THE GEOLOGY OF THE AREA NORTH-WEST OF THE CONFLUENCE OF THE CROCODILE AND PIENAARS RIVERS.

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I. INTRODUCTION.

The area investigated is situated in the district of Rustenburg, about 55 miles due north of the town of Rustenburg.

The area of approximately 150 square miles was mapped by plane table during the winter seasons of 1946 and 1947.

Previous reports pertaining to the area were compiled by H. Kynaston and W.A. Humphrey (4) from 1907 to 1912. These reports, and the accompanying maps, greatly simplified the work.

II. PHYSIOGRAPHY AND DRAINAGE.

Apart from the cultivation of the rich alluvial soil along the banks of the Crocodile river, the area is used almost exclusively for grazing.

In the dolomite regions the relief is usually low, but gradually increases higher up in the succession. Prominent hills are built by the resistant handed ironstones which overlie the dolomite. The contact of the dolomite and banded ironstone is usually found along the crests of these hills, which sometimes lie 1,000 feet above the surrounding, low-lying country. All the trignometrical stations are located on the tops of these hills, the most conspicuous of which are found on Karoobult, Boschkop and a very prominent chain passing over Elandsfontein, Geluk, Ramakokskraal and Pylkop. They are, however, almost

dwarfed/...

dwarfed by the Kroemahoek mountain range which is constituted by the same type of formation. The characteristic ridges with their bush-clad tops continue northwards up to the farms Kwikstaart, Liverpool and Buffelskraal. The following are the elevations, in English feet, of the trigonometrical beacons plotted on the map:-
Slipfontein 3,846, Karoobult 4,177, Geluk 4,584, Kroemahoek 4,709.

Southwards, on the farm Kruidfontein, the volcanic breccias form a circle of hills covered with loose boulders. The low ground between these hills is formed by porphyries and dolomite xenoliths.

Another important topographical feature is afforded by the anticlinal ridges of the Black reef series. In some places the quartzites, with intercalated shales, stand out conspicuously above the dolomite as a result of differential erosion. This is well illustrated on Boschkop, Elandsfontein and Doornpoort, where the Black reef rocks have an anticlinal disposition. The strip of Black reef on these farms stands about 1,000 feet above the surrounding country. High quartzite hills are also present on Nooitgedacht 610 and northwards on Hardekoolpan and Krokodilkraal. Along the Crocodile river the quartzites and shales of the Black reef form low-lying ground.

Outcrops are thus generally abundant, and rarely covered by surface deposits, except along the river and at localities where calcrete has formed. The soil covering on the lower dolomite (shaly phase) attains a thickness of about 5 feet, whereas the upper (cherty phase) has little or no soil covering but a greater development of ferricrete.

The drainage of the area is effected mainly by the Crocodile river, which enters it on the farm Rooisloot, flowing westward. In the centre of Boschkop it swings northwards to pass over banded ironstones and the Black reef series, thereby proving its superimposed character. On Knopieskop it again cuts through the Black reef and leaves the area on Liverpool, curving north-westwards.

The tributaries of the Crocodile river are good examples of obsequent streams where they flow down the scarps of the banded ironstone ridges and across the dolomite. On passing over the Black reef anticline, however, they take on a resequent character.

III. VEGETATION.

The vegetation, although variable in density, is usually fairly thick, especially along the lower slopes of the hills where wag-'n-bietjie varieties abound.

On the dolomite plains, rooibos, hardekool (Combretum imberbe), karee (Rhuslancea), geelhaak, fynhaak, sekelbos, blouhaak, blinkblaar, sweet thorn (Acacia karroo) and maroela trees all occur abundantly. On the dolomite-banded ironstone hills kiepersol (Cussonia spicata) makes its appearance, whereas on the Black reef quartzites Acacia species and boekenhout (Faurea saligna), are common.

IV. GEOLOGY.

A. General geology:

The following conformable succession of sedimentary formations is represented on the map:-

Black reef series, Dolomite series and Pretoria series. In addition to these sediments there are a number of intrusive dykes of varying compostion, as well as a large volcanic pipe on the southern part of the area.

The Black reef is best studied on Nooitgedacht 610, Elandsfontein and Doornpoort. The series is made of quartzites, shales and conglomerates. A highly altered sheet occurs in the sediments.

By far the greater part of the area is occupied by the Dolomite series. Owing to its relative susceptibility to denudation, it forms flat, undulating landscape. Although it is fairly homogeneous it may, nevertheless, be divided into a lower phase with interbedded shales (deposited in shallow water), separated from an upper chert-bearing phase (deposition in deep water) by a succession of interbedded quartzites and shales.

At the top of the dolomite, and stratigraphically grouped with them, lie banded ironstones. They also have a wide distribution and form the boundary of the investigated area, except along the southern margin where they are interrupted by a volcanic pipe.

The Pretoria series is represented by a small outcrop on the farm Boschkop, where it consists of a small ridge of quartzite and altered shale. This remnant of the Pretoria series (Timeball Hill stage) owes its position to the formation of the volcanic vent in the Pretoria series (see map).

The volcanic rocks on Kruidfontein consist of porphyries, partly covered with felsitic breccias. They are all highly altered so that their original compositions are hardly determinable. The volcanic pipe from which they originated has pierced the Pretoria series near its contact with the underlying banded ironstones.

The dykes and sills occurring in the area may be divided into five different types:-

1. Bostonite dykes which seem to be related to the volcanic body.
2. Dioritic dykes which radiate from the volcanic body. they are extensively altered, and are not shown on the geological map.
3. Nepheline-bearing dykes varying in composition from feldspar-poor to feldspar-rich types. These dykes have a haphazard distribution and possess characteristics reminiscent of certain Pilansberg dykes.
4. A sill consisting mainly of aegirine-augite and alkali feldspars. It is of variable composition, but the main type is shonkinitic Its age is uncertain.
5. Sills of dolerite (not shown on the map).

These are also siliceous fault breccias forming prominent scarps in places along the faults shown on Boschkop and Elandsfontein. Fockema (2), who completed a survey of the area south-east of the Crocodile and Pienaars rivers, determined fault breccias of similar type as being of post-Karroo age.

The Recent deposits are:-

1. Alluvium along the Crocodile river.
2. Piedmont deposits at the base of the Black reef ridges.

Borehole/...

Borehole evidence has proved some of these deposits to depths of 30 feet.

3. Surface limestone has formed on the dolomite, and attains a thickness of up to 90 feet, according to one farmer's report of a borehole.

B. <u>Transvaal system</u>:

(1) <u>Black reef series</u>:

(a) <u>Distribution</u>:

The Black reef sediments are exposed mainly along the crest of a subsidiary fold forming part of a large complex dome in this area. It commences on Knopieskop and extends southwards across Karoobult to Nooitgedacht 610 (on the eastern side of the Crocodile river). On Nooitgedacht 610 the outcrop curves towards the river and cannot be seen owing to the alluvial cover. Along the river-bed a small outcrop of shale occurs. On the western side of the river the series is once again exposed, and strikes east to west. A little further on the Black reef has been laterally displaced by a tension (tear) fault which strikes south-north. The main outcrop was found to continue on Boschkop. The displacement measures about 1,000 yards. Thence it builds a high mountain on Elandsfontein. On the north-western boundary of Doornpoort the series is not visible, but an outcrop was seen again on the Rustenburg road just across the boundary between Doornpoort and Nooitgedacht 610. Here the Black reef series turns sharply and re-enters the farm Doornpoort, where it builds a series of ridges. From here the circular line of outcrops may be followed through Elandsfontein, Pylkop, Roodepan and Nooitgedacht 610. Thus, west of the main road to Rustenburg on Nooitgedacht 610 the minor limbs of the large complex dome have been compressed, forming a complete bottleneck between the dolomite of the central dome on Krokodilkraal and Nooitgedacht, and that of the south-western dome on Doornpoort, Pylkop and Roodepan. This structure may be compared with a similar type more south-eastwards, described by Fockema on the farms Border and Vaalkop, where the Black reef is also involved (2, p.8).

The series then trends northward over Nooitgedacht 604, Hardekoolpan and Krokodilkraal to Buffelskraal, where it disappears under the alluvium of the Crocodile river, and where it is apparently cut by the large (post - Karroo?) tension fault, with an apparent downward displacement, on its western side.

(b) General and microscopical description:

The Black reef series as developed in the investigated area may be subdivided as follows:

1. Upper quartzites.
2. Upper blue shales.
3. Lower red shales.
4. Lower quartzites containing gritty phases and a conglomerate.

1. Lower quartzites:

The lower quartzites are hard, compact, fine to medium-grained rocks, grey to deep blue in colour. After prolonged exposure the quartzites become deep red or brown. The typical dark to black quartzites mentioned in reports on the Black reef elsewhere, were not found here. These quartzites often show alternation of bluish and brownish bands, respectively about 1 inch and 2 inches thick.

In thin section the rock is seen to consist of closely packed inequidimensional granoblastic quartz grains, the majority of which show undulatory extinction. Brown weathered oxides are present in small amount, and also a little interstitial sericite. In one section as many as 13 zircons where seen, the majority being well rounded. The crystals are turbid and traversed by many cracks. In some places fairly large muscovite flakes were noticed in hand specimens. No quartz veins are present in this zone.

Thin lenticular bands of grit often occur in the lower quartzites. Cross-bedding and ripple marks were noticed.

