. The Vaal Reef, for instance, no longer reflects traction control and the floor topography is a primary but indirect control, which, by comparison, is only a secondary control factor at the central fanbase (Randfontein phase) and generally of a lower order control for the proximal phases.

The thin, small pebbled, highly carbonaceous economic horizons, situated at the terminal end of the fanbase, e.g. the Carbon Leader (Far West Rand), often accumulated mainly as erosional products due to degradation-aggradation cycles. This influence was already introduced in associated reefs deposited in less distal areas, such as the Kimberley 9A and the down-slope phase of the Basal Reef (O.F.S.). The carbon seams are now important as binding materials, acting as absorbing and retaining mats for the very small heavy mineral particles, e.g. in the Carbon Leader and South Reefs. The colonies of lichens and other miniature forms of associated primitive life could only flourish under conditions which were stable for relatively long periods, thus implying longer intervals of quiescence than those of the more rapidly formed upfan phases.

7. ECONOMIC APPLICATIONS

The controls applicable to the White Reef are those that affected the fan between the midfan and central fanbase. The dominant control of the payshoots of the best mineralised western lobe, was the axial position of the Randfontein trough. The only important mining operations done on West Rand Consolidated on this reef, since 1965, have been concentrated in the south-western corner of the mine, along the upstream part of the main streambed, which is controlled by this trough (map 24, p. 249). The only prediction (F) of first order importance, made for this mine in 1965, has been successful. Mining has also been recommenced during 1973 in another distributary payshoot (C), recommended for further attention in 1965, after the completion of the field phase of this investigation. The other mines concerned are dormant at present, but the increasing interest in uraninite will probably re-activate mining in other areas, similarly singled out. This investigation has thus been proved of worth in the field of economic exploration.

LIST OF REFERENCES

Allen, J.R.L., 1963. The classification of cross-stratified units. Sedimentology V. 2, 93 - 114.

Allen, J.R.L., 1965. A review of the origin and characteristics of recent alluvial sediments. Sedimentology V. 5, no. 2, 91-191.

Allen, J.R.L., 1970. Physical processes of sedimentation. George Allen and Unwin Ltd., London, 248 p.

Armstrong, G.C., 1965. A sedimentological study of the U.K. 9 Kimberley reefs of the East Rand. Unpublished M.Sc. thesis, University of the Witwatersrand, 65 p.

Blissenbach, E., 1954. Geology of alluvial fans in semi-arid regions. Bull. geol. Soc. Amer. V. 65, 175-190.

Brock, B.B. and Pretorius, D.A., 1964a. An introduction to the stratigraphy and structure of the Rand goldfield. 25-61: in S.H. Haughton, ed. "The Geology of Some Ore Deposits in Southern Africa." Geol. Soc. S. Afr. V. I, 625 p.

Brock, B.B. and Pretorius, D.A., 1964b. Rand Basin sedimentation and tectonics. 549-599: in S.H. Haughton, ed. "The Geology of Some Ore Deposits in Southern Africa". Geol. Soc. S. Afr. V. I, 625 p.

Bull, W.B., 1964a. Geomorphology of segmented alluvial Fans in Western Fresno County, California (Erosion and Sedimentation in semi-arid environment). U.S. Geol. Surv. Prof. Paper 352-E, 89-128.

Bull, W.B., 1964b. Alluvial fans and near-surface subsidence in Western Fresno County, California. U.S. Geol. Surv. Prof. Paper 437-A, 71 p.

Cailleux, A., 1945. Distinction des Galets Marins et Fluviatiles. Bull. Soc. Geol. France V. 15, 375-404.

Curray, J.R., 1956. The analysis of two-dimensional orientation data. J. Geol. V. 64, 117-131.

De Kock, W.P., 1964. The geology and economic significance of the West Wits Line. 323-391: in S.H. Haughton, ed. "The Geology of Some Ore Deposits in Southern Africa" Geol. Soc. S. Afr. V. I, 625 p.

Denny, C.S., 1967. Fans and pediments. Amer. J. Sci. V. 265, 81-105.

Eynon, G. and Walker, R.G., 1974. Facies relationships in Pleistocene outwash gravels, southern Ontario: a model for bar growth in braided rivers. Sedimentology V. 21, 43-70.

Feather, C.E. and Koen, G.M., 1975. The mineralogy of the Witwatersrand reefs. Minerals Sci. Engng V. 7, no. 3, 189-224.

Folk, R.L. 1961. Petrology of sedimentary rocks. The University of Texas Geol. Hemphills, Austin, Texas, 154 p.

Friedman, G.M., 1962. On sorting, sorting coefficients and the lognormality of the grain-size distribution of sandstones. J. sediment. Pet. V. 70, 737-753.

Hallbauer, D.K., 1973. The biological nature of the carbon in some Witwatersrand Reefs and its association with gold. Chamber of Mines of S. Africa, Research Report no. 9/73, 14 p.

Hallbauer, D.K. and Joughin, N.C., 1973. The size distribution and morphology of gold particles in Witwatersrand reefs and their crushed products : J. S. Afr. Inst. Min. Metall. V. 73, 395-405.

Hallbauer, D.K. and Van Warmelo, K.T., 1974. Fossilized plants in thucholite from Precambrian rocks in the Witwatersrand, South Africa. Precambrian Res., V. 1, 199-212.

Hargraves, R.B., 1962. Cross-bedding and ripple-marking in the Main-Bird series of the Witwatersrand system in the East Rand area. Trans. geol. Soc. S. Afr. V. 65, 263-275.

Hiemstra, S.A., 1968. The mineralogy and petrology of the uraniferous conglomerate of the Dominion Reefs Mine Klerksdorp area. Trans. geol. Soc. S. Afr. V.71, 1-65.

Hodgson, F.D.I., 1967. The relationship between the sedimentology and the gold distribution of the Basal Reef Zone, Harmony Gold Mines. Unpublished M.Sc. thesis, University of the Orange Free State, 97 p.

Knowles, A.G., 1966. A paleocurrent study of the Ventersdorp Contact Reef at Western Deep Levels Limited on the far West Rand. Unpublished M.Sc. thesis, University of the Witwatersrand, 125 p.

Koen, G.M., 1961. The genetic significance of the size distribution of uraninite in Witwatersrand bankets. Trans. geol. Soc. S. Afr. V. 64, 23-54.

Krumbein, W.C., 1941. Measurement and geological significance of shape and roundness of sedimentary particles. J. sediment. Pet. V. 11, 64-72.

Krumbein, W.C., 1942. Flood deposits of Arroyo Seco, Los Angelos County, California. Bull. geol. Soc. Amer. V. 53, 1355-1402.

Krumbein, W.C. and Sloss, L.L., 1963. Stratigraphy and sedimentation. Second Edition. W.H. Freeman and Co., London, 660 p.

Lustig, L.K., 1965. Clastic sedimentation in Deep Springs Valley, California. U.S. Geol. Surv. Prof. Paper 325-F.

McKinney, J.S., 1964. Geology of the Anglo American group of mines in the Welkom area, Orange Free State Goldfield. 451-506: in S.H. Haughton, ed. "The Geology of Some Ore Deposits in South Africa." Geol. Soc. S. Afr. V. I, 625 p.

Mellor, E.T., 1913. Structural features of the Western Witwatersrand. Trans. geol. Soc. S. Afr. V. 16, 32 p.

Mellor, E.T., 1917. The geology of the Witwatersrand. Explanation of the geological map of the Witwatersrand goldfield. S. Afr. Geol. Surv., Pretoria, 42 p.

Minter, W.E.L., 1972. Sedimentology of the Vaal Reef in the Klerksdorp area. Unpublished Ph.D. thesis, University of the Witwatersrand, 170 p.

Moss, A.J., 1962. The physical nature of common sandy and pebbly deposits. Part I, Amer. J. Sci. V. 260, 337-373.

Moss. A.J., 1963. The physical nature of common sandy and pebbly deposits. Part II, Amer. J. Sci. V. 261, 297-343.

Olivier, H.J., 1963. The tectonics of the Upper Division of the Witwatersrand System in the Loraine area of the Orange Free State Goldfield. Trans. geol. Soc. S. Afr. V. 68, 143-175.

Olson, J.S. and Potter, P.E., 1954. Variance components of cross-bedding direction in some basal Pennsylvanian sandstones of the Eastern Interior basin: statistical methods. J. Geol. V. 62, 26-49.

Pegg, C.W., 1950. A contribution to the geology of the West Rand area. Trans. geol. Soc. S. Afr. V. 53, 209-227.

Pelletier, B.E., 1958. Pocono Paleocurrents in Pennsylvania and Maryland. Bull. geol. Soc. Amer. V. 69, 1033-1064.

Pettijohn, F.J., 1957. Sedimentary rocks. Second Edition. Harper and Bros., New York, 718 p.

Pettijohn, F.J., 1962. Paleocurrents and paleogeography. Bull. Amer. Ass. Petrol. Geol. V. 46, no. 8, 1468-1493.

Plumley, W.J., 1948. Black Hills terrace gravels. A study in sedimentary transport, J. Geol. V. 56, 526-577.

Potter, P.E., 1955. The petrology and origin of the Lafayette Gravel. J. Geol. V. 63, 1-38, 115-132.

Potter, P.E., 1957. Sand bodies and sedimentary environments: A review. Bull. Amer. Ass. Petrol. Geol. V. 51, no. 3, 337-365

Potter, P.E. and Pettijohn, F.J., 1963. Paleocurrents and basin analysis. Springer-Verlag, Berlin, 296 p.

Pretorius, D.A., 1964. The geology of the Central Rand Goldfield. 63 - 108. In S.H. Haughton. ed. "The Geology of Some Ore Deposits in Southern Africa." Geol. Soc. S. Afr. V. 1, 265 p.

Pretorius, D.A., 1966. Conceptual geological models in exploration for gold mineralisation in the Witwatersrand basin. In: "Symposium on mathematical statistics and computor applications in ore valuation." S. Afr. Inst. Min. Metall. 225-275

Pretorius, D.A., 1974a. The nature of the Witwatersrand gold-uranium deposits. Econ. Geol. Res. Unit, University of the Witwatersrand, Inform. Circ. no. 86, 50 p.

Pretorius, D.A., 1974b. Gold in the Proterozoic sediments of South Africa: systems, paradigms, and models. Econ. Geol. Res. Unit, University of the Witwatersrand, Inform. Circ. no. 87, 22 p.

