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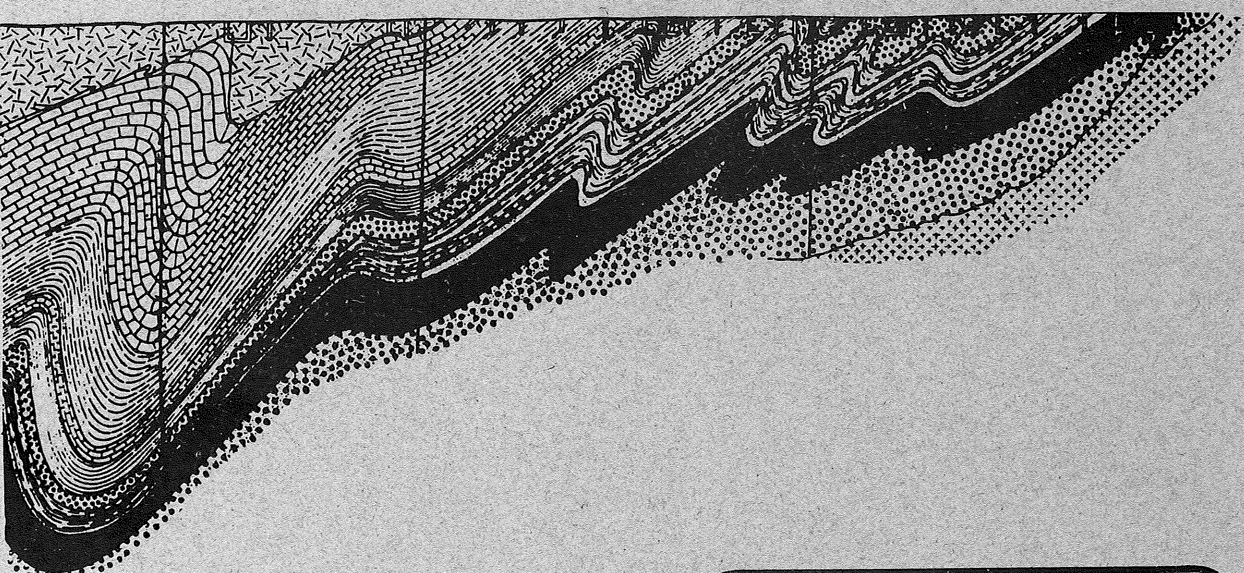

ECONOMIC GEOLOGY

RESEARCH UNIT

UNIVERSITY OF THE WITWATERSRAND

JOHANNESBURG

THE GEOLOGY OF THE NORTHERN SECTION OF THE ORANGE FREE STATE GOLDFIELD

by

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THE GEOLOGY OF THE NORTHERN SECTION OF THE ORANGE FREE STATE GOLDFIELD

A B S T R A C T

The stratigraphical succession is more complete and thicknesses somewhat greater than in the type section around Welkom.

Isopach maps reveal the nature of marginal unconformities associated with the Basal Reef, the "B" Reef and the upper portion of the Elsburg Stage. Regular overlaps developed in the direction of the limit of the depositional basin.

Downwarps and arches were produced during Kimberley times and were intensified subsequently. Folding on an axis parallel to the elongation of the sedimentary basin was particularly prominent during Elsburg time. A marginal synclinal trough formed and was filled with coarse sediments as subsidence, due to folding, continued. These coarse sediments contain the gold-bearing conglomerates called Elsburg Reefs, which are limited to a narrow strip along the western limb of the syncline. The folding ceased towards the end of Elsburg time, when a new zone of disturbance, the Border Fault, was developed about two miles further west.

Lava of the Ventersdorp Lower Volcanic Stage poured out over the newly-formed sediments, and its weight and the depletion of the magma chamber eventually caused the sediments to tilt westwards. A northerly plunge of the axis of the marginal syncline probably was produced during a later stage of Ventersdorp time. Step faults associated with the tilting have dislocated the Witwatersrand beds. Later faults are tentatively considered to have been brought about by the processes responsible for the plunge of the axis of the fold. A less spectacular marginal downwarp occurs west of the De Bron Fault in the east. The Witwatersrand beds are tilted towards the De Bron Fault in the south-easterly portion of the area, resulting in a broad zone of interference structures trending north-east across the Freddies Mine.

The intimate relationship between the nature of the subsidence and the composition and distribution of the sediments that entered the basin is clearly revealed and its importance in unravelling the succession, facies changes, areal distribution of conglomerates, and the nature of

the environments in which they were emplaced, cannot be overemphasized. Sedimentational features in the various reefs show that there might be a relationship between directions of transport of sedimentary material, especially heavy minerals, and pay-shoots. The conglomerates are considered to have been deposited subaqueously near the shore-line of a body of water and within range of the sorting action of currents and waves.

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THE GEOLOGY OF THE NORTHERN SECTION OF THE ORANGE FREE STATE GOLDFIELD

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THE GEOLOGY OF THE NORTHERN SECTION OF THE ORANGE FREE STATE GOLDFIELD

INTRODUCTION

A. LOCATION

The area shown on the accompanying structure contour map of the Basal Reef (fig. 1.) includes the country around the towns of Odendaalsrus and Allanridge, and forms the northern portion of the Orange Free State Goldfield.

The working mines are Freddies Consolidated Mines, Limited, at Odendaalsrus, and Loraine Gold Mines, Limited, around Allanridge and to the northwest of Odendaalsrus. The former Riebeeck Gold Mining Company, Limited, now amalgamated with Loraine Gold Mines, Limited, forms the southern portion of the latter property. Jeanette Gold Mines, Limited, to the northeast of Odendaalsrus, conducted some underground exploration, but is now on a caretaker basis.

The southern boundary is arbitrary, and separates Free State Geduld Mines, Limited, from the Freddies Mine. On the west this portion of the field is terminated by an abrupt unconformity. The northern boundary is defined by the limits of economic mining caused by a combination of depth of reef and deterioration in the gold content. The De Bron Fault defines the eastern limit.

B. GENERAL GEOLOGY

The surface of the area is generally very flat, being underlain over extensive areas by horizontally disposed Karroo formations. Local, slightly elevated stretches are produced by outcrops of lava, conglomerate and quartzite of the Ventersdorp System. Much of the surface, especially the higher-lying ground, is covered with a red sandy soil considered to be of aeolian origin and of Kalahari age. The low-lying areas consist mainly of residual clay derived from Karroo mudstones. This clay creates unfavourable conditions for building foundations owing to its tendency to swell after taking up moisture. The development of pans on the Karroo beds is conspicuous, many of these adjoining pre-Karroo outcrops. The drainage pattern is centripetal into the pans.

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Where the Karroo System extends deeper than some 400 feet, one or two coal seams occur in the Ecca Series. Dwyka tillite occurs in pre-Karroo valleys. The maximum depth of the Karroo System in these valleys is about 700 feet.

The Ventersdorp System consists of the Lower Volcanic Stage (Coetzee, 1960 - formerly Ventersdorp Lower Lava) at the base. This accumulation of green-grey amygdaloidal lavas reaches a thickness of over 6,000 feet in the west. In the centre of the field it is slightly over 3,000 feet thick, whereas near the De Bron Fault in the east, it is only about 1,500 feet thick, having been eroded before being overlain by conglomerates and tuffaceous shales of the Ventersdorp Sedimentary Stage. The conglomerates and quartzites outcropping in the inliers apparently lie unconformably on these sediments and on the Lower Volcanic Stage, and are succeeded by thin remnants of dark green-grey amygdaloidal lava of the Upper Volcanic Stage. Lava flows also occur high up in the conglomerate-tuffaceous shale succession (see fig. 2).

The Upper Division of the Witwatersrand System underlies the Ventersdorp Lower Volcanic Stage with an apparently conformable contact, marginal coarse conglomerates, known locally as the Boulder Beds, being developed on this contact.

Along the western boundary of the area a remarkable structure is present. The Witwatersrand sediments, which eastwards are of relatively uniform thickness, rapidly thin out westwards and curve upwards to meet the Boulder Beds with a marked unconformity, thus forming a marginal syncline. With the exception of this marginal area, the Witwatersrand beds dip westwards at angles of between fifteen and thirty degrees. South and east of Freddies Mine the dip is to the east, but the strike remains approximately the same.

In comparison with the type area at Welkom, the sediments are generally not as coarse-grained, although their thicknesses are somewhat greater. The maximum thickness of the strata between the Basal Reef and the Lower Volcanic Stage is 2,800 feet in contrast to 2,375 feet for the average Orange Free State column. The Upper Footwall Beds are 880 feet thick, as against the average thickness of 720 feet.

