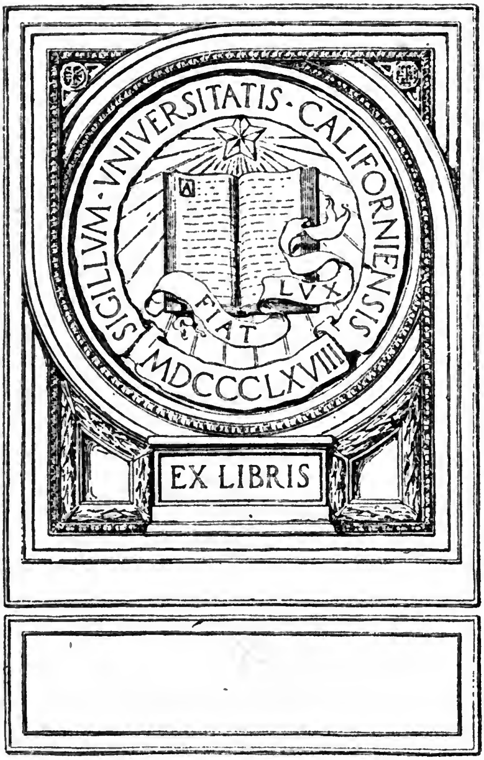
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THE BANKET

A STUDY OF THE AURIFEROUS CONGLOMERATES OF THE WITWATERSRAND AND THE ASSOCIATED ROCKS

PLATE I.

G. B. Neilson, Photo.

Banket "reef" exposed on face of stope, City and Suburban Gold Mine.

[*Frontispiece.*

THE BANKET

A STUDY OF THE AURIFEROUS CONGLOMERATES OF THE WITWATERSRAND AND THE ASSOCIATED ROCKS

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WITH NUMEROUS DESCRIPTIVE PHOTOMICROGRAPHS

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PREFACE

EVER since the banket leapt into prominence thirty years ago it has received much attention from geologists, and around it a voluminous literature has sprung up. In this, however, there is noticeable a tendency to devote more energy to the discussion of the origin of the gold than to the serious investigation of the rock.

That the banket, apart from its economic interest, will amply repay even a more exhaustive study than the writer has given to it, there can be no doubt. The rock is of ancient date and has come under a variety of influences which have induced in it many mineral changes, the full elucidation of which, more especially those of a metasomatic nature, would constitute an important contribution to mineralogical and geochemical knowledge. It is true that the changes referred to are by no means unique, but the facilities for their investigation afforded by the banket are unrivalled. These are, first, the simplicity of its original mineral composition, the rock being made up principally of quartz, and second, its extensive exposure. With regard to the latter, it may be mentioned that the banket is now exposed in the direction of the dip to a vertical depth of about a mile, while hundreds of miles of mine workings traverse it at varying depths along the strike.

The staffs of the mines are in great part composed of men who have had some training in the methods of petrology, and it is hoped that the publication of the present Memoir, by providing a basis for further study, will induce some members of this army of potential investigators to enter the field of research. It will scarcely be gainsaid that a thorough investigation of the banket and associated rocks is of value to the gold-mining industry, or that an intelligent interest on the part of the mine officials in the rocks with which they deal will add to efficiency.

The present work is based largely on the following papers contributed by the writer to the *Transactions of the Geological Society of South Africa*:—

"Notes on the Auriferous Conglomerates of the Witwatersrand," vol. x., 1907.
"Further Notes on the Auriferous Conglomerates of the Witwatersrand, with a Discussion of the Origin of the Gold," vol. xii., 1909.
"The Replacement of Quartz by Carbon in Rand Banket," vol. xiii., 1910.
"The Problem of the Rand Banket," Presidential Address, 1911.
"Notes on the Pebbles of the Rand Banket," vol. xv., 1912.
"Note on the Origin of the Iridosmine in the Banket," vol. xv., 1912.
"Note on Diamonds in the Banket," vol. xvi., 1913.
"Metasomatism in Banket," vol. xvii., 1914.

Due acknowledgment is made in the text of any indebtedness to the work of others.

With regard to the vexed question of the origin of the gold in the banket, the writer was inclined during the earlier stages of his research to favour the infiltration theory. However, as the work proceeded, he was gradually led, by the difficulties that appeared in the way of accepting that hypothesis, to the belief that a more satisfactory solution of the problem was provided by the placer theory. This belief has been greatly strengthened by the recent stratigraphical work of Dr E. T. Mellor. Nevertheless, as it is necessary on this theory to assume that the detrital gold has undergone solution and reprecipitation, it has been thought advisable to include the descriptions of the gold in the chapter dealing with the authigenic constituents of the banket.

The writer takes this opportunity of acknowledging his great indebtedness to former students and others connected with the mining industry for much valuable assistance received during the progress of his investigations, and to Dr Robert Campbell of Edinburgh University for seeing the work through the press.

JOHANNESBURG, *December* 1916.

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THE BANKET

CHAPTER I

INTRODUCTION

The object of this brief introduction is to enable the reader to take a general view of the conditions under which gold occurs in South Africa, and to appreciate references which are made in later chapters.

The Auriferous Region of South Africa is contained almost entirely within the borders of the Transvaal and Southern Rhodesia. In this area gold occurrences of economic importance have been found in the rocks of the Swaziland, Witwatersrand and Transvaal Systems.

Of these the Swaziland System is the oldest, and consists of metamorphic rocks, which have been invaded by huge granitic bathyliths, as well as by other minor intrusions both acid and basic. The area over which these rocks outcrop is very considerable, but unfortunately, except in a few districts, they have not been subjected to detailed study. The nature, too, of the rocks, the disturbances which they have undergone, and the absence of fossils make this study very difficult.

The Geological Survey of Southern Rhodesia has arrived at the following tentative classification :[1]

1. A Series consisting of three groups :—
   - (*a*) Greenstones and greenstone schists including epidiorite, hornblendic, chloritic and talcose schists, serpentine, and rocks of intermediate and perhaps acid composition. The group probably includes volcanic rocks and intrusive sills, and is doubtless capable of sub-division.
   - (*b*) Banded ironstone, with subordinate black and grey phyllites and limestones.
   - (*c*) A group of conglomerates and grits, associated in Lomagundi with limestones, etc. The group is considered to be younger than the preceding one, but the exact relationship is not known. It is a possibility to be borne in mind, that the conglomerates in different parts of the Territory are not all of the same age.
2. A Series of ultrabasic intrusions, now represented by serpentine and talc-schist, which contain chromite and asbestos.
3. A Series of acid intrusions of varied character, consisting in the main of felsite or quartz-porphyry, but frequently altered to porphyroid and sericite-schist.

Series 2 is intrusive into Series 1, and Series 3 into Series 1 and 2.

In the Transvaal the general character of the rocks of the Swaziland System is much the same,

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[1] *Geological Survey Bulletin*, No. 2, Bulawayo, 1913, p. 3.

except that in the distinctly sedimentary facies (Moodies Series) there is sometimes a greater development of shales and slates.

The metamorphic rocks occur in narrow, irregular belts flanked by wide areas of granite. They are generally highly folded and dip at steep angles, their strike conforming more or less to the edges of the belts.

The granite is mainly the biotite variety, though muscovite and hornblende are occasionally present. Frequently, and more especially in the neighbourhood of its contact with the schists, it assumes a gneissose structure. This, in most cases, is obviously due not to subsequent pressure but to differential movement during consolidation.

A considerable resemblance is observable between the rocks of the Swaziland System, and the auriferous Archaean schists of Western Australia and Southern India.

Gold deposits are found in all the types of rock composing the metamorphic belts, and also occasionally in the granite and gneiss of the bathyliths. They occur as quartz veins or as impregnated bodies of rock.

Of the numerous quartz veins that traverse the country, a small proportion only are auriferous, and of these the majority repay mining only to a small depth. The gold occurs in shoots, and is usually accompanied by sulphides, of which the most common is pyrite, others being pyrrhotite, chalcopyrite, galena, blende, stibnite, and mispickel. Of the other minerals sometimes present, mention may be made of calcite, dolomite, siderite, scheelite, and tourmaline. Occasionally quartz of two periods can be distinguished in the veins, bearing witness to a re-opening of the fissures. The quartz of earlier date generally carries all the gold.

The deposits of the second type, usually spoken of as "impregnations," are of considerable economic importance because of the dimensions which they sometimes assume, notwithstanding that some of them owe much of their gold to secondary enrichment. They consist of bodies of shattered or sheared rock, which has been impregnated with sulphides (most often pyrite), quartz, and gold. Carbonates, such as dolomite, siderite, and calcite are sometimes present in large amount. Numerous auriferous quartz veinlets generally traverse the mass.

The work of the Geological Survey of Southern Rhodesia points to a close connection between the gold deposits of that country and the acid rocks of Series 3.[1] This had not previously been observed owing to the intrusions having in many cases undergone alteration to such an extent as to render them almost unrecognisable. The rocks vary from fine-grained felsitic rocks, sometimes banded, through quartz-porphyries to coarse-grained granites. Some of them, as the result of movement, have been changed to porphyroids, or even further to sericite-schists and phyllites; while, in the neighbourhood of gold deposits, the action of mineralising solutions is frequently manifested by the presence of a large amount of sericitic mica, carbonates, chlorite, and other minerals.

Most of the intrusive masses are roughly oval or circular in outline. They are supposed to belong to the same period as the granite bathyliths.

That the gold deposits and the acid intrusives are closely related is deduced from their frequent

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[1] *Loc. cit.*

association. Some of the quartz veins, however, appear to be more directly connected with the intrusion of the bathyliths, as they occur at the contact of the granite and the schists.

Similar acid rocks are found in the Swaziland System in the Transvaal, but their relation to the gold deposits has not been investigated.

The Witwatersrand System consists of a thick body of sediments derived from the waste of the Swaziland System. Where the base is seen, it is found resting on granite or the associated schists.

The rocks outcrop in several districts of the Transvaal, but those in the Witwatersrand area, which reach a thickness of 24,000 feet, are, from an economic point of view, by far the most important, and have been the most closely studied.

Throughout the greater part of the district they strike roughly east and west, and dip to the south at steep angles, which, however, decrease with depth. In the extreme west of the Rand the beds bend round in a southerly direction, and finally disappear under a covering of rocks belonging to the Transvaal System. They take another turn to the south in the far East Rand, in which area the rocks form a shallow synclinal basin, largely covered by horizontal or slightly inclined beds of later age.

They have been separated into two divisions distinguished by their general petrological characters, the lower being composed of slates with some prominent beds of quartzite, and a few conglomerate beds, while the upper consists of a succession of quartzites, grits, and conglomerates, with oneconspicuous band of slates.[1]

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[1] The term "slate" is used loosely on the Rand to designate any hardened argillaceous rock with or without slaty cleavage.

The rocks are much faulted and have been invaded by numerous dykes and sills.

While all the Witwatersrand conglomerates are to some extent auriferous, those sufficiently rich to be at present of economic value are confined to the Upper Division. They occur in definite zones, and are remarkable for their persistence both along the strike and the dip. The term "series" is applied to the group of conglomerates belonging to any one horizon. Thus we have the following, beginning with the youngest.

Elsburg Series,[1]
Kimberley Series,
Bird Reef Series,
Livingstone Series,
Main Reef Series.

Dr Mellor, in his recent description of the Witwatersrand System, avoids this misuse of the word "series" by substituting the terms "Elsburg Reefs," "Bird Reefs," etc.

The conglomerates of the various zones, though differing somewhat in minor respects, are all of the type known as "banket." Those of the Main Reef Zone have yielded all but a very small fraction of the gold output of the Rand. In this horizon three principal bands of conglomerates are recognised, the Main Reef, Main Reef Leader, and South Reef.

The Main Reef, which is the lowest, is the most strongly developed, and averages from 4 to 8 feet in thickness. It is characterised by the uniform average

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[1] This "series," though assigned by some geologists to the overlying Ventersdorp System, is placed provisionally by Dr Mellor, of the Geological Survey, in the Witwatersrand System, as being apparently conformable to the Upper Division, though lying unconformably on the Lower.

size of its pebbles, among which those composed of white vein-quartz greatly preponderate. They show little or no evidence of grading, the largest pebbles being scattered indifferently throughout the rock. The reef appears to have been laid down less evenly than the overlying conglomerates, and in some portions of the Rand exhibits marked undulations. It is frequently divided into two or more bands by layers of quartzite, which is sometimes pebbly. The gold values are on the whole lower than those of the other two reefs.

The Main Reef Leader sometimes lies directly on the Main Reef, from which, however, it is usually separated by a variable thickness of other beds. It averages from 2 to 6 feet in thickness, and may be divided into several bands by thin quartzite partings. Its pebbles have a considerable range in size, and frequently show signs of grading, the larger pebbles being disposed towards the foot of the reef, which is generally sharply defined, especially so when it is underlain by the "Black Bar," an altered argillaceous rock, or other material strongly contrasting with the banket. The gold sometimes shows a marked preference for the footwall portion of the reef.

The South Reef is generally separated from the Main Reef Leader by a considerable thickness, sometimes as much as 80 or 90 feet, of quartzitic rock. It is made up of fairly continuous bands of reef, separated by layers of quartzite. The lowest of these bands, which has usually a higher gold content than the others, is known as the South Reef Leader. It is remarkable that, even when this leader becomes so attenuated as to be represented by a single layer of pebbles, or by a parting-plane, which is frequently the case in the West Rand, it may still carry sufficient gold to allow of its being mined with profit. The pebbles in the South Reef have much the same characteristics as those of the Main Reef.

While the three principal reefs just described are found fully developed side by side in the Central Rand, the Main Reef and South Reef are not represented in the far East Rand, nor the Main Reef Leader in the West Rand.

In the quartzites below the Main Reef and those lying above the South Reef, less persistent bands of conglomerates are sometimes met with. The beds between the Main Reef and the Main Reef Leader, which in the Central Rand usually consist of a few feet of quartzite or of slaty rock (Black Bar) or of both, attain a considerable thickness towards the east, and at the same time show marks of irregular deposition, such as false bedding and contemporaneous erosion. Along with this they exhibit great variation of texture, ranging from argillaceous rocks to coarse conglomerates. Frequently a mingling of the types just mentioned produces the rock known as the "Bastard Reef," in which pebbles similar to those of the Main Reef, along with coarse grains of quartz, are scattered sparsely through an argillaceous matrix. Over the greater part of the far East Rand, where the Main Reef and its footwall quartzites are absent, the Main Reef Leader rests on a thick succession of slates and fine-grained quartzites which appear to be identical with the uppermost beds of the Lower Division of the Witwatersrand System.[1]

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[1] For further information regarding the Witwatersrand System, see papers by Dr E. T. Mellor in the *Trans. Geol. Soc. S.A.*, vol. xiv., 1911, pp. 24-42, 99-131; vol. xvi., 1913, pp. 1-32; vol. xviii., 1915, pp. 11-71; in which references to other literature on the subject will be found.

The long period of sedimentation represented by the Witwatersrand System was succeeded by one of great volcanic activity, during which the rocks of the Ventersdorp System were formed. These consist of lavas, principally diabase and quartz-porphyry, with associated tuffs and breccias, as well as boulder beds.

It is probable that many of the basic rocks intrusive in the Witwatersrand System belong to this period.

The rocks of the Ventersdorp System were subjected to considerable erosion before the deposition of the overlying Transvaal System.

The Transvaal System outcrops over a great area in the Transvaal, Griqualand West and British Bechuanaland. It is, however, with its development in the Transvaal, where alone it is markedly auriferous, that we are immediately concerned.

In the Central Transvaal the rocks form a basin about 300 miles long, and a third of that in breadth, while a smaller basin appears to the south. They reach a thickness of about 18,000 feet, and are arranged in three conformable series, the Black Reef, the Dolomite and the Pretoria Series.

The lowest and least important of these is the Black Reef Series, which rests unconformably on older rocks, and consists of quartzites, shales, and conglomerates.

The Dolomite Series consists mainly of dolomitic limestone, with some shales and quartzites, and, in the Western Transvaal, magnetic slates. The limestone contains numerous bands of chert.

The Pretoria Series is made up of a succession of shales and quartzites. Conglomerates and limestones also put in an appearance, while andesitic lavas and tuffs occur about the middle of the Series.

Intrusive in the main basin of the Transvaal System, and spreading out between that and the overlying Waterberg System to form a vast sheet or laccolite, is a body of igneous rocks known as the Bushveld Igneous Complex. This consists in the main of a red, coarse-grained biotite granite with a basic periphery, though every gradation is to be observed in the mass from ultra-acid to ultra-basic rocks. The intrusion of the complex was accompanied by faulting and folding movements in the Transvaal System, by intense contact metamorphism, and by the injection of numerous sills and dykes of diabase and other rocks.

The gold deposits of the Transvaal System take the form of quartz veins or of banket "reefs."

The veins are either of the interbedded type or fissure veins. The former are the more important, and reach their greatest development in the Lydenburg district, where they occur in definite belts or horizons which maintain their mineralised character over a very extensive area. They appear in all three divisions of the system, but those found in the Dolomite Series have proved of greatest value. The veins generally contain a large quantity of sulphides, mostly pyrite, though chalcopyrite is common. Owing to their interbedded character and the gentle dip of the rocks in this district, an unusually large portion of the veins is in an oxidised state, being generally very cellular, and including much limonite and other earthy matter.

In the formation of the veins replacement of the sedimentary beds seems to have been the dominant process. It would appear, too, that they are genetically related to the numerous sills and dykes that have been injected into the rocks of the Transvaal System. These intrusions are principally diabases, diorites, and gabbros, and were derived from the same magma as the Bushveld Igneous Complex.[1]

The Banket "reefs" are auriferous patches occurring in conglomerates at or near the base of the Black Reef Series. The gold, which is accompanied by pyrite and sometimes chalcopyrite, is usually most abundant in the footwall portion.

With regard to the age of the Swaziland, Witwatersrand, and Transvaal Systems, all that can be said with certainty is that they are pre-Devonian.

Rocks of later origin, *e.g.*, those belonging to the Table Mountain Series and the Karroo System, in some cases far removed from what is here designated the "Auriferous Region," have been shown to contain gold, but only in trifling quantity.

Alluvial gold has been found in recent deposits, notably in the Lydenburg district.

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[1] For further information regarding these deposits see Memoir No. 5, *Geological Survey of the Transvaal.*

CHAPTER II

ALLOGENIC CONSTITUENTS OF THE BANKET

THE term "allogenic" may be applied to all the detrital material in a conglomerate, whether occurring as pebbles or as matrix.

The Pebbles.

In order to distinguish a pebble from a sand grain on the one hand and a boulder on the other, we shall assume that the mean diameter of a pebble lies between 2.5 millimetres and 10 centimetres.[1]

In typical banket the pebbles constitute about 70 per cent. of the bulk.

Pebbles of Vein-quartz.—The great majority of the pebbles are composed of vein-quartz.

On microscopic examination they exhibit all the variety of structure which vein-quartz is known to assume. As reference will have to be made later to these structures, a brief description of them is necessary.

The original structure of vein-quartz is most often coarsely granular, the grains being roughly equi-

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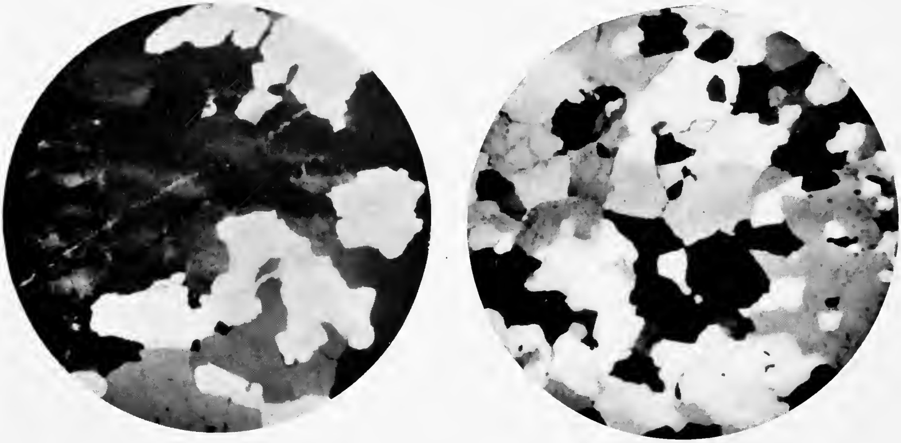
[1] See Hatch and Rastall, *The Petrology of the Sedimentary Rocks*, p. 31.

FIG. 1.—Marginal portion of a vein-quartz pebble, showing strain shadows, fracturing, and innumerable minute inclusions. To the left appears some of the matrix of the banket.
Crossed nicols ; diam. × 24.

FIG. 2.—Portion of a vein-quartz pebble, showing fracturing of a somewhat different character. Small individuals of clear recrystallised quartz are to be seen here and there.
Crossed nicols ; diam. × 12.



FIGS. 3 and 4.—Portions of the same pebble as in Fig. 1, showing different degrees of recrystallisation. The recrystallised quartz is unstrained and free from inclusions.
Nicols crossed ; diam. × 24.

dimensional. Deviations from this result mainly from dynamic metamorphism. The first obvious effect of stresses is to produce a variable amount of permanent molecular distortion of the individual quartz grains, which is revealed by the familiar "strain shadows" seen between crossed nicols. That this is usually accompanied by rupture is shown by the planes, containing innumerable minute inclusions, by which the grains are traversed. Such planes may be taken to indicate imperfectly healed fractures accompanied by infinitesimal or no displacement.

Another more marked effect is the production of interlacing systems of numerous, comparatively close fractures along which has occurred very small but distinct displacement, as is demonstrated by abrupt though slight differences in orientation on either side of the fractures, thus producing a somewhat mottled appearance between crossed nicols (Plate II., Fig. 1). In such cases, the quartz is crowded with minute inclusions. Sometimes the fracturing and displacement proceed much further without any other conspicuous result, but not uncommonly, about the stage just described, recrystallisation sets in.

The recrystallised quartz grains are distinguished from the original grains by their smaller dimensions, and, if they have not subsequently been subjected to great pressure, by their comparative freedom from inclusions, and the absence of marked strain shadows (Plate II., Figs. 3 and 4). The mosaics of recrystallised quartz, when examined between crossed nicols, can often be differentiated into areas which have definite positions of maximum and minimum illumination, owing to the majority of the grains in each area varying only slightly in crystallographic orientation. There is little doubt that each aggregate of this kind is the result of recrystallisation of one of the original and larger grains.

Generally, in a large body of quartz, the intensity of metamorphism varies considerably from place to place, and even within the narrow limits of a microscopic section, very different degrees of change are exhibited. The recrystallised areas may take the form of small patches or strands, and even when the metamorphism has been more general, remnants of the original grains can usually be detected. A schistose structure is frequently produced (Plate III., Fig. 1).

The widely varying degrees of metamorphism exhibited by adjacent pebbles, in contrast with the comparative uniformity of the surrounding matrix, sufficiently demonstrate that, on the whole, the structures possessed by the pebbles antedate their inclusion in the banket.

The quartz of the pebbles is most commonly white, dark grey, black, or colourless, and a mingling of these varieties in the same pebble is frequent. Among the smaller pebbles a bluish opalescent quartz is not uncommon. A reddish tint is very rare.

With regard to the causes of the colouration, it is well known that the white colour is due to the reflection of light from inclusions of liquid or gas of normal size. The origin of the darkening of vein-quartz has been explained in various ways.

The most obvious explanation is that it is due to the absorption of light by dark-coloured, probably solid, inclusions. Rosenbusch[1] attributes the jet-black or blue-black colour of the quartz in many porphyroids and phyllitic rocks to carbonaceous inclusions such as graphite and coal, rarely to magnetite,

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[1] *Microscopical Physiography of Rock-making Minerals* (trans. Iddings), p. 169.

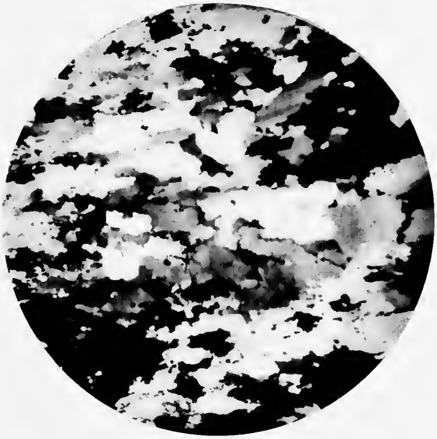

FIG. 1.—Portion of a vein-quartz pebble, showing recrystallisation to a schistose aggregate. That recrystallisation has been incomplete is proved by the presence of isolated patches of strained quartz containing numerous inclusions.
Nicols crossed ; diam. × 12.

FIG. 2.—Portion of a black vein-quartz pebble, showing innumerable minute inclusions arranged in two superimposed systems, one forming an irregular mesh-work, while the other runs in straight lines across the section.
Ordinary light ; diam. × 71.

FIG. 3.—Portion of coarse-grained quartzite pebble. Nicols crossed ; diam. × 21.

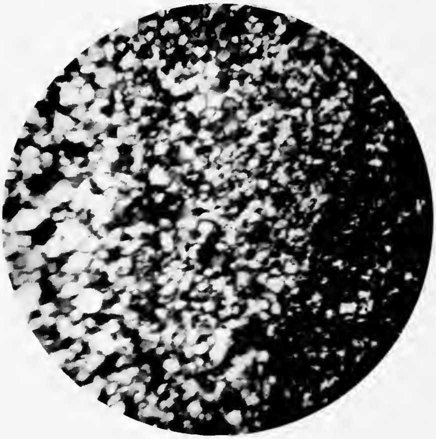

FIG. 4.—Portion of fine-grained quartzite pebble, showing banding produced by inclusions, and the varying dimensions of the grains of the quartz mosaic.
Nicols crossed ; diam. × 45.

while the colour of cairngorm or smoky quartz is believed to be due probably to the presence of carbon-nitrogen compounds.[1] An explanation of quite a different kind is advanced by Maclaren[2] in connection with the dark-coloured auriferous vein-quartz of the Dharwars in Southern India. In that region two kinds of veins, of different ages, occur in association. The younger are of white quartz, and under the microscope show only normal strain phenomena, whereas the older, which are intensely metamorphosed and schistose in structure, are composed of greyish to bluish-black quartz. He ascribes the colour of the latter to "total internal reflection from strain surfaces." A similar distinction in the colour of associated quartzes of different ages has also been noted in the Western Australian goldfields, and in the Barberton goldfield of South Africa. Mr Richardson,[3] in describing the Sheba Reef in the latter locality, states that the black quartz veins, which he considers the older, carry the gold, and, while mentioning that M. Bordeaux attributes the colour to the presence of bituminous particles, he adopts Maclaren's explanation.

A natural inference from the above-mentioned facts is, that there is a tendency in vein-quartz which has been subjected to intense dynamic metamorphism to darken in colour, and this is confirmed by the writer's study of the auriferous vein-quartzes of Rhodesia and the vein-quartz pebbles of the banket. However, a simpler and more demonstrable explanation of the connection between the metamorphism and the darkening than that of total internal reflection from strain surfaces can be offered.

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[1] Dana, *System of Mineralogy* (6th edit.), p. 187.

[2] *Gold, its Geological Occurrence*, p. 248.

[3] *Trans. Chem. Met. and Min. Soc. of S.A.*, vol. x., p. 126.