Pretorius, D.A., 1975. The depositional environment of the Witwatersrand goldfields : a chronological review of speculations and observations. Miner. Sci. Engng V. 7, no. 1, 18-47.

Ramsay, J.G., 1961. The effects of folding upon the orientation of sedimentation structures. J. Geol. V. 169, 84-100

Reimer, T.O., 1975. The age of the Witwatersrand System and other gold-uranium places : Implications on the origin of the mineralisation. N. Jb. Miner. mh.2, 79-98.

Reineck, H.E. and Singh, I.B., 1973. Depositional Sedimentary Environment. Springer-Verlag, New York, 439 p.

Rittenhouse, G., 1943. The transportation and deposition of heavy minerals. Bull. geol. Soc. Amer. V. 54, 1725-1780.

Roering, C., 1968. The tectonics of the West Rand syncline: A field study of brittle failure in the Witwatersrand basin. Econ. Geol. Res. Unit, University of the Witwatersrand, Inform. Circ. no. 48, 28 p.

Rubey, W.W., 1933. Settling velocities of gravel, sand and silt particles. Amer. J. Sci. V. 25, 325-338.

Sceffe, H., 1959. The analysis of variance. Wiley and Sons Inc., New York, 477 p.

Schlee, J., 1957. Upland gravels of southern Maryland. Bull. geol. Soc. Amer. V. 68, 1371-1410.

Sims, J.F.M., 1969. The stratigraphy and paleocurrent history of the Upper Division of the Witwatersrand system on President Steyn mine and adjacent areas in the Orange Free State goldfield, with special reference to the origin of the auriferous reefs. Unpublished Ph.D. thesis, University of the Witwatersrand, 181 p.

Sloss, L.L., 1962. Stratigraphic models in exploration. Bull. Amer. Ass. Petrol. Geol. V. 46. no. 7, 1050-1057.

Smith, N.D., 1970. The braided stream depositional environment: Comparison of the Platte River with some Silurian clastic rocks, north-central Appalachians. Bull. geol. Soc. Amer. V. 81, 2993-3014.

Snedecor, G.W., 1965. Statistical Methods. Fifth edition. Iowa State University Press, 534 p.

Snyman, C.P., 1965. Possible biogenetic structures in Witwatersrand thucholite. Trans. geol. Soc. S. Afr. V. 68, 225 - 235.

Steyn, L.S., 1963. The sedimentology and gold distribution pattern of the Livingstone Reefs on the West Rand. Unpublished M.Sc. thesis, University of the Witwatersrand, 132 p.

Steyn, L.S., 1965. The sedimentological control of gold-uranium mineralisation in the White Reef of the West Rand Goldfield (abstract). Synopses of papers, Eighth Annual Congress, Geol. Soc. S. Afr. 19-20.

Toens, P.D. and Griffiths, G.H., 1964. The geology of the West Rand. 283-321 : in S.H. Haughton, ed. "The Geology of Some Ore Deposits in Southern Africa." Geol. Soc. S. Afr. V. I, 625 p.

Twenhofel, W.H., 1950. Principles of sedimentation. Second Edition. McGraw-Hill, New York, 673 p.

Twenhofel, W.H., 1961. Treatise on sedimentation. Second Edition. Dover Publications, New York, 926 p.

Viljoen, R.P., 1963. Petrographic and mineragraphic aspects of the Main Reef and Main Reef Leader of the Main-Bird series, Witwatersrand system. Unpublished M.Sc. thesis, University of the Witwatersrand, 193 p.

Weatherburn, C.E., 1961. A first course in mathematical statistics. Cambridge University Press, 277 p.

Winter, H.D., 1965. Trough cross-stratification in the upper division of the Witwatersrand System at Hartebeesfontein Mine, Klerksdorp. Econ. Geol. Res. Unit, University of the Witwatersrand, Unpublished report, 88 p.

APPENDIX I

PILOT STUDY - WHITE REEF CONGLOMERATE

TEXTURAL AND METAL PROPERTIES MEASURED OVER FULL WIDTH OF CONGLOMERATE

1-6, 8 and 10 Samplings : 6" wide sampling sections over conglomerate

7&9 " 12" wide sampling sections over conglomerate

Column Headings : P-Location

M-Mean size of pebbles (mm)

N-Number of pebbles measured

St.D-Standard deviation of pebble size (mm)

P.p-Pebble packing percentage

Ch-Reef channel width (inches)

Dwt-Gold, pennyweight/ton

I.Dwt-Gold, inch-pennyweight/ton

Oz-Uranium ounces/ton

I.Oz-Uranium inch-ounces/ton

Ag-Silver pennyweight/ton

S-Sulpher, weight percent of total rock

First Sampling:

P	M	N	St.D	P.p	Ch	Dwt	I.Dwt	Oz	I.Oz	Ag	S
1	10,8	50	5,0		1½"	58	145	328	820		
2	11,8	50	5,1		3"	28	110	190	760		
3	11,2	50	4,6		3"	13	42	122	488		
4	13,6	50	6,6		4"	14	70	118	708		
5	14,2	50	6,4		2½"	17	60	133	466		
6	11,3	50	5,7		2½"	98	341	758	2653		
7	12,1	50	6,2		3"	26	102	129	516		
8	11,7	50	5,5		3"	11	44	64	256		
9	12,1	50	6,1		5"	5	30	35	210		
10	12,3	50	5,3		6"	7	49	53	371		
11	11,1	50	6,1		12"	4	51	27	356		
12	12,1	50	5,2		12"	7	92	71	920		
13	12,1	50	6,1		14"	10	155	53	791		
14	12,0	50	7,4		16"	3	50	22	366		
15	12,3	50	5,4		20"	3	64	20	420		

16	13,8	50	4,8		10"	12	127	96	1056		
17	13,1	50	6,7		5"	29	174	88	528		
18	11,7	50	5,2		9½"	11	114	40	458		
19	12,8	50	5,5		8"	5	51	35	315		
20	12,1	50	5,3		10"	12	128	55	606		
21	11,0	50	5,8		10"	7	73	35	367		
22	9,4	50	4,7		12"	4	42	28	364		
23	11,7	50	4,7		8¾"	9	85	42	408		
24	8,6	50	3,6		9¼"	12	123	61	623		
25	12,3	50	5,5		11"	23	270	45	545		
26	12,5	50	5,5		13¾"	14	216	59	927		
27	11,7	50	4,9		3½"	7	38	34	153		
28	10,4	50	4,4		4"	4	20	30	200		

<u>Note</u>

N = 50 for all of first sampling
no Ag or S values for first sampling, also no P.p

Second Sampling:

P	M	N	St.D	P.p	Ch	Dwt	I.Dwt	Oz	I.Oz	Ag	S
30	16,4	11	9,3	51%	1½"	101	375	458	1145	8,0	
31	11,6	40	3,4		2½"	43	152	388	1358	11,6	
32	9,0	41	4,6	38%	2½"	14	50	82	287	2,4	
33	9,3	32	4,8	28%	2½"	24	83	176	616	5,7	
34	10,0	21	4,8	21%	2½"	11	39	81	284	2,2	
35	8,6	41	4,1	30%	2¾"	26	96	165	578	5,6	
36	8,5	81	4,0	37%	4"	15	75	108	540	3,3	
37	8,6	71	5,0	18%	7"	8	64	25	200	1,3	
38	9,1	72	4,6	21%	7"	11	84	33	264	2,7	
39	8,7	85	4,2	17%	9½"	10	110	65	678		
40	7,7	57	3,9	7%	12"	3	41	21	274		
41	8,3	103	2,2	12%	14"	7	109	48	720		
42	8,9	110	4,7	23%	10"	5	52	47	519		
43	8,0	137	3,6	17%	13"	6	84	43	603		
44	10,1	101	4,5	25%	10"	7	74	42	461		
45	7,8	107	3,7	17%	9½"	13	140	89	932		
46	8,1	144	5,4	25½%	10"	6	71	44	479		
47	8,9	86	4,5	21%	8"	8	79	49	441		
48	9,3	92	5,0	22%	9¼"	2	27	17	186		
49	10,2	86	5,0	36%	6"	16	112	86	602		
50	9,2	154	5,2	38%	9¼"	4	46	26	266		
51	8,5	112	3,9	19½%	10"	4	41	26	285		
52	8,1	140	4,6	18%	13"	8	121	45	632		
53	9,3	109	6,1	27%	9"	11	118	38	383		
54	8,6	134	4,4	26%	10"	6	65	43	478		
55	9,0	91	4,9	22%	9"	8	85	50	488		
56	9,0	27	5,7	15%	4"	23	115	78	390		
57	10,1	58	7,2	46%	4"	5	25	29	145		

Third Sampling:

P	M	N	St.D	P.p	Ch	Dwt	I.Dwt	Oz	I.Oz	Ag	S
58	13,5	15	4,5	41	1½	6	14	50	113		
59	9,7	20	4,6	18	2½	22	78	72	252		
60	11,8	35	6,1	41	3	21	85	217	868		
61	7,6	77	3,3	10	10	3	35	41	456		
62	8,4	79	4,6	11	13	7	111	52	739		
63	8,0	58	4,2	6	14	3	44	23	345		
64	9,4	81	5,2	31	13	12	178	55	773		
65	9,1	95	5,1	21	10	3	39	42	463		
66	9,2	95	5,3	27	8	10	94	41	369		
67	10,5	63	3,6	22	7	8	64	61	488		
68	9,6	40	3,9	14	6	20	146	107	749		
69	9,0	88	3,7	15	11	2	32	35	389		
70	10,0	84	5,0	20	11	7	84	38	454		
71	8,6	111	3,8	18	11	2	33	22	264		
72	9,0	79	4,0	21	7½	7	61	28	242		

Fourth Sampling:

73	9,9	30	4,8	74	1	12	26				
74	14,0	18	6,0	38	2½	27	97				
75	8,8	69	4,4	32	4	17	106				
76	10,5	70	5,1	24	8	6	59				
77					8	5	49				
78	9,9	76	4,9	19	10	5	62	36	402		
79	8,7	91	3,5	12	13½	6	87	67	977		
80	10,8	69	5,9	17	12	5	68				
81	9,5	80	5,6	16	12	4	53	37	488		
82	11,6	50	6,4	22	8	6	56	36	324		
83	8,8	98	4,1	18	10½	4	48	26	299		
84	10,1	64	5,0	25	7	13	110	64	448		
85	9,2	112	4,4	28	8½	11	106	53	504		
86	9,7	114	4,7	45	6	9	67	48	336		
87	9,4	83	4,6	31	6	9	68	62	434		
88	8,7	143	5,1	22	13	3	53	25	356		
89	8,5	119	3,9	19	11	8	103	53	633		
90	9,4	65	5,5	52	3	4	19	33	132		