Boreholes drilled west of the sub-outcrop of the Elsburg Stage against the Boulder Beds intersected steeply-dipping quartzites correlated with Upper and Middle Footwall Beds. Borehole WE.9 (see fig. 1) passed through the Boulder Beds at 6,714 feet after intersecting 6,019 feet of the Lower Volcanic Stage, and was stopped in steeply-dipping beds of the Jeppestown Series at 8,103 feet. Borehole WE.2, on the farm Dammetjie 247, situated 8,700 feet west of Borehole WE.9, is off the map on Fig. 1. This borehole passed through Upper Ventersdorp Volcanics and sediments at 1,347 feet into steeply-inclined magnetic shales of the Lower Witwatersrand System. Between these two boreholes is the Border Fault (Coetzee, 1960, pp. 122 - 124). West of the Border Fault, remnants of Lower Witwatersrand rocks and formations of pre-Witwatersrand age were intersected.

The De Bron Fault bounding the eastern side of the field is a major fault with a complicated history (Coetzee, 1960, pp. 121 - 122; Borchers, 1950; Feringa, 1954). The western block moved down relative to the eastern mass during the Ventersdorp Sedimentary Stage. A great wedge of coarse boulder conglomerate and tuffaceous shale formed east of Freddies. The underlying Witwatersrand beds were tilted to the east. On the upthrow side to the east of the fault, the Sedimentary Stage lies directly upon beds of the Lower Witwatersrand Division. At least three boreholes intersected the Jeppestown Amygdaloid, which attains a thickness of 286 feet in borehole WE.7.

In a block, known as the Waterpan area, to the northeast of Jeanette Mine, a number of boreholes intersected, at shallow depths, quartzites and conglomerates correlated with the Upper Witwatersrand Division. The grain sizes of the sediments are finer than in the rest of the field and the gold content is low.

A regional dip of the Witwatersrand System to the northwest, in the horst block, east of the De Bron Fault, is assumed on the evidence of the Waterpan area and on the positions of the boreholes which intersected the Jeppestown Series.

UPPER DIVISION OF THE WITWATERSRAND SYSTEM

A. SUCCESSION

Each mine has its local scheme of subdivision. The writer has followed the general proposals by Coetzee (1960, folder 6, pp. 85 - 86), but where a local facies is described, the writer has referred to the local terminology. Table I gives a summary of the stratigraphical succession and the schemes of subdivision used on the mines.

TABLE I

Stratigraphy

Correlation		Subdivision [1]	Loraine	Freddies	Jeanette	Remarks
Kimberley - Elsburg Series	Elsburg Stage	Zone VS.1	Boulder Beds Zone EA	Zone VS.1	Upper Elsburg	
		Zone VS.2[2]	Zone EB	Zone VS. 2/4		
		Zone VS.3	Zone EC		Middle Elsburg	
		Zone VS.4				
		Zone VS.5	Zone ED	Zone VS.5	Lower Bastard	Conglomerate at base
	Kimberley Stage	Zone T.1	Zone UK. 1[3]	Zone T. 1[3]	Gold	small pebble conglomerates at base
		Zone EC.1	Zone UK. 2 Zone UK. 3	Zone EC. 1[3]	Estate	"A" Reef at base
		Zone EC.2	Zone MK	Zone EC. 2[3]	Reef	"Glassy" Quartzite Marker Big Pebble Conglomerate at base
		Zones EC.3 and EC.4	Zone LK	Zones EC.3 and EC.4	Zone	Channel-type sediments at various horizons "B" Reef at base
		Zone ES.1	Upper Shale Marker	Zone ES.1	Upper Shale Marker	known throughout as Upper Shale Marker

Correlation		Subdivision	Loraine	Freddies	Jeanette	Remarks
Main - Bird Series	Bird Stage	Zone ES.2	Upper Main Bird Qte.	Zone ES.2	Upper Main Bird Qte.	
		Zone ES.3	Leader Reef Zone	Zone ES.3	Leader Reef Zone	Leader Reef at base
		Zone EL.1	Leader Quartzite	Zone EL.1	Leader Quartzite	
		Zone EL.2	Khaki Shale	Zone EL.2	Khaki Shale	Khaki Shale
		Zone EL.3	Basal Quartzite		Basal Quartzite	Basal Reef at base
		Upper Footwall Beds	UF.1 Zones 1 - 5	EF.1	UF.1 Zones 1 - 5	
			UF.2	UF.2	UF.2	
			UF.3 Upper / Lower	UF.3 Upper / Lower	UF.3 Upper / Lower	
			MF.1[4]	MF.1	MF.1	Intermediate Reefs
	Main Stage	Middle Footwall Beds	MF.2 Upper / Lower		MF.2 Upper / Lower	
			MF.3		MF.3	
			MF.4		MF.4	
		Lower Footwall Beds	LF.		LF.	
			Green Quartzite			

1. Coetzee (1960, pp. 85 - 86)

2. The limits of the various subdivisions in different schemes are not always represented by the same boundaries.

3. Feringa (1954), quoted in Coetzee (1960, p. 38), proposed a subdivision of the Kimberley Stage which was not generally accepted, owing to difficulties in its practical application.

4. The symbols used in this portion of the field and in the central area do not coincide with those in use in the Virginia area from this point down to the base of the Middle Footwall beds.

B. LITHOLOGY

According to Coetzee (1960, p. 31) and the majority of geologists in the Orange Free State Goldfield, the contact between the Ventersdorp System and Witwatersrand System is taken at the base of the Lower Volcanic Stage.

(a) Kimberley - Elsburg Series

(i) Elsburg Stage

This stage can be distinguished from the underlying Kimberley Stage by differences in the lithology of the sediments. The quartzites range from dark to very light grey in colour, the former approaching a subgreywacke in composition, the latter almost a pure quartzite. A yellowish-grey quartzite occurs locally near the western margin. Upwards, there is a general gradation to coarser-grained material, ending in a massive conglomerate with cobble-sized pebbles. The composition also generally changes upwards through subgreywacke to greywacke. Facies variations are more marked in this stage than in any other. Inwards from the marginal trough the pebble size decreases rapidly, and the conglomerates grade into quartzites, becoming more quartzose in composition. A similar trend from conglomerate to quartzite occurs along and parallel to the margin from south to north. Dark subgreywacke beds replace polymictic conglomerates. Light grey quartzite bands are intercalated with the former and become more prominent northwards. Facies variations along the margin are not as prominent in Zones EB to ED.

The Boulder Beds overlap all the underlying subdivisions and towards the west rapidly become unconformable on the latter, the angular difference increasing from negligible to 120 degrees over a distance of about 1,000 feet. At borehole WE.9, the Boulder Beds overlie quartzites in the footwall of the Main Reef zone. These beds and the overlying lavas dip westwards, gradually thinning in the same direction.

The Elsburg Reefs occur as quartz-pebble conglomerates in Zones EA to ED along the western limb of the marginal syncline, rarely crossing the trough, and deteriorating rapidly eastwards into grits.

Many of the reefs also diminish in pebble size laterally.

The maximum thickness of the Elsburg Stage is 1,800 feet.

(ii) Kimberley Stage

A feature of the sediments of this stage is their somewhat argillaceous nature, yellowish-brown tinge, and medium to coarse grain-size. The yellow tinge is due to a preponderance of sericitic materials in the matrix. Numerous polymictic conglomerates are present, composed of white quartz, grey, black and banded chert, and black and yellow sericitic shale pebbles which are more abundant in the lower portion (Zones EC.3 and EC.4).

Except for local concentrations of quartzose pebbles at the base of Zone T.1, the "A" Reef is the uppermost well-developed conglomerate found in this sequence. It is a quartz-pebble conglomerate containing some chert and yellow silicified shale pebbles in the poorly-developed sections. The presence of abundant "buckshot" pyrite is an indication of possible payability. Both contacts are sharp and there is a local disconformity at its base in places. It is lenticular over some portions of the field.

