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THE STRATIGRAPHY OF THE WITWATERSRAND SEQUENCE IN THE DELMAS AREA, TRANSVAAL

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UNIVERSITY OF THE WITWATERSRAND

JOHANNESBURG

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by

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ABSTRACT

A stratigraphic column of the Witwatersrand Sequence in the Delmas area, constructed from all the available stratigraphic data, is presented. Rock types developed are described with respect to their colour, mineralogical composition, and textures. Detailed pebble studies were undertaken on some of the rudaceous horizons of the sequence.

The stratigraphy of the Lower Witwatersrand is described in less detail. The complete Lower Witwatersrand stratigraphic sequence could not be established due to problems of correlation and a lack of borehole control.

Within the uppermost portion of the Lower Witwatersrand strata, a pattern of cyclic sedimentation was established. A study of cycles can be of use in problems of correlation. Stratigraphic subdivisions based on cyclical patterns are more meaningful than a number of the stratigraphic subdivisions presently used.

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INTRODUCTION

A. LOCATION OF AREA

The area considered surrounds the village of Delmas in the south-central Transvaal (Figure 1). Delmas is situated some fifteen miles east of the northeastern limit of the East Rand Goldfield and some thirty-five miles northwest of the Evander Goldfield.

B. GEOLOGICAL SETTING OF AREA

The East Rand Basin, a structural depression in which the Precambrian Witwatersrand and Transvaal Sequences and the Paleozoic Karroo Sequence are preserved, is situated some twenty miles to the southwest of Delmas. Two Early Precambrian structural culminations, the Johannesburg and Devon granite domes, flank the East Rand Basin to the northwest and southeast, respectively. The Evander Basin, which preserves the same stratigraphic succession as the East Rand Basin, abuts against the Devon Dome on its eastern side. In an area north of the Devon Dome are preserved, beneath Transvaal strata, an extensive area of Lower Witwatersrand rocks and more limited areas of Upper Witwatersrand sediments. The latter are situated along the Delmas Syncline in two small structural basins, the Middelbult and Bultfontein basins which lie southwest and north, respectively, of the village of Delmas.

The Transvaal Sequence, which crosses the Delmas area in an outcrop belt which trends northwest-southeast, covers most of the pre-Transvaal formations in the area. To the south and east of Delmas, Transvaal and Witwatersrand rocks are largely concealed beneath a veneer of Karroo Sequence sediments.

In Figure 2, the Upper Witwatersrand stratigraphy of the Delmas area is shown in its regional setting. The stratigraphic section developed there is considerably thinner than that developed over the major portion of the East Rand Basin. It can be seen that, in common with the easternmost portion of the East Rand Basin, the uppermost formations of the Witwatersrand Sequence have been stripped away by pre-Transvaal erosion in the Delmas area.

C. PREVIOUS WORK

In the East Rand Basin, aspects of Witwatersrand stratigraphy have been described by a number of authors. Sharpe (1949) and de Jager (1957) have given detailed accounts of the Kimberley-Elsburg Series rocks. Later papers by Antrobus (1964), Antrobus and Whiteside (1964), and de Jager (1964) have provided a more general picture of the stratigraphy of the East Rand Basin.

Fox (1939) described a suite of pre-Transvaal strata intersected in boreholes in the vicinity, and to the southwest, of the town of Leslie. It is now known that Upper Witwatersrand sediments, in an extremely attenuated form, are represented in this pre-Transvaal assemblage. The stratigraphy of the Kimberley Shales in the Evander Basin has been discussed in detail by Tweedie (1968). A more generalized account of the Witwatersrand stratigraphy in the Evander Basin is to be provided by the Mines Geological Department, Evander, of Union Corporation Limited, in a publication by Jansen and others (in preparation).

The isolated outcrops of Witwatersrand quartzite and shale found to the south of Delmas were mentioned by Venter (1934), who correlated these quartzites with the Black Grit Quartzite (Hospital Hill Series) of the Heidelberg area, on the basis of black chert granules found in the quartzite. Despite fairly extensive drilling operations in the area surrounding Delmas, no published accounts of pre-Transvaal stratigraphy have been made available.

D. SCOPE OF PRESENT INVESTIGATION

In the past forty years, a number of exploration programs have been conducted to the east, northeast, and north of the East Rand Basin in search of extensions of Upper Witwatersrand sediments under a cover of Transvaal and Karroo Sequence strata. The Evander Goldfield was discovered in the 1950's, and presently supports four gold mines. In the area between this goldfield and the East

Rand Basin, Witwatersrand and pre-Witwatersrand rocks have been found to underlie the Transvaal sediments. Logging of borehole core by the geologists of mining companies has resulted in a volume of stratigraphic data which varies from moderately detailed to highly generalized.

The writer examined selected sections of core from the most recent exploration program, conducted by the Anglo-Transvaal Consolidated Investment Company, Limited, between the years 1960 and 1964. In this paper, the results of the writer's observations have been integrated with those of the mining company geologists, to produce as comprehensive an account of the stratigraphy of the Witwatersrand Sequence as possible. The stratigraphy has been compared to, and contrasted with, that of the East Rand and Evander basins.

E. ACKNOWLEDGEMENTS

The Consulting Geologists of Anglo-Transvaal Consolidated Investment Company, Limited, Anglo American Corporation of South Africa, Limited, Rio Tinto Management Services of South Africa (Pty.) Limited, and Union Corporation, Limited, are thanked for the unpublished information used in this paper, which they made available to the author. Acknowledgement is made to the thoroughness of the work of the many geologists whose contributions are collated in this paper.

DESCRIPTION OF STRATIGRAPHY

The composite geological column (Figure 3) was constructed by averaging the stratigraphic thicknesses of the various units intersected in different boreholes. The density of drilling, the confidence in correlation, and the small amount of structural disturbance made this a comparatively simple task in the case of the Upper Witwatersrand rocks. Stratigraphically downwards, the number of boreholes intersecting any one unit and the certainty of correlation of that unit decreased. Correlation became increasingly more tentative downwards, until it could not be effected at all. In the column presented, the major part of the Government Reef Series and the upper portion of the Hospital Hill Series are missing. Although fragments of this missing interval are present in a number of boreholes, their position in the sequence and the dimensions of the gaps separating them could not be determined.

During the writer's logging of the Witwatersrand core, particular attention was paid to such features as pebble size, sorting, composition and maturity, composition and colour of sediments, and type of mineralization in the conglomerates and quartzites.

The geologists of the Anglo-Transvaal Consolidated Investment Company, Limited, recognized the usual subdivisions of the Upper Witwatersrand (namely, the Elsburg, Kimberley, Bird, and Main Stages) in the Delmas area. They erected a codified local nomenclature for Upper Witwatersrand lithologic units by using the initial letter or letters of the stage name. Thus EL represented the Elsburg Stage, K the Kimberley, B the Bird, and M the Main Stage. Within each of these four stages, they recognized a number of useful and distinctive lithologic units. These were numbered 1, 2, 3, etc., in descending stratigraphic order.

The stratigraphic succession is presented below in descending order. The nomenclature used in describing the stratigraphy is broadly chrono-stratigraphic, with subsidiary units referred to by their informal or local names.

Figure 3 is a composite stratigraphic column of the Witwatersrand Sequence in the Delmas area. On the left hand side of the column, the average stratigraphic thickness (in feet) of the various units is shown.

A. THE ELSBURG STAGE

The Klipriviersberg Lava and the underlying Elsburg Conglomerate were not encountered in boreholes in the Delmas area. These units are present in both the East Rand and the Evander goldfields (Jansen and others, in preparation); there is no reason to believe that they were not developed in the Delmas area as well. The Delmas area suffered more severely from pre-Transvaal erosion than the East Rand and Evander goldfields, so that these two stratigraphic units were probably stripped away.

The uppermost preserved portion of the Witwatersrand Sequence in the Delmas area is the thick quartzite zone separating the Elsburg from the Kimberley conglomerates. This unit was intersected in four boreholes to the north of Delmas, but in no case was its full thickness penetrated. The maximum thickness encountered was 670 feet in Borehole KST.2. This unit has a thickness of some 1400 feet in the western portion of the East Rand (Antrobus, 1964), and could be expected to have a thickness of 700 to 900 feet in the area studied.

In the Delmas area, this zone consists essentially of a medium-grained siliceous to argillaceous (usually sub-siliceous) quartzite. It ranges in colour from light grey (N7), in the case of siliceous quartzite, to dark grey (N3), in the case of argillaceous quartzite. It may show banding due to the alternation of darker and lighter quartzites, or due to the presence of heavy mineral stringers. Black speckling, due to black chert fragments and chlorite shreds, is common. Thin phyllosilicate partings are present, but are volumetrically insignificant. They often carry pyrite, and typically have a dark greenish grey colour (5GY 4/1). Feint quartzose and pyritic grits may occur. Conglomerates, in the form of a single line of pebbles, are very rare.

B. THE KIMBERLEY STAGE

The Anglo-Transvaal geologists changed conventional East Rand nomenclature by assigning the correlates of the Upper Kimberley Substage, in the Delmas area, to the Elsburg Stage. Thus, Zones EL4 and EL7 are more properly classified as belonging to Upper Kimberley Substage.

The Upper Kimberley Substage is typified by a cyclical succession of quartzites, alternating with zones made up of closely spaced conglomerate and quartzite. The latter were referred to as conglomerate-quartzite zones (Sharpe, 1949). In the type area for the Upper Kimberley, a succession of five conglomerate-quartzite and four quartzite zones is developed (Sharpe, 1949). The succession is coded UK1, UK2 ..... UK9, with even numbers representing quartzite zones and odd numbers conglomerate-quartzite zones. The uppermost conglomerate-quartzite zone (UK1) is weakly developed, and is not found away from the type section at Government Gold Mining Areas. Similarly, the UK7 Zone dies out in the eastern and southern portions of the East Rand Basin (de Jager, 1957). In the light of this, the two conglomerate-quartzite zones developed in the Delmas area (Zones EL4 and EL6) are probably the lithologic equivalents of Sharpe's (1949) UK3 and UK5 Zones, respectively. The UK9 Zone is represented by a single thin conglomerate band referred to as the Kimberley Reef.