Fifth Sampling:

91	10,5	26	6,8	72	1	26	59				
92	10,8	17	4,4	24	2	5	17				
93	11,4	50	4,8	56	3	69	278				
94	14,8	22	6,0	47	2	26	79				
95					3	27	111				
96	11,0	56	6,0	60	3	17	68				
97	7,8	94	3,6	17	8						
98	8,5	71	4,7	21	6½	3	25				
99	10,4	72	5,5	25	7½	3	30				
100	9,4	90	4,9	18	10	5	63				
101					10	6	71				
102	9,1	113	5,6	18	14	12	180				
103	9,4	98	4,7	20	11	3	45				
104	9,2	98	4,1	17	12	4	55				
105	10,4	73	4,9	20	9½	5	73				

P	M	N	St.D	P.p	Ch	Dwt	I.Dwt	Oz	I.Oz	Ag	S
106	9,1	78	4,3	21	7½	2	22				
107	9,2	105	4,0	22	9½	4	42				
108	10,2	88	5,1	31	7½						
109	10,7	98	5,1	26	9½	6	63				
110	9,7	128	4,5	37	8	5	46				
111	9,2	116	4,4	27	9	4	49				
112	9,8	100	5,0	22	11½	7	90				
113					15	14	231				
114					11	3	36				
115	8,8	51	4,7	20	5	5	32				

Sixth Sampling:

116	15,6	18	6,5	52	2	35	107				
117	11,4	18	5,9	38	2	26	79				
118	10,7	14	4,9	40	1	37	76				
119	12,1	29	6,2	43	2½	60	213				
120	11,8	23	4,9	25	3	38	152				
121	12,7	28	5,4	36	3	20	84				
122	8,1	103	4,8	34	5½	13	87				
123	10,8	73	5,3	26	8	8	74				
124	11,0	42	5,9	16	8	4	38				
125	10,0	39	5,0	14	6½	4	32				
126	8,9	76	4,0	18	8	2	23				
127	7,7	78	4,0	8	15	6	97				
128					10	13	146				
129	9,3	67	4,8	15	10	5	59				
130	8,7	112	5,1	23	10	8	96				
131	9,0	82	4,4	22	7½	6	52				
132	9,0	116	4,3	23	10	5	57				
133	11,0	95	6,1	35	8½	12	116				
134	9,1	106	4,4	26	8½	8	83				
135	9,0	102	4,2	27	7½	5	43				
136	8,7	146	4,4	33	8½	11	107				
137	8,6	136	5,2	23	12	5	70				
138					11	6	81				
139	8,7	76	4,1	28	5	4	28				
140					4	3	18				

Seventh Sampling:

141	11,2	20	9,3	43	1	33	66	164	328	5,4	
142					2	31	94	134	402	7,7	
143					1½	23	58	109	273	6,6	
144	14,6	29	6,1	24½	3	93	37	354	1416	18,2	
145					2	68	205	301	903	8,7	
146	11,2	51	5,8	28½	3	32	129	260	1040	8,0	
147					3						
148	9,5	141	4,9	30½	$5^{1}/_{3}$	10	63	73	456	3,0	
149					8	11	105	33	297	1,8	
150	8,6	182	4,1	18½	9	7	74	44	440	1,9	
151					12	7	97	65	905	1,7	
152	9,9	201	4,5	20	12	5	76	44	566	1,4	
153					10	19	208	89	974	2,6	
154	10,3	163	5,0	21	11	11	132	78	936	2,2	
155					10	7	87	71	710	1,7	
156	8,5	192	4,2	17	11	2	25	18	216	1,2	

P	M	N	St.D	P.p	Ch	Dwt	I.Dwt	Oz	I.Oz	Ag	S
157					8	6	60	60	480	2,4	
158	9,2	261	4,8	36	8	10	91	49	441	2,1	
159					9	8	81	54	540	2,7	
160	9,7	211	4,8	31	8	6	60	45	405	2,0	
161					7	3	26	27	216	1,0	
162					9	9	91	59	590	2,2	
163	8,4	247	3,7	20	10½	3	36	27	284	1,0	

Eighth Sampling:

164					½	22	46	113	170		
165					1	6	12	42	84		
166					2½	24	84	85	298		
167					3	21	87	77	308		
168					4	29	147	208	1040		
169					3½	22	102	158	711		
170					6	18	130	116	812		
171					7	2	22	16	128		
172					6	7	54	54	378		
173					15	7	122	40	653		
174					12	4	62	37	481		
175					13	4	57	50	702		
176					11	12	146	67	804		
177					11	14	172	89	1073		
178					16	6	114	40	680		
179					9	6	66	46	460		
180					7	7	52	46	368		
181					7	8	62	65	520		
182					6½	13	103	56	420		
183					6	13	91	63	441		

Ninth Sampling:

184	11,2	18	5,2	65	½	9	18	45	90		
185					1½	4	11	40	100		
186	12,6	17	7,2	72	½	16	32	59	118		
187					1	43	86	216	432		
188	10,5	60	4,6	28	2½	17	60	101	378		
189					2½	18	63	102	357		
190	11,8	60	5,2	40	2½	12	43	82	287		
191					5	10	62	69	414		
192	9,9	170	4,9	23	9	5	50	43	428		
193					6	5	41	39	273		
194	9,7	194	5,4	20	12	4	53	27	345		
195					11	5	62	39	468		
196	8,9	272	4,2	22	12	8	103	53	693		
197					10	8	95	58	639		
198	8,9	196	4,6	15	13½	9	139	35	509		
199					11	3	42	23	272		
200	8,0	188	3,6	13	8½	5	49	28	267		
201					7	9	72	42	334		
202	9,2	235	4,5	25	10	5	60	44	480		
203					6	12	84	61	427		
204	10,3	151	4,9	20	10	7	78	49	539		
205	10,6	163	4,8	34	8	11	100	49	441		

Tenth Sampling:

P	M	N	St.D	P.p	Ch	Dwt	I.Dwt	Oz	I.Oz	Ag	S
206					1	33	66				
207					1	24	49				
208					1	5	11				
209					1	8	17				
210					2	56	169				
211					1	17	35				
212					2¾	29	104				
213					2	28	84				
214					5	9	58				
215					10	13	151				
216					10	4	53				
217											
218					9	6	60				
219					14	6	99				
220					13	3	47				
221					14	3	47				
222					14	2	37				
223					13	4	61				
224					10	5	57				
225					11	4	49				
226					6	24	174				
227					7	9	72				
228					10	8	88				
229					9	11	111				

APPENDIX 2

CHECKS ON PILOT STUDY

TEXTURAL AND METAL PROPERTIES

Column Headings : P-Location

M-Mean size of pebbles (mm)

N-Number of pebbles measured

St.D-Standard deviation of pebble size (mm)

P.p-Pebble packing percentage

Ch-Reef channel width (inches)

Dwt-Gold, pennyweight/ton

S-Sulpher, weight percent of total rock

Oz-Uranium ounces/ton

Ag-Silver pennyweight/ton

Upcurrent - 7^{A}VW18 - West Rand Consolidated

P	M	N	St.D	P.p	Ch	Dwt	S	Oz	Ag
21	12,5	216	6,3	40	10½	26	3,4	113	2,1
22	12,1	143	6,9	32	17½	25	3,4	147	2,6
23	12,7	241	6,1	58	8½	80	3,4	140	3,5
24	11,8	205	6,1	43	9½	33	3,2	133	3,3
25	11,1	150	5,7	26	19	9	3,1	59	2,0
26	10,4	179	6,2	35	15	16	3,1	66	2,1
27	11,5	260	6,2	35	17	16	2,2	85	2,4
28	11,7	142	6,3	25	13¼	11	2,1	50	1,6
29	8,2	193	3,6	11	22	8	2,5	61	

Downcurrent - 26/0 - Randfontein Estates

31	11,2	79	3,7	21	5½	38			
32	11,2	163	4,2	34	7½	17			
33	11,2	81	5,1	35	3½	68			
34	11,9	97	5,6	30	5½	27			
35	11,1	209	4,8	34	9	24			
36	9,2	114	4,6	15	8	12			
37	11,1	134	5,0	19	11	7			
38	10,9	196	5,1	24	12	11			

APPENDIX 3

ANALYSIS OF VARIANCE - PILOT STUDY

TESTS FOR DIFFERENT METAL AND SEDIMENT POPULATIONS RELATED TO VARIABLE FLOOR TOPOGRAPHY

BASIC STATISTICS

Column Headings : A-Elevated floor, reef thicknesses 0 - 4,9"

B-Intermediate floor, reef thicknesses 5 - 9,9"

C-Low floor, reef thicknesses 10" +

N-Number of Observations (reef sections)

$\bar{X}$-Mean for Group

S-Standard deviation for group

		A	B	C
Pebble Sorting (st. dev. in mm)	N	44	56	48
	$\bar{X}$	5,5	4,8	4,6
	S	1,2	0,7	0,7
Pebble Packing (percentage)	N	33	49	40
	$\bar{X}$	41,4	25,5	18,8
	S	15,7	7,0	5,4
Pebble Size (m.m.)	N	34	49	43
	$\bar{X}$	11,4	9,5	9,0
	S	2,2	,9	,8
Gold Content (dwts/ton)	N	66	77	81
	$\bar{X}$	27,0	8,8	6,9
	S	21,6	4,7	3,9
Uranium Content (ounces/ton)	N	42	49	55
	$\bar{X}$	155,4	51,7	44,9
	S	140,0	20,9	18,3

GRAND MEANS:

Group A+B+C

Sorting 4,96 Standard deviation m.m.

Packing 27,61 percent

Size 9,82 m.m.