The thickness of the succession between the "A" Reef and the base of the Elsburg Stage normally ranges between 70 and 165 feet, being thicker in the north and in the vicinity of the marginal syncline. Between the "A" Reef and the Big Pebble Reef is a thickness of 30 - 80 feet of quartzite, within which is a bed of some 15 feet of light grey "glassy" [1] quartzite. This quartzite serves as a useful marker in the correlation of the sequence in Jeanette and Loraine mines, but has not been recognised in the western portion of Freddies Mine. Locally, quartz pebble conglomerates occur on one or both contacts of this quartzite. The Big Pebble Reef is similar in appearance to the "A" Reef, the size of its pebbles and the nature of its mineralization not differing appreciably from that of the latter north of the Freddies Mine. It overlies a group of conglomerates called the "mixed pebble conglomerates", that gradationally become more polymictic in appearance and of smaller pebble-size downwards.

(Footnote 1 : The term "glassy" is used extensively on the Witwatersrand field to describe the appearance of a hard quartzite consisting predominantly of quartz grains and containing a minimum amount of phyllosilicates. The grains are usually densely packed, compressed into a mosaic texture, and the remaining openings are filled with secondary silica.

The "B" Reef forms the base of a conformable sequence of quartzite and polymictic conglomerates which ranges from less than 100 feet to 275 feet in thickness, and which includes the "mixed pebble conglomerates" near the top. In this sequence, and possibly also in the Big Pebble Reef, are elongated lenticular bodies of conglomerate and dark, flaggy shale in fairly pure quartzite. These are obviously channel deposits, such as are found in this zone elsewhere in the field. These sediments are known to constitute more than one horizon in this sequence, but occur mainly near the top.

The Upper Shale Marker consists of two beds of yellow-brown to brownish-grey arenaceous shale, separated by a bed of quartzite 20 to 30 feet thick. Towards the northeast a zone of alternately argillaceous and arenaceous quartzites occurs between the "B" Reef and the arenaceous shale. The Upper Shale Marker is included in the Kimberley-Elsburg Series to conform with Mellor's (1915, p. 15) subdivision, but it must be realized that a disconformity occurs at the base of the "B" Reef, whereas the lower contact of the Upper Shale Marker is conformable. The thickness of the marker horizon ranges between 100 and 300 feet.

(b) Main - Bird Series

(i) Bird Stage

Quartzites between the Upper Shale Marker and the Leader Reef are dull, greenish-brown in colour and contain pebble-washes of polymictic type. Pebbles of green quartzite are numerous and are useful for correlation purposes. The pebble-washes are scattered through an ill-defined zone some three-quarters of the distance towards the top of this sequence. Near the Leader Reef the quartzites become less argillaceous and contain beds of "glassy" quartzite and quartz-chert grits. The Leader Reef is poorly developed, being merely the lowermost member of these grits, and is apparently conformable.

Only a few narrow beds of the typical "waxy"-textured, brown argillaceous quartzite occur in Zone EL.1. The bulk of the constituents is stratified, cross-bedded and similar to the quartzites above the Leader Reef, except that the gritty horizons are somewhat less well-defined so that subangular black chert appears to be more widely scattered than above the reef.

The Basal Reef occurs as a mineralized grit zone containing occasional small pebbles a few feet below the Khaki Shale Marker. The

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stratigraphic thickness of the interval between the "B" Reef and the Basal Reef is about 550 feet, and the Lower Reef is approximately 60 feet above the Basal Reef.

The total thickness of Zone UF.1 increases from the Welkom area into the northern area, even if erosion under the Basal Reef is left out of account. Zone UF.2, however, thins out northwards. This is a gritty unit which is quite distinctive in appearance and which has a thick conglomeratic facies to the southwest of Western Holdings Mine. In the northern part of Loraine Mine the grain-size decreases to sand-grade, and the colourful material is diluted with purer quartzose sand, until this zone becomes indistinguishable from the underlying and overlying quartzites. It seems to be a deltaic sediment with its point of influx about ten miles south of Freddies Mine. The underlying Footwall Beds again thicken northwards. The contact between Upper and Lower Zone UF.3 is sharp and distinguishable throughout the field, separating a purer "glassy" type of quartzite from yellow, sericitic quartzite below. Zone UF.3 contains mineralized quartz-pebble conglomerates and grits.

The Intermediate Reefs occur as a group of conglomerates within the yellow quartzite. They have pebbles up to $1\frac{1}{2}$" in diameter. Both the top and the base of this group change gradationally into quartzite. A feature of these reefs is a very low gold value accompanied by appreciable values of uranium.

(ii) Main Stage

Several white bands occur in the Middle Footwall Beds. Between them, in Zone MF.3, is a zone of grits, consisting mainly of granules of quartz. The argillaceous quartzite beds are generally more chloritic than those of the Upper Footwall Beds. The Lower Footwall Beds are very imperfectly known. They consist of dull, green-grey, chloritic and sericitic quartzites containing numerous ill-defined pebble bands. The pebbles are mainly of quartz, but contain variable quantities of chert. The paucity of intersections and the lack of reliable markers have made it impossible to subdivide these beds. Numerous pebble bands occur near the top of the zone.

Below a gap in the column covering the Main Reef horizon, quartzites overlying the Upper Jeppestown Shale were intersected in Borehole WE.9. They are fine-grained and "glassy", with a distinct green tinge, and are gradational into the shale.

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C. STRUCTURE

The northern section of the field lies in a graben bounded on the west by the Border Fault and on the east by the De Bron Fault. The Witwatersrand System and part of the Ventersdorp System are tilted to the west in the northern part, and to the east in the southern part. The western margin of the Upper Witwatersrand Division is determined by synclinal folding of Elsburg age along an axis trending N 15^{o} W adjacent to the western boundaries of the mines. The Witwatersrand System dips steeply eastwards, west of the fold axis, and forms a major angular unconformity against the Boulder Beds and the Lower Ventersdorp Volcanics which dip to the west. East of the fold axis, over the major portion of the area covered by the mines, the Ventersdorp System follows apparently conformably on the Witwatersrand System. The marginal syncline plunges to the north at an angle that ranges from nearly horizontal near Loraine No. 3 Shaft to about 12^{o} near Loraine No. 2 Shaft. The plunge is locally disturbed in the vicinity of transverse faults.

Different sets of normal step faults occur in the two tilted parts. In a zone trending northeast over Freddies Mine, the rocks are not tilted, and the two sets of step faults interfere and die out rapidly. South of this zone, step faults dip west and can be followed out of this section into the Welkom area. Here the marginal syncline changes into a monoclinal flexure. The De Bron Fault is displaced considerably by the Arrarat Fault and by another fault further to the south.

(a) Folding

Folding occurred at the western margin, and arching further into the basin, during the later stages of sedimentation of the Upper Witwatersrand Division. Along the steep western limb of the marginal syncline, where the dip of the beds exceeds 55^{o}, minor folding occurred repeatedly on almost flat axial planes. On the lower limits of some of these folds, thrust faults occur, over which the beds have been transported eastwards. Siliceous quartzites near these faults have a sago texture. These structures are small in scale, with the amplitudes of the folds being about one foot, but, locally, thrusts of up to 40 feet have been mapped. The general affect of these phenomena on the structure is to increase the dip of the strata. The higher-lying masses of rock have been pushed towards the axis of the subsiding syncline.

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The attenuation of the limbs on some of the minor folds, strong drag features on the thrusts, and indications of slump structures point to a semi-consolidated, or unconsolidated, state of the sediments involved in the folding. The absence of pebbles and boulders of rocks of the Upper Division in the Elsburg beds and, especially, in the Boulder Beds, also points to an unconsolidated state of the sediments. The folding was completed by the time the Boulder Beds were emplaced and, assuming that the latter were laid down on an almost level surface, the beds of Zone EB and those lower down must have been nearly vertical or even overturned in early Ventersdorp times.

Success in the correlation of steeply-dipping Footwall Beds that have been logged in boreholes drilled near the Basal Reef sub-outcrop, depended on the recognition of repetitions of strata caused by the minor folds and thrusts. These holes (BH.2 Tredenham, BH.1 Diamant, WN.3, WN.6, WE.9, SB.2, EC.1, pp.1 and BH.1 Eureka) tended to remain in the same stratigraphic succession despite apparently cross-cutting strata, as read from dips on cores. Some of these holes were deep enough to have intersected beds curving at smaller dips towards the axis of the syncline.

Large monoclinal folds also occur on the western limb of the syncline. Their axes strike almost parallel to the synclinal axes and dip to the west. Their amplitudes vary between 50 and 200 feet.

A zone trending roughly northeast through Freddies Mine divides the area underlain by Basal Reef into two parts. North of the zone the dip averages 20° to 25° to the west, the strike being north-south at Loraine Mine, swinging to N 20° E at Jeanette Mine. South of the zone the dip ranges from 10° to 30° in the direction E 20° S. The Basal Reef in this zone is essentially horizontal, and local dips are affected by faulting. This feature has been described as an anticlinal zone or axis, or as a zone of compensation.