(i) *Zone EL4*

As outlined above, this unit is the probable equivalent of Zone UK3 on the East Rand. It was intersected in four boreholes, and has an average thickness of 80 feet.

The zone consists of quartzite, conglomerate, and phyllosilicate partings. In Borehole KST.3, 79 per cent of the zone was made up of quartzite, 19 per cent of conglomerate, and 2 per cent of phyllosilicate partings. The conglomerates are small-pebbled and gritty. They vary from compact to poorly packed. White vein quartz is the predominant pebble type; there are lesser amounts of smoky vein quartz, banded grey or black chert, and chlorite and shaly fragments. The conglomerate matrix is dark and lightly to moderately mineralized with pyrite, leucoxene, and zircon. The dark colour of the matrix probably reflects the presence of chlorite. The quartzite is medium-grained, and is usually slightly argillaceous with a greenish grey colour (5GY 5/1). A smaller percentage of quartzite is sub-siliceous with light grey colour (N7). Both types are speckled with small black chlorite fragments, and carry feint pyritic stringers. The quartzite may show striping on a wet, drilled surface. The phyllosilicate partings have a dusky yellow-green colour (5GY 5/2), and carry fine yellow leucoxene specks and pyrite grains.

(ii) *Zone EL5*

This unit has an average thickness of 138 feet. It consists essentially of quartzites, with minor phyllosilicate partings and rare, small-pebbled conglomerates.

The quartzites are generally medium-grained and siliceous to slightly sericitic, but may be moderately argillaceous. The colour ranges from dark grey (N3) to light grey (N7), depending upon the composition. Gritty phases may be developed, with black chert, chlorite, and smoky grey or opalescent quartz granules. Fine-grained black speckling is common. The quartzites may be feintly striped, due to the presence of pyritic stringers. Quartz-bearing phyllosilicate partings are common. They are thin (usually less than one inch thick), and range in colour from light olive (10Y 5/4) to dusky yellow-green (5GY 5/2). Thin bands of small-pebbled conglomerate are rarely developed.

(iii) <u>*Zone EL6*</u>

This zone is composed of quartzite and conglomerate, with minor phyllosilicate phases. The zone has an average thickness of 60 feet.

The quartzite is medium-grained, light grey (N7) to white in colour, and is siliceous or, less commonly, sericitic. It is black-speckled, due to the presence of chlorite and chert fragments. Pyritic stringers are rare. Conglomerates may be poorly packed or compact, and are small-pebbled. They are lightly mineralized, and often gritty.

(iv) <u>*Zone EL7*</u>

Zone EL7 consists essentially of siliceous to highly sericitic quartzite. The quartzites are medium-grained, and range in colour from greenish grey (5GY 6/1) and pale olive (10Y 6/2), for the sericitic and slightly sericitic quartzites, to a light olive-brown colour (5Y 5/6), for the highly sericitic quartzite. They are usually black-and-yellow-speckled, and may carry infrequent pyritic stringers. The siliceous quartzites are fine- to medium-grained, and vary in colour from light grey (N7) and very light green (10G 7/2) to greenish grey (5G 6/1). They commonly show fine black speckling and pyritic stringers. A siliceous quartzite, less than ten feet thick, was found a variable distance above the Kimberley Reef in a number of instances. This could be the equivalent of the UK9A Marker (Armstrong, 1965) and the Siliceous Quartzite Bar (de Jager, 1957). Phyllosilicate partings are common in Zone EL7. They are light olive-brown in colour (5Y 5/6), and are yellow-speckled. Thin layers of heavy minerals (pyrite, chromite, zircon, and leucoxene) are often concentrated at the upper contact of the phyllosilicate partings.

(v) <u>*The Kimberley Reef*</u>

The horizon here referred to as the Kimberley Reef is the probable lithologic equivalent of the conglomerate known as the UK9A Reef or the May Reef, developed over much of the East Rand Basin. It is a thin band of conglomerate, in the Delmas area, having a maximum intersected thickness of 6.5 inches. It is commonly auriferous, but intersected values were not high. The reef is a well packed, small- to medium-pebbled conglomerate. Its matrix is usually mineralized, in some places heavily so, with pyrite, chromite, zircon, and leucoxene. The pebble types include black, grey, banded and greenish grey chert, milky and smoky vein quartz, and grey, siliceous quartzite. In the two borehole intersections of the reef studied in detail, the relative abundances of the various pebble types were determined as follows :

Borehole	Number of Pebbles	Vein Quartz	Chert	Siliceous Quartzite
KST.3	38	47.4%	47.4%	5.2%
WK.1	65	38.4%	55.4%	6.2%

The numbers of pebbles studied reflect the small amount of material which was available in the two boreholes. The maturity indices for the pebbles are 17.9 and 15.1 for Boreholes KST.3 and WK.1, respectively. The number of pebbles available for pebble-size measurements in the two boreholes was not enough for the construction of separate cumulative curves. The pebble measurements from WK.1 and KST.3 were combined to give a total of 103 measurements. The median and the mean pebble-size were found to be 8.8 mm. The graphic standard deviation for the Kimberley Reef pebbles in the two boreholes was found to be 0.68ϕ. This reflects the relatively poor sorting of this reef, when compared to that of the UK9A Reef in the East Rand. The average sorting for twelve localities on the East Rand (Armstrong, 1965) was significantly better, as reflected by the average value of the graphic standard deviation of 0.53ϕ.

The Middle Kimberley sediments are usually defined as the assemblage lying between the Kimberley (UK9A) Reef, at the top, and the LK.1 quartzite or the Kimberley Shale, at the base. In the Delmas area, the Middle Kimberley sediments have been subdivided into four distinctive lithologic units which are described below.

(vi) *Zone K1*

This unit is a fairly uniform, pebbly, and somewhat sericitic quartzite. It has an average thickness of 141 feet. The quartzite is medium-grained, and is invariably speckled. The usual colours of speckling are black, yellow, and grey. The quartzite varies in composition from siliceous to highly sericitic or argillaceous. Most of the quartzites have a dusky green-yellow colour (5GY 5/2 or 5GY 5/1); the more siliceous members have a light greenish grey colour (5G 8/1), while the extremely argillaceous quartzites have a dark greenish grey colour (5G 4/1). The quartzite carries occasional leucoxene-chromite-pyrite stringers. Phyllosilicate partings are usually olive-grey (5Y 3/2) in colour, are usually less than six inches thick, and carry pyrite and leucoxene concentrations.

Pebbles and granules are scattered throughout the quartzite, and are occasionally concentrated in thin, poorly packed conglomerate bands. In a pilot study in Borehole WK.1, the sizes and the composition of all the pebbles in the core available were recorded. Pebble types present were predominantly chert (black, banded, and often pyritic; pale green or grey), white and smoky grey vein quartz, and, more rarely, phyllosilicate and quartzite. In the sample of 278 pebbles studied, the percentage abundance of pebble types was as follows :

Chert - 69.5 per cent (made up of 47.5 per cent black chert,
10.8 per cent grey chert, and 11.2 per cent banded chert)

White Vein Quartz - 16.9 per cent

Smoky Vein Quartz - 6.5 per cent

Quartzite - 3.2 per cent

Phyllosilicate - 4.0 per cent

The pebble assemblage had a maturity index of 12.9, significantly lower than for the Kimberley Reef.

A cumulative curve for the 278 pebble measurements was constructed. A feature of this curve was that it was identical to the curve prepared for the Kimberley Reef for pebble sizes less than 8 mm. For pebble-sizes greater than 8 mm, the curve for the Zone K1 pebbles was displaced appreciably towards the coarse end, with respect to the curve for the Kimberley Reef. The median pebble size for Zone K1 was found to be 9.8 mm. The graphic mean was calculated to be 9.8 mm, also. The former figure is 1 mm greater than the equivalent figure for the Kimberley Reef. The graphic standard deviation in pebble-size was found to be 0.84ϕ. This figure reflects the poorer size-sorting of Zone K1 pebbles, when compared to the Kimberley Reef pebbles.

When studying the types of pebbles present in the Kimberley Reef and in Zone K1, it was seen that, with the exception of phyllosilicate pebbles, all the pebbles found in Zone K1 are represented in the Kimberley Reef. In addition, the order of magnitude for the abundances of various pebble types is the same, the main divergence being the greater amount of chert and smaller amount of quartz in the Zone K1 pebble population. Armstrong (1965) noted that all published accounts of the Kimberley (UK9A or May) Reef agreed on one fact, namely, the local source of the pebbles making up the reef. The sources normally quoted are the conglomerates and pebbly quartzites which usually form the footwall of the reef. The pebbles of these footwall sediments were inferred to have been released during a period of erosion immediately preceding the deposition of the Kimberley Reef. It is believed that this reasoning can be applied to the Delmas area. It is postulated that the source of the pebbles of the Kimberley Reef is the underlying Zone K1 pebbly quartzites. This reasoning is supported by a number of facts :

(1) The median pebble size of the Zone K1 quartzite is 9.8 mm, while that of the Kimberley Reef is 8.8 mm. A period of pre-Kimberley Reef erosion and re-working would have been expected to have yielded somewhat smaller pebbles.

(2) The re-working of the Zone K1 pebbly quartzite would have been expected to have caused Kimberley Reef pebbles to be better sorted. This is borne out by the change in the graphic standard deviation of 0.84ϕ, for the Zone K1 pebbles, to 0.68ϕ, for the Kimberley Reef pebbles.

(3) The maturity index of a suite of pebbles would have been expected to have increased during a period of re-working. In this respect, the change in the maturity index from 12.9, for Zone K1 pebbles, to 16.5, for Kimberley Reef pebbles, is significant. The change in the maturity index was brought about

by the elimination of phyllosilicate pebbles and the reduction in the amount of quartzite pebbles during pre-Kimberley Reef erosion.

