Table 9. The vertical distribution of Marker-beds in the Ouplaas-Botha area

| Marker-bed | Thickness | Rock-type | Remarks |
|---|---|---|---|
| Potsherd Marker | approximately two feet | Disc-like fragment of white-grey chert set in a matrix of ferruginous chert | Impersistent. Found about 340 feet above Main Marker. |
| Magnetite-chert Marker | Six to eight feet | Thickly bedded banded ironstone | Very conspicuous. Approximately 220 feet above Main Marker. Seams of crocidolite (Griqualandite in outcrop) commonly associated. |
| Speckled Marker | Approximately one foot | Chocolate-brown chert with concretions of yellow chert | Impersistent. About 160 feet above the Main Marker. |
| Main Marker | 40 to 60 feet | Poorly bedded jasper and intercalations of banded ironstone and fragmental material | Conspicuous. Often contains seams of crocidolite. |

(c) The vertical distribution of crocidolite-bearing zones

The crocidolite zones which are found above the Main Marker may be correlated with the First Upper, Second Upper (associated with the magnetite-chert bed some 30 to 40 feet below the Magnetite-chert Marker) and the Third Upper (associated with the Magnetite-chert Marker) of the Kuruman area. The First Upper Zone continues well into the Main Marker and is an important crocidolite-bearing zone in the area. This zone is mined on a large scale in the Ouplaas Mine. At this centre very little fibre is actually located above the zone of fragmental material which represents the top of the Main Marker; seams are developed only over a vertical distance of about one foot immediately above this zone. The remainder of the mineable reefs