Gold 13,46 dwts/ton

Uranium 78,97 ounces/ton

TABLES OF ANALYSIS OF VARIANCE

Column Headings : SV-Source of variance

DF-Degrees of freedom

SS-Sum of squares between groups

MS-Sum of squares within groups

F-Calculated F ratio

A. SORTING OF PEBBLES

SV	DF	SS	MS	F
Between	2	22,00	11,00	13,89
Within	145	114,82	0,79	
Total	147	136,82		

F is significant at the one percent level ($F_{.01}$=4,60)

B. PEBBLE SIZE

SV	DF	SS	MS	F
Between	2	115,06	57,53	36,13
Within	123	195,88	1,59	
Total	125			

F is significant at the one percent level ($F_{.01}$=4,60)

C. PEBBLE PACKING

SV	DF	SS	MS	F
Between	2	9610,83	4805,42	50,49
Within	119	11325,05	95,17	
Total	121			

F is significant at the one percent level ($F_{.01}$=4,60)

D. GOLD

SV	DF	SS	MS	F
Between	2	17293,33	8646,92	57,67
Within	221	33135,79	149,94	
Total	223			

F is significant at the one percent level ($F_{.01}$=4,60)

E. URANIUM

SV	DF	SS	MS	F
Between	2	345706,96	172853,48	29,33
Within	143	842797,87	5893,69	
Total				

F is significant at the one percent level ($F_{.01}$=4,60)

APPENDIX 4

PILOT STUDY

REGRESSION ANALYSIS OF PAIRWISE RELATIONSHIPS

BASIC STATISTICS

Column Headings : N-Sample size
$\bar{x}$-Mean of x
S_x-Standard deviation of x
$\bar{y}$-Mean of y
S_y-Standard deviation of y
R-Correlation coefficient

x	y	N	$\bar{x}$	S_x	$\bar{y}$	S_y	R	
CONGLOMERATE THICKNESS	GOLD	222	7,50	4,13	13,17	15,09	0,52	A
CONGLOMERATE THICKNESS	MEAN PEBBLE DIAMETER	126	7,59	3,77	9,82	1,59	-,60	B
CONGLOMERATE THICKNESS	PEBBLE PACKING	125	7,63	3,76	27,39	13,07	-,72	C
MEAN PEBBLE DIAMETER	PEBBLE PACKING	23	10,13	1,52	29,08	14,93	,54	D
For reef thicknesses exceeding 3" only		16	9,38	,78	22,93	6,65	,49	
MEAN PEBBLE DIAMETER	STANDARD DEVIATION	23	10,15	1,52	5,07	1,20	,66	E
For reef thicknesses exceeding 3" only		16	9,39	,78	4,58	,49	,84	
PEBBLE PACKING	STANDARD DEVIATION	23	29,09	14,91	5,06	1,22	,57	F
For reef thicknesses exceeding 3" only		16	22,94	6,61	4,56	,53	,43	
MEAN PEBBLE DIAMETER	PEBBLE PACKING	196	11,58	2,43	31,77	16,14	,72	G *
MEAN PEBBLE DIAMETER	STANDARD DEVIATION	198	11,60	2,42	6,22	1,93	,91	H *
PEBBLE PACKING	STANDARD DEVIATION	196	31,77	16,14	6,21	1,95	,60	I *

* Regional study

MEAN PEBBLE DIAMETER	GOLD CONTENT	23	10,13	1,52	14,10	18,91	,77	J
For reef thicknesses exceeding 3" only		16	9,38	,80	7,02	2,82	,45	
PEBBLE PACKING	GOLD CONTENT	23	29,09	14,91	14,09	18,92	,09	K
For reef thicknesses exceeding 3" only		16	22,94	6,61	7,00	2,83	,50	
STANDARD DEVIATION	GOLD CONTENT	22	5,06	1,24	14,14	19,38	,48	L
For reef thicknesses exceeding 3" only		16	4,57	,50	6,94	2,86	,38	

FAMILY REGRESSION

FIT OF REGRESSION MODELS:

Column Headings : Model 1 - Exponential $y = ae^{bx}$

Model 2 - Power $y = a\,x^b$

Model 3 - Logarithmic $y = a + b\ln x$

L - Linear Model $y = a + bx$

P - Parabolic or Quadratic Model $y = a + bx + cx^2$

Model 1 a = Constant, b = x Coefficient, r^2 = Square of the correlation coefficient

2 a = Constant, b = Power , r^2 = "

3 a = " b = ln x Coefficient, r^2 = "

L a = Intercept, b = Slope , r^2 = "

P a = " , b = Linear Coefficient, c = Quadratic Coefficient

r^2 = Square of the multiple correlation coefficient

A. CONGLOMERATE THICKNESS/GOLD

	1	2	3	L	P
a	21,79	28,40	31,97	27,97	35,53
b	- ,12	- ,64	- 10,51	- 1,93	- 4,74
c					,19
r^2	,35	,37	,29	,27	,32
Best fit model 2. Model P plotted on figure 4(a)					

B. CONGLOMERATE THICKNESS/MEAN PEBBLE DIAMETER

	1	2	3	L	P
a	11,63	12,16	12,23	11,74	12,49
b	- ,02	- 0,12	- 1,32	- ,25	- ,55
c					,02
r^2	,37	,38	,38	,36	,39
Best fit model P plotted on figure 4(b)					

C. CONGLOMERATE THICKNESS/PEBBLE PACKING

	1	2	3	L	P
a	47,58	54,82	52,73	46,43	53,28
b	- ,09	- ,43	- 13,81	- 2,50	- 5,15
c					,19
r^2	,53	,52	,61	,51	,55
Best fit model 3. Model P plotted figure 4(c)					

D. MEAN PEBBLE DIAMETER/PEBBLE PACKING

	1	2	3	L	P
a	5,02	,36	-108,23	- 24,67	-207,31
b	,16	1,86	59,54	5,30	39,45
c					- 1,56
r^2	,34	,38	,32	,29	,41
Best fit model P plotted on figure 5(a)					

For reef thicknesses exceeding 3" only

	1	2	3	L	P
a	3,57	,35	- 64,87	- 15,88	-237,31
b	,19	1,85	39,29	4,14	51,77
c					- 2,54
r^2	,29	,30	,25	,24	,29
Best fit model 2					

E. MEAN PEBBLE DIAMETER/STANDARD DEVIATION

	1	2	3	L	P
a	1,84	,41	- 8,15	- ,21	- 10,69
b	,10	1,08	5,73	,52	2,48
c					- ,09
r^2	,53	,56	,46	,43	,49
Best fit model 2. Model P plotted on figure 5(b)					

For reef thicknesses exceeding 3" only

	1	2	3	L	P
a	1,47	,36	- 6,61	- ,39	- 23,56
b	,12	1,14	5,00	,53	5,51
c					- ,27
r^2	,73	,75	,74	,72	,82
Best fit model P					

F. PEBBLE PACKING/STANDARD DEVIATION

	1	2	3	L	P
a	3,89	1,80	- ,53	3,72	2,34
b	,01	,31	1,71	,05	,13
c					0
r^2	,35	,39	,36	,32	,37
Best fit model 2. Model P plotted figure 5(c)					

For reef thicknesses exceeding 3"

	1	2	3	L	P
a	3,76	2,42	1,86	3,77	2,05
b	,01	,20	,87	,03	,18
c					,00
r^2	,19	,21	,21	,19	,24
Best fit model P					

G. MEAN PEBBLE DIAMETER/PEBBLE PACKING

	1	2	3	L	P
a				- 23,39	- 38,28
b				4,76	7,28
c					- ,10
r^2				,52	,52
Best fit model L plotted in figure 6(a)					

H. MEAN PEBBLE DIAMETER/STANDARD DEVIATION

	1	2	3	L	P
a				- 2,24	- 1,85
b				,73	,66
c					0,00
r^2				,83	,83
Model L best fit plotted in figure 6(c)					

I. PEBBLE PACKING/STANDARD DEVIATION

	1	2	3	L	P
a				3,90	4,41
b				,07	,04
c					,00
r^2				,36	,37
Model L plotted in figure 6(b)					

J. MEAN PEBBLE DIAMETER/GOLD

	1	2	3	L	P
a	,50	,02	-26,00	- 7,84	-19,78
b	,27	2,55	14,78	1,58	4,16
c					- ,14
r^2	,21	,21	,20	,20	,20
Model 1 and 2 are best fit.					

For reef thicker than 3"

	1	2	3	L	P
a	,12	,00	-206,56	- 82,90	228,07
b	,43	4,53	95,69	9,57	- 48,66
c					2,66
r^2	,64	,62	,52	,60	,82
Best fit is model P. Model P plotted in figure 9(a)					

K. PEBBLE PACKING/GOLD CONTENT

	1	2	3	L	P
a	5,49	,71	- 6,49	10,82	- 8,85
b	,02	,79	6,29	,11	1,31
c					- ,01
r^2	,11	,16	,02	,01	,05

For reef thicker than 3" only

	1	2	3	L	P
a	2,87	,57	- 7,52	2,13	10,43
b	,03	,78	4,69	,21	- ,50
c					,01
r^2	,22	,20	,21	,25	,29
Best fit is model P plotted on figure 9(b)					

L. STANDARD DEVIATION/GOLD CONTENT

	1	2	3	L	P
a	1,00	,12	- 60,60	- 24,05	- 96,88
b	,44	2,70	46,76	7,55	32,57
c					1,99
r^2	,41	,45	,26	,23	,29
Best fit is model 2.					