A small pebble conglomerate occurs as lenses in the lower quartzites. It has small pebbles, which measure up to about 0.75 inches in length, set in a groundmass of fine-grained quartz. The shape of the pebbles varies from spherical through spheroidal to sub-angular. The spherical pebbles have an average diameter of about 0.15 inches. For the spheroidal types the average lengths of the major and minor axes are about 0.3 inches and about 0.2 inches, respectively. All the pebbles seen in sections and hand specimens consist of vein quartz.

Under the microscope the pebbles are seen to be composed of a mosaic of irregularly shaped quartz grains. Cracks in the pebbles are sometimes filled with carbon, which may be of metasomatic origin. The interstices between the quartz grains of the groundmass are filled with carbon-like material as well as mica. A few quartz grains show marked strain effects. Hematite is also present in small amounts. Another very common constituent of the groundmass is zircon, which occurs as well rounded, water-worn, crystals. An assay of a typical conglomerate showed no trace of any

gold/

PLATE 1.

A large concretionary body in lower Black reef quartzites from Boschkop.

gold (analysed at the division of chemical services, Chemical Laboratories, Johannesburg.) A thin band of pebbly quartzite is developed wherever the conglomerate outcrops.

A large ellipsoidal concretionary body was found in the lower quartzites. It is made up of alternations of silica and an iron oxide and measures about 3.5 feet along the major axis (Plate 1).

2. Lower red shales:

The lower quartzites are followed by the reddish shales, which may be compared with the micaceous phyllites described by Fockema (2, p.12). They are fine-grained, well laminated, sandy, micaceous rocks.

These rocks contain almost no clay minerals. They consist mainly of quartz and interstitial limonitic material. The average diameter of the quartz grains, which constitute about 75% of the rock sections, is about 0.09 m.m. Sericite is well represented and a little hematite also occurs. Some biotite with pleochroism from colourless to light brown, is present. It does not show the typical pleochroism from brown to pale yellow, presumably because it has only reached the early stages of formation.

3. Upper blue shales:

The upper blue shales are separated from the red shales by a few thin subordinate quartzite and shale bands, with grits at the top. The outstanding feature of the blue shales is that they are nearly always carbonaceous.

Ripple marks are common along this horizon. The

PLATE 2.

Symmetrical ripple marks, with typical branching pattern, in the upper blue shales of the Black reef series, Nooitgedacht 610.

PLATE 3.

An outcrop of blue shales dipping north in the Kroemahoek area.

ripples are well formed and clearly symmetrical. They consist of broad troughs that are convex downwards, separated by sharp crests. The ripple marks show a characteristic branching pattern (Plate 2). The presence of the symmetrical ripples suggests that the shales were formed in a body of standing water, where currents were absent and wave action considerable. The wave length of the ripples varies from 1.3 inches to 1.4 inches, and the amplitude from 1.9 inches to 2.1 inches, giving a ripple index of about 3.2

These shales are more susceptible to alteration than the lower shales, and have undergone varying degrees of thermal metamorphic alteration. Pressure apparently played a minor role in their metamorphism.

Along the eastern outcrops of the Black reef these shales have been affected by low grade metamorphism resulting in the formation of spotted shales or "Knotenschiefer" (3, p.24).

Typically, the shales consist of alternations of siliceous and carbonaceous bands. The darker bands mainly consist of minute irregular flakes of cabonaceous matter together with small sericite flakes. It is in these dark bands that the clots or nodules, which give the shale its spotted appearance, have been developed. The nodules are due to the aggregation of the graphitic and sericitic material in the rock (Plate 4). The siliceous bands are peculiar in that they are not continuous, as seen in thin section, which gives one the impression, that they have a lense-like distribution. (Plate 4). The seliceous bands have about 50% fine-grained quartz, the rest being

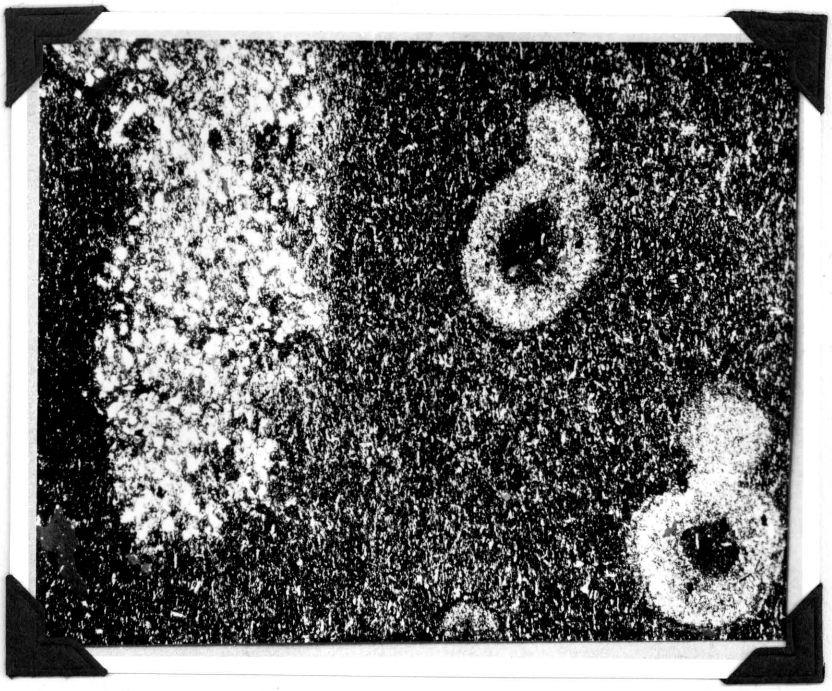

PLATE 4 -

shows the peculiarly shaped nodules in the dark shale bands due to the aggregation of the graphitic and sericitic material.

Note the lense-like distribution of the quartz X21 (crossed nicols).

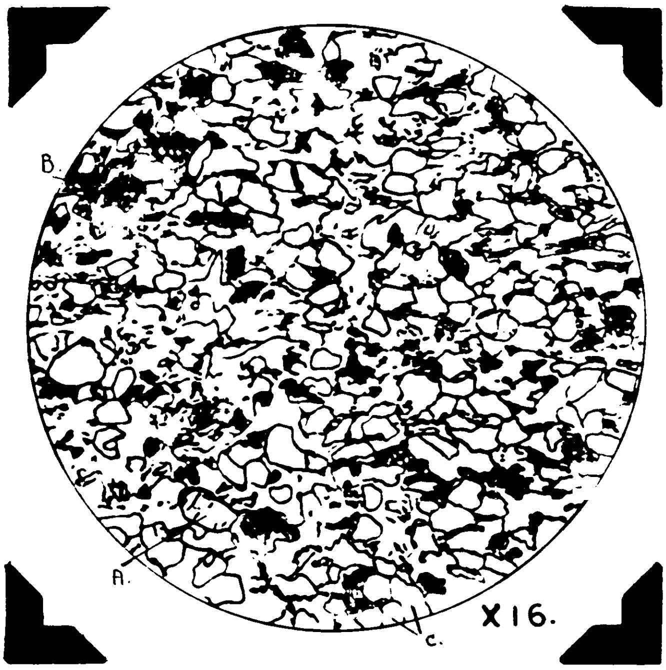

PLATE 5.

Camera lucida sketch of a shaly grit
from the Black reef series.
A. Tourmaline crystal.
B. Carbonaceous matter.
C. Quartz.

made up of sericite and carbon of the same texture as in the dark bands. The carbon has probably been metamorphosed to graphite. No nodules were seen in the siliceous portions. The size of the nodules varies from 0.25 m.m. to 0.95 m.m. in diameter. The majority are circular, but others are oval and of the peculiar shape seen in Plate 4.

Another variety in this area is a shaly grit not metamorphosed to any appreciable degree. The quartz is fairly equidimensional. Mica streaks and carbonaceous matter are present in fair amount. A few fairly long oval zircon grains, and chlorite, also occur. Crystals of tourmaline were noticed and show conspicuous pleachroism: E = light brown, O = green (Plate 5).

Followed further westward, the shales reveal progressively higher grades of metamorphism, although the spotted structures are still to be seen. Xenoblastic biotite is a common mineral here. This mineral makes its appearance as shapeless patches, but the characteristic development of flakes is already in progress. A few magnetite grains are invariably present. A high percentage of silica is present and sericite is also abundant.

A further grade of metamorphism is furnished by andalusite-bearing shales. According to Harker (3, p.24), andulasite may either come from the decomposition of kaolin, if present originally, or it may be produced jointly with biotite by reactions involving sericite, chlorite and iron-ore. In thin section biotite, in well-formed flakes, is seen together with the andalusite, suggesting that the two were formed jointly. The andalusite forms idioblastic crystals, showing the chiastolite cross almost to perfection. $2V_\alpha$ of the andalusite is 83° and $n_\beta = 1.633$ ($\pm$ 0.005). In one or two instances samples were collected where the chiastolite cross has apparently disappeared. The groundmass still contains ample sericite, quartz and ore. The andalusite alters readily to sericite. The sericitation usually commences along cracks and cleavage planes. Some crystals have been completely altered to a sericitic mass.

4. The upper quartzites:

They differ from the lower quartzites by being more massive and having a grey-blue colour. On weathering they sometimes take on the blue-black colour of the typical Black reef quartzite. Quartz veins are more common in this zone than elsewhere. Grit lenses occur sporadically.

Under the microscope a specimen of this quartzite shows the larger quartz grains to be equidimensional with irregular and dentated outlines. They are set in a mosaic of conspicuously smaller grains (gritty appearance). The majority of the larger grains show undulose extinction. A few muscovite flakes were noticed. The spaces between the quartz grains are fitted with mica (sericite). A twinned crystal of amphibole was found included in a clastic quartz grain.