(b) Faults

Thrust faults occur in association with minor folds on the western limb. Thrusts are also associated with the larger monoclinal folds where these are most intense. A related reverse fault of late Elsburg age causes local truncation of the EA.1 Reef on the upthrow side of the fault by a conglomerate of subgreywacke composition known locally as the Lag Conglomerate (the term is derived from "lower agglomerate" - an early description). The Lag Conglomerate curves into a cusp which is faulted for two or three feet on the reverse fault. The throw on the EA.1 Reef at the point described is 40 feet. Thus, faulting and folding took place intermittently, while sediments of Zone EA were being deposited.

The oldest north-south strike faults occur in the southern part of the area and are normal faults dipping west at an average angle of 45°. They continue across the anticlinal zone, losing much of their displacement, but their dips remain unchanged. They have not been encountered in the underground workings of Loraine Mine. The last movements, as assessed from slickensides, were down dip, but some of the faults north of the anticline have nearly horizontal slickensides - splay features indicating that the extremities of these faults have been reached (De Sitter, 1956, p. 151). North-south strike faults younger than these occur only north of the axis at Freddies Mine. This is true over a length of 10,000 feet along the axis. They dip east at angles ranging between 60° and vertical. Slickensides are more often down dip than inclined. On Loraine Mine one fault of this type has displaced east-west dykes dextrally by about 300 feet.

A major fault intersected in Borehole KK.3 and underground at Freddies Mine is occupied by a dyke. The Uitkyk Fault at Loraine Mine is also filled with dyke material and also has a downthrow to the east. It is assumed that the fault at Borehole KK.3 is the extension of this fault. Fault-scarp conglomerates occur in Ventersdorp sediments, proving that this fault is a major structural feature which might have acted as a lava feeder. The results of recent drilling indicate that this fault continues across the anticlinal structure.

A set of faults striking E 30° N cuts through Loraine Mine and, possibly, Jeanette Mine. Most of them dip to the south. These faults are younger than the strike faults and might have originated with the development of the plunge on the syncline. Transverse normal faults, not shown on the plan because of their relatively smaller displacements, occur in two sets of which the dominant one strikes N 50° - 60° W. They are sympathetic to the general structure in that their downthrows are in the direction in which the fault block tends to sag. The westerly dips of these faults on the south limb are flat, while the easterly dips in the north tend to be steep. Over the anticlinal zone of Freddies Mine the reef is approximately horizontal and these transverse faults have no throw. Fractures have, however, opened up and the gashes have been filled with Khaki Shale material which has flowed into them. These gashes are lenticular, up to 3 feet in thickness, and form an en echelon pattern.

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Steep SW - NE faults, with a dextral horizontal slip displace the east-dipping strike faults. Faults striking in a direction between these and the strike faults have also been recorded. A fault striking northwest and younger than the other structures on Freddies Mine, carries strong flows of water under pressure. This fault has recently been encountered in underground development workings south of No. 3 Shaft, Loraine Mine.

Besides these, faults of the order of a few feet occur within the blocks formed by major faults. As these are the result of local stresses within individual blocks, their dips and strikes are variable. The intensity of this type of faulting differs widely over the field, but is greatest on Freddies Mine where the amounts of displacement of major sets of faults change over short distances, indicating that the fault-blocks were subjected to abnormally large amounts of torque.

D. DYKES

Old east-west dykes are displaced by strike faults. Such intrusives are fine-grained, green-grey rocks which resemble members of the Lower Volcanic Stage of the Ventersdorp System. In the Freddies Mine they are nearly vertical, have slickensided contacts, and have their downthrows to the north. The displacement across these dykes is different in each fault-block. They range in thickness from 5 to 10 feet.

A younger set of east-west dykes on Freddies Mine passes through the strike faults without being displaced. They have a fine-grained inter-granular texture and dense grey selvages. No movement has taken place on their contacts since their intrusion. They are also nearly vertical, but somewhat thicker, averaging 20 feet in thickness. Similar younger dykes on Freddies Mine strike at about 20^{o} east of the general strike of the sediments. They also cut through all the faults undisturbed.

A narrow dyke on Freddies strikes almost north-south, cutting slightly eastwards through the main strike faults. It is vertical south of the anticline, then tilts to a dip of 70^{o} east in the most northerly exposure underground, where the Basal Reef dips 40^{o} west. The dyke is only about 10 inches wide and is a grey dense rock with dark grey specks. Since the dip of the Basal Reef is greater than the average of 20^{o} for that section of the mine, the difference in dip of the dyke could be accounted for by the further tilting of a local fault-block after the emplacement of the intrusive.

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Young dykes of medium-grained, pyroxene-bearing diabase, trending northwest and northeast, occur on Loraine Mine. They have chilled margins and extensive contact metamorphic and metasomatic zones. In their vicinity the following sulphides are usually abundant: pyrite, chalcopyrite, galena and sphalerite. These intrusives are throught to be of Bushveld age. They form tongues into existing faults and tend to follow the bedding-planes for some distance in localities where these nearly coincide with the strike and dip of the intrusive.

A kimberlite dyke has been exposed in underground workings on Jeanette Mine, its strike is N - S and its dip 83^{o} E. A lamprophyric dyke younger than Karroo dolerite, striking almost E - W and dipping 75^{o} N, cuts through Jeanette No. 28 Shaft (Antrobus, 1956).

E. WATER-BEARING FISSURES

The water encountered underground in this area appears to be stored in fissures, such as the Freddies Fault, or along east-west faults, dykes and fractures. The control of rock type on the storage capacity of fissures is well illustrated on Loraine Mine where widely different stratigraphic horizons have been penetrated. Generally, it can be stated that in sericitic rocks faults tend to develop gouge or mylonite which retards the flow of water. Pure quartzites, such as the Footwall Beds or Zone EB, are more brittle and more water is then stored in fissures. The higher-lying units of such brittle rock-types tend to contain the most water. The Boulder Beds are known to store large quantities of water in numerous fractures near water-bearing faults, especially in areas where the general fracture pattern indicates tensional conditions. A brittle, much fractured rock in an area which has been under compression can be dry, whereas the same rock at the same elevation can contain water-bearing fissures in a nearby area of tensional faulting. Many fractures in brittle quartzose rocks have been closed by vein quartz, and it is only close to younger structures such as the Freddies Fault that these fractures have been reopened and are water-bearing.

The interconnection of several extensive fissures seems to be remote, since the drainage of one does not seem to affect another or the levels of the flooded shafts of Jeanette Mine. The water-level in Freddies South No. 1 Shaft is dropping steadily. The workings of this abandoned shaft are connected underground with the Freddies Fissure which is thought to continue southwards where the system is being

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drained through one of the mines in the Welkom area. The fact that considerable quantities of water were confined near Loraine No. 3 Shaft, in spite of the drainage from the south, indicates that the lateral flow of water in these major fissures is somewhat restricted. Draining the water was successful in that initial flows in the vicinity of 30,000 gallons per hour decreased to a few hundred gallons per hour within three months. Methane gas is dissolved in the water under pressure and fills the fissure as the water is drained away.

The salinity of the underground water in the northern area ranges between 150 and 300 parts per million, whereas that of the Freddies Fissure area is about 1,700 p.p.m. Because of this fact, the water in the northern area is thought to be replenished from the surface through the Ventersdorp inliers. Impervious Karroo cover seals off the fissures in the southern area.

ECONOMIC GEOLOGY

The reefs worked in this area are the Elsburg Reefs (formerly known as the Van Den Heevers Rust or Rainbow Reef), the "B" Reef and the Basal Reef in the Elsburg, Kimberley and Bird Stages respectively. Boreholes have penetrated the Main-Bird Series down to the top of the Lower Footwall Beds. The Main Reef horizon has not been intersected anywhere in this area.

A. ELSBURG STAGE

(a) Succession and Lithology

The Elsburg Stage has been subdivided locally into the Boulder Beds and four zones (fig. 3).