It has already been pointed out that, in addition to permanent strain, an intimate shattering and a recrystallisation of the original large quartz individuals to form a mosaic are common effects of pressure on vein-quartz. In this way the avenues by which solutions can penetrate among the quartz are vastly multiplied, and the precipitation from these solutions of dark-coloured solid inclusions, would be sufficient to alter the colour. That this is what has usually happened, whatever may be the case with respect to the vein-quartz of the Dharwars, can be demonstrated by microscopic examination of sections, especially if these are made comparatively thick. An abundance of dark-coloured inclusions can be seen, and the distribution of these shows a correspondence with the shattering, and less commonly with the recrystallised areas (Plate III., Fig. 2). Of course, it does not follow that in all, or even most cases, where shattering or recrystallisation has occurred, a darkening of colour has supervened.

Frequently the pebbles are darkened only about their margins or about their points of contact with other pebbles, but, as this can be shown to be an effect produced subsequent to the inclusion of the pebbles in the banket, it will be dealt with in another section.[1]

The bluish opalescent pebbles consist, in most cases at least, of single quartz individuals. When viewed by transmitted light they appear brown. The explanation would seem to be that the inclusions in this variety of quartz have a great range in size, some of them being so minute as to reflect the components of incident white light towards the violet end of the spectrum, while allowing the other components of greater wave length to be transmitted.

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[1] See p. 29.

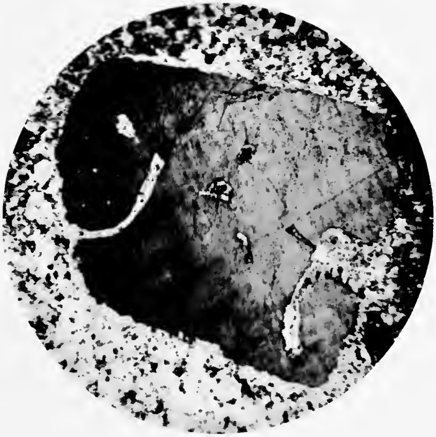

FIG. 1.—Portion of pebble of altered quartz-porphyry, showing corroded quartz phenocryst.
Nicols crossed ; diam. × 21.

FIG. 2.—Portion of quartz-tourmaline pebble. The tourmaline crystals occur in radiate clusters.
Ordinary light ; diam. × 22.

FIG. 3.—Portion of pebble of tourmalinised porphyritic igneous rock. The matrix has been replaced by tourmaline, and phenocrysts by quartz mosaics.
Nicols crossed ; diam. × 22.

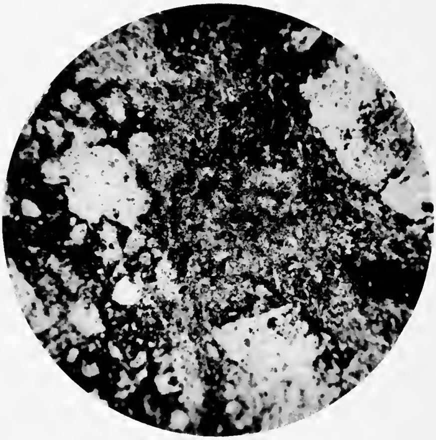

FIG. 4.—Portion of pebble of tourmalinised porphyritic igneous rock. The phenocrysts, represented by the light patches, have been replaced by larger tourmaline crystals than the matrix.
Ordinary light ; diam. × 21.

[*Face page* **16.**

The nature of the pigment which colours the reddish pebbles has not been investigated.

Pebbles of Quartzite.—Next in frequency to vein-quartz pebbles come those composed of very fine-grained quartzite, sometimes referred to as "cherty" pebbles. Under the microscope these are seen to consist of a fine mosaic of quartz, often containing minute magnetite or hæmatite inclusions. Many of them appear to be uniform in grain, but frequently the alternation of layers, in which the average diameters of the individuals making up the mosaic are different, and the disposition of the inclusions give them a banded structure more or less evident to the naked eye. The colours which the various bands show vary very much, being light to dark grey, white, black, light green or red (Plate III., Fig. 4).

Normal coarse-grained quartzite also occurs as pebbles. The quartzite varies from light to dark grey, and is of the metamorphic type in which the original clastic structure tends to complete obliteration (Plate III., Fig. 3).

Pebbles of Quartz-porphyry. — The pebbles of quartz-porphyry are light grey in colour, and show phenocrysts of quartz lying in a compact groundmass. That there is nothing in their colour, size, or shape, to differentiate them sharply from the pebbles among which they lie, explains why they have been overlooked by other observers. Under the microscope the quartz phenocrysts show crystalline outlines to some extent, and also the corrosion effects so characteristic of quartz-porphyry and similar rocks (Plate IV., Fig. 1). The groundmass is microcrystalline and consists of quartz and sericite. The latter is generally scattered more or less uniformly throughout the mass, but occasionally it occurs in patches, and less commonly in streaks which suggest an incipient schistosity.

No felspar has been observed, though it is possible that in the fine groundmass orthoclase grains may have escaped notice. The rocks may be described as quartz-porphyries which have undergone silicification with the production of sericite.

Pebbles containing Tourmaline.—Quartz-tourmaline pebbles are occasionally met with. To the naked eye they appear to be composed of very dark-coloured quartzite, but, when microscopically examined, it is not always clear whether they are the result of the tourmalinisation of quartzite or of vein quartz. The tourmaline, which is present in variable amount, is generally brown, with here and there a bluish tint, and most frequently occurs in radiate bundles, though occasionally it forms a granular aggregate (Plate IV., Fig. 2).

Pebbles of tourmalinised igneous rocks also occur. These are black, and might at first sight be taken for fine-grained basalt. One of them got in the Ferreira Deep Gold Mine is about 3 inches in diameter, and on being wetted appears to contain numerous dull grey phenocrysts, some of them as much as 7 mm. in length, but the majority much smaller. Under the microscope the apparent phenocrysts are resolved into quartz mosaics containing numerous inclusions, mainly of tourmaline, which is often in radiate groups. The groundmass is composed almost entirely of small tourmaline crystals. The colour of these is generally brown, but there are also numerous groups of larger crystals that are vivid blue. Growths of the larger crystals also project from the groundmass into the

FIG. 1.—Portion of chloritoid-schist pebble. The matrix is mainly a fine-grained quartz mosaic.
Ordinary light ; diam. × 22.

FIG. 2.—Portion of white quartz pebble, showing concentric arrangement of quartz and sericite.
Ordinary light ; diam. × 21.

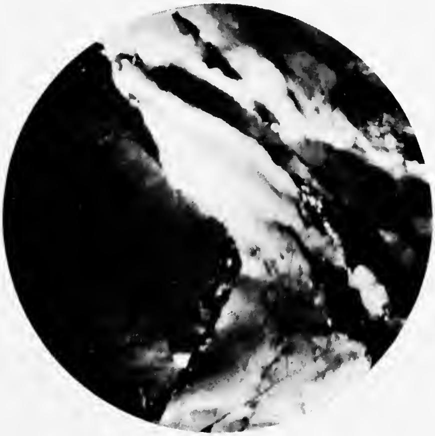

FIG. 3.—Portion of indented contact of two vein-quartz pebbles. Note the strain shadows. The pebble on the left is partly replaced by sericite at the contact.
Nicols crossed ; diam. × 15.

FIG. 4.—Margin of a vein-quartz pebble, showing a growth of secondary quartz in continuity with that of the pebble, whose original outline is indicated by a line of inclusions.
Nicols crossed ; diam. × 70.

[*Face page* 18.

phenocryst pseudomorphs. A little pyrite and some patches of an opaque non-metallic grey material are present (Plate IV., Fig. 3).

A smaller pebble from the Cason Gold Mine resembles the one just described, with the difference that the tourmalinisation has proceeded still further, the phenocrysts being represented mainly by areas of tourmaline crystals much larger than those of the groundmass. Only rarely is a little quartz still to be seen in the centre of these areas. This pebble contains coarse gold lying along cracks (Plate IV., Fig. 4).

Though pebbles of this character are obviously of igneous origin, the alteration of the rock from which they were derived has been too great to allow of identification. It would not, however, be rash to say that probably it was originally an acid rock containing porphyritic felspars.

Notwithstanding that a little tourmaline of authigenic origin occurs in the banket, no good grounds exist for doubting that the tourmalinised pebbles are representative in their present condition of the rocks from which they were derived.

Pebbles of Schist.—Pebbles of schist are exceedingly rare in the banket, and only one occurrence of them in considerable number, and that of very limited extent, is known. They are coloured various shades of brown, grey, and green, and vary in composition from sericite-schist to chloritoid-schist.

In one type plates of chloritoid about the size of a pin's head are scattered thickly through the rock. Under the microscope the crystals show, many of them, hour-glass structure, and in approximately basal sections two cleavages inclined about 60° to each other can sometimes be seen. The matrix consists of quartz and sericite and is very fine-grained, though occasional patches of coarse-grained quartz occur, and also a little chalcopyrite and pyrite (Plate V., Fig. 1). In another type the chloritoid crystals are smaller and more numerous, and the matrix coarser and more quartzose, sericite being present in very small amount. A variety consisting of a fine-grained aggregate of quartz and sericite with an occasional crystal of chloritoid is common. In all the schists, rutile, either in minute isolated crystals or in clumps, is present in the matrix and as inclusions in the chloritoid.

In what degree the mineral composition and the structure of these pebbles have been affected since they became part of the banket, it is impossible to say.

Pebbles with Concentric Structure.—In some rare instances concentric structures have been observed in white quartz pebbles. By way of example, one from the Randfontein Central Gold Mine may be briefly described. It is seen with the naked eye to contain several ellipsoidal and spherical bodies about 2 mm. or less in diameter. Under the microscope these are resolved each into three to six concentric layers of somewhat radiate quartz, alternating with similar but thinner layers of sericite. At one place two of the bodies are seen to be wrapped together by other surrounding layers of quartz and sericite. In the centre of one of these bodies are two very small spherical aggregates of the same minerals. The origin of the structure is uncertain (Plate V., Fig. 2).

Size of Pebbles.—The pebbles of the banket are of

PLATE VI.

FIG. 1.—Group of boulders from the banket to show their prevalent shape. Diam. × $\frac{1}{3}$.

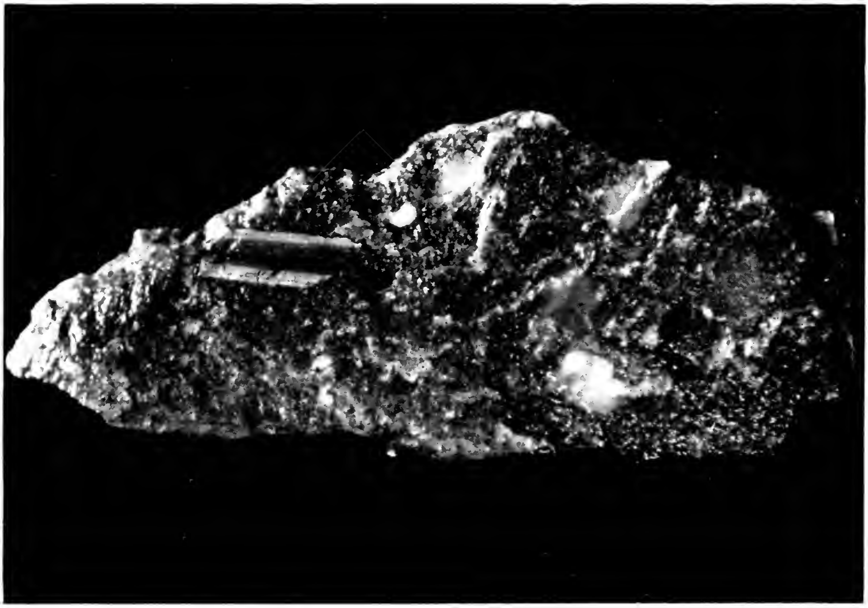

FIG. 2.—Piece of banket, showing banded fine-grained quartzite pebble. Diam. × $\frac{5}{7}$.

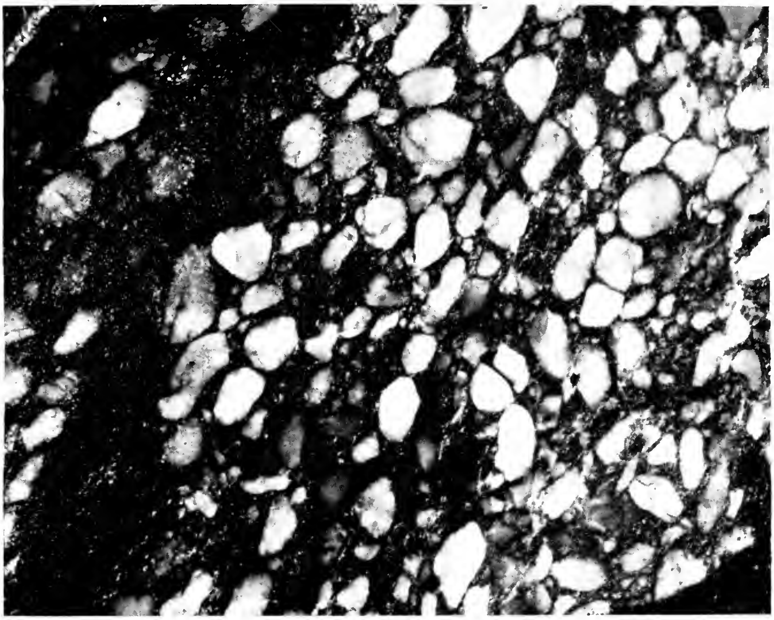

FIG. 1.—Fractured surface of banket. The direction of the bedding is shown by the thin band of quartzite to the left. The outlines of some of the pebbles appear more angular than they really are. Diam. × $\frac{4}{7}$.

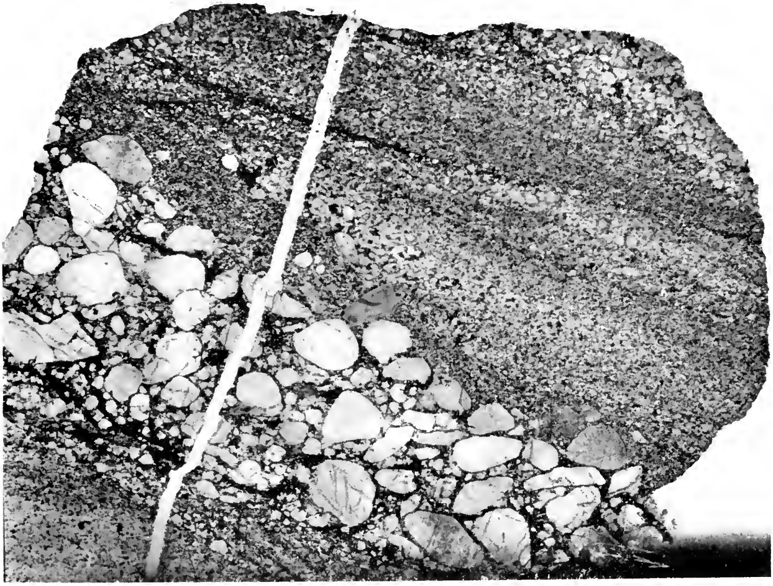

FIG. 2.—Large-sized thin section photographed by transmitted light, showing the full width of the South Reef Leader, New Unified Gold Mine, with the quartzite above and below. The dark lines which show up the false bedding of the quartzite are composed of chlorite and pyrite. The white band crossing the section is a crack in the section. Diam. × $\frac{3}{4}$.

[*Between pp.* **20** *and* **21.**

all sizes within the limits previously mentioned,[1] but the average size is about that of a pigeon's egg. The upper limit for pebbles is occasionally exceeded, and boulders having diameters as great as 8 inches are found. Pebbles of normal quartzite tend to be larger than the vein-quartz pebbles associated with them. The explanation of this is that usually the cracks in vein-quartz are closer than in quartzite, so that the latter rock tends to break into larger fragments.

Shape of Pebbles.—The shape of the pebbles can be better observed in the "freemilling" or oxidised banket, where they generally break away easily from the loose matrix, than in the unoxidised rock, in which the pebbles are seen only in random sections. The great majority of the boulders and large-sized pebbles are muffin-shaped, *i.e.*, rounded but approximating to flatness on one side (Plate VI., Fig. 1). Though this shape is also very common among the smaller and more normal pebbles, the proportion is much less. Muffin-shaped pebbles must owe their form largely to their having been pushed along or moved to and fro on one face, a kind of motion to be found in marine and estuarine shingles, where a considerable proportion of the pebbles are of this shape.

The other forms met with are approximately ellipsoidal and spherical, or, though rounded, quite irregular, while individuals with plane parallel faces, but rounded edges, are common in the case of the more or less banded fine-grained quartzite pebbles (Plate VI., Fig. 2). These flat forms are due to the tendency of banded rocks to break into slab-like fragments, whose movement would be a gliding

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[1] p. 12.

one. In section such pebbles are sometimes as much as fourteen times as long as broad, though generally the proportion is much less. Pebbles of fine-grained quartzite are sometimes well rounded, but, when this is the case, banding is invariably absent.

Occasionally pebbles are observed that have been rounded and then fractured shortly before their final deposition. De Launay[1] mentions a case in which a pebble has apparently been broken *in situ*, and the fragments shifted a little from one another. Judging from the sketch which accompanies his description, the same appearance would be produced by a partial replacement of the pebble along cracks by sericite or chlorite, an occurrence not uncommon in banket.

Distortion and other secondary changes, which have affected the shapes of pebbles after their inclusion in the banket, are referred to later.[2]

Disposition of Pebbles.—Most of the pebbles lie with their longer axes parallel to, or making small angles with, the direction of the bedding. The writer has observed in the Meyer and Charlton Gold Mine a singular occurrence, in which over a short distance in a narrow banket bed the pebbles were mostly disposed at right angles to the normal position. Imbrication or overlapping of pebbles can always be observed, but the direction of this is not uniform even within a small area.

Distribution and Source of Pebbles.—The features of the vein-quartz composing the pebbles are uniform from one end of the Rand to the other, though the

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[1] *Les Richesses Minérales de L'Afrique*, Paris, 1903, p. 59.

[2] p. 31.

proportions of pebbles of the different colours and their average size vary, to a certain extent, from reef to reef, and from place to place in the same reef. By this variation the various reefs may, in many cases, be distinguished from one another within a limited area. The Main Reef Leader shows more evidence of grading than the other reefs, the larger pebbles being frequently congregated in the footwall portion.

The milky-blue opalescent pebbles, though frequent in the normal banket, are commonest in the so-called "bastard reefs."[1] This is accounted for by the almost uniformly small sizes of such pebbles, their average diameter being about 5 mm.

It is probable that the quartz veins from which the pebbles of the banket were derived are of at least two distinct ages, the older being represented by the black and dark grey pebbles. It has already been pointed out[2] that, though the dynamic metamorphism of vein-quartz is not always followed by a darkening of the colour, yet it is generally a necessary prelude to this; so that if two sets of veins, one white and the other black, occur in association in the same region, there is always a presumption that the latter is the older of the two.

The source of the blue opalescent quartz pebbles is uncertain. Their uniformly small size suggests that they may have been derived from igneous or metamorphic rocks. Hall[3] describes the occurrence in the Murchison Range of schists of igneous origin, which are characterised by the presence in them of small grains of quartz "which on a fresh surface have the characteristic pale bluish appearance of boiled sage"; while the present writer has observed in a

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[1] p. 84.

[2] p. 16.

[3] Memoir, No. 6, *Geol. Survey of S. Africa*, p. 90.

quartz-porphyry, found as boulders in the so-called "Rhodesian-banket" at Lomagundi, blue quartz grains similar to those in the banket occurring as phenocrysts. On the other hand, they may result from the breaking-up of thin quartz stringers, such as are sometimes very common in metamorphic areas—*e.g.*, in the Lewisian Gneiss of the North-West of Scotland—where blue opalescent quartz occurs in abundance as veinlets and small patches.

The pebbles of fine-grained quartzite vary somewhat in their characters in different portions of the Rand. The differences lie in colour, width, frequency, and definiteness of the bands, which they very commonly possess. Most of them are obviously fragments of the rock variously known in South Africa as "banded ironstone," "calico rock," "quartz-hæmatite-magnetite rock," etc. This type of rock occurs at various horizons, but is especially conspicuous in the Swaziland System. It is possible that some of these pebbles are really derived from fine-grained igneous rocks of acid composition which have undergone silicification.

The "pink" pebbles, whose presence in banket is supposed by some to be an invariable indication of high gold content, are usually composed of unbanded fine-grained quartzite. Their coloration might frequently be described rather as reddish-brown than pink, and is generally very faint. The writer has on various occasions observed a conspicuous number of such pebbles, as well as similarly tinted vein-quartz pebbles, in banket very rich in gold, but it is doubtful whether any more general statement can be substantiated. The manner of their occurrence makes it certain that the colouring matter was introduced subsequent to the formation of the banket.

Coarse-grained quartzite pebbles are not very common in the Main Reef horizon, but appear to be more frequent in that of the Kimberley Reefs. The rock of which they are composed is similar in structure to the quartzites of the Swaziland System.

The distribution of pebbles of altered quartz-porphyry has not been sufficiently studied for one to say whether they are of general occurrence along the Rand or confined to certain areas. The writer has observed them in banket from the New Goch, Glencairn Main Reef, Ferreira Deep, New Kleinfontein, and Apex Gold Mines, and on a visit to the last-mentioned mine he found them occurring in considerable numbers. They are occasionally seen in microscopic sections cut at random from the banket. Thus it would appear that they are not an uncommon constituent of the rock. Altered quartz-porphyries and quartz-felsites have been described as occurring in the Swaziland System at Mulder's Drift[1] (about 13 miles to the north-west of Johannesburg), in the Murchison Range,[2] and in Southern Rhodesia,[3] and the descriptions leave no doubt that the quartz-porphyry pebbles in the banket are derived from a similar assemblage of rocks. The fact that in Southern Rhodesia the gold deposits are associated with such rocks may have some significance in connection with the gold content of the banket.

The tourmalinisation of rocks belonging to the Swaziland System has been observed in various localities, and the occurrence in the banket of pebbles of tourmalinised rocks proves that this process must have operated in pre-Witwatersrand times.

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[1] Kynaston, *Report Geol. Surv. Transvaal*, 1906, pp. 14-15.

[2] Hall, *op. cit.*, pp. 80-81.

[3] p. 4.

Pebbles composed of schist are very rare in the banket. This is doubtless due to the very prolonged attrition to which the pebbles in the rock have been subjected, thus permitting in general the survival of only the hardest quartzose individuals. Only one occurrence in which schist pebbles are present in considerable numbers in the banket has been observed by the writer. This was in the Ferreira Deep Gold Mine, at a point in the tenth level drive, where the Main Reef Leader is seen to bulge abruptly into the footwall, presenting on each side of the drive an appearance resembling a section through a small contemporaneously eroded channel. Not only are numerous schist pebbles to be seen in the downward bulging portion, but a few scattered individuals are found in the evenly bedded part of the reef immediately above it. Though some of the pebbles are small, yet the average size is greater than that of the normal pebbles of the banket, and their shapes are more irregular. They are almost all of them comparatively soft, and many of them show a tendency to fall away in small or large flakes. Though doubtless their friability is in great part due to changes they have undergone subsequent to their inclusion in the rock, they must from the beginning have been much softer than the normal pebbles of the banket. It may have been that they were transported from the land more or less directly to their present position by a current or stream, and thus escaped the wear and tear to which the more evenly distributed pebbles were subjected. As stated elsewhere,[1] the pebbles vary in composition from sericite schist to chloritoid schist, and some of them show a marked resemblance to rocks occurring

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[1] p. 19.

in the Swaziland System at Barberton, Mount Maré, and elsewhere.

A comparison of banket pebbles with the corresponding rocks of the Swaziland System shows that, at the Witwatersrand Period, the latter had already, in the main, assumed those petrological characters which distinguish them at the present day.

Alteration of Pebbles.—The pebbles possess certain features, some of them occasional and others more general, that were impressed upon them after their inclusion in the banket. These are partial or total replacement, partial solution, indentation, secondary enlargement, partial darkening of colour, the development of fissure systems, and distortion.

One of the commonest features of the quartzose pebbles is replacement about their margins by one or more of the three minerals, sericite, chlorite, and pyrite. Occasionally pyrrhotite, chalcopyrite, sphalerite, or calcite, plays the same part. To irregular marginal replacement by the first-mentioned minerals is frequently due the almost angular outlines that the pebbles sometimes present on fractured surfaces of banket. Though pebbles of vein-quartz are not by any means exempt, yet those composed of fine-grained quartzite are especially liable to replacement by pyrite, and it would be difficult to find a pebble of the latter that on close examination did not show evidence of this process. When the pebbles are homogeneous in texture, the replacement takes place mostly round the margins, but in the banded varieties there is generally a well-marked preferential replacement of certain of the bands. Sometimes the pebbles are wholly replaced by pyrite, their original character being indicated only by their shape and by the rows of inclusions, which may still persist. The points of contact of quartzose pebbles also appear to be peculiarly favourable to replacement by pyrite and other minerals, doubtless owing to the quartz in such positions being in a condition of strain (Plate V., Fig. 3). The partial or total replacement of quartz pebbles by calcite occurs in the Meyer and Charlton Gold Mine, and the Paarl Central Gold Mine, but as this, as well as the other metasomatic changes affecting pebbles, is shared by the matrix of the banket, detailed description of the phenomena will be given in a later section.[1]

A slight etching of pebbles on the faces of joints or other fissures passing through the banket is occasionally observed. On the 2300 feet level in the Robinson Deep Gold Mine a fissure was encountered some years ago, along which water was flowing, and on the walls of which extensive solution of both matrix and pebbles of the banket had taken place. The pebbles most affected were in a highly cavernulous condition and capable of being crushed in the hand, while the others were deeply etched. The process of solution, as was to be expected, had proceeded most rapidly along the surfaces of contact of the quartz individuals composing the pebbles. The pyrite in the rock showed no trace of alteration.

Pebbles, more especially those of large size, when extracted from the loose matrix of the oxidised rock frequently show patches more or less deeply indented by the adjacent pebbles, while the rest of their surface may be smooth and unbroken. In some cases the indentations are so deep and irregular as to give the appearance of corrosion. The welded surfaces are almost invariably coated with glistening flakes of

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[1] p. 52.

PLATE VIII.

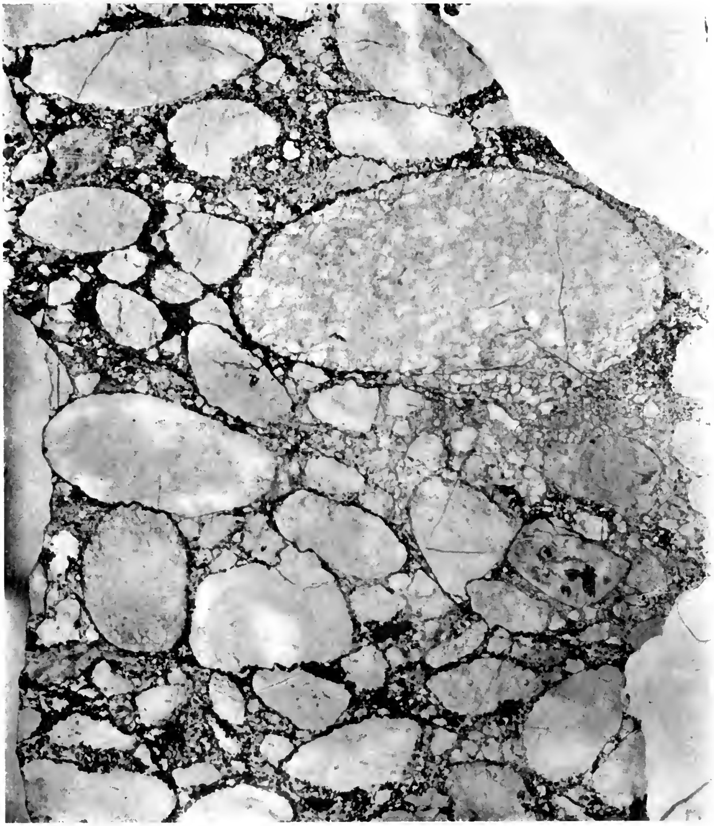

FIG. 1.—Large-sized thin section of banket, photographed by transmitted light, to show the shapes of the pebbles and other features referred to in the text. The opaque material is mainly pyrite. Diam. × $\frac{4}{5}$.