Under the microscope a specimen of a grit from this zone shows highly rounded quartz grains set in a white siliceous groundmass. Other constituents are mica, zircons and apatite.

(c) Correlation of the quartzites, shales and conglomerates:

Regarding all the lowest visible quartzites and shales on Doornpoort and Elandsfontein Humphrey (12, p.166) states: "These might be taken as representing the Black reef series exposed along the axis of the dolomite anticline, but on the northern boundary of the farm Elandsfontein, the quartzite anticline is still further weathered and divides into two arms, exposing first shale and then dolomite". On the strength of this he assigns them to the dolomite series and regards them as shales and quartzites interbedded with dolomite.

The writer has had occasion to visit this particular zone and, although it seems in one place that the shales are underlain by dolomite, it is merely an illusion caused by a break in the outcrop due to a tension fault with a 100 feet displacement. When the outcrop is picked up again it can be followed further west without any sign of a division of the anticline into two arms. Indeed, a superimposed stream cuts the anticline at right angles, and the lowest layer thus exposed is in the bed of this stream, which, when followed, shows the presence of the blue shales but no dolomite.

Furthermore, the shales which are seen here are of the bluish type, which could, according to sequences elsewhere as on Hardekoolpan, still be separated from the base of the Black reef by a red shale and a quartzite zone with impersistent lenses of small pebble conglomerates.

In addition, the main points in favour of correlating these sediments with the Black reef are:-

1. The presence of an outcrop of small pebble conglomerates in the lower quartzites. Its thickness is about 6 feet

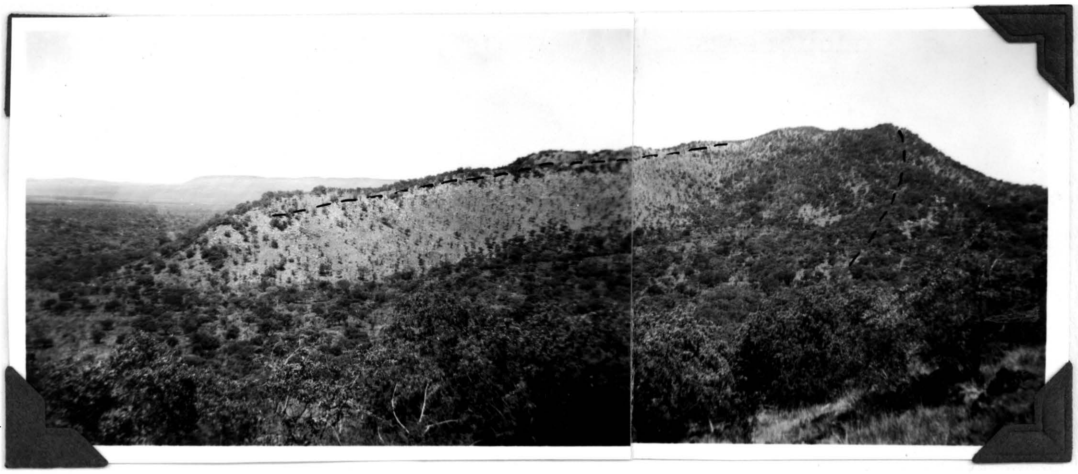

PLATE 6.

The denuded anticline of Black reef beds on Doornpoort and Elandsfontein.

and apparently occurs as lenses in the quartzite. These small pebble conglomerates are typical of the Black reef in all the areas described.

2. The occurrence of a soft reddish brown shale above the lower quartzites and conglomerates. Similar shales are found in the Black reef of Ventersdorp district (10) as well as at the Randfontein mines. According to Swiegers (15), red shales are sometimes noticed above the small pebble conglomerate.
3. The bluish shales become more prominent higher up and are carbonaceous. This is in accordance with the findings of L.T. Nel in the Ventersdorp district (10).
4. There is a definite transional phase between the upper limits of the Black reef and the lower dolomite. Most commonly the zone is made up of several thin layers (some 5 feet thick) of a brown marble alternating with a fine-grained blue-black carbonaceous shale (sometimes metamorphosed to a Knotenschiefer. This corroborates the evidence furnished by geologists who have studied the Black reef in the Transvaal (for instance, in the Klerksdorp area (15)). The "passage" layers are followed by the normal blue dolomite.
5. The fact that the main quartzites exhibit cross-bedding, although this was found to be more the exception than the rule. The quartzites in the dolomite series are free from cross-bedding.
6. The higher quartzites are often traversed by quartz veins varying in thickness from a fraction of an inch to about 3 inches, which is a typical feature of the Black reef quartzites in the Thaba Zimbi area.
7. The precise thickness of this series could not be

determined/...

determined owing to the nature of the anticlinal exposures, but an estimate of some 300 feet, or more, would be justifiable. Nowhere has such a thick intercalation of quartzites and shales in the dolomite been recorded, the thickest being 100 feet in the Eastern Transvaal.

8. The fact that a series of interbedded layers were found to exist in the dolomite of this area, bearing no relationship whatever to the Black reef beds. They attain a thickness of some 70 feet, consisting of quartzites and bluish shales (see page 17).

9. The presence of fairly persistent grit bands in the quartzites. These bands were often noticed between the shale and quartzite contacts. They are absent from the Dolomite.

10. In other areas, especially around Klerksdorp, thin black carbonaceous shale bands are present in the lower dolomite above the "passage" layers - a phenomenon which was also noticed in the area under examination.

(2) Dolomite series:

(a) Distribution:

This thick succession of carbonate rocks, and its well-defined overlying Banded ironstones, follows conformably upon the Black reef series. The succession varies markedly owing to variations in deposition and subsequent metamorphism.

Normally, the dolomite is of the grey-blue type, which resembles an elephant's hide on weathered surfaces. This holds especially for the lower half of the series which is more dolomitic than higher up in the succession.

PLATE 7.

An exposure of a small anticline in the lower dolomite phase, showing the presence of carbonaceous shale hands (A) which can be distinguished from the contiguous dolomite bands (B) by their darker colour and finer grain.

The dolomite and banded ironstones form the greater part of a large complex dome, which is the major structure in the area. Because of the subsidiary folds, and of the thickness of this series, the dolomite covers a relatively large area.

Along the north-eastern boundary the higher phases, together with the banded ironstones, have been downfaulted, possibly during post-Karroo times, causing a break in the series. The absence of the banded ironstones and upper, (cherty) dolomite phase, along the northern boundary on Kwikstaart, is probably due to a transgression of the Bushveld granite.

(b) <u>Succession and general characteristics</u>:

The general succession is as follows:-

Just above the Black reef the dolomite is of the normal blue type, prevailing for some 2,000 feet. A few marble lenses occur sporadically in this zone. Its most striking feature, however, is the persistent presence of dense, black, carbonaceous shales. These shales signify a return to the conditions under which the youngest Black reef members were deposited. Although these shale bands may attain thicknesses of up to a few feet, they are usually from 1 inch to 1 foot across, being separated by dolomite bands of approximately the same thickness. As many as 20 separate bands were encountered over a thickness of about 25 feet (Plate 7). The shale bands are confined to a definite horizon over a large area, and the contact lines between the shale and contiguous dolomite bands is sharply defined. The bands follow the general stratification of the dolomite. Elsewhere lenses and patches of black carbonaceous material were seen to be orientated obliquely to the bedding of the dolomite, but it is unlikely that they bear any relation to the interbedded shales already mentioned. These lenses and patches are most probably of metasomatic origin.

Intercalated in the blue dolomite, there occur a bed of quartzite and a band of shale which are well developed on Nooitgedacht 610 and Nooitgedacht 604. A good section is seen along a small stream running more or less parallel to the boundary of these two farms. The quartzites are compact, greenish, recrystallised rocks, and the shales are of the fine-grained bluish type. These intercalated sediments are seen on both sides of the Black reef anticline, for instance on Nooitgedacht 610. In each case the outcrops along the outer limb are small and only the quartzites are visible. They form fairly prominent ridges on Wachteenbeetje where they appear to be duplicated by faulting.

Following the sequence, the upper 5,700 feet (possibly this is a high estimate attributable to localized folding) may be regarded as the upper, cherty phase of the dolomite in agreement with Fockema's findings further south-eastwards (2). They do not follow immediately above the intercalated group of quartzite and shale, being preceded by the continuation, for a short distance, of the shallow water group. This upper stage is easily distinguished by the absence of shale - and the presence of well-defined chert bands. Also, the dolomite is now of a darker blue colour, and massive stratification is more common. At first these rocks are fairly dolomitic, but higher up they can be described as dolomitic limestones. Recrystallisation in this phase is not so widespread as in the shallow water phase.

According/...

According to Young (20, p.165), the expulsion of inclusions, which gives to the limestones their colour, is frequently accompanied by recrystallisation. Attention has been drawn to the fact that the deep phase dolomites in this area are a darker blue than the types of the shallow phase lower down. Following Young's explanation, it would mean that the darker colours of the cherty dolomite deposited in deep water are due to the absence of, or less advanced recrystallisation, compared with the lower members, which owe their lighter colour to the expulsion of inclusions by recrystallisation.

The chert bands are decidedly more common in the middle and lower parts of the deep, cherty, phase. They are numerous, appearing as lenses which are sometimes up to 10 feet thick. Evidence shows that these chert bands were puckered during a period of dymamical deformation. In the vicinity of the chert horizon the stress mineral tremolite is always developed. It may appear as needles in the dolomitic limestones. It is not uncommon to see tremolite bands up to about 9 inches thick, adjoining the chert for long distances. Some chert bands have often been completely replaced by tremolite.

