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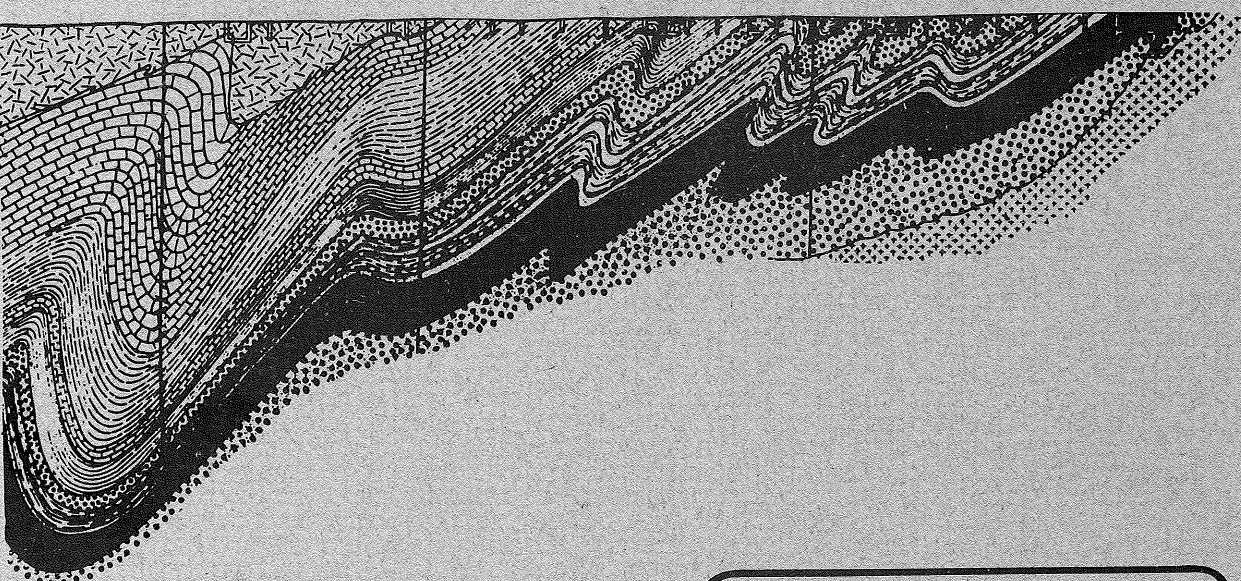

ECONOMIC GEOLOGY

RESEARCH UNIT

UNIVERSITY OF THE WITWATERSRAND
JOHANNESBURG

THE GEOLOGY OF THE CENTRAL RAND GOLDFIELD

by

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THE GEOLOGY OF THE CENTRAL RAND GOLDFIELD

ABSTRACT

This account of the geological setting of the gold mines of the Central Rand represents a compilation and collation of previously published data. It constitutes a summary of the version of the geology which has received general acceptance over the years. The historical background of the discovery and development of the Central Rand between the years 1852 and 1890 is presented. A general review covers the nature of all geological formations encountered in the area as a whole, and this is followed by a description of the particular reefs worked in the various mines, the relative economic importance of each reef, the mineralogy of the reefs, and the distribution pattern of the gold in relation to pebble size, reef widths, mineral assemblages and sedimentary features. In the final section data are given concerning tonnages of ore treated, amounts of gold recovered, and average grades of ore worked.

The Central Rand is contained within a distance of 29 miles in a west-east direction from the Roodepoort Fault, through Johannesburg, to the Boksburg Gap. At the end of 1962, ten major deep-level mines and twelve small outcrop mines were working. Two other deep-level mines are located within the geographic confines of the area, but, because of significant differences in geology, have not been considered as typical members of the Central Rand group of mines.

The total thickness of the Swaziland System in the Central Rand area is 700 feet, of the Old Granite an unknown figure, of the Witwatersrand System 24,300 feet, of the Ventersdorp System 5000 feet, of the Transvaal System 3600 feet, and of the Karroo System 200 feet. The five subdivisions of the Witwatersrand System have the following thicknesses : Hospital Hill Series, 4900 feet; Government Reef Series, 6300 feet; Jeppestown Series, 3700 feet; Main-Bird Series, 3300 feet; Kimberley-Elsburg Series, 6100 feet. The age of the Old Granite which underlies the Lower Division of the Witwatersrand System has been determined as 3200 $\pm$ 65 million years, whereas the age of the Ventersdorp lavas which overlie the Upper Division is probably 2120 $\pm$ 10 million years.

The Central Rand forms part of the northern limb of a synclinorium, the axial plane trace of which strikes ENE. The southward dips of successively higher strata on the limb become progressively flatter. Younger folds with axial trends in a NNW. direction are superimposed upon older east-west folds. Cleavage parallel to the axial planes of the older folds is developed in quartzites and shales, whereas small puckers in shales are products of the later folding. Longitudinal faults, such as the Rietfontein, Witpoortje, Roodepoort and Doornkop faults, are responsible for the most significant displacements of the strata. The oldest faults, many of which are of a thrust nature, strike

approximately east-west. The next group are predominantly normal faults and strike northeastwards and northwestwards. The youngest faults have a north-south strike.

A total of 2000 feet of conglomerate represents about 8% of the thickness of the Witwatersrand System. With the exception of two thin bands in the Government Reef Series, all the conglomerates occur in the Upper Division. There is a general coarsening in grain-size of all strata upwards from the base of the Witwatersrand System, and there is also a progressive thickening upwards of the various conglomerate groups. Ten separate conglomerate horizons have been mined in the Upper Division, nine of these occurring in the Main-Bird Series and one in the Kimberley Stage. The three horizons of greatest economic importance have proved to be the Main Reef, the Main Reef Leader and the South Reef, all developed in the lower portion of the Main-Bird Series. In addition, banded pyritic quartzites, present between the Main Reef and the Main Reef Leader, and the Black Reef conglomerate, at the base of the Transvaal System, have been mined on the Central Rand. The reefs are not payable over the whole area, and the different conglomerate horizons attain their optimum economic development in different sections of the Central Rand.

If all reefs are considered collectively, there is no obvious direct relationship between reef widths, pebble sizes and gold content, but along a single reef horizon lateral variations in reef width or pebble size are frequently associated with sympathetic lateral variations in the amount of gold present. Generally, reefs with larger and better-sorted pebbles contain more gold. The gold is either evenly distributed over the full width of the reef, or is concentrated near the footwall or hanging-wall contact. Frequently, the greater the sulphide content of the conglomerate, particularly pyrite, the higher the amount of gold.

Paystreaks in the Main Reef Leader, the most important reef horizon, swing from NW-SE, through east-west, to NE-SW, from west to east across the Central Rand. They form a braided pattern. Material originally flowed from the north and northwest along southeasterly and southwesterly directions into the basin. The land surface from which the sediments were derived occupied a position, with time, progressively nearer to the present outcrop. The strata presently preserved, as followed stratigraphically upwards, thus represent material originally deposited closer and closer to the shoreline. Maximum gold concentration took place in these reefs (Main Reef, Main Reef Leader and South Reef) that were deposited at a certain optimum distance from the shore-line, where conditions of concentration were most favourable.

In the 76 years since gold was first won from the Central Rand, no less than 140 mines have been in operation at various times. Less than 50 of these became significant producers. A total of 1023 million tons of Witwatersrand ore has been treated, from which 261 million ounces of gold have been recovered. The average grade of all reefs worked is thus 5.1 dwts. per ton. In addition, 425,000 tons of Black Reef conglomerate have yielded 195,000 ounces of gold at an average grade of 9.2 dwts. per ton. The gold won from the Central Rand represents more than 40% of all gold produced from all goldfields within the Witwatersrand Basin.

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THE GEOLOGY OF THE CENTRAL RAND GOLDFIELD

INTRODUCTION

The Central Rand section of the Witwatersrand Goldfield extends for a distance of 14 miles due west of the centre of the City of Johannesburg, and for 15 miles due east. It forms part of the northern fringe of the Witwatersrand Basin, and is bounded on the east by the East Rand area and on the west by the West Rand area.

Historically, the Central Rand is of major significance. Exploitable auriferous conglomerates were first discovered in this section, and the early mines established round Johannesburg provided the nucleus for the gold mining industry which was subsequently to play such a dominant role in the economy of South Africa. The exploration and development of the Witwatersrand Goldfield as a whole, including the Klerksdorp and Orange Free State fields, proceeded outwards from the Central Rand. Johannesburg still remains the controlling centre of mining activities within the whole of the basin.

To date, more than 40 per cent of all gold mined in the Witwatersrand Basin has been won from the mines of the Central Rand. During the 76 years since the proclamation of this section of the Witwatersrand, no less than 140 individual mines have contributed to this output.

Geologically, the Central Rand has come to be regarded as the type area of development of the Witwatersrand System. Outcrops are among the best in the whole basin. The first principles of geological control of the gold mineralisation were deciphered in this section, and, due to the extent of mined areas, it still affords the most fruitful field for the detailed study of mineralisation, sedimentation and structure.

A. HISTORICAL BACKGROUND

(a) The Period 1852 - 1883

The story of the Witwatersrand Goldfield might have had its prelude in the month of July, 1852, when, it is alleged, J.H. Davis found gold in a quartz vein on the farm Paardekraal, immediately north of the present town of Krugersdorp, 17 miles WNW. of the centre of Johannesburg. On October 8 of the following year, P.J. Marais panned alluvial gold in the Jukskei River north of where Johannesburg now stands. It is also possible that he might have found gold in the Magaliesberg area as well, near where subsequent discoveries were made on Blaauwbank. The presence of gold in conglomerate beds was possibly first indicated in 1856, when a Lieutenant Lys is alleged to have obtained a tail in a panning from the Elsburg beds where they outcrop south of what was to become the Knights Central Gold Mine on the eastern portion of the Central Rand. For various economic and political reasons, these finds encouraged no further prospecting, and for the next eighteen years the search for gold in the vicinity of the Witwatersrand appears to have been discontinued.

Alluvial and reef gold, in quartz veins, was discovered by Henry Lewis at the end of 1874 on the farm Blaauwbank, 34 miles WNW. of Johannesburg. As a result, the first gold mining company on the Witwatersrand, the Nil Desperandum Co-Operative Quartz Company, was formed on January 28, 1875, to exploit this and adjoining occurrences. The discovery at Blaauwbank marked the beginning of an almost continuous search which culminated in the discovery of the Main Reef group of conglomerates on Langlaagte at Johannesburg twelve years later. The next strike was made in October, 1876, by T. Mare who panned alluvial gold on the farm Wilgespruit, only 11 miles WNW. of the centre of Johannesburg. Five years were to elapse before another significant discovery was made, this by J.G. Bantjes at Kromdraai, 21 miles northwest of the centre of Johannesburg. It was this find that started to attract to the Witwatersrand a number of prospectors and mining men who were later to play a dominant role in the opening up of the Main Reef along the Central Rand.

In the same year, 1881, the Klip River Goldfields Company was formed to work alluvial gold along the Klip River near where Henley-on-Klip is now located, 20 miles south of the centre of Johannesburg. It is doubtful whether any gold was ever found to justify the formation of the Company.

The first period in the history of the Central Rand was brought to a close by the arrival of F.P. Struben in December, 1883. Up to this date none of the discoveries, except that of Lys, represented the stratified gold deposits which were to make the Witwatersrand the greatest goldfield in the world.

(b) <u>The Period 1884 - 1886</u>

Fred Struben, joined by his brother Harry, started prospecting in January, 1884, and soon thereafter discovered gold in quartz veins at Sterkfontein, beyond Krugersdorp. In April, they sampled two outcrops of conglomerate at Paardekraal, the same farm where Davis was alleged to have found gold 32 years previously. However, neither of the crushings showed the presence of the metal. On September 18, 1884, the Strubens located the Confidence Reef, also gold in quartz veins, on Wilgespruit, where Mare had panned alluvial gold in 1876. This was the richest strike yet made in the area. In March of the following year, Fred Struben panned a small amount of gold from a conglomerate, called Struben's Reef, on the boundary of Honingklip farm, immediately north of Paardekraal. No indication was obtained of this conglomerate possibly constituting an exploitable horizon. While on this farm, he prepared, in April, 1885, the first geological section across the Witwatersrand showing the positions of the Confidence Reef plus three other auriferous quartz veins - the Surprise, Governor and Mirella Reefs - discovered in the Lower Witwatersrand strata during the same month.

In June, 1885, the first crushing battery in the vicinity of the Witwatersrand was erected on the farm Tweefontein to crush the gold-bearing quartz won from this farm and Kromdraai workings. This crusher was the property of S. Hammerschlag.

Henry Nourse took over the Kromdraai venture from Bantjes in October, 1885, as a result of which the latter moved back to prospect the Central Rand. In December, Kromdraai became the first farm in the vicinity of the Witwatersrand to be proclaimed officially as a goldfield. On December 20, 1885, the Struben brothers completed the erection of their five-stamp mill on the Confidence Reef at Wilgespruit.

J.G. Bantjes, C.M. Douthwaite and H. Bantjes crushed samples of conglomerate from the northwestern portion of the farm Roodepoort in January, 1886, but obtained no gold. These conglomerates probably represented members of the Lower Division of the Witwatersrand System. In the same month, F.E. and C.D. Geldenhuys found an auriferous quartz reef on the farm Braamfontein, immediately west of the present centre of Johannesburg, but the gold content was low and erratic. On February 3, Fred Struben moved away from the Confidence Reef, which was proving unpayable, and started prospecting on the farm Driefontein, near where the town of Germiston now stands. It was in this same locality that Lys had recorded the presence of gold in the Elsburg conglomerates 30 years earlier. In March, 1886, the Bantjes brothers collected 50 tons of Bird Reef conglomerate from the farm Roodepoort, where the Durban Roodepoort Deep Gold Mine is now situated, crushed the rock at Strubens' battery on Wilgespruit, and recovered 18 ounces of gold. Shortly thereafter, Fred Struben returned from Driefontein to sample the Bird Reef on the adjoining farm Vogelstruisfontein, where the Rand Leases Gold Mine is now located. Although gold was also recovered, both his results and those of Bantjes were not considered economically significant.

Very shortly after these Bird Reef crushings had taken place, George Harrison and George Walker discovered, at the end of March, 1886, the outcrop of the Main Reef Leader on Portion C (belonging to G.C. Oosthuizen) of the farm Langlaagte four miles west of the centre of Johannesburg. Harrison is credited with the actual discovery on Main Reef Claim No. 19. This claim, now an historical monument, is located in the upper northwest corner of the present Crown Mines property. The old, long-abandoned Proprietary Incline Shaft of the defunct Langlaagte Estate Gold Mine was sunk on this site.

The Witwatersrand Goldfield proper had been discovered. Between April and June, Jan Meyer, the Veld Cornet of Kliprivier, found the Main Reef group on the farms Turffontein, where Johannesburg now stands, and Roodepoort. He traced the outcrop eastwards from Langlaagte to where the rich Robinson and City and Suburban mines were subsequently to come into existence. In the latter half of June, J.G. Bantjes found the same reef horizons on one half of the farm Vogelstruisfontein and Fred Struben on the other half. In July, Henry Nourse, having abandoned Kromdraai, established the presence of the Main Reef group on the farm Doornfontein, starting the search for the eastwards extension of the reefs from Johannesburg. Later the same month, one of the Geldenhuys brothers located the Main Reef on the adjoining farm Elandsfontein. In August, Fred Struben, returning to Driefontein from his discoveries on Vogelstruisfontein, traced the reef horizons on the former farm to the point where they disappeared beneath the cover of younger Karroo rocks.

Thus, in the five months since Harrison's original discovery on Langlaagte, at the end of March, 1886, the Main Reef group had been traced along the whole strike length of what was to become known as the Central Rand. Over 25 miles of continuous outcrop of gold-bearing conglomerate were ready for exploitation, if capital could be obtained. In July, 1886, J.G. Bantjes met F.W. Alexander, a prominent financial figure in the Kimberley Diamond Fields, who was visiting Potchefstroom at that time, and informed him of the potentialities of the discoveries along the Rand. Alexander returned to Kimberley and interested Cecil Rhodes, H. Eckstein, W. Knight, C.D. Rudd, J.B. Robinson, G.H. Goch and H.S. Caldecott. The money needed for the opening of the Central Rand was guaranteed.