A marginal, coarse conglomerate, locally called the Boulder Beds, is of significance in that it is transitional between the Ventersdorp and Witwatersrand Systems. Towards the northeast this conglomerate gradually acquires more and more intercalations of sand-grade material and the pebbles themselves become somewhat smaller and more loosely packed. Near the limit of the area a conglomerate occurs only at the top of the zone and eventually disappears altogether, the formation then consisting of coarse, gritty quartzites mainly of subgreywacke-type intercalated with a few, narrow, glassy quartzite bands. In composition, the Boulder Beds range from greywacke in the southwest and west to subgreywacke containing bands of glassy quartzite in the northeast. The pebbles and cobbles are poorly rounded and consist of a variegated selection of dark quartzite, greenstone, black shale, yellow and green shale, pale and dark grey chert, altered porphyritic rocks, and quartz. In the upper half of this Stage, some ferruginous chert pebbles are oxidised to red and maroon colours. There is an increase in the number of yellow shale and quartz pebbles towards the base. Some peculiar pebble-types can be matched with pre-Witwatersrand rocks intersected west of the Border Fault, beyond the southwestern limit of the map (fig. 1) (van der Vyver, 1956, p. 9).

Zone EA underlies the Boulder Beds and consists of dark grey subgreywacke intercalated with pure, highly siliceous quartzite generally described as "glassy", the latter often forming sharp contacts against the former. Numbers have been allocated to the reefs occurring in these alternating rock-types. Individual beds have been followed for as much as 4,000 feet along strike and a little over 1,000 feet down dip. They thicken rapidly from the suboutcrop towards the trough. Conglomerates are locally developed at the upper and lower contacts of the "glassy" quartzite beds and occur only towards the centre of the bed where conglomerates are already present at the contacts. Other conglomerates exist at the contact of some subgreywacke beds. In contrast with the former, which are oligomictic and contain rounded granules of pyrite up to 1/4" in diameter, the latter conglomerates have a larger variety of pebbles which are generally of smaller size and less perfectly rounded, and contain pyrite rarely greater than 1/8" in diameter.

Zone EA is thickest in the northern portion of the area, about 10,000 feet north of Loraine No. 3 Shaft, where it exceeds 450 feet in the trough. The Boulder Beds and Zone EA together form what is known as Zone VS.1 in the remainder of the field.

Zone EB consists of speckled, "glassy" quartzites and contains a zone of conglomerates at the base, which tend to develop into groups of ore-bodies. Immediately north of Loraine No. 3 Shaft, pebble bands occur near the middle of the zone, near the top, and at the base where the thickest development of conglomerates is attained.

Zone EC consists of dull, yellowish-grey, speckled, sericitic quartzites and contains at least two pebble horizons, which also become conglomeratic north of Loraine No. 3 Shaft. The quartzites underlying the lowermost conglomerate bands are distinctly yellow-brown and argillaceous. South of this shaft, the quartzites above the uppermost conglomerate bands become almost indistinguishable from those of Zone EB.

In Zone ED the quartzites are generally speckled and siliceous. The abundance of green fragments in the quartzite and grits is useful as an additional criterion of correlation. A group of conglomerates occurs near the upper limit, and, of these, one or two near the top and, locally, one near the bottom contain enough gold to be workable. Though narrow, these conglomerates are more wide-spread than those in the overlying two zones.

A light-grey glassy quartzite, correlated with Zone VS.4, occurs below the reefs of Zone ED. Between this and the VS.5 conglomerate, which forms the base of the Elsburg Stage, a bed of highly variegated grits occur. Fragments, many of them elongated, of yellow and green shale, bright green quartzite and black chert give the bed a distinctive appearance. Southwards the grain-size diminishes and the composition of the grits is more uniform. In general, the VS.5 conglomerate is similar to the occurrence of Zone VS.5 over the remainder of the field, but locally it is associated with an oligomictic conglomerate which contains some gold and in which "buckshot" pyrite is abundant.

The vertical range over which Elsburg Reefs occur in Zones EA to ED is 1350 feet at the trough. Owing to rapid thinning and truncation, all the reefs are overlapped by barren Boulder Beds at about one thousand feet west of the trough.

Pebble sizes range from about $\frac{1}{2}$-inch to $1\frac{1}{2}$-inches in diameter, but locally pebbles as large as 3 inches occur in robust conglomerates. In the latter case the thickness of the conglomerate is also above average, the concentration of "buckshot" pyrite is high, and the reef is of an exceptionally high grade. Individual conglomerates in the Elsburg Stage cannot be distinguished and classified on the basis of lithology, so that their correlation is dependent on distinctive features in the barren quartzite partings.

A local disconformity was mapped in 2/52 Elsburg Haulage West on Loraine Mine, where the VS.5 conglomerate transgresses over the "A" Reef. This might have resulted from the arching that occurred in Kimberley times on the basin side of the marginal trough. Similar disconformable relationships are known from the logs of Boreholes KK.7 and KK.8 (Coetzee, 1960, Table 13, p. 62). A number of reverse faults, of a type rarely

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found in that particular area of Loraine Mine, has repeatedly brought the VS.5 conglomerate and the "A" Reef into the elevation of the haulage. These faults were caused by a force from the west and their effect is to increase the thickness of the sediments in the area where the disconformity occurs.

(b) Sedimentational and Structural Aspects

The Boulder Beds took part in the synclinal folding to a minor extent, so that their lower contact is exposed in the trough in 2 - 48 E Haulage West in Loraine Mine. There is a rapid thickening of these beds over the trough, however, so that the upper contact could have presented a planar surface on which the lava extruded. The oxidised chert pebbles in the upper half are an indication that these conglomerates were exposed to an oxidising atmosphere and they might, therefore, be considered as a terrestrial deposit.

The most prominent Elsburg Reefs are associated with marginal unconformities. Reefs tend to cluster into vertically superimposed groups, as would be expected in subsiding deltaic deposits, and many grade laterally into small-pebble conglomerates and grits. Several such groups of conglomerates have been discovered along the marginal syncline. Partings between reefs in such groups range up to 30 feet at the trough, but thin out westwards until some reefs merge, while others are truncated by higher-lying reefs of Zone EA or by the Boulder Beds. In Zones EB, EC and ED the tendency of individual bands of conglomerate in such groups is to remain separated up to the sub-outcrop.

The thinning out of the sediments and the positions of the conglomerate beds in the succession can be seen most clearly in Zone EA. Each sedimentary unit was deposited on a floor which subsided more rapidly in the trough area than at the margin. At intervals, the marginal sediments were eroded due to tilting and the succeeding conglomerate truncated the underlying sediments. This erosion was regular and sheetlike, typical of a shallow subaqueous environment. Erosion channels do not occur in the Elsburg Reefs, although thick sheets of conglomerate are known to terminate abruptly. The combination of thinning out and truncation points to a rising basin edge with a shoreline not far west of the present sub-outcrop. Sedimentation and folding took place concurrently throughout Elsburg times.

The reef at the base of Zone EA in the Loraine No. 2 Shaft area usually has a sharp upper contact and seldom shows any marked signs of being unconformable on its footwall. The quartzite within the reef is the light grey, glassy, speckled type of Zone EB. This EA.1 Reef, however, overlaps local marker beds in Zone EB and must, therefore, be unconformable. In some areas it is overlapped by a higher-lying unit in Zone EA, before abutting against the Boulder Beds, and this higher-lying conglomerate is distinctly unconformable on Zone EB. In the Loraine No. 3 Shaft area the EA.1 Reef itself is distinctly unconformable on various zones in the Elsburg Stage and even on the Kimberley Stage. Rare, shallow scour-and-fill structures occur locally at the base of the EA.1 Reef.

Coetzee (1960, fig. 3, p. 34) indicated in a section across the field from the southwest to the northeast that the percentage of conglomerate in the Elsburg Stage decreases in this direction from 70% at borehole RP.1 to 9% at borehole WT.6, east of Freddies Mine. He also showed that there were variations in the thickness of the Elsburg Stage along this section.

Figure 4 is an isopach map of Zone VS.1, with superimposed contours of the percentage of conglomerate, calculated on the same basis as employed by Coetzee (1960). The italic figures above a borehole on the map give the percentage of conglomerate and the roman figures below the thickness of Zone VS.1. Faulting (denoted by f) and intrusions (denoted by i) have affected the thicknesses intersected in many boreholes. Conglomerate percentages could be calculated for some boreholes where faulting has removed only part of the quartzite in Zone EA, and the total thickness could be calculated from the isopachs. These figures should, however, be treated with reserve. Figures in brackets indicate that no dip correction was applied to obtain the true thickness of the strata. The effect of most faults is to eliminate a portion of the succession, so that the remaining thickness could be considered as a minimum thickness for that point. Some difficulties were encountered where the base of Zone VS.1 is gradational. In such instances, grits persist for some distance below the base of the subgreywacke and the contact was taken at the base of these grits. A bed of subgreywacke, 20 feet thick and 50 feet below Zone VS.1 in portions of Loraine and Jeanette Mines, caused difficulty in determining the base. The affect of deviation of boreholes from the vertical has been taken into account. This was especially necessary along the western margin where the isopachs are closely crowded.