Some 200 feet below the Banded ironstones, which constitute the uppermost horizon of the Dolomite series, there occurs a zone of dolomitic and calcitic marbles. Although these marbles have a lenticular distribution in the dolomite, the zone is developed extensively throughout the area. Red, brown and dark coloured varieties are the most common.

Below the marbles, lies a thick stratum of massive dolomitic limestone, which, on being stained with ferric chloride and sulphuretted hydrogen, shows an oölitic structure.

The oölites are circular with an average diameter of 1.5 m.m., and have not yet been silicified.

The marbles are followed by a bed of laminated dolomitic limestone with thin lenses of shale. These shale bands, together with the oölitic limestones, suggest a final return to shallow water conditions.

(c) <u>Macroscopical and microscopical descriptions:</u>

The Dolomite series varies greatly in its textural and structural properties. Some of these properties may be original but others have been produced after consolidation of the rocks. Gradational alteration caused by pressure and the work of pervading solutions, may also be seen.

Some fifteen samples of the dolomite rocks were taken along different heights in the series. In section it was seen that no two samples were alike in texture and structure. Many thin sections were also made of metamorphosed rocks but these will be discussed separately.

(i) <u>Sections from the shallow water (shale-bearing) phase</u>:

The dolomite is about medium-grained, of grey colour and, according to the analysis (see page 23) almost a true dolomite. The thin section shows the dolomite to consist of an admixture of well-formed dolomite rhombs and anhedral grains, together with calcite with gliding lamellae. A few flakes of white mica lie scattered in the section.

The black carbonaceous shale is mostly cryptocrystalline and indeterminable, under the microscope. Microcrystalline quartz grains are present. The silica shows a slight elongation in the direction of schistosity. A qualitative test for carbon, probably in the form of graphite, gave a positive result (Analyst, Mr. C.J.Liebenberg, Division of Chemical Services, Pretoria). Quantitative analyses of similar shales in the dolomite of the West Rand proved that the amount of carbon actually present, viz. from 2.5 to 6% ( ), is much less than it appears in thin section.

A little higher up the dolomite is characterized by a greater content of muscovite. It is a fine to medium-grained dolomitic limestone with alternating dark and light coloured bands. The dark zone weathers more rapidly than the lighter one, suggesting that it is more calcitic. This unevenly weathered dolomite resembles a ripple-marked surface. The mica flakes, which are small, are more abundant in the darker bands (about 5%).

Together with these dolomites occur brownish, dolomitic limestones. The calcite is fine-grained, possessing gliding lamellae; it has irregular, broken outlines indicating signs of flow. The brown colour is possibly attributable to the presence of manganese or ferric oxides.

One interesting specimen, an impure limestone, was collected near the interbedded quartzite - shale horizon on Nooitgedacht 610 (east side of river). The rock contains irregular quartz grains, large calcite crystals, orthoclase, andesine, chlorite and cordierite with inclusions of slender needles - probably sillimanite. In a groundmass, consisting of these minerals, lie angular "pebbles" of dolomitic limestone and chert. This impure limestone shows little or no signs of metamorphism. This rock is probably an intercalation representing an interrruption in the regular deposition of pure limestone. Although the rock does not resemble Young's "mud cake - and "edgewise conglomerates" (21, p.124), it may be compared with them and probably also signify shallow water deposition.

One sample of dolomite from the shaly group showed minor development of oölitic structures (on staining) and is mainly a dolomitic limestone.

(ii) Sections from the deep water (cherty) phase:

The rocks in the lower half of this group are true dolomites according to microscopic evidence and stain tests. They are generally fine-grained, blue-black, equigranular rocks, weathering brown. A little silica is present. Staining proved that in some places the dolomitisation is uniform, but in others it is decidedly patchy in which case the dolomitisation has been less complete (30% dolomite and 70% calcite).

Higher up the rocks become progressively richer in silica and take on a slightly lighter colour. They are crystalline, dolomitic limestones. The quartz grains, which are larger than the grains of calcite, protrude on weathered surfaces, giving a "sand paper effect". The calcite crystals, of medium size, all have gliding lamellae. Some biotite has developed and tremolite fibers lie scattered here and there.

The following is a description of a specimen taken along a dolomite-chert contact on the farm Karoobult:-
The chert mosaic. Generally the quartz gives good uniaxial figures, but in a few cases biaxial interference figures were observed, this anomaly probably being due to stress. There are patches where small specks of calcite are mixed

with/...

with "flowed" silica, showing a schistose structure.
The dolomite: Large calcite crystals with gliding lamellae, and smaller grains comprise the groundmass of the dolomitic limestone.

Some distance above the main chert zone the dolomite limestones still contain large amounts of disseminated silica. A chert patch noticed in thin section contained finely disseminated carbonate and ore material. Other minerals observed in these dolomitic limestones are: pyrite, often visible to the naked eye; plagioclase feldspar; tourmaline, of which two or three grains can usually be seen in one thin section. The latter have strong pleochroism with E red-violet and O dark green. A patch of chlorite and sericitic material was also observed, These rocks are thus fairly impure limestones.

Not much can be added to the discussion of the marbles and oölitic strata (see p.19). In some places, as on Pylkop, the marble zone is followed by a coarse-grained, dedolomitisized limestone. The whole thin section consists mainly of large anhedral to subhedral calcite grains, together with some smaller grains of the same mineral. They all show cleavages, mostly along two directions.

A sample of typical fine-grained, dark blue, dolomitic limestone was taken just below the banded ironstone contact on the farm Nooitgedacht 610. A chemical analysis of this sample is tabulated on page 23.

Calcite veins in the dolomite.

Calcite veins form irregular lenses with zig-zag patterns throughout the dolomite. Large patches of cleavage rhombohedrons of calcite lie scattered over the dolomite surface. They have a fairly pure white colour, are translucent to opaque, and the cleavage planes are often stained black by manganese oxides. The calcite of the veins exhibit gliding lamellae, some with biaxial negative interference figures, ($2V_{\gamma\alpha}$ about 6^{o}). They appear to have undergone a certain amount of stress. The biaxial clacite usually has broader twin lamellae which are often bent. The calcite bands are undoubtedly of metasomatic origin and older than the period of plastic flow - Fockema (2, P.25).

Quartz veins in the dolomite.

In both the lower and upper phases of the Dolomite series, quartz veins are found, aligned parallel to the general strike of the dolomite. A vein, some 7 feet thick on the farm De Hoop, just below the Banded ironstone horizon, was seen to consist of a milky-white, translucent mosaic of quartz. A vein in the lower dolomite is well exposed on Nooitgedacht 610, on the west side of the river.

(d) Analyses of two rocks from the Dolomite series:

	I	II
SiO_2	0.7%	21.53%
Al_2O_3		0.36
Fe_2O_3		2.24
MgO	22.1	3.48
CaO	30.1	38.80
H_2O^+	0.0	
H_2O^-	0.0	
CO_2	46.3	31.96
	99.6%	98.37%

Rock No. I was collected just above the contact of the Black reef and the dolomite, on the farm Karoobult

536/...

536 (Analyst Dr. C.F.J. van der Walt, Division of Chemical Services, Pretoria). Rock. No. II was collected just below the contact of the dolomite and the Banded ironstone, on the farm Nooitgedacht 610 (Analyst, C.J. Liebenberg, Division of Chemical Services, Pretoria).

The ratio of carbonates in rock No. I is: 57.66% $CaCo_3$ to 42.34% $MgCo_3$. In rock No. II the figures are 9.177% and 8.23% respectively. The main difference between the two rocks lies in the fact that No. II contains about 20% more silica and about the same weight less of $MgCo_3$ than No. I. The nearby presence of chert bands to the locality where rock No. II was collected, and the rounded nature of the silica in the thin section, favour the possibility that the original limestone contained more quartz and that dolomitisation was less complete.

(e) Metamorphism of the Dolomite series:

1) Regional metamorphism:

The dolomite occurring in the limbs of the complex dome is traversed in all directions by bundles of tremolite. This mineral is most common in the chert horizon, where it makes its appearance as small fibres and prisms along the contact planes of the dolomite and chert bands. It may also be found in the siliceous dolomitic limestones. This form of tremolite is clearly the product of low degree regional metamorphism (3, p.257).

The following are descriptions of thin sections to illustrate the more common occurrences of this important stress mineral:

(i) A highly tremolitic dolomite below the chert horizon on Karoobult.

The/...

The tremolite occurs as colourless, radiating clusters of long bladed tremolite crystals. In the absence of impurities it is possible that the tremolite persisted into a higher grade of metamorphism, with the crystals taking on larger dimensions (3, p.257). The crystals are extensively cracked and broken up as well as being bent, leading one to conclude a period of deformation after their formation (2, p.27).

(ii) Specimen from Nooitgedacht 610 (west side of river).

A grey dolomite from the lower shaly phase with an even distribution of long tremolite needles. In this section large tremolite needles are seen to lie in a groundmass of finely distributed calcite and small tremolite needles. About 80% of the section comprises tremolite, the rest being calcitic. The tremolite has $2V\gamma = 80^{\circ}$ and $Z/C = 15^{\circ} - 16^{\circ}$.

(iii) Specimen from the main chert zone on Nooitgedacht 610 (along the Rustenburg road).

This section constitutes that part of the Dolomite series where the thinner chert bands have been almost completely replaced by tremolite. Carbonate material remains as well as some chert. Some biotite and a little muscovite have formed, representing the chloritic and micaceous impurities originally present. This type of metamorphic product is widespread and was also noticed on Karoobult and Boschkop.