If the suggestion that the Kimberley Reef was formed by re-working of the Zone K1 pebbly quartzites is correct, then the gold potential of the former can possibly be related to that of the latter. The amount of gold intersected in Zone K1 was, in all cases, very low. If Zone K1 were the sole source of the gold in the Kimberley Reef, then an excessive thickness of Zone K1 quartzites would need to have been re-worked to have given rise to an economic deposit of gold in the Kimberley Reef. These facts could, perhaps, explain the low gold content of the Kimberley Reef.

The Zone K1 lithology, as described above, bears little resemblance to any published accounts of the suite of sediments usually called the Chloritoid Shale Marker. The latter sediments usually occupy the same stratigraphic position as the Zone K1 in the Delmas area, namely, below the Kimberley Reef and above the Big Pebble Conglomerate. It is believed that the Zone K1 pebbly quartzites represent an arenaceous phase of the Big Pebble Conglomerate, and that the Chloritoid Shale Marker suite of sediments was not deposited to the north of Delmas, or was eroded in pre-Kimberley Reef times. This would not appear to be the case to the south of Delmas. In Boreholes Mb.2, Mb.4, and Mb.5, the presence of puddingstone (a typical member of the Chloritoid Shale Marker suite of sediments) was recorded. Unfortunately, the detailed borehole logs and the borehole core from the Middelbult group of boreholes have been destroyed or lost.

(vii) *Zone K2*

This unit, intersected in seven boreholes, has an average thickness of 36 feet. It is, broadly speaking, a zone of large- and medium-pebbled conglomerates, with subordinate quartzite intercalations. The intercalated quartzites and the conglomerate matrix vary in composition from sub-siliceous to highly argillaceous or sericitic. The quartzites are generally medium-grained, and may be gritty and carry isolated pebbles. Phyllosilicate partings, some with a vivid green colour, are developed, as are heavy mineral stringers. The quartzite varies in colour from light greenish grey (5G 8/1), for the sub-siliceous quartzite, to dusky yellow-green (5GY 5/2), for the more argillaceous members. In the pilot study in Borehole LP.2, it was found that Zone K2 was made up of some 32 per cent quartzite, the balance consisting of conglomerate.

The pebble types developed in Zone K2 include the following :

Vein Quartz pebbles are spheroidal, rounded, or well-rounded, and are either white or smoky grey. Sulphide specks in the vein quartz pebbles are common.

Chert pebbles are present in a large variety of types. Included are black or greenish black chert (often pyritic, sometimes brecciated and quartz-veined), grey chert, banded black-and-grey chert, banded greenish grey-and-black chert, greenish grey chert, and banded red-and-black chert. The shape and rounding of chert pebbles vary widely.

Phyllosilicate fragments are dusky yellow-green (5GY 6/2) in colour, soft, and irregular in shape.

Tuff pebbles are dark yellowish orange (10YR 6/6), or yellow-green, or brownish in colour. They are lithologically similar to the uppermost phase of the Bird Lava. This phase, which is rich in chloritoid crystals, has been interpreted as a tuff elsewhere in the Witwatersrand Basin.

Quartzite pebbles are white, grey, or dark grey, medium- to fine-grained, and siliceous. The quartzite pebbles are generally spheroidal and rounded. Argillaceous quartzite pebbles with a green-grey colour were only distinguished with difficulty from the matrix of the conglomerate.

Acid Lava pebbles are buff or grey in colour, and may be speckled. Spheroidal and rounded pebbles predominate.

The percentage composition of pebbles was studied in detail in Boreholes LP.2 and WK.1. In Borehole WK.1, a total of 912 pebbles was measured, while, in LP.2, 529 were studied. The table below summarizes the results of this study :

Borehole	Chert	Vein Quartz	Tuff	Quartzite	Acid Lava	Phyllosilicate
WK.1	63.2%	23.8%	6.9%	2.8%	2.5%	0.8%
LP.2	66.4%	23.1%	6.4%	1.3%	2.8%	-

The maturity indices are 8.5 and 12.0 for WK.1 and LP.2, respectively. In calculating this index, acid lava was grouped with the stable constituents, and phyllosilicate, quartzite, and tuff with the unstable.

The pebble sizes were recorded for the same boreholes noted above. The table below summarizes the results of this study :

Borehole	Number of Pebbles	Median Size (mm)	Mean Size (mm)	Graphic Standard Deviation (ϕ units)
WK.1	912	13.4	13.7	0.96
LP.2	529	14.7	15.0	0.83

The pebbles in Zone K2 are thus significantly larger than those in Zone K1. They are also, on the average, more poorly sorted.

In Borehole WK.1, a pilot study was conducted to determine the variation of pebble-size with pebble composition. Cumulative curves for the various pebble types in WK.1 were constructed, with the following results :

Pebble Type	Number of Pebbles	Median Size (mm)	Graphic Standard Deviation (ϕ units)
Vein Quartz	217	15.6	0.93
Black Chert	345	11.9	0.96
Grey Chert	104	10.7	1.04
All Chert	577	12.3	0.98
Tuff	63	15.4	0.79

The table above indicates that the different pebble types have markedly different size and sorting parameters. The median pebble-sizes of vein quartz and tuff are significantly larger than those of the chert pebbles. When differentiating between the various types of chert, it is seen that black and grey chert have a smaller median size than the remaining chert types. From the above, it is evident that the pebble composition of a conglomerate may affect its overall pebble-size parameters. The important conclusion is reached that to compare pebble-size parameters of the same conglomerate in different localities, without taking account of the pebble composition, is to invite spurious results.

A further pilot study conducted on the pebbles of Zone K2 in Borehole WK.1 involved the vertical variation of pebble-size. In the borehole under study, Zone K2 had a drilled thickness of some 41 feet. This unit was subdivided into five arbitrary subdivisions. Each division measured 9 feet, except the lowest which measured some 5 feet. The pebbles in each division were measured, and five cumulative curves were constructed. The results of this study are summarized in the table below (Division 1 is the uppermost, Division 5 is the lowermost) :

Division	Number of Pebbles	Median Size (mm)	Graphic Standard Deviation (σ_G)
1	194	16.0	1.01
2	226	14.3	0.94
3	155	12.3	0.96
4	241	11.5	0.88
5	96	12.7	0.99

It is evident from this table that there is a general decrease in size and a decrease in graphic standard deviation towards the base of the unit. This trend is reversed in the last subdivision in which the size increases and the sorting becomes poorer. It was concluded that comparisons of pebble-sizes within this zone should consider the same portion of the stratigraphy in various boreholes. Alternatively, pebble-size comparisons should be based on the entire thickness of the zone.

(viii) <u>Zone K3</u>

This unit has an average thickness of 23 feet in the seven boreholes in which it was intersected. The gross lithology of the unit is that of a pebbly and slightly argillaceous quartzite. It is the probable lithologic equivalent of the unit referred to as the Chert Pebble Quartzite by de Jager (1957) and as the MK3 Quartzite by Sharpe (1949).

The quartzite ranges in composition from slightly sericitic and argillaceous to highly argillaceous. It is medium-grained and speckled black, due to the presence of black chert grains and granules. Yellow-and-grey speckling is also common. The colour of the quartzite ranges from light greenish grey (5G 8/1) and medium light grey (N6), for the more siliceous quartzites, to dusky yellow-green (5GY 5/2), for the highly argillaceous quartzite. Yellow-speckled phyllosilicate partings and pyritic stringers are not uncommon.

The distribution of pebbles in the quartzite varies from evenly distributed, in some sections, to absent, in others. In a qualitative way, it was observed that pebbles tend to become smaller and more sparsely scattered towards the base of the unit. Pebbles are generally rounded. Pebble types include vein quartz (white or grey), chert, quartzite (medium-grained and siliceous), and trace amounts of the tuff and acid lava observed in Zone K2.

In a pilot study in Borehole WK.1, the composition and sizes of all the pebbles available (a total of 252) were recorded. The percentage abundance of pebble types was as follows :

Chert - 76.2 per cent (made up of 60.3 per cent black chert,
11.1 per cent grey chert, 2.0 per cent yellowish chert,
and 2.8 per cent banded chert)

Vein Quartz - 19.4 per cent

Tuff - 2.4 per cent

Quartzite - 1.2 per cent

Acid Lava - 0.8 per cent

The pebbles are petrologically very mature, as is indicated by the maturity index of 26.8. The median pebble-size for this zone was found to be 10.1 mm. The graphic standard deviation was calculated to be 0.89ϕ.

(ix) <u>Zone K4</u>

The upper limit of Zone K4 has been taken as the highest fine-grained and highly siliceous quartzite band below the pebbly and somewhat argillaceous Zone K3 quartzite. Zone K4 consists essentially of an alternation of quartzite and small-pebbled conglomerate. The lowermost conglomerate is usually better packed, and carries larger pebbles than the other conglomerates. This conglomerate is the possible lithologic equivalent of the conglomerate referred to as the Bottom Reef by de Jager (1957).

In the seven boreholes in which it was intersected, Zone K4 had a maximum corrected thickness of eleven feet, and an average thickness of six feet. The Zone K4 quartzite is fine-grained, highly siliceous, and light grey (N7) to medium light grey (N6) in colour. It may show very light greenish grey banding, due to the presence of slightly sericitic quartzite layers. The quartzite is black-and-white-speckled, and carries numerous heavy mineral stringers. Scattered gritty fragments are common in the quartzite. The siliceous nature of the quartzite is reflected by the presence of stylolites which were observed in a number of cases. The conglomerates are usually well-packed, small-pebbled, and often gritty. The median pebble-size was estimated to be in the vicinity of 4 mm. In such conglomerates, measurement of pebble-size with a 4 mm cut-off would yield meaningless results. For this reason, pebble sizes were not measured.

The composition of the pebbles and granules was, however, investigated. These consist of vein quartz, chert, and, rarely, a vivid green phyllosilicate mineral. A total of 68 pebbles and granules was studied in Borehole WK.1. Vein quartz accounted for 13.2 per cent of the population, white chert for 2.9 per cent, grey chert for 38.2 per cent, black chert for 27.9 per cent, banded chert for 11.8 per cent, green chert for 4.4 per cent, and phyllosilicate for 1.5 per cent.

The grits and conglomerates are usually mineralized, rounded pyrite and chromite being visible to the naked eye, and zircon under low-power magnification. The conglomerates of Zone K4 are often auriferous, but the gold content is erratic.