The isopach map reveals several features not shown by Coetzee's (1960) section. Firstly, the Boulder Beds are unconformable

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on Zone EA from the trough of the marginal syncline westwards and, hence, there is a concentration of isopachs, the westernmost of which indicates approximately the position of the shore-line at the end of EA time. This is clearly illustrated by the section (fig. 5). Where the 200 and 300 feet isopachs occur, only the Boulder Beds remain and the source of this conglomerate must be sought further to the west. The Boulder Beds do not occur in cores of boreholes on the farms Merino 74, Dammetjie 247, Modderfontein 343 and Middelburg 246, west and southwest of the map, all of which boreholes are assumed to be west of the Border Fault. Moreover, the Boulder Beds contain pebbles of pre-Ventersdorp formations encountered in these holes. The conglomerates can, therefore, be attributed to upheaval of the ground west of the Border Fault which must have taken place as the folding of the marginal trough of the Elsburg Stage ceased.

The trend of the conglomerate percentage curves show that the main source of the conglomerates lay to the southwest. In the area where the percentage of conglomerate is more than 40%, appreciable amounts of polymictic conglomerate are present in Zone EA. The wide zone of fairly constant ratio between the 30% and 40% curves indicates that the conglomeratic facies of the Boulder Beds overlies the quartzitic facies of Zone EA. Northeastwards the Boulder Beds are intercalated with and grade into subgreywacke (fig. 5).

In the middle of the graben between the marginal trough and the De Bron Fault, a longitudinal arch is developed. The arch is broken into domes by transverse warping trending northeast. One such upwarp coincides with the trend of the anticlinal zone on Freddies Mine. Owing to the presence of the longitudinal arch, coarse sediments of Elsburg time were restricted to the marginal trough. Influx of the bulk of the sediments probably took place along the direction of the transverse synclinal warps. It is significant that the greatest number of reefs discovered in Zone EA occurs in the area where the transverse syncline crosses the marginal trough.

Coetzee (1960, p. 63) came to the conclusion that the Lower Volcanic Stage and the Elsburg Stage appear to be essentially conformable. Figure 4 shows that if arching took place at that time, no great thickness of conglomerate could have been removed. The total lack of sorting in the uppermost few feet of conglomerate indicates that lava flowed over material which had not been reworked. Lastly, the Lower Volcanic Stage is assumed to effuse from fissures in the Border Fault zone, since

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this formation has not been encountered in boreholes to the west of the fault. Since both sediments and lava had their source on the same linear feature, it seems logical to assume that no great period of time intervened between deposition of the conglomerates and outflow of lava.

The strata appear to thin again against the De Bron Fault. The relationship here is not clear owing to the elimination of portions of the succession by faulting. The fact that most of the succession intersected in boreholes close to the fault is thinner than normal, indicates that the ground east of the fault was already rising relative to the graben area in Upper Witwatersrand time.

(c) Distribution Patterns of Gold and Uranium Values

Reefs in Zone EA tend to occur in "glassy" quartzites at the contact against beds of subgreywacke. One of the contacts of the reef is then sharp and regular. The other contact is gradational, forming a rapid change from pebbles packed loosely in a "glassy" quartzite, to quartzite without pebbles. It is notable too, that the concentration both of buckshot pyrite and of gold and uraninite increases towards the sharp contacts. Reef pebbles may be only sparsely distributed on such a plane, accompanied by clusters of buckshot pyrite, but still constitute a payable gold-bearing reef. A conglomerate band developed in subgreywacke has a characteristic gold and uranium concentration which differs from that of conglomerate occuring in "glassy" quartzite, even where those two conglomerates combine to form one reef. The pyrite has the shape of small pebbles, and is concentrated wherever heavy mineral pebbles can be expected to do so, e.g. wedged behind big quartz pebbles, caught in slight irregularities of the footwall, or aligned in cross-bedded layers where the cross-bedding of the sediments is distinct.

The concentration of buckshot pyrite is a gold-bearing reef is an indication of high gold content. However, some conglomerates contain much pyrite but little gold. The coarsest pebble development is near the thickest portions of the reef and in the richest zones. Pebbles decrease in size towards the centre of the basin as well as laterally along most conglomerate bands, with the result that the reef eventually grades into a grit, losing its gold content as it does so. A study presently being made of the gold content of reefs where one is transgressed by another has so far furnished no proof that the overlying reef is enriched near the sub-outcrop of the other.

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The conglomerates in the other zones of the Elsburg Stage do not have persistently sharp contacts. The mineralization is more often concentrated towards the base of such a reef than towards the top. The highest values are usually associated with conglomerate bands near the base and near the top of a group, but the distribution of gold in each band is highly variable, so that localities are found where reefs nearer the centre of the group have a higher payability.

Although the distribution of gold in the reefs seems erratic, it is possible to trace "pay-streaks" running from sub-outcrop towards the trough across the direction of the "pay-shoot". The "pay-shoot" is elongated parallel to the axis of the syncline in accordance with the broad fan-shaped nature of the conglomerates in which the gold occurs and parallel to the direction of the margin of the sedimentary trough. The paystreaks resemble the pattern made by distributaries in a delta-head. Where two such paystreaks combine, spectacular values have been obtained.

The gold-uranium ratios can vary remarkably from reef to reef. For instance, the EA.1 Reef is known for its extremely low uranium content. The EA.2 Reef overlying it, is characterized by an uranium: gold ratio higher than the average for the remaining reefs in Zone EA. The variation in the ratios of superimposed reefs indicates a strong sedimentary control of the economic minerals contained in the reefs.

The most persistent gold-bearing horizons are the ED Reefs, the EA.1 Reef and the EA.8 and 9 Reefs.

B. KIMBERLEY STAGE

Reefs in the Kimberley Stage are the "A" Reef, the Big Pebble Reef and the "B" Reef, all of which are erratic gold-bearers. Of these, only the "B" Reef is mined at present, stoping being confined to the No. 2 Shaft area of Loraine Mine.

(a) Succession and Lithology of "B" Reef

It is the basal conglomerate of the Kimberley Stage, resting on the Upper Shale Marker. Usually it is less than 24 inches in thickness and contains more shale and jasper pebbles than the other reefs. Local sorting has removed all constituents other than pebbles of quartz and chert. Overlying polymictic conglomerates and grits rarely merge with

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the reef itself. In some localities the "B" Reef is not developed at all, and only a sharp contact plane denotes this particular horizon. On Freddies Mine the "B" Reef attains a thickness of up to 8 feet.

(b) Sedimentational and Structural Aspects

The "B" Reef is unconformable on its footwall (figs. 5 and 6). The intense faulting in this area makes the compilation of an isopach map difficult, particularly as old borehole logs do not always indicate whether contacts are sedimentary or faulted. Bedding-plane faults, which are extremely difficult to detect in borehole cores, occur in argillaceous sediments and can eliminate or duplicate part of the succession. The isopach map prepared from the original borehole logs, (fig. 6) should, therefore, be treated with caution. The symbols used in the preparation of this isopach map are similar to those used in the isopach map of Zone VS.1 (fig. 4).

Two main factors have produced the present pattern of the isopachs. Firstly, the basin floor warped during subsidence, causing a variable thickness of sediments to be deposited over the area, and, secondly, there was a transgressive overlap of the "B" Reef over its footwall (fig. 7).

The pattern of warping is similar to that shown on the isopach map of Zone VS.1 (fig. 4) in that marginal troughs occur at the western margin and near the De Bron Fault. However, it differs in that two complementary arches, connected with a low basin, occur towards the centre of the basin, whereas only a single well-defined arch was present during Elsburg times. The northeast-trending depression can also be seen, especially where it crosses the marginal troughs, but the parallel rise across Freddies Mine is poorly developed and masked by the "B" Reef unconformity.

The section line chosen (fig. 7) indicates that the "B" Reef progressively overlaps lower units of its footwall to the southwest and that the shoreline, therefore, lay in that direction. It is an erosional unconformity. The position of the quartzite bed in the Upper Shale Marker (fig. 7) is only an approximate one and a more detailed investigation of the cores of southerly boreholes might prove that the thinning-out of the argillaceous members of the Upper Shale Marker is greater than shown on the section. The thickest "B" Reef occurs on Freddies Mine, suggesting that sediments probably were derived from an area along the western margin of this mine.