(iv) Specimen from the south-eastern corner of the farm Brosdoornhoek.

Occurring just above the chert zone, this rock consists of approximately equal amounts of euhedral crystals of tremolite and calcite. There is also some biotite. Optical axial angle 2Va of the tremolite is 82° and $Z/C = 15^{\circ} - 16^{\circ}$.

2) Thermal metamorphism produced by the Bushveld igneous complex:

Fockema noticed an uneven increase in intensity of regional metamorphism from the centre of the area investigated by him to the granite contact (2, p.78). He further mentions that, at the actual contact, thermal metamorphism predominates. Somewhat similar conditions were found to exist in the area under discussion, and that thermal metamorphism may even predominate some distance from the granite contact. The following examples may be quoted:

(i) Dolomite contact with metamorphosed chert bodies:

In the field the chert appears as nodular bodies and small lenses completely surrounded by dolomite. Microscopical examination of a sample from Pylkop, along the main road to Rustenburg, shows that the nodular part consists of diopside and recrystallised calcite. The diopside shows signs of incipient alteration along cleavage lines. A few small tremolite needles are also present. According to Harker (3, p.85) this rock corresponds to a thermally metamorphosed impure, magnesium limestone "in which the original dolomitic rock contained more silica than would suffice to convert all the magnesia to forsterite, a lime-bearing silicate making its appearance". This lime-bearing silicate is diopside. The diopside has $2V\gamma = 60^{\circ}$, $Z/C = 37^{\circ} - 38^{\circ}$.

(ii) Along the north-eastern boundary of Buffelskraal the shales in the lower dolomite have also undergone thermal metamorphism.

These carbonaceous shales were originally probably fairly rich in calcite and quartz. They have been altered to cordierite plagioclase - hornfelses (3,p.92).

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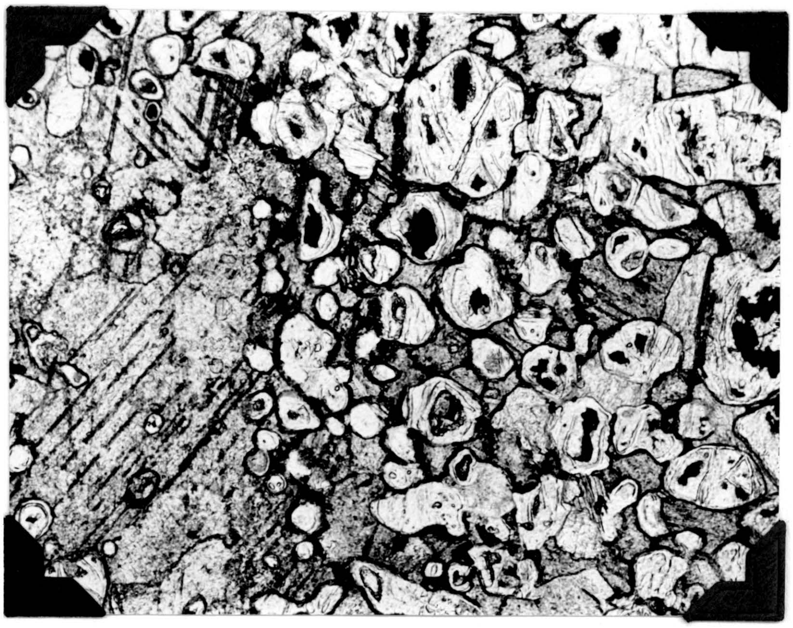

PLATE 8.

Photomicrograph of a forsterite-marble showing anhedral forsterite crystals which have been altered to serpentine. The central, dark portions consist of separated, ferruginous matter. The mineral showing cleavage is calcite.

In thin section the cordierite is stained by inclusions of carbonaceous matter. A little biotite is also present. The plagioclase feldspar is a subordinate constituent appearing as very small crystals.

(iii) Along the northern boundary of the farm Wachteenbeetje the dolomites have been altered by low grade thermal metamorphism to forsterite marbles.

The calcite recrystallised to a coarser grain. The forsterite appears as round, anhedral crystals in an interlocking mass of large calcite crystals. Most of the forsterite has now altered to serpentine with the concomitant separation of ferruginous matter, which in this particular instance has settled in the central part of the serpentine (See Plate 8). Some crystals have shells of light coloured serpentine, the core being unaffected by alteration. It appears that the rocks have been affected by directed pressure subsequent to their metamorphism, as the bands are often broken up and interflowed.

3) Pneumatolytic metamorphism produced by the Bushveld igneous complex:

Extensive outcrops of dull white, metamorphosed dolomitic limestones are present on the farm Nooitgedacht 610, on the western side of the river. They are remarkable in that they show definite signs of having undergone pneumatolytic transformation superimposed on thermal metamorphism.

The most important constituent of this rock is phlogopite, occurring as well-formed, tabular prismatic crystals (see Plate 9). Macroscopically the crystals are brownish but in thin section they are almost colourless and only slightly pleochroic. In some places the phlogopite

is/...

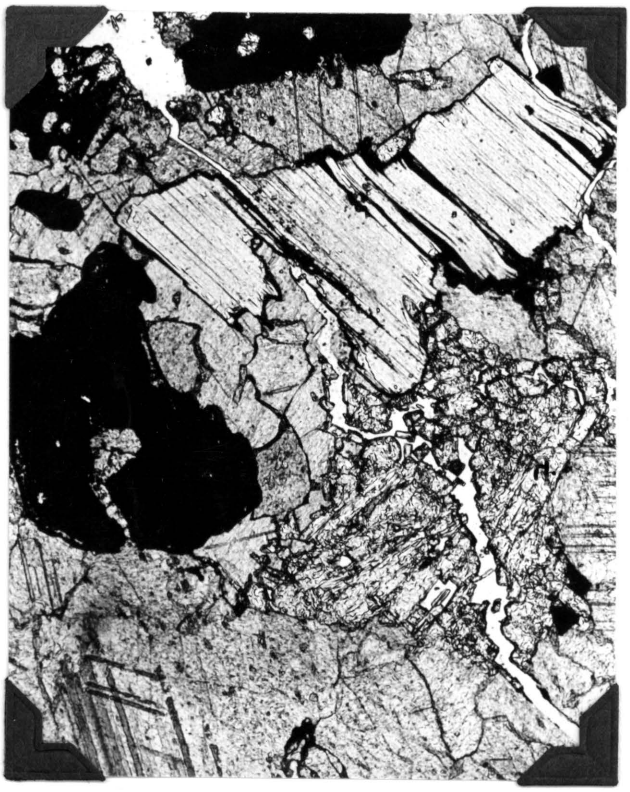

PLATE 9.

Photomicrograph of an altered magnesian limestone. A large crystal of phlogopite (upper-centre) is in contact with a cluster of forsterite crystals (centre-right). The dark mineral is magnetite. Calcite grains, some with good cleavage, are also present.

is evenly distributed throughout the groundmass but in others it shows distinct signs of segregation to nodular aggregates. A copper-rich mineral (determined from a spectrographic analysis) is another typical pneumatolytic product, occurring in the rock as small irregular specks.

Idioblastic crystals of forsterite also occur, set in a matrix of large calcite crystals (Plate 9). A few slightly bioxial calcite grains are also present. The original rock was a magnesium limestone with silica as its only impurity (3, p.84).

A specimen collected further west of the one just described, revealed, in addition to the above mentioned minerals, some anhedral apatite, and magnetite with inclusions of apatite. The phlogopite in this section is fairly pleochroic with x = colourless, z = light brown (Plate 9). This darkening of colour is explained by the relatively high content of iron in the molecule (18, p.274). The refractive index $n\beta$ of the phlogopite is 1.588 ($\pm$ 0.005). The phlogopite gives an interference figure which is pseudo-uniaxial.

From the preceding description of the metamorphism of the dolomite it seems likely that an igneous intrusion, in all probability granitic, lies in the core of the dome structure. This magma first produced the thermal metamorphism, followed by pneumatolysis in the late magmatic period.

4) Thermal metamorphism along dykes:

The dolomite has in places been altered by nepheline-bearing dykes. Along the dykes on Krokodilkraal and Nooitgedacht 604 the dolomites have been affected, tremolite and muscovite being the products of the

metamorphism/...

metamorphism. These two minerals are clearly visible in the field, the tremolite needles often measuring over 1 inch in length. Muscovite flakes may be seen protruding on the weathered surfaces.

The muscovite flakes are subhedral to euhedral and are evenly distributed throughout the dolomite groundmass. The tremolite appears as conspicuous radiating clusters and is partly altered to calcite. Tremolite and muscovite are developed all along the strike of the dykes, where they are visible. About 20 feet away from the dyke contact these two minerals do not appear in the dolomite.

There are no signs of stress which may have aided the formation of the tremolite, and it certainly does seem in this specific instance that the tremolite formed as a result of the thermal metamorphism produced by the intrusion of the dykes.

5) Pneumatolytic metamorphism in the Kruidfontein volcanic pipe:

On the northern boundary of the farm Kruidfontein a large mass of dolomitic limestone lies xenolythically in the pipe and is bounded on both sides by prominent ridges built by breccias.

The magnesian limestones have altered to dolomitic marbles, showing a great diversity in colour but being mostly light or dark brown. The calcite crystals have irregular forms and discontinuous outlines due to recrystallisation. Near the breccia contact the dolomite has been altered to a hard, compact, fine-grained, light-grey marble with small specks of hematite.