C. <u>THE BIRD STAGE</u>

The Bird Stage extends from the top of the Kimberley Shale to the base of the Bird Reef group. In the Delmas area, the Bird Stage has been subdivided into nine lithologic units. These units (Zone B1 to B9 are described below).

(i) <u>Zone B1</u>

Zone B1 consists essentially of a fine-grained to very fine-grained quartzite. It is light coloured, and is usually medium light grey (N6) or light greenish grey (5G 8/1). The quartzite is commonly sparsely speckled with black fragments and pyrite grains. The quartzite may be cross-bedded. It is distinguished from the overlying Zone K4 quartzite by the fact that it is free of gritty fragments or pebbles.

Phyllosilicate partings are particularly common in this zone. They vary in colour from moderate greenish yellow (10Y 7/4) to greyish olive (10Y 4/2). They are usually less than one-eighth of an inch thick. In Borehole WK.1, it was noted that they had an average frequency of two partings per foot, over some twenty feet.

The Zone B1 quartzite is the possible lithologic equivalent of the LK1 Quartzite of Sharpe (1949). This unit is developed in portions of the East Rand Basin (the Government Gold Mining Areas-Brakpan area and the Dunnotar-Heidelberg area), according to de Jager (1957), and is developed over much of the Evander Goldfield (Tweedie, 1968).

(ii) <u>Zone B2</u>

This unit consists of a sediment which varies between a very fine-grained, highly argillaceous quartzite and a quartzitic siltstone. It varies in colour from medium dark grey (N4) and dark greenish grey (5G 4/1) to greenish black (5GY 2/1).

The rock may be conspicuously banded and cross-bedded, elsewhere it may be massive. Banding is due to an alternation of coarser- and finer-grained argillaceous quartzites, or to the presence of heavy mineral layers. The upper portion of this unit carries numerous dark greenish grey (5G 4/1) phyllosilicate partings which are only distinguished with difficulty from the argillaceous quartzite.

The lower contact of this zone is gradational with the underlying Kimberley Shale (Zone B3). The gradation commonly involves the following units :

(1) argillaceous quartzite-quartzitic siltstone, with thin black shale bands;

(2) dark-coloured shale some 60 inches thick; and

(3) some 20 to 50 feet of highly argillaceous quartzite, with black shale bands increasing in width and frequency downwards.

Unit (3) eventually consists predominantly of black shale. At this point, Zone B3 is considered to begin. Units (2) and (3) will be described here, although they could equally well be included in Zone B3.

Unit (2) is a banded rock, consisting of alternating dark-coloured shale and a lighter coloured rock termed calcisiltite by the geologists of the Evander Goldfield (Tweedie, 1968). The calcisiltite is a very fine-grained, argillaceous, carbonate-bearing rock which usually carries finely disseminated pyrite. It is white or light grey in colour on a wet, drilled surface, but is dark greenish grey (5GY 3/1) on a freshly broken surface. It shows moderate to vigorous effervescence with dilute hydrochloric acid. The borehole cores often showed evidence of pre-consolidation movement involving the shale and the calcisiltite in slump structures. Carbonate veinlets, presumably caused by remobilisation of carbonate in the calcisiltite layers, typify this unit. The shale commonly carries pyrite nodules up to 10 mm in diameter.

Unit (3) consists of highly argillaceous quartzite with thin, black shale bands which become more prominent downwards. This unit includes sporadic carbonate-bearing layers. In addition to the type of calcisiltite described above, a spheroidal carbonate rock may be developed. In the latter rock-type, fragments of carbonate are spheroidal in shape, and are separated from one another by a black shale matrix. The carbonate effervesces weakly to moderately with dilute hydrochloric acid. It is greenish black to dark greenish grey in colour (5G 3/1), and carries finely disseminated sulphide specks.

(iii) Zone B3

Zone B3 corresponds to the Kimberley Shale proper. It is essentially a thickness of non-magnetic banded shale. The banding is due to an alternation of coarser- and finer-grained material. The coarser phase has a sharp lower contact, and grades upwards to a finer-grained material. The coarser phase is usually medium or medium-light grey in colour (N5 to N6), and would probably be classified as a siltstone on the basis of its grain-size. The sharp lower contact often shows an undulating pattern in two dimensions, suggestive of ripple-marking or scouring of the finer phase below it. The basal contact of the graded unit is often marked by the presence of very fine-grained quartz grains and rounded pyrite blebs. The latter may be disseminated, or may form a discrete layer at the base of the unit. The quartz grains at the base of graded units may be concentrated to such an extent that a thin layer of very fine-grained sericitic quartzite results. Isolated pyrite nodules and disseminated carbonate minerals typify the coarser phase of the graded units. The basal phase of the graded unit passes upwards to a greyish black (N2) or dark grey (N3) shale. The shale is non-pyritic, and is barren of carbonate disseminations. Slumped bedding structures, similar to those described above, were observed in the Kimberley Shale.

In a pilot study in Borehole WK.1, the thicknesses of some 320 graded units were measured. They range from less than 1 mm to over 128 mm. The arithmetic mean of the graded bed thicknesses was calculated to be 17.4 mm. This figure might prove to be of use in distinguishing the Kimberley Shale from other shales lower down in the succession.

The Kimberley Shale has a gradational contact with the underlying Zone B4 quartzites. The gradation usually takes place in a thickness of less than five feet. The suite of sediments involved in the gradation includes highly argillaceous quartzite, slightly argillaceous quartzite, and shale. The quartzite becomes more siliceous downwards, and the shale bands thinner and more widely spaced.

(iv) Zone B4

This unit consists essentially of fine- to medium-grained siliceous quartzite. The quartzite is prominently black-speckled, due to the presence of small chert grains, and is less conspicuously yellow-and-white-speckled. It is medium (N5) or medium-light grey (N6) in colour. Black chert granules, often concentrated into grit layers, typify the Zone B4 quartzite. Heavy mineral stringers are particularly abundant in this zone.

The quartzite may be banded lighter and darker grey, reflecting subtle compositional changes in the quartzite. Stylolitic seams, marking sites of intrastratal solution, were observed. The stylolites are loci of heavy mineral concentrations. The heavy minerals were, presumably, insoluble under the conditions which were responsible for the intrastratal solution of silica.

Thin, dark greenish black (5G 2/1) shale partings occur in the uppermost portion of the unit. They reflect the gradational contact between this unit and the overlying Kimberley Shale, Phyllosilicate partings become more abundant towards the base of the unit. They are usually black-and-yellow-speckled, and range in colour from dusky yellow-green (5GY 5/2) to olive-grey (5Y 3/2) and greyish olive (10Y 4/2). They may carry variable amounts of discrete quartz grains.

(v) *Zone B5*

This unit, which has an average thickness of 213 feet, is commonly known as the Upper Bird Amygdaloid.

The main body of the lava consists of greyish green (5G 5/2), fine-grained, amygdaloidal or massive lava. Calcite and chert amygdales predominate. Epidote veinlets are not uncommon. Rare, thin, quartzite layers attest to the activity of normal sedimentation, while the lavas were being extruded. The uppermost few feet of the lava usually exhibit a lighter colour, which may be interpreted either as a tuffaceous zone or as the topmost layer of the lava which was subjected to weathering before the deposition of the Zone B4 quartzite. In Borehole WK.1, the weathered lava could be subdivided into two portions. The upper had a light olive-brown colour (5Y 5/6), and was soft and micaceous. It was distinctly banded, the banding often showing a wavy or contorted appearance. It carried white, spherical bodies, less than three millimetres in diameter. A thin-section of this rock showed an abundance of chloritoid laths. A macroscopic description of this rock and the presence of chloritoid led the author to believe that this rock could be the equivalent of the Bird Reef Marker which is developed elsewhere in the eastern segment of the Witwatersrand Basin. According to Antrobus (1964), the Bird Reef Marker is thought to have been derived from a volcanic ash. If this rock represents the Bird Reef Marker, then its position is rather anomalous, since it is usually developed some twenty feet above the Bird Lava, as an intercalation in the overlying quartzite.

The lower of the two weathered zones in the lava had a pale olive colour (10Y 6/2). It showed indistinct contorted banding, and commonly carried white pinhead-sized amygdales. Drilled surfaces of this rock showed vertical and sub-vertical wavy black lines. These lines were the surface manifestation of winding pipe-like bodies (less than five millimetres in diameter) of a hard, black mineral. They could represent pipe amygdales.

(vi) *Zone B6*

Zone B6 consists mainly of siliceous or sub-siliceous, medium- to fine-grained quartzite. It is medium or medium-light grey (N6) in colour, and is usually black-speckled. The quartzite may take on a greenish grey (5G 6/1) colour where sericitic. There is a tendency towards development of a highly argillaceous quartzite towards the base of the zone; this quartzite is yellow-speckled and is dusky yellow-green (5GY 5/2) or dark greenish grey (5G 4/1) in colour.

The quartzites are typically gritty, and may carry rare, small-pebbled conglomerates. Granules and pebbles consist of vein quartz and red, black, or grey chert. Some of the small-pebbled conglomerates may be well-packed, mineralized, and auriferous. Heavy mineral stringers are particularly abundant in the Zone B6 quartzite. Phyllosilicate partings are common in the quartzite. They are yellow-speckled, and are dusky yellow-green (5GY 5/2) in colour. Their upper contacts may carry heavy mineral concentrations.

(vii) *Zone B7*

Zone B7 is usually referred to as the Lower Bird Amygdaloid. Its top contact is a sharp sedimentary contact. The top foot or so of the lava is often fissile and non-amygdaloidal, and has a greyish green colour (10GY 5/2).

The upper half of the lava is predominantly amygdaloidal, and is greenish black (5GY 2/1) in colour. Spheroidal amygdales, which average some five millimetres in diameter, consist of quartz, calcite, and chlorite. The lower half of the volcanic is predominantly non-amygdaloidal, and is dusky yellowish green (10GY 3/2) or dark greenish grey 5G 4/1) in colour. It is often veined by quartz, calcite, and epidote veinlets. The lowermost few feet of the lava may, once again, be amygdaloidal. In Borehole LP.2, seven inches of a massive, black-veined, dusky yellow (5Y 6/4) rock were developed. This rock, which rested with a sedimentary contact on the Zone B8 quartzite, could represent a fine-grained pyroclastic.