The discovery of Walker and Harrison was reported in the Pretoria press on June 28, 1886. The proclamation of the first farm as a goldfield was announced in the Government Gazette on September 8, the area being referred to as the Heidelberg Goldfields. Between September 20 and October 11, 1886, all the remaining farms along the Central Rand were officially proclaimed, and the Witwatersrand Goldfield was in existence.

The first systematic stripping of the outcrop started in July on the Ferreira and Wemmer mines. In August, work commenced on the Bantjes Mine on the farm Vogelstruisfontein, and was carried out by J.G. Bantjes himself. In the same month, L. Geldenhuis opened up the Geldenhuis Mine on Elandsfontein, and Fred Struben the Knights Mine on Driefontein. All the ore from these first workings was transported to Wilgespruit and crushed in Strubens' original stamp battery on the Confidence Reef. On September 14, the first large mining company on the Witwatersrand was formed by W. Knight and George Goch and was called the Witwatersrand Gold Mining Company (Knights). Its purpose was to amalgamate a number of claims on Driefontein into a large, workable unit.

This second period, the one of discovery, in the story of the Central Rand came to an end in December, 1886, and was marked by the opening of the first stamp battery specifically erected to crush conglomerate reefs. This battery was located on the southern portion of the farm Turffontein, adjacent to the farm Klipriviersberg, and was intended to crush the Elsburg Reefs which, however, were to prove uneconomic.

(c) <u>The Period 1887 - 1890</u>

Early in 1887 underground mining started at Langlaagte. In February, Cecil Rhodes formed the first large financial mining corporation - Consolidated Gold Fields of South Africa - for the purpose of amalgamating various gold interests. Following the example set by Knight and Goch, other claim owners began forming companies to exploit their holdings, and between January and April, 1887, the Crown Reef Gold Mining Company, the Robinson Gold Mining Company, the Ferreira Gold Mining Company, the Jumpers Gold Mining Company, and the Langlaagte Estate and Gold Mining Company were formed.

On April 22, 1887, a three-stamp mill was opened on the Jubilee Mine to treat Main Reef ore. This small installation was the forerunner of hundreds of recovery plants that were to contribute to the building of the most conspicuous monuments to the gold mining industry - the mine dumps. By the end of 1887, fourteen mines were in production and gold was being won from the Main Reef, the Main Reef Leader and the South Reef. In addition, small amounts of alluvial gold were being recovered on the farms Witpoortje, Roodepoort and Rietvlei, the last-mentioned lying about seven miles south of Johannesburg, where gold in gravels along the Klip River originated from the erosion of the Black Reef. The total gold output for 1887, the first year of mining on the Central Rand, was 19,080 ounces valued at £81,045, and constituting less than one per cent of the world's gold production for that year.

The number of producing mines continued to increase in 1888 and the gold production for that year increased 900 per cent to reach a figure of 171,789 ounces valued at £729,715. To recover this gold, 114,000 tons of ore were crushed.

During 1889 the second large financial mining group - the Johannesburg Consolidated Investment Corporation - was formed. The first real deep level mine - the Village Deep - was formed in the same year. In December, the first borehole drilled on the Witwatersrand was

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started on the Village Main Reef Mine. This was completed in March, 1890, at a final depth of 665 feet below surface, the Main Reef Leader having been intersected at a depth of 581 feet.

The future of the Witwatersrand Goldfield was assured by the end of 1890. From then on, it proceeded from strength to strength through the continual amalgamations of the small mines and companies into the large deep-level mines which have persisted to the present day.

B. THE EXTENT OF THE CENTRAL RAND

(a) Towns and Farms

The Central Rand is contained within a distance of 29 miles, east-west, from the Roodepoort Fault in the west, through Johannesburg, to the Boksburg "Gap" in the east. The towns of Maraisburg, Florida and Roodepoort lie $6\frac{1}{2}$ miles, 8.1/4 miles and 11 miles west respectively of the centre of Johannesburg. To the east, Germiston is $7\frac{1}{2}$ miles, and Boksburg $13\frac{1}{2}$ miles, distant from Johannesburg. The centre of this city is located approximately at longitude $28^{o}02$'E. and latitude $26^{o}12$'S. The highest elevation reached on the Central Rand is 5965 feet above sea-level at a point near the southern municipal boundary. The whole of this area lies above an altitude of 5000 feet, and constitutes the highest portion of the entire Witwatersrand Basin.

From west to east, the outcrop of the Main Reef group of auriferous conglomerates is located on the farms Witpoortje 245 (44) in the District of Krugersdorp; Roodepoort 237 (43), Vogelstruisfontein 231 (62), and Paardekraal 226 (42), in the District of Roodepoort; Langlaagte 224 (13), Turffontein 96 (21), and Doornfontein 92 (24) in the District of Johannesburg; Elandsfontein 90 (11) and Driefontein 87 (12), in the District of Germiston; and Driefontein 85 (1), Vogelfontein 84 (12), and Leeuwpoort 113 (4), in the District of Boksburg. (The numbers in brackets refer to the old farm numbers as shown on the existing geological maps of the Central Rand).

(b) Gold Mines

From Roodepoort to Boksburg, the major mines still in production in 1962, were as follows:

1. Durban Roodepoort Deep, Ltd. : on the farms Witpoortje 245, Roodepoort 237, Vogelstruisfontein 231, Vlakfontein 238, and Vogelstruisfontein 233.

2. Rand Leases (Vogelstruisfontein) G.M. Co., Ltd. : on the farms Roodepoort 237 and Vogelstruisfontein 231.

3. Consolidated Main Reef Mines and Estates, Ltd. : on the farms Vogelstruisfontein 231, Paardekraal 226, Diepkloof 319, Mooifontein 225, and Klipspruit 318.

4. Crown Mines, Ltd. : on the farms Langlaagte 224, Turffontein 96, Mooifontein 225, Diepkloof 319, Vierfontein 321, and Ormonde 99.

5. Robinson Deep, Ltd. : on the farms Turffontein 96, Booysens Estate 98, Village Deep 89, Turffontein 100, and Kliprivier sberg 106.

6. Village Main Reef G.M. Co. (1934), Ltd. : on the farms Turffontein 96, Doornfontein 92 and Village Deep 89.

7. City Deep, Ltd. : on the farms Doornfontein 92, Klipriviersberg 106, and Elandsfontein 107.

8. Simmer and Jack Mines, Ltd. : on the farms Doornfontein 92, Elandsfontein 90, Elandsfontein 107 and Elandsfontein 108.

9. Rose Deep, Ltd. : on the farms Elandsfontein 90 and Driefontein 87.

10. East Rand Proprietary Mines, Ltd. : on the farms Driefontein 87, Driefontein 85, Vogelfontein 84, Klippoortje 110, and Leeuwpoort 113.

In addition to the above major producers there were the following small mines working along the outcrop, reopening and reclaiming old mines which had previously ceased production:

11. Princess G.M. Co. (1957), Ltd. : on the farm Witpoortje 245, working the outcrop above Durban Roodepoort Deep.

12. Wilford G.M. Co., Ltd. : on the farm Roodepoort 237, working the outcrop above Durban Roodepoort Deep.

13.	Roodepoort G.M. Co. (1957), Ltd.	: on the farm Roodepoort 237, working the outcrop above Durban Roodepoort Deep.
14.	Croesus G.M. Co. (1959), Ltd.	: on the farm Langlaagte 224, working the outcrop above Crown Mines on the old Langlaagte Estate G.M.
15.	Mayfair G.M. Co., Ltd.	: on the farm Langlaagte 224, working the outcrop above Crown Mines, on the old Langlaagte Estate G.M.
16.	Old Heriot Mine, Ltd.	: on the farm Doornfontein 92, working the outcrop above Simmer and Jack, on the old Geldenhuis Deep G.M.
17.	Jumpers Consolidated G.M. Co., Ltd.	: on the farms Doornfontein 92 and Elandsfontein 90, working the outcrop above Simmer and Jack, on the old Geldenhuis Deep G.M.
18.	Stanhope G.M. Co., Ltd.	: on the farm Elandsfontein 90, working the outcrop above Simmer and Jack, on the old Geldenhuis Deep G.M.
19.	Primrose G.M. Co. (1934), Ltd.	: on the farms Elandsfontein 90 and Driefontein 87, working the outcrop above Rose Deep.
20.	Waverley G.M., Ltd.	: on the farm Driefontein 87, working the outcrop above E.R.P.M., on the old Witwatersrand G.M.
21.	Driefontein G.M. Co., Ltd.	: on the farm Driefontein 85, working the outcrop above E.R.P.M., on the old Witwatersrand Deep G.M.

22. Balmoral G.M. Co., Ltd. : on the farm Driefontein 85, working the outcrop above E.R.P.M., on the old Witwatersrand Deep G.M.

(c) Nature of the Boundaries

The Central Rand has well-defined structural and sedimentological boundaries, and, therefore, exists as both a geographical and geological entity.

On the west, the strike of the Upper Witwatersrand sediments terminates against the Roodepoort Fault which trends in a northeasterly direction. On the northwestern side of the fault, the Lower Witwatersrand beds have been upthrown into a horst which exists between the Roodepoort and Witpoortje Faults. To the northwest and west of this horst is the West Rand section of the Witwatersrand Goldfield. The structural break between the Central Rand and the West Rand is thus conspicuously demarcated. Towards the western boundary of the Central Rand there are also marked sedimentological changes in the nature of the Upper Witwatersrand strata. The various conglomerate horizons tend to thin out, as well as the partings of quartzite between them. Coupled with this wedging phenomenon, there are indications of transgressive overlaps of one reef over another, showing that a sedimentational break, of an as yet undetermined nature, also occurs between the Central Rand and the West Rand.

The boundary between the Central Rand and the East Rand is not as striking as that described above. The Boksburg "Gap" represents an anticline which appears to have existed in an embryonic form during sedimentation, and, consequently, to have been a controlling factor in the development of wedging and transgressive overlaps similar to those described for the western boundary of the Central Rand. Although the broad subdivisions of the Upper Witwatersrand can be traced, without a break, from the Central Rand into the East Rand, yet there are significant differences in lithology and sedimentational patterns which strongly favour the Boksburg anticlinal structure, or "gap", as the easterm limit of the Central Rand.

The Central Rand is the most structurally elevated area within the Witwatersrand Basin, and the regional plunge away from the Johannesburg-Pretoria granite dome causes the Witwatersrand beds to become covered by progressively younger formations. The western limit of the Central Rand coincides approximately with the zone where the Witwatersrand rocks disappear beneath a continuous cover of the Transvaal System, and the eastern limit with the zone where the older strata plunge beneath the cover of Karroo sandstones and shales.

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In the early years of the history of the Witwatersrand, the term "Central Rand" was applied to that portion of the country lying between Roodepoort and Germiston. The area to the east, from Germiston, through Boksburg, to Benoni, was known as the "East Rand", while the portion of the Witwatersrand Basin beyond, from Springs to Nigel to Heidelberg, was called the "Far East Rand". In later years, the term "Central Rand" was extended to include the former "East Rand", while the original "Far East Rand" became the "East Rand Basin".

C. SCOPE OF PRESENT PAPER

The present paper is concerned only with the geological setting of the ten major mines listed above, including, in some instances, the outcrop workings above these mines. The emphasis is thus on the rocks of the Upper Witwatersrand Division, particularly on the various conglomerate horizons exploited for gold. Some information is provided on the Lower Division, but only brief mention is made of the formations underlying and overlying the Witwatersrand System. No attempt has been made to compile a comprehensive geology of the Central Rand. The paper is essentially a broad study of the economic geology of the larger mines that have produced, or are still producing, significant amounts of gold.

Within the geographic confines of the Central Rand are two important producers which are not included in the present description. These are South Roodepoort Main Reef Areas, Ltd., situated to the south-west of the Durban Roodepoort Deep Mine, and Rietfontein Consolidated Mines, Ltd., lying to the north-north-east of Rose Deep Mine. Both these mines show differences in geology which do not allow them to be satisfactorily included in the line of contiguous mines along the Main Reef group of conglomerates. The South Roodepoort Mine exploits the Ventersdorp Contact Reef only, and thus has a closer affinity with the West Rand where the same reef, under the name of the Montana Reef, has been mined to a limited extent. The mine is isolated from the line of Central Rand mines. The Rietfontein Mine is also structurally detached from the other mines, and is separated from the Rose Deep Mine by Lower Witwatersrand rocks and a thin wedge of Old Granite. Uncertainty is also attached to the correlation of the various reef horizons worked, and it has been suggested that the general geology of the mine is more closely related to that of the East Rand than to that of the Central Rand.

The geology of the gold mines of the Central Rand, as outlined in this paper, represents a compilation and collation of published data. No attempt has been made to incorporate the results of new research studies which are of too recent a date to have received final assessment.

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What is presented, is a summary of the version which has received general acceptance over the years. Within the first thirty years of the life of the Central Rand there was a proliferation of publications dealing with the geology of this portion of the Witwatersrand Goldfield. However, the most important and significant contributions to the understanding of the geological problems were made during the next twenty years. Since then, with one or two exceptions, very little has been added to the published knowledge of the geological setting of the Central Rand Mines. Only in the case of production and grade figures, obtained from the annual reports of the individual mining companies, is new information provided.

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GENERAL GEOLOGY

A. STRATIGRAPHY

A granite dome, composed of some of the oldest rocks in South Africa, occurs between Johannesburg and Pretoria. On the southern flank of this dome is a succession of sedimentary and volcanic rocks, predominantly of Precambrian age. The rocks belong to the Witwatersrand, Ventersdorp, Transvaal and Karroo System, the last-named being the only relatively young group, having a Carboniferous - Permian age. The sediments and lavas lie unconformably on the Old Granite and associated remnants of ancient Swaziland System schists. The outcrops assume a gently arcuate shape, concave to the north. The regional strike of the sediments is approximately east-west, and the dip to the south, the angle of dip decreasing stratigraphically upwards due to unconformities within and between the four systems.

(a) Type Succession

The succession along a north-south line more or less through the centre of Johannesburg has come to be regarded as the type section of the Witwatersrand System. Table 1, compiled from Mellor (1917 and 1921) shows the regional stratigraphic succession from the Old Granite, through the Witwatersrand System, to the Karroo System, in the area of the Central Rand.

The detailed stratigraphic succession within the Lower Division of the Witwatersrand System is shown in Table 2, for the Hospital Hill Series; in Table 3, for the Government Reef Series; and in Table 4, for the Jeppestown Series. The type succession for the Main - Bird Series and Kimberley - Elsburg Series, of the Upper Division, is presented in Table 5. All these tables have been drawn up from data presented by Mellor (1917).

(b) Stratigraphic Markers in the Witwatersrand System

In the mapping and exploration of the Witwatersrand System in the Central Rand, several stratigraphic marker horizons have come to be recognized, and many of these have been identified and used for correlation as the investigation of the System has proceeded beyond the limits of this portion of the basin.

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System	Series	Thickness (ft.)
Karroo System : 200 ft.	Ecca Series	200
Transvaal System : 3600 ft.	Pretoria Series	1500
	Dolomite Series	2000
	Black Reef Series	100
Ventersdorp System : 5000 ft.	Ventersdorp Lavas	5000
Witwatersrand System : 24,300 ft.	Kimberley-Elsburg Series	6100
	Main-Bird Series	3300
	Jeppestown Series	3700
	Government Reef Series	6300
	Hospital Hill Series	4900
Old Granite	Granite and Gneiss	-
Swaziland System : 700 ft.	Onverwacht Series	700

Table 1 : Regional Stratigraphic Succession along a North-South Line through the Central Portion of Central Rand.

Series	Horizon	Thickness (ft.)	Distance (ft.)
Hospital Hill Series 4900 ft.	quartzites	300	4900
	shales	100	4600
	quartzites	450	4500
	shales	400	4050
	Hospital Hill Quartzites	600	3650
	Hospital Hill Shales and Contorted Bed	700	3050
	Speckled Bed	5	2350
	Red Shales	750	2345
	Ripple-Marked Quartzites	25	1595
	Water Tower Slates	800	1570
	quartzites	220	770
	shales	150	550
	Orange Grove Quartzites	400	400

Table 2 : Detailed Stratigraphic Succession of the Hospital Hill Series, Lower Witwatersrand Division, along a North-South Line through the Central Portion of the Central Rand. (Last column shows stratigraphical distance of top of horizon above contact of Old Granite and Witwatersrand System).