The course of metamorphism is somewhat varied from place to place, owing to the amount of impurities originally present. In one section long subhedral crystals of biotite have formed. In contrast to other sections, sericite is not present here because it (and most of the chlorite) has been used in the formation of the biotite. Other minerals are titanite and magnetite. The pneumatolytic mineral fluorite is well represented in most thin sections.

THE BANDED IRONSTONES.

(a) Distribution:

The Banded ironstones represent the uppermost horizon of the Dolomite series. On Karoobult they are separated from the underlying upper, blue dolomitic limestones by a thin layer of chert, whereas on Brosdoornhoek the contact layer is a compact jaspilite about 10 - 15 feet thick. Along the strike westwards this jaspilite changes to a banded chert. On Pylkop the banded ironstones follow immediately on the dolomite. The areal distribution of the banded ironstones was discussed together with that of the Dolomite series (p.15).

(b) Succession, general characteristics and microscopical description:

In the Thaba Zimbi area (11) the banded ironstones have been subdivided into three distinct horizons. This division is also applicable in this area.

The lower horizon:

It is made up of alternating black iron-rich and brown silica-rich bands. The iron may be in the form of hematite, limonite, or magnetite. Generally the contact

PLATE 10.

A portion of the Kroemahoek mountain range showing the lower (A), middle (B), and upper (C) horizons of the banded ironstones.

between the bands is sharp. The individual bands vary in thickness from a fraction of an inch to about 1 inch. Iron and silica are present in about equal amount, but in some specimens silica predominates.

The following is a microscopical description of a sample from the farm Brosdoornhoek:-
The iron-layers, having an average thickness of about 0.33 inches, comprise fine-grained magnetite with little or no silica. The silica bands consist of an equidimensional fine-grained mosaic of quartz with small magnetite specks spread throughout. Magnetite forms about 5% of these bands.

Small concretions of silica in the banded ironstones of this horizon are common, and clearly of syngenetic origin. They are spheroidal in shape, the average dimension being 0.4 x 0.15 inches.

Asymmetrical ripple marks were seen, but it is possible that they are the pseudo-ripples mentioned by Fockema (2 p.34).

<u>The middle horizon</u>:

This horizon weathers more easily than the other two horizons and the banding is not well-defined (Plate 10).

<u>The upper horizon</u>:

The individual bands of silica and iron, measuring respectively on the average 0.5 and 0.3 inches across, are much thicker in the lower and middle horizons.

North of the Kroemahoek trigonometrical station a band of brown medium-grained limestone was seen in the upper horizon near its contact with the overlying Pretoria series.

PLATE 11.

Camera lucida sketch of pyroxene-granulite from Liverpool.
A. Acmite.
B. Hornblende.

It is but a few feet thick and is equi-granular with the major dimension of the calcite grains averaging 0.7 m.m. Also present are interstitial mica flakes, probably muscovite, with slight pleochroism - x = colourless, z = pale yellow.

Thickness: The thickness of the Banded ironstone group varies from about 100 feet, as on De Hoop, to a maximum of about 700 feet along a well-exposed section east of the Kroemahoek trigonometrical station.

(c) Metamorphism of the Banded ironstones:

On Elandsfontein, silicified bands of asbestos measuring from 0.5 inches to mere streaks, appear in the upper horizon of the banded ironstones. The asbestos has developed in the iron-bearing bands. According to A.L. du Toit (17), the magnetite, which was not used up in the formation of the asbestos, collected along the edges of the bands. This is evident in thin section and can also be observed macroscopically.

In specimens collected from Elandsfontein, it could be observed that where one seam of asbestos thins out the contiguous one thickens and vice versa. This phenomenon of the antipathetic relations in reefs has also been well-established by du Toit (17, p.181).

The silica, which replaced the asbestos, has retained the fibrous habit. The fibres stand at right angles to the banding and are bent.

On Liverpool the banded ironstones have been altered to crocidolite-bearing rocks. With the Bushveld igneous transgression just to the west, and definite signs of deformation such as drag folding and dislocations in the banded ironstones, it is probable that the metamorphism took place during Bushveld times.

Following is a microscopical description of a thin section from Liverpool:-

The silica bands contain about 40% of small, slender, blue crocidolite needles. The iron-rich bands consist of large subhedral magnetite crystals, closely interlocked. A third type of band contains silica, magnetite and crocidolite. One band was found to consist of large magnetite crystals with interstitial silica and amphibole. The amphibolitisation does not necessarily follow the banding as there are two strips of crocidolite which lie at an angle of 80° to it. The needle crocidolite has pleochroism with blue parallel to the crystallographic axis and light-yellow at right angles to it.

A pyroxene-granulite was collected from the metamorphosed banded ironstones on Liverpool. Due to lack of outcrops, its exact stratigraphical position could not be determined, but it would seem to occur in the lower horizon of the banded ironstones. In thin section acmite is seen to be the predominant mineral (Plate 11). The acmite is pleochroic with x = clear green, y = light-green, z = pale-yellow; $2\,V_{\gamma} = 64°$; $x/c = 4° - 6°$.

Hornblende appears as a thin vein traversing the section (Plate 11). The hornblende is pleochroic with x = pale-brown, z = dark-green, and has z/c = 16°. A somewhat similar rock is mentioned by A.L. du Toit (17) in which acmite is the only mineral developed.

Xenoliths of banded ironstones occur in the volcanic pipe on Kruidfontein. They have been much brecciated, but have undergone no metamorphism.

(3) Pretoria series:

A small strip of the Pretoria series has been isolated by the volcanic pipe on the farm Boschkop. The exposure, measuring about half a mile along the strike, is made up of a thin, brown, medium-grained quartzite-layer, overlying altered shales. The shales, which have been slightly affected by thermal metamorphism, contain a fair amount of weathered biotite, and muscovite is distributed throughout. Several grains of glaucophane are present and are apparently altering to a green sodic hronblende. Inequidimensional quartz, with a granoblastic distribution, is well represented.

This outcrop, being underlain by banded ironstones, probably belongs to the lower part of the Timeball Hill stage of the Pretoria series.

C. The Kruidfontein volcanic intrusion:

On Kruidfontein, porphyritic rocks in the form of a volcanic pipe, have intruded into a synclinal basin of sediments belonging to the Transvaal system. Breccias, forming elevated ground, also resulted from the volcanic activity. Only the western portion of this diatreme, which has an average diameter of 2 miles, was mapped. The eastern extension of the vent has been described by Fockema (2, p.60).

Good outcrops of the porphyries occur on the southern portion of Boschkop. On Kruidfontein certain rocks were encountered which have been highly altered by the invasion of carbonates. Since some doubt exists about their origin,

they/

they have not been designated by any symbol on the geological map.

The volcanic breccias form two prominent ridges on Kruidfontein and Boschkop. Near the Elandsfontein-Kruidfontein boundary the two ridges converge, striking south for about 2½ miles before finally swinging eastwards.

The porphyries are dark-coloured rocks which develop a pitted surface on weathering due to the rapid alteration of the insets which may attain lengths of up to 6 m.m. Microscopical examination shows that the phenoclasts consist of calcite and chlorite, pseudomorphous after pyroxene (Plate 12). These phenoclasts, and idiomorphs of magnetite having an average diameter of 0.4 m.m., occur in a groundmass which consists of approximately equal amounts of fine magnetite dust and alkali feldspar. The mineralogy of this rock is similar to that of a lamprophyric monchiquite from the Franspoort line (13, p.86).

The porphyries show great variation in texture. In Plate 12 a distinct contrast exists between the texture of the groundmass on either side of a well defined line. This suggests subsequent fracturing and brecciation of the porphyries.

In the volcanic breccias the included fragments vary greatly in size. They are chert, dolomite, banded ironstone, porphyry, quartzite and bostonite. The latter occurs as small fragments consisting exclusively of small red alkali feldspars showing trachytic textures. These fragments may be compared with the non-porphyritic bostonite dyke from Nooitgedacht 610 (See p.39).

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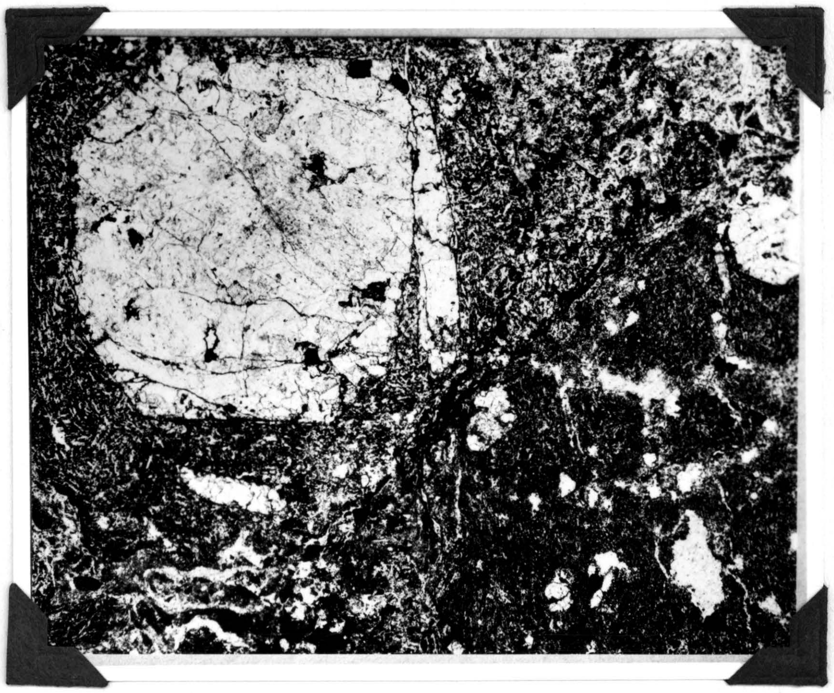

PLATE 12.