In Figure 2, the regional variation in the development of the Bird Lava can be seen. The lavas are best developed in the southeastern portion of the Witwatersrand Basin. If thickness of lava is controlled by the proximity of the centre of eruption, then the Bird lavas were probably extruded in an area lying to the southeast of a line joining the South Rand and Evander goldfields.

(viii) *Zone B8*

The Zone B8 quartzite is medium- to fine-grained, and is usually siliceous or sub-siliceous in composition. The colour varies accordingly from light grey (N7) to greenish grey (5GY 6/1). Dark greenish grey (5G 5/1) and dusky yellow-green (5GY 5/2) argillaceous quartzites are more rarely developed. The quartzites are black-speckled, often gritty, and may carry heavy mineral stringers. Phyllosilicate partings are common in this zone. They are yellow-speckled, and are dusky yellow-green (5GY 5/2) or greyish olive-green (5GY 3/2) in colour.

(ix) *Zone B9*

This zone is the equivalent of the succession of conglomerates known as the Bird Reefs or the Bird Reef Group elsewhere in the Witwatersrand. In the Delmas area, this zone has an average thickness of 21 feet. It consists essentially of an alternation of quartzites and conglomerates. The zone was studied in detail in Boreholes WK.1 and LP.2, in which the precise thicknesses and the number of conglomerate bands were recorded. Conglomerate bands were arbitrarily defined as being greater than one inch thick, and as being spaced a minimum of three inches apart. The results of the study are shown below :

Borehole	Percentage Conglomerate	Conglomerate/ Quartzite Ratio	Number of Conglomerate Bands
WK.1	21.1	0.27	7
LP.2	20.2	0.25	8

The conglomerates are concentrated at the top, in the middle, and at the base of the zone. They are loosely packed or compact, small-pebbled conglomerates. Pebbles consist of vein quartz (white, smoky grey, or opalescent bluish) and chert (black, grey, or banded). The matrix of the conglomerates is usually a dark, argillaceous quartzite. The conglomerates are barren to moderately mineralized, and are auriferous and usually uraniferous.

The quartzites interbedded with the conglomerates range in composition from slightly argillaceous to highly argillaceous. They are often pebbly and gritty. Phyllosilicate partings may also be developed.

D. THE MAIN STAGE

The Main Stage is defined as falling between the base of the Bird Reef Group and the Main Reef Horizon. Antrobus (1964) distinguished six different lithological units in the Main Stage quartzites of the East Rand. In the Delmas area, these quartzites are divisible into two units only.

(i) *Zone M1*

The Zone M1 quartzite is predominantly an argillaceous quartzite with scattered pebbles. It ranges in composition from subsiliceous, with a light greenish grey (5G 8/1) or greenish grey (5GY 6/1) colour, through argillaceous to highly argillaceous quartzite, greyish olive-green (5GY 4/2) in colour. The quartzites are medium-grained, and are speckled black, yellow, grey, and green. Banding, due to an alternation of more, and less, highly argillaceous quartzite, is common. Heavy mineral stringers are frequently developed.

The quartzite carries widely spaced, small pebbles of vein quartz, chert, and chlorite. Phyllosilicate layers are particularly common, are rich in pyrite and leucoxene, and often carry isolated quartz grains. They are olive-grey (5Y 3/2) in colour. The Zone M1 quartzite carries rare pyrite nodules up to two inches in diameter.

(ii) Zone M2

The contact of Zones M1 and M2 is marked by the onset of siliceous quartzite, and by the presence of poorly packed, small-pebbled conglomerates and grits.

The main body of the zone is made up of a medium- or medium-to-fine-grained quartzite. The quartzite is dominantly siliceous or sub-siliceous in composition, but may become argillaceous towards the centre of the zone. The siliceous quartzite is light greenish grey (5G 8/1) in colour, the sub-siliceous quartzite is greenish grey (5G 7/1), while the argillaceous quartzite is dusky yellow-green (5GY 6/2) in colour. Heavy mineral stringers are present, and often stain the adjacent quartzites a vivid green colour. The quartzite is commonly banded, due to the alternation of more, and less, highly argillaceous quartzite. Black chlorite granules may be scattered through the quartzite which usually shows black, yellow, and greenish grey speckling. Phyllo-silicate partings, which are black-and-yellow-speckled, become more abundant towards the base of the zone. They are dusky yellow-green (5GY 5/2) or light olive (10Y 5/4) in colour.

(iii) The Main Reef Horizon

The Main Reef Horizon is represented by a thin conglomerate band which, in the Delmas area, had a maximum intersected thickness of nine inches.

A study of pebbles in the Main Reef Horizon conglomerate was not conclusive, mainly due to the small amount of material on which to make measurements. Pebbles are generally rounded and spheroidal. In Borehole LP.2, of the 86 pebbles studied (all that were available), 59 per cent were of white vein quartz, 22 per cent of clear vein quartz, and 19 per cent of chert. The chert pebbles were banded, jasperitic, black or grey. The pebble size varied from 4 mm to some 20 mm. The arithmetic mean of the 66 measurements made was found to be 9.0 mm.

The matrix of the conglomerate varies from mineralized to barren. The conglomerate is auriferous

E. THE LOWER WITWATERSRAND STRATIGRAPHY

As has been pointed out, the entire stratigraphic column for the Witwatersrand Sequence could not be constructed. It was calculated that, on the average, the thickness of stratigraphic units in the Delmas area was some 64 per cent of their thickness in the Nigel area. On this basis, the Lower Witwatersrand stratigraphy was expected to be of the order of 6000 feet thick in the Delmas area. The thickness of the stratigraphic gap in Figure 3 was then calculated to be some 2500 feet. The gap is that portion of the Lower Witwatersrand normally assigned to the lower portion of the Government Reef Series and the upper portion of the Hospital Hill Series.

The subdivisions normally used to differentiate the Lower Witwatersrand strata are not employed in this description. In particular, the standard practice of placing the lower limit of the Jeppestown Series at a gradational contact at the base of the first shale below the Jeppestown Amygdaloid was not adhered to. For this reason, the stratigraphy has been described in units which were defined with respect to certain conveniently placed marker horizons in the stratigraphic column. These units were not intended to act as lithostratigraphic units; they are merely units of convenience.

Before commencing the description of the Lower Witwatersrand stratigraphy, it must be acknowledged that the majority of the descriptions were drawn from the borehole logs of the Anglo-Transvaal and Anglo American geologists. The author was, however, responsible for much of the correlation of lithologic units, and for the compilation of the stratigraphic column.

(i) The Interval : Main Reef Horizon to Jeppestown Amygdaloid

In the Delmas area, the footwall of the Main Reef Horizon is formed by a shale which has an average thickness of 96 feet. This shale decreases in thickness from 150 feet in the western portion of the Bultfontein Basin to 40 feet in the eastern and southeastern portions. It is believed that this thinning can be ascribed to a period of pre-Main Reef Horizon erosion. In the East Rand Basin, this erosion caused a decrease in thickness of the same shale from 500 feet to 300 feet from west to east over the basin.

The shale referred to above has a weathered phase of lighter coloured material which overlies the darker green unweathered shale. Most boreholes stopped in the weathered phase, so that only this portion can be described in any detail. In the weathered phase, the shale consists of a succession of siltstone-shale graded units. The graded units are not perfectly developed, in a number of cases isolated siltstone or shale units being observed. The siltstone has a greenish grey (5GY 6/1) or dusky yellow-green (5GY 5/2) colour. It has a sharp contact with the underlying shale. This contact is often marked by concentrations of quartz grains, pyrite grains, and yellow leucoxene specks. On a smooth surface, the siltstone was often seen to be banded on a millimetre scale. Pre-consolidation slump structures were not infrequently observed. Flame structures, where shale was injected into the overlying siltstone phase, are developed. The siltstone usually grades upwards into a uniform greenish black (5GY 3/1) or dark greenish grey (5GY 4/1) shale.

The thickness of graded units varies considerably. The arithmetic mean of the thickness of 100 graded units in Borehole WK.1 was found to be 29.6 mm. This figure contrasts sharply with that of 17.4 mm for the Kimberley Shale. The systematic measurement of the graded unit thickness and the study of the population statistics of these measurements are thought to be potentially powerful tools in the identification and the correlation of Witwatersrand Sequence shales.

This shale is separated from the underlying quartzite by a transition zone of alternating argillaceous quartzite and shale. The quartzite is medium- to fine-grained, and is usually dark greenish grey (5GY 4/1) in colour. In addition, it shows prominent banding and cross-bedding. The banding is due to an alternation of lighter coloured, carbonate-bearing quartzite with a darker coloured, argillaceous quartzite.

The transition zone is underlain by a thickness of quartzite which varies from argillaceous at the top to siliceous in the centre to argillaceous at the base. These quartzites are medium- to fine-grained, and vary in colour from light grey to dark greenish grey, depending on their composition. They are often striped and cross-bedded, carry heavy mineral stringers and shale bands, and are carbonate-bearing in sections.

The quartzite grades downward into a shale zone, viá a suite of alternating argillaceous quartzites and shales. The shale is an assemblage of siltstone-shale graded units. The siltstone is greenish grey in colour, and may carry isolated quartz grains. The shale is greenish black (5G 2/1) in colour, and may be strongly magnetic in sections. Downwards, argillaceous quartzite bands become prominent, and the shale grades into an argillaceous quartzite. The quartzite is fine-grained, dark grey in colour, and is often striped. Carbonate minerals may give the quartzite a spotted appearance. In most cases, this quartzite rests directly on the Jeppestown Amygdaloid. In one borehole, however, the quartzite was separated from the lava by a few feet of grey, banded shale.