Isopachs of the sediments accumulated in the interval between the Big Pebble Reef and the "B" Reef, during which no marked unconformities seem to have influenced the thickness of the sediments laid down, also indicate that the source might have been somewhere to the northwest of Freddies Mine, where these sediments are thickest (fig. 8). The longitudinal arch is present, but there are no signs of warping in the northeasterly direction. The top of the Big Pebble Reef was used as a reference instead of its base, as is the usual practice, because of the difficulty in distinguishing the Reef from the underlying "mixed pebble conglomerates" in descriptions contained in borehole logs. Channel deposits in the above sediments on Loraine Mine fall along a line trending northwards from a position west of No. 3 Shaft, indicating that streams must have flowed from the source area to the north during that time.

The isopach map (fig. 8) indicates that there is a sharp truncation of the "B" Reef on the western side of the field. A borehole drilled from underground below the level of unconformity (GBH 70, figs. 3 and 6) proved that the thickness of the Upper Shale Marker, and of all the other strata intersected, diminishes rapidly as the sub-outcrop position is approached. The shoreline during "B" Reef time, calculated from the rate of thinning at Loraine No. 3 Shaft, could have been not more than 1,500 feet west of the present sub-outcrop. As in Elsburg times, the land towards the west was rising actively, so it is safe to assume that the sediments came in from the west. Also, the greater thickness towards the southwest points to an influx mainly from that direction. The increase in thickness of sediments near the De Bron Fault could have been due to a flexure initiating the De Bron disturbance.

Sedimentological data available for the "B" Reef is scanty and cannot be fitted into an environmental pattern.

(c) Distribution Patterns of Gold and Uranium Values in "B" Reef, Big Pebble Reef and "A" Reef

An area of "B" Reef, some 7,000 feet long by 4,000 feet broad, is sufficiently rich in gold to be mineable. It is situated at Loraine No. 2 Shaft, and is elongated roughly in the direction N 35° E, but it is not yet certain that the breadth given defines the limits of the payshoot or that it will continue in the direction of elongation. Gold is patchily distributed, and is concentrated in isolated lenses of columnar thucholite. The length of exposures rarely exceed 25 feet. Gold is streaked in the columnar grooves of some of these lenses and on the contacts of the thucholite with the rock. In these patches the reef is remarkably rich. Block value plans show that uranium values increase down dip. The reason for this trend is not apparent.

Of the many "B" Reef borehole intersections, only a few returned payable assay results, the majority containing only a trace of gold. As a result the patchy distribution is thought to persist throughout the area, although underground exploration at Loraine No. 1 Shaft and Freddies Mine failed to expose reef of economic interest. A number of encouraging borehole intersections of the "B" Reef, and also of the Big Pebble and "A" Reefs, has been obtained in the vicinity of the marginal trough, where fig. 8 shows a linear downwarp, or generally thicker sedimentation. The "B" Reef in this environment contains much "buckshot" pyrite and differs from the reef at Loraine No. 2 Shaft in having very little thucholite. Recent drilling in Freddies Mine indicates that values in this "trough facies" might improve southwards, towards the source. On Freddies Mine the "B" Reef seldom has buckshot pyrite and contains thucholite only in very isolated narrow lenses.

There are no other areas in this part of the field where Kimberley Reefs are expected to be of higher than average grade.

C. BIRD STAGE

(a) Succession and Lithology

The thickness of the Khaki Shale averages 8 feet in Freddies Mine. Towards the southwest a lens of quartzite is present in the shale. A bed of argillaceous quartzite also overlies the lowermost three feet of shale in the Loraine No. 2 Shaft area. In some places the shale is thinner and the argillaceous quartzite is strong enough to form the hangingwall of a stope. From the maximum in Freddies Mine, the Khaki Shale thins out in all directions. In the extreme northeast of Jeanette Mine it tends to peter out altogether. The quartzite between the Basal Reef and the overlying Khaki Shale thins from approximately 3 feet in Freddies and the Loraine No. 3 Shaft area until it lies almost against the shale in the Loraine No. 1 Shaft area.

The Basal Reef consists of a sedimentary surface covered with sparse grit and an occasional small quartz or chert pebble. On this surface fine-grained pyrite, gold, uraninite and other heavy minerals are concentrated. Thucholite is abundant, forming narrow seams usually about one eighth of an inch in thickness.

(b) Sedimentational and Structural Aspects

Slump structures in the Khaki Shale have been found in the No. 1 Shaft area of Loraine Mine. These structures are confined to narrow layers of arenaceous shale between thicker layers of shale. Where asymmetric folds occur, the direction of the overriding force has a northern and an eastern vector. At one locality, a clay pebble conglomerate occurs near the bottom of a unit of argillaceous quartzite overlying the slump structure. The crests of the slump folds are not truncated.

The Basal Reef overlaps its footwall, cutting across it in a south-westerly direction (figs. 9 and 10). On the western limb of the marginal syncline the truncation becomes more rapid and the isopachs swing towards the axis of the fold, proving that the marginal trough had started its development in pre-Basal Reef time. Even the Upper Footwall Beds thin out rapidly on the western limb. The distance between the Leader and Basal Reefs diminishes rapidly on the western limb of the marginal fold, showing that a shoreline was not far distant from the present sub-outcrop. The pebbles of the Leader Reef are even less abundant than in the basin and there are no signs of an influx of fresh material from the west.

The distances between isopachs are regular, proving that the floor of the basin did not warp. Some disturbance could have occurred in the vicinity of the De Bron Fault. The isopachs of the quartzite between the Basal Reef and the Khaki Shale trend in the same direction as those in the above figure.

A very limited amount of sedimentational data is available on the Basal Reef. Eight measurements of ripple marks indicate that currents moved parallel to the trend of the isopach lines, i.e. N 30° W. Sand waves (two measurements) are orientated with their axes parallel to the postulated direction of the shoreline, i.e. N 18° W. (fig. 9). The cross-bedding laminae in the Basal Reef and in the more siliceous portion of the Footwall beds have concave, curved surfaces of erosion as the lower boundaries of the sets. The units are lenticular and trough-shaped. This type of cross-bedding is the equivalent of the trough cross-stratification of McKee or the festoon type of Pettijohn as shown by Hargraves (1961, pp. 2 - 6). With this type of cross-bedding a considerable spread in directions, as measured on individual sets, can be expected. One trough was measured and the elongation was in the direction N 23° W. The lower contact of the Basal Reef at Loraine No. 2 Shaft has a scalloped appearance owing to trough cross-bedding. Pyritic stringers often accentuate the cross-laminae.

(c) Distribution Patterns of Gold and Uranium

On Loraine Mine, two payshoots occur at No. 1 and No. 2 Shafts respectively. They trend N 30° W i.e. parallel to the isopach lines in that area. They are each about 2,000 feet wide and are separated by a similar breadth of unpayable reef. On Freddies Mine, the payshoots trend east-west. The largest is underlain by a narrow bed of yellow, argillaceous quartzite. The surface on which the Basal Reef was laid down was hummocky. A series of ridges elongated in the direction N 45° W can be discerned. This peculiar surface seems to have acted as a trap for the gold, but nothing is known about the nature of the irregular wave-like ridges. All the payshoots on Freddies Mine can be included in a broad zone which extends into an area at Loraine No. 3 Shaft, where drilling has revealed a higher-than-average tenor of gold in the Basal Reef. This broad zone is nearly parallel to the two northerly ones.

From south to north, each zone of payability is progressively lower in average grade of gold but the grade of uranium increases progressively northwards.

The isopach map on the Basal Reef unconformity (fig. 9) shows that the pre-Basal Reef strata underlying this reef in the northern area of Jeanette Mine are younger than in the remainder of the field and that a conformable succession is being approached in that direction. Attempts at correlating the composition of the footwall quartzite with the trends and positions of payshoots have not met with success.