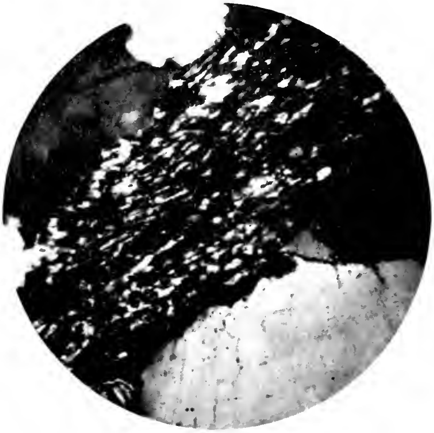

FIG. 2.—Schistose quartz at the contact of two vein-quartz pebbles.
Nicols crossed ; diam. × 57.

FIG. 3.—Pebble from much fissured banket in the Ferreira Gold Mine, showing how the pebbles sometimes fall into slices when extracted from the rock.
Diam. × 2

PLATE IX.

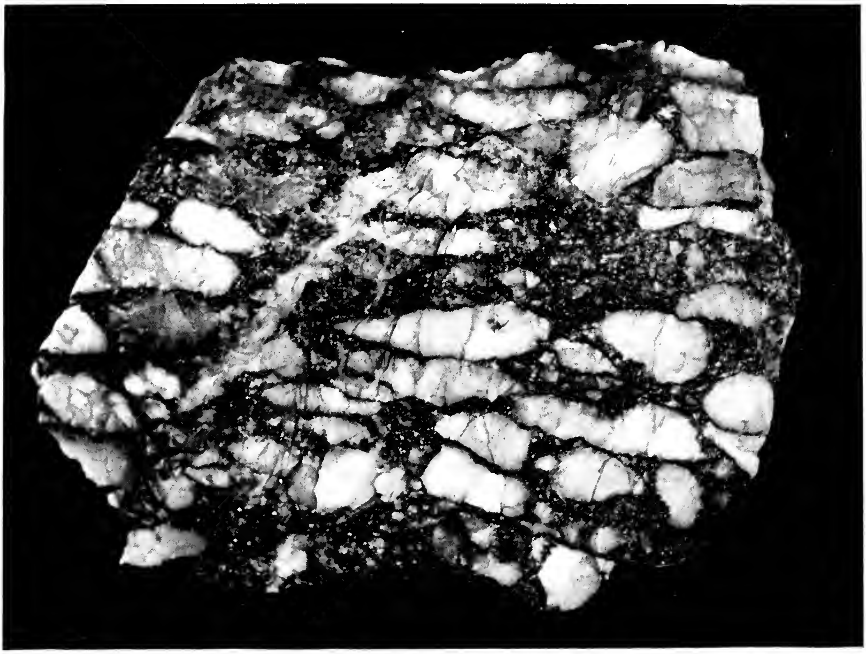

FIG. 1.—Banket from the neighbourhood of a fault in the Robinson Deep Gold Mine. The rock is markedly fissured, and the pebbles drawn out. Diam. × $\frac{2}{3}$.

FIG. 2.—Banket from the Robinson Deep Gold Mine. It is bounded on the right by a fault plane, along which the pebbles are drawn out, clearly indicating the direction of the movement that has occurred. Diam. × $\frac{4}{5}$.

[*Between pp.* 28 *and* 29.

light-coloured mica, and may be pitted with the moulds of crystals of pyrite. When indented contacts are met with in microscopic sections, the local strain induced by pressure in the quartz is often clearly indicated by the strain shadows (Plate V., Fig. 3). It is also common to find a layer of sericite, with which may be mingled some chlorite, pyrite, or rutile, intervening between the two welded surfaces of quartz. This is most probably due to replacement subsequent to indentation. There is no doubt that the indenting is effected by the solution of quartz at the points of contact of the pebbles. As indentation of pebbles is a common feature of conglomerates in general, and has been noted even where the matrix was comparatively loose and incoherent, it is not unlikely that in the banket this process dates back to a period when the rock had not arrived at its present highly compact state (Plate VIII., Fig. 1).

The secondary enlargement of vein-quartz pebbles by a marginal growth of quartz in optical continuity with that of the pebbles is frequently noticeable in microscopic sections (Plate V., Fig. 4). The growth, however, is usually slight and not continuous round the pebbles. A pebble may at one point show loss of substance by indentation, and at another, secondary enlargement. In one instance, in the Robinson Deep Gold Mine, the writer has observed in a small cavity connected with a fault the outward growth of the constituent grains of fractured quartz pebbles to form well-shaped crystals. A specimen of banket from the Simmer Deep Gold Mine showing a similar growth is exhibited in the Johannesburg Museum.

The vein-quartz pebbles are sometimes coloured dark grey or black in their peripheral zones, or in the neighbourhood of their points of contact. This alone would lead one to suspect that the colouring process has to a certain extent operated on the pebbles after their inclusion in the banket. Microscopic examination puts this beyond doubt, and in moderately thick sections of the rock the infiltration of dark-coloured material from the matrix into some of the pebbles, apparently along those parts most affected by pressure, is quite evident. It is not always easy to determine the composition of the infiltrated material, but in some cases dark green chlorite and iron sulphides can be clearly discerned. It is not improbable that the pressure to which the pebbles have been subjected while in the banket has assisted the process of infiltration by re-opening the fracture systems of the vein quartz. It is only in the case of some of the parti-coloured pebbles that definite evidence can be found for assigning the darkening of the colour to so late a date (Plate VIII., Fig. 1).

The occurrence of pebbles of a faint pink or reddish-brown tint in some patches of abnormally rich banket has already been referred to, and the fact that not only fine-grained quartzite pebbles are so coloured, but sometimes the vein-quartz pebbles also, appears, when we add to this the patchy character of the occurrences, to point unmistakably to staining subsequent to the formation of the banket.

The larger or macroscopic cracks of pebbles have often become filled with films of pyrite or of chlorite, and when such cracks are frequent and close, as in some portions of banket, they may affect to a slight degree the colour of the pebbles.

Intersecting systems of narrow or widely-spaced cracks have been developed in the banket. The intensity of this fissuring varies from place to place. The cracks are most evident in the pebbles, and the larger quartz grains of the matrix (Plate XIX., Fig. 1). When one of the systems is more marked than the other, the pebbles are broken into a varying number of slices with more or less parallel surfaces, along which they tend to fall apart on being extracted from the matrix, more especially in the case of the oxidised rock (Plate VIII., Fig. 3). A slight degree of shifting among the segments causes distortion of the pebbles. The fracturing of the associated quartzites appears to be in general less complicated and more widely spaced than in the banket. This is probably due to the greater homogeneity of the former rock.

Distortion of pebbles of a different character to that just referred to is sometimes seen, especially in proximity to faults. The pebbles may be markedly drawn out, as is common in intensely sheared conglomerates, and, if close to a fault, bent in the direction of the movement that has taken place (Plate IX., Figs. 1 and 2). Careful attention to this bending, even where it is very slight, is often sufficient to solve some of the difficult faulting problems that are encountered in the course of mining. Microscopic examination of a vein-quartz pebble thus drawn out and bent showed it to consist of a moderately fine-grained mosaic, in which the quartz grains were full of minute inclusions, except in narrow zones round their margins, which were clear.

On removing pebbles from the matrix their surfaces are sometimes seen to be slickensided at places, probably where they were in contact with other pebbles. Occasionally thin layers of the slickensided quartz are seen to partially overlap each other with a little sericitic mica between. This probably corresponds to the fine-grained schistose quartz and sericite between pebbles frequently revealed by the microscope in thin sections of banket (Plate VIII., Fig. 2).

Bodies erroneously regarded as Pebbles.—" Pyrite pebbles" are sometimes referred to in the literature on the banket. Becker[1] applies this term to the minute rounded grains of pyrite (average diameter 0.1 mm.) that are common in the rock; but the name has been more often given to larger rounded bodies of pyrite, varying in size from that of small shot to that of a marble. However, it is not now seriously contended that these were actually deposited as pebbles in the banket, but it has been suggested that they are pseudomorphs after pebbles of quartz, iron oxide, or other material. Occasionally much larger bodies, several inches in diameter, sometimes composed mainly of pyrite and marcasite, at other times largely of chloritoid, occur, and are regarded as pebbles by miners. The origin of all of these bodies will be considered later.[2]

The Matrix.

The matrix of the banket has undergone considerable metamorphism, and there are grounds for believing that certain of its original constituents have entered into new mineral combinations or suffered other changes which have obliterated the marks of their

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[1] *Annual Report U.S.A. Geol. Surv.*, 1896-97, pp. 166-67.

[2] pp. 44 and 65.

origin. Those minerals that can be clearly demonstrated to be of allogenic origin are naturally of comparatively stable composition. They comprise quartz, zircon, chromite, tourmaline, diamond, iridosmine and platinum.

Quartz.—By far the most abundant, as might be expected from the nature of the pebbles, is quartz. The grains have been affected in varying degrees by processes which tend to destroy their original outlines, but, so far as the latter can be made out, they indicate that the grains were rounded, subangular, and angular in form, the degree of rounding being to some extent proportional to the size of the grain. They occasionally enclose small crystals of zircon and apatite, flakes of biotite, and, more rarely, clusters of long hair-like crystals, too thin to identify with certainty. Doubtless the quartz was derived not only from the rocks represented in the banket by pebbles, but also from granite, gneiss, and other rocks.

Zircon.—Zircon is a fairly constant constituent of the banket, and can be observed in about 20 per cent. of the microscopic sections of the rock. In each of these sections generally only one or two zircons are present, but occasionally there are as many as a dozen. They occur either as well-formed crystals exhibiting prismatic and pyramidal faces, sometimes with rounded edges, or as irregular grains. Their average length is about 0.2 mm., while their thickness is about two-thirds or one-half the length. They are transparent, and vary from colourless to pink, sometimes with a brownish tint. The crystals are occasionally conspicuously zonal in structure (Plate X., Fig. 1).

There is nothing to be observed in their occurrence, such as the interference of any other mineral with their growth, which would make the assumption of an allogenic origin improbable. Instances frequently occur in which pyrite is moulded on zircon, demonstrating conclusively that in some cases at least the zircon was in the rock before the pyrite (Plate XVII., Fig. 4). Occasionally chloritoid is also found moulded on zircon (Plate XVII., Fig. 1).

Zircons are found in the quartzites associated with the banket, but apparently in much less quantity.

Chromite.—Chromite occurs in the banket with much the same frequency as zircon. In section the grains of chromite are usually irregular and rounded in outline, but occasionally they are square or rectangular. Their diameter averages slightly under 0.3 mm. Sometimes in thin sections the chromite is translucent, appearing brown by transmitted light, but it is generally quite opaque. The grains have occasionally the appearance of having been fractured *in situ*, the cracks being afterwards filled with secondary material such as chlorite, quartz, or pyrite. In concentrates from banket the chromite is seen to consist of rounded and irregular grains, with a few octahedra. The mineral has every appearance of being allogenic in origin, its probable source being the ultrabasic rocks of the Swaziland System.

Tourmaline.—As might be expected from the presence in the banket of pebbles composed entirely or in part of tourmaline, fragments of this mineral occur in the matrix of the rock. Tourmaline is, however, often clearly a secondary constituent, and the detrital grains almost invariably show a later growth of the same mineral round their borders. On this account the detailed description of the tourmaline will be given when dealing with the authigenic constituents.

Diamond.—In only one instance has a diamond been reported to have been found *in situ* in banket, but a considerable number have been got in the black sands from the battery mortar boxes.

In 1889 two diamonds were found at the Wolhuter Gold Mine, and the Percy Gold Mine (afterwards amalgamated with the Treasury Gold Mine).[1] The stone from the latter mine was described as being of a light bottle-green colour. Early in 1913 a diamond was found at the Modderfontein "B" Gold Mine. This was a hexoctahedron of a light greyish olive-green colour, and weighed about three-quarters of a carat. The faces were curved and slightly worn. The present writer, into whose hands this diamond came, urged the advisability of subjecting the black sands collected at the various mines to careful examination, and since then some hundreds of stones have been found at the Modderfontein "B" and other mines.

Many years ago numerous diamonds were obtained at Klerksdorp from the "Gold Estates Reef" (Elsburg Series), a fact which was advertised in the name of a company that worked the reef, viz., the Klerksdorp Gold and Diamond Company, Ltd. The diamonds were usually small, averaging from one to two carats, though one of eight carats has been recorded.[2] The

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[1] *Trans. Geol. Soc. S.A.*, vol. i., 1896, p. 30.

[2] Denny, *The Klerksdorp Gold Fields*, London, 1897, pp. 65 and 97-98; see also *Trans. Geol. Soc. S.A.*, vol. i., 1896, p. 30, and vol. iii., 1898, p. 14.

colour of the stones has been variously described as light green, darkish green, and olive green. Mr G. A. Denny states that they frequently occurred as rhombic dodecahedra, but there exists no confirmation of this.

It is noteworthy that the colour, when recorded, of the many diamonds stated to have come from the banket has invariably been green. This should be sufficient to dispel any doubt that might arise as to the genuineness of any of the finds.

It may be considered as certain that the diamonds in the banket were deposited with the pebbles during sedimentation, and the occurrence is interesting as proving that there exists a source of diamonds in the Swaziland System, from which the banket was derived.

Iridosmine and Platinum.—Iridosmine and platinum have for long been known to occur in the Black Reef at Klerksdorp.[1] According to Mr G. A. Denny, metals of the Platinum Group are present in the proportion of 5 grains to the ton of ore, while an analysis mentioned by Mr F. W. Bawden revealed 3 grains of platinum per ton.

The presence of iridosmine and platinum, principally the former, was detected by Mr A. F. Cross[2] in the banket of the Main Reef Series at Modderfontein and at the East Rand Proprietary Mines. At the latter he found as much as 10 dwts. of iridosmine per ton of black sands from the batteries. Metals

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[1] Wilson-Moore, *The Minerals of South Africa*, Johannesburg, 1893, p. 50; Denny, *op. cit.*, p. 66; Bawden, *Trans. Geol. Soc. S.A.*, vol. iii., 1898, p. 13; Watkins, *The S.A. Mining Journal*, May 20, 1912.

[2] *Trans. Geol. Soc. S.A.*, vol. xv., 1912, p. 52.

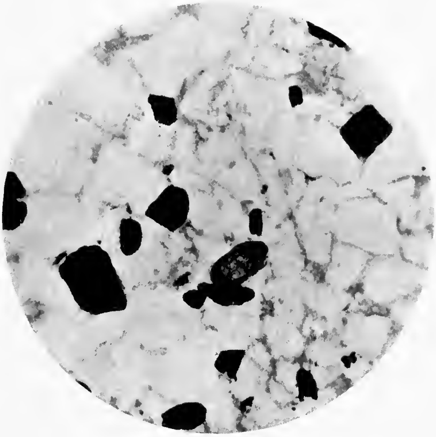

FIG. 1.—Matrix of banket with zircon crystal, showing zonal structure.
Ordinary light ; diam. × 32.

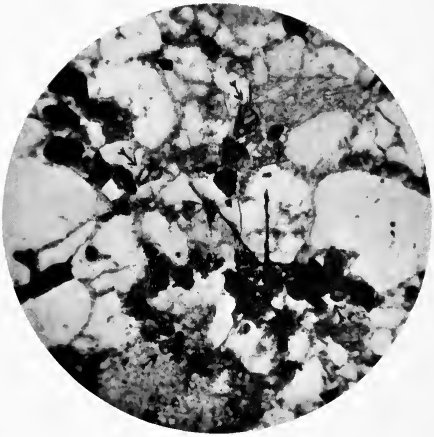

FIG. 2.—Matrix of banket with several small grains of zircon (indicated by arrows).
Ordinary light ; diam. × 22.

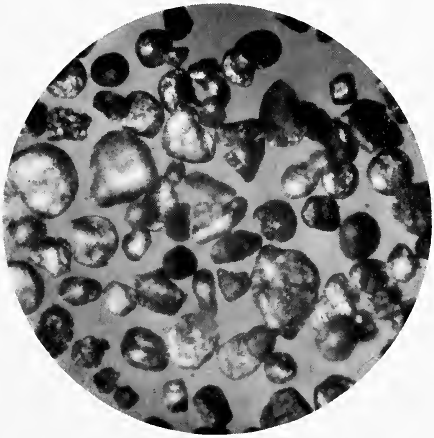

FIG. 3.—Iridosmine from the Eastleigh Gold Mine, Klerksdorp, showing the rounding of the grains.
Reflected light ; diam. × 52.

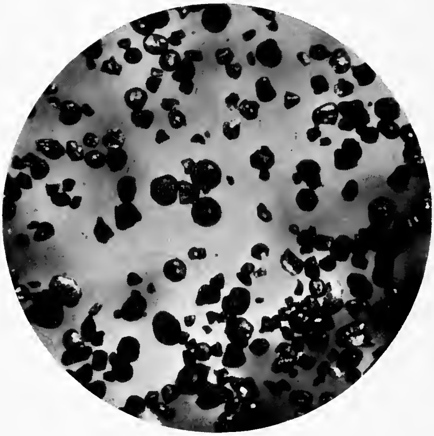

FIG. 4.—Iridosmine from Rietfontein "A" Gold Mine. The hexagonal outlines of some of the grains can be clearly seen. Reflected light ; diam. × 29.

of the Platinum Group have been recorded from the Randfontein Mines.[1]

The earliest description of iridosmine from the banket was given by the writer[2] in 1907, the material examined having been obtained from the Du Preez Series (Main Reef Series?) at Rietfontein. In 1912 attention was again directed to the occurrence in this locality by Mr C. Baring Horwood,[3] who states that about 910 grains of heavy concentrates (mainly iridosmine) were recovered from 102,800 tons of ore. While the impression which these data produce of the extreme rarity of iridosmine in the banket at Rietfontein is doubtless correct, yet there is no reason to conclude that all of the mineral present in the ore was recovered. Mr Horwood is inclined to believe that most of the iridosmine at Rietfontein is contained in a narrow but rich banket bed, characterised by the presence of carbon, and known as the Carbon Leader.

The iridosmine when recovered is mainly in the form of rounded grains, but cleavage flakes, many of them hexagonal, and definite crystals are fairly common. The crystals are somewhat tabular, and show *plus* and *minus* rhombohedra combined with the base. Their edges are invariably rounded, and every stage can be noted, from crystals in which the faces are quite distinct to rounded grains in which one can just trace the original hexagonal form. The average diameter of the grains and crystals is about 0.12 mm. The colour varies from tin-white to steel-grey, and the lustre from splendent to dull (Plate X., Figs. 3 and 4).

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[1] Stokes, etc., *Textbook of Rand Metallurgical Practice*, London, 1912, p. 331.

[2] *Trans. Geol. Soc. S.A.*, vol. x., 1907, p. 17.

[3] *Trans. Geol. Soc. S.A.*, vol. xv., 1912, pp. 51-63.

An analysis of a sample of iridosmine from Rietfontein, made at the Imperial Institute, South Kensington, gave about 45 per cent. of iridosmine.[1] At the same time, a small amount of apparently free platinum was detected in the sample. On a similar sample being subjected to spectroscopic analysis by Dr W. J. S. Lockyer, the presence of ruthenium, iron, and other elements was revealed.[2]

With regard to the origin of the iridosmine, Mr Horwood contends that the mineral was introduced into the banket from the basic dykes by which it is cut. Of the arguments with which he attempts to support this hypothesis, only one might be considered to have any weight, and this rests on a statement by Mr Horwood, quite contrary to fact, to the effect that the iridosmine shows no signs of being waterworn.[3] The microphotographs (Plate X., Figs. 3 and 4) show the typical form of the mineral, which suggests prolonged attrition. The occurrence among the iridosmine of occasional crystals of other minerals exhibiting no trace of rounding, while the hard iridosmine crystals without exemption have rounded edges, disposes of any contention that the rounding was produced during the various processes to which the ore was subjected before the iridosmine was finally extracted.

Though metals of the Platinum Group have been found in a variety of rocks, it would appear that the ultra-basic olivine-bearing rocks are the usual source of the metals in alluvial deposits, and that chromite derived from the same source is the most characteristic

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[1] *Trans. Geol. Soc. S.A.*, vol. xv., 1912, p. 55.

[2] *Ibid.*, pp. 54-55.

[3] *Ibid.*, p. 58; see also *Trans. Geol. Soc. S.A.*, vol. xv., 1912, p. 113.

of the associated minerals. Now, chromite is a normal constituent of the banket, and in concentrates from the Carbon Leader, which Mr Horwood thinks is the principal source of iridosmine at Rietfontein, chromite is very conspicuous once the pyrite is removed. That the chromite is detrital there can be no doubt.

The grounds on which the iridosmine may be considered to be of detrital origin are, then, the rounded form of the mineral grains, and their association with detrital chromite, taken in conjunction with the circumstance that it occurs in conglomerates, where the concentration of heavy minerals would naturally take place.

It seems probable that the iridosmine, like the chromite, was derived from the ultra-basic rocks of the Swaziland System.

Hypothetical Allogenic Constituents.—It is a moot question whether the gold in the banket is mainly of detrital origin or has been introduced into the rock by percolating waters. If the former alternative is correct, then the gold must have undergone subsequent solution and re-deposition, as nuggets and other forms characteristic of placer deposits are entirely absent. It has also been contended that the rounded particles of pyrite in the banket are allogenic. These questions of origin will be discussed in a later chapter.[1]

The apparent absence of both magnetite and ilmenite from the banket and the pyritic bands in the banded pyritic quartzite, in both of which a concentration of heavy minerals such as chromite and zircon has taken place, is remarkable, especially when we reflect on the variety of rocks whose disintegration

[1] pp. 102-117.

contributed to the deposition of the Witwatersrand System, and the fact that in the beds of rivers flowing at the present day through tracts of country composed of the rocks of the Swaziland System, local concentrations of normal black sands are found. If, as seems possible, iron ores were originally present, there may be truth in the suggestion that they have entered into combination with sulphur to form pyrite. The rutile, which is invariably present in banket in patches and isolated crystals, may have been derived from the breaking-up of titaniferous iron ore.

Though grains of orthoclase, microcline, and plagioclase felspars, as well as obvious pseudomorphs after felspar, occur in certain of the quartzites of the Witwatersrand System,[1] the writer has in only one instance observed a grain of felspar in the banket of the Main Reef Series. At the same time there occasionally occur patches of secondary quartz mingled with sericite, that might be interpreted as being pseudomorphous after felspar.

The interstices between the smallest grains of quartz in the matrix, that can with any certainty be considered original, are filled very commonly by a fine-grained mixture of minerals, among which sericite, chlorite, quartz, and sometimes chloritoid are prominent. Some of this might reasonably be regarded as re-constituted argillaceous material.

[1] Young, *Trans. Geol. Soc. S.A.*, vol. x., 1907, pp. 62-64.

CHAPTER III

AUTHIGENIC CONSTITUENTS OF THE BANKET

THE term "authigenic" may be applied to all the constituents of a conglomerate other than those that are of detrital origin. Such constituents may have been introduced into the rock from without, or have resulted from the alteration of allogenic material.

Quartz.—The cementation of the banket has been largely brought about by the precipitation of quartz within its interstices, but the partial obliteration of the outlines of the fragmental quartz frequently makes it difficult to distinguish clearly between this and quartz of later date.

Generally the authigenic quartz presents no features specially worthy of note. Sometimes it occurs as a secondary enlargement of the quartz pebbles or of the fragmental quartz grains of the matrix. Perhaps more frequently it forms fine mosaics mingled with sericite, chlorite, or other minerals. It often partially replaces chloritoid. Occasionally it occurs in a fibrous or columnar form.

The last-mentioned variety of quartz is always found in contact with pyrite that has replaced quartz, sometimes appearing round the borders of crystals, nodules, and irregular growths of pyrite, at other times filling cracks in the same material. When the fibrous quartz forms a border to the pyrite, and is in contact on one side with the quartz grains of the matrix or pebbles, it is frequently found that some of the fibres are continuous with such grains, showing that the growth of the former has proceeded from the outside towards the pyrite, and that the fibrous quartz is an infilling of a cavity. When transverse and longitudinal sections are studied in conjunction, the fibres are very commonly seen to bend, branch, and become entangled with each other in a very intricate manner as they approach the pyrite. In other cases, especially when the quartz is columnar rather than fibrous, these irregularities tend to disappear. When the pyrite is in contact with vein-quartz pebbles there sometimes appears to be a gradual transition of the material of the latter into fibrous quartz. The fibres may be roughly parallel to the bedding of the rock, or they may run independently of this, as when they are more or less perpendicular to the faces of distinct crystals of pyrite. When the latter is the case, the growth of fibrous quartz may occur only on certain faces of the crystals. The circumstances which have determined the formation of this variety of quartz are not at all clear, though in many cases it would appear to be related to the contraction and fracturing of pyrite (Plate XI., Figs. 1-4).

Though, doubtless, the bulk of the authigenic quartz in the banket was introduced in solution from without, yet the source of part of it may have been the detrital quartz itself, as the process of indentation already described as operative in banket, involves partial solution. A considerable amount of silica must, of course, have been brought into solution during the replacement of quartz by pyrite and other

FIG. 1.—Fibrous quartz at the acute ends of two pyritic nodules. The same substance fills a crack in the upper nodule. Nicols crossed; diam. × 15.

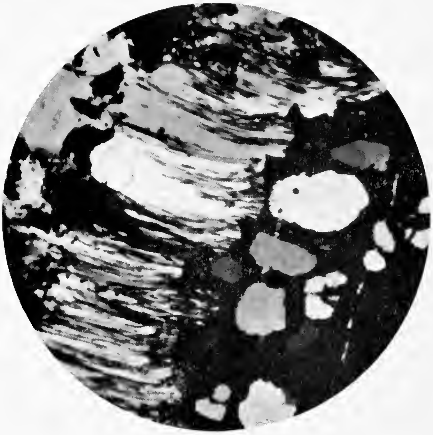

FIG. 2.—Fibrous quartz in a pyritic nodule which encloses quartz grains. The nodule has apparently contracted and torn itself away from the banket matrix (on the left) to which some of its margin is still adhering.
Nicols crossed; diam. × 15.

FIG. 3.—Pebbly quartzite, oxidised, in which are numerous cavities partly filled with iron oxides, the products of the oxidation of pyrite nodules. The cavities are bordered by fibrous quartz, the fibres of which are parallel to the bedding.
Diam. × $\frac{1}{2}$.

FIG. 4.—Coarsely fibrous, or columnar, quartz in contact with well-formed pyrite crystals. Note that the fibrous quartz appears on certain faces only of the crystals. The pyrite replaces the material of a "cherty" or fine-grained quartzite pebble.
Nicols crossed; diam. × 12.

minerals, but these metasomatic processes appear to have acted subsequent to the complete cementation of the banket.