For reef thicker than 3" only

	1	2	3	L	P
a	1,16	,48	- 8,24	- 2,95	- 88,34
b	,37	1,71	10,03	2,16	40,84
c					- 4,32
r^2	,14	,16	,16	,14	,28

APPENDIX 5

CHECK ON PILOT STUDY AT UPCURRENT LOCALITY

7A-VW18 STOPE

BASIC STATISTICS

Column Headings : N-Sample size

$\bar{x}$-Mean of x

S_x-Standard deviation of x

$\bar{y}$-Mean of y

S_y-Standard deviation of y

R-Correlation coefficient

x	y	N	$\bar{x}$	S_x	$\bar{y}$	S_y	R
MEAN PEBBLE DIAMETER	GOLD	9	11.38	1.39	24.89	22.34	.56
PEBBLE PACKING	GOLD	9	34.56	12.95	24,89	22.34	.86
STANDARD DEVIATION	GOLD	9	5.99	.95	24.89	22.34	.26

FAMILY REGRESSION

FIT OF REGRESSION MODELS:

Model 1 - Exponential		$y = ae^{bx}$
Model 2 - Power		$y = a\ x^b$
Model 3 - Logarithmic		$y = a + b \ln x$
Linear Model (L)		$y = a + bx$
Parabolic Model (P)		$y = a + bx + cx^2$

A. MEAN PEBBLE DIAMETER/GOLD CONTENT

	1	2	3	L	P
a	.29	.00	- 185.93	- 77.23	518.08
b	.37	3.63	86.97	8.98	- 107.53
c					5.57
r^2	.49	.46	.28	.31	.55
Best fit is model P, curve plotted on fig. 12-a					

B. PEBBLE PACKING/GOLD CONTENT

	1	2	3	L	P
a	3.11	.16	- 98.15	- 26.41	25.77
b	.05	1.38	35.50	1.48	- 1.91
c					.05
r^2	.88	.72	.50	.74	.97
Best fit is model P. Curve is plotted on fig. 12-b					

C. STANDARD DEVIATION/GOLD CONTENT

	1	2	3	L	P
a	2.11	.75	- 30.27	- 11.19	- 96.82
b	.37	1.83	31.07	6.02	41.44
c					- 3.45
r^2	.23	.23	.07	.07	.09
Best fit is models 1 and 2					

APPENDIX 6

CHECK ON PILOT STUDY AT DOWNCURRENT LOCALITY

26-0 NO. 4 SOUTH NO. 3 PANEL

BASIC STATISTICS

Column Headings : N-Sample size

$\bar{x}$-Mean of x

S_x-Standard deviation of x

$\bar{y}$-Mean of y

S_y-Standard deviation of y

R-Correlation coefficient

x	y	N	$\bar{x}$	S_x	$\bar{y}$	S_y	R
MEAN PEBBLE DIAMETER	GOLD CONTENT	8	11.03	.79	25.50	19.91	.29
PEBBLE PACKING	GOLD CONTENT	8	27.00	8.26	25.50	19.91	.51
STANDARD DEVIATION	GOLD CONTENT	8	4.80	.60	25.50	19.91	.02

FAMILY REGRESSION

FIT OF REGRESSION MODELS:

Model 1 - Exponential	$y = ae^{bx}$
Model 2 - Power	$y = a\,x^b$
Model 3 - Logarithmic	$y = a + b \ln x$
Linear Model (L)	$y = a + bx$
Parabolic Model (P)	$y = a + bx + cx^2$

A. MEAN PEBBLE DIAMETER/GOLD CONTENT

	1	2	3	L	P
a	.56	.01	- 154.63	- 54.25	- 209.75
b	.32	3.31	75.09	7.23	37.39
c					- 1.45
r^2	.12	.12	.08	.08	.08
All models have a poor fit					

B. PEBBLE PACKING/GOLD CONTENT

	1	2	3	L	P
a	4.93	.32	- 71.42	- 7.66	37.35
b	.05	1.28	29.82	1.23	- 2.52
c					.07
r^2	.34	.33	.25	.26	.28
Model 1 is best fit. Curve P is plotted on fig. 14-b					

C. STANDARD DEVIATION/GOLD CONTENT

	1	2	3	L	P
a	35.00	59.70	26.97	22.60	425.57
b	- .12	- .70	- .94	.60	- 176.18
c					19.08
r^2	.01	.02	.00	.00	.12
All models have a poor fit					

APPENDIX 7

PILOT STUDY

T-TEST TO DETERMINE WHETHER PROPERTIES AT AVERAGE REEF WIDTH COULD COME FROM A POPULATION WITH MEAN = GRAND MEAN

$$t_{n-1} = \frac{\bar{x} - \text{Grand Mean}}{S.D./\sqrt{n}}$$

where $\bar{x}$ = Mean of all observations at average width

S.D. = Standard deviation of above observations

Column Headings : Group 1 = Total observations with grand mean X

Group 2 = Samples at average reef width with mean x

n-Number of observations (Conglomerate sections in group)

S_x-Standard deviation of group

S-Mean pebble size in m.m.

P-Mean pebble packing per cent

So-Mean pebble sorting as standard deviation in m.m.

Au-Gold dwts/ton

U-Uraninite lbs/ton

T-Calculated T-value

D-Degrees of freedom

t-Tabled t value at 95% level for > 120 degrees of freedom = 1,960

	Group 1			Group 2				
	N	$\bar{X}$	S_x	N	x	S_x	T	D
S	126	9.82	1.58	6	9.52	.61	.47	130
P	125	27.40	13.07	6	25.17	3.87	.41	129
So	126	4.89	.98	6	4.62	.56	.68	130
Au	224	13.45	15.04	5	5.00	1.58	1.25	227
U	147	78.45	90.23	19	42.32	13.95	1.74	164
Conclusion : Since T<t the hypothesis of no difference between the means of the two groups is accepted								

Remarks:

Average reef width for group 1 = 7,5 inches. All reef widths for group 2 samples except U = 7,5 inches. As there are not adequate samples for U at 7,5 inches, samples were increased to include these between 7 and 8 inches.

Adjustment for unequal variances:

In view of the large differences in standard deviation between the two groups, especially for the metals, and considering also the unequality in sample numbers, it becomes necessary to adjust the degrees of freedom (D)° associated tabled t-value and the calculated T.

Da (adjusted degrees of freedom) $= 1 \Big/ \left(\dfrac{C^2}{n_1 - 1} + \dfrac{(1 - C)^2}{n_2 - 1} \right)$

where $C = \dfrac{S_1^2 / n}{\dfrac{S_1^2}{n_1} + \dfrac{S_2^2}{n_2}}$

with S_1 and S_2 = standard deviations of the two groups

n_1 and n_2 = number of observations of the two groups

Ta (adjusted calculated T-value) $= \dfrac{x_1 - x_2}{\sqrt{\dfrac{S_1^2}{n_1} + \dfrac{S_2^2}{n_2}}}$

(See Two sample T-tests with unequal variances, Welch's treatment described in Brownlee K.A. Statistical Theory and Methodology. John Wiley 1965, pp 299 - 303).

	Da	ta	Ta	Result
S	8.7	2.34	1.05	Ta < ta
P	11.8	2.20	1.14	Ta < ta
So	6.6	2.41	1.10	Ta < ta
Au	34.1	2.03	6.88	Ta > ta
U	160.3	1.96	7.96	Ta > ta
Conclusion: The hypothesis of no difference is valid for S, P and So but not for Au and U				

APPENDIX 8

REGIONAL STUDY - WHITE REEF CONGLOMERATE - TEXTURAL PROPERTIES MEASURED

Column Headings : P-Location Prefix R = Randfontein Estates, W = West Rand Cons., L = Luipaardsvlei Estates, E = East Champ D'Or.

Y-Coordinate of Longitude

X-Coordinate of Latitude

N-Number of pebbles measured

M-Mean size of all pebbles present in 6" wide vertical section of conglomerate (mm)

St.D-Standard deviation of pebble sizes (mm)

Pp-Pebble packing percentage

Ch-Channel width of White Reef (inches)

Cp-Percentage of conglomerate in White Reef

Randfontein Estates

P	Y	X	N	M	St.D	Pp	Ch	Cp
R_1			218	9,7	4,3	8	2,6	100
R_2			149	10,3	5,1	38	10	50
R_3			240	9,7	4,2	22	10	100
R_6			296	9,5	4,1	27	10	100
R_7			235	9,8	4,9	28	5	100
R_8			382	7,8	3,2	22	7	100
R_9			174	9,0	4,3	27	7	100
R_{10}			97	6,7	1,7	4	20	100
R_{11}			224	8,2	4,1	15	8	100
R_{12}			193	9,4	5,0	18	7	100
R_{13}			68	10,1	5,0	32	3	100
R_{14}			101	8,9	4,7	29	14	43
R_{15}			171	10,0	4,4	18	14	100
R_{16}			202	11,2	5,8	27	1	100
R_{17}			133	10,8	4,6	14	3½	100
R_{18}			259	10,9	5,4	32	2	100
R_{19}			229	12,2	5,7	33	3	100
R_{20}			294	11,0	4,8	36	3	100
R_{21}			247	11,3	5,0	32	3	100
R_{22}			275	10,6	5,9	25	3	100
R_{23}			337	9,7	4,6	33	6	100
R_{24}			265	11,5	5,9	48	1	100
R_{25}			279	11,6	5,5	37	3	100
R_{26}			189	9,3	4,6	16	10	100
R_{27}			307	10,8	4,7	35	16	100
R_{28}			248	8,9	3,7	19	14½	100
R_{29}			209	10,3	5,4	23	10	100
R_{30}			219	9,8	4,9	21	5	100
R_{31}			346	9,2	3,9	29	9	100
R_{32}			219	12,4	6,0	37	3	100

R_{33}			299	11,5	4,8	39	4	100
R_{34}			162	11,6	5,4	47	3	100
R_{35}			243	10,5	5,6	29	6	100
R_{37}			187	12,3	5,7	31	4	100
R_{38}			230	12,0	6,1	32	4	100
R_{39}			306	11,4	5,1	40	2	100
R_{44}			266	8,8	4,2	22	10	100
R_{45}			324	10,0	4,6	32	7	100
R_{48}			319	10,1	4,8	32	10	100
R_{49}			345	9,2	4,5	29	7½	100
R_{51}			309	8,4	3,9	22	8	100
R_{52}			339	10,0	4,9	33	5	100
R_{53}			197	9,4	4,7	18	6	100
R_{54}			182	10,6	5,8	22	18	100
R_{55}			214	9,3	3,7	18	16	100
R_{56}			204	8,8	5,5	15	30	100
R_{57}			162	8,3	3,5	7	35	55
R_{58}			145	9,2	4,8	13	4	100
R_{59}			194	9,6	4,5	20	3	100
R_{60}			224	9,2	4,1	17	10	60
R_{61}			139	8,4	3,2	9	6	64
R_{62}			220	10,0	4,3	26	3	100
R_{63}			253	8,0	3,5	16	8	100
R_{64}			416	10,8	5,0	51	2	100
R_{65}			168	8,8	5,0	14	12	100
R_{66}			97	7,5	2,8	5	12	100
R_{67}			242	10,9	5,2	31	3	100
R_{68}			267	10,8	5,3	32	3	100
R_{69}			369	10,3	5,2	42	6	100
R_{70}			285	9,8	4,9	30	16	100