(ii) *The Jeppestown Amygdaloid*

The Jeppestown Amygdaloid consists predominantly of a dark greenish grey (5GY 4/1) lava. The lava is prominently amygdaloidal in its upper half. White calcite and zoned greenish black chlorite amygdales are the most common types. In the lower half, the lava is sparsely amygdaloidal, and often carries scattered feldspar phenocrysts. The lowermost few feet of the lava may, once again, be amygdaloidal. At intervals, the lava carries bands of fine- and medium-grained pyroclastic material. For example, in Borehole LP.2, a very fine-grained, uniform greenish grey (5GY 6/1) tuff was developed at the base of the lava.

(iii) *The Interval : Jeppestown Amygdaloid to Slipper Horizon*

This interval consists of quartzites which vary from argillaceous at the top to siliceous at the base. The argillaceous quartzite is fine-grained, and prominently banded and cross-bedded. The banding is due to an alternation of dark greenish grey (5GY 4/1) argillaceous quartzite and greenish grey (5GY 6/1) sub-siliceous quartzite. The lighter coloured quartzite is, almost invariably, carbonate-bearing. Siliceous quartzite sections become more prominent downwards, until the quartzite is predominantly siliceous. The siliceous quartzite is fine- to medium-grained, and is light grey or very light grey in colour. It is striped to varying degrees, due to the presence of more sericitic sections. The quartzite is typically black-speckled, and commonly carries heavy mineral stringers and shale partings.

At the base of this quartzite, a thickness of gritty quartzite, with disseminated crystalline and detrital pyrite and associated heavy minerals, is developed. This gritty quartzite was called the Slipper Horizon by the Anglo-Transvaal geologists. It rests with a sharp, probably erosive, contact on the underlying shale.

(iv) The Interval : Slipper Horizon to Veldschoen Reef

The shale immediately underlying the Slipper Horizon may show a bleached, or weathered, appearance in its top few feet. The main body of the shale is broadly banded. The banding is due to the presence of the normal graded siltstone-shale units. The siltstone phase is light greenish grey, and may be quartzitic. The shale phase is dark greenish grey or black. This zone is slightly magnetic in sections.

This shale grades downwards into a predominantly massive argillaceous quartzite which, in turn, grades into a siliceous quartzite. The siliceous quartzite is light coloured, black-speckled, and is often stylolytic. Coarser phases, in the form of gritty quartzites, grits, and, rarely, gritty small-pebbled conglomerates, may be developed. In a number of boreholes, a thickness of argillaceous quartzite, with dark grey or black shale bands, was intersected about midway in the siliceous quartzite. At, or near, the base of the siliceous quartzite are developed one or two bands of gritty small-pebbled conglomerate or grit. The conglomerate varies from loosely packed to compact. Pebbles are of vein quartz, chert, and banded jasper. The matrix of the conglomerate varies from well-mineralized to barren. The conglomerate may be auriferous.

This conglomerate was termed the Veldschoen Reef by the Anglo-Transvaal geologists. This is an unfortunate choice of names, since the Veldschoen Reefs, in their type area, lie at the base of the first quartzite below the Jeppestown Amygdaloid (Collender, 1960). On this basis, the Slipper Horizon would more correctly coincide with the Veldschoen Reefs, as developed in their type area. The Veldschoen Reef of the Delmas area occupies a similar stratigraphic position to the Government Reef on the East Rand. The two could be equivalent.

(v) The Interval : Veldschoen Reef to Tilloid Horizon

In the interval between the Veldschoen Reef and the Tilloid Horizon, four shale zones and three quartzite zones are developed. They are described below in descending stratigraphic order.

The shale immediately underlying the Veldschoen Reef is dark greenish grey to black in colour, and is massive or banded. This shale zone is commonly slightly magnetic, but may be strongly magnetic in some sections. The shale grades downward to a thickness of fine-grained, light to medium grey, argillaceous quartzite. This quartzite is carbonate-bearing in sections. Downwards, this quartzite includes a greater percentage of shale bands. It grades into a dark green or black banded shale. This shale is strongly magnetic in sections.

The shale described above grades downwards to a fine-grained, medium grey, argillaceous quartzite, and this in turn grades into a fine- or medium-grained, medium or light grey, siliceous quartzite. This quartzite shows all the usual features associated with the siliceous quartzites of the Lower Witwatersrand. It has a sharp, probably erosive, contact on the top of the third shale below the Veldschoen Reef.

The third shale below the Veldschoen Reef is broadly banded, and dark grey to black in colour. The shale becomes massive and dark greenish grey towards its base. The major part of this shale zone is non-magnetic or only slightly magnetic. However, near the base of the zone, some sections are strongly magnetic.

The third shale grades downward to an argillaceous quartzite which, in turn, grades downwards into a siliceous quartzite. This siliceous quartzite is separated from the siliceous quartzite at the base of the zone by a thickness of argillaceous quartzite and shale. The quartzites and argillaceous quartzites of this zone are typified by the presence of scattered carbonate-bearing sections.

A shale with gradational upper and lower contacts overlies the Tilloid Horizon. This shale is broadly banded, and is dark grey to light greenish grey in colour. The bedding may show pre-consolidation slump structures. The shale is often moderately magnetic, but may be strongly magnetic in sections.

The shale is underlain by gritty or pebbly argillaceous rock which has been termed a tilloid. The fragments are usually angular or subangular, and consist of quartz, quartzite, chert, and red jasper. The groundmass of the tilloid is highly argillaceous, and dark greenish grey or dark green in colour. Intercalated in the tilloid, there may be developed a variable thickness of quartzite. The tilloid is underlain either by siliceous quartzite or, more commonly, by a shale which grades downward to a highly argillaceous quartzite.

The stratigraphy of the Witwatersrand Sequence becomes ill-defined below this point.

(vi) The Hospital Hill Shale and Orange Grove Quartzite

The description of the stratigraphy is continued near the base of the Hospital Hill Shales, some 2500 feet below the Tilloid Horizon. The description has been based on the logs of Boreholes KN.1, DSt.1, and RGh.1.

In Borehole DSt.1, a stratigraphic thickness of 174 feet of dark green to black magnetic shale was encountered beneath the Transvaal Sequence. This shale has a thin band of siliceous quartzite near its base, and is underlain by 37 feet of medium-grained, light grey, siliceous and stylolytic quartzite. This quartzite is, in turn, underlain by 133 feet of magnetic shale which carries two chert-pebble layers and one thin quartzite band.

The Orange Grove Quartzite is split into three layers by two shale bands. The uppermost quartzite alternates between siliceous and argillaceous. It is underlain by a thin, inconspicuous shale band. The middle quartzite is mainly siliceous, medium-grained, and varies in colour from light to dark grey. This quartzite rests with a sharp contact on a dark coloured, ripple-marked shale. The lowermost quartzite is siliceous, medium-grained, and varies in colour from light to dark grey. At the base of the third quartzite, resting on the Basement granite, is developed a variable thickness of arkosic quartzite, grit, and conglomerate. These rudaceous sediments are particularly well-developed in Borehole KN.1. In this borehole, quartzite for ten feet or so above the granite is feldspathic, and carries scattered grit and pebble-sized fragments. At or near the contact is developed a conglomerate band up to twelve inches in thickness. This conglomerate is auriferous and uraniferous.

F. CYCLIC SEDIMENTATION IN LOWER WITWATERSRAND SEDIMENTS

Cyclic sedimentation is very well displayed in the Lower Witwatersrand sediments of the Delmas area. In the interval between the Main Reef Horizon and the Tilloid Horizon, the seemingly jumbled succession of conglomerate, quartzite, and shale can be shown to make up a well-ordered series of sedimentary cycles.

In Figure 4 (right-hand side), the stratigraphy of the above-mentioned interval is shown. The cyclical nature of sedimentation is illustrated by a plot of energy against stratigraphic thickness. The energy of sediments represents a qualitative assessment of the competency of the transporting medium from which the sediments were deposited.

In Figure 4, two cycle types may be distinguished. The first involves a succession which may be represented as ABCDCBAB......., where the letters represent lithologies. Such a cycle is termed symmetrical, and consists of two hemicycles. If the hemicycle A to D involves successively lower energy rock-types stratigraphically upwards, it is called a transgressive hemicycle. If the opposite is true, the hemicycle is termed regressive. The lithologies A and D, being at the same time portions of regressive and transgressive hemicycles, are termed pivotal lithologies (Pearn, 1964). The second type of cycle may be represented as ABCDABCD......., and is termed an asymmetrical cycle. In the Delmas stratigraphy, three such asymmetrical cycles are seen. They are characterized by sharp, non-gradational contacts at their bases. At these contacts, the high energy phase of the asymmetrical cycle rests directly on a lower energy phase of the previous cycle.

It is well established that these sharp contacts represent planes of erosion (see, for example, Collender, 1960). The absence of regressive hemicycle sediments below these erosion contacts can be explained in the following way. The process of regression is thought to have involved a relative upward movement of the basin rim, with respect to the basin itself. If the regression was carried far enough, the sediments deposited during regression could have been elevated above base-level and eroded away.

The usefulness of subdividing the stratigraphic column on the basis of sedimentary cycles was clearly recognized by Collender (1960). He erected a number of stages, the upper and lower limits of which were erosion contacts of the type described above. In the Delmas area, the stratigraphic section under consideration can be subdivided into four units. The upper three units (see Figure 4) consist of similar cyclical patterns, which commence at the base with a transgressive asymmetrical cycle and are followed upwards by a symmetrical cycle. The lowermost unit consists of two symmetrical cycles.

The illogical nature of the lower and upper limits usually accepted for the Jeppestown Series was also illustrated by the study of cycles. The upper limit of the series is usually placed at the top of the second shale above the Jeppestown Amygdaloid. This shale has a perfect gradational contact with the overlying quartzite in areas to the west of the East Rand. The lower limit of the Jeppestown Series is placed at the base of the first shale below the amygdaloid. This shale is gradational downwards to quartzite. It is contended that subdivisions based on cycles such as those outlined in Figure 4 provide a more logical basis for the subdivision of much of the Lower Witwatersrand stratigraphy.