Chloritoid.—Chloritoid is a common though not invariable constituent of banket. It is also found in some of the associated rocks, such as the banded pyritic quartzite, the dark slaty-looking rock frequently found underlying the Main Reef Leader, and the much sheared portions of quartzites and basic intrusions.

In the banket it occurs in small irregular plates, averaging about 0.5 mm. in diameter, and about a tenth of that in thickness. Generally in thin sections the mineral appears in lath-like forms, in which can be distinguished the basal cleavage and another less perfect at right angles to this. When the chloritoid is cut approximately parallel to the base, it shows cleavages intersecting each other at about 60°. The presence of these is sufficient to distinguish the mineral from ottrelite.[1] In thin sections it is almost colourless, or has a greenish tint, in which latter case it may exhibit a slight pleochroism. Between crossed nicols the characteristic twinning is revealed. It is frequently found in isolated crystals, but also commonly in clumps of crystals, which may have a sheaf-like or fan-shaped arrangement. Occasionally the crystals are bent (Plate XII., Figs. 1 and 2).

The appearance of the chloritoid is much affected by partial replacement by quartz. Owing to this change the crystals become ragged in outline. The replacement is often well marked along cleavage planes, and it is not uncommon to find a crystal

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[1] See Iddings, *Rock Minerals*, p. 440, and Dana, *A System of Mineralogy*, pp. 640-42.

broken apart into several ragged segments which retain their original orientation. Sometimes the original crystals are represented only by groups of residual particles of the mineral lying in quartz, and doubtless complete replacement has often occurred. Occasionally the chloritoid appears as if partially or wholly replaced by chlorite, but in such cases the correct interpretation may be that the chlorite has taken the place of quartz which had previously replaced chloritoid (Plate XII., Figs. 3 and 4).

The determination of the relations of the chloritoid to the other minerals of the banket is very useful in unravelling the sequence of mineral changes in the rock. The growth of the chloritoid has been mainly at the expense of the quartz, which it appears to replace most easily where the grains are small. On the other hand, the chloritoid crystals have been effectively obstructed by zircon and pyrite, though generally the latter mineral was precipitated subsequent, not only to the formation of chloritoid, but also to its partial replacement by quartz (Plate XVII., Figs. 1 and 2).

Variously shaped bodies with rounded outlines, several inches in longest diameter, and composed in great part of chloritoid but also containing quartz, chlorite, and pyrite, are occasionally met with in the Main Reef Leader. They have a concentric structure, the various shells being distinguished mainly by the different proportions they contain of the minerals just mentioned. With regard to the origin of these bodies, it is difficult to find an explanation that is consistent with all the facts, but it seems significant that they have been found only in the Main Reef Leader, which is underlain by an altered argillaceous bed, and there is considerable plausibility in the theory

PLATE XII.

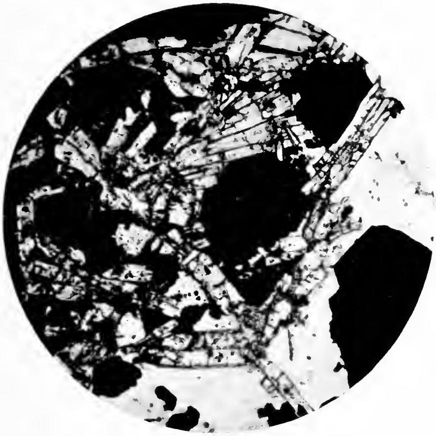

FIG. 1.—Cluster of lath-like sections of chloritoid. Traces of two cleavages at right angles to each other may be discerned. The chloritoid is partly imbedded in pyrite which has replaced quartz. Ordinary light; diam. × 57.

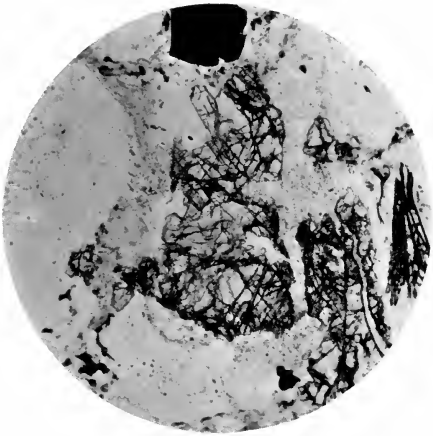

FIG. 2.—Approximately basal section of chloritoid, showing cleavages intersecting at 60°.
Ordinary light; diam. × 57.

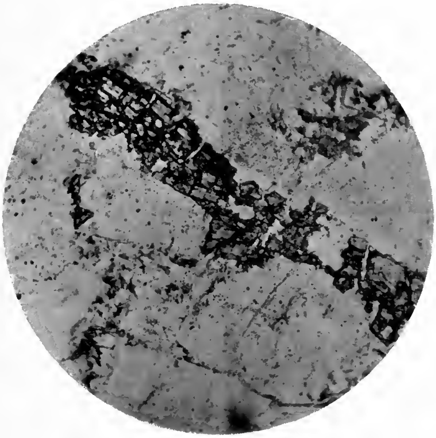

FIG. 3.—Chloritoid crystal partly replaced by quartz.
Ordinary light; diam. × 57.

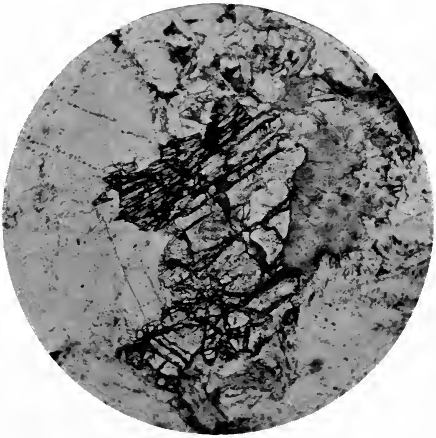

FIG. 4.—Chloritoid apparently replaced by chlorite (see p. 44).
Ordinary light; diam. × 57.

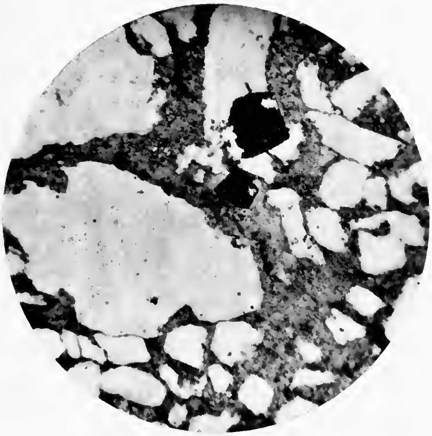

FIG. 1.—Typical fine scaly aggregate of chlorite replacing quartz. The dark mineral is pyrite.

Polarised light ; diam. × 22.

FIG. 2.—Relatively coarse, scaly aggregate of chlorite replacing quartz ; also a dolomite rhomb.

Polarised light ; diam. × 66.

FIG. 3.—Relatively coarse crystalline aggregate of chlorite, showing the basal cleavage and replacing quartz. The dark mineral is pyrite.

Polarised light ; diam. × 66.

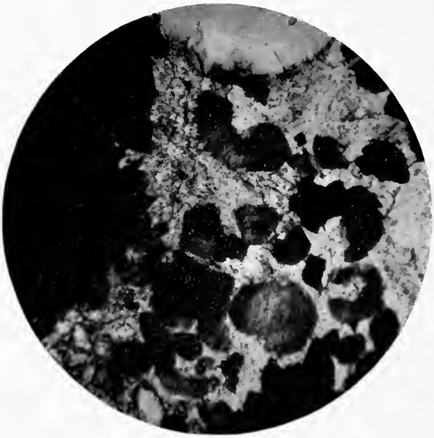

FIG. 4.—Vermicular chlorite in dolomite which is replacing quartz. The dark mineral is pyrite.

Polarised light ; diam. × 66.

that the bodies are pieces of this bed that were caught up and rolled by the current in which the overlying conglomerates were deposited. That the argillaceous bed was disturbed during the deposition of the Main Reef Leader is frequently very evident from an examination of the contact of the two beds.

Chlorite.—Members of the chlorite group are of common occurrence in the banket and associated quartzites. That they vary in composition is evident from the differences they exhibit in colour, pleochroism, interference colours and crystalline habit. However, no detailed study with a view to establishing their identity has been undertaken. They occur most frequently as aggregates of fine scales, but also in distinct individuals of relatively large size. Occasionally vermicular aggregates are met with. They are coloured different shades of green, varying from a very faint coloration through a moderately intense dull green to bright emerald. They are pleochroic in varying degree, the colours exhibited being shades of green and yellow. The interference colours are very low; sometimes the indigo-blue of penninite can be seen (Plate XIII., Figs. 1-4).

Chlorite is most conspicuous within the banket in the vicinity of basic intrusions. So invariably is this the case, that in the course of driving, or other mining operations, the approach to a dyke may be safely deduced from the darkening of colour of the banket or associated quartzites, due to the presence of chlorite. This rise in the amount of chlorite is usually accompanied by an increase in the quantity and variety of sulphides present. Where replacement of quartz by calcite or dolomite occurs in the banket, chlorite is always conspicuous. Microscopic examination proves conclusively that the chlorite has replaced quartz, the matrix naturally suffering more than the pebbles, which are, however, frequently deeply indented by the chlorite (Plate XIII., Figs. 1 and 3).

A most remarkable instance of wholesale replacement of rock by chlorite is to be seen in the eastern section of the Rose Deep Gold Mine. Between the eighth and ninth levels of that mine there has been partially exposed a replacement of banket, mainly South Reef Leader, and the associated quartzites by a mixture of chlorite and sericite. The full dimensions of the replacement body cannot be given, but the portion exposed and partly worked out is, roughly, a rectangle extending about 170 feet along the strike, and 60 feet on the dip, which here averages about 30°. At the western limit of the body, which is visible, the thickness of the rock replaced is approximately 3 feet, while at the furthest point exposed to the east it has increased to about 8 feet. Some small dip faults occur in this area, the maximum vertical displacement observed being only a few inches.

The altered rock has the appearance of a soft compact clay and is coloured a dull green by the chlorite which is the predominant mineral, though, on examining it closely, it is seen to be dotted throughout by light grey patches of sericite. On being immersed in water it almost immediately disintegrates and collapses. There is a sharp passage from this soft material to hard rock, on which the hammer rings. On microscopic examination, however, the hard rock shows a certain amount of replacement by chlorite and sericite, while the soft material contains at places numerous small cores of hard partly altered banket and quartzite.

The South Reef Leader, which is the body principally affected, frequently consists in this portion of the mine of several bands of conglomerates separated by quartzite. The latter rock, owing doubtless to the less amount of fracturing, evidently offered greater resistance than the banket to chloritisation, and reveals itself among the soft material as somewhat continuous less altered bands.

The chloritisation has been accompanied, not only by the production of sericite, but also by partial solution of pyrite and the substitution of anatase for rutile.

Deviations from the normal course of alteration are met with, *e.g.*, a tough, highly porous, and dark coloured variety of chloritised rock occurs, which on microscopic examination is seen to consist of a fine network of chlorite with a little sericite and scattered pyrite and anatase crystals. The pyrite crystals are well formed and show no signs of corrosion. The rock is apparently an altered quartzite, which in the later stages of change has had the remains of the quartz grains dissolved out without replacement. The pyrite and anatase were probably introduced from without.[1]

Muscovite.—Muscovite, sometimes in fairly large flakes, but more often as sericitic aggregates, appears to be a constant constituent of banket. It is generally colourless but occasionally the larger flakes have a faint greenish-yellow tint and are pleochroic. It is sometimes present in large amount, and is then quite obviously a replacement of the quartz of the matrix and pebbles (Plate XIV., Fig. 1). In the chloritic replacement at the Rose Deep Gold Mine, referred to above, patches of sericite are very frequent, as well as

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[1] See pp. 50-52.

isolated foils of muscovite, which average about 2.0 mm. in diameter. Similar foils occur in the banket adjoining the replacement body. Banket abnormally rich in gold shows very commonly a marked replacement by muscovite.

A portion of the muscovite in the banket was probably derived from felspathic material originally present in the rock. However, when the muscovite is present in large amount and is a replacement of quartz, it was doubtless, like the chlorite occurring similarly, precipitated from solutions which entered the rock from outside.

Tourmaline.—The frequency with which tourmaline occurs in the banket may be measured by the fact that the mineral is found in about 15 per cent. of the microscopic sections in the writer's collection. Some of the grains in the matrix are of detrital origin, as is evident from the outlines which they display. This was to be expected from the occurrence in the rock of tourmaline-bearing pebbles. Much of the tourmaline, however, is of authigenic origin, as is demonstrated by the form of the grains and their relation to the other associated minerals. The grains vary in size, but their longest diameters seldom exceed 0.5 mm. In colour they are generally brown or green in the centre and blue round the margin, the finer needles, however, being invariably blue. Sometimes the grains consist of more than one crystalline individual, the boundaries between the different individuals being generally blue. The occurrence may consist of a cluster of close or scattered fine needles lying in the normal matrix of the rock. Occasionally the tourmaline is moulded on another mineral, such as chloritoid. From the borders of what are apparently fragmentary grains, a secondary growth of fine needles frequently projects into the surrounding matrix. Tourmaline is usually present in abnormal amount in intensely sericitised rock, and is often closely associated with coarse gold (Plate XIV., Figs. 2 and 3).

Tourmaline also occurs in veins in the banket. These will be described in a later chapter. It may be mentioned here, however, that they are largely of metasomatic origin, and that in the interior of the rock penetrated by the veins there occur numerous small patches of tourmaline needles, having a radiate arrangement.

Rutile.—In descriptions of the microscopic features of the banket reference is sometimes made to the presence of leucoxene. The material thus named is plentiful in the rock, and occurs in fine aggregates, yellow, brown, and occasionally grey in colour. When not highly magnified it appears to be opaque or almost so, but is easily distinguished in reflected light from the other opaque minerals present. The cores of the aggregates are generally darker in colour and coarser than the marginal layers. When highly magnified the material is seen to be translucent and doubly refracting, and the marginal portion can sometimes be made out to be composed of a loose aggregate of minute rutile needles, about 0.01 mm. in length. Sometimes a little secondary quartz lies between the outer layer and the core. The patches have an average diameter of about 0.3 mm., and are generally moulded on grains of quartz, pyrite, or other minerals, or lie embedded in fine mosaics of secondary quartz (Plate XIV., Fig. 4).

Grains of this material, on being isolated, were found to resemble rutile in lustre, colour, and fracture.

In some cases the marginal layers of these isolated grains broke away from the core, but both core and crust gave strong titanium reactions. No evidence of the presence of calcium or silica could be obtained, and it is probable that it consists throughout of rutile.

The aggregates seem to be almost entirely confined to pyritic rock, and not scattered throughout the associated quartzites barren of pyrite. They are plentiful in the banded pyritic quartzite. This distribution gives some support to the hypothesis that among the detrital matter originally deposited among the pebbles of the banket, and in the layers now represented by pyrite bands in some of the quartzites, titaniferous iron-ore was included, and that from this mineral the rutile was afterwards derived.

Apart from the fine rutile aggregates just described, small clusters of minute rutile needles, as well as isolated individuals and characteristic twins, can be detected in almost any microscopic section of the normal banket (Plate XIV., Fig. 3). Occasionally the mineral occurs in the network known as sagenite.

There can be no doubt that the bulk of the rutile in the banket is of authigenic origin.

Anatase.—In the description[1] previously given of the chloritic replacement of banket and quartzite, reference was made to the substitution of anatase for rutile. The anatase does not occur as pseudomorphs after rutile, but as well-formed tetragonal crystals, which may be roughly described as acute bipyramids. The regularity of the faces is frequently spoilt at places by chlorite or sericite, on which they have grown. They vary in length from 1 mm. to

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[1] pp. 46-47.

one-sixth of that, the average lying midway between these extremes. By reflected light they are a deep indigo-blue in colour, rarely yellow. The lustre is adamantine. By transmitted light they are most of them blue, a few yellow, and some of them partly blue, partly greenish-yellow. In polarised light they are pleochroic in different shades of blue and yellow. Very many of the crystals are partially or wholly opaque (Plate XV., Fig. 1).

Owing to the nature of the altered rock, the anatase can be obtained easily in considerable quantities in a pure state, and without injury to the crystals.

A detailed description of the crystals has been given by Mr W. von Bonde[1] from material supplied by the writer. The forms observed in the crystals are (111), (101), (001), (1.1.14), (117), (331), (5.5.11), and (021). From the distribution of the faces von Bonde is led to suspect that "anatase may not have the tetragonal holohedral symmetry of class 15 hitherto assigned to it."

As the mineral is not pseudomorphous after rutile, and is found, not only in altered banket, but also in what was originally quartzite, practically free from the rutile, it would appear that the rutile was entirely taken into solution, and the anatase either subsequently or contemporaneously precipitated.

Though, in many instances of the natural occurrence of titanium oxides, the factors that determine which of the three modifications, rutile, brookite, and anatase, should be precipitated from solution remain obscure, there can be little doubt that in this case they were of a purely chemical nature. The fact that all three forms have been obtained artificially by the same

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[1] *Trans. Roy. Soc. S.A.*, vol. vi., pt. 3, 1915, pp. 299-303.

process, but at different temperatures, might suggest that the varying occurrences of titanium oxide in rocks was due to temperature limits; but Koenigsberger,[1] after a careful study of sericite and mica schists of the Alps, where all three modifications occur, inclines to the belief that in that instance the determining factor was the presence of other chemical compounds in the titanium solutions, *e.g.*, magnesium silicate when anatase was formed. This supposition would be quite in accord with the occurrence at the Rose Deep Gold Mine.

Calcite.—Extensive replacement of banket and associated quartzite by calcite has been observed in the Paarl Central Gold Mine, and the Meyer and Charlton Gold Mine. In each case the rock affected by the alteration extends for several hundred feet along both the dip and the strike. In the calcified areas there exist numerous fissures along some of which a certain amount of faulting has occurred. In the rock outside the main calcified body replacement may be observed for about an inch on either side of narrow fissures from which water is issuing. Though the quartzites are to a certain extent altered, it is the banket that is principally affected, owing probably to the greater permeability of the latter rock produced by fracturing. Much of the banket is wholly replaced by calcite, no quartz being left, but in some portions of the rock, while the quartzitic matrix is replaced, the pebbles are only partially calcified. Occasionally the pebbles show almost no trace of alteration. The calcite is frequently stained by ferric oxide. Calcite veins occur, especially along fault planes.

On microscopic examination the replacing calcite

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[1] *Economic Geology*, vol. vii., 1912, p. 697.

FIG. 1.—Muscovite in matrix of banket. The dark mineral is pyrite.
Ordinary light; diam. × 59.

FIG. 2.—Tourmaline (dark) moulded on chloritoid crystals, which have previously been partly replaced by quartz.
Ordinary light; diam. × 59.

FIG. 3.—Tourmaline, rutile and muscovite in matrix of banket. The radiate clump of crystals is tourmaline. The brown rutile crystals have come out black in the photograph.
Ordinary light; diam. × 138.

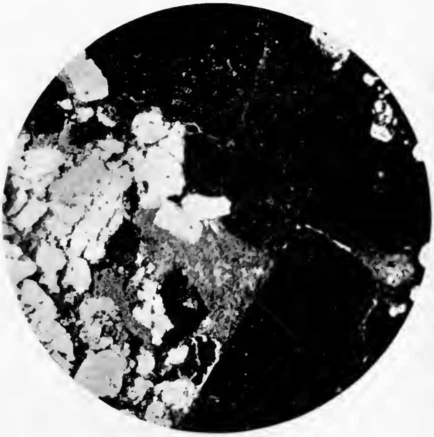

FIG. 4.—Matrix of banket as seen by reflected light. The white patches are pyrite; the speckled, granular rutile; and the black, quartz. Diam. × 28.

FIG. 1.—Crystals of anatase from banket replaced by chlorite and sericite. Rose Deep Gold Mine.
Reflected light; diam. × 15.

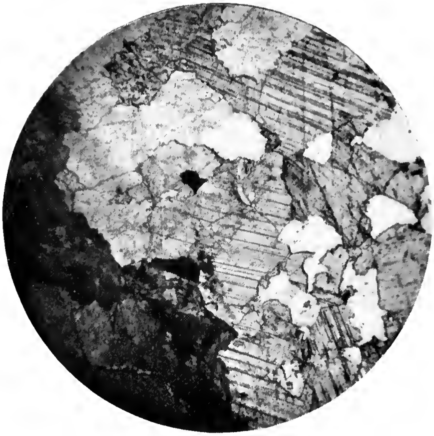

FIG. 2.—Banket, showing replacement of quartz by calcite. The remnants of the quartz, which can be distinguished from the calcite by the absence of cleavage, are portions of one crystalline individual. Meyer and Charlton Gold Mine. Ordinary light; diam. × 12.

FIG. 3.—Banket from the Meyer and Charlton Gold Mine. The quartz, except in the heart of some of the pebbles, is replaced by calcite. Towards the top the rock is traversed by a vein of calcite. The dark colour of the matrix is due to abundant chlorite. Diam. × $\frac{4}{5}$.

is seen to be coarse-grained, showing frequent and well-marked lamellar twinning. Several individuals of calcite may replace a single individual of quartz, and, on the other hand, several individuals of quartz may be replaced by a single individual of calcite. In the replacement of the matrix the calcite grains formed are generally smaller than in the case of the pebbles. In sections which show remnants of unaltered quartz within the pebbles, no quartz appears in the matrix. The grains of pyrite, which are unaffected, are sometimes partially or wholly enclosed in calcite, but more generally they are surrounded by a mixture of chlorite and sericite. The latter minerals are abundant in the altered matrix, frequently occurring in large irregular patches (Plate XV., Figs. 2 and 3).

A portion of the banded pyritic quartzite of the Meyer and Charlton Gold Mine is calcified. In the pyritic bands of the altered rock there is an abundance of chlorite with a little sericite. In the non-pyritic bands large individuals of calcite have each replaced groups of quartz grains, the original outlines of which are still roughly indicated by lines of chlorite enclosed in the calcite (Plate XVI., Fig. 1).

A slight replacement of quartz by calcite is occasionally observable in banket from other localities than those mentioned above.

In no case has the calcification of the banket had any appreciable effect on the gold content.

Dolomite.—Dolomite, replacing quartz, is occasionally met with in the banket. Under the microscope it is easily distinguished from calcite by its tendency to form rhombohedral crystals and by the absence of twinning. It usually occurs in rock showing marked replacement of quartz by chlorite, pyrite, and frequently pyrrhotite (Plate XIII., Figs. 2 and 4).

Carbon.—The first occurrence of carbon in the banket and associated quartzites to attract attention was that in the Buffelsdoorn Gold Mine near Klerksdorp, to which reference was made by M. Jules Garnier[1] and Mr Munnik[2] in 1895. Since then it has been shown to be of wide distribution. In 1909 the author gave a detailed description of the substance.[3]

Carbon has been observed in banket from the following mines: Rietfontein "A" (Du Preez Series), Crown Deep, Van Ryn, Cason, Simmer and Jack, May Consolidated, Meyer and Charlton, Durban Roodepoort Deep, N. Randfontein, Robinson Randfontein, Bon Accord (Greylingstad), Buffelsdoorn, Machavie (Black Reef), and Orion (Black Reef).

The form in which the carbon commonly occurs is that of small, black, opaque, spheroidal or nodular grains, having a somewhat warty, dull outer surface, but lustrous on the surface of fracture, and ranging in diameter from about 1 mm. downwards. Sometimes, as in the Buffelsdoorn specimens, the grains as they increase in number blend together into vein-like compact masses, which are anthracitic in appearance. The veins are sometimes over half an inch thick. Still another form is met with at Rietfontein, where it occurs not only in granules but also in veinlets with

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[1] *C.-R. Soc. Géogr. Paris*, 1895, pp. 277-279, quoted in *Trans. Geol. Soc. S.A.*, vol. i., 1896, p. 124.

[2] *Trans. Geol. Soc. S.A.*, vol. i., 1896, p. 31.

[3] *Trans. Geol. Soc. S.A.*, vol. xii., 1909, p. 86; see also vol. xiii., 1910, pp. 105-106, and Pres. Address, *Proc. Geol. Soc. S.A.*, 1911, p. xxv.

a columnar structure, the columns being perpendicular to the walls of the veinlets. In one of the writer's specimens the thickness of the veinlets varies from 2.0 mm. to 1.5 mm., while the columns are about 0.5 mm. thick, and of variable form in cross section. Between the columns there are generally present very thin films of sericite. Occasionally the carbon occurs in very minute particles, mixed with sericite material, and has then a sooty appearance.

The hardness of the carbon lies between 2 and 3, and the specific gravity is about 1.5.

With regard to the composition of the substance, the author obtained from Dr James Moir, Chemist to the Mines Department, the following report on an impure specimen occurring as a vein in the Buffelsdoorn Gold-mine:—

"On submitting to destructive distillation, only water containing H_2S and suspended sulphur were obtained, and the gases were CO and CS_2. Only a trace of sulphuric acid and of arsenic was obtained.

"The following is the approximate composition of the sample as given by analysis:—

	Per cent.
Carbon	34.2
Silica, insoluble	23.1
Iron pyrites	20.8
Aluminium silicate ash	10.0
Combined water	11.9
	100.0

"The carbon is remarkably resistant to heat, but is not graphitic. Lime and magnesia are practically absent from the ash."

Of another sample he wrote:—

"Extraction with organic solvents gave only a very small trace soluble, viz., 0.22 per cent., which was found to be sulphur. There is no bituminous or hydrocarbon constituent. On heating, no certain evidence of tar or coal-gas was obtained."

In this sample Dr Moir found traces of cobalt arsenide, titanic acid, and gold.

The distribution of carbon in the rock can be best studied at Rietfontein, Buffelsdoorn, and Randfontein.

Though carbon is present in all the reefs worked at Rietfontein, it is most conspicuous in the Carbon Leader and the Buckshot Reef. The former is in quartzite, and varies in thickness from a mere streak to 2 or 3 inches. A few scattered pebbles may occur in it. The carbon, which is of assistance in indicating the payable body, may be confined to a single plane, apparently coinciding with the bedding, or may be scattered through 2 or 3 inches of rock. Occasionally it lies along planes oblique to the bedding. It most commonly occurs in the granules already described, or as a soot-like deposit, though sometimes it is found as distinct veinlets having a columnar structure. The Buckshot Reef is characterised by the presence of small spheroidal nodules of pyrite, known as "buckshot." Like the Carbon Leader, it may be a mere line, but more generally it consists of a layer of single pebbles, though it may swell out to as much as 4 inches in thickness. The occurrence of carbon is much the same in this reef as in the Carbon Leader.

The Buffelsdoorn or White Reef is a quartzite with occasional narrow stringers of quartz pebbles. The footwall is not well defined, while there may be said to be no hanging wall, the width stoped varying within wide limits. The carbon appears in the ore about a foot above the footwall, mainly as granules which are irregularly scattered through a varying thickness of rock, but also in the veinlets already referred to. The latter have no defined direction, though they are generally more or less parallel to the strike. They occasionally show traces of shearing.