West Rand Consolidated

P	Y	X	N	M	St.D	Pp	Ch	Cp
W_{1}			375	12,1	5,7	57	$1\frac{3}{4}$	100
W_{3}			272	11,9	5,3	39	$4^{1}/_{3}$	100
W_{4}			226	13,0	5,8	38	2	100
W_{5}			220	10,1	4,7	22	4	100
W_{6}			306	11,0	5,1	38	7	100
W_{10}			220	10,6	5,3	25		100
W_{12}			359	9,5	4,7	34	6	100
W_{13}			215	9,5	4,1	27	14	100
W_{15}			140	8,7	4,2	17	15	100
W_{17}			209	11,7	5,1	25	7	100
W_{21}			86	9,9	4,2	38	$3\frac{1}{2}$	100
W_{19}			133	10,2	3,3	11		
W_{23}			230	11,1	4,5			
W_{25}			120	12,5	6,6			
W_{28}			332	8,8	3,8	26	21	100
W_{29}			231	11,1	5,8	30	11	100
W_{30}			341	8,9	4,0	27	6	
W_{31}			123	13,5	9,0	27	16	100
W_{35}			265	12,0	7,1	29	36	100
W_{37}			150	8,8	4,3	6	44	100
W_{42}			425	8,2	3,7	28	5	100
W44			144	12,2	8,0	23	22	100
W_{47}			300	8,1	3,8	10	22	
W_{54}			207	8,9	4,9	12	36	100
W_{57}			206	9,4	4,4	11	42	100
W_{59}			399	9,4	4,4	16	62	100
W_{66}			276	10,3	5,2	24	24	100
W_{63}			380	9,0	4,8	17	$38\frac{1}{2}$	100
W_{60}			352	8,2	3,8	11	33	100
W_{67}			358	10,3	6,0	18	20	100
W_{68}			298	9,7	4,4	31		
W_{69}			182	12,4	7,2	17	40	
W_{72}			154	14,6	9,9	28	26	100
W_{74}			236	14,3	8,5	31	42	
W_{76}			178	10,2	6,3	21	24	100
W_{77}			248	10,8	6,9	11	60	
W_{80}			267	9,6	5,4	10	$32\frac{1}{2}$	100
W_{81}			101	9,7	5,7	6	44	
W_{82}			230	12,6	9,8	15	52	
W_{83}			398	9,9	5,5	19	43	
W_{86}			284	9,5	5,5	11	62	
W_{89}			207	10,5	6,0	17	28	
W_{90}			433	9,3	4,7	20	47	
W_{95}			259	9,0	3,9	16	32	
W_{96}			355	11,4	6,6	46	$13\frac{1}{2}$	
W_{97}			401	9,3	4,6	20	43	
W_{98}			277	12,4	7,2	48	8	
W_{99}			210	11,4	7,9	34	16	
W_{100}			334	12,9	6,3	42	31	
W_{101}			141	11,5	5,8	37	9	
W_{102}			223	12,4	8,0	56	12	
W_{103}			167	12,6	7,1	29	12	
W_{104}			296	12,3	7,9	53	3	
W_{105}			301	10,6	6,3	33	40	
W_{107}			262	10,7	6,2	25	69	
W_{108}			137	9,0	5,1	12	16	
W_{109}			187	9,9	7,4	18	24	

W_{113}			393	10,6	5,7	42	23	
W_{114}			116	8,7	4,5	16	14	
W_{117}			331	8,6	5,2	12	43	
W_{119}			271	11,3	6,4	30	27	
W_{121}			323	10,0	5,5	42	20	
W_{122}			219	9,0	4,1	9	36	
W_{126}			304	10,0	5,6	11	67	
W_{127}			315	12,8	6,8	27	36	
W_{128}			150	9,5	4,6	11	31	
W_{129}			36	10,8	5,2	35	3	
W_{130}			261	12,3	7,2	54	17	
W_{132}			546	12,8	7,8	46	99	
W_{133}			255	9,3	5,8	18	34	
W_{134}			220	11,5	7,0	27	40	
W_{135}			148	10,1	6,3	4	78	
W_{136}			132	12,0	6,3	43	6	
W_{139}			198	10,7	4,8	44	6	
W_{140}			239	12,2	5,7	36	3	

Luipaardsvlei Estates

P	Y	X	N	M	St.D	Pp	Ch	Cp
L_1			128	14,9	8,9	19	24	100
L_2			242	13,2	7,6	42	26	100
L_4			490	11,4	4,6	27	60	100
L_5			267	11,8	5,2	36	27	80
L_6			193	14,8	8,5	46	18	100
L_8			180	18,6	12,7	76	23	100
L_{10}			248	15,5	9,1	63	15	100
L_{12}			261	13,3	7,7	51	35	
L_{13}			231	14,0	7,0	47	21	100
L_{14}			257	15,0	7,7	30	50	100
L_{15}			185	14,7	9,3	38	45	50
L_{16}			206	16,4	7,7	57	22	
L_{17}			241	16,7	10,2	78	12	100
L_{18}			168	19,7	11,9	74	4	100
L_{19}			249	13,7	7,9	51	30	
L_{20}			90	14,9	9,8	24	25	100
L_{23}			243	14,9	8,9	62	14	100
L_{24}			148	15,1	9,4	40	11	100
L_{25}			238	14,9	8,9	60	14½	100
L_{26}			225	13,7	7,7	44	24	100
L_{27}			127	9,8	5,7	19	28	
L_{28}			353	13,5	8,3	56	32	100
L_{29}			246	13,2	8,7	38	80	
L_{31}			236	12,8	8,4	26	40	
L_{32}			308	14,2	8,5	47	36	100
L_{33}			206	13,6	7,3	41	24	100
L_{34}			417	12,4	7,7	60	35	
L_{35}			201	10,2	7,0	14	52	
L_{36}			141	13,6	6,9	14	50	100
L_{37}			547	12,7	6,5	43	55	100
L_{38}			169	15,1	8,9	29	36	100
L_{39}			121	15,6	10,7	36	18	100
L_{40}			212	12,9	6,9	38	13	100
L_{41}			137	15,9	9,6	40	9	100
L_{42}			293	13,1	6,1	55	9	100
L_{43}			325	14,1	7,4	70	17	100
L_{44}			225	15,7	9,2	45	33	100
L_{45}			167	16,7	9,5	52	8	100
L_{46}			214	16,6	9,0	65	9	100
L_{48}			322	14,3	7,6	71	24	100
L_{49}			202	16,7	9,5	61	18	100
L_{50}			331	15,2	8,7	49	42	100
L_{51}			255	13,1	7,3	37	31	100
L_{52}			277	14,7	8,3	66	20	100
L_{53}			182	12,8	6,6	49	24	
L_{54}			275	10,7	6,1	20	42	100
L_{56}			124	13,5	8,2	24	26	100
L_{57}			222	14,4	9,2	53	18	100
L_{58}			145	14,4	8,5	26	31	100
L_{61}			217	12,6	7,6	38	21	100
L_{62}			243	11,7	6,2	20	40	100
L_{63}			172	15,8	8,2	40		100

East Champ D'Or

P	Y	X	N	M	St.D	Pp	Ch	Cp
E_1			399	17,8	11,0	44	64	100
E_4			556	15,7	9,0	42	87	100
E_5			295	14,3	8,0	17	40	75
E_6			197	13,5	7,1	14	33	100
E_7			164	13,9	8,9	29	30	54
E_8			280	15,0	8,7	64	51	45
E_9			310	15,3	8,2	46	33	100
E_{10}			243	14,1	8,9	59	35	78
E_{11}			257	14,7	8,0	66	11	100
E_{12}			512	13,9	7,9	55	47	100

APPENDIX 9

THE WHITE REEF FOOTWALL PALEOCURRENT SYSTEM

MOVING-AVERAGES OF DIP AZIMUTHS OF CROSSBEDS MEASURED WITHIN A DISTANCE OF 5 FT BELOW THE WHITE REEF

(EACH AVERAGE REPRESENTS AN AREA OF 4000 SQUARE FEET)

Column Headings : Y-Coordinate of Longitude in ft.

X-Coordinate of Latitude in ft.

n-Number of crossbedded units, each with a minimum of 3 measurements per unit

$\bar{X}_V$-Vectoral Mean Azimuth in degrees from T.N.

R-Vectoral Magnitude as a percentage of the Consistency Ratio

Y	X	n	$\bar{X}_V$	R
15000	26000	2	180	85
16000	26000	2	188	94
17000	26000	2	168	99
19000	26000	3	220	90
	27000	3	148	89
	28000	4	150	91
	29000	2	175	97
	30000	3	154	98
20000	25000	3	211	77
	26000	4	223	80
	27000	6	146	93
	28000	6	140	94
	30000	2	148	96
	31000	3	137	81
21000	26000	3	145	96
	27000	4	138	96
	28000	4	158	89
	31000	2	135	90
22000	26000	2	135	97
	28000	2	197	98
	31000	2	182	97
23000	26000	2	155	80
	30000	3	215	98
	31000	4	201	92
24000	26000	4	161	91
	30000	2	220	98
	31000	3	201	90
25000	26000	3	168	99
	32000	2	118	94
26000	30000	2	148	100
	31000	2	152	77
	32000	5	139	85

27000	30000	3	146	100
	31000	4	168	90
	32000	5	159	87
28000	29000	2	158	95
	30000	2	152	99
	31000	3	160	93
29000	29000	3	154	94
	30000	3	149	97
30000	33000	3	190	83
31000	29000	4	188	85
	30000	2	205	90
	31000	3	181	82
	32000	3	163	75
32000	31000	2	165	90
33000	31000	2	143	68
34000	31000	5	155	80
35000	26000	2	188	99
	31000	5	189	85
36000	28000	2	150	99
	29000	5	140	84
	30000	4	152	61
37000	27000	3	189	92
	28000	2	187	87
	30000	3	128	78
38000	22000	7	199	97
	27000	4	235	94
	28000	7	187	69
39000	15000	4	198	87
	16000	5	166	87
	22000	8	207	93
	27000	4	234	95
	28000	7	208	77
40000	15000	7	195	89
	16000	4	205	98
	17000	5	196	85
	18000	3	150	78
	19000	4	142	79
	23000	9	212	68
	24000	11	203	90
	25000	10	187	87
	26000	6	175	41
41000	13000	5	134	98
	14000	8	168	85
	15000	7	174	74
	16000	5	185	65
	17000	5	195	81
41000	18000	5	177	75
	19000	3	166	90
	22000	4	195	92
	23000	9	210	90
	24000	10	212	87
	25000	5	208	80
42000	13000	11	160	87
	14000	9	175	86
	15000	6	169	68
	16000	7	159	75
	17000	4	191	81
	21000	7	195	68
	22000	9	199	73
43000	13000	12	182	92
	14000	8	180	91
45000	11000	2	180	98

APPENDIX 10

THE WHITE REEF PALEOCURRENT SYSTEM

MOVING-AVERAGES OF DIP AZIMUTHS OF CROSSBEDS

(EACH AVERAGE REPRESENTS AN AREA OF 4000 SQUARE FEET)

Column Headings : Y-Coordinate of Longitude in ft.