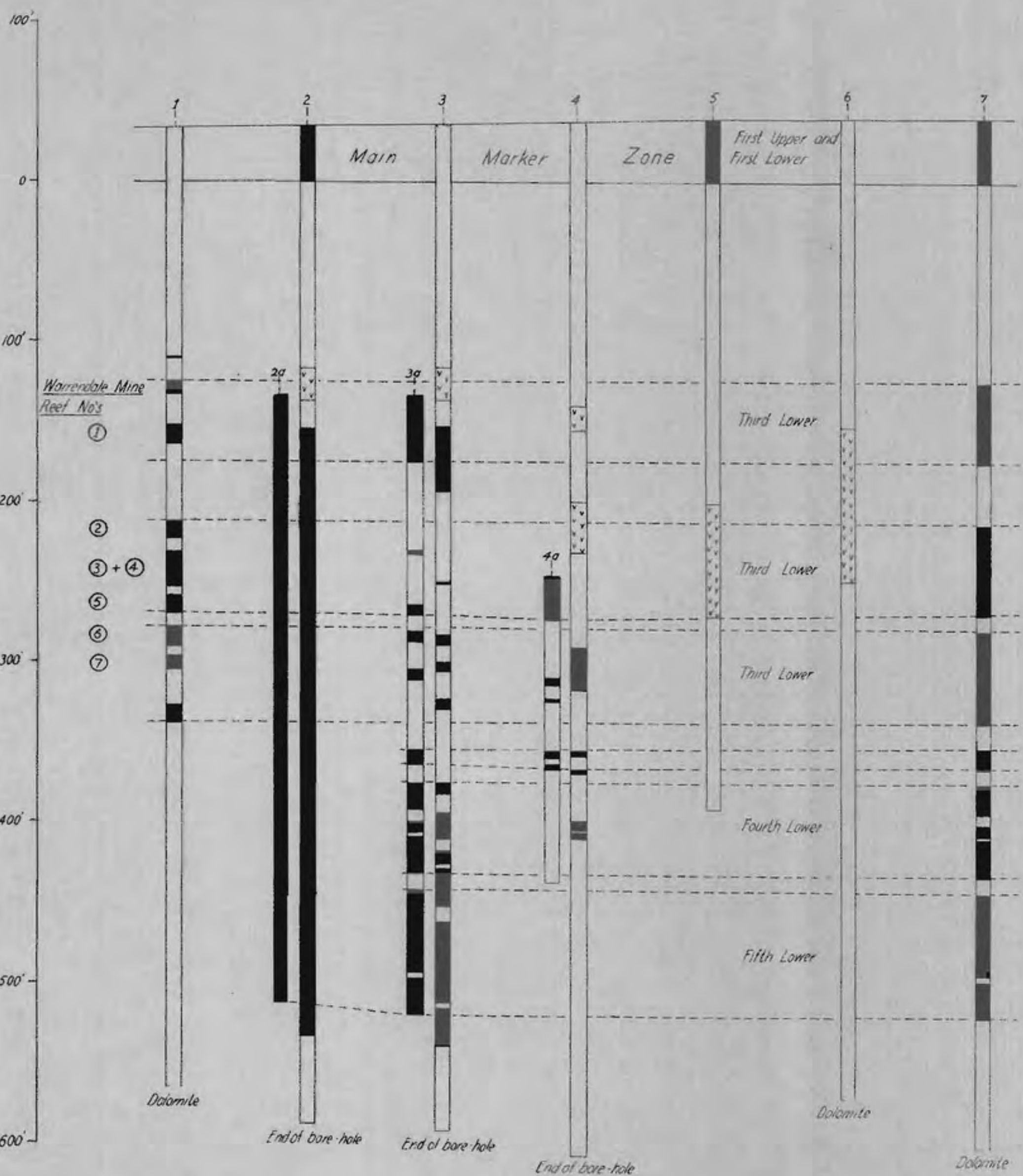


FIGURE 5 THE VERTICAL DISTRIBUTION OF CROCIDOLITE — BEARING INTERSECTIONS WITH REFERENCE TO THE MAIN MARKER, BOTHA—OUPLAAS AREA.

Note: For correlation purposes the width of the sills have been subtracted

Legend

Diabase

Banded ironstone

Crocidolite-bearing zone

1 Bore-hole on Botha
2,3 + 4 Bore-holes on Owendale
5 Bore-hole on Ouplaas
6 Bore-hole on Lemoenkloof
7 Generalised section showing the distribution of crocidolite-bearing zones

Sections 2a, 3a and 4a show vertical depths of crocidolite-bearing zones after elimination of diabase in the sections of bore-holes 2, 3 and 4 at this mine are located within the Main Marker so that in this area this zone should actually be referred to as the Main Marker Zone. The crocidolite seams immediately above the Main Marker in the Ouplaas Mine are separated by fragmentary material, about four feet thick, from an underlying fibre-bearing zone ranging in width from 20 to 30 feet. The crocidolite seams become thinner and eventually disappear completely towards the base of the Main Marker. The base of the Main Marker in the mine is characterised by a second zone of fragmental material which measures about three feet in thickness. Immediately below this zone, crocidolite-bearing seams are developed over a negligible width only. These secondary seams of fibre actually represent the First Lower which is generally poorly developed in the area around Danielskuil.

The vertical distribution of crocidolite-bearing zones below the Main Marker in the Ouplaas-Botha area can hardly be correlated in detail with the crocidolite-bearing zones in the Kuruman area. This is due to the fact that the crocidolite seams in the former area are in places closely distributed over vertical distances of about 400 feet. Such thick crocidolite-bearing zones have been penetrated in bore-holes on the farm Owendale.

The vertical distribution of crocidolite in this area as obtained from bore-hole results, field and underground observations is shown in figure 5. From the combination of the bore-hole results shown in figure 5 it becomes evident that crocidolite-bearing seams may be found at close intervals from about 120 to 520 feet below the Main Marker, if the widths of the intrusive diabase sills in the areas are excluded. Such extensive widths over which crocidolite seams are developed could only be expected where structural conditions for the formation of crocidolite are extremely favourable. It should be pointed out that in the case of crocidolite seams associated with steeply dipping, narrow brachyanticlines and synclines a bore-hole could give the wrong impression of the true width of the crocidolite-bearing zone. This is particularly the case where jump-drills or air-drills are used for drilling. Other bore-holes drilled in the vicinity indicate a more haphazard vertical distribution of crocidolite-bearing zones and from their results it would appear that crocidolite-bearing