In the bankets of the Main Reef Series carbon is not generally conspicuous. It has, however, been observed in several of the mines, as will be seen from the list previously given. Except at Randfontein, where it sometimes occurs as distinct veinlets with columnar structure, the carbon is in the typical form of granules. These usually lie scattered along irregular planes in the banket. The carbon, however, is generally visible in the rocks over areas of very limited extent. In one instance, in the Simmer and Jack Gold Mine, it occurs in a very rich but narrow shoot, which runs through very poor rock and is defined by a system of parallel fissures. At Randfontein carbon is comparatively common, and its mode of occurrence there is somewhat similar to that at Rietfontein.[1] In some cases carbon has been proved by analysis to be present in ore from the Main Reef Series, when it was not apparent to the eye.[2]

The carbon in the banket occurs principally in the matrix of the rock, and only very rarely in the pebbles. In the matrix it is common to find the relations of the carbon to the quartz such as to suggest that the latter had been partially replaced by the former (Plate XVI., Fig. 3). However, the quartz in the matrix has almost invariably undergone

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[1] A detailed description of the reefs at Rietfontein and Randfontein is given by Mr Horwood, *Trans. Geol. Soc. S.A.*, vol. xiii., 1910, p. 67.

[2] Horwood, *op. cit.*, p. 75; see also Croghan, *Jour. Chem. Metal. and Min. Soc. S.A.*, vol. xi., 1910, p. 157.

a certain degree of recrystallisation, and, as this may have been brought about subsequent to the inclusion of the carbon in the rock, no reliable conclusions can be drawn from the relations of these minerals. It is not so when the carbon occurs in the pebbles.

The author has observed carbon in the pebbles in specimens of banket from the Meyer and Charlton Gold Mine, and the Bon Accord Gold Mine. In both cases the matrix contained an unusual amount of carbon, mostly in the usual granular form. In the specimen from the Meyer and Charlton Gold Mine, only a few grains of carbon are noticeable in the pebbles, which are of white vein-quartz. In the specimens from the Bon Accord Gold Mine, carbon is conspicuous on the fractured surfaces of quite a number, mostly of the cherty pebbles (fine-grained quartzite), which are sometimes banded, but also in a few of the white vein-quartz pebbles. The carbon principally occurs as rounded particles, which are embedded in the material of the pebbles, generally in the neighbourhood of the minute cracks which traverse all the pebbles of the banket. The material can be picked out of the pebbles leaving behind distinct pits, and is not a filling of the cracks, though narrow irregular veinlets traversing both matrix and pebbles also occur.

A microscopic section made of one of the fine-grained quartzite pebbles was found to pass through a number of the carbon bodies, ranging in diameter from about 1.0 mm. to about a tenth of that. The material in which they are imbedded is identical in composition and structure with that composing the rest of the pebble, and under the microscope appears as a very fine mosaic of quartz grains (Plate XVI., Fig. 2). There is some pyrite in the pebbles, and occasionally a narrow zone of this mineral surrounds the carbon grains. In most cases there is a very narrow empty space between the pyrite and carbon, which are in actual contact only at places. In one instance there is not only a ring of pyrite surrounding the carbon but also another within the carbon itself.

It might be contended that the carbon has replaced some other substance previously imbedded in the pebble, or that it has merely filled pre-existing cavities, but the shape of the carbon grains is against both of these suppositions. The grains, whether they occur in pebbles or matrix, and from whatever locality derived, have most frequently a warty, almost botryoidal form, which is best seen in microscopic sections. Cracks are often seen passing in from the outside, but seldom or never persisting to the centre of the grains. There is no other known constituent of the unoxidised banket possessing such a form, which the carbon might be imagined to have replaced ; nor does it seem at all probable that cavities of this particular shape ever existed in great numbers in the banket and associated quartzites. The most natural conclusion, then, is that we have here a replacement of quartz.

The radially disposed cracks, which many of the particles show in section, and the empty spaces between them and the zones of pyrite by which they are occasionally surrounded, seem to indicate contraction, and thus suggest the loss of certain of the original constituents. It cannot, therefore, be assumed that the analysis of Buffelsdoorn carbon given above represents the original composition of the substance.

Carbon in banket or in quartzite is very frequently accompanied by an unusually high gold content, the gold being often visible to the naked eye. It is not unusual to find gold lying as films on the surface of the carbon granules and in still larger quantity, both as films and as hackly particles, in the enclosing rock in close proximity to the carbon. When the latter occurs in the form of columnar veins, gold is found on the surfaces of the columns and in the sericitic partings between them. The coarse veins at Buffelsdoorn are sometimes very rich in gold. In all such cases there can be no doubt that the gold was precipitated by the reducing action of carbon or hydrocarbons. It must not, however, be supposed that a marked association of gold with the carbon is invariably the case. In the Buffelsdoorn Reef, for instance, the distribution of the carbon is more extensive than that of gold, which is confined to definite zones within the carbon-bearing rock.[1]

It was for long assumed that the carbon had a similar origin to coal, by which name it was known, and that it represented vegetable matter which had been deposited with the sediments in which it lay. This supposition has been made to play a very important part in theories regarding the mineralisation of the banket. In 1909, the author[2] expressed a doubt as to its being an original constituent of the rock, and the further study of the occurrence of the carbon has made it clear that it cannot be regarded as the residue *in situ* of vegetable or animal matter, but that it was deposited where we now find it at a later date from some liquid which has penetrated the minutest cracks of the rocks. The substance has in the course of time lost some of its original constituents. It might even be hazarded that it was at one time a solid bitumen, such as occurs in veins in

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[1] Denny, *The Klerksdorp Gold Fields*, London, 1897, p. 88.

[2] *Trans. Geol. Soc. S.A.*, vol. xii., 1909, p. 86.

PLATE XVI.

FIG. 1.—Banded pyritic quartzite with quartz replaced by calcite. Note that several grains of quartz (outlines indicated by chlorite) are replaced by one crystalline individual of calcite, clearly defined by the cleavage cracks. Meyer and Charlton Gold Mine.
Ordinary light; diam. × 12.

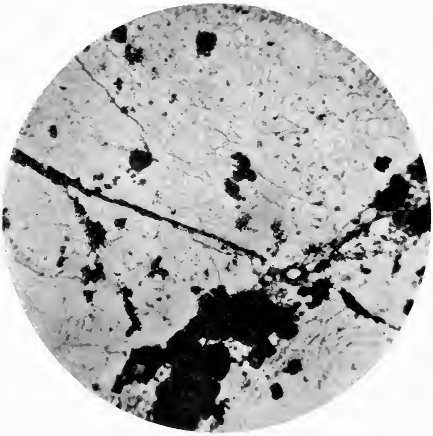

FIG. 2.—Portion of fine-grained quartzite pebble containing carbon. The veinlet is composed of pyrite, which is also associated in small quantity with the carbon. Bon-Accord Gold Mine.
Ordinary light; diam. × 22.

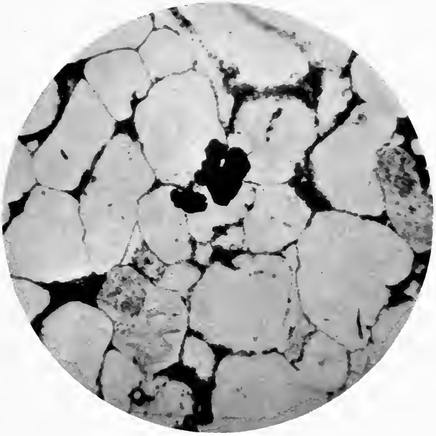

FIG. 3.—Matrix of banket, showing partial replacement of quartz grains by carbon (near centre). Bon-Accord Gold Mine.
Ordinary light; diam. × 22.

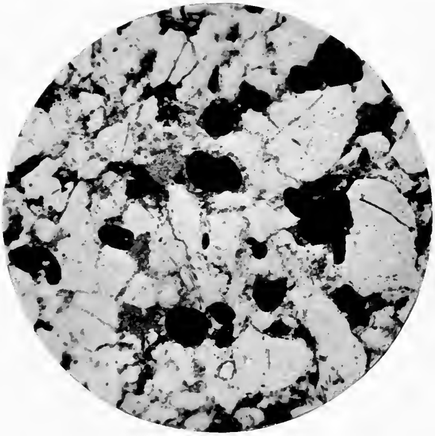

FIG. 4.—Matrix of banket containing numerous rounded grains of pyrite.
Ordinary light; diam. × 22.

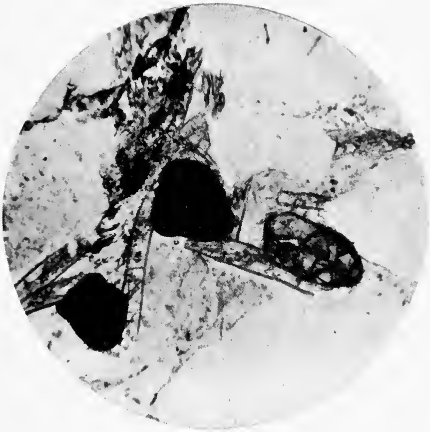

FIG. 1.—Chloritoid crystals moulded on zircon and rounded grains of pyrite.
Ordinary light; diam. × 59.

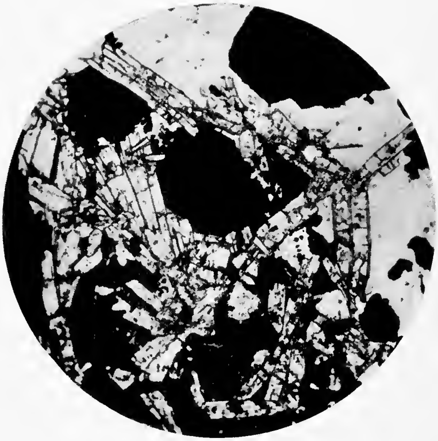

FIG. 2.—Pyrite replacing quartz and moulded on chloritoid.
Ordinary light; diam. × 56.

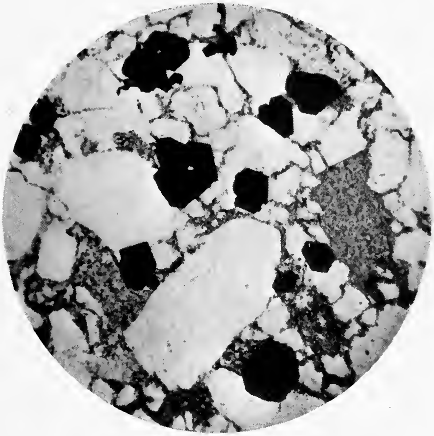

FIG. 3.—Matrix of banket containing well-formed crystals of pyrite partly replacing quartz grains.
Ordinary light; diam. × 12.

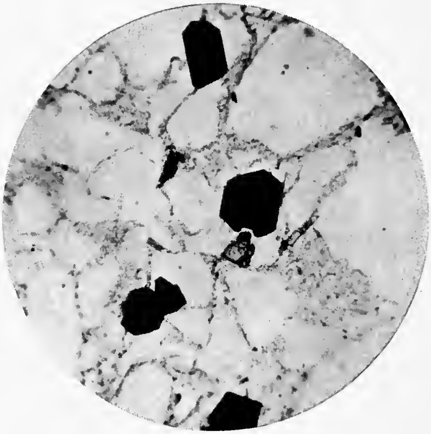

FIG. 4.—Pyrite crystal moulded on zircon. Between the two minerals lie some flakes of colourless sericite.
Ordinary light; diam. × 24.

[*Between pp.* **60** *and* **61**.

other parts of the world. Mr Horwood[1] has shown that carbon occurs in small quantities in certain basic dykes intersecting the banket at Rietfontein and Randfontein, and, reasoning largely from this, he comes to the conclusion that it was originally an emanation from these intrusions before their final solidification. While this is most likely the case, it does not necessarily follow from the evidence available, for, assuming some other source, the liquid from which the carbonaceous material was probably derived might easily have penetrated the dykes as well as the sedimentary rocks.

Other Carbonaceous Matter.—Some years ago, a carbonaceous substance of a very different character from that just described was found at places in a parting between the Main Reef and Main Reef Leader at the Rose Deep Gold Mine. It is almost umber-brown in colour, with a resinous lustre, and was variously known in the mine as "sealing-wax" and "pitch." A specimen of this material was submitted by the author to Dr J. Moir, who made the following report on it:—

"The sample is lustrous and gives a russet-brown powder. Contrary to previous carbonaceous deposits from the banket, this one is mostly hydrocarbon, about 12 per cent. being soluble in alcohol (yellow fluorescent gum, resembling the anthracene fraction of coal-tar); 60 per cent. (insoluble in alcohol) is soluble in CS_2, and is a lacquer-like brittle hydrocarbon melting at 150° to 160° C. The balance of 26 per cent. is insoluble in organic solvents, and is roughly two-thirds organic and one-third ash of a clayey nature. The main product does not correspond

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[1] *Op. cit.*, pp. 76-81.

exactly with any of the text-book descriptions of natural hydrocarbons, and may possibly be an oxygenated body."

The author had no opportunity of observing this substance *in situ*, and the information regarding its occurrence was obtained from Mr W. Lawrie Hamilton, a local mining engineer.

In some of the deeper workings on the Witwatersrand, escapes of inflammable gas, presumably methane, have occurred from time to time, and have given rise to explosions.

Pyrite.—Pyrite is by far the commonest sulphide in the banket, and constitutes about 3 per cent. (by weight) of the typical rock. It occurs in several distinct forms, namely, rounded grains, grains of irregular form, well-formed crystals, irregular crystalline aggregates, and spherical, discoidal, and irregularly rounded bodies.

The rounded grains are of fairly common occurrence, and average in diameter about 0.1 mm. They formed part of the banket before the chloritoid appeared, as is demonstrated by the moulding of the latter on the pyrite (Plate XVII., Fig. 1). These grains are referred to by Becker[1] as "pyrite pebbles," and are considered by him to be of detrital origin, not only on account of their form, but also because of the alleged alteration round their borders to ferric oxide. This latter observation has never been confirmed, and no instance of oxidation of these pyrite grains has been detected by the writer in the hundreds of microscopic sections of the banket which he has examined, except, of course, those from the oxidised zone, where the oxidation of pyrite is general. It is

[1] *Annual Report, U.S.A. Geol. Survey*, 1896-7, pp. 166-67.

probable that the material which Becker took to be ferric oxide was in reality the fine-grained aggregates of rutile, which are of frequent occurrence in the banket and which occasionally border pyrite granules.

Gregory,[1] who agrees with Becker in assigning an alluvial origin to the gold in the banket, is unable to accept the views of the latter regarding the pyrite, and it seems highly improbable that so brittle and easily oxidised a mineral as pyrite could have been deposited broadcast as rounded and unaltered grains in a shallow-water deposit. To the writer, the hypothesis that the rounded form of these grains is due to their being pseudomorphous after some other detrital mineral, *e.g.* some oxide of iron, seems more plausible.

Most of the pyrite in the banket occurs in the other forms already mentioned, and cannot possibly be detrital. This class of pyrite can generally be demonstrated to be, in part at least, a replacement of quartz. It is frequently found moulded on chloritoid and other authigenic minerals, as well as on primary constituents, such as zircon (Plate XVII., Figs. 2 and 4).

Well-formed crystals of pyrite, cubes, octahedra, pyritohedra, and various combinations of these simple forms, are a conspicuous feature of many portions of the banket. These occur not only in the matrix, but also encroaching on the borders of pebbles and within the pebbles themselves, more especially those consisting of fine-grained quartzite. Pyrite crystals are most abundant in the neighbourhood of basic intrusions, where they are usually associated with a large amount of chlorite. In the quartzite associated with the banket numerous and fairly large cubes of pyrite are sometimes met with, in some cases as much

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[1] *Bulletin No.* 35 *Inst. Min. and Metall., London*, 1907.

as 2.0 cm. in diameter. Occasionally the crystals are found wholly or partially surrounded by fibrous or columnar quartz.

Irregular patches of pyrite are sometimes a conspicuous macroscopic feature of the banket. Their longest diameters do not generally exceed 1.5 cm., and are frequently not more than half this length. Under the microscope they are seen to consist of aggregates of crystals usually enclosing abundant fresh chloritoid crystals (Plate XVII., Fig. 2). Where the pyrite crystals are not closely packed together, they are frequently linked by thin veins of pyrite, which run along irregular cracks in the quartz grains or round their borders. The pyrite aggregates are usually obvious replacements of quartz. Frequently they partially replace quartz pebbles at their points of contact with one another (Plate XIX., Fig. 1). This is doubtless due to the circumstances that in such positions the quartz is abnormally strained, and therefore more liable to solution or replacement than elsewhere.

The "cherty" or fine-grained, frequently banded, quartzite pebbles are very liable to replacement by pyrite. The replacement is sometimes complete, and then the characteristic shape and the occasional appearance of rows of minute inclusions are the only indications of the original nature of the pebbles.

The finer the grain of a quartz aggregate the more liable is it to replacement, and when, as sometimes happens, a vein quartz pebble suffers some degree of replacement by pyrite, this naturally occurs in conjunction with replacement of the contiguous finer-grained quartzitic matrix, so that the rounded outlines of the pebble are not preserved; and it may be safely assumed, notwithstanding the assertions of

Mr Horwood[1] to the contrary, that none of the rounded pyritic bodies, to be described later, are replacements of vein-quartz pebbles. The statements of the same writer[2] to the effect that the structure of the replaced quartz is preserved by the pyrite, are also contrary to fact.

Spherical, discoidal, and irregularly rounded bodies of pyrite and marcasite occur in some portions of the banket, often in great numbers. Their diameters may attain a length of 2.0 cm., but generally they are less than 1.0 cm. The spherical type, sometimes known as "buckshot pyrite," is best seen in the beds of the Du Preez series at Rietfontein (Plate XX., Fig. 1). They average 2.0 mm. in diameter. Their surfaces have sometimes a hackly appearance, due to the projecting corners and edges of pyrite crystals, while internally a radially fibrous structure is common. They occasionally enclose crystals of chloritoid. Some of the nodules are plastered or gilded over with coarse gold. The discoidal type is best seen in the rocks of the Battery or Kimberley Reef Series on the West Rand. They vary in diameter from 1.0 mm. to nearly 2.0 cm. Their surfaces are generally smooth. The fractured surfaces have commonly a finely granular appearance with a dull lustre, but those of some of the nodules reveal a coarse texture and have a bright lustre. Many of the nodules when examined with the naked eye appear to be composed entirely of pyrite or marcasite, while others evidently enclose particles of quartz and other minerals. A radially fibrous structure is much less common than in the case of the "buckshot

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[1] *Quart. Jour. Geol. Soc. London*, vol. lxiii. (1907), p. lxx., and *Mining and Scientific Press*, vol. 107 (1913), pp. 648 and 721.

[2] Horwood, *loc. cit.*, pp. 648-50.

pyrite." They are frequently traversed by veinlets of fibrous quartz, which evidently run along planes of fracture. Sometimes secondary quartz, filling contraction cavities somewhat similar to those found in septaria, may be observed in the centres of the nodules. When examined in microscopic sections, they are seen to be obviously of late secondary origin, replacing the quartz of the matrix and of the pebbles (Plate XVIII., Figs. 3 and 4). They frequently enclose, wholly or partially, crystals of chloritoid. They have generally a border of the fibrous quartz already described, and this is especially developed along the acute edges of the nodules. Occasionally between the fibrous quartz and the compact pyritic core is a zone composed mainly of pyrite and partially replaced grains of quartz. One specimen of banket from the Battery Reef Series, which the writer has examined, contains a large dark-coloured quartzite pebble, which is broken through, exposing to view a pyrite nodule, in section 1.7 cm. by 1.0 cm., embedded mostly in the pebble but partly in the surrounding matrix.

The forms of irregularly rounded nodules frequently suggest that they owe their shape to attrition, or that they are pseudomorphous after pebbles, but a close examination almost invariably reveals features which are inconsistent with this supposition.

That some of the nodular bodies consist partly at least of marcasite, is shown by their comparatively rapid alteration on the outside to ferrous sulphate after long exposure.

Rounded pebble-like pyritic bodies, differing considerably from those described above, occur in the Black Reef in the Klerksdorp district. With a view to determining their origin the writer has made a detailed study of specimens of banket from the Machavie Gold Mine.

The specimens are dark in colour owing to an abundance of chlorite. The pebbles consist mainly of vein-quartz, quartzite, and cherty rocks. Pebble-like bodies of pyrite occur in great numbers, and constitute a considerable portion of the rock. They vary in size from about 3 cm. in longest diameter to very small dimensions. Though some of them approach a spherical shape, the majority are flat with rounded edges, and exhibit such irregularities as one would expect in pebbles of a comparatively soft, slaty rock. Their surfaces are slightly roughened by projecting edges and corners of pyrite crystals. A few of the bodies on being fractured show internally a radiate structure. Their arrangement within the rock is what one would expect of genuine pebbles.

A microscopic examination shows that the matrix of the rock is quartzitic. Grains of felspar, mostly plagioclase of intermediate composition, are conspicuous. Pyrite in crystals, sometimes several millimetres in diameter, as well as rounded grains, occurs plentifully. The other minerals present are chlorite and, in much less amount, zircon, chromite, rutile, muscovite, and a greenish mica.

The pebble-like bodies of pyrite have, most of them, clear-cut outlines, and never entrench on the quartz pebbles or quartz grains of the matrix. The pyrite composing them consists of mosaics varying in coarseness of grains, or of very fine granular aggregates. Usually there occur scattered through the pyrite minute grains of quartz, or small patches of quartz mosaic, accompanied frequently by chlorite. Some of the bodies may be described as networks of pyrite crystals, with quartz and chlorite in the interstices.

Pebbles of a slaty rock composed of chlorite, with minute scattered grains of quartz, and having shapes similar to those of the majority of the pyrite bodies, are occasionally seen in all stages of replacement by pyrite. The same change is exhibited by other pebbles, differing from those just mentioned only in having a larger proportion of quartz. The pebbles composed entirely of quartz, whether vein-quartz or quartzite, show no greater tendency towards replacement by pyrite than do the similar pebbles in the normal banket of the Main Reef Series. The fibrous quartz which is so characteristic an accompaniment of the pyrite nodules in the banket of the Battery Reef Series and Du Preez Series appears to be absent.

All the evidence points to the pebble-like bodies of pyrite in the Machavie banket being replacements of pebbles of a quartz-chlorite rock of a more or less fissile or slaty character. As rocks of this kind occur in the Ventersdorp System, it is not unlikely that this is the source of the pebbles.

The radiate structure occasionally exhibited may be due to recrystallisation, or it may be that the pyritic bodies possessing this structure are of different origin from the majority.

There occasionally occur in the banket rounded bodies mainly composed of pyrite, or of pyrite and marcasite, of much larger size than those already described, being several inches in diameter. The marcasite is sometimes present in the form of numerous rudely spherical aggregates, with a coarse radiate structure. Silica in the form of chalcedony and quartz mosaics and veins, as well as some

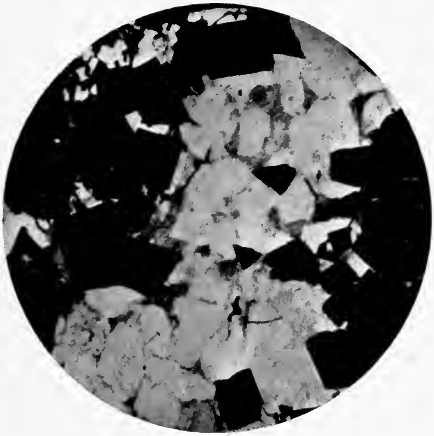

FIG. 1.—Quartzite partly replaced by pyrite. Rose Deep Gold Mine.
Ordinary light; diam. × 17.

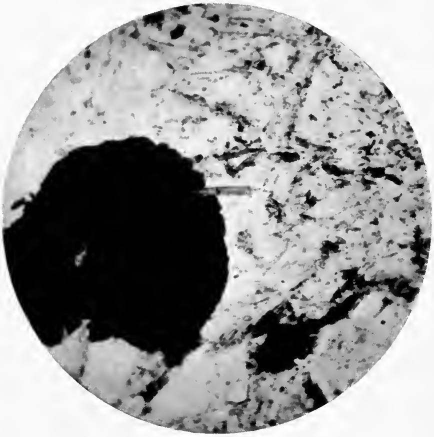

FIG. 2.—Pyrite partially enclosing a tourmaline needle. Other needles of tourmaline lie in the vicinity.
Ordinary light; diam. × 38.

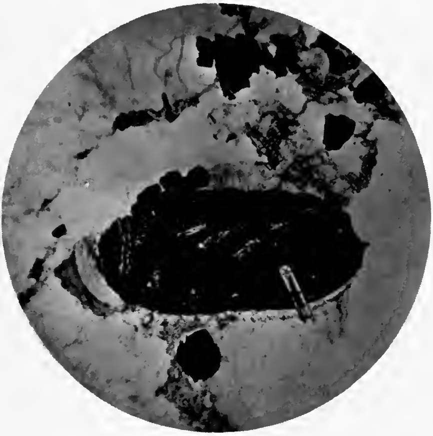

FIG. 3.—Pyrite nodule enclosing chloritoid crystals. Battery Reef Leader, Lancaster West Gold Mine.
Ordinary light; diam. × 22.

FIG. 4.—Pyrite nodule replacing portions of matrix and vein-quartz pebble (at top). Note that the pebble is partly bordered by sericite (to the right), which is not replaced. Battery Reef Leader, Lancaster West Gold Mine.
Nicols crossed; diam. × 27.

PLATE XIX.

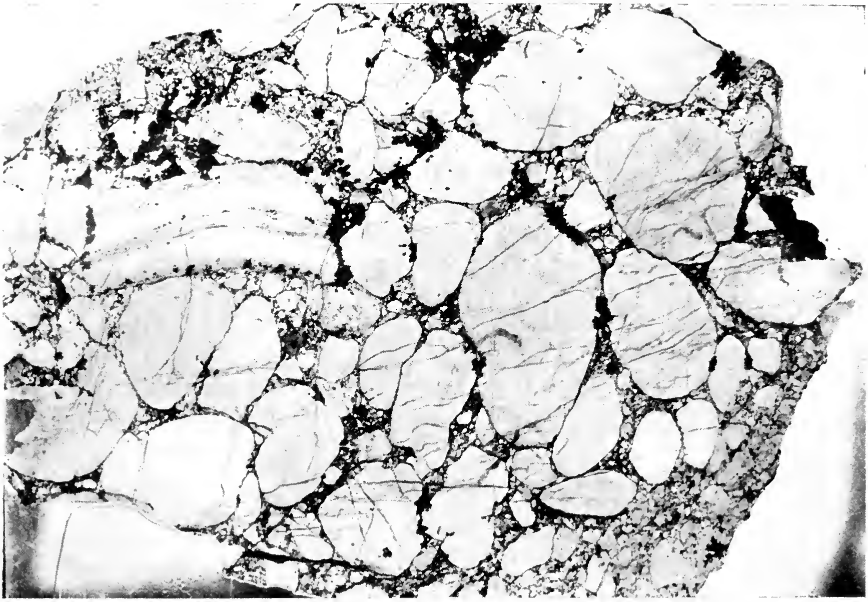

FIG. 1.—Large-sized thin section of banket, photographed by transmitted light. The pebbles are of vein quartz, with the exception of the fine-grained quartzite pebble to the left. Note the marked replacement of pebbles at their points of contact by pyrite and pyrrhotite. Diam. × $\frac{2}{3}$.