The study of cycles goes further than just facilitating subdivision of the stratigraphic column. It is a valuable aid in the correlation of sediments from one area to another. Thus, for example, on studying a diagram similar to Figure 4, the strikingly similar patterns of cyclic sedimentation give a confidence in correlation that might otherwise not have been felt, on account of the disparity of thicknesses and rock-types developed in the different areas. On theoretical grounds, the study of cycles allows the delimitation of time planes in Witwatersrand sediments. A consequence of this is that sedimentary facies changes can be demonstrated. As a starting point, the cyclical patterns developed immediately above the Jeppestown Amygdaloid in the Delmas area, the West Wits, Klerksdorp, and Orange Free State Goldfields, as shown in Figure 4, can be considered. These instances were chosen because they are well-documented, and are separated by large distances. The Jeppestown Amygdaloid is developed in all these localities, and probably represents a time-plane as near perfect as any time planes delineated by paleontological evidence. The near identical pattern of cyclic sedimentation developed above the amygdaloid over the distance considered leaves little doubt that these cycles were caused by a mechanism which operated at the same time on a regional scale. It follows that the change from transgression to regression (or vice-versa) occurred at the same time throughout the basin. Such changes are marked by the presence of pivotal lithologies in the stratigraphic record. The conclusion is reached that pivotal lithologies associated with the same cycles in different areas have the same age.

Using these arguments, it is contended that the lines joining the pivotal points (marked as P) in Figure 4 approximate time planes. However, as shown in this figure, the lithology of the pivotal points varies. For example, the third pivotal point (Pc) is represented by argillaceous quartzite with shale bands in columns 1, 2, and 3, but is represented by a true shale in colume 4. The shale lithosome which makes up P4c is inferred to pinch out somewhere along the line joining P4c and P3c. It is believed that a sedimentary facies change has been demonstrated. The facies changes detected are rather subtle. This can be explained by the fact that all four of the localities chosen lie along the northwestern rim of the basin, more-or-less parallel to the paleostrike of the Witwatersrand depositional floor. Facies changes might be more marked in a direction parallel to the paleoslope. Unfortunately, the sort of detailed information required in a study of this type is not available for the southeastern rim of the Witwatersrand Basin, where the sedimentary facies might be expected to be markedly different from those of the northwestern rim.

SUMMARY AND CONCLUSIONS

In the Delmas area, the relative severity of pre-Transvaal erosion resulted in the removal of the Klipriviersberg Lava and the Elsburg Conglomerates. The Kimberley-Elsburg Intermediate Quartzite was the highest stratigraphic unit intersected in drilling to the north of Delmas.

The Upper Kimberley Substage, formed of five conglomerate-quartzite and four quartzite zones in its type area, is represented in the Delmas area by two conglomerate-quartzite zones, two quartzite zones, and one compact conglomerate. The last-mentioned, here called the Kimberley Reef, is the probable equivalent of the UK9A or May Reef of the East Rand. A pebble study of the Kimberley Reef and of the pebbly quartzite which underlies it indicated that the Kimberley Reef pebbles (and thus possibly the matrix) could have been derived from the underlying quartzite. The low gold content of the Kimberley Reef can then be explained by the low gold content of the Zone K1 Quartzite and the fact that pre-Kimberley Reef erosion has nowhere progressed deep enough to incorporate the auriferous Big Pebble Conglomerate and Bottom Reef. The intersection of the Kimberley Reef by six boreholes to the north of Delmas and three to the southwest of the town is, however, not considered sufficient evidence to eliminate entirely the possibility that narrow zones of payable ore may be present along this reef in the area.

The Chloritoid Shale Marker suite of sediments, developed to the south of Delmas, was not intersected beneath the Kimberley Reef to the north of the town. The Zone K1 pebbly quartzite is thought to represent an arenaceous phase of the underlying Big Pebble Conglomerate. Within the Big Pebble Conglomerate, pebbles tend to become smaller and better sorted towards the base. In addition, it was found that, on the average, vein quartz and tuff pebbles are some 30 per cent larger than grey and black chert pebbles. It was concluded that vertical variation and pebble composition should be taken into account when studying pebble sizes in the Big Pebble Reef.

The Chert Pebble Quartzite of the East Rand is poorly developed in the Delmas area. At its base, a thickness of siliceous quartzite, alternating with mineralized and auriferous grit or conglomerate, is developed.

The Kimberley Shale is represented by three phases in the Delmas area. The uppermost is a light coloured, fine-grained, siliceous quartzite, and is the probable equivalent of the LK1 Quartzite. This is underlain by a fine-grained, highly argillaceous quartzite, which carries black shale bands towards its base, and is, in turn, underlain by the Kimberley Shale proper. The latter is composed of a succession of siltstone-shale graded units. Carbonate-bearing rocks, often showing contorted bedding, are developed.

Downwards, the Kimberley Shale grades rapidly to a light coloured, black-speckled, sometimes gritty, siliceous quartzite. This quartzite is underlain by the two layers of Bird Lava which are separated by a gritty quartzite. The Bird Reef Zone follows beneath the Lower Bird Amygdaloid. The Bird Reef Zone is made up of alternating small-pebbled conglomerate and quartzite, the former making up some 20 per cent of the total thickness of the zone.

The six lithologic units recognized in the Main Stage Quartzites of the East Rand Basin are not developed in the Delmas area. Here, only two units were identified. The upper is an argillaceous quartzite which carries scattered pebbles, while the lower is a siliceous quartzite. The Main Reef Horizon is represented by a single, thin, medium-pebbled conglomerate which carries small amounts of gold. The base of this conglomerate is a plane of contemporaneous erosion.

In the Delmas area, the Lower Witwatersrand strata consist predominantly of shale, argillaceous quartzite, siliceous quartzite, and insignificant amounts of grit and conglomerate. Shales are usually greenish-grey, may be magnetic, and are often graded-bedded. All gradations between shale and siliceous quartzite are present. The quartzites often carry carbonate minerals.

Two fundamental cycle-types, the symmetrical and the asymmetrical, were recognized within the Lower Witwatersrand strata. Recognition of such cycles allows a more meaningful subdivision of the stratigraphic column to be made in a number of cases. In addition, a study of cycles can be of use in problems of correlation and can show that subtle sedimentary facies changes are present along the northwestern rim of the Witwatersrand Basin.

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KEY TO FIGURES

Figure 1 : Locality map, showing the position of Delmas in relation to the East Rand and Evander goldfields.

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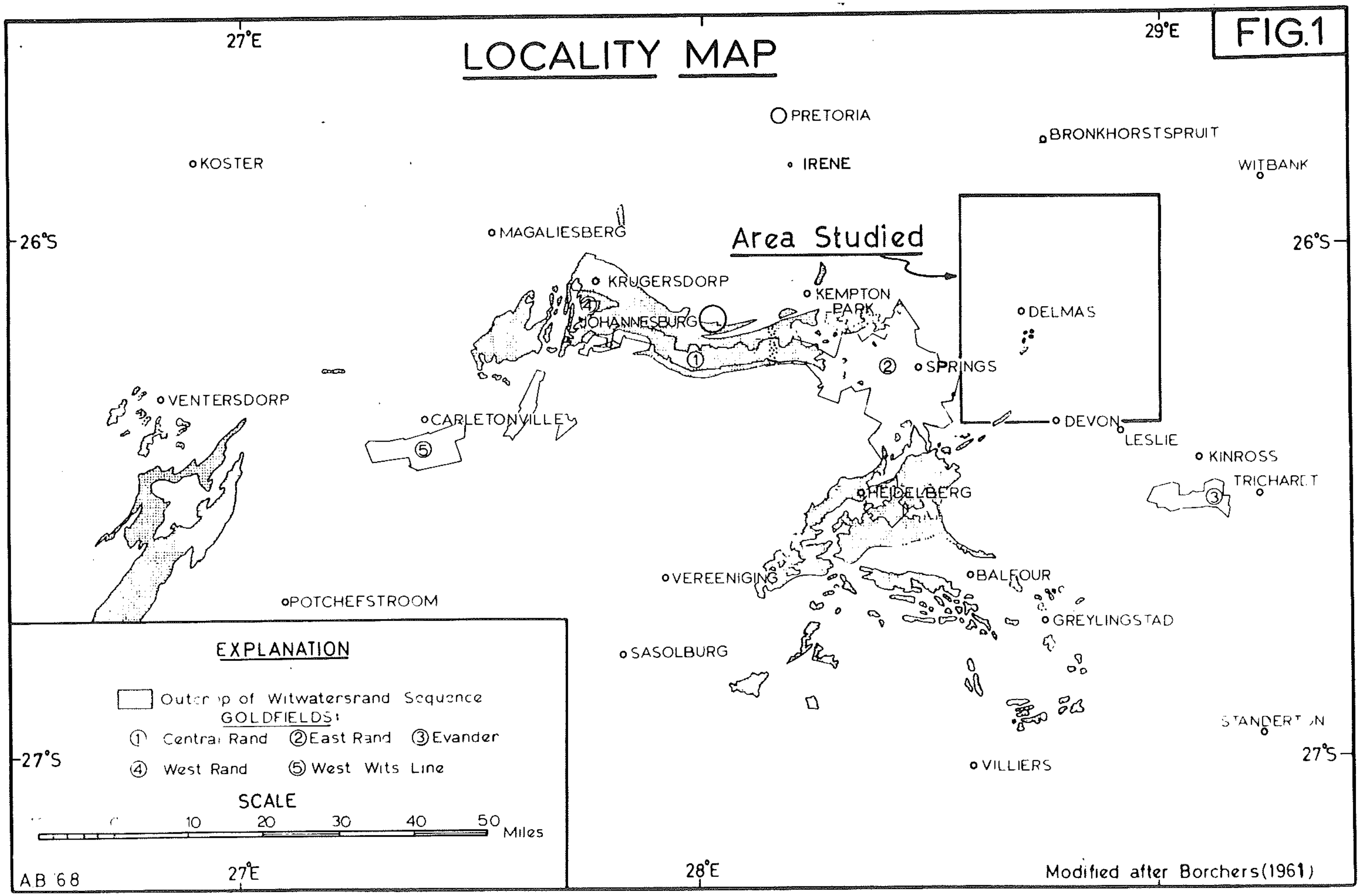