Series	Horizon	Distance (ft.)	Distance (ft.)
	Upper Government Quartzites	480	11,200
	shales	110	10,720
	quartzites	500	10,610
	Government Reef	1	10,110
	Government Reef Shales	450	10,110
	Lower Government Quartzites	300	9,660
	shales	480	9,360
Government Reef	Coronation Quartzite	600	8,880
Series	Coronation Reef	3	8,280
	Coronation (West Rand) Shales	600	8,275
6,300 ft.	Lower Coronation Quartzite	825	7,675
	shales	100	6,850
	quartzite	300	6,750
	shales	100	6,450
	Promise Quartzites	800	6,350
	Promise Reef	1	5,550
	quartzite	250	5,550
	shale	400	5,300

Table 3 : Detailed Stratigraphic Succession of the Government Reef Series, Lower Witwatersrand Division, along a North-South Line through the Central Portion of the Central Rand. (Last column shows stratigraphical distance of top of horizon above contact of Old Granite and Witwatersrand System).

Series	Horizon	Thickness (ft.)	Distance (ft.)
Jeppestown Series 3,700 ft.	shales	450	14,900
	quartzite	200	14,450
	shales	350	14,250
	quartzite	150	13,900
	shales	200	13,750
	quartzite	350	13,550
	shales	450	13,200
	quartzite	450	12,750
	shales	350	12,300
	quartzite	200	11,950
	shales	550	11,750

Table 4 : Detailed Stratigraphic Succession of the Jeppestown Series, Lower Witwatersrand Division, along a North-South Line through the Central Portion of the Central Rand. (Last column shows stratigraphical distance of top of horizon above contact of Old Granite and Witwatersrand System).

Series	Horizon	Thickness (ft.)	Distance (ft.)
Kimberley-Elsburg Series 6,100 feet	Elsburg Reef Group	1700	24,300
	quartzites	2800	22,600
	Kimberley Reef Group	1000	19,800
	Kimberley Shales	600	18,800
Main-Bird Series 3,300 feet	Bird Reef Group	750	18,200
	quartzites	1900	17,450
	Main Reef Group	150	15,550
	quartzites	500	15,400

Table 5 : Detailed Stratigraphic Succession of the Upper Witwatersrand Division along a North-South Line through the Central Portion of the Central Rand. (Last column shows stratigraphical distance of top of horizon above contact of Old Granite and Witwatersrand System).

In the lower portion of the Hospital Hill Series, the most useful marker horizons have proved to be : the Orange Grove Quartzites at the base of the whole System; the Water Tower Slates, because of the magnetic nature of these ferruginous argillites; the Ripple-Marked Quartzites; and the Speckled Bed, because of its spotted appearance caused by the presence of decomposed felspar grains. In the upper portion the two most conspicuous horizons are : the Contorted Bed, with its spectacular structural deformation and high degree of magnetism; and the Hospital Hill Quartzites, because of the distinctive green coloration imparted to the beds by the presence of the chrome mica, fuchsite.

In the Government Reef Series, the three conglomerate horizons, the Promise Reef, the Coronation Reef and the Government Reef, have been frequently used for correlation purposes. The third, highly magnetic horizon in the Witwatersrand System, the Coronation (or West Rand) Shales, occurs about mid-way up in this Series. In the Heidelberg, East Rand, West Wits Line, and Klerksdorp areas, a group of alleged tillites occurs immediately below the Coronation Shales, and has been employed as a marker. However, on the Central Rand, these tillites appear to be absent, except at the western extremity, near Roodepoort.

The Jeppestown Series is conspicuously devoid of marker horizons on the Central Rand. Elsewhere, the Jeppe Amygdaloid, a thin andesitic lava flow, occurs about in the middle of the Series, but this marker has not been positively identified between Roodepoort and Boksburg, except in the vicinity of the old Saxon Mine right against the Saxon and Roodepoort faults at the extreme western limit of the area.

In the Upper Division of the System, the most important markers are the various conglomerate horizons, some of which contain gold in economically exploitable quantities. Stratigraphically upwards, these reefs are successively : the North Reef, the Main Reef, the Bastard Reef, the Main Reef Leader, the Middle Reef, the South Reef, the South South Reef, the Livingstone Reef, the Bird Reef group, the Kimberley Reef group, and the Elsburg Reef group. In the mines, the Kimberley Reef group is the highest of the marker horizons worked. Using the base of this group as a datum-plane, the stratigraphic depths of some of the conglomerates below the Kimberley Reefs have been listed in Table 6. Variations in the disposition of the reefs from mine to mine along the strike of the Central Rand have been determined from data presented by Jones (1936).

As only two shale horizons are present in the mass of quartzites, grits and conglomerates which make up the Upper Division, both have acted as extremely useful guides to correlation. Between the Main Reef and the Main Reef Leader is the thin and erratically developed Black Bar. Above the Bird Quartzites are the thick, persistent and ubiquitous Kimberley Shales. Mellor (1917) placed these shales at the base of the Kimberley - Elsburg Series, but, from a sedimentary history point of view, they actually form the top of the Main - Bird Series. The variations in the stratigraphic positions of these two horizons, from mine to mine, are shown in Table 7, also compiled from Jones (1936)

Another important stratigraphic marker in the Main - Bird Series is the Bird Amygdaloid or Bird Reef Marker. This is present on the Central Rand only from the eastern boundary of Crown Mines eastwards. The Bird Reef Marker, essentially an altered tuffaceous sediment, is developed in this section, while the Bird Amygdaloid, a lava of basaltic composition, appears only in the eastern extremity, near Boksburg. This marker horizon occurs between the Bird Reef group of conglomerates and the Kimberley Shales.

B. LITHOLOGY

(a) Old Granite

The granites and gneisses outcrop in an elliptical dome measuring 28 miles, east-west, by 20 miles, north-south, and covering 300 square miles. A very much smaller, faulted wedge of granite also occurs between the Rietfontein Mine and the Rose Deep and E.R.P.M. mines. The Witwatersrand beds overlie the granite with a sedimentary contact. The minerals in the granite assume a preferred orientation which becomes progressively stronger as the sediments are approached, so that the southernmost exposures of the granite appear as schistose gneisses. The shearing persists for a short distance into the Orange Grove Quartzites.

Horwood (1905) described the Old Granite outcropping at Orange Grove as a dark grey, biotite granite, carrying muscovite in some places, but rarely becoming a muscovite granite. Orthoclase and plagioclase are generally cloudy and turbid, but the abundant microcline is usually clear. The biotite is of a light green colour. Green hornblende, some of it fibrous, is commonly developed. Small amounts of chlorite are present and particles of sphene are abundant. Undulatory extinction in the quartz, bent and shattered felspars, broken needles of rutile in the quartz, and contorted mica, all indicate that the granite has been subjected to considerable pressure which probably produced the sheared nature of the contact with the overlying sediments. Mellor (1921) states that the normal granite is composed of quartz, pale pinkish-grey felspar, muscovite, biotite (partly chloritised), apatite and epidote.

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Name of Mine	top KS (ft.)	bottom KS (ft.)	top BRG (ft.)	bottom BRG (ft.)	LR (ft.)	SR (ft.)	MRL (ft.)	NR (ft.)	top JS (ft.)
Durban Roodepoort Deep	230	810	1540	1750	2680	3700	3780	3820	4300
Rand Leases	340	900	1520	1800	2630	3640	3740	3780	4190
Consolidated Main Reef	450	1050	1430	1790	2560	3550	3650	3710	4100
Langlaagte Estate	370	890	1150	1490	2290	3270	3360	3400	3760
Crown Mines	250	760	1000	1340	2190	3080	3170	3250	3550
Robinson Deep	290	860	1250	1480	2310	3120	3200	3270	3500
City Deep	270	900	1300	1500	2310	3180	3220	3270	3560
Nourse Mines	240	880	1170	1470	2450	3250	3290	3330	3620
Geldenhuis Deep	210	830	1190	1500	2500	3260	3280	3320	3630
Simmer and Jack	210	830	1170	1490	2520	3250	3270	3320	3710
Rose Deep	210	800	1140	1430	2510	3210	3220	3270	3670
Witwatersrand G.M.	230	730	1140	1450	2420	3130	3140	3180	3580
Witwatersrand Deep	220	720	1160	1470	2360	3080	3090	3120	3510
E.R.P.M. (Angelo Section)	250	720	1200	1500	2240	2900	2940	2910	3280
E.R.P.M. (Hercules Section)	260	740	1210	1430	2170	2760	2770	-	2990
E.R.P.M. (Cinderella Section)	220	720	1150	1330	1930	2400	-	-	2400

Table 6 : Variations in Stratigraphic Depths of Members of Main-Bird Series below Datum at Base of Kimberley Reef Group, from West to East along Strike of Central Rand.

KS : Kimberley Shales
BRG : Bird Reef Group
LR : Livingstone Reef
SR : South Reef
MRL : Main Reef Leader and/or Main Reef
NR : North Reef
JS : Jeppestown Shales

Name of Mine	JS - BB (feet)	BB - KS (feet)	MBS (feet)	BRG (feet)	KS (feet)
Durban Roodepoort Deep	520	3550	4070	210	580
Rand Leases	450	3400	3850	280	560
Consolidated Main Reef	450	3200	3650	360	600
Langlaagte Estate	400	2990	3390	340	520
Crown Mines	380	2920	3300	340	510
Robinson Deep	300	2910	3210	230	570
City Deep	340	2950	3290	200	630
Nourse Mines	330	3050	3380	300	640
Geldenhuis Deep	350	3070	3420	310	620
Simmer and Jack	440	3060	3500	320	620
Rose Deep	450	3010	3460	290	590
Witwatersrand G.M.	440	2910	3350	310	500
Witwatersrand Deep	420	2870	3290	310	500
E.R.P.M. (Angelo Section)	380	2650	3030	300	470
E.R.P.M. (Hercules Section)	230	2500	2730	220	480
E.R.P.M. (Cinderella Section)	JS - KS :	2180	2180	180	500

Table 7 : Variations in Stratigraphic Thicknesses of Members of the Main-Bird Series, from West to East along Strike of Central Rand.

JS - BB : thickness from top of Jeppestown Shale to top of Black Bar Shale.

BB - KS : thickness from top of Black Bar Shale to top of Kimberley Shale.

MBS : total thickness of Main-Bird Series.

BRG : thickness of Bird Reef group of conglomerates.

KS : thickness of Kimberley Shale.

Chemical analyses of Old Granite from Halfway House and Orange Grove are shown in Table 8 which has been prepared from data contained in Horwood (1905) and Hall (1938).

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	J	K	L	M	N	O
SiO_2	73.92	78.61	59.65	53.00	73.80	46.30
Al_2O_3	14.07	7.76	13.70	19.70	14.88	12.70
Fe_2O_3	0.52	4.51	1.80	10.93	-	3.50
FeO	0.89	1.69	7.50	2.88	-	6.43
CaO	1.22	2.60	3.95	7.20	1.55	10.16
MgO	0.38	0.90	1.05	4.00	-	4.82
K_2O	4.35	1.74	0.95	0.79	2.63	0.85
Na_2O	3.83	2.10	5.20	0.82	6.17	2.75
MnO	0.04	-	0.15	tr.	-	0.04
FeS_2	-	-	-	0.25	-	0.10
TiO_2	0.21	-	0.85	-	-	-
P_2O_5	0.09	tr.	0.70	tr.	-	0.09
CO_2	-	-	-	tr.	-	3.20
Cl	-	-	0.25	-	-	-
H_2O	0.44	-	2.55	-	-	8.50
Total %	99.96	99.91	98.30	99.57	99.03	99.44
S.G.	2.63	2.71	-	2.86	-	2.76

Table 8 : Chemical Analyses of Igneous Rocks from the Central Rand.

J : Old Granite, Halfway House.

K : Old Granite, Orange Grove, Johannesburg.

L : Jeppe Amygdaloid, Saxon Mine, Witpoortje.

M: Ventersdorp Lava, Kliprivi ersberg.

N : Granite Porphyry Dyke, Rand Deep Level Borehole, Alberton.

O : Dolerite Dyke, Rietfontein Mine.

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(b) Swaziland System

Rocks belonging to this System outcrop in a semicircular area on the farms Rietfontein 61, Rietfontein 63, Modderfontein 35, and Zuurfontein 33, to the north of the Rietfontein Mine, and in a long strip between the granite and the Orange Grove Quartzites on the farms Waterval 211, Weltevreden 202, Wilgespruit 190 and Roodekrans 183, westwards from Northcliff.

Mellor (1917 and 1921) recorded the presence of amphibolites, actinolite schists, hornblende schists, talc schists and serpentinites. The central portions of the larger bodies of basic rocks consist of massive serpentinite or of an amphibole-serpentine rock, in which chrysotile asbestos is found in places. The schists are contorted and highly sheared, and show the effects of a high degree of metamorphism in places. Their petrological nature indicates that the rocks probably belong to the Onverwacht Series at the very base of the Swaziland System. If higher members were ever present, they were eroded, either prior or subsequent to the deposition of the Witwatersrand and younger beds.

(c) Lower Division of the Witwatersrand System

According to Mellor (1921), the Lower Witwatersrand assemblage of rocks is distinguished from the members of the Upper Division by the more abundant shale horizons, the comparatively poor development of conglomerate bands, the presence of numerous quartzite bands less than 300 feet in thickness, and by the occurrence of conspicuous ferruginous horizons. Horwood (1905) classified the quartzites of the Lower Division as having more chlorite and less sericite, and as being more compact and more crystalline than the arenaceous rocks above the Jeppestown Series.

It is possible that the conclusions drawn by Fuller (1958a) for the members of the Lower Division on the East Rand, also apply to the Central Rand. The Orange Grove and Hospital Hill Quartzites correspond to true orthoquartzites, whereas the so-called quartzites of the Government Reef and Jeppestown Series are more correctly subgraywackes. The Orange Grove Quartzites consist of detrital quartz grains with chert in minor concentrations only. Sericite, derived from altered felspar, amounts to less than one per cent of the constituents. No recrystallised quartz is present. A poorly developed basal conglomerate occurs in a few isolated localities along the Central Rand. The Hospital Hill Quartzites consist of 95 per cent detrital quartz and one per cent chert, the quartz being recrystallised. The rest of the matrix is made up of muscovite and pale-green chromiferous mica associated with detrital

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chromite. These rocks occupy the highest ground underlain by members of the Lower Division. According to Mellor (1917), the number of bands which make up the Hospital Hill Quartzites decreases eastwards, there being three quartzite horizons on Witpoortje, two at Maraisburg, and only one from Johannesburg eastwards.

The quartzites of the Government Reef and Jeppestown Series, according to Fuller (1958a), are composed of 50-60 per cent quartz, felspar up to 10 per cent, biotite up to 5 per cent, rock fragments, calcite up to 5 per cent, sericite resulting from altered felspar, chlorite resulting from altered biotite, pyrite, leucoxene, epidote, apatite, zircon and tourmaline. In the arenaceous beds of the Jeppestown Series, felspar, rock fragments and epidote are more abundant than in the underlying quartzites. Mellor (1917) found the Government Reef quartzites to be less purely siliceous than those of the Hospital Hill Series. Old prospect shafts indicate that the cream-to-buff colour of the former on outcrop changes to a bluish- or greenish-grey with depth.

The shales of all three series of the Lower Division weather to a red or reddish-brown colour on surface, but at depth they become grey, dark grey-green, or dark bluish-green. Fuller (1958a) showed that all the shales have more or less the same composition : quartz and chlorite predominate, while small amounts of muscovite and disseminated, fine-grained, euhedral magnetite are also present. Felspar and calcite are rare. Pirow (1920) examined the topmost members of the Jeppestown Series on 19 Level, Crown Mines, and found that the shales, which are very fine-grained and dark, gradually change upwards into coarser-grained, light grey, shaley quartzites as the basal quartzites of the Main-Bird Series are approached. The number of true shale bands alternating with the shaley quartzite, also decreases upwards so that the topmost few hundred feet are totally devoid of shale layers. Similar conditions were noted on the old Ferreira Deep Mine.

There is a progressive coarsening of the grain-size of the arenaceous members of the Lower Division from the base upwards. Quartzites in the Hospital Hill Series are essentially fine-grained, while those in the Government Reef Series are not only coarse, but frequently become gritty and, in some places, even conglomeratic. This coarsening continues upwards into the Upper Division so that the bands of conglomerate become thicker and more frequent and the pebbles become larger.