X-Coordinate of Latitude in ft.

n-Number of crossbedded units, each with a minimum of 3 measurements per unit

$\bar{X}_V$-Vectoral Mean Azimuth in degrees from T.N.

R-Vectoral Magnitude as a percentage of the Consistency Ratio

Y	X	n	$\bar{X}_V$	R
15000	26000	3	153	88
16000	26000	5	160	92
	27000	3	131	98
17000	26000	4	153	94
	27000	5	145	92
18000	26000	3	155	92
	27000	5	158	92
19000	26000	3	158	91
	27000	2	153	87
22000	28000	2	183	98
	31000	2	158	98
23000	31000	2	158	100
24000	28000	2	193	92
24000	31000	2	180	96
	32000	2	200	99
25000	31000	3	178	90
	32000	4	167	82
26000	31000	2	165	90
	32000	2	130	97
29000	32000	3	149	87
30000	33000	3	149	87
31000	29000	5	202	76
32000	31000	4	237	55
33000	31000	6	215	63
34000	22000	2	198	95
	31000	5	215	72
35000	31000	5	223	95
36000	28000	9	215	93
	29000	11	216	94
	30000	7	219	93
	31000	7	220	97
	32000	7	206	90
37000	27000	7	184	77

	28000	10	215	92
	29000	8	213	93
	30000	4	230	95
	31000	7	226	97
	32000	6	205	88
38000	22000	2	206	99
	31000	3	214	85
39000	16000	4	134	86
40000	20000	3	164	90
42000	13000	3	141	93
43000	13000	2	163	98

APPENDIX 11

THE WHITE REEF HANGINGWALL PALEOCURRENT SYSTEM

MOVING-AVERAGES OF DIP AZIMUTHS OF CROSSBEDS MEASURED WITHIN A DISTANCE OF 5 FT ABOVE THE WHITE REEF

(EACH AVERAGE REPRESENTS AN AREA OF 4000 SQUARE FEET)

Column Headings : Y-Coordinate of Longitude in ft.

X-Coordinate of Latitude in ft.

n-Number of crossbedded units, each with a minimum of 3 measurements per unit

$\bar{X}_V$-Vectoral Mean Azimuth in degrees from T.N.

R-Vectoral Magnitude as a percentage of the Consistency Ratio

Y	X	n	$\bar{X}_V$	R
15000	26000	4	164	95
16000	26000	8	175	97
	27000	4	167	97
17000	26000	6	177	98
	27000	5	175	98
18000	26000	5	175	98
	27000	5	178	98
19000	26000	4	180	97
	27000	5	181	96
	28000	3	161	95
	29000	3	145	97
	30000	3	146	97
20000	26000	3	176	98
	27000	4	178	99
	28000	2	158	93
	30000	2	150	98
	31000	2	150	98
21000	26000	4	157	96
	27000	3	168	99
	28000	2	150	98
21000	30000	2	149	99
	31000	2	145	99
22000	26000	5	174	88
	28000	2	165	98
	30000	2	149	98
	31000	3	145	98
23000	26000	4	187	97
	28000	2	183	85
24000	26000	4	172	96
	31000	2	186	99
25000	26000	4	163	74
	30000	4	195	95
	31000	5	197	98

	32000	2	200	98
26000	25000	4	189	81
	30000	4	196	94
	31000	4	206	99
	32000	2	197	98
27000	25000	4	193	90
	30000	4	190	92
	31000	2	192	99
	32000	2	150	72
28000	30000	3	139	87
	31000	3	140	87
29000	31000	3	150	75
	32000	3	227	94
30000	33000	2	214	98
31000	29000	3	188	91
32000	31000	6	180	63
33000	31000	10	187	82
34000	22000	2	155	98
34000	28000	4	151	98
34000	31000	10	185	69
35000	31000	4	140	69
36000	28000	10	210	87
	29000	7	185	64
	30000	2	128	73
	31000	2	171	80
	32000	4	167	90
37000	27000	6	209	97
	28000	12	220	91
	29000	8	200	87
	30000	3	177	98
	31000	2	178	99
	32000	2	162	98
38000	22000	23	199	88
	28000	5	192	93
	31000	2	179	100
	21000	9	216	90
	22000	20	205	88
	27000	2	220	98
40000	15000	2	160	85
	17000	5	180	86
	18000	7	158	76
	19000	10	131	71
	22000	5	200	91
	24000	13	220	98
	25000	15	223	94
	26000	5	221	83
41000	14000	2	88	54
	15000	3	52	57
	23000	10	220	90
	24000	21	222	92
	25000	15	227	92
42000	14000	2	66	80
	15000	5	50	55
43000	14000	2	80	85

APPENDIX 12

PEBBLE FABRIC ON TWO-DIMENSIONAL EXPOSURES, LUIPAARDSVLEI FACIES

Exposure Parallel to paleo-current	Localities				Exposure Parallel to paleo-strike	Localities			
	D_{25}	D_{27}	G_{28}	I_{20}		D_{25}	D_{27}	G_{28}	I_{20}
Paleo-current direction	145°	140°	170°	185°	Paleo-strike direction	55°	50°	80°	95°
Exposure direction	125°	125°	125°	225°	Exposure direction	55°	50°	50°	100°
Flat pebbles (p.c.)	0	8	8	3	Flat pebbles (p.c.)	6	10	10	0
Dipping up-current (p.c.)	66	70	70	65	Dipping west (p.c.)	54	42	42	55
Dipping down-current (p.c.)	34	22	22	32	Dipping east (p.c.)	40	42	48	45
Av. dip, up-current	24°	16°	15°	11°	Av. dip, west	7°	11°	11°	15°
Av. dip, down-current	16°	22°	22°	13°	Av. dip, east	9°	15°	15°	19°

APPENDIX 13

PEBBLE FABRIC ON TWO-DIMENSIONAL EXPOSURES, WEST RAND FACIES

Exposure Parallel to paleo-current	Localities				Exposure Parallel to paleo-strike	Localities			
	B_{10}	D_{11}	D_{13}	G_{10}		B_{10}	D_{11}	D_{13}	G_{10}
Paleo-current direction	200°	200°	190°	200°	Paleo-strike direction	110°	110°	100°	110°
Exposure direction	215°	170°	180°	210°	Exposure direction	100°	80°	90°	120°
Flat pebbles (p.c.)	10	6	2	12	Flat pebbles (p.c.)	24	22	26	34
Dipping up-current	20	38	20	26	Dipping west (p.c.)	50	36	38	26
Dipping down-current	70	56	78	62	Dipping east (p.c.)	26	42	36	40
Av. dip, up-current	12°	11°	10°	14°	Av. dip, west	9°	7°	11°	8°
Av. dip, down-current	13°	13°	14°	17°	Av. dip, east	9°	11°	8°	18°

APPENDIX 14

PEBBLE FABRIC ON TWO-DIMENSIONAL EXPOSURES, RANDFONTEIN FACIES

Exposure Parallel to paleo-current	Localities				Exposure Parallel to paleo-strike	Localities			
	J_7	K_5	M_8	S_6		J_7	K_5	M_8	S_6
Paleo-current direction	210°	220°	200°	170°	Paleo-strike direction	120°	130°	110°	80°
Exposure direction	220°	225°	150°	200°	Exposure direction	115°	144°	80°	90°
Flat pebbles (p.c.)	10	26	18	10	Flat pebbles (p.c.)	20	20	44	48
Dipping up-current (p.c.)	45	52	44	74	Dipping west (p.c.)	43	28	30	28
Dipping down-current (p.c.)	45	22	38	16	Dipping east (p.c.)	37	52	32	24
Av. dip, up-current	18°	25°	17°	21°	Av. dip, west	17°	5°	15°	12°
Av. dip, down-current	12°	12°	13°	14°	Av. dip, east	14°	8°	14°	9°

APPENDIX 15

PEBBLE SHAPE AND SPHERICITIES AT OUTCROPS OF THE WHITE REEF ON THE WEST RAND

Locality	Pebble-size Range	Pebble Shapes (per cent)				Average Sphericity	No. of pebbles Measured
		Disc	Spheroid	Blade	Roller		
B_{10}	32-64mm	31	50	2	17	0,74	62
B_{15}		25	6	25	44	0,59	16
C_{26}		28	65	3	4	0,74	53
B_{10}	16-32mm	27	54	3	16	0,77	84
B_{15}		43	32	6	19	0,72	180
C_{26}		26	67	3	4	0,79	67

APPENDIX 16

Pairwise relationships between and within the four sedimentological measures (mean Pebble diameter, standard deviation of Pebble diameter, Pebble Packing and channel width) and the yields of gold, silver and uranium were studied by means of bivariate linear regression. In cases where the relationships were not linear, the regressions were fitted to log transformations of the variables.

The model is of the form:

$$y = a + bx + e$$

where y is the dependent variable

x is the predictor variable

and e is the error which is assumed to be distributed independently of x, with constant variance.

a and b are the parameters which are estimated by the least squares method.

In each case the data was checked for linearity and homoscedasticity (constancy of variance) before fitting the model.

Most of the regressions were fitted from the regional data, because of the greater number of observations involved. However, in five cases regressions were also fitted to the pilot study area.