FIG.1
LOCALITY MAP
27°E
28°E
29°E
26°S
27°S
PRETORIA
BRONKHORSTSPRUIT
KOSTER
IRENE
WITBANK
MAGALIESBERG
Area Studied
KRUGERSDORP
KEMPTON PARK
JOHANNESBURG
DELMAS
SPRINGS
VENTERSDORP
CARLETONVILLE
DEVON
LESLIE
KINROSS
HEIDELBERG
VEREENIGING
BALFOUR
POTCHEFSTROOM
GREYLINGSTAD
SASOLBURG
VILLIERS
EXPLANATION
Outcrop of Witwatersrand Sequence
GOLDFIELDS:
① Central Rand ② East Rand ③ Evander
④ West Rand ⑤ West Wits Line
SCALE
10 20 30 40 50 Miles
AB 68
Modified after Borchers (1961)

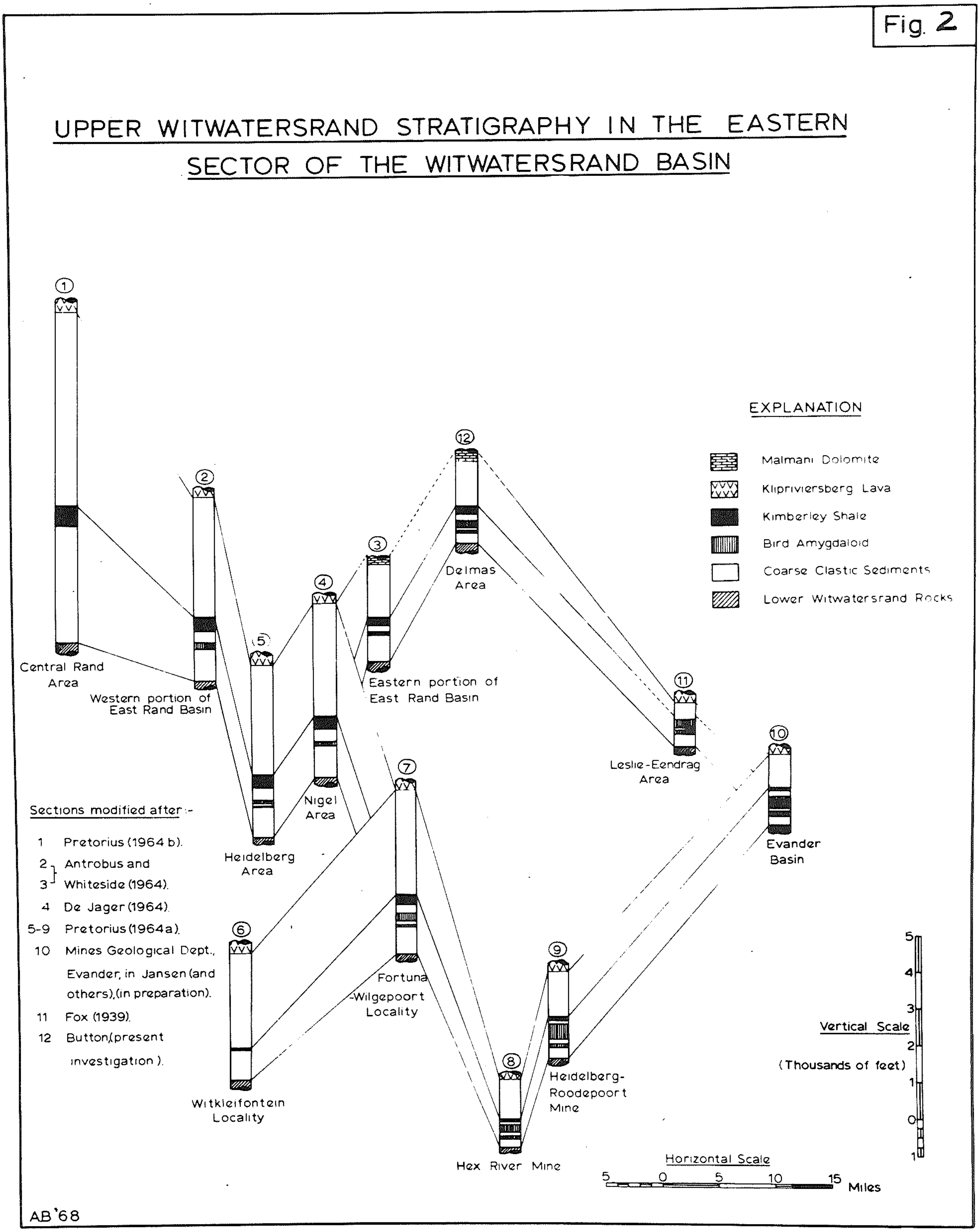
Fig. 2
UPPER WITWATERSRAND STRATIGRAPHY IN THE EASTERN SECTOR OF THE WITWATERSRAND BASIN
EXPLANATION
Malmani Dolomite
Klipriviersberg Lava
Kimberley Shale
Bird Amygdaloid
Coarse Clastic Sediments
Lower Witwatersrand Rocks
1
Central Rand Area
2
Western portion of East Rand Basin
5
Heidelberg Area
4
Nigel Area
3
Eastern portion of East Rand Basin
12
Delmas Area
11
Leslie-Eendrag Area
10
Evander Basin
7
Fortuna -Wilgepoort Locality
6
Witkleifontein Locality
8
Hex River Mine
9
Heidelberg-Roodepoort Mine
Sections modified after:-
1 Pretorius (1964 b).
2, 3 Antrobus and Whiteside (1964).
4 De Jager (1964).
5-9 Pretorius (1964 a).
10 Mines Geological Dept., Evander, in Jansen (and others), (in preparation).
11 Fox (1939).
12 Button (present investigation).
Vertical Scale (Thousands of feet)
5 4 3 2 1 0 1
Horizontal Scale
5 0 5 10 15 Miles
AB '68

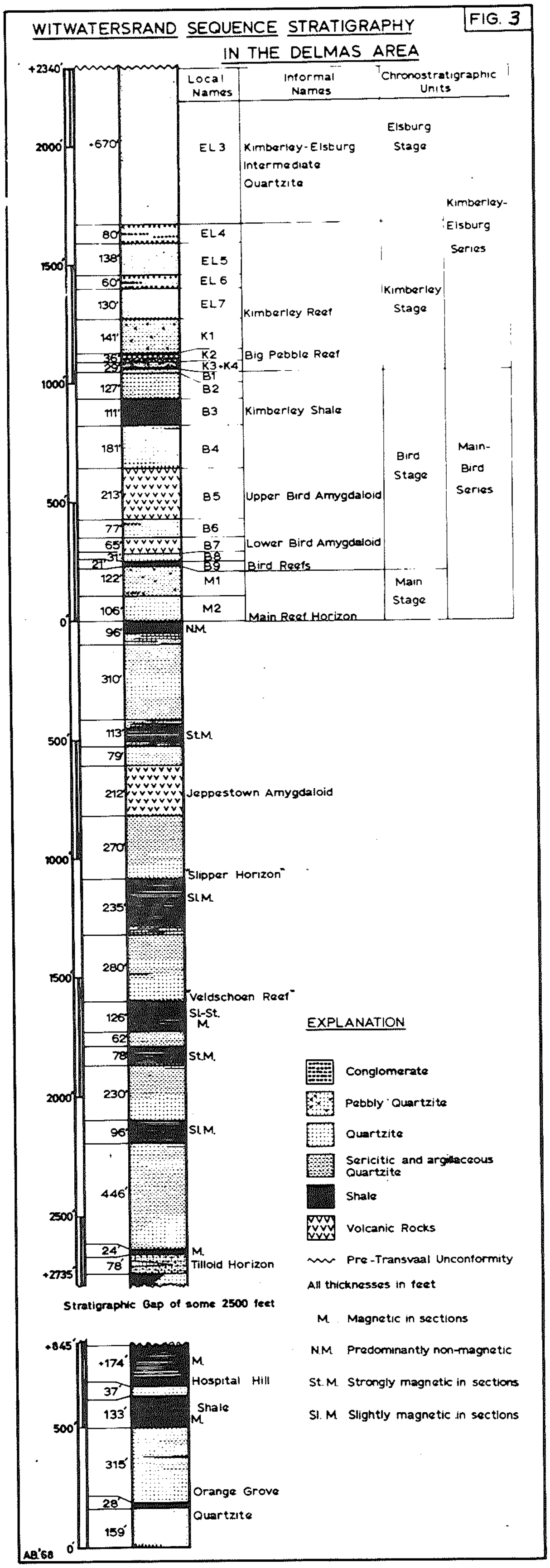
FIG. 3
WITWATERSRAND SEQUENCE STRATIGRAPHY
IN THE DELMAS AREA
Local Names
Informal Names
Chronostratigraphic Units
EL3
Kimberley-Elsburg Intermediate Quartzite
Elsburg Stage
Kimberley-Elsburg Series
EL4
EL5
EL6
EL7
Kimberley Reef
Kimberley Stage
K1
K2
Big Pebble Reef
K3+K4
B1
B2
B3
Kimberley Shale
B4
Bird Stage
Main-Bird Series
B5
Upper Bird Amygdaloid
B6
B7
Lower Bird Amygdaloid
B8
B9
Bird Reefs
M1
Main Stage
M2
Main Reef Horizon
N.M.
St.M.
Jeppestown Amygdaloid
"Slipper Horizon"
Sl.M.
"Veldschoen Reef"
Sl-St. M.
St.M.
Sl.M.
M.
Tilloid Horizon
Stratigraphic Gap of some 2500 feet
M.
Hospital Hill Shale
M.
Orange Grove Quartzite
EXPLANATION
Conglomerate
Pebbly Quartzite
Quartzite
Sericitic and argillaceous Quartzite
Shale
Volcanic Rocks
Pre-Transvaal Unconformity
All thicknesses in feet
M. Magnetic in sections
N.M. Predominantly non-magnetic
St.M. Strongly magnetic in sections
Sl. M. Slightly magnetic in sections
AB.'68

Fig. 4

CYCLIC SEDIMENTATION IN SOME LOWER WITWATERSRAND SEDIMENTS