Chemical analyses of two specimens from the Hospital Hill Series are given in Table 9 which is based on information contained in Horwood (1905), Young (1917), and Hall (1938). In Table 8, an analysis

	A	B	C	D	E	F	G	H	I
SiO_2	89.26	51.56	86.76	85.60	83.20	73.35	74.14	58.11	0.94
Al_2O_3	0.92	tr.	6.91	3.50	2.85	13.40	13.00	31.93	-
Fe_2O_3	8.48	47.48	2.65	8.60	11.00	7.65	7.70	1.32	-
FeO	0.18	0.90	-	-	-	-	-	-	1.35
CaO	nil	nil	tr.	tr.	tr.	1.25	0.91	1.02	29.61
MgO	nil	nil	0.70	-	-	1.35	1.41	0.05	19.71
K_2O	-	-	-	-	-	-	-	1.10	-
MnO	-	-	-	-	-	-	-	-	1.18
FeS_2	-	-	2.75	2.15	2.35	1.87	1.78	-	-
TiO_2	-	-	-	-	-	-	-	0.97	-
P_2O_5	-	-	-	0.10	0.15	-	-	-	-
CO_2	-	-	-	-	-	-	-	-	44.94
H_2O	-	-	-	-	-	2.23	2.63	5.65	1.75
Total %	98.84	99.94	99.77	99.20	99.55	101.10	101.57	100.15	99.48
S.G.	-	-	2.79	-	-	2.76	2.77	-	2.88

Table 9 : Chemical Analyses of Sedimentary Rocks from the Central Rand.

A : Hospital Hill Banded Ironstone, Milner Park Showgrounds, Johannesburg.

B : Contorted Bed, University Grounds, Milner Park, Johannesburg.

C : Main Reef Leader, Witwatersrand Deep Mine.

D : Main Reef Leader (complete with pebbles), Durban Roodepoort Deep Mine.

E : Main Reef Leader (pebbles removed), Durban Roodepoort Deep Mine.

F : Bastard Reef, Simmer and Jack Mine.

G : Bastard Reef, Witwatersrand Deep Mine.

H : Shale band underlying Kimberley Reef, Rand Leases Mine.

I : Transvaal Dolomite, Jackson's Drift.

is shown of the Jeppe Amygdaloid as it occurs on the Saxon Mine, adjacent to the Roodepoort Fault.

(d) Upper Division of the Witwatersrand System

The finer-grained arenaceous members of the Upper Division have been classified by Fuller (1958a) as hydrothermally altered felspathic quartzites. Those of the Main-Bird Series are strongly recrystallised, and consist of detrital quartz and chert grains in almost equal abundance. Of the phyllosilicates, muscovite is the most common, then chlorite, then pyrophyllite (previously identified as talc, usually on slip surfaces), and, then, least common, chloritoid, which is often present where secondary silica is abundant. The quartzites of this Series frequently show cross-bedding and ripple-marking. The Kimberley-Elsburg quartzites generally have a 10-15 per cent lower silica content than those of the Main-Bird Series. Muscovite is present in all the horizons, but recrystallised quartz is apparently absent. Pyrophyllite is present only in the lower section of the Kimberley-Elsburg Series, while chlorite is developed in the upper section only. Conglomerates in this Series may occur as single bands or as groups with more than 100 individual pebble bands. Horwood (1905) concluded that the quartzites of the Upper Division contain more sericite, muscovite and talc (now identified as pyrophyllite) than those of the Lower Witwatersrand, and that they are more inclined to a schistose structure.

Chemical analyses of the Main Reef Leader from the western portion of the Central Rand, and of the Bastard Reef from the eastern portion are given in Table 9.

The shales of the Upper Division are similar in appearance to those stratigraphically lower. They are actually argillites, and alternate with argillaceous quartzites. Reinecke (1927) concluded that the lath-shaped chloritoid crystals were a distinguishing component of the Black Bar, the shaley horizon which immediately underlies the Main Reef Leader in certain localities within the Central Rand. A common feature of the Black Bar is the development of quartz veins parallel to the bedding planes with a degree of consistency not noted in other shale horizons in the System. Fuller (1958a) states that the main minerals in the Kimberley Shales are quartz, chlorite, muscovite and rutile needles. Although carbonate is present in these shales in the East Rand, and dolomitic zones in the West Rand, there is no recorded instance of calcareous layers having been observed on the Central Rand. A chemical analysis of the shale horizon immediately underlying the exploited Kimberley Reef at Rand Leases, is given in Table 9.

The Bird Amygdaloid, where observed on the extreme eastern boundary of the Central Rand by Horwood (1905), is described as being macroscopically, petrologically and chemically almost identical with the Ventersdorp lavas as they occur south of Johannesburg. The Bird Reef Marker which occupies the same stratigraphic horizon west of this locality, is described by Mellor (1921) as a hard, dark green, dense rock which resembles indurated quartzitic mudstone in appearance. It contains chlorite and chloritoid, and is partly composed of volcanic ash.

(e) Ventersdorp System

Volcanic rocks of this System are disposed conformably on the Elsburg beds to the south of Johannesburg. Towards the western boundary of the Central Rand, the outcrop swings northwards and the lava transgress on to the Kimberley strata. A second, less extensive occurrence of members of the Ventersdorp System is present in a downthrown fault block which widens out from its apex near the centre of Johannesburg, in an ENE. direction past the Rietfontein Mine towards the area north of the East Rand. According to Mellor's (1917) mapping, the lavas and sediments in this occurrence transgress from the Upper Witwatersrand rocks over members of the Lower Division, on to the Old Granite. However, it is feasible that the contacts might be of a faulted nature, with the result that it is not possible to say whether the lavas originally flowed on to the granite. Mellor (1917) stated that the Elsburg beds overlap on to the Lower Witwatersrand strata in this trough, and that the Ventersdorp lavas are still conformable with the Elsburg, as they are along the Klipriviersberg to the south of the mines.

The lavas outcropping in the Klipriviersberg are described by Horwood (1905) as having a matrix composed of lath-shaped crystals of felspar in a micro-crystalline groundmass in which are embedded porphyritic crystals of plagioclase and augite, small amygdales of quartz, patches of calcite and chlorite, and abundant leucoxene. The colour of fresh specimens is light to dark olive-green. The larger amygdales reach up to 12 inches in length and are filled with calcite. Smaller amygdales, up to one inch in diameter, are usually filled with quartz, and even smaller ones sometimes contain dark green or black chlorite. Pyrite and chalcopyrite may be present in both the amygdales and the matrix. A chemical analysis of a typical lava found in the Klipriviersberg is given in Table 8.

The System, as developed in the Klipriviersberg, is composed entirely of andesitic lavas. Along the western boundary, southwest of the Durban Roodepoort Mine, boulder beds and tuffaceous layers, originally mapped by Mellor (1917) as belonging to the Dwyka Series at the base of the Karroo System, are now considered to be Ventersdorp sediments overlying the lavas. In the trough running past the Rietfontein Mine, shales, tuffaceous sediments and breccias occur interbedded in the normal lavas.

(f) Transvaal System

To the south of Johannesburg, the Transvaal System overlies the Ventersdorp lavas with a slight angular unconformity. In the extreme western portion of the Central Rand the Black Reef Series and Dolomite Series transgress across the lavas on to rocks of the Kimberley Stage. Strata of Transvaal age have not been recognised above the lavas in the trough containing the Rietfontein Mine.

The Black Reef Series at the base of the System averages less than 50 feet in thickness. A thin, black, carbonaceous shale immediately overlies the Ventersdorp lava and this is succeeded by the Black Reef itself, a bed of scattered-pebble conglomerate. This, in turn, is overlain by alternating bands of quartzite and shale. The conglomerates and quartzites weather to a greyish-white or light yellow colour, but at depth they become very dark grey. Down dip there is a tendency for the quartzites to become more shaly, and in certain localities in the Klip River valley, it is alleged that no quartzites at all are present in the Black Reef Series. On and near the outcrop, the quartzites are hard, gritty, and thickly-bedded. Horwood (1905) indicated that the main differences between the Witwatersrand and Black Reef quartzites are that the latter have (a) a greater hardness, (b) a more persistent crystalline nature, (c) greater roundness of individual granules, (d) closer packing of granules, (e) a trace of manganese, (f) no sericite or talc, (g) no schistosity, and (h) a very high percentage of silica.

The Dolomite Series is composed of dolomitic limestone and chert, the latter being particularly well-developed near the top and bottom of the Series. Zones of relatively pure dolomite occur within the Series and near Jackson's Drift such material has been shown to have a composition of 53 per cent $CaCO_3$ and 41 per cent $MgCO_3$. The base of the Pretoria Series, overlying the Dolomite apparently conformably, is marked by the Bevets Conglomerate, consisting of brecciated chert talus cemented by sandstone. Higher in the succession are the quartzites and shales of the Timeball Hill and Daspoort Series, both of which outcrop far to the south of the Central Rand. The thicknesses of the Dolomite and Pretoria Series are accentuated by the presence of a number of interbedded sheets of igneous material.

A chemical analysis of dolomite from Jackson's Drift, in the Klip River Valley, is given in Table 9.

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(g) Karroo System

The sandstones and shales of this System, which occur unconformably over the Witwatersrand, Ventersdorp and Transvaal Systems, belong to the Ecca Series. Basal conglomerates, which were previously throught to be members of the Dwyka Series, have now been shown to belong to the Ventersdorp System.

The cover of horizontally disposed strata becomes progressively more extensive in an easterly direction with the result that from the western portion of E.R.P.M. Mine onwards, the Witwatersrand System no longer outcrops. In the relatively small outliers of Ecca beds which lie south and southwest of Johannesburg, thin coal seams are found and, in the early days of the City Deep Mine, the coal was actually mined and used for firing the hoist boilers.

(h) Post-Witwatersrand Intrusive Rocks

Although there are numerous surface indications of the presence of dykes and sills in the Central Rand, yet the abundance of their numbers has been brought to light only as a result of the extensive underground workings. Intrusives of basic composition predominate, but intermediate and acid varieties are also common. Weber (1909) and Young (1917) list the following types of dykes and sills as being present in the mines between Roodepoort and Boksburg: granite porphyry, microgranite, granophyre, granodiorite, syenite, elaeolite syenite, quartz keratophyre, quartz diorite, diorite, enstatite andesite, quartz dolerite, dolerite, diabase, olivine dolerite, epidiorite, basalt, syeno-gabbro, gabbrodiorite, gabbro, norite, olivine norite, and pyroxenite.

The oldest and most abundant dykes and sills are considered to be of Ventersdorp age. They are highly altered, and frequently sheared and faulted. They are usually diabases and epidiorites, and many are characterised by the presence of ilmenite and leucoxene. The next oldest intrusives are pyroxenites, gabbros, dolerites and quartz dolerites which are believed to have been intruded at the same time as the emplacement of the Bushveld Complex to the north. Pilanesberg-age intrusives are mainly syenites, diorites, quartz diorites, dolerites, gabbrodiorites and granodiorites. They are often of a composite character with marginal dolerite, intermediate gabbrodiorite, and a core of granodiorite. The Robinson Dyke on Robinson Deep, described by Schreiner and van Niekerk (1958), and the Simmer and Jack Dyke on the Simmer and Jack Mine (van Niekerk, 1959), are examples of such intrusives. The youngest, and least abundant dykes and sills, are normal dolerites of Karroo age.

Chemical analyses of a Karroo dolerite dyke on Rietfontein Mine and a granite porphyry dyke encountered in a borehole between the town of Alberton and the southern boundary of Simmer and Jack Mine, are given in Table 8. The age of the latter dyke is not known.

Dykes predominate by far over sills. The dip of the dykes is generally vertical or very steep. The thickness of the intrusive bodies varies between a few feet and less than 100 feet, but there are a number of bodies which attain widths of several hundred feet. Many fault-planes are occupied by dykes. Where sills cut across the reef horizons from footwall to hangingwall, the reef is often displaced vertically by an amount equivalent to the thickness of the intrusive. According to van Niekerk (1959), Pilanesberg dykes usually strike NNW. The ilmenite diabase dykes of Ventersdorp age are frequently aligned east-west approximately. The remainder of the intrusives tend to strike in a north-south direction.

C. METAMORPHISM

The schists, amphibolites and serpentinites of the Swaziland System have suffered metamorphism of the greenschist to amphibolite facies, and appear to have been subjected to these changes in pre-Witwatersrand times. There is no doubt that the Witwatersrand beds have undergone some degree of alteration other than normal diagenesis, but it is difficult to define what grade or type of regional metamorphism has been effective. Fuller (1958a) simply states that the quartzites of the Upper Division are hydrothermally altered. Pyrophyllitisation, particularly of the Main-Bird Series, occurred during hydrothermal activity preceeding the consolidation of the sandstones. Fuller (1958b), in another investigation, found that the sphalerites in the Bird Reefs on the West Rand formed at a temperature of about 450^{o}C, which is too high a figure to have been brought about by burial of the sediments alone. Emanations of volatiles, associated with the extrusion of the Ventersdorp lava, probably permeated the beds and caused the re-distribution of the metals previously concentrated by sedimentary processes.

In broad terms, the main effects of regional metamorphism have been the alteration of argillaceous sediments to compact shales and slates with the formation of sericite, chlorite and chloritoid, and the change of the arenaceous members to quartzites showing secondary silicification and pyrophyllitisation. In the conglomerates, sericite, chlorite and chloritoid have also been produced. Reinecke (1927) cites the widespread occurrence of secondary pyrrhotite, rutile and tourmaline as an indication of intense heat and pressure, while the development of chlorite and sericite is believed to give evidence of the presence of much water, but less heat and pressure.

The effects of local metamorphism and metasomatism are prominent in many localities, and are frequently, but not invariably, associated with the presence of intrusive rocks. The local and restricted darkening of quartzites near faults and dykes is due to the formation of chlorite, sericite, calcite, dolomite, and metallic sulphides. Mineralised quartz veins are often developed between the selvedge of the intrusive and the quartzites. Young (1909) reported the presence of talc and kyanite in such veins on the old Roodepoort United Mine, of tourmaline at the Croesus Mine, and of epidote at the Simmer and Jack Mine.

Zones of intense metasomatism on a local scale have been reported on the Rose Deep, Crown Mines and E.R.P.M. mines by Pirow (1920). These extend longitudinally over several thousand feet and have a width varying between a few feet and 150 feet. The alteration has resulted in a clayey product with rounded boulders of quartzite, reef, and footwall shale up to 2 feet in diameter, with a mass of quartz, calcite and pyrite covering the boulders and other included fragments. Elsewhere, the hangingwall and footwall of the Main Reef group of conglomerates contain thin bands of altered quartzite with stalagmites and stalactites of calcium carbonate and lesser amounts of magnesium carbonate and kaolin, with some iron and calcium sulphate. In contrast to the large zones described above, these thin bands are interbedded and do not crosscut the reef horizons, have no boulders, and are not as highly mineralised. Between 2 and 5 Levels on the old Meyer and Charlton Mine, Denny (1909) found that over a length of 500 feet the quartz pebbles in the reef had been replaced by calcite, set in a matrix of calcareous matter and pyrite with high gold values. In some places the quartz and calcite pebbles were equally numerous, in other places there was a preponderance of one type or the other.

D. AGE OF FORMATIONS

With the exception of the Karroo strata, all the rocks present on the Central Rand are of Precambrian age. Information on age measurements, cited by Nicolaysen (1961), dates the Old Granite, in the Johannesburg-Pretoria dome at 3200 $\pm$ 65 million years, with respect to the time of its original formation. The initial crystallisation of the detrital uraninite grains found in the auriferous conglomerates took place at 2950 $\pm$ 150 m.y. On the Sub Nigel Mine on the East Rand, chlorite, sericite and monazite replace the conglomerate, and the authigenic monazite has been dated at 2150 $\pm$ 100 m.y. The age of the Witwatersrand System is thus between 2100 and 3000 million years.

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There is evidence of the reheating of the granite at 2120 $\pm$ 10 m.y., and the intense chemical alteration, diagenesis and hydrothermal activity which appear to be associated with this reheating, are considered to have been brought about by the extrusion of the Ventersdrop lava. Dykes on the Central Rand belonging to the Bushveld intrusive cycle have been dated at 1950 $\pm$ 150 m.y. Schreiner and van Niekerk (1958) concluded that the Robinson Dyke, of Pilanesberg type, and occurring on the Robinson Deep Mine had an age of 1290 $\pm$ 180 million years.