Photomicrograph of a typical porphyry from Boschkop showing a large phenoclast of replaced pyroxene in a groundmass of minute alkali feldspar laths and magnetite dust. X21 (parallel nicols).

The material cementing the fragments is usually red and consists of slightly devitrified glass with iron oxides, plagioclase and alkali feldspar. Calcite occurs as veins and could also be seen to replace plagioclase. Irregular veins of fluorite and chloritic material are also present.

The rocks surrounding the diatreme are sediments of the Pretoria and Dolomite series. Large xenoliths of dolomite and banded ironstone which were already mentioned under the discussion of these sediments, occur isolated in the volcanic vent.

On the western portion of Kruidfontein a xenolith of conglomerates and quartzites was encountered. The outcrop measures approximately 3/4 mile along the strike, and is about 1/4 mile wide. In the conglomerate well rounded pebbles, mainly of vein quartz and brown hornfels, are unevenly distributed in a brown, fine-grained matrix. Under the microscope the matrix is seen to consist mainly of quartz grains, the interstices being filled with very fine-grained quartz and mica. Many of the larger quartz grains show undulatory extinction. The majority of them show undisputable signs of secondary growth. The original outline, as revealed by a thin strip of dark mineral matter, indicates that the quartz grains were well rounded before the period of secondary enlargement.

Away from the main conglomerate zone the pebbles become less numerous, and the groundmass now comprises the bulk of the rock. Finally, the latter gives rise to quartzites with a rounded pebble embedded here and there. These rocks may belong to the Waterberg or Rooiberg formations (16, p.162).

Following/...

Following on the conglomerate and pebbly quartzite, reddish brown, medium-grained quartzites occur, which look like typical Waterberg sediments (16, p.186).

D. Post-Karroo fault breccias.

(a) Distribution:

The breccias are best developed on Boschkop mountain forming fairly precipitous scarps. They commence at the river bend (see map) and follow a straight course to the summit of the mountain. They are also to be seen on the farm Elandsfontein, where a dip fault has displaced the banded ironstones.

Previous work:

On sheet No. 12 (Pilansberg) of the Geological Survey of the Union of South Africa these fault breccias have been designated as Kruidfontein volcanic breccias. In thin section silica and iron ores are seen to be the main constituents. Further, the linking of the Boschkop breccias with the fault cutting the banded ironstones eastward along the Crocodile river (see map), and the presence of similar breccias along the dip fault in Elandsfontein, clearly indicates an association of these breccias with faulting and not with volcanic breccias, as was previously supposed.

(b) General and microscopical description:

The Boschkop breccias attain a maximum visible thickness of about 100 feet. They are usually red-coloured, but more striking varieties have angular fragments and smaller particles of white chert material embedded in the matrix. This typical mortar structure is representative of an advanced stage of crushing. The silica of the groundmass is

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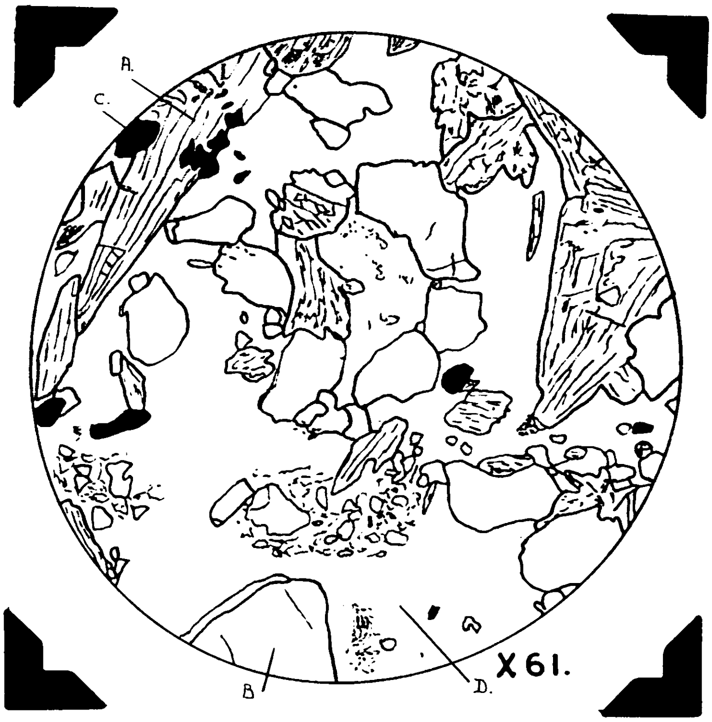

PLATE 13.

Camera lucida sketch of altered sheet showing anthophyllite (A), quartz (B), and magnetite (C) in a base of optically continuous cordierite (D).

bound by interstitial oxides of iron which causes the red colour of the rocks.

Near the top of Boschkop mountain the breccias have a darker colour and fragments of banded ironstone are visible. Usually the banded ironstones are "hematised". The original banding is still preserved, although the bands are discontinuous owing to brecciation. In the darker breccias the silica of the groundmass has been completely replaced by hematite and magnetite.

These fault breccias are almost identical with those described by Fockema, who forwarded definite proof in favour of their post-Karroo origin (2, p.75). In the discussion of the tectonics of the area, it will be shown that they are younger than the dislocations of Bushveld age.

E. Sills and dykes:

(1) Sill of anthophyllite - cordierite - quartz-rock:

This rock which has a sheet-like disposition in the upper part of the Black reef series at, or near, the contact of the shales and quartzites, generally attains a thickness of some 15 feet. It outcrops extensively on Knopieskop, Karoobult and near the western border of Nooitgedacht 610.

The rock consists mainly of quartz and anthophyllite, lying in a matrix of optically continuous cordierite (Plate 13). The quartz shows signs of having undergone stress as it is slightly fractured and the larger grains show undulatory extinction. The anthophyllite is colourless, occurring as columnar crystals and smaller needles. It has $2V_{\gamma} = 76°$. Diamond-shaped cleavages are well developed. The cordierite

has/...

has 2Va = 71°. A small amount of magnetite and apatite is also present.

Harker describes an anthophyllite rock which resulted from the metasomatism of a dolerite (3, p.134). Except for the presence of quartz, this sheet shows a marked similarity to the rock described by Harker.

Taking the fracturing of the quartz into account, it is possible that the original rock suffered the combined effect of metasomatism and dynamical metamorphism. In all the instances mentioned by Harker, the alteration is mainly ascribed to the agency of heated waters from granite magmas. It is possible that the Bushveld red granite afforded the volatiles necessary for the metasomatic transformation in this area. This consideration furnishes further evidence in favour of the Crocodile river sedimentary fragment lying in granite (see page 35).

(2) Bostonite dykes:

Two bostonite dykes occur to the north-east of the Kruidfontein vent on Nooitgedacht 610. The dykes are about 10 feet thick and can be traced for about one mile and half a mile respectively.

The longer dyke has tabular phenocrysts of orthoclase set in a medium-grained groundmass of red alkali feldspar showing trachytic texture. The phenocrysts, which sometimes measure up to 0.75 inches along their major axies, are all orientated with this axis parallel to the direction of flow. The rock may be termed a porphyritic, trachytic bostonite (6, p.27). In the shorter dyke the porphyritic texture is not developed. The presence of a few patches of secondary calcite-chlorite material suggests the former presence of ferro-magnesium silicates. The groundmass feldspars clearly flowed around these calcite-chlorite patches. In one instance the crystal-outline of the original mineral is still visible. The chlorite possesses a peculiar radiating extinction. A little hematite is present.

(3) Dioritic and syenitic dykes occuring around the Kruidfontein diatreme.

On the eastern side of the Kruidfontein vent Fockema describes certain dykes which have a radiate arrangement in the dolomite around the pipe (2, p.62). Similar dykes which seem to be restricted to the area immediately surrounding the volcano, were also observed on its western side. The dykes form discontinuous outcrops, are very thin, fine-grained and highly altered. These dykes have not been mapped.

Fockema was able to establish that the more basic varieties are diorites to quartz diorites (2, p.64). In the alkali-rich varieties alkali feldspar constitutes about 40 to 65% by volume of the rock. Hypersthene with $2V_{\gamma} = 78^{\circ}$ and pleochroism x = light brown, z = brown usually accompanies the feldspar and occurs as insets or smaller needles in the groundmass. Wedge-shaped titanite with pleochroism x = brown, z = light brown and idomorphic apatite are accessories.

(4) Sill of peralkaline shonkinite:

A sill-like intrusion of dark green alkaline shonkinite occurs near the upper contact of the interbedded quartzites and the dolomites on Nooitgedacht 610.

Aegirine/...

Aegirine-augite is usually the main constituent of the rock. The pyroxene is intensely pleochroic with x = green, y = light green, z = light brown. The optical axial angle is about 90° and z/c = 67° - 70°. The alkali feldspar is mainly microperthite with orthoclase and microcline present in subordinate amounts. Andesine (An 35) is sparingly distributed. Apatite, calcite and brown wedges of sphene are the other accessories (Plate 14).

The mineral composition of the shonkinite sill is variable. Sometimes the alkali feldspar increases at the expense of the aegirine-augite to such an extent that the rock becomes a syenite.