TECTONICS AND SEDIMENTATION

A. SHORELINE POSITIONS

Some measurements were made on the western limb of the marginal syncline at Loraine Mine in an attempt to define shoreline positions more accurately than can be shown on the isopach maps. On the assumption that the rate of thinning out is constant the results obtained are summarized in Table II. It was found that the sediments

TABLE II

Shoreline positions relative to present sub-outcrop position at Loraine Mine

Stratigraphic Interval	Distance from Sub-outcrop (feet)	Thickness of Strata (feet)	Calculated Minimum Shoreline Distance West of Sub-outcrop (feet)
No.3 Shaft Area			
Zone EA below massive conglomerate (LAG)	150 0	20 0	At sub-outcrop or not more than about 50 feet
Group of conglomerates at base of Zone EB	550 0	45 15	225
Base Zone EB to ED Reefs	600 * 350 0	260 150 110	 440 960
ED Reefs to base Zone ED	500 130	56 46	1700
ED Reef to base Zone ED	650 0	150 120	2600
Big Pebble Reef to "B" Reef	1500 * 500 0	200 80 60	 640 1500
Area near borehole TV.2, 6,000 feet north of No. 3 Shaft			
ED Reefs to base Zone ED	650 0	150 120	2600
Area 10,000 feet north of No. 3 Shaft			
Base Unit 4 Zone EA to base of Zone EA	1000 150	80 40	700
Base Unit 7 Zone EA to base Zone EA	1000 230	190 110	830
Base Upper Shale Marker to Basal Reef	2000 550	400 165	690
Area 13,000 feet north of No. 3 Shaft			
EA7B Reef to EA5 Reef	222 130	50 35	75

* When thicknesses at the trough are compared with thicknesses near the sub-outcrop, the results almost always indicate shorelines closer than that obtained when two sets of thicknesses were measured near the sub-outcrop. The profiles of most of the bedding units must therefore be similar to that of Zone VS.1 (fig. 5).

do not form a prism-shaped deposit, but one rather like that of fig. 5, commencing as a thin coarse unit near the shoreline, then thickening rapidly towards the trough where the greatest thickness is attained.

The table shows an encroaching shoreline up to the beginning of Boulder Bed time. The shoreline in Basal Reef time was not as far away as appears from the lack of coarse constituents in the Reef. In the area 10,000 feet north of No. 3 Shaft, where an influx of sediments is assumed to have occurred during Zone EA time, the shoreline positions are much further west than elsewhere, pointing to a lower-lying depositional embayment.

B. RELATIONSHIP BETWEEN TECTONIC STRUCTURES, SEDIMENTATIONAL FEATURES AND MINERALIZATION

The rising land to the west had a profound influence on the sedimentation of the basin. As the elevated ground advanced eastwards with time, the removal and redeposition of previously accumulated sediments took place, and gold from the Basal Reef, "B" Reef and other reefs was reconcentrated into the Elsburg Reefs. The growth of an arch in the basin from Kimberley time onwards might have been a factor in the change of facies of the "B" Reef between Loraine No. 2 Shaft and the marginal trough. Folding of the western limb of the marginal syncline took place concurrently with the deposition of Elsburg sediments. Coarse material was confined to this marginal trough owing to the rising of the arch further east.

The shoreline or margin of the depositional area was never very far from the present sub-outcrop. Sediments entered the basin in localized areas. Such points have been mentioned in regard to the Elsburg Reefs, the "B" Reef and the coarse material of Zone UF.2. During Leader and Basal Reef times coarse material did not enter this area from the western shoreline, and it is considered that the bulk of the material came from an area southwest of this part of the field. The narrow "carbon"-rich Basal Reef of this area probably represents the facies developed deep into the sedimentary basin and furthest removed from the area from which the material was derived. The "B" Reef at Loraine No. 2 Shaft possibly represents an intermediate facies, while the same reef where present at the trough, as well as the Kimberley and Elsburg reefs, a facies close to the point of ingress of coarse material. The uptilting of the sedimentary basin in the southwest, as shown by the isopach maps of the "B" and Basal Reefs (Figs. 6 and 9), might be linked with a progressive northwards advance of the points of introduction of detritus.

The sedimentary structures are those developed in a subaqueous environment, and some of them, such as the oscillation ripple marks, indicate shallow-water conditions. The smooth surfaces of the marginal unconformities and their graded profiles are typical of unconformities occurring in an epineritic environment. The overlapping of strata westward towards the source of the material is in the nature of a marine overlap. A non-marine overlap would have advanced progressively from west to east (Grabau, 1913, p. 740). Channel deposits, denoting transitional marine and continental environments, occur only in the Kimberley Stage, where the abundance of conglomerates and the numerous disconformities also point to a shallow-water environment. There is evidence that deltaic conditions existed at certain times.

It would thus appear that the deposition of the Upper Witwatersrand rocks took place subaqueously in a sedimentary basin, large enough to be called a sea, and that the area described was close enough to the shore so that transitional environments left their imprints on the succession. There is no direct evidence of glaciation and the absence of erratic boulders and pebbles in the sand-grade deposits argue against a glacio-marine environment and an extremely cold climate in the source area. Also, no evidence supporting the hypothesis of an arid environment has been found.

The affect of sorting agents on the nature of the sediments deposited can be seen in the alternating "glassy" quartzites and subgreywackes of Zone EA and their relationships to economic gold-bearing conglomerates. Local transitional beds occur which prove that the "glassy" quartzite is but a well-sorted derivative of the subgreywacke. Material of subgreywacke composition was introduced into the basin in pulses of sedimentation. The upper portions of such layers were winnowed of clayey materials and soft rock-types were comminuted. Heavy minerals were concentrated together with the coarse constituents. Until the succeeding pulse of sedimentation, all material above the base level of deposition came under the influence of waves and currents. The beds of subgreywacke were deposited below the base level of erosion and, therefore, not reworked. Influx of detritus must, therefore, in general, have kept pace with subsidence. Almost pure quartzose "bars", occurring close to mineralized conglomerates throughout the Witwatersrand System, have also been seen in association with other Elsburg and Kimberley conglomerates. These quartzite "bars" are considered to be the sorted products of the underlying rock-types, and thus to have been reworked in the same way as the "glassy" quartzites of Zone EA.

There seems to be some relationship between payshoot trends and sedimentary environments in every payable conglomerate. All the Elsburg Reefs are confined to a narrow strip, controlled by folding, in which shoreline positions did not fluctuate widely and payable reefs were superimposed. The affects of deltaic conditions are present in the form of groups of payable conglomerates and of paystreaks trending transversely across the main payshoots. In the case of the "B" Reef, the Loraine No. 2 Shaft payable area is elongated in a direction coinciding with the trends of the isopachs in fig. 6. The possible affect of the marginal downwarp on payability of this reef has already been discussed. Payshoots in the Basal Reef follow the trends of isopachs on Loraine Mine where fairly strong currents flowed in the general direction of the shoots.

The contact between the Kimberley and the Elsburg Stages marks a change from sericitic quartzites to dominantly chloritic quartzites. This change culminates in the subgreywacke and greywacke conglomerates formed towards the end of the Elsburg period. The rock-types contained in these conglomerates can be matched with sediments of the Lower Division, and with greenstones and other metamorphic rocks of Archean formations, similar to those intersected in boreholes about 5 miles west of the mines (van der Vyver, 1956, p. 9). Further west, boreholes penetrated Archean granite at comparatively shallow depths. It is thus apparent that an extensive granitic terrain existed beyond a belt of more chloritic metamorphic rocks. The bulk of the sediments accumulated during Elsburg time is assumed to have come from the metamorphic belt within 10 miles of the boundary of the basin, whereas those of Kimberley age are thought to have come from the granitic province.

The overlap of the Boulder Beds across the whole of the Upper Division shows that the folding of the marginal trough had been virtually completed before the end of the Elsburg Stage and that a line of weakness had developed further to the west, coinciding with the zero isopach line of the Boulder Beds. The disturbance that developed on this new line has been named the Border Fault. It is assumed to have been of major significance, tapping magma at depth and forming fissures out of which great thicknesses of the Lower Volcanic Stage poured. The Lower Lava does not occur west of the Border Fault, but to the east it is known to thicken considerably as this fault is approached. The increase in thickness of the lava westwards is sufficient to account for the westerly tilt of the Witwatersrand System.

The normal east-dipping faults can be accounted for by the outpouring of lava on to the Witwatersrand System, mainly from the Border Fault, and the subsidence of the eastern block containing the recently deposited sediments as the lavas were extruded. The block arched down towards the fault and tensional stresses developed step faults and tilted fault-blocks. Lava, or sediments derived mainly from the lava, filled the tilted fault-block and the weight of the prism-shaped mass of lava accelerated the formation of the normal faults. (Cloos, 1937; Jacobsen, 1940, p. 273). The northward plunge of the marginal syncline might have resulted from the emplacement of the acid phase of the Ventersdorp System further north, and the cross-faults which are younger than the strike faults, could have been formed in the same way as the step faults.

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KEY TO FIGURES

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