E. STRUCTURE

(a) Folding

The Central Rand forms portion of the northern limb of the main synclinorium of the Witwatersrand Basin, which strikes from southwest of Klerksdorp in an ENE. direction, between Potchefstroom and the Vredefort Dome, to the centre of the East Rand Basin. The axial plane of this major fold lies well to the south of Johannesburg, between the Klip River Valley and the Vaal River, and the core of the fold is occupied by the members of the Pretoria Series, in the area described in the present paper. The limb dips southwards off the Johannesburg-Pretoria granite dome, and has an average inclination, within the boundaries of the mines, of 30° with respect to the Upper Witwatersrand beds. Along a north-south line through Johannesburg, there is a progressive decrease in the inclination of successively higher strata. The Jeppestown shales dip at 75° to the south, the Main-Bird horizons at 50°, the Kimberley Reefs at 40°, the Elsburg conglomerates at 20°, and the Black Reef Series at only 5°. In places, beds belonging to the Government Reef and Hospital Hill Series dip at angles of between 70° and 90°, and there are instances in the eastern section of the area where the strata are overturned to the north.

In the extreme western section of the Central Rand, the beds in the upper levels of the mines, including the outcrop portions, have dips of the order of 30°, but at depth the dip increases to vertical, and below 8000 feet on the Rand Leases Mine, the strata are slightly overturned and dip northwards at a very steep angle. The dip in the upper levels of the mines increases progressively eastwards so that, in the vicinity of Johannesburg, the Main Reef group is inclined at angles of over 70° at the surface. This dip flattens with depth and on the bottom levels of Crown Mines, at a depth of 9000 feet, the reefs are inclined at angles of as little as 10° to the south. In the eastern portion of the Central Rand, the dip at surface decreases again and the variation with depth does not appear to be as marked as in the localities mentioned above. Mellor (1921) stated that dips in the extrème east remain fairly constant at about 20° from the outcrop down to the deeper levels of the mine workings.

These variations in the attitude of the beds are believed to be due to gentle folding along axial planes trending parallel to the strike of the beds and to the axial plane of the Potchefstroom synclinorium. These east-west folds are thus small synclines and anticlines on the limb of the major synclinorium described above. Evidence of this trend of folding is also provided by the suggestion of a syncline being present in the trough filled with members of the Ventersdorp System, which extends ENE. from the centre of Johannesburg, through Bezuidenhout Valley, to beyond the Rietfontein Mine. Mellor (1917) mapped two folds with this axial plane direction at the western end of the Central Rand. A detached occurrence of Transvaal Dolomite occupies a small basin on the farms Vlakfontein 238 and Vogelstruisfontein 233, south of the Durban Roodepoort Deep Mine. Detailed work has shown the basin to be a syncline, the axis of which strikes a little south of east. To the south of this fold is an anticline in the Elsburg beds on Doornkop 239 with an axis which is parallel to that of the syncline. At the old Black Reef workings at Roodekop, near Natalspruit, Stonestreet (1897) recorded the presence of east-west-trending folds in the Black Reef Series itself and in the underlying Ventersdorp lavas. The wavelength of these folds was reported to be 300-400 feet, and the amplitude 50-200 feet.

The results of Mellor's (1917) and Reinecke's (1927) investigations, coupled with the information provided by the extensive mining operations, show that a second direction of folding can be recognised on the Central Rand. The axes of these folds trend NNW. and are virtually at right angles to those previously mentioned. It is apparent that the last pulse of deformation in the area tended to preferentially activate the NNW. folds, so that they now appear to be younger than the ENE. folds. Folding about the NNW. axes is also gentle and open, and can only be satisfactorily recognised on the detailed mine plans showing reef elevations. The more important of such folds are : (i) an anticline through Doornkop 239 and Vlakfontein 238, the axis of which terminates against the Roodepoort Fault, (ii) a syncline through Vogelstruisfontein 233 and the Durban Roodepoort Mine, (iii) an anticline through Palmietfontein 141, Turffontein 100, the southwestern corner of the Robinson Deep Mine and the northeastern corner of Crown Mines, this fold effectively dividing the Central Rand into two sections, (iv) a syncline through the boundary between Leeuwpoort 113 and Klippoortje 110, the old Witwatersrand Deep Mine, the Rietfontein Mine, and through the remnant of Swaziland schists surrounding the Modderfontein Dynamite Factory, and (v) an anticline - the Boksburg "Gap" - through Rietfontein 115, Witkoppie 64 and Zuurfontein 33, which forms the eastern boundary of the Central Rand.

Mellor (1917) found that slatey cleavage was frequently, but not always, present in the shales of the Lower Division of the Central Rand. This cleavage appears to be an axial-plane cleavage parallel to the ENE.-trending folds. The Kimberley Shales show a similar cleavage in places. Puckering along the NNW. direction has been observed in certain shales of the Hospital Hill Series.

(b) Faulting

The most conspicuous faults in the area between Roodepoort and Boksburg were considered by Mellor (1921) to be the important longitudinal faults which are subparallel to the strike of the beds. The Rietfontein, Roodepoort, Doornkop and Witpoortje Faults fall into this category.

The Rietfontein is the most persistent of these faults, extending across the whole length of the Central Rand and continuing into the West Rand as the Witpoortje Fault. According to Mellor (1917), this fault is actually a group of closely-spaced parallel faults, dipping northwards and with a downthrow to the north. Intense crushing has taken place along the planes of the faults and the alternating bands of shales and quartzites are so sheared as to render individual horizons indistinguishable. The shales are drawn out in long lenticles between the quartzites or are eliminated altogether. In the Johannesburg area, this displacement faults out most of the Government Reef Series, while north of Florida, it is the Hospital Hill Series which is mainly eliminated. Faulting along the Rietfontein line is essentially of post-Ventersdorp and pre-Transvaal age, with the movement probably initiated prior to the extrusion of the Ventersdorp lava. Further movements, of a relatively small order, took place along the same planes in post-Transvaal times.

The western limit of the Central Rand is marked by the Roodepoort Fault and a sub-parallel offsplit, the Saxon Fault. The former has an upthrow on the northern side, with the result that a conspicuous horst of Lower Witwatersrand rocks is developed between it and the Witpoortje Fault. The Main Reef group is cut off on the old Princess Mine by the Roodepoort Fault, while the Bird and Kimberley Reefs further to the south, terminate against the Saxon Fault.

In addition to these extensive normal faults, Reinecke (1927) concluded that there are three other groups of major faults: (i) an east-west set, more or less parallel to the Rietfontein type, but with overthrusting and resultant displacements of up to 300 feet vertically, (ii) a northwest-trending set of mainly normal faults, and a northeast-trending set of similar dislocations, with vertical displacements of up to several hundred feet, and of younger age than the east-west faults, and (iii) a set of north-south displacements, younger in age than either of the other two groups.

In a detailed investigation of the Consolidated Main Reef Mine, Reinecke (1927) found that the older major faults, both normal and reverse, were oriented along the directions 010°-025° (true) and 050°-065°, while the apparently younger faults had their strikes along 065°-080° and 335°-350°. The vertical displacements along these directions varied between 40 and 300 feet, and normal faults outnumbered reverse faults in the ratio 5:1. The strike of the Main-Bird Series on the Mine is 300°.

Minor strike and transverse faults are abundant, and are mostly of the normal type, although reverse faults and tear faults are common. Pivotal faults and dislocations with variable throws have also been recorded on numerous occasions. According to Pirow (1920), the strongest evidence for the recognition of tear faults is the sudden termination of zones of high gold values against a fault-plane and the reappearance, some distance away horizontally, of a similar payshoot on the other side of the dislocation. Fault-planes are often occupied by dykes, and the so-called "chert dykes" are, in fact, zones of intense mylonitisation along lines of shear.

A very conspicuous and persistent fault which does not appear to extend into the Witwatersrand rocks is marked by a line of crushed granite and quartz-fill which strikes for a distance of 25 miles. The fault runs NNE. across the Johannesburg-Pretoria granite dome from Northcliff in the south to near the Swartkops Aerodome, south of Pretoria. The dip of the dislocation appears to be vertical and the downthrow side is on the west.

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ECONOMIC GEOLOGY

A. NATURE OF GOLD MINERALISATION

(a) Types of Occurrence

Gold mineralisation is present in the Upper Witwatersrand Division in (i) the matrix of conglomerate beds, (ii) banded pyritic quartzites, (iii) thin films on parting planes between unconformities or disconformities, (iv) quartz veins, and (v) dykes. Of these, only the first two constitute exploitable ore-bodies, the remainder contributing to the output on rare occasions only and to a very limited extent.

The presence on parting-planes of gold, together with uranium and carbon, is not as common on the Central Rand as in other sections of the Witwatersrand Goldfield. Pirow (1920) found on the Consolidated Main Reef Mine that the Main Reef Leader in places thins to nothing but a contact plane on which scattered pebbles of over 2 inches in diameter are sporadically present together with fair amounts of gold. Low-grade gold mineralisation is present in certain dykes, particularly where such intrusives cut across the reef horizons. Pirow (1920) cited an example of a north-south dyke, grey in colour and extremely fine-grained, which was stoped on Crown Mines where it intersected the reef horizon. Away from the reef the gold content dropped to a negligible quantity. According to Reinecke (1927), the South Rand Dyke on 19 Level, near 16 Shaft, Crown Mines, averaged 1.3 dwts./ton over a length of exposure of 380 feet. The highest values recorded reached up to 4.5 dwts./ton.

Gold in quartz veins appears to be more prevalent in the shales of the Lower Division of the Central Rand than in the quartzites of the Upper Witwatersrand beds. The first discoveries of gold on the Central Rand proper, such as Strubens' Confidence Reef on Wilgespruit, were made in quartz veins, and there are numerous instances of short-lived mining companies formed to work such gold-bearing veins in the Government Reef and Jeppestown Series. Young (1909) describes rich pockets of gold in quartz veins on the Jumpers, Simmer and Jack and Geldenhuis Deep mines, where the veins also carried pyrite and lesser quantities of chalcopyrite. One such quartz blow on the Jumpers Mine measured 10 ft. x 10 ft. x 10 inches and was partly in contact with a fine-grained basic dyke. The gold occurred as coarse hackly masses in the quartz and as layers in cracks in quartz, pyrite and apatite. The most common sulphides present in the quartz veins are pyrite and chalcopyrite, while pyrrhotite, galena, sphalerite and arsenopyrite occur less frequently.

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(b) Conglomerate Reefs

Of the thickness of over 24,000 feet of the Witwatersrand System on the Central Rand, conglomerate beds, bands and zones total approximately 2000 feet, or about 8 per cent. With the exception of two thin horizons in the Government Reef Series, all these conglomerates are present in the Upper Witwatersrand Division where, according to Mellor (1921), they occur as single beds or as large groups containing, in some instances, more than 100 individual pebbly bands. Almost all of these conglomerates contain gold, but only a small percentage acts as hosts to economically exploitable concentrations of the metal.

The most important auriferous conglomerates, or banket, from an economic point of view, occur in the Main-Bird Series, while the most conspicuous with reference to number and thickness are developed in the Kimberley-Elsburg Series. The reefs in the former series can be divided into : (i) a group comprising the North Reef, Main Reef and Bastard Reef, which lies between the Jeppestown Shales and the Black Bar, (ii) a group containing the Main Reef Leader, Middle Reef, South Reef, and South South Reef, which is located at the base of the mass of quartzites separating the Black Bar and the Kimberley Shales, (iii) a poorly-developed group containing the Livingstone Reef about half-way between the two shale horizons, and (iv) the Bird Reef group which occurs in the upper portion of the Series. The minable reefs in the Kimberley Stage occur in the bottom portion of the Kimberley-Elsburg Series, while the Elsburg Reefs, which have not been found to be economic on the Central Rand, occur at the very top of this Series. The stratigraphical positions of the more important of these groups in the type section across the Central Rand, are shown in Table 5.

Differences in thickness of the important Main-Bird Series, as it occurs in the mines along the strike of the Central Rand, are shown in Table 7. The variable stratigraphic distances between the North Reef, Main Reef Leader, South Reef, Livingstone Reef, Bird Reef group and Kimberley Reef group are indicated in Table 6. Table 10, compiled from data contained in Jones (1936) and in the annual reports of the individual mining companies, lists, more precisely, the variations in the average thickness of the partings between the North Reef and Main Reef, between the Main Reef and the Main Reef Leader, and between the Main Reef Leader and the South Reef. The average channel widths of the Main Reef, Main Reef Leader and South Reef from west to east across the Central Rand are shown in Table 11 which is based on information gathered from annual reports of mining operations. The Bird Reef and the Kimberley Reef are exploited in the western portion of the Central Rand only, and the average thickness of the channel widths of these reefs, as well as those of the North Reef in this portion, are given in Table 12, which has also been compiled from the annual reports.

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Name of Mine	NR - MR (feet)	MR - MRL (feet)	MRL - SR (feet)
Durban Roodepoort Deep	35	MR - SR :	80
Rand Leases	40	2	95
Consolidated Main Reef	55	4	105
Langlaagte	40	4	90
Crown Mines	75	4	90
Robinson Deep	65	4	75
Village Main Reef	30	4	55
City Deep	45	6	35
Nourse Mines	40	3	35
Geldenhuis Deep	40	1	20
Simmer and Jack	45	6	15
Rose Deep	40	8	10
Witwatersrand G.M.	40	5	10
Witwatersrand Deep	35	1	5
E.R.P.M. (Driefontein Section)		MR - SR :	15
E.R.P.M. (Angelo Section)		MRL - SR :	10
E.R.P.M. (Hercules Section)		SR only developed	

Table 10 : Variations in Average Thicknesses of Partings between North Reef and Main Reef, between Main Reef and Main Reef Leader, and between Main Reef Leader and South Reef, from West to East along Strike of Central Rand.

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

Table 11 : Variations in Average Channel Widths of Main Reef, Main Reef Leader and South Reef, from West to East along Strike of Central Rand.

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

Table 12 : Variations in Average Channel Widths of North Reef, Bird Reef (exploited horizon), and Kimberley Reef (exploited horizon), from West to East along Strike of Western Portion of Central Rand.

There is a progressive increase in thickness, stratigraphically upwards, of the various conglomerate groups, as can be seen from the following figures which apply to a north-south line through the Robinson Deep Mine :

Elsburg Reefs group	:	1300 feet thick
Kimberley Reefs group	:	700 feet thick
Bird Reefs group	:	230 feet thick
Main Reef Leader/ South Reef group	:	150 feet thick
North Reef/Main Reef group	:	90 feet thick

Table 13, compiled from the annual reports of mining operations and from Jones (1936), indicates the relative economic importance from mine to mine, of the various reefs which have contributed to the gold output of the Central Rand.

(i) Promise Reef

Mellor (1917) described this horizon in the bottom portion of the Government Reef Series as having predominantly small pebbles, with a few of larger diameter up to 2 inches. A considerable proportion of the pebbles consists of fine-grained quartzite. The conglomerate bed is usually only a few inches thick, but increases to 2 feet over short

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

Table 13 : Variations in Relative Economic Importance of Reefs Present in Upper Witwatersrand Division, from West to East along Strike on Central Rand.

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

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

distances in a few places. Gold values have not proved to be economic in any portion of the Central Rand.

(ii) Government Reef

This conglomerate lies directly on a 500 feet thick shale band near the top of the Government Reef Series. Mellor (1921) recorded its thickness as varying between a single line of pebbles and a maximum of 24 inches.

The pebbles are well-rounded and consist mainly of white quartz up to 2 inches in diameter where the reef attains its optimum development at Witpoortje. From here to north of Florida the reef is well-developed, but it then thins eastwards although still present to the east of Johannesburg. There is no recorded production of gold from this reef on the Central Rand.