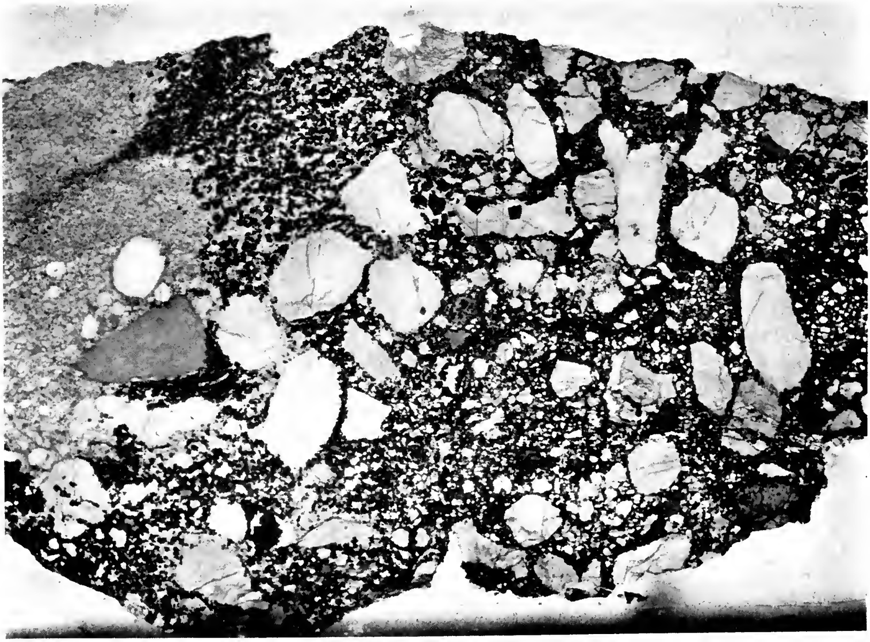

FIG. 2.—Large-sized thin section of banket, photographed by transmitted light. The rock exhibits very marked replacement by pyrite, which affects both matrix and pebbles. To the left is a portion of the rock unaffected by the change. Diam. × $\frac{4}{5}$.

[*Between pp.* 68 *and* 69.

chlorite, accompanies the sulphides. These bodies appear to be replacements, but the nature of the material replaced is not evident.

As the history of the investigations, which led to the demonstration of the metasomatic origin of much of the pyrite in the banket, has been made a subject of controversy,[1] a brief review of the subject may be given.

In 1898, Mr F. White[2] showed that what were usually termed "pebbles" of pyrite occurred not only in the matrix of the banket, but also deeply indenting the quartz pebbles. From this he concluded they could not be detrital.

In 1904, Drs Hatch and Corstorphine[3] expressed the opinion that "the bulk of the so-called 'rolled' pyrites owes its shape to growth by accretion."

On the 4th February 1907, Professor Gregory,[4] at a lecture at the Society of Arts, suggested the "pseudomorphic origin" of the pyrite in the banket.

On the 7th February of the same year, Mr Horwood[5] read a paper (afterwards published in abstract) before the Geological Society of London, in which he described the occurrence of pyrite "pebbles" in the Crown Reef Mine, and concluded from their features as seen in hand specimens that they were pseudomorphs after quartz pebbles.

On the 18th March 1907, the present writer[6] read

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[1] *Mining and Scientific Press*, 27th Dec. 1913, pp. 1019-20, and 22nd Aug. 1914, pp. 297-299.

[2] *Trans. Geol. Soc. S.A.*, vol. iv., pt. iii. pp. 55-56.

[3] *Trans. Geol. Soc. S.A.*, vol. vii., p. 141.

[4] *Trans. Inst. Min. and Metall.*, vol. xvii., footnote on p. 37.

[5] *Quart. Jour. Geol. Soc. London*, vol. lxiii., p. lxx.

[6] *Trans. Geol. Soc. S.A.*, vol. x., pp. 17-29.

a paper before the Geological Society of South Africa in which was given a detailed microscopic study of the occurrence of pyrite in the banket. In this paper will be found, though in greater detail, the observations on the occurrence and origin of the pyrite "pebbles" in the banket of the Witwatersrand area which are included in the present work, and also a demonstration of the metasomatic origin of much of the pyrite occurring in the banket in other forms besides that of "pebbles." This paper was supplemented by another[1] in 1909. Since the publication of these papers, the metasomatic nature of a large proportion of the pyrite has been generally acknowledged, and become a commonplace in the literature on the banket.

Before the publication of the papers just referred to, Professor Gregory expressed the opinion that some pyrite "pebbles" he had examined were pseudomorphs after ironstone pebbles.

In October 1913, Mr Horwood commenced a series of articles in the *Mining and Scientific Press*, in the course of which he describes at some length the replacement of quartz by pyrite, without, however, adding to what was previously known.

Pyrrhotite.—Pyrrhotite is occasionally conspicuous in the banket and the accompanying quartzites. It usually occurs as irregular patches, not only in the matrix, but also in the marginal portions of the quartz pebbles. The diameters of the patches are generally under 3 mm. but sometimes reach as much as 2 cm. The mineral obviously replaces quartz, and its formation was of later date than the pyrite, which it very frequently envelops. The pyrrhotite is usually

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[1] *Trans. Geol. Soc. S.A.*, vol. xii. pp. 87-89.

accompanied by an abnormal amount of chlorite, also not infrequently by chalcopyrite, and occasionally by dolomite. This association of minerals may be taken as an indication of the influence of basic intrusives.

In some portions of the banded pyritic quartzite of the Meyer and Charlton Gold Mine, pyrrhotite patches, the largest of which are almost 3 mm. in diameter, are very common. They occur not only in the pyritic layers, but also in the intervening bands. In a specimen of banket from the Nourse Deep Gold Mine, exhibited in the Johannesburg Museum, pyrrhotite is present throughout the rock in sufficient quantity to hide the pyrite, which however becomes visible in microscopic sections, and is then seen to be enveloped by pyrrhotite. At one locality (depth 800 feet) in the Block "B" Langlaagte Estate Gold Mine, quartzite was found containing cavities, mostly cubical and obviously the moulds of pyrite crystals, which had been dissolved out. Some of these cavities were lined by pyrite crystals, but in other cases they were completely filled with pyrrhotite.

Other Sulphides.—There appears to be a considerable variety of other sulphides in the banket. Of these the most easily recognised are chalcopyrite, sphalerite, and galena. Chalcopyrite is common in the vicinity of the contact of the rock with basic intrusions, and, as already mentioned, is sometimes associated with pyrrhotite. Sphalerite is unusually frequent in the Geduld Gold Mine. Small scattered grains of grey metallic sulphides are frequently seen in microscopic sections, but these are not easy to identify with certainty. Analyses of the banket and pyritic quartzite show that cobalt-bearing minerals are sometimes present, and Mr A. F. Cross[1] records the occurrence of cobaltite. In the chloritic replacement of banket in the Rose Deep Gold Mine, already described, pyrite is sometimes found coated by a cobalt mineral, probably a sulphide. Stibnite and arsenopyrite have been mentioned as occurring in banket.

When met with in microscopic sections the sulphides referred to in the last paragraph are always seen to be late replacements of quartz.

There is usually a clear connection between basic intrusives and the abundance and variety of sulphides in the banket and associated quartzites, the sulphides increasing in quantity with proximity to the dykes. This is sometimes very noticeable in the pannings.

Gold.—Gold is one of the rarest constituents of the banket—as will be realised by anyone who takes the trouble to calculate what percentage of a ton is, say, 6½ dwts.[2] In some of the Witwatersrand mines none of the gold in the rock mined has ever been seen until after it has passed through the mill or been panned. At the same time, there are numerous occurrences of exceptionally rich banket in which much gold is visible to the naked eye. In thin sections of normal banket generally, no gold can be seen with the microscope; consequently material for the microscopic study of the occurrence of gold in banket has to be sought for mainly in unusually rich specimens of rock. This is a serious drawback, and doubtless considerably affects the results obtained.

"Visible" gold is frequently found in the "free-

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[1] *Proc. Chem. and Metal. Soc. S.A.*, vol. v., p. 135.

[2] The average gold content of the ore treated on the Rand at present.

milling" or oxidised banket, which usually extends to a depth of 100 to 200 feet from the surface. In a specimen of this rock taken from the Wemmer Gold Mine the gold is seen occurring in small hackly grains and larger films, the latter being sometimes as much as 4 mm. in longest diameter; the smaller grains are congregated in the neighbourhood of moulds and pseudomorphs after pyrite, occasionally within them, but oftener in the surrounding rather loose quartzitic matrix. The films, which are in some cases dendritic in form, have obviously been precipitated along cracks, sometimes in the pebbles.

When present in the non-oxidised banket, the visible gold may occur as hackly grains of varying size scattered throughout the rock, or it may be concentrated along definite planes, which are not necessarily parallel to the bedding. Sometimes, more especially in the West Rand, thin, more or less continuous, layers of gold are found lying along bedding planes or plastered over slickensided surfaces. At other times, the gold takes the form of minute flakes and specks, scattered thickly over surfaces along which the rock (banket, or quartzite) fractures easily. Gold is occasionally found coating the nodular pyrite or marcasite ("buckshot") of the Du Preez Series. Carbon is frequently accompanied by coarse gold, the latter presumably having been precipitated by the reducing action of the carbon or of hydrocarbons. Gold has never been found in banket in any of the forms which are characteristic of placer deposits.

In microscopic sections of banket the gold is seen to occur generally in irregular grains, the forms of which resemble those in which gold is found in quartz veins. Sometimes they are small, nearly equidimensional, hackly particles, but at other times their different dimensions are very unequal, and they may thin and thicken out very irregularly, occasionally assuming quite fantastic forms (Plates XX. and XXI.).

The gold, as is well known, occurs almost exclusively in the matrix of the banket, but in some instances it has been found in the pebbles. In one such case observed by the writer the gold lay along a crack in a fine-grained quartzite pebble. As the surrounding matrix contained an abundance of gold obviously precipitated *in situ*, and as there was a certain amount of replacement of both pebble and matrix by pyrite, there could be little hesitation in concluding that the gold entered the pebble along the crack about the same period as it was being precipitated in the contiguous matrix. In another instance, the writer found a tourmaline pebble in banket from the Cason Gold Mine in which there was a considerable amount of gold lying along a parallel series of fine cracks. Here again the matrix immediately adjoining the pebble contained much coarse gold.

Occasionally distinct well-formed crystals of gold are found in the quartz of the matrix of the banket. Their diameters vary from 0.01 mm. to 0.04 mm. On account of their small size and frequent distortion it is often difficult to determine the forms present with any degree of certainty, but some of them are fairly symmetrical octahedra, combined with some other minute faces. Several crystals may occur within a very small radius. They are generally associated with a little chlorite, and in one such occurrence a stringer of chlorite can be observed leading continuously from the outside of the quartz grain to the octahedron of gold in its interior. In this instance larger irregular grains of gold lie round the outside of the quartz grain, and needles of rutile, as well as sagenitic and granular aggregates of the same mineral, are present in unusual quantity, associated with needles of authigenic tourmaline (see Fig. 1).

In several specimens of banket examined by the writer much gold is associated with an unusually large amount of tourmaline. In such cases the gold is close to, or in actual contact with, the tourmaline, which it may partly envelop. Muscovite in sericite aggregates, or in moderately large flakes, is always present in banket showing coarse gold, and in some cases it is in considerable quantity, replacing to a marked degree the quartz of the matrix and of pebbles. Chlorite is occasionally present in large amount, but is frequently subordinate to muscovite,

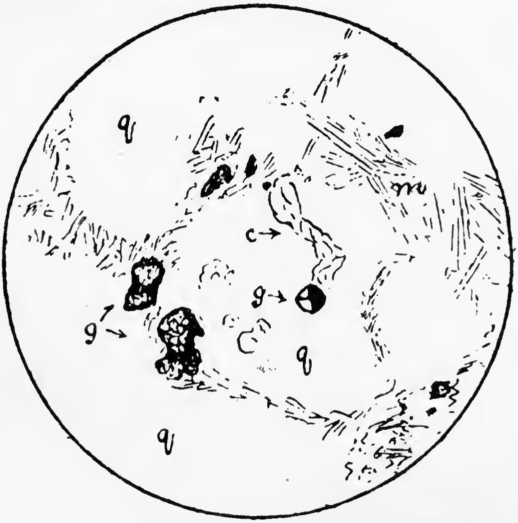

FIG. 1.—Crystal of Gold (octahedral faces predominant) within quartz grain in the matrix of banket: *g*=gold, *q*=quartz, *c*=chlorite, *m*=muscovite. Diam. × 200.

and may be present in quite negligible quantity. Replacement of quartz by pyrite is a common feature of this class of rock.

In studying the occurrence of gold in banket one frequently comes on instances where it is clear that a replacement of quartz by gold has taken place.

The immediate circumstances under which gold occurs in the banket and associated quartzites may be summarised as follows:—

(*a*) As irregular grains.

1. In quartz grains—near their margins, or in cracks, or between two crystalline individuals. In such cases it is occasionally accompanied by chlorite.
2. Between quartz grains, to the exclusion of any other mineral.
3. In secondary quartz mosaics, which frequently contain an admixture of sericite.
4. In contact or intergrown with pyrite.
5. In bodies of sericite.
6. In and surrounding patches of rutile.
7. In bodies of chlorite.
8. In or associated with carbon.
9. In contact with or partially surrounding tourmaline.
10. In contact or intergrown with sulphides other than pyrite.

(*b*) As crystals.

1. In quartz grains generally with some associated chlorite.

The quality of the bullion recovered from the

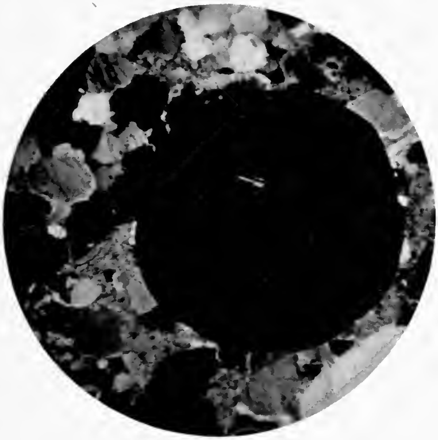

FIG. 1.—Pyrite nodule (buckshot) replacing quartzitic matrix, and enclosing a crystal of chloritoid. Rietfontein A Gold Mine.
Nicols crossed; diam. × 15.

FIG. 2.—Coarse gold from abnormally rich specimen of banket.
Reflected light; diam. × 28.

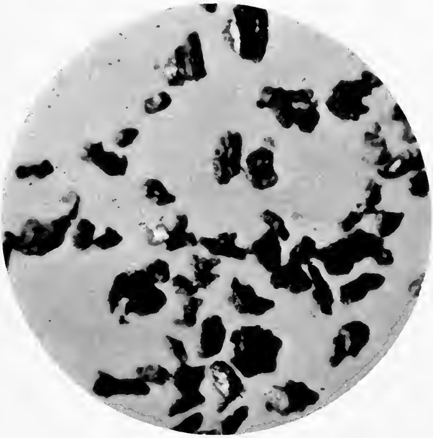

FIG. 3.—Fine particles of gold obtained by crushing and panning normal banket.
Reflected light; diam. × 72.

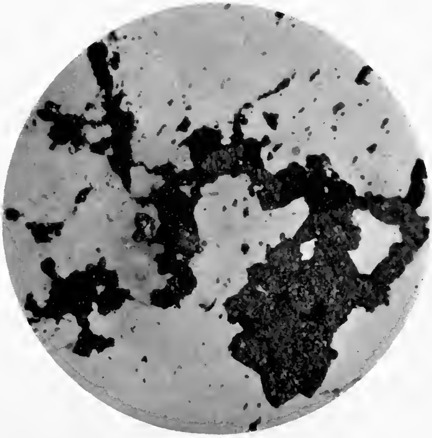

FIG. 4.—Pyrrhotite and gold (the darker of the two minerals) replacing sericitised quartzite in footwall of Main Reef Leader. Owing to the manner in which the photograph was taken, the grain of the quartzite is not seen.
Reflected light; diam. × 28.

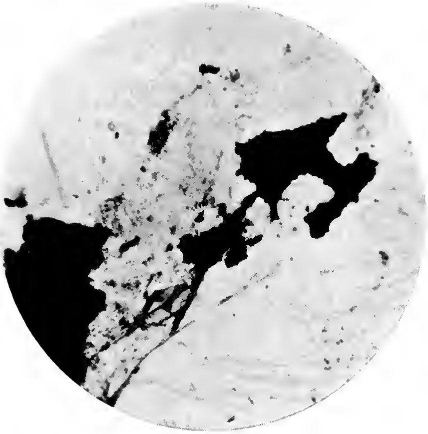

FIG. 1.—Coarse gold and tourmaline in sericitised banket. The black material, with the exception of the patch on the left border which is pyrite, is gold largely replacing quartz. A tourmaline grain is seen towards the left in contact with gold.
Ordinary light; diam. × 77.

FIG. 2.—Coarse gold in sericitised banket. All the irregularly shaped black material in the centre of the figure is gold, which lies mainly in quartz. The rock contains much sericite replacing quartz.
Nicols crossed; diam. × 72.

FIG. 3.—Oxidised banket ("free milling"). Diam. × $\frac{2}{5}$.

[*Between pp.* 76 *and* 77.

banket varies in different localities, and even in different reefs in the same mine. The "fineness" seldom exceeds $\frac{925}{1000}$, and is very rarely under $\frac{860}{1000}$.[1] The remainder of the bullion is almost entirely silver. The "finest" bullion is produced by the mines of the Roodepoort district. The purity of the gold appears to vary to some extent with the size of the particles in which it occurs in the rock, the coarser grained being the purer.[2]

Gold Telluride.—While examining with the microscope some iridosmine from Rietfontein "A" Gold Mine, the writer observed amongst it a few small clumps of crystals of an opaque brass-yellow mineral having a bright metallic lustre. The longest diameters of the largest crystal clumps were about 0.3 mm., the individual crystals being generally very minute. The appearance of the clumps suggested that they occurred as minute druses in the rock. The mineral was easily broken by pressure to hackly fragments. On heating it to redness, there were left slightly spongy pseudomorphs of light yellow gold. The quantity of the mineral obtained was too small for satisfactory analysis, but the properties observed point to its being a telluride of gold.

[1] *A Textbook of Rand Metallurgical Practice*, by R. Stokes, etc., London, 1912, p. 331.

[2] *Jour. Chem. Met. and Min. Soc. S.A.*, vol. v., pp. 72, 74, and 153.

APPENDIX TO CHAPTER III

The Oxidised Banket.—The oxidised or "free-milling" banket generally extends to a depth of 100 to 200 feet. The rock, which is less coherent than the unaltered banket, and in consequence may break round the pebbles rather than through them, is deeply stained by ferric oxides, which vary in colour from brownish-red to light yellow, according to the degree of hydration. The iron stain is not confined to the matrix, but lies also along cracks in the pebbles. The spaces previously occupied by pyrite grains usually contain some iron oxide, which may be black or dark brown in colour, but this is very frequently insufficient to fill them, and they may be quite empty or only lined with a thin coating of oxide. The iron oxides in the rock are probably not derived entirely from the pyrite, but also to some extent from the alteration of chlorite and chloritoid, which never appear in the "free-milling," though muscovite and sericite remain unaltered. Dr W. A. Caldecott,[1] in discussing some metallurgical difficulties, expresses the opinion that free sulphuric acid liberated by weathering pyrite decomposes any silicates of alumina or magnesia present, with the formation of silicic acid or colloidal silica hydrate and of aluminium and magnesium sulphates. If this is generally true, then muscovite forms an exception to the rule.

The analysis of mine waters on the Witwatersrand reveals the presence of free sulphuric acid and sulphates of iron (ferrous and ferric), calcium, aluminium, and magnesium.

In the Meyer and Charlton Gold Mine, where a large body of calcified banket occurs, the walls of some of the old drives are coated with small gypsum crystals. A dense growth of fairly large gypsum crystals has been observed in a sump in the Ferreira Deep Gold Mine. In this case, however, most of the calcium was probably derived from lime added to neutralise the sulphuric acid in the water.

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[1] *Journ. Chem. Met. and Min. Soc. S.A.*, vol. vii., 1907, p. 217.

In the Simmer and Jack Gold Mine and the Witwatersrand Gold Mine iron carbonate, in the form of sphærosiderite and as rhombohedra, has been found lining the walls of narrow cavities in the rock at a depth of about 200 feet, *i.e.*, in the neighbourhood of the lower limit of oxidation.

Analyses of Banket.—The following analyses are by Mr A. M'A. Johnston[1]:—

	BANKET ORE.	BASTARD REEF.	
	Knights Deep.	Simmer East.	Knights Deep.
Silica (SiO_2) . .	86·76	73·35	74·14
Pyrite (FeS_2) .. .	2·75	1·87	1·78
Ferric Oxide (Fe_2O_3)	2·65	7·65	7·70
Alumina (Al_2O_3) .	6·91	13·40	13·00
Lime (CaO) . .	Trace	1·25	0·91
Magnesia (MgO) .	0·70	1·35	1·41
Water (combined) .	...	2·23	2·63
	99·77	101·10	101·57
Specific gravity .	2·79	2·76	2·77

Some of the iron oxide reported above as Fe_2O_3 exists as ferrous oxide in silicates.

The Use of the Term Banket.—A considerable diversity of opinion exists regarding the proper use of the term "banket."[2] The word is of Dutch origin, and was originally applied to the upper oxidised portion of the Rand conglomerates on account of the fancied resemblance of the rock to the sweetmeat known as "hardbake," which consists of almonds lying in a brown sugary base. When the literature on the Witwatersrand goldfields had made the term

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[1] *A Textbook of Rand Metallurgical Practice*, p. 382.

[2] See Gregory, *Trans. Inst. Min. and Metal.*, 1905-06, vol. xv., pp. 563-586.

generally known, a tendency showed itself to apply the name to other auriferous rocks, some of which bore little or no resemblance to the Rand conglomerates. Thus, in Southern Rhodesia, a boulder-bed with a matrix of glaucophane schist, a crushed quartzite, and a diorite dyke have all been described as "banket." The term has also been for long applied more fittingly to the auriferous conglomerates of Tarkwa. Some writers, like Gregory, would call any African auriferous conglomerate "banket," while others would stretch the meaning of the word still further, as, for example, Rickard,[1] who defines banket as "a conglomerate containing sufficient gold or any other valuable metal to be exploited as an ore deposit."

In the writer's opinion the inclusion of rocks having little in common under a term which, to the great majority of those who make use of it, has a well-defined meaning, can serve no useful purpose, and should be abandoned.

The name "banket" should be applied only to conglomerates possessing the outstanding characteristics of the Witwatersrand rock. The pebbles should consist almost entirely of vein quartz, and in size, shape, and disposition should be comparable to those of the Rand banket. The matrix should be quartzitic and compact.

Neither pyrite nor gold can be regarded as essential constituents. Though normally pyrite forms from 2 to 3 per cent. by weight of the Witwatersrand banket, and is visible to the naked eye, yet, on the other hand, it is sometimes present in very small amount, and is then quite inconspicuous. Gold, though conferring great economic importance on the rock, is one of the rarest accessory minerals, and therefore cannot, from a petrological point of view, be considered essential. Further, to make either of these minerals essential would be contrary to ordinary usage. The addition of qualifying terms, such as pyritic, non-pyritic, and auriferous, would prevent any possible misconception.

There are no logical grounds for limiting the use of the word "banket" to African rocks.

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[1] *Mining and Scientific Press*, 8th November 1913, p. 712.

FIG. 1.—Large-sized thin section of banded pyritic quartzite, photographed by transmitted light. The dark bands are pyrite. Meyer and Charlton Gold Mine. Diam. × $\frac{3}{4}$.

FIG. 2.—Portion of pyritic band in banded pyritic quartzite. Towards the top is seen a grain of zircon. Chloritoid and chlorite lie amongst the pyrite grains. The pyritic bands in this quartzite are identical in composition with the matrix of the banket.

Ordinary light ; diam. × 28.

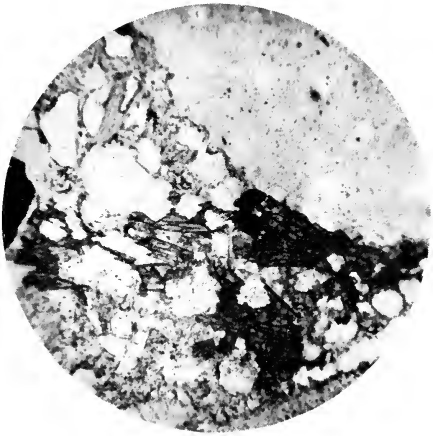

FIG. 3.—Bird Reef banket, from bore-hole core, containing chloritoid, sericite, and a little pyrite.

Ordinary light ; diam. × 28.

CHAPTER IV

ASSOCIATED ROCKS—METASOMATISM

Quartzites.—There is usually nothing very noteworthy in the quartzites of the Main Reef Zone. The quartz grains show a considerable range in size, and are rounded, angular, and subangular, the largest grains showing the greatest degree of rounding. The outlines of the grains are frequently obscured by secondary changes. Zircon is occasionally seen in microscopic sections of the rock. Among the authigenic minerals, sericite, muscovite, and chlorite are the most common. A little pyrite is generally present. Other minerals occasionally met with are chloritoid, rutile, tourmaline, pyrrhotite, chalcopyrite, and very rarely gold.

A special interest is attached to an auriferous quartzite traversed by bands of pyrite (generally known as the banded pyritic quartzite), which occurs in many of the Witwatersrand Mines, including the Meyer and Charlton, Wolhuter, Ferreira, Wemmer, Jubilee, Geldenhuis Estate, Geldenhuis Deep, Angelo Deep, Cinderella Deep, and Jumpers Deep.[1]

The writer has studied the occurrence of this rock in the Meyer and Charlton Gold-mine, where it is particularly well developed. From the surface down

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[1] See Voit, "The Genesis of the Rand Banket," *Mining Journal*, Sept. 1908.

to the 7th level in this mine the Main Reef consists of two bodies of conglomerates, both payable. Beneath this level the "reef" shows great irregularities, attaining sometimes a great thickness, and at the same time diminishing in gold content. Thin bands of pyrite make their appearance in the associated quartzites, and these increase in number until, at the 14th level, the banded quartzite forms two well-defined bodies, separated by 3 feet of light grey non-pyritic quartzite, and has an aggregate thickness of about 15 feet. The banded quartzite is here dark in colour, and traversed by pyritic layers, which are generally not more than an inch apart, and vary in thickness from a hair line to about 3 inches (Plate XXII., Fig. 1). The layers run with the bedding, and individual bands can be followed for a considerable distance. The average gold content over 15 feet is 10 dwts. to the ton. Above and below the banded quartzite are unpayable bodies of banket (Main Reef). Beneath the lowest banket bed more banded quartzite is met with, but the bands are not well defined and the gold content is low. From an inspection of different parts of the mine the lenticular character of the bodies of banded quartzite becomes apparent. Where the lenticles are thinning out the quartzite shows current bedding, and the pyritic bands consequently become more irregular and less persistent.[1]

On microscopic examination the pyritic bands of the quartzite are seen to be identical in composition and structure with the pyritic matrix of the banket (Plate XXII., Fig. 2). Detrital grains of chromite and zircon are moderately common, while in the inter-

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[1] The above description of the occurrence of the banded pyritic quartzite in the Meyer and Charlton Gold Mine applies to the rock as exposed in the mine several years ago.

vening non-pyritic quartzite bands these minerals are absent or extremely rare. Chloritoid and chlorite are plentiful. Much of the pyrite has obviously replaced quartz, and is moulded on chloritoid Pyrrhotite is often conspicuous in hand-specimens.