Results:

Variable	Notation
Mean Pebble diameter	1
Standard Deviation of Pebble diameter	2
Density of Pebble Packing	3
Channel Width	4
Gold in dwts/ton	5
Uranium in oz/ton	6
Silver in dwts/ton	7

Variables x	Variables y	No. of Observations	Correlation Coefficient	a	b	Standard deviation of error	Comments	95% confidence interv for correlation coeff cient
1	3	23	.545	-24.512	5.281	12.078		(.171, .782)
1	2	23	.651	- 0.167	0.516	0.897		(.327, .838)
3	2	23	.574	3.695	0.047	0.966		(.212, .797)
Log (5)	Log (7)	29	.919	- 0.749	0.725	0.279		(.833, .961)
Log (5)	Log (7)	17	.703	- 0.144	0.412	0.200	values not considered when reef thickness ≤ 3"	(.336, .884)

Regional Data x	Regional Data y	No. of Observations	Correlation Coefficient	a	b	Standard deviation of error	Comments	95% confidence interv for correlation coeff cient
1	3	212	.720	-24.066	4.826	10.948		(.648, .779)
1	2	213	.911	- 2.313	0.732	0.777		(.885, .931)
3	2	211	.605	3.848	0.072	1.507		(.512, .684)
Log (4)	3	96	-.538	52.625	-13.807	6.396		(-.666, -.378)
Log (4)	1	96	-.188	10.383	- 0.532	0.824		(-.374, +.013)
Log (4)	5	168	-.358	19.087	- 5.189	4.654		(-.483, -.218)
Log (4)	Log (5)	168	-.306	3.013	- 0.521	0.558		(-.437, -.162)
Log (5)	Log (6)	113	.699	2.537	0.678	0.410	values not considered when reef thickness ≤ 3"	(.590, .783)

Statistical Analysis by D.M. Hawkins and P.L. Fatti, June, 1971.

APPENDIX 17

MATRIX ANALYSIS, STEPWISE REGRESSION AND PREDICTION

PILOT AND FOLLOW-UP STUDIES

A matrix analysis and stepwise regression routine was done on the data of the pilot study in order to determine the relative strengths of correlations established between sedimentary and metal properties of the conglomerate. The mathematic relationship derived was then applied in gold value prediction at both the pilot study and upslope check localities.

Attributes involved:

Metals:	Gold	(dwts/ton)
	Uranium	(lbs/ton)
Sediment properties:	Mean diameter	(mm)
	Standard deviation	(mm)
	Packing	(%)
	Reef Width	(inches)

RESULTS

1. Correlation Matrix

	Peb.diam	St.dev.	Peb.pack	Rf.width	Gold	Uranium
Peb.diam	1.0000	0.6645	0.3706	-0.5966	0.4056	0.4760
St.dev.	0.6645	1.0000	0.3489	-0.4526	0.2996	0.3307
Peb.pack	0.3706	0.3489	1.0000	-0.5881	0.7402	0.7097
Rf.width	-0.5966	-0.4526	-0.5881	1.0000	-0.4268	-0.4780
Gold	0.4056	0.2996	0.7402	-0.4268	1.0000	0.9615
Uranium	0.4760	0.3307	0.7097	-0.4780	0.9615	1.0000

2. Stepwise Regression

(i) The variable dependant is Gold
Pebble packing enters the regression
The multiple correlation is 0.7402
Pebble diameter enters the regression
The multiple correlation is 0.7536
Reef width enters the regression
The multiple correlation is 0.7596
Standard deviation enters the regression
The multiple correlation is 0.7613

(ii) /2...

(ii) Conclusion: The correlation is stabilised by the pebble packing and pebble diameter parameters being responsible for 0.7536.

(iii) Standard deviation leaves the regression
The multiple correlation becomes 0.7595
Reef width leaves the regression
The multiple correlation becomes 0.7536
Variables left in the regression are
Pebble diameter (x_1) and Pebble packing (x_2)
Locally stable sub-regression:-

$$\text{Constant} = \bar{y} - B_1 \bar{x}_1 - B_3 \bar{x}_2$$

$$= 13.9014 - (2.32798 \times 9.8006) - (0.86630 \times 28.4913)$$

$$= - 33.5962$$

Regression equation:

$$Y \text{ (gold)} = - 33.5962 + 2.32798X_1 + 0.86630X_2$$

note : The above equation could be used for the prediction of gold and uranium values which are related to the extend of 0.9615

3. Prediction of gold content utilising pebble packing and size

(i) Pilot Study Area

The above formula can be applied to predict the gold content of samples taken for the pilot study.

Observed Gold dwts/ton (X)	Predicted Gold dwts/ton (Y)
101	48
14	20
24	12
11	7
26	12
15	18
8	2
11	5
10	1
3	-9
7	-3
5	7
6	0
7	11
13	0
7	7
9	5

3/...

Observed Gold dwts/ton (X)	Predicted Gold dwts/ton (Y)
3	7
16	21
4	20
4	3
8	0
11	11
6	8
8	6
23	0
5	29
6	33
220	144
21	29
3	-7
7	-4
3	-9
12	15
3	5
10	11
8	9
20	0
2	0
7	7
7	5
12	53
27	31
17	14
6	11
5	5
6	-2
5	6
4	2
6	12
4	2
13	11
11	12
9	27
9	15
3	5
8	2
4	33
26	53
5	12
69	41
26	41
17	43
3	4
3	12
5	3
12	3
3	5
4	2
5	7
2	5

/4...

Observed Gold dwts/ton (X)	Predicted Gold dwts/ton (Y)
4	6
6	13
5	21
4	11
7	8
5	4
35	47
26	25
37	25
60	31
38	15
20	27
13	14
8	14
4	5
4	1
2	2
6	−8
5	1
8	6
6	6
5	7
12	22
8	10
5	10
11	15
5	6
4	10
33	29
93	21
32	16
10	14
7	2
5	6
11	8
2	0
10	19
6	15
3	3
9	48
16	58
17	15
12	28
5	9
4	6
8	6
9	0
5	−3
5	9
7	7
11	20

/5...

Basic statistics (pairwise analysis)

Average $\bar{x}$ = 14.62 dwt/ton, standard deviation 25.11
Average $\bar{y}$ = 15.56 " " " " 18.06

CORRELATION COEFFICIENT = 0.76

Nature of correlation as determined by family regression:-

Best fit (parabolic) $y = a + bx + cx^2$

with $a = 8.78$

$b = .41$

$c = 0.0$

Degree of fit = 0.60

(ii) Check on Pilot Study (7AVW18 West Rand Consolidated)

Observed gold dwts/ton	Predicted gold dwts/ton
26	30
25	22
80	46
33	31
9	14
16	20
16	23
11	15
8	− 4
38	10
17	22
68	22
27	20
24	21
12	0
7	8
11	12

Basic statistics of above.
Average Gold observed 26.25 dwts/ton, standard deviation 20.74
Average Gold predicted 20.30 dwts/ton, " " 10.38

CORRELATION COEFFICIENT = 0.67

CONCLUSION: The prediction is correct to the extend of 67 per cent, which indicates 12 per cent loss in prediction accuracy over a distance of 1700 feet from the pilot study area.

APPENDIX 18

RELATIONSHIP OF LARGER PEBBLES AND GOLD

7AVW18 LOCALITY, WEST RAND CONSOLIDATED

Gold content, dwts/ton (x)	Percentage of pebbles larger than 12 mm (y)
101	68
93	73
69	47
61	35
43	50
38	19
33	57
28	64
26	55
26	57
26	38
22	30
6	24
5	15
5	34
4	31
3	20
2	23

Basic statistics - Pairwise analysis

number	: N	=	18		
means	: $\bar{x}$	=	32.83, $\bar{y}$	=	41.11
standard deviation	: $\Delta 1$	=	30.41, $\Delta 2$	=	18.21
correlation coefficient	: R	=	0.69		

CONCLUSION: The correlation increases to 0.69 (from 0.56) when percentages of pebbles larger than 12 mm are substituted for mean pebble sizes (see appendix 5, fig. 11 and table 14).

APPENDIX 19

WHITE REEF

VARIANCE ANALYSIS OF PEBBLE SIZES

(a) Statistics:

Facies	Luipaardsvlei	West Rand	Randfontein
No.of stations.	62	75	60
Grand mean (mm)	14,30	10,66	9,94
St.deviation (mm)	1,83	1,53	1,24

(b) Analysis of variance, West Rand and Randfontein facies:

Source	df	SS	MS	F
Between	1,00	17,59	17,59	8,83
Within	133,00	264,91	1,99	-
Total	134,00	282,50	-	-

(c) CONCLUSION : At the 95% level with 1 and 133 degrees of freedom the F-table value is 4,35. Since the calculated F value is 8,83 it is concluded that there is a significant difference between the means of the two groups.

APPENDIX 20

WHITE REEF

VARIANCE ANALYSIS OF PEBBLE SPHERICITIES AT THE C26 LOCALITY

(a)

Statistics	+32mm size class	-32mm size class
No. of measurements	53	67
Mean	0,74	0,79
St. deviation	0,06	0,09

(b) Analysis of variance

Source	df	SS	MS	F
Between	1	,06	,06	11,26
Within	121	,69	,01	
Total	122	,75		

(c) CONCLUSION : From a table of F values with 1 and 121 degrees of freedom the F value is 4,35 at the 95% confidence level. With the calculated F value at 11,26 there is a significant difference between the means of the two groups.

APPENDIX 21

VARIANCE ANALYSIS OF PEBBLE SPHERICITIES OF THE WHITE REEF AT THE B_{10} AND C_{26} LOCALITIES

Minus 32 mm size class:-

Statistics	B10	C26
no. of measurements	84	67
average value	,77	,79
st. deviation	,08	,09

Degrees of freedom (between	1
(within)	149
F value	2,93

Conclusion: There is no significant difference between the means of the groups with the table value for F = 4,35

APPENDIX 22

PAIRED T-TEST

Relationship between pebble lithology and gold mineralisation (data of table 15)

Facies	r	D.F.	T.P.	t	C
Luipaardsvlei	,06	3	-1 76	3,18	No
West Rand	,41	3	-12 71	3,18	Yes
Randfontein	93	5	-3 99	2 57	Yes

r = correlation coefficient

D.F. = degrees of freedom

T.P. = T-paired value, calculated

t = 95% t-table value for the related degrees of freedom**

C = significance of correlation

** Hewlett-Packard 9805A statistics calculator, expanded stat. operating guide (table p. 59).

APPENDIX 23

WHITE REEF

PAIRED T-TEST BETWEEN URANIUM AND PEBBLE TYPE

(DATA OF TABLE 16)

FACIES	r	D.F.	T.P.	t	C
Luipaardsvlei	0,34	3	3,73	3,18	Yes
West Rand	0,68	3	-4,69	3,18	Yes
Randfontein	0,97	5	-4,33	2,57	Yes

r = correlation coefficient

D.F. = degrees of freedom

T.P. = t-paired value, calculated

t. = 95% t-table value for the related degrees of freedom.

C. = Significance of correlation. T.P.> t indicates a positive correlation.