(iii) North Reef

In the central and western portions of the area, the North Reef consists of small, white and grey pebbles up to $\frac{1}{2}$-inch in size, although on the old Ferreira Deep and the City Deep mines, where the reef is particularly well-developed, sporadic boulders up to 6 inches have been observed. The conglomerate is generally poorly mineralised (Jones, 1936). From the old Witwatersrand Mine eastwards the horizon is known as the Angelo Reef and is separated from the Main Reef by a progressively thinner quartzite parting, so that in the Hercules section of E.R.P.M. Mine, the latter reef has transgressed across the Angelo Reef. The reef is also much thinner in the eastern section of the Central Rand, generally being less than 6 inches thick, as compared with the widths of up to 40 inches on the Robinson Deep Mine (see Table 12). Except for some very limited stoping on the old Nourse Mine and on the Rose Deep Mine, the North Reef is of negligible economic importance.

(iv) Main Reef

This horizon, according to Denny (1909), is the most strongly developed of the reefs occurring in the Main Reef group, but, at the same time, is poorer in gold values than either the Main Reef Leader or the South Reef. Pebbles of up to 2 inches in diameter are common, and in the City Deep and old Langlaagte mines, boulders of up to 6 inches were reported by Pirow (1920). Sorting is poor. From Table 13, it can be seen that the Main Reef is economically more important in the eastern portion of the area than elsewhere, with the possible exception of the Durban Roodepoort Mine. In the eastern portion, the reef generally consists of three or four conglomerate bands separated by thin quartzite partings (Jones, 1936). Pebbles attain diameters of up to one inch, are white to grey in colour, and are set in a well-mineralised matrix. In the Cason section of E.R.P.M. the Main Reef is transgressed by the Main Reef Leader, and does not continue eastwards to the East Rand. Average channel widths of the Main Reef across the whole of the Central Rand are given in Table 11, while the variations in the thickness of parting between this reef and the underlying North Reef and the overlying Main Reef Leader are given in Table 10.

(v) Bastard Reef

According to Jones (1936), the Bastard Reef is present only in the relatively small portion of the Central Rand lying between the eastern boundary of the old Geldenhuis Deep Mine and the centre of the E.R.P.M. Mine. It is not a true conglomerate, but appears to be an arenaceous equivalent of the Black Bar which separates the Main Reef from the Main Reef Leader elsewhere on the area. The matrix is usually a very fine-grained shaly quartzite in which are scattered quartz pebbles. The thickness is extremely variable and erratic over short distances, the maximum observed being 45 feet in the old Witwatersrand Mine. The average thickness, where mined, is between 5 and 10 feet. On the E.R.P.M. Mine the Bastard Reef is transgressed by the Main Reef Leader, more or less along the same line as the transgression of the latter reef over the Main Reef.

(vi) Main Reef Leader

This reef is the most important source of gold on the Central Rand. Except for the extreme eastern and western portions of the area, it is mined continuously along strike for over 20 miles and down dip for a maximum of almost 4 miles along the plane of the reef from the outcrop. In general, the Main Reef Leader is narrower than the Main Reef, but the pebbles are larger - up to 3 inches and more in diameter - and are better sorted and graded. Towards the east the pebbles become smaller, but frequently more closely packed, while the intensity of mineralisation of the matrix still remains high. The pebbles are well-rounded and are composed mainly of quartz, quartzite and chert. Reinecke (1927) observed that this reef is frequently of a much darker colour than either the hangingwall or footwall quartzites, due, probably, to the presence of significant amounts of secondary minerals. Where the reef is particularly dark, the footwall often has a darker colour than the hangingwall. In the eastern and central portions of the area, the footwall of the Main Reef Leader is constituted by the Black Bar, but in the west this shale becomes sporadically developed, and the Main Reef and Main Reef Leader are in contact in many places. The thickness of the reef decreases towards the eastern and western boundaries of the Central Rand. The horizon can no longer be recognised from the centre of Durban Roodepoort Deep Mine westwards, and between this point and the Consolidated Main Reef Mine, in addition to becoming progressively thinner, it also assumes a more patchy and lens-like character. According to Jones (1936), the Main Reef Leader is transgressed by the South Reef near the common boundary between the old Witwatersrand Mine and the E.R.P.M. Mine, and does not exist on the extreme eastern portion of the Central Rand. The distances between the Main Reef Leader and the Main and South Reefs, from west to east across

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the area, are shown in Table 10. Variations in average channel widths from mine to mine are given in Table 11.

(vii) Middle Reef

This reef is of economic importance only in the locality in which the Bastard Reef is mined, but it persists as a relatively barren conglomerate band well to the west of these limits. According to Jones (1936), on the Rose Deep Mine the reef consists of several conglomerate bands totalling 30 inches in thickness spread over an average channel width of 70 inches. The pebbles average 1 inch in diameter, are bluish-grey to white in colour, and are very closely packed. The matrix is well mineralised. Here the reef is about 15 feet above the Main Reef, but on the old Nourse Mines the parting increases to 40 feet, while the reef width decreases to 15 inches. Further west the parting increases still further to a maximum of 60 feet, the reef width narrows to less than 6 inches, the pebbles become smaller, and the conglomerate gives way to a grit from Crown Mines westwards. East of the old Witwatersrand Mine the Middle Reef no longer exists, having been transgressed by the South Reef.

(viii) South Reef

This reef is the next most important after the Main Reef Leader, from a gold production point of view. Along strike it is more persistent than any of the underlying reefs, but the payable gold content does not extend as far down dip as that of the Main Reef Leader, with the result that, in all the mines, stoping of the reef has ceased some distance before the southern boundaries of the properties have been reached. The reef zone usually consists of a number of individual conglomerate bands separated by quartzite partings, and the lower bands, sometimes called the South Reef Leader or the Footwall Leader, frequently have the higher gold content. The pebbles are smaller than those of the Main Reef Leader, and the degree of sorting is markedly lower, so that the South Reef bears some resemblance to the Main Reef. Blue, opalescent quartz pebbles are present in large numbers in some localities (Pirow, 1920). The same author found a number of schist pebbles on the Rose Deep Mine, where the footwall of the South Reef is a coarse-grained quartzite. No such pebbles were observed in the underlying reefs. The reef decreases in thickness towards the west, and at its narrowest, in the western section of the Durban Roodepoort Deep Mine, it is underlain by a carbon seam (Jones, 1936). In this locality, the narrower the reef, the richer the gold content. The reef can be traced up to both the eastern and western boundaries of the Central Rand, and continues into the East Rand and the West Rand. The variations in its position above the Main Reef Leader, from mine to mine along the Central Rand, are shown in Table 10. In Table 11, the average channel widths of the

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exploited sections of the South Reef are tabulated for all the major mines in the area.

(ix) South South Reef

This is actually a zone composed of a number of narrow reefs situated about 100 feet above the South Reef, and of economic importance to a very limited extent, having been mined only on the Simmer and Jack Mine.

(x) Livingstone Reef

The only mining of the Livingstone Reef on the Central Rand was carried out in the very early days on the old Livingstone Mine which was subsequently to become part of the Witwatersrand Mine. Here, the reef consists of a succession of narrow pebbly bands (Mellor, 1921). Westwards the reef deteriorates into a grit, less than 6 inches thick, containing very little pyrite and negligible amounts of gold (Jones, 1936).

(xi) Bird Reef

According to Jones (1936), the Bird Reef is actually one of three to six conglomerate bands which form a group, separated by quartzite partings, over a thickness of 200 - 400 feet. The variations in thickness of this group in the mines, are shown in Table 7. Most of the bands are discontinuous and lenticular and only one has a high enough gold content to warrant exploitation. Mellor (1921) stated that the Bird Reef conglomerates are not as strongly developed as the Kimberley Reefs. Denny (1909) found the pebbles to average $\frac{1}{2}$-inch in diameter, but many ranged in size up to $1\frac{1}{2}$ inches. Mellor (1917) reported the pebbles to be smaller and less smooth in outline than those to be found in the overlying Kimberley Reefs. The Bird Reef is of economic importance only in the western portion of the Central Rand. Its average thickness from mine to mine in this locality is given in Table 12.

(xii) Kimberley Reefs

This group of conglomerates is distributed over a zone of between 500 and 900 feet of coarse-grained quartzites and grits. As many as 17 individual reef bands occur, varying in width from 18 inches to 11 feet (Jones, 1936). Individual bands are lenticular and do not persist for any great distance along strike (Mellor, 1921). The average pebble size is considerably larger than that for any of the underlying reefs, and according to Denny (1909), reaches 4 inches in places, with numerous pebbles of over 6 inches in size. Sorting is poor and the smaller pebbles are less smooth and less round than the larger ones. As with the Bird Reef, the Kimberley Reef has proved payable only in the western section of the Central Rand. In places, two separate conglomerate horizons

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have been worked, of which the more important occurs immediately above a narrow bed of shale, about midway in the zone of conglomerates. The variations in the average channel widths of the reef exploited west of Johannesburg are given in Table 12.

(xiii) Elsburg Reefs

These consist of numerous conglomerates lying within a zone of coarse-grained quartzite and grit between 1300 and 1900 feet thick. Hundreds of pebble bands occur, but none has any persistence along strike or down dip. Boulders up to 10 inches are found, and numerous pebbles averaging 6 inches are present. The pebbles, in general, are larger than those of the Kimberley Reefs. Mellor (1917) stated that coarse-grained vein quartz pebbles are the most abundant, and Pirow (1920) found that those consisting of jet black glassy quartz, green banded chert, schist, grey banded chert, and quartz porphyry are prominent. Bands with the largest pebbles occur over a zone 350 - 500 feet wide, and below this the conglomerate horizons are less numerous and contain smaller pebbles. The beds associated with the conglomerates are very coarse grits with very irregular and impersistent bedding planes. The average pebble size shows a marked decrease both eastwards and westwards from the exposures south of Johannesburg. No payable gold values have yet been found in the Elsburg Reefs along the Central Rand.

(xiv) Ventersdorp Contact Reef

This reef, which is developed at the base of the Ventersdorp lavas, is not present in the eastern, central and near western portions of the Central Rand. At the western extremity, in the South Roodepoort Mine, it is exploited, but this mine is not included in the scope of the present paper.

(xv) Black Reef

This reef at the base of the Transvaal System has been mined to some extent south of Johannesburg, particularly on the farms Roodekop 139 and Rooikop 140, near Natalspruit. The more important mines in this locality were the Orion, Minerva, Meyer and Leeb, Black Reef and Cornucopia. According to Horwood (1905), the reef consists of a hard, siliceous conglomerate containing small pebbles and fragments of quartz, quartzite, chert and Ventersdorp lava. The reef width varies between a few inches and 14 feet, and generally the lowest 6 inches are heavily mineralised with pyrite and contain the most gold. The footwall of the conglomerate is a dark, ferruginous clay, changing to shale at depth, which is well mineralised with gold and pyrite in places (Stonestreet, 1897). The hangingwall is composed of 30 - 70 feet of alternating quartzite and shales which are succeeded

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by 10 - 100 feet of quartzite, these, in turn, being overlain by the dolomite. In addition to its development in the conglomerate, pyrite is also present in the hangingwall quartzites and, in places, in the dolomite (Stonestreet, 1897).

(c) Banded Pyritic Quartzites

These reefs have constituted an important source of gold on the east central portion of the area between Roodepoort and Boksburg. They represent infillings of erosion channels which have been scoured in the shales, quartzites and conglomerates immediately underlying the Main Reef Leader. The cutting and filling of these channels took place in post-Main Reef and pre-Main Reef Leader times, and, though the Main Reef might be missing entirely where the scour was deep enough, the Main Reef Leader is continuous and uninterrupted across the channels.

The material filling the channels consists mainly of an inhomogeneous assemblage of cross-bedded quartzites, irregular and lenticular conglomerates, and sandy argillaceous layers. The mineralised horizons are composed of dense, dark quartzites containing alternating layers of pyrite and barren quartzite, the layers being parallel to the bedding planes. The thickness of the pyrite bands varies between a single line of granules to many feet. In addition to pyrite, the mineralised bands contain zircon, chromite, arsenopyrite and pyrrhotite. Secondary quartz veins, in fractures in the pyrite layers, contain pyrrhotite and, to a lesser extent, sphalerite, with visible gold also present in some instances. The barren quartzose layers between the mineralised bands rarely contain isolated grains of pyrite and zircon, but chloritoid is present and the quartz grains contain needles of tourmaline in many instances. There is generally an antipathetic relationship between the banded pyritic quartzites and lenses of poorly-sorted conglomerate in the erosion channels, the former not being present where the latter are developed.

The banded pyritic quartzites that have been mined on the Central Rand are confined to two broad channels which are located in the area between the Simmer and Jack Mine on the east and the Robinson Deep Mine on the west. The general strike of the channels is ENE. The northern one occurs on the Village Main Reef Mine and attains a maximum width of 3000 feet, with the depth of scour being over 100 feet in places. It has been traced for over 3 miles from the outcrop. The second channel lies parallel to the first, has a width of between 2000 and 2500 feet, a depth of scour of over 270 feet, and a strike length of over 5 miles from Geldenhuis Deep, through Nourse Mines and City Deep to Robinson Deep (Fowler, 1948). The termination of both channels occurs on the eastern side of the NNW. anticline through the southwestern corner of Robinson Deep. The northern channel swings from ENE. to NNE. before petering

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out, while the southern one changes direction to north-south before it ends.

The direction of flow of water-borne sediments in the channels appears to have been from the east-north-east to the west-south-west. The width of the channel and the depth of scour become greater in the direction of apparent flow, whereas the gold content decreases to the WSW. Pirow (1920) believed that the Bastard Reef, as developed on the Rose Deep Mine, might be located in the continuation of the southern channel. The cut-off of the channel fillings against the Main Reef is usually, but not invariably, steep and sharp and there is a tendency for the northern bank of the scour channels to be more precipitous than the southern bank (Fowler, 1948).

In the eastern section of the old Geldenhuis Deep Mine, the payable pyritic quartzites formed a vertically continuous zone 25 feet wide in places. The average grade of the exploited bands in this section was 4 dwts. per ton whereas in the western section, the grade dropped to 3 dwts. per ton. Here four economic zones were present in the Pyritic Quartzites at depths of 15 - 20 feet, 30 - 35 feet, 50 - 55 feet, and 75 - 85 feet below the Main Reef Leader. The bottom horizon contained the most gold and was payable over the full width of 20 feet. In the old Nourse Mines, the percentage payability in this channel dropped to 34 per cent. On the City Deep Mine only three bands are present at depths of 60, 100 and 180 feet below the Main Reef Leader and the values are generally too low to permit any systematic mining.

According to Fowler (1948), 1,980,000 tons of banded pyritic quartzites (6.3 per cent of total tonnage milled) were mined from the old Geldenhuis Deep Mine at an average grade of 3.25 dwts. per ton.

Other erosion channels occur on the Central Rand, some of which also contain exploitable banded pyritic quartzites. Jones (1936) described payable pyritic quartzites in a channel between the 36 and 40 Levels on the Simmer and Jack Mine, which attained a length of 3500 feet in an east-west direction, a width of 600 feet, and a depth of up to 25 feet. On the eastern portion of the old Geldenhuis Deep Mine, there are small sinuous channels in which the flow of material was to the east and southeast. These are not deep, not clearly defined, and do not contain payable values (Fowler, 1948). On the extreme western portion of the Central Rand, erosion channels have been observed below the Kimberley Reef in places, but no exploitable pyritic quartzites have been found in them.

(d) Mineralogy of Reefs

(i) Pebbles of the Conglomerates

The pebbles are allogenic constituents of the auriferous conglomerates, comprise about 70 per cent of the rock, and consist of the following types, in approximate order of abundance:-

1. vein quartz, ranging in colour through white, cream, grey, mottled grey and black, jet black, opalescent blue, emerald green; the white, cream and grey pebbles by far predominate; the blue opalescent pebbles appear to be most common in the South Reef, but not exclusive to it; the jet black glassy quartz pebbles occur in all reefs, but seem to be most frequent in the Elsburg horizons; the light emerald green pebbles are relatively rare, small, and possibly present in the Main Reef - South Reef group only, as Pirow (1920) has reported for the City Deep and Consolidated Main Reef mines.

2. quartzite, white, grey, cream and buff in colour, sometimes gritty, and identical with interbedded quartzites in the underlying members of both the Lower and Upper Divisions of the Witwatersrand System.

3. chert, ranging in colour from white to light grey to dark grey to green; the white and grey pebbles are the most abundant, while the green chert pebbles are comparatively rare and have been recorded in abundance only on the Rose Deep and E.R.P.M. mines in the Main Reef - South Reef group (Pirow, 1920).