The identity of the pyritic bands with the banket matrix is very clearly demonstrated when, as occasionally happens, pebbles appear in the bands and the rock passes into typical banket.

There can be little doubt that what are now pyritic bands were at one time layers of sand, in which a certain degree of concentration of heavy minerals had taken place, as in the pebbly beds.[1]

It would be well if those advocates of the infiltration theory of the genesis of the gold in the banket, who lay stress on the original greater permeability of the banket compared with the associated quartzites, would turn their attention to the banded pyritic quartzite.

The Black Bar.—For a considerable distance along the Rand the Main Reef Leader is underlain by a hard, dark-coloured, and fine-grained rock variously known as the "black bar," "interbedded dyke," etc. This rock is frequently traversed, in a direction more or less parallel to the bedding, by quartz veins of varying thickness. On fractured surfaces it usually has a slight satiny lustre.

On microscopic examination it is seen to consist, typically, of numerous small crystals of chloritoid, lying in a very fine grained aggregate composed mainly of quartz and chlorite (Plate XXIII., Fig. 2). The chloritoid occurs in well-formed crystals, averaging about 0.15 mm. in length, showing in lath-shaped

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[1] See Gregory, *Trans. Inst. Min. and Metal.*, vol. xvii., p. 35.

sections the characteristic twinning, and in basal sections traces of two cleavages intersecting approximately at 60°. It contains numerous minute inclusions, and is frequently distinctly pleochroic. The quartz grains are usually very minute. The chlorite has a very low birefringence.

Variations from the normal are not uncommon. The quartz grains may increase considerably in number and size. Sometimes the rock is distinctly banded, thin layers of ordinary chloritic quartzite alternating with bands of normal black bar. Occasionally aggregates of sericite and isolated flakes of muscovite are fairly abundant, and rutile and pyrite may also appear in some quantity.

At places the black bar passes into a species of conglomerate known as "bastard reef,"[1] in which the pebbles are more sparsely distributed, and the matrix darker than in typical banket. The matrix of this rock, when microscopically examined, is seen to be a chloritic quartzite, with numerous strands and irregular patches of normal black bar (Plate XXIII., Fig. 1).

Igneous Rocks.—The igneous rocks of the Witwatersrand System are all intrusive, with the single exception of a contemporaneous sheet of amygdaloidal diabase, which lies between the Bird Reefs and the Kimberley shales, and extends from the Far East Rand to the Central Rand.

The bodies of intrusive rock occasionally form sheets or sills, but generally they occur as dykes, which in many cases lie along fault planes. They vary in thickness from a few feet to several hundred

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[1] This term is also applied on the mines to small-pebble conglomerates.

FIG. 1.—" Bastard Reef," Blue Sky Gold Mine. Diam. × ½.

FIG. 2.—" Black Bar." The crystals giving lath-shaped sections are chloritoid. The fine-grained material consists mainly of quartz and sericite. Simmer and Jack Gold Mine. Ordinary light ; diam. × 31.

FIG. 1.—Granite porphyry. Rand Deep Level bore-hole.
Nicols crossed ; diam. × 28.

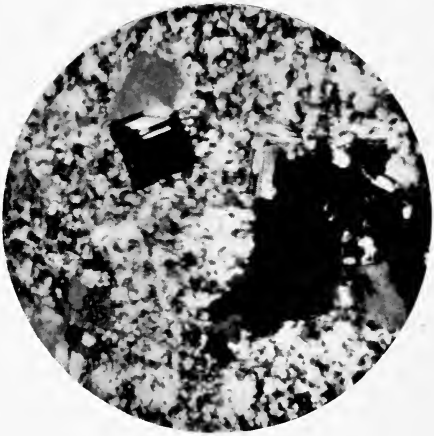

FIG 2.—Microgranite porphyry. Blue Sky Gold Mine.
Nicols crossed ; diam. × 28.

FIG. 3.—Enstatite andesite. The large crystal to the left is composed of uralite. The others are mostly plagioclase felspars. Blue Sky Gold Mine.
Ordinary light ; diam. × 28.

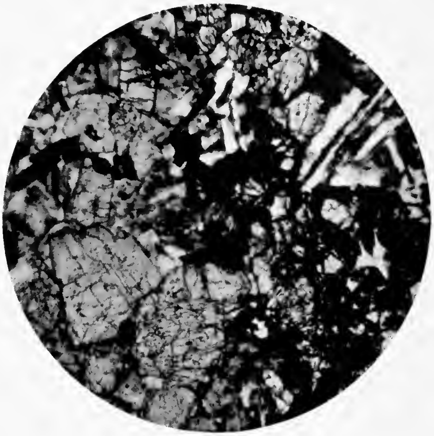

FIG. 4.—Olivine dolerite. The olivine crystals are decomposed to magnetite, etc. Randfontein.
Ordinary light ; diam. × 15.

feet. They are principally basic in composition, acid and intermediate types being rare. The following is a list of the rocks that have been recorded :—

ACID :

- Granite-porphyry.
- Microgranite.

INTERMEDIATE :

- Syenite (Tonalite ?)
- Diorite.
- Enstatite Andesite.

BASIC :

- Gabbro.
- Norite.
- Olivine Norite.
- Dolerite (Diabase).
- Olivine Dolerite.
- Epidiorite.

1. ACID ROCKS.[1]—Granite-porphyry has been met with in the Rand Deep Level borehole. The rock is medium grained and porphyritic, the phenocrysts consisting of albite, albite-oligoclase, and oligoclase. The same minerals appear in the groundmass in addition to quartz, orthoclase, microcline, some flakes of biotite, and fairly large crystals of sphene. The orthoclase is occasionally idiomorphic. The microcline is generally interstitial, and sometimes cements together the parts of fractured crystals of plagioclase felspar (Plate XXIV., Fig. 1). The secondary minerals present are

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[1] See Weber, *Trans. Geol. Soc. S.A.*, vol. xii., 1909, pp. 67-77, and M'Donald, *Trans. Geol. Soc. S.A.*, vol. xiv., 1911, p. 89.

calcite, epidote, chlorite, muscovite, and a little quartz. The following is an analysis of the rock :—

	Per cent.
SiO_2	73.8
K_2O	2.63
Na_2O	6.17
Al_2O_3	14.88
CaO	1.55
	99.03

Microgranite or microgranite-porphyry has been recorded from the Blue Sky Gold Mine, the Cinderella Deep Gold Mine, and Witfontein (29) in the West Rand. The rock consists of a finely crystalline aggregate of quartz and orthoclase, in which lie phenocrysts of orthoclase, acid plagioclase, and quartz. Biotite and sphene are present, and some chloritic pseudomorphs may represent hornblende. The quartz phenocrysts are bipyramidal and often show signs of magmatic corrosion (Plate XXIV., Fig. 2). By the development of sericite at the expense of the felspars, the microgranites pass into quartz-sericite rocks. Analyses of the Cinderella Deep rock show 74.85 per cent. of silica, and gold varying from a trace to 2.8 dwts. per ton.

Some of the acid rocks show in places granophyric and spherulitic structures.

2. Intermediate Rocks. — Sheets of a rock variously described as syenite and tonalite have been met with in the Dolomite in the course of boring in the Far East Rand.[1] A similar rock occurs as a dyke in the Bezuidenhout valley, east of the dump

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[1] F. A. Hatch, *Trans. Geol. Soc. S.A.*, vol. vii., 1904, p. 63; C. B. Horwood, *The Dolomite Formation of the Transvaal*, Johannesburg, 1905, pp. 9-10.

of the Geldenhuis Estate Gold Mine.[1] The rock from the Simmer and Jack Gold Mine, described by Mr D. P. M'Donald[2] as a basic granophyre, very evidently belongs to the same group.

The rocks, which are generally reddish, but occasionally grey in colour, are coarse-grained holocrystalline aggregates of plagioclase (oligoclase ?), with a less amount of red, turbid orthoclase felspar, yellow and greenish brown biotite, green hornblende, and a little interstitial quartz. Some chlorite is present. The quartz is sometimes intergrown with the orthoclase to form micropegmatite. In the granophyre, already referred to, a pale green augite is seen partially altered to uralitic hornblende and chlorite, and it seems probable that some of the chlorite and hornblende in the other rocks, in which no augite is visible, has had a similar origin. There appears to be a considerable variation in the acidity of the rocks, one analysis giving 62 per cent. and another 54 per cent. of silica. Xenoliths of red granitic material have been observed by Mr M'Donald in one of the syenite sheets cut in the shaft of the Rand Klip Gold Mine. The following analysis of one of the syenites is given by Mr Horwood :—

SiO_2	62.20
Al_2O_3	16.58
Fe_2O_3	5.00
FeO	2.80
CaO	4.40
MgO	4.20
K_2O	1.80
Na_2O	2.10
P_2O_5	0.37
FeS_2	0.17
	99.62

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[1] Hatch and Corstorphine, *Trans. Geol. Soc. S.A.*, vol. vii., 1904, p. 107.

[2] *Op. cit.*, p. 90.

Dr J. A. L. Henderson[1] has described a diorite from the Angelo Gold Mine. "It is a dark-green, close-grained rock, consisting of long lath-shaped crystals of hornblende, and clouded, low extinguishing, xenomorphic plagioclase, together with numerous grains and aggregates of secondary quartz and epidote, titanic iron ore, leucoxene, iron pyrites, and chlorite. The hornblende is pleochroic, from brown to green, and nearly every individual is singly twinned parallel to (100). The decomposed felspar gives rise to a saussurite-like decomposition product."

A dyke of enstatite andesite occurs in the Blue Sky Gold Mine. It is a fine-grained black rock, and consists of phenocrysts of enstatite, andesine, and labradorite, with some grains of augite, in a groundmass of glass, partly devitrified and containing microlites of felspar, a few augite granules, and a little secondary calcite. The enstatite is very frequently altered to bastite[2] (Plate XXIV., Fig. 3).

Mr J. P. Johnson[3] has called attention to a thick dyke of andesitic (?) composition passing through the Saxon Gold Mine. It consists mostly of devitrified glass, in which can be observed fine laths, ragged skeletal growths, and occasional larger corroded crystals of plagioclase felspar, also, in some parts of the rocks, biotite and hornblende. The rock shows marked fluxion structure, but its outstanding feature is its amygdaloidal character. The amygdales, which consist of quartz with some chlorite, are very numerous. Towards the centre of the dyke they are large and irregular, whereas near the edges they are much

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[1] *Petrographical and Geological Investigations of certain Transvaal Norites, etc.*, London, 1899, p. 54.

[2] D. P. M'Donald, *loc. cit.*

[3] *Trans. Geol. Soc. S.A.*, vol. ix., 1906, pp. 17-18.

FIG. 1.—Dolerite without olivine. Government Gold Mining Areas.
Ordinary light; diam. × 15.

FIG. 2.—Porphyritic dolerite, showing to the left replacement of felspar and augite by pyrite. The clouded appearance of the large felspar crystal is due to the development of sericite. The groundmass is composed of felspar microlites and granules of augite.
Ordinary light; diam. × 15.

FIG. 3.—Epidiorite. Paarl Central Gold Mine. Ordinary light; diam. × 28.

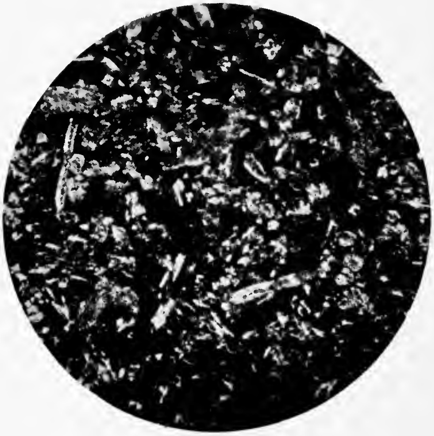

FIG 4—Much altered igneous rock, now consisting of quartz, chlorite, calcite, and leucoxene. The original structure is preserved. Randfontein Central Gold Mine.
Ordinary light; diam. × 15.

smaller and usually oval in shape, being drawn out in the direction of flow.

3. Basic Rocks.—Gabbro and olivine norite are mentioned by Dr Hatch[1] as occurring on the Witwatersrand, but no description of these rocks is given. A much decomposed rock from the Angelo Gold Mine, supposed to be a norite, is briefly described by Dr Henderson.[2] The rock has a schistose structure, and shows only here and there traces of the original pyroxenic constituent, which gives straight extinction and is probably enstatite. The usual decomposition products of felspar and pyroxene are present.

The great majority of the dykes on the Rand belong to the dolerite (diabase) family.[3] Some of the rocks are comparatively fresh, but most of them are intensely altered. Among the rocks that have suffered little alteration the following varieties occur:—

(a) *Dolerites without olivine.* — The commonest type may be described as a coarse, holocrystalline aggregate of lath-shaped plagioclase felspar and brown augite, the two minerals being in ophitic intergrowth. Ilmenite partly altered to leucoxene is present as an accessory mineral (Plate XXV., Fig. 1).

Another type is distinctly porphyritic, the plagioclase phenocrysts being conspicuous in hand specimens. Under the microscope the rock is seen to consist of phenocrysts of labradorite (some of them large and markedly zonal) and light brown augite, in

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[1] Hatch and Chalmers, *The Gold Mines of the Rand*, p. 58.

[2] *Loc. cit.*

[3] See F. H. Hatch, *Trans. Geol. Soc. S.A.*, vol. vii., 1904, p. 62; and D. P. M'Donald, *op. cit.*, pp. 91-97.

a groundmass of small laths of labradorite and granular augite in ophitic intergrowth. Magnetite in grains and rods is common (Plate XXV., Fig. 2).

(b) *Olivine dolerites.*—Generally these are fairly coarse, holocrystalline aggregates of augite, plagioclase, olivine, magnetite, and, frequently, brown or green hornblende. The augite and olivine are idiomorphic, plagioclase having been the last mineral to crystallise.

Sometimes the crystals of augite and olivine lie in a groundmass consisting of a plexus of lath-shaped felspars or of felspar microlites.

The olivine in the dolerites is usually represented by pseudomorphs of serpentine, iron oxides, calcite, etc., in which fragments of the original mineral may sometimes be observed. Occasionally it is comparatively fresh, and is altered to serpentine only about the edges and cracks (Plate XXIV., Fig. 4).

At the margins of the dykes the dolerite becomes fine-grained and sometimes tachylitic. In the latter case the glassy selvedge is partly or wholly devitrified, and contains slender crystals of felspar or other minerals which, however, are frequently much altered. Narrow veins of similar material occasionally run into the sedimentary rocks by which the dykes are bounded. An examination of microscopic sections sometimes confirms what the behaviour of the veinlets suggests, viz., that there has been some absorption of the material of the quartzite and banket which they penetrate (Plate XXVI., Fig. 4).

The commonest intrusives on the Rand are much altered basic rocks,[1] most of them originally dolerites.

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[1] See D. P. M'Donald, *loc. cit.*

From what remains of their original structure, there would appear to have been two distinct types, one coarse-grained, holocrystalline, and the other distinctly porphyritic with a moderately fine-grained groundmass. The course of alteration varied. Sometimes typical epidiorites have been produced. In these the felspar is altered to a saussuritic aggregate, and the augite to uralitic hornblende (Plate XXV., Fig. 3). Other minerals present in variable amount are chlorite, quartz, leucoxene, epidote, calcite, and apatite. In the epidiorites the original structure, though imperfectly preserved, is generally discernible.

In the dykes that have been affected by internal movement the felspars, though broken or ground down, may remain remarkably fresh, while the ferromagnesian minerals are represented by chlorite, needles of uralite, and some calcite. Near their margins such rocks may pass into chlorite schists. Many dykes of this class have lost every trace of igneous structure, and consist of a confused mixture of secondary minerals, among which chlorite, quartz, epidote, leucoxene, and sometimes sericite, show on microscopic examination, especially in reflected light, well-defined "shadows" of the original minerals. Such dykes have sometimes developed within them fairly large crystals of pyrite and chloritoid, and, less frequently, rhombs of dolomite (Plate XXVI., Figs. 1-3).

The influence of the dykes on the quartzitic rocks in contact with them is very marked. An abnormal amount of chlorite appears in the latter, rendering them distinctly darker in colour for a variable distance from the intrusives. The chlorite is a replacement of quartz. The metallic sulphides increase in quantity and variety. There are grounds for believing that these effects were largely produced, long after the intrusion of the igneous rocks, through the agency of solutions emanating from the dykes during the course of their alteration.

With regard to the periods at which the dykes were intruded, it is probable that the comparatively fresh dolerites are the youngest, and were formed contemporaneously with the Karroo dolerites, which they resemble in several respects. The syenites show some affinity in composition and structure to certain intrusives associated with the Bushveld Igneous Complex, and may have been intruded during a late phase of the igneous activity of that period. This hypothesis is strengthened by the presence in one of the dykes of xenoliths of granite very similar to the red granite of the Bushveld.[1] The age of the much altered basic rocks, of which the great majority of the dykes of the Rand are composed, cannot be determined, though it has been surmised that they belong to Ventersdorp times. It is quite possible that they were intruded at different periods. Truscott,[2] from a study of the intersections of the dykes in the Central Rand, arrives at the conclusion that generally the longitudinal dykes, *i.e.*, those that run approximately with the strike of the sedimentary rocks, are older than the transverse. As to the acid dykes, all that can be said of them is that, as they show signs of dynamic metamorphism, they probably belong to an early period.

Veins.—Quartz veins, both with and across the bedding, are common throughout the Witwatersrand

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[1] D. P. M'Donald, *loc. cit.*

[2] *The Witwatersrand Goldfields*, p. 115.

FIG. 1.—Much altered porphyritic igneous rock composed of a very fine aggregate of quartz, chlorite, leucoxene, etc., and conspicuous crystals of dolomite. With higher magnification the structure of the groundmass can still be seen, even within the dolomite rhombs. Randfontein Central Gold Mine. Ordinary light ; diam. × 17.

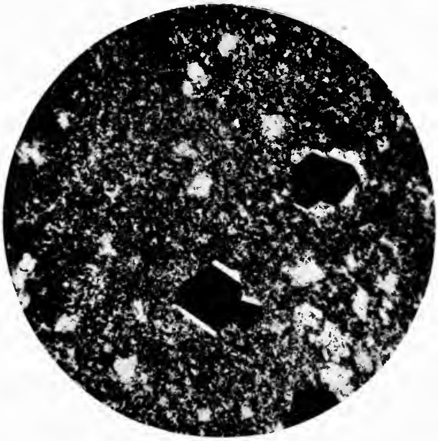


FIG. 2.—A somewhat similar rock containing patches of coarse quartz mosaic with abundant leucoxene inclusions. In some of these patches pyrite crystals with borders of fibrous quartz are developed. Robinson Deep Gold Mine. Ordinary light ; diam. × 15.

FIG. 3.—Much altered porphyritic igneous rock, now composed of a very fine aggregate of quartz grains, also chlorite, leucoxene, and fairly large crystals of chloritoid. The structure of the rock can still be clearly seen, the light patches representing the original phenocrysts. Randfontein Central Gold Mine.
Ordinary light ; diam. × 15.

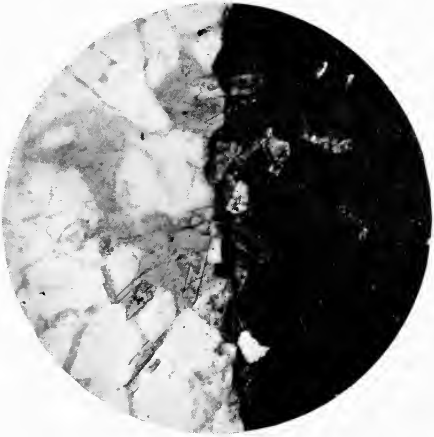


FIG. 4.—Contact of quartzite with narrow offshoot from basic dyke. The quartz is evidently more easily absorbed than the chloritoid crystals, which project unbroken into the igneous material. The latter is mainly devitrified glass. Jumpers Gold Mine.
Ordinary light ; diam. × 28.

FIG. 1.—Tourmaline, in felted mass of fine needles, replacing quartzite at margin of tourmaline vein. A cluster of tourmaline needles is seen within the quartzite. Crœsus Gold Mine.
Ordinary light ; diam. × 28.

FIG. 2.—Contact of two vein-quartz pebbles showing strain. The black patch to the right of the centre is pyrite replacing quartz.
Nicols crossed ; diam. × 28.

FIG. 3.—Kimberley Reef banket, from bore-hole core, with much pyrite, also chloritoid, sericite, zircon, etc.
Ordinary light ; diam. × 28.

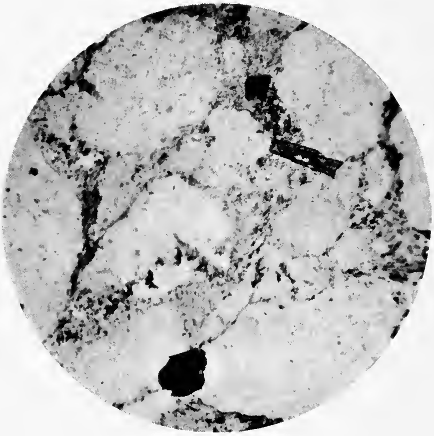


FIG. 4.—Almost barren Main Reef banket, containing only a little pyrite, also chloritoid, sericite, and chlorite.
Ordinary light ; diam. × 28.

System, and are frequently met with in the Mines on the Main Reef Zone. Usually they occur in haphazard fashion, though it is not uncommon to find them associated with faults and igneous intrusions. They generally consist of quartz alone, or with only a negligible quantity of other minerals. Sometimes other constituents are present in considerable amount. Of silicates the commonest is talc, which usually occurs as a border on both sides of the veins. A splendid example of this is to be seen in the Luipaardsvlei Estate Gold Mine, where the talc is bright green in colour, with well-defined columnar structure, and is frequently several inches thick. Kyanite in radiating aggregates of long, bladed, somewhat decomposed crystals may occur imbedded in the talc, as at the Roodepoort United Gold Mine. Another fairly common silicate is epidote, which is associated usually with calcite, and, in one instance (at the Vogelstruis Estate Gold Mine), with red garnet.

Tourmaline is occasionally met with. Thus, in a drive on the 8th level of the Crœsus Gold Mine, the quartzite and banket exposed on the two walls and floor are traversed for some distance by a reticulating system of quartz and tourmaline veins, giving the rocks a brecciated appearance. The veins vary in thickness from an inch downwards, and at places are of quartz only, but generally they contain tourmaline as well, most often massed in the centre. Sometimes quartz is entirely absent from the veins, or in very small proportion to the tourmaline. The tourmaline is generally in the form of a hard mass of fine needles firmly felted together, but it also occurs as loose friable aggregates of needles.

Under the microscope the tourmaline needles are seen to be light blue or brown, sometimes blue at one extremity and brown at the other. In the closely felted masses they vary in length from about 0.5 mm. downwards, though the more scattered crystals are sometimes over a millimetre in length. At the contact of the veins with the quartzite and banket the tourmaline can be seen replacing these rocks, passing into and around the quartz grains in radiating bundles of needles. In the interior of the rocks penetrated by the veins occur scattered patches of radiating tourmaline needles (Plate XXVII., Fig. 1).

A somewhat similar occurrence was met with at the Robinson Deep Gold Mine, in the Main Reef west drive, on the 1700 feet level. As far as observed, the veins are almost entirely composed of tourmaline, and at places they may be seen enveloping and partially replacing the vein-quartz pebbles of the banket. In microscopic sections it is noticeable that the tourmaline crystals replacing the pebbles are much larger than those that replace the matrix (Plate XXVIII., Fig. 2).

Of sulphides occurring in the quartz veins the commonest are pyrite, both massive and in distinct crystals, and chalcopyrite, usually massive. Less frequently are found pyrrhotite, galena, sphalerite, and arsenopyrite.

In a vein in the May Consolidated Gold Mine sphalerite, galena, and chalcopyrite are found closely associated. In another vein in the same mine massive chalcopyrite, sometimes showing a very distinct cleavage, and altering to covellite and malachite, is got.

Gold is also got in the veins, and occasionally very rich "pockets" have been encountered, *e.g.*, in the Jumpers, Simmer and Jack, Geldenhuis Deep,

FIG. 1.—Quartz veinlet in epidiorite. The needles are amphibole. An examination of the figure shows that the veinlet is mainly the result of replacement of the igneous rock, and that the banded structure is due to the inability of the replacing solution at recurring intervals to dissolve the amphibole needles. Some of the larger needles have entirely escaped replacement. At the top of the figure calcite is seen replacing the veinlet. Ordinary light; diam. × 75.

FIG. 2.—Pebbly quartzite, traversed by veinlets of tourmaline, from the Robinson Deep Gold Mine. Diam. × $\frac{1}{3}$.

and Robinson Deep Gold Mines. The gold is generally associated with quartz, pyrite, and, in much less amount, chalcopyrite. In the Robinson Deep occurrence the associated sulphide is galena.

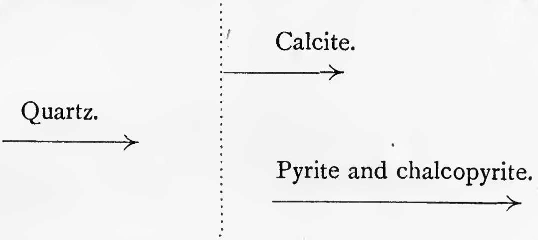
The very rich occurrence met with in the Jumpers Gold Mine in 1908 is worthy of description. It was struck in the 3rd level, between the Main Reef and the Main Reef Leader, and was partly in contact with a fine-grained basic dyke. Its dimensions were roughly 10′ × 10′ × 10″. In addition to gold the mineral contents were mainly quartz, pyrite, and apatite. The writer is not acquainted with any other occurrence of the last-mentioned mineral in veins in the Witwatersrand System. It is light grey in colour, and occurs frequently as distinct hexagonal crystals, averaging about 6 mm. in diameter, though some are much larger. The quartz and pyrite are moulded on the apatite. The gold, which was evidently late in order of precipitation, occurs as coarse hackly masses, and also as layers along cracks in the quartz and pyrite, as well as along the cleavage planes of the apatite. The maximum gold content is reported to have been got where apatite or spongy pyrite occurred in the vein. Another quartz vein in proximity to that just described is practically barren of gold.

The veins are found to lose their gold contents rapidly on being followed even a short distance from the banket beds.

The veins traversing the Main Reef Zone sometimes show signs of having been subjected to considerable movement, enclosed cubes of pyrite being fractured and twisted out of shape, while massive sulphide occurrences are intensely sheared and rendered very friable.

Drusy cavities met with throughout the mines exhibit remarkable similarity in their mineral contents, and in the order of precipitation of the same. The minerals present are generally quartz, calcite, pyrite, and chalcopyrite.

The quartz is always next the walls, *i.e.*, first in order of precipitation, and occurs as well-formed crystals of varying sizes. These may be quite clear, or the inner and first formed portions may have a clouded or milky appearance, and occasionally beautiful "ghost quartz" crystals are found. On the top of many of the quartz crystals are crystals of calcite, through which the former may project. The calcite is generally in flat rhombohedra ("nail-head spar"), which may be several inches in lateral diameter. Other faces may be present, and sometimes the crystals are of a very complicated character. Barrel-shaped crystals are not infrequent, and occasionally a crystal is found combining an acute rhombohedron with a scalenohedron. The cuboid is of rare occurrence. Pyrite and a subordinate amount of chalcopyrite are present in varying proportions. The sulphides are in small crystals, and their precipitation must in some cases have commenced before the precipitation of the calcite was completed, and in such instances they are found in innumerable minute crystals in the outer zone of the calcite crystals, giving that portion a greenish tint. The most of the sulphides lie on the outside of crystals of calcite, as well as on such crystals of quartz as are not embedded in calcite, and they have very evidently been precipitated by preference on edges and corners of crystals. It is quite common to find the rhombohedral terminations wholly or partially covered by an aggregation of pyrite crystals. The general order of precipitation may be represented graphically thus :—



The veins described above appear to be of various ages. Some are sheared, while others are unaffected by mechanical disturbances; some, lying along fault planes, show casts of the slickensides on the wall-rock.