(5) Nepheline-bearing dykes:

The nepheline-bearing dykes in this area have a haphazard distribution and do not seem to be aligned in any prominent tectonic direction. They are probably of Pilansberg age.

The nepheline content in the individual dykes is variable. The dykes striking N-S on Nooitgedacht 610 (near the Crocodile river) on Wachteenbeetje and on Liverpool (just east of the Slipfontein trigonometrical beacon), as well as the dyke striking N.W.-S.E. on Nooitgedacht 604, have a rock type intermediate between urtite and ijolite in their central portions, and syenite along their walls. The field evidence suggests that the contact between the two rock types is sharp rather than gradational. No chilled contacts could be observed but the transition takes place within 8 feet at the most. In the dyke on Krokodilkraal the same relation seems to hold for nepheline-rich (foyaitic) in the central portion and nepheline-poor (syenitic) along the margins.

(a)/...

PLATE 14.

Camera lucida sketch of a shonkinite from Nooitgedacht 604 illustrating the following minerals: a. Perthite. b. Apatite
c. Calcite. d. Pyroxene (aegirine-augite).

(a) Composite urtite ijolite and syenite dyke:

The urtite-ijolite is a green rock in contrast with the reddish syenite.

Microscopical examination of urtite-ijolite shows prismatic crystals of nepheline which usually constitute about 70% of the rock by volume. The nepheline invariably contains inclusions of pyroxene and occasionally also of apatite. Twinning of the nepheline was observed. The pyroxenes generally form about 30% by volume of the rock and occur as large phenocrysts and short prismatic crystals (Plate 14). The clinopyroxene is usually zonally built with the core varying from diopside ($2V_\gamma = 58^\circ$ Z/c = $33^\circ - 37^\circ$) to augite ($2V_\gamma = 57^\circ$- 60°, Z/c = $42^\circ - 48^\circ$). The mantle invariably consists of aegirine with x/c = 3° and pleochroism x = green, z = light brown. Homogeneous pyroxene crystals have $2V_\gamma = 57^\circ$ and Z/c = 42°. Apatite and titanite are accessories.

The syenites bordering the ijolite-urtite are generally altered. They are fine to medium-grained and consist of red alkali feldspar, altered pyroxene and magnetite. The acicular pyroxene has been altered to sericite and chlorite. The magnetite also seems to be pseudomorphous after pyroxene. Apatite is a common accessory mineral in the syenite, and calcite sometimes occurs associated with magnetite.

(b) Composite nepheline syenite and foyaite dyke:

The alkali feldspar which constitutes about 65% of the nepheline syenite is microperthite with subordinate orthoclase. The pyroxene has the same composition and habit

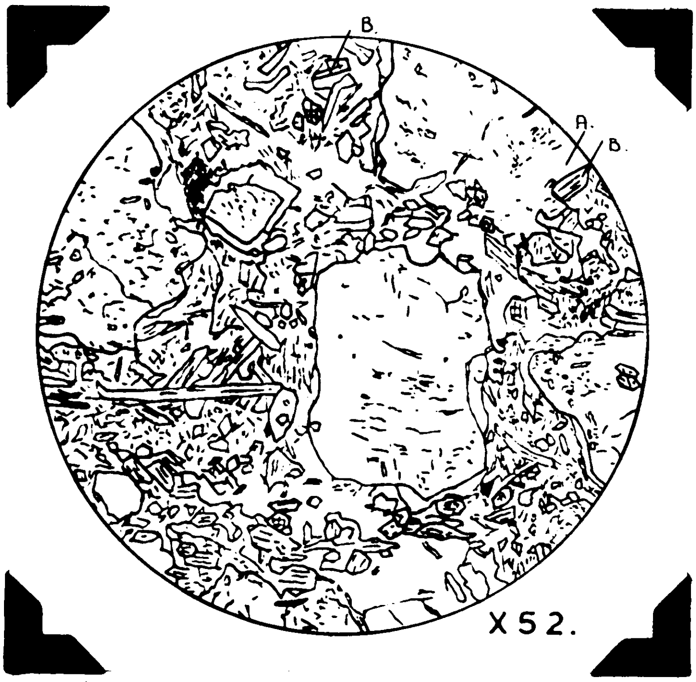

PLATE 15.

Camera lucida sketch of an urtite-ijolite from the Nooitgedacht-Boschkop boundary. A. Nepheline. B. Pyroxene.

as in the urtite-ijolites, and forms about 25% by volume of the rock. The nepheline shows signs of alteration to sericite. Abundant apatite is present. Along the inner borders of the dyke nepheline becomes more abundant and this foyaitic variety forms a composite structure with the variety poorer in nepheline (syenite).

(6) Dolerite dykes:

Discontinuous outcrops of dolerite occur throughout the area. These dykes have not been mapped. At the base of the Kroemahoek mountains, one dyke could be followed for some distance. Two dolerite dykes were also observed cutting through rocks of the Kruidfontein diatreme.

The rocks consist of labradorite laths having a sub-ophitic relation to augite. Magnetite, secondary chlorite and calcite are also present.

V. TECTONICS AND STRUCTURE.

The tectonic characteristics of the great Crocodile river fragment, including that part investigated by the writer, has been described by Fockema (2, p.91). The major structures in the area are two major anticlines with two complementary synclines. This structure originated during the intrusion of the Bushveld igneous complex. Fockema suggests that the structure developed either as a result of the rising of the fragment from the floor (A.L. du Toit), or, sinking from the roof (F.C. Truter - verbal communication). In the latter case it is assumed by Truter that the magma welled up in a dome structure, comprising sediments of the Transvaal system. This dome structure may have been centrally

PLATE 16.

Photomicrograph of nepheline-syenite from Krokodilkraal showing zoned pyroxene crystals in a base of alkali feldspars. The cores of the pyroxenes vary from diopside to augite, whereas the rims are always aegerine. Elsewhere in the section nepheline may be seen.
X170 (parallel nicols).

centrally dimpled. The roof foundered through failure of the elastic strength and granite forced through the gap formed in this way.

Fockema goes on to say that gabbro probably consolidated in the cores of the anticlines. The development of pneumatolised dolomite (see page 37), and of the metasomatised sheet (see page 50), points to the presence of granite rather than gabbro. It must then be assumed that, while the fragment floated in the granite, the latter solidified so that the more dense basic gabbro was not reached.

The forces mainly responsible for this structure are the upward force x (2,p.81), the downward force of gravity, and horizontal compressional forces produced by the surrounding granite. The compressional forces, acting in all azimuths, collectively produced the effect of a couple with a S - N configuration; this is exemplified by the Nooitgedacht complex dome, which has its major axis lineated in that direction.

Other small folds are visible, as on Doornpoort (a small syncline in Black reef sediments) and Roodepan (drag folds in the banded ironstones) (Plate 17).

As a result of the compression undergone by the Crocodile river fragment, faulting resulted and relieved the compression. Several smaller dip faults have been mapped (Plate 18), but the most important fault is the S - N striking tear fault from Boschkop and Nooitgedacht 610 with a maximum separation of about 1200 yards measured parallel to the strike of the fault. This fault may be compared

with/...

PLATE 17

showing a small drag fold in the lower horizon of the banded ironstones on Roodepan.

PLATE 18.

A well-defined fault in the upper horizon of the banded ironstones (Kroemahoek mountain range). The fault strikes towards the observer and passes along the little neck in the centre of the photograph.

with the N - S striking faults from the Kameelfontein trigonometrical station (2, p.82). The Boschkop fault cannot be followed in the Kruidfontein diatreme, and is therefore older than the latter. A similar fault with a much smaller displacement developed on Doornpoort (page 13). Here fractures in the quartzites of the Black reef have been filled with dolomite, which flowed plastically. This plastic deformation of the dolomite is noticeable in many places and it is for this reason difficult to locate faults in this series.

Post-Karroo faulting:

The fault breccias from Boschkop have been previously correlated with post-Karroo faults (see page 37). East of Boschkop mountain the banded ironstones have been down-faulted, and on the mountain two smaller faults with typical breccias, are apparently linked with the main fault.

Similarly on Elandsfontein, the post-Karroo fault, accompanied by the inevitable red breccias, has apparently downfaulted the banded ironstones.

VI. ECONOMIC ASPECTS.

1. Asbestos:

(a) The silicified asbestos bands from Elandsfontein are fairly thick and extensive, but it would be necessary to make fairly deep prospecting pits in order to obtain fresh material.

(b) The bands of needle crocidolite which occur on Liverpool are so thin and inconsistent as to be of no economical significance.

2. Iron deposits:

(i) Hematite from Boschkop mountain:-

Intimately associated with post-Karroo faults are several lense-like deposits of hematite. In some, the original banding, although much broken, is preserved, and they are clearly "hematised" banded ironstones. The association of the hematite with the faults, and its presence in the breccias, suggests that the mineralisation occurred in post-Karroo times.

(ii) In the Kroemahoek mountain range a small hematite deposit is linked with a fault.

3. Lead:

The lead deposits of Boschkop are dealt with in the "Lead deposits in the Union and S.W.A." (19).

Since this report further prospecting has been conducted, and the small stringers of galena in the cherty phase of the Dolomite series were found to remain thin and inconsistent. The lead occurs in a much brecciated zone.

In thin section it was seen that the galena has replaced the calcite. On either side of the galena is a fine-grained mass of unreplaced carbonate.

4. Marble:

(a) The marble bands below the banded ironstones have been described on page 18; they are unsuitable for decorative purposes.

(b) Near the lead occurrence is a zone of well-banded light coloured travertine marble.

VII/...

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