4. banded chert, the bands being either black and white, or green and white in colour, with the former predominating; the black bands are often completely replaced by pyrite; the bands are usually parallel to the long axes of the pebbles, but transverse banding is not uncommon; the bands are frequently bent, folded and faulted.

5. quartz porphyry; such pebbles increase in number from west to east across the Central Rand, but they are much less abundant than on the East Rand.

6. shales and schists, often indistinguishable from the shales which form the immediate footwall of the Main

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Reef Leader and the Kimberley Reef.

7. red jasper, generally rare.

8. tourmalinised rock, also rare.

Table 14 has been prepared from data contained in Pirow (1920) to show the variation in frequency of certain, more easily recognisable types of pebbles in selected mines along the Central Rand. Vein quartz, quartzite and ordinary chert pebbles are not included due to the fact that it is impossible to distinguish between these macroscopically in underground workings. The marked concentration of the listed pebbles in the far eastern section of the Central Rand can be clearly seen.

The larger pebbles in the conglomerates are generally oval and well-worn, with a tendency towards a muffin-shape (Pirow, 1920). The smallest pebbles are more often angular to sub-angular in outline. Chert pebbles usually tend to be flattish with sharp edges.

Pirow (1920) concluded that the different varieties of pebbles are irregularly distributed over the whole of the Central Rand and that no one type of pebble is characteristic of any one reef. No conglomerate band contains material which can distinguish it from any other band. The more uniform size of the pebbles, and the smoother and rounder outlines can be used, with reservations, to differentiate between the Main Reef - South Reef group and the overlying Bird and Kimberley reefs (Mellor, 1921).

(ii) Matrix of the Conglomerates

The matrix of the gold reefs is composed essentially of quartz, pyrite and phyllosilicates (muscovite, sericite and pyrophyllite). Among the lesser minerals present are, in approximate order of abundance (Young, 1917) : chlorite, chloritoid, rutile, tourmaline, carbon, zircon, calcite, dolomite, pyrrhotite, galena, sphalerite, chalcopyrite, chromite, gold, uraninite, ilmenite, leucoxene, platinoids, pentlandite, linnaeite, cobaltite, niccolite, bismuth, tellurium, anatase, monazite, xenotime, garnet and diamond. Stonestreet (1897) reported the presence of limited amounts of pure graphite in the Black Reef at the old Orion Mine. In the Angelo Section of the E.R.P.M. Mine, Horwood (1905), observed pink corundum, biotite, and colourless to pale green amphibole in the Main Reef and South Reef.

The banket has undergone metasomatism on a regional scale and has also suffered additional mineral alteration in localised areas. Reinecke (1927) lists the allogenic constituents of the reefs as quartz, zircon, chromite and tourmaline, with the remainder being mainly authigenic minerals. Secondary silicification and pyrophyllitisation have taken place, and, according to Reinecke (1927), there are at least two, and possibly more, generations of quartz, pyrite, sericite, chlorite,

Type of Pebble	CMR	CM	FD	CD	RD	ERPM
jet black and glassy	2.0	1.0	1.0	1.0	4.5	10.0
banded chert	1.2	2.5	3.3	5.0	5.0	20.0
green chert	1.0	2.0	2.5	2.5	12.5	10.0
soft schist	0.5	0.5	1.2	1.0	2.0	1.0
quartz porphyry	1.0	1.0	3.3	1.0	5.0	12.5
Total of above types	5.7	7.0	11.3	10.5	29.0	53.5

Table 14 : Variations in Number of Pebbles (per 100 sq. ft. of Reef) of Particular Compositions in Conglomerates of Main Reef Group, from West to East along Strike of Central Rand.

CMR : Consolidated Main Reef Mine

CM : Crown Mines

FD : Ferreira Deep Mine

CD : City Deep Mine

RD : Rose Deep Mine

ERP : East Rand Proprietary Mines

chloritoid and gold. The matrix of the reef becomes dark in many localities, especially in the vicinity of dykes and sills. Reinecke (1927) indicated that these localised patches of alteration of the banket contain introduced chlorite, pyrite and chalcopyrite, with smaller amounts of chromite, tourmaline, pyrrhotite and sphalerite. The darkening of the matrix might be further accentuated by an increase in the whiteness of the quartz pebbles due to these becoming crushed and fractured as a result of the emplacement of the intrusive.

Of the sulphide minerals present in the matrix of the banket, pyrite is by far the most common. In the Main Reef Leader it averages about 3 per cent by weight, but in places this figure becomes as high as 20 per cent (Reinecke, 1927). For all the conglomerate reefs, the average content of this mineral is 3 per cent of the total rock, and 12 per cent of the matrix only. In portions of the reef where the gold values are still relatively high, the pyrite content might drop as low as $\frac{1}{2}$ per cent. The composition and microscopic structure of the pyrite in the conglomerate reefs and in the auriferous banded pyritic quartzites appear to be identical. Buckshot pyrite, which resembles small pebbles in outline and shape, and which is locally well-developed in some conglomerates, is, according to Macadam (1936), of secondary origin, possibly resulting from the replacement of small pebbles, although there is an indication that some fragments might represent large, waterworn detrital grains of primary pyrite. The same author reports the development of pyritic 'nodules' up to 12 inches in diameter in the quartzites above the Main Reef in the old Nourse Mines. Pyrrhotite is the second most common sulphide and is generally most abundant in the vicinity of basic intrusives or in quartz-filled vugs in the rocks surrounding the reefs (Macadam, 1936). The relative amounts of other sulphides present can be gauged from the fact that in the gravity concentrates of the banket, cobalt is present in greater quantities than copper which, in turn, is more abundant than nickel (Horwood, 1910).

Carbon is present in most of the mines in the form of small, black, opaque, nodular grains (fly-speck carbon), less than 1 millimetre in diameter (Horwood, 1910). It also occurs as a smear on parting planes, especially underlying the South Reef in the extreme west of the Central Rand, but carbon-uraninite (thucholite) seams of over $\frac{1}{2}$-inch in width, do not appear to be present to the same degree as in the other sections of the Witwatersrand Goldfield. Carbon is relatively most abundant on the Rietfontein Mine, but there is a marked decrease southwards, eastwards and westwards from this locality (Horwood, 1910). Uraninite grains, of the order of 0.01 mm. in diameter, are found in all the reefs on the Central Rand, and in the concentrates it is frequently associated with galena, niccolite, bismuth and tellurium (Cooper, 1924). In no locality is the uraninite sufficiently concentrated to render it a source of economically exploitable uranium, and in this respect the Central Rand is unique, being the only portion of the Witwatersrand Goldfield which has not produced uranium as well as gold.

The composition of the platinoids in the heavy mineral concentrates obtained from the banket can be seen in the following analysis of osmiridium from the City Deep Mine (Hall, 1938) :

gold	4.10 per cent
platinum	8.41
iridium	29.02
osmium	37.11
rhodium	0.19
ruthenium	12.45

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The balance of the concentrate consisted of sulphides and non-metallic heavy minerals.

The gold is present in the matrix in submicroscopic sizes, which range between 0.001 and 0.100 mm. in diameter, the average being 0.04 mm. According to Reinecke (1927), between 45 and 65 per cent of the grains lie within the range between 0.01 and 0.07 mm. A size analysis of gold particles for two mines on the Central Rand was carried out by Graham and Wartenweiler (1924) and the results are presented in Table 15. Apparently the gold is coarser in the central portion of the Central Rand, with the particle size becoming smaller towards Roodepoort and Boksburg.

Name of Mine	+ 60 mesh	-60 + 90 mesh	-90 + 200 mesh	-200 + 260 mesh	-260 mesh
Consolidated Main Reef	2.30	10.90	20.60	19.50	46.70
City Deep	1.30	5.90	18.90	28.70	45.20

Table 15 : Size Analyses of Gold Particles in Main Reef Leader : Percentages of Total Gold Present in Whole Sample.

+ 60 mesh : + 0.254 mm.
-60 + 90 mesh : -0.254 + 0.152 mm.
-90 + 200 mesh : -0.152 + 0.076 mm.
-200 + 260 mesh : -0.076 + 0.050 mm.
-260 mesh : -0.050 mm.

Some of the grains of gold are more or less rounded, but most occur as jagged, hackly grains or flakes. The metal replaces constituents of the matrix and occupies cavities. According to Reinecke (1927), gold also occurs in veinlets in pebbles, metasomatically replacing the quartz, the veinlet passing from the matrix into the pebble. Gold in the heart of a pebble, without any evidence of fractures along which it could have been introduced, has been reported from the old Meyer and Carlton Mine by Denny (1909). Local concentrations of gold have been observed by Liebenberg (1955) in the Main Reef at Simmer and Jack where clusters of up to 200 grains are present in the matrix. Lighter gold resting against darker-coloured gold with sharp edges has been cited as evidence of at least two generations of the metal.

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B. DISTRIBUTION PATTERN OF GOLD MINERALISATION

(a) Distribution Related to Pebbles and Reef Width

In some of the conglomerate reefs the gold is more or less evenly distributed. In other reefs there is either a definite concentration within a thin layer near the hangingwall contact or an equally definite concentration at the bottom of the reef. In the Black Reef the gold is almost entirely restricted to the bottom 6 inches of the conglomerate band, with values being very poor above this. Where there is more than one band developed in the South Reef, either the very bottom band - the South Reef Leader - or the topmost band is the main gold carrier with the middle bands containing lower values. In the Main Reef Leader the gold generally lies in greater concentrations along the contact with the footwall. According to Mellor (1936), the most highly mineralised auriferous conglomerates are often underlain by a shaly or talcose bed, such as the mud-seam which occurs below the Black Reef, the thin shale below the exploited Kimberley Reef, and the Black Bar below the Main Reef Leader. Pirow (1920) stated that, as a rough guide to gold values, a brown, coppery film - an alteration product of sericite, pyrite and chalcopyrite - on the footwall might indicate high values in the overlying reef.

If all the conglomerate reefs are considered collectively, there is no obvious, direct relationship between reef widths, pebble sizes and gold content. However, along a single reef horizon, a lateral variation in pebble size or reef width produces a sympathetic lateral variation in gold content in many localities. Macadam (1936) concluded that the higher gold values are usually to be found in moderately wide reefs with large pebbles and abundant pyrite. Pirow (1920) stated that the larger the pebbles and the wider the body of reef, the better the values. Reinecke (1927) found that, in nine cases out of ten, reefs with larger and better-sorted pebbles contain more gold than reefs with smaller and poorly-sorted pebbles. Well-rounded,rather than angular, pebbles are characteristic of richer portions of the reef. The degree of sorting would appear to be most important guide to higher gold values, a well-sorted reef, such as the Main Reef Leader, being a far more important source of gold than a poorly-sorted conglomerate, such as the Main Reef or the Kimberley Reef.

Reinecke (1927) also found that the aggregate reef width is thickest in the centre of a paystreak and that, as the values dropped off on the flanks of the paystreak, so the reef width decreased. The pebbles in these paystreaks have their long axes oriented parallel to the long axis of the streak, which is also parallel to the direction of transport of the material forming the conglomerate.

Locally, certain pebbles might be associated with increased concentrations of gold. Pirow (1920) stated that pink quartz pebbles are often found where good values are present. On the middle levels of the Consolidated Main Reef Mine high gold values were found to occur where there was an abundance of jet black glassy pebbles.

(b) Distribution Related to Mineral Assemblages

(i) Gold and Pyrite

Pirow (1920) and Macadam (1936) both state that reef with large amounts of pyrite generally contains good gold values in most of the mines on the Central Rand. This rule does not apply universally, as in a number of instances, high values might be present where the reef has thinned to a mere line of poorly mineralised pebbles or to a parting plane with a thin film of gold on the contact. Table 16, compiled from data gathered by Macadam (1936), shows the relationship, on the Village Deep Mine, between the pyrite and gold contents of the Main Reef Leader, the South Reef and the Banded Pyritic Quartzites. In each case very rich reef shows a much higher pyrite content than banket of average grade.

(ii) Gold and Other Sulphides

On the Village Main Reef, Macadam (1936) found that there was no relationship between the pyrrhotite content of the reef and the gold values. However, in the Main Reef Leader on the Robinson Deep Mine, and in both the Main Reef and Main Reef Leader on the Simmer and Jack Mine, Liebenberg (1955) recorded a close association between gold and pyrrhotite. Pirow (1920) was of the opinion that where the conglomerates of the Main Reef group contain unusually high amounts of chalcopyrite, as well as abundant pyrite and rutile, particularly high gold values are present. Liebenberg (1955) found that good gold values were associated with increased cobaltite content in the Main Reef on the Simmer and Jack Mine, and with a higher linnaeite content in the Main Reef Leader on the City Deep Mine.

(iii) Gold and Silver

The relationship between the gold values and the silver content of the bullion produced from the various reefs, is shown in Table 17 for the Rand Leases Mine, in Table 18 for the Consolidated Main Reef Mine, and in Table 19 for the old Geldenhuis Deep Mine. The first two tables are from Hargraves (1961), and the third from Fowler (1948). In general, the silver content decreases as the gold content of the reef increases, but there is no systematic relationship between grade and the percentage of silver in the bullion. There is also no apparent characteristic silver content for any one reef that will distinguish it from other reefs in the

Grade of Reef (dwts. Au/ton)	Weight % of Pyrite in Reef		
	PQ	MRL	SR
0 - 5	7.0	0.5	1.4
5 - 15	18.0	3.6	1.8
15 - 40	21.6	3.3	3.0
40 - 100	30.5	4.5	3.6
+ 100	51.2	6.2	3.9

Table 16 : Variations in Pyrite Content of Reefs with Reference to Increase in Gold Content of Reefs on Village Main Reef Mine.

PQ : Pyritic Quartzites

MRL : Main Reef Leader

SR : South Reef

same mine. Table 20, obtained from Hargraves (1961), shows the variation in the average silver content of the various reefs mined from west to east along the Central Rand. Again, there is no clearly-defined pattern to the variation, although, in the cases of the Main Reef and the Main Reef Leader, there appears to be a decrease in the silver content from the western extremity of the Central Rand to the central portion, and then an increase again towards the eastern boundary. Hargraves (1961) also found that on the E.R.P.M., Rose Deep, Simmer and Jack, City Deep and Crown Mines, the average silver content dropped progressively from the outcrop down dip in the same direction as the decrease in the average gold content of the ore and the thinning of the reefs.

Grade of Reef (dwts. Au/ton)	Weight % of Silver in Bullion from Reef			
	MR	MRL	BR	KR
0 - 2	19.0	20.9	13.2	20.6
2 - 3	17.7	19.0	16.4	23.7
3 - 4	16.3	16.3	13.8	16.7
4 - 5	13.9	15.0	11.7	14.7
5 - 10	11.8	11.7	9.8	13.5
10 - 20	9.6	9.7	-	11.6
Average	14.3	11.5	12.4	18.9

Table 17 : Variations in Silver Content of Bullion from Various Reefs with Reference to Increase in Gold Content of Reefs on Rand Leases Mine.

MR : Main Reef BR : Bird Reef
MRL : Main Reef Leader KR : Kimberley Reef

Grade of Reef (dwts. Au/ton)	Weight % of Silver in Bullion from Reef			
	MR	MRL	SR	BR
tr - 2	9.5	9.0	12.3	9.3
2 - 5	11.1	11.0	11.3	10.0
5 - 10	9.4	9.1	9.1	8.3
10 - 20	8.4	8.1	8.5	7.0
+ 20	8.6	7.8	7.8	8.7
Average	9.5	7.6	8.2	8.7

Table 18 : Variations in Silver Content of Bullion from Various Reefs with Reference to Increase in Gold Content of Reefs on Consolidated Main Reef Mine.

MR : Main Reef SR : South Reef
MRL : Main Reef Leader BR : Bird Reef

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Grade of Reef (Dwts. Au/ton)	Weight % of Silver in Bullion from Reef			
	MR	PQ	MRL	SR
1 - 5	11.5	16.3	16.3	14.0
6 - 12	13.0	10.6	16.2	12.5
13 - 25	9.7	9.6	10.3	10.4
+ 25	9.6	10.9	9.5	11.7
Average	11.0	11.9	13.1	12.1

Table 19 : Variations in Silver Content of Bullion from Various Reefs with Reference to Increase in Gold Content of Reefs on Geldenhuis Deep Mine.