Metasomatism in the Banket and Associated Rocks.— The frequent references in the preceding pages to metasomatism must have made it evident that this process has played a very important part in the mineralisation of the banket. In most of the cases described the mineral replaced was quartz, the minerals taking its place being pyrite and other sulphides (marcasite, pyrrhotite, chalcopyrite, and sphalerite), also calcite, dolomite, chlorite, chloritoid, sericite, muscovite, tourmaline, gold, and a carbonaceous substance. Microscopic examination generally reveals that the replacements occurred subsequent to the cementation of the rock by quartz. Other instances of metasomatism are the replacement of chloritoid by quartz, and the somewhat hypothetical one of the alteration of detrital iron ores, probably titaniferous, to pyrite. Replacements identical with those just quoted have also affected the quartzites associated with the banket.

When quartz in the banket or quartzites has been replaced by calcite or chlorite, these minerals tend to form a continuous body, the limits of which are fairly well defined. In the first stage of replacement the secondary mineral forms a body which, in section, resembles a network, the threads of which follow the lines of contact of the quartz grains and individuals, as well as cracks, however minute, within the quartz. When chlorite is the replacing mineral, such fine networks may be extensive, and generally constitute the total result of the metasomatic action. In the case of replacement by calcite the action has been more localised and intense, and the limits in consequence well marked; or, to put it otherwise, the threads of the network tend rather to thicken than to extend, with the result that there is produced a compact body of calcite (with inclusions of minerals unaffected by the operating solutions), the marginal portions of which enclose residual cores of the pebbles or of the larger grains of quartz. While fine net-like, or rather sponge-like, replacement bodies of chlorite are very frequently met with in the banket and quartzites, only one instance is known, that in the Rose Deep Gold Mine, already described,[1] in which intense local action of solutions has produced a replacement body mainly composed of chlorite, from which all quartz has been eliminated except about the margins. In this case the action of the operating solutions was characterised by other exceptional features; thus the titanium oxide, originally present as rutile, was taken into solution and reprecipitated in the form of anatase crystals, the pyrite and gold (?) were partly dissolved, and lastly, a considerable amount of sericite and comparatively large flakes of muscovite were precipitated.

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[1] p. 46. Since the above was written two other instances have come to the writer's notice.

The replacement of quartz by pyrite and other metallic sulphides, as well as by chloritoid, gold, and carbonaceous material, has taken a somewhat different course. The metasomatic action has occurred at a great number of isolated points within the rock, so that in general no continuous body of the replacing mineral has been produced. Sometimes, however, the centres of replacement are so closely placed, that the metasomes have coalesced or come near to doing so (Plate XIX., Fig. 2). Such occurrences are usually of small extent. In most cases it is not possible to say with any certainty why certain points within the rock have been selected by solutions as metasomatic centres and others not. In some instances, however, the determining factors are sufficiently clear. For example, the points of contact of pebbles are specially liable to replacement by pyrite and other minerals, and this may be ascribed to the circumstance that, in such positions, the quartz is in a condition of strain, and therefore more readily soluble (Plate XXVII., Fig. 2). Again, it is frequently obvious that the presence of one mineral has brought about the precipitation of another, even where room had to be provided by the solution of a third; thus, carbon and pyrite have caused the precipitation of gold and sulphides at the expense of quartz. Fine-grained aggregates of quartz are more liable to replacement than coarse, doubtless on account of the greater surface available for attack by solutions. This is illustrated by the frequent partial or total replacement of "cherty" pebbles by pyrite and other sulphides.

Some of the replacing minerals show a greater tendency than others to assume crystalline form. Crystal faces are developed almost invariably by metasomatic chloritoid, dolomite, and tourmaline, frequently by pyrite, but never by calcite.

The grain of the replaced quartz is never reproduced in the replacing mineral, as has been asserted, though it is true that when the metasomatic mineral is pyrite, its grain is coarser when it has replaced a coarse quartz aggregate than when it has taken the place of a fine one, a natural consequence of the greater limitation of starting points for growth in the one case than in the other. The same phenomenon may be observed in the replacement of quartz by tourmaline. The structure of a rock may, however, be preserved in outline in various degrees during replacement by the resistance of minor constituents to metasomatism. An example of this is shown on Plate XVI., Fig. 1, where the grain of a quartzite, which has been replaced by calcite, is preserved by chlorite that originally followed the contact surfaces of the quartz grains. In some of the much altered igneous rocks, occurring as dykes in the Witwatersrand System, the original structures are preserved in outline, even when the rocks consist essentially of a fine-grained aggregate of quartz and chlorite, throughout which large crystals of chloritoid are scattered (Plate XXVI., Fig. 3).

In some instances of metasomatism in the banket and associated quartzites a definite relation can be made out between the areas affected and dykes or fissures. Thus many of the dykes are bordered by zones in which there is present an abnormal amount of chlorite and sulphides, both metasomatic. The calcified areas in the Meyer and Charlton and Paarl Central Gold Mines are traversed by fractures along which at present water freely percolates. The chloritic replacement in the Rose Deep Gold Mine is associated with a system of continuous openings or passages which have been dissolved out along the joints and bedding-planes of the quartzites.

On the other hand, the distribution of the chloritoid, and of much of the metasomatic pyrite, does not appear to have any obvious relation to conspicuous channels, or to any extraneous source of mineral matter, such as dykes.[1]

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[1] For general information regarding metasomatism, see W. Lindgren, "Metasomatic Processes in Fissure Veins," *Trans. Amer. Inst. Min. Eng.*, vol. xxx., pp. 578-692, "The Nature of Replacement," *Econ. Geol.*, vol. vii., pp. 521-35, *Mineral Deposits*, New York, 1913; and J. D. Irving, "Replacement Ore-Bodies and the Criteria for their Recognition," *Econ. Geol.*, vol. vi., pp. 527-61 and 619-99.

CHAPTER V

THE HISTORY OF THE BANKET

It is impossible, in the present state of our knowledge, to give a connected account of the history of the Witwatersrand bankets which does not involve conjectural elements, and some fluctuation of opinion on debatable points may be expected from time to time as further information regarding the rocks becomes available.

The original deposition of the sediments composing the Witwatersrand System has been variously assigned to marine, fluviatile, and lacustrine agencies, but the general opinion has been in favour of a marine origin. Becker,[1] who upheld this view, thought that the sediments had been laid down off a subsiding shore which ran in an east and west direction, and he ascribed the formation of the extensive pebble beds, now bankets, to the action of vigorous easterly currents. Mellor,[2] however, while admitting that some of the conglomerates show unmistakable evidence of irregular deposition, such as we associate with coarse littoral deposits, maintains that others, notably in the Main Reef Zone, present features which are inconsistent with a purely marine origin. This, he thinks,

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[1] *Annual Report, U.S. Geol. Surv.*, 1896-97, p. 163.

[2] *Trans. Geol. Soc. S.A.*, vol. xviii., 1915, pp. 47-55; and *Journ. Chem. Metal. and Min. Soc. S.A.*, vol. xvi., 1916, pp. 162-63.

is well exemplified by the Main Reef Leader, which extends as an individual bed of wonderful regularity over a great area in the central and eastern portions of the Rand. His general conclusion is that the bulk of the Witwatersrand sediments represent the discharge from one or more continental rivers of considerable magnitude, and that some at least of the conglomerates of the Main Reef Group were laid down under deltaic conditions. The regular, and apparently rapid, deposition of the Main Reef Leader and similar beds he ascribes to the action of unusually violent floods. For the details of the argument in support of these conclusions, the reader is referred to Mellor's papers dealing with the subject. To the writer the prevalent shape of the pebbles of the conglomerates of the Main Reef Group, as well as their irregular shingling, both of which suggest marine deposition, appear to be inconsistent with Mellor's view of the origin of these beds.

When we approach the consideration of the original condition of the bankets and the subsequent changes which they have undergone, we are immediately confronted with questions which are still subjects of controversy. The principal of these concerns the manner in which gold and pyrite found their way into the beds. The theories advanced regarding this may be briefly summarised as follows[1]:—

1. *The Placer Theory.*—The auriferous bankets

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[1] References to the literature on the subject published before 1907 are given in Gregory's paper, *Trans. Inst. Min. and Metal.*, vol. xvii., 1907-8, pp. 2-41. Among more recent literature may be mentioned: Voit, *The Mining Journal*, 1908, Sept. 5 and 12; Young, *Trans. Geol. Soc. S.A.*, vol. xii., 1909, pp. 94-101, and *Proc. Geol. Soc. S.A.*, 1911, pp. xxi.-xxix.; Hatch in *Types of Ore Deposits*, ed. by H. F. Bain, pp. 202-219; Horwood, *Mining and Scientific Press*, 1913.

are marine placers in which the original detrital gold has been dissolved and then re-deposited *in situ.* The principal advocates of this theory, Becker and Gregory, differ in opinion about the origin of the accompanying pyrite, the one regarding it as an allogenic constituent which has in part undergone recrystallisation, while the other maintains that it has resulted from the action of sulphuretted waters on detrital iron oxides.

2. *The Infiltration Theory.*—The gold and pyrite were introduced by percolating waters subsequent to the deposition of the banket. Most of the advocates of this theory regard the bankets as having been, before cementation, somewhat analogous to fissures, the larger spaces between the pebbles affording an easy passage for solutions, from which the metallic contents were precipitated mainly or wholly by physical causes. Others take the view that the precipitation was due to the presence in the conglomerates of some reducing agent.

3. *The Precipitation Theory.* — The gold and pyrite were chemically precipitated from the waters in which the conglomerates were deposited. The latest advocate of this theory presents it in a form which approaches the infiltration theory, as he supposes that the gold was derived from ascending metalliferous solutions, which overflowed at the surface and mingled locally with the sea-water, while the conglomerates were being laid down.[1]

Though the last-mentioned theory had at one time some vogue, it does not appeal to present-day students of ore-deposition, and the field is held by the other two, whose merits will now be considered.

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[1] Voit, *Mining Journal*, 1908, Sept. 5 and 12.

The condition of the gold in the banket does not lend support to the placer theory. The particles of the metal show no signs of attrition, but are similar to those occurring in quartz veins and other undoubted epigenetic deposits. Furthermore, in rich specimens of banket, the gold can frequently be demonstrated to be of metasomatic origin, quartz having been replaced. On the other hand it is not at all unlikely that in so ancient a rock any detrital gold originally present would have undergone a certain amount of solution and re-precipitation.

A study of the mineral associations of the gold leads one to differentiate between the normal banket and unusually rich patches of the rock. In the latter evidence of metasomatic action is frequently well-marked, quartz being largely replaced by muscovite, sericite, metallic sulphides, or tourmaline. In other cases the gold has obviously been precipitated by the reducing action of carbon or carbon compounds. The metal usually occurs in relatively coarse grains, and has undoubtedly been introduced after the cementation of the rock by quartz. In the normal rock—in which the gold is very fine grained—the secondary minerals, with the exception of pyrite, are generally similar in kind and quantity to those found in barren banket, and might quite well have resulted from the alteration *in situ* of some argillaceous and felspathic material originally present. The impression is given from the examination of thin sections that the heavy authigenic minerals, zircon and chromite, are present in less quantity in the barren rock, though this cannot be regarded as an established fact.

The distinction made in the preceding paragraph between very rich and normal banket is emphasised by the circumstance that the analyses available, though few in number, indicate that the coarse gold has a smaller admixture of silver than the fine.

If it is assumed that the gold in normal banket was originally detrital, some plausible explanation must be found for the intimate association of the metal with pyrite. A considerable portion of the pyrite occurs as small rounded grains, and this suggested to Becker[1] that the mineral was an original clastic constituent of the banket. In support of this view, he mentions having observed a coating of ferric oxide surrounding some of the grains in the unweathered rock, but this observation has never been confirmed, and it is probable that the material was in reality granular rutile, which might be easily mistaken for limonite. To the writer it appears highly improbable, notwithstanding the fact that clastic pyrite has occasionally been found in placers, that so vast a quantity of the mineral as occurs in the banket could have completely escaped oxidation during the long journey from its parent rock. Others[2] class this portion of the pyrite with the much larger concretionary bodies of pyrite already described,[3] and ascribe the rounded form of the particles to the same mode of growth. These two occurrences of pyrite, however, bear no resemblance to each other, except in shape, the larger bodies being replacements of quartz subsequent to the formation of the secondary silicates in the banket, while the relations of the small rounded particles of pyrite to the other minerals in the rock are those of an allogenic mineral.[4] The

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[1] *Annual Report*, *U.S.A. Geol. Surv.*, 1896-97, pp. 166-167.

[2] Hatch and Corstorphine, *Trans. Geol. Soc. S.A.*, 1904, vol. vii., p. 141.

[3] p. 65.

[4] See Plate XVII., Fig. 1.

suggestion of Gregory[1] that the rounded pyrite is pseudomorphous after detrital iron oxides is more plausible, though the author is mistaken in supposing that the larger pebble-like bodies of pyrite and marcasite have had the same origin. A strong argument in favour of this hypothesis is the absence of black iron oxides from the banket, the mineral described as magnetite by some writers being really chromite. When we consider the varied assemblage of Swaziland rocks from which the banket was derived, and that the rock contains a concentration of other heavy minerals like zircon and chromite, it seems hardly credible that magnetite and ilmenite were not originally present. The transformation of the iron oxides through the agency of sulphuretted waters would explain, not only the absence of these minerals from the rock, but also certain features in the distribution of much of the pyrite, which, considered alone, would suggest a detrital origin. The titaniferous iron ores might be regarded as the source of the rutile which is so conspicuous in the banket.[2]

If this mode of origin is attributed to the bulk of the pyrite, then, in order to account for the circumstance that a large part of the mineral occurs in crystalline forms, often replacing quartz, and that rounded pyrite is very frequently entirely wanting, it must be further assumed that, subsequent to the transformation of the iron oxides, much of the resultant pyrite underwent solution and reprecipitation.

An intimate association of gold and pyrite would

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[1] *Trans. Inst. Min. and Metal.*, vol. xvii., p. 37.

[2] First suggested by Koch in Schmeisser, "Vorkommen und Gewinnung der nutzbaren Mineralien in der Sudafrikanschen Republic," Berlin, 1894, p. 49.

on this hypothesis be a natural consequence, if the formation and later changes of the pyrite were contemporaneous with the solution and precipitation of the detrital gold.

It would seem possible, then, to reconcile with the placer theory those features of the gold and pyrite in the normal banket, which, *primâ facie*, provide the strongest argument for the infiltration theory.

An important consideration in judging between the rival theories is their ability to account for the manner of distribution of the gold, the outstanding features of which are these. While all the conglomerates in the Witwatersrand System are to some extent auriferous, those of the Main Reef Zone, and more especially the Main Reef Leader and South Reef, are distinguished not only by a much greater concentration of the gold, but also by the persistence of values over extensive areas. The gold, however, is not confined to the conglomerates, and the banded pyritic quartzite[1] affords a notable instance of the occurrence of the metal in quantity in a fine-grained rock. Though the Main Reef Leader and South Reef show on a broad survey a remarkable uniformity in their gold content, they are found on closer inspection to be made up of alternating rich and poor patches, the former of which are often sufficiently elongated in form to merit the name of "shoots" or of "pay-streaks" according to the mode of origin attributed to them. Mellor[2] has recently described these so-called shoots as they occur in the extreme East Rand, and has shown that such patches of "reef" are characterised generally by a more robust

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[1] p. 82.

[2] *Jour. Chem. Metal. and Min. Soc. S.A.*, vol. xvi., 1916, pp. 151-152.

development and by larger pebbles than the poorer rock by which they are flanked. Their orientation, too, is identical with that of the bodies of banket, which lie isolated amongst quartzites farther to the south, and which are mined in the Nigel area. In general there is no apparent relation between the richer portions of the banket beds and the dykes, faults, or fissures, which intersect them. The gold frequently shows a preference for those parts of the banket which contain the largest pebbles. Such then are some of the facts which any theory of the origin of the gold in the banket must be called upon to explain.

The majority of the advocates of the infiltration theory regard the conglomerate beds as having been before cementation somewhat analogous to fissures, the larger spaces between the pebbles affording an easy passage for solutions, from which the metallic contents were precipitated mainly or wholly by physical causes. Thus Sawyer[1] in 1894 writes, "Conglomerates are more porous than the encasing rocks, hence they would be the paths chosen by ascending hot waters or vapours containing gold, and it would be deposited in the matrix of the conglomerates and to some extent in the pores of the encasing rocks as well. . . . The fact that frequently the larger the pebbles the richer the reef would thus be explained. . . . Were it not for the pebbles a piece of banket would resemble a piece of ordinary vein-quartz in depth." Kuntz[2] in 1895 says, "The conglomerates before the formation of a water-tight cement can be taken as hollow spaces. . . . Why in such hollow space should there not occur actions

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[1] *Proc. Chem. Metal. Soc. S.A.*, vol. iii., pp. 370-371.

[2] *Trans. Geol. Soc. S.A.*, vol. i., 1896, pp. 119-120.

which are usual in other similar hollow spaces, for instance, in the clefts in which veins are formed?" While Maclaren[1] in 1908 writes, "The absence of an undoubted precipitant of gold within the conglomerates points rather to a general deposition arising from physical changes in the solution than to one from chemical reaction." Somewhat similar views have been expressed by Hays Hammond,[2] Hatch and Chalmers,[3] Phillips and Louis,[4] Beck,[5] Curtis,[6] Rathbone,[7] Horwood,[8] and others.

The contention that the gold was precipitated in the conglomerates in preference to the finer-grained rocks, because of the greater permeability of the former, does not explain why the conglomerates in the Main Reef horizon were so specially favoured. Kuntz[9] appears to think that the richer "reefs" were originally the more permeable, owing to the interstices between the pebbles being imperfectly filled with sand. Curtis[10] briefly disposes of the question by saying, "The gold is unquestionably limited to certain seams of conglomerates. It is also limited to certain quartz lodes in formations where the deposition of the gold is unquestionably due to infiltration." Horwood[11] appeals to the retaining influence of underlying shales. Now that Mellor has pointed out that

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[1] T. M. Maclaren, *Gold, its Geological Occurrence, etc.*, 1908, p. 97.

[2] S. T. Truscott, *The Witwatersrand Goldfields*, 3rd ed., p. 12.

[3] Hatch and Chalmers, *The Gold-mines of the Rand*, p. 72.

[4] Phillips and Louis, *A Treatise on Ore Deposits*, 2nd ed., p. 64.

[5] R. Beck, *The Nature of Ore Deposits*, p. 518.

[6] *Jour. Chem. Metal. and Min. Soc. S.A.*, vol. viii., p. 200.

[7] *Proc. S.A. Assoc. Eng. and Arch.*, vol. i., p. 96.

[8] *Mining and Scientific Press*, 15th Nov. 1913.

[9] *Op. cit.*, p. 121.

[10] *Loc. cit.*

[11] *Loc. cit.*

the Main Reef Zone differs from the other important conglomerate belts in possessing banket beds which persist as distinct individuals over great areas, the exceptional gold content of the zone might be put down to its providing uninterrupted channels for the percolation of the auriferous waters. Further, if the assumption is made that the larger the pebbles in a conglomerate the more permeable it is, the features of the shoots in the eastern Rand may be easily explained. Other objections that have been raised to this theory might be overcome by assuming that the auriferous solutions entered the conglomerate beds at greater depths than have yet been reached by mining.

Unfortunately for the theory, evidence against it of the most damaging nature is afforded by the banded pyritic quartzite. As will be seen from the description[1] previously given, the pyrite bands were at one time differentiated from the body of sand, of which they formed part, solely by their mineral composition. The minute grains of chromite, zircon, and other minerals which they contained could not possibly have added to their permeability. Nevertheless, these bands are now identical in composition and structure to the matrix of the banket, and contain sufficient gold to justify the mining of the quartzite in which they occur. It does not seem possible to reconcile the features of the banded quartzite with the theory just described. Its advocates, too, appear to entertain an exaggerated notion of the permeability of conglomerates. It may be mentioned, in conclusion, that the microscopic examination of the banket reveals very clearly that the metasomatic changes which have taken place within the rock, and which have been appealed to in support of the infiltra-

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[1] p. 82.

tion theory, have occurred in great part subsequent to the cementation of the rock by quartz, and therefore after the banket had lost its original permeability.

According to the second form which the infiltration theory takes, the precipitation of the gold was due to the presence of a reducing agent in the conglomerates and other rocks in which the metal occurs. No stress is laid on the differences in permeability among the beds, and Hatch and Corstorphine,[1] who were the first to adopt this theory, consider it necessary to assume that there was a general percolation of auriferous waters through the whole thickness of the Witwatersrand System. Accordingly, the distribution of the gold depended on that of the precipitant. Regarding the identity of the latter no definite statement is made, though the authors just mentioned suggest that the agent may have been iron salts or possibly carbonaceous matter. In 1908 the present writer[2] was led, by certain features of the distribution of the gold, to express his belief that the infiltration theory was tenable only on the assumption that the gold was precipitated by a heavy detrital mineral, whose distribution would naturally be similar to that of gold in a placer deposit. However, no mineral of this description capable of exercising a reducing influence can be detected in the banket. Though this form of the infiltration theory can be made to account for the principal features of the distribution of the gold in much the same way as the placer theory, the obscurity which surrounds the hypothetical precipitant is a serious obstacle to its acceptance.

The recent work of Mellor has very materially

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[1] *The Geology of South Africa*, 2nd ed., p. 150.

[2] *Trans. Geol. Soc. S.A.*, vol. xii., 1909, pp. 97-98.

strengthened the argument in support of the placer theory. The remarkable persistence as individuals, which he has shown to be the distinguishing feature of the principal gold-bearing beds, argues that the conditions that governed their deposition were essentially different from those that prevailed during the formation of the other bodies of conglomerate, and, though there may be a difference of opinion as to what these conditions were, they may be pointed to as a possible cause of the exceptional concentration of gold. The more robust development and the larger pebbles of those patches of "reef" in the eastern Rand, which are referred to as "shoots" by the infiltrationists, as compared with the poorer areas of banket by which they are separated, and the correspondence in the orientation of their longer axes, with those of the isolated bodies of conglomerate lying in the same horizon farther to the south, indicate that the patches are in reality "pay streaks," whose courses were determined by the stronger currents. The characteristics of the banded pyritic quartzite are consistent with the hypothesis that the bands in this rock were originally layers of auriferous black sands. Other exceptional occurrences of gold in the Main Reef Zone, as, for example, where the metal is found associated with carbon in shoot-like bodies, sometimes in rock devoid of pebbles, or where it occurs in quartz veins in the immediate neighbourhood of the banket beds, may be accounted for by the precipitation, owing to chemical or physical conditions, of the gold taken up in solution from the banket by waters permeating the rocks. It is significant that the quartz veins just alluded to are found to lose their gold contents on being followed even a short distance from the conglomerates.

From the course which the above argument has taken it will be seen that, with the data at present available, the writer is inclined to accept the placer theory.

The influence on the sedimentary rocks of the numerous dykes, which traverse the Main Reef Zone, has been referred to in a previous chapter, but deserves further attention. The most obvious effect that they have produced is the addition of chlorite and metallic sulphides to the rocks in their immediate vicinity. The dykes, too, were probably the source of the chlorite, sericite, and calcite that have already been described as replacing large bodies of rock in the Rose Deep,[1] Meyer and Charlton,[2] and Paarl Central[2] Gold Mines. The question arises, whether these results were produced by emanations from the dykes during their intrusion and subsequent cooling, or by meteoric waters carrying in solution material derived from the alteration of the constituent minerals of the intrusives at a very much later period. Reference to the description previously given[3] of the extreme alteration that the majority of the common basic dykes have undergone, will reveal that the products of alteration remaining within the dykes are largely identical with those that have just been mentioned as having been introduced into the neighbouring quartzitic rocks. In the case of the Rose Deep occurrence, in which a large body of banket and quartzite has been almost entirely replaced by chlorite and sericite, there is evidence in the presence of open passages which have been dissolved out of the overlying rock along the joints and bedding planes, that the solutions that brought about this alteration were probably descending. These facts

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[1] p. 46.

[2] p. 52.

[3] p. 91.

appear to support the latter of the alternatives stated, though doubtless some of the effects observed are to be ascribed to the cooling magma. It may be that the carbon, which has undoubtedly acted as a late precipitant of gold at places within the banket and associated quartzites, represents a carbonaceous substance given out by intrusives. Only in the case of one or two, out of the hundreds of dykes intersected in the mines, has anything been observed which might be interpreted as indicating a relation between igneous rocks and any of the gold content of the banket, and it is not unlikely that the small quantities of gold, which have been detected in some of the dykes, have been introduced from the sedimentary rocks. The various metallic sulphides, as well as the calcite, epidote, and talc sometimes found associated with quartz in veins, were most probably derived from the basic dykes during the course of their alteration. As for the authigenic tourmaline occurring in banket and in veins, though this seems to indicate the influence of acid intrusions, the facts that detrital tourmaline is fairly common in banket, and that the matrix of the banket in the immediate vicinity of tourmaline pebbles sometimes contains an unusual amount of tourmaline which has obviously originated *in situ*, suggest that the source of the mineral may have been the allogenic tourmaline. The various intrusions of igneous material, besides directly producing mineral changes within the neighbouring rocks, doubtless promoted others by heating the permeating waters and accelerating their circulation.

To conclude, the view which the writer takes of the probable history of the conglomerates in the Main Reef Zone may be briefly stated as follows :—

They were laid down in the sea, probably at no great distance from the mouth of a large continental river. Among their allogenic constituents were gold and iron oxides. The conditions of deposition, that resulted in the unusual persistence of the principal gold-bearing beds as individuals, were also the cause of the exceptional concentration of gold within them. Among the more patent features of the history of the beds since their deposition are their burial beneath younger sediments, cementation by quartz, subjections to orogenic forces, resulting in folding, faulting, etc., and their invasion at different periods by igneous material. At the same time the banket was the seat of complicated mineral changes, and there are grounds for believing that these included the following:—

(1) Solution and reprecipitation of the gold.

(2) Conversion of the iron oxides into pyrite by sulphuretted waters, accompanied by the formation of rutile.

(3) Solution and reprecipitation of a portion of the pyrite.

(4) Formation of chloritoid, sericite, and chlorite at the expense of argillaceous and felspathic material.

(5) Addition of metallic sulphides, chlorite, sericite, calcite, and carbonaceous matter derived from dykes during their cooling and subsequent alteration.

All of the above, excepting (2), were attended by a certain amount of replacement of quartz. Though (1) and (3) were probably more or less active during a great part of the history of the banket, this did not very greatly affect the distribution of the gold and pyrite, owing possibly to the circumstance that the solutions concerned in the actions were mainly confined to subcapillary spaces, and consequently capable of little movement. The intimate association of some of the gold with pyrite is probably accounted for by (1) being to some extent contemporaneous with (2) and (3).

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