MR : Main Reef MRL : Main Reef Leader
PQ : Pyritic Quartzites SR : South Reef

Name of Mine	Weight % of Average Silver Content in Bullion				
	MR	MRL	SR	BR	KR
Durban Roodepoort Deep	9.4	-	7.9	-	11.2
Rand Leases	14.3	11.5	-	12.4	18.9
Consolidated Main Reef	9.5	7.6	8.2	8.7	8.7
Crown Mines	9.6	7.9	-	-	-
Robinson Deep	-	10.1	-	-	-
City Deep	12.0	8.5	9.3	-	-
Geldenhuis Deep	11.0	13.1	12.1	-	-
Simmer and Jack	11.1	10.9	11.1	-	-
Rose Deep	10.4	10.7	10.3	14.8	-
E.R.P.M.	10.5	12.2	11.5	-	-

Table 20 : Variations in Average Silver Content of Bullion from Various Reefs, from West to East along Strike of Central Rand.

MR : Main Reef BR : Bird Reef
MRL : Main Reef Leader KR : Kimberley Reef
SR : South Reef

(iv) Gold and Osmiridium

The relationship between the amounts of gold and osmiridium recovered from some of the mines on the Central Rand is shown in the following tabulation, compiled from Papenfus (1957) - the figures indicate the number of ounces of osmirdium recovered per one million ounces of gold won from the conglomerates:

E.R.P.M.	287 ozs.	City Deep	220 ozs.
Rose Deep	271 ozs.	Crown Mines	377 ozs.
Geldenhuis Deep	211 ozs.	Consolidated Main Reef	216 ozs.
Nourse Mines	231 ozs.	Durban Roodepoort Deep	168 ozs.

Again, there is no immediately obvious pattern to the variations. The highest concentrations of osmiridium occur in the eastern and central portion of the Central Rand, whereas the western portion contains the lowest amounts of the platinoids.

(v) Gold and Carbon

Pirow (1920) concluded that in 95 per cent of the instances where carbon is conspicuously developed in the banket, very high gold values are also present. This is the case particularly in the E.R.P.M. and Rose Deep mines, suggesting that carbon might attain a greater concentration in the conglomerates in the extreme eastern portion of the Central Rand than elsewhere. Although high values invariably go with significant amounts of carbon, yet the greater majority of patches of exceptionally rich reef contain no carbon.

(vi) Gold and Gangue Minerals

Reinecke (1927) stated that variations in the amounts of secondary, non-metallic minerals in the matrix of the conglomerates are not accompanied by sympathetic variations in the quantity of gold present. Studies on the Consolidated Main Reef Mine showed that the relative concentrations of sericite, chloritoid and chlorite varied in the plane of the reef without any reference to the pattern of variation of the gold content.

(c) Distribution Related to Sedimentary Features

The two most important of the large-scale sedimentary features which exert control on the distribution of the gold in the banket are the depositional distance of the reef from the original shoreline of the basin, and the development of oriented zones of higher values within the reef, called paystreaks.

(i) Gold and Depositional Environment

According to Reinecke (1927), the material which subsequently filled the basin was derived from an area north of the Central Rand, and flowed southeastwards, and to a lesser extent, southwestwards into the depository. Mellor (1917) concluded that the land surface from which the material was derived, occupied a position, with time, progressively nearer to the present outcrop of the reefs along the Central Rand, and that there was a gradual encroachment of the land from the north or northwest upon the inland sea filling the Witwatersrand Basin. The sediments presently preserved, as they are followed stratigraphically upwards, thus represent material originally deposited closer and closer to a shoreline. The coarsening in grain-size and the increase in the frequency of conglomerates are taken as indicators of this phenomenon. The Lower Division of the Witwatersrand System on the Central Rand, because of its finer grain, prevalence of shales and relative absence of conglomerates, is considered to have been deposited deep into the basin at a considerable distance from the discharge points of large continental rivers (Mellor, 1917). With the continued elevation of the land to the north and northwest, the present reef outcrop zone came within range of in-shore and deltaic conditions, and, at the end of Witwatersrand times the very coarse sediments were deposited close to the actual coast-line.

The thin, erratic, and sporadically developed Promise and Government Reefs of the Lower Division, as exposed on the Central Rand, represent material swept far into the basin as it existed during the development of the Government Reef Series. Although limited amounts of pebbles were transported over that distance, the gold was not brought in as far, with the result that these reefs on the Central Rand are of no economic significance. By the time of deposition of the conglomerates lying between the North Reef and the South Reef group, in the bottom portion of the Main-Bird Series, the shore-line had moved southeastwards over a considerable distance, and the reefs were formed in a deltaic environment where optimum conditions for the concentration of gold prevailed. The Bird, Kimberley and Elsburg Reefs were deposited closer to the existing coast-line than those in the Main Stage, and there conditions led to the development of less continuous bands of conglomerate with larger and more poorly sorted pebbles, and less gold.

Thus, the maximum gold concentration along the Central Rand appears to have taken place in those reefs that were deposited at a centain optimum distance from the shore-line, where conditions of concentration were most favourable. The reefs of the Lower Division were laid down too far from the shore-line and those of the Elsburg State too close. Intermediate between the optimum conditions which prevailed during the Main Stage of the Upper Division and the decidedly unfavourable conditions of Elsburg times, were the environments which existed during the formation of the conglomerates of the Bird and Kimberley Stages, in which reefs of limited economic potential and lower overall payability are found.

(ii) Gold and Paystreaks

Paystreaks, or zones of higher gold values surrounded by reef of average or lower-than-average values, in the Main Reef Leader of the Central Rand, can be divided into two types (Reinecke, 1927). In the one variety, the richer portion of the paystreak contains a narrow reef with large pebbles, all of which are approximately of the same size, and are closely packed or at some distance apart on the bedding plane with no pebbles between. These paystreaks are bordered by bands with no pebbles at all or by grits. In the second type of paystreak, the values are more evenly distributed over a greater reef width, up to 10 feet, in several individual conglomerate bands, of which the one at the base is often the richest. When the values in the top band are high, the bottom band is generally also richer.

The paystreaks in the Main Reef Leader are usually 5 - 10 times as long as they are broad. In the Central Rand they are up to 1700 feet long and between 50 and 450 feet broad (Reinecke, 1927). The broadest point usually occurs in the middle of the paystreak. Individual streaks are often aligned with their long axes parallel. Cross streaks, at right angles to the major feature, are common. The long axes of the paystreaks tend to swing from one line to the next parallel line, forming a braided pattern, in which the streaks are separated by barren ground or by reef of very low gold content. In the area between Roodepoort and Boksburg the high value zones swing in direction from northwest to southwest and the braided pattern is very apparent (Reinecke, 1927). The paystreaks tend to spread apart and the areal percentage payability shows a tendency to diminish in a southwesterly direction. The gold content is lower and the streaks smaller and less consistent on the Central Rand than is the case with the well-known paystreaks of the East Rand Basin.

Good examples of both types of paystreak were encountered between 14 and 15 levels, west of 7 Shaft, Crown Mines (Reinecke, 1927). Another well-defined paystreak was found between 28 and 33 Levels, east of 3 Shaft, Consolidated Main Reef Mine, measuring 1100 feet long by 25 - 50 feet wide and striking southwestwards. On its northwestern edge, there was an abrupt drop in gold content from 3000 inch-dwts. to 40 inch-dwts. in the conglomerate surrounding the streak. On Crown Mines a paystreak was found extending from the outcrop to 2000 feet down the plane of the reef, the strike being parallel to the strike of the beds. Lower down, other paystreaks tended to strike northwest and southwest, and in a few instances, north-south. Between the Croesus Shaft of the old Langlaagte Estates Mine and the Central Shaft of the Consolidated Main Reef Mine, the Main Reef Leader carried poor values from the outcrop down to 3000 feet below surface, and the first important zone of high values on this reef was encountered only below this depth (Reinecke, 1927).

From the relative positions of the streaks on Crown Mines, Langlaagte Estates and Consolidated Main Reef mines, it appears that the zones of richer values in the Main Reef Leader vary in distance down dip from the outcrop, the depth of the upper limit of the major streaks moving progressively further down from the surface from east to west. This feature and the fact that the Main Reef Leader thins westwards from Crown Mines, spreads apart with intercalated quartzite partings and contains less gold, indicate that the original transport currents flowed westwards in this portion of the Central Rand during the time of deposition of this reef horizon.

In a detailed study of some of the streaks on the Consolidated Main Reef Mine, Reinecke (1927) confirmed this conclusion by showing that the directions of the more important zones of higher values were W 15° S. and W 60° S. Cross-streaks had an orientation of E 35° S. Other detailed investigations on the old Langlaagte Estates Mine indicated the directions of paystreaks in the Main Reef Leader to be E 40° S., E 65° S., W 5° S., and W 45° S. The main directions of the long axes of the pebbles in these streaks were E 40° S and W 5° S., both of which were parallel to two of the directions of the long axes of the streaks themselves.

The streaks in the Main Reef Leader on the Central Rand do not appear to be related in any way to major synclines or minor folds, to fractures or faults, to dykes, or to the composition of the footwall (Reinecke, 1927). They can be considered to represent original, primary sedimentation features. In many instances paystreaks stop abruptly against faults, but it has been found that the dislocation is of the tear-fault type, with the continuation of the paystreak displaced some distance horizontally.

In the Main Reef horizon on the old Witwatersrand Deep Mine, Jones (1936) reported that the paystreaks were represented by large, oval-shaped patches averaging 600 inch-dwts. of gold. The long axes of these streaks were oriented east-west. Stonestreet (1897) found that the paystreaks in the Black Reef, at Roodekop, were also oriented east-

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west. Here they occupied synclines, the axes of which had the same direction of strike. No reef was developed over the anticlines separating the synclines. The folds had an amplitude of 50 - 200 feet and a wave-length of 300 - 400 feet. Laterally, the high values faded as the pebbles gradually disappeared and the conglomerate changed to a hard quartzite over a distance of 20 feet.

(d) Migration of Gold

As a result of the metasomatism which the banket has undergone, there has been a certain amount of migration of the gold and other components of the matrix of the conglomerates. In most instances this migration is exceedingly small with the result that the gold can be regarded as still occupying the same position in the reef as when it was deposited.

However, in rare cases, there is evidence of the migration of gold over unusual distances, such as has been reported on the City Deep Mine (Keep, 1934). In two localities 3600 feet apart, between 5700 and 6100 feet below surface, large gold crystals were interwoven in a series of small mats between quartz crystals in fissures. The surrounding quartzites were desilicified and sericitised by the intrusion of dykes. The gold had apparently migrated into the fissures from an impoverished and altered conglomerate reef 20 - 120 feet away.

C. GOLD PRODUCTION FROM THE CENTRAL RAND

In the 76 years that have elapsed since the first gold was won from the outcrop workings on the Central Rand, about 140 individual producers have contributed to the total output, from this portion of the Witwatersrand Basin, of more than 261 million ounces of gold. Many of these mines had very short lives, being amalgamated with adjoining properties soon after the formation of the large mining finance companies. The recorded production from such early mines is either missing or incomplete, with the result that it is not possible to determine the true figure for the amount of gold which has been won from the Central Rand. Less than 50 properties became significant producers and operated for any length of time and the figure quoted above applies to these mines only. It is difficult, if not impossible, to estimate by how much this figure would be increased if the complete production data for the Central Rand were available right from September, 1887, when the Jubilee and Wemmer mines started recovering gold.

The richest mine on the Central Rand was the old Bonanza Mine located on what is now the common boundary between the Village Main Reef Mine and Crown Mines. Between August, 1896, and March

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1908, a total of 668,443 ounces of gold was recovered from 772,908 tons of ore milled, to give an average recovery grade of 17.3 dwts. per ton. Other rich mines were the Robinson and the Ferreira which adjoined the Bonanza, and which returned averages of 9.9 and 9.5 dwts. per ton respectively. These three were outcrop mines. Other outcrop producers which had a recovery grade above 8 dwts. per ton were the Meyer and Charlton at 9.3, the New Heriot at 8.9, the Jumpers at 8.5, the City and Suburban at 8.5, the Village Main Reef at 8.2, and the Treasury at 8.0. Significantly, all these mines were located in and immediately east of Johannesburg. The poorest mines on the outcrop were all located in the eastern portion of the Central Rand. The average recovery grade of the Glencairn was 4.6 dwts. per ton, the Knights Deep 4.4, the Simmer Deep 4.3, and the Witwatersrand 3.9.

Of the deep level mines, the richest have been the Village Deep with an average recovery grade of 6.4 dwts. per ton, the Nourse Mines with 6.0, and the Crown Mines with 5.2. The poorest of the major mines have been Consolidated Main Reef at 3.9 dwts. per ton, and Rand Leases at 3.5.

Table 21, compiled from the annual reports of the mining companies, lists the production data for the 17 largest mines which have existed on the Central Rand. In Table 22, prepared from the same sources, are shown the average annual production and grade figures of all the mines that were still actively engaged in mining during the five-year period 1957 - 1961.

On the mines which have worked the Upper Witwatersrand reefs and for which reliable information is available, a total of 1,023,063,519 tons have been milled, from which 260,934,953 ounces of gold have been recovered in 76 years, with the result that the average recovery grade of all reefs mined on the Central Rand is 5.1 dwts. per ton. In addition, the mines south of the Central Rand proper, which exploited the Black reef, contributed a further 194,656 ounces of gold which were recovered from 425,099 tons at an average grade of 9.2 dwts. per ton.

Name of Mine	Years of Production	Tonnage Milled	Ozs. Gold Recovered	Dwts. per Ton
Crown Mines	1897 - 1961	163,833,924	42,988,063	5.248
East Rand Proprietary Mines	1894 - 1961	119,807,566	30,842,327	5.149
City Deep	1910 - 1961	60,500,733	15,844,077	5.238
Simmer and Jack	1888 - 1961	63,988,688	14,357,558	4.488
Consolidated Main Reef	1898 - 1961	72,021,023	14,308,218	3.973
Robinson Deep	1898 - 1961	54,902,998	14,177,301	5.164
Durban Roodepoort Deep	1898 - 1961	64,499,377	13,396,995	4.154
Langlaagte Estate	1888 - 1946	46,540,234	12,057,627	5.182
Nourse Mines	1896 - 1948	31,875,082	9,564,149	6.001
Rose Deep	1897 - 1961	43,840,493	9,497,837	4.333
Rand Leases	1936 - 1961	53,056,500	9,255,793	3.489
Geldenhuis Deep	1895 - 1947	35,871,713	9,219,681	5.140
Ferreira Deep	1902 - 1929	14,208,281	6,716,225	9.454
Witwatersrand	1889 - 1953	33,272,466	6,465,694	3.887
Robinson	1888 - 1926	11,924,775	5,876,566	9.856
Witwatersrand Deep	1902 - 1944	19,983,198	5,099,084	5.103
Village Deep	1905 - 1930	13,648,061	4,349,770	6.374

Table 21 : Total Gold Production and Average Grade of Reef Mined on the Seventeen Largest Mines on the Central Rand, of which Complete Records Exist.

Name of Mine	Average Annual Tons Milled	Average Annual Ozs. Gold Won	Average Recovery Grade (dwts./ton)
Princess	38,600	5,765	2.98
Wilford	53,200	9,715	3.65
Roodepoort	31,600	5,960	3.77
Durban Roodepoort Deep	2,244,500	407,355	3.63
Rand Leases	2,131,200	315,515	2.96
Consolidated Main Reef	1,358,800	217,085	3.20
Croesus	64,600	11,200	3.47
Crown Mines	2,644,000	415,190	3.14
Mayfair	44,300	7,235	3.26
Robinson Deep	748,600	157,455	4.21
Village Main Reef	368,100	57,455	3.12
City Deep	1,505,200	302,970	4.03
Old Heriot	33,900	6,845	4.04
Jumpers	29,500	5,680	3.86
Stanhope	35,000	7,010	4.00
Simmer and Jack	1,028,700	192,010	3.73
Primrose	42,500	8,605	4.05
Rose Deep	488,000	71,700	2.94
Waverley	76,400	11,555	3.02
Driefontein	35,400	7,420	4.19
Balmoral	30,200	5,810	3.85
E.R.P.M.	2,647,500	669,060	5.05
Average Annual for Central Rand	15,679,800	2,898,595	3.70

Table 22 : Average Annual Production and Grade Figures for the Five-Year Period : 1957 - 1961 for the 22 Mines, from West to East along Strike of Central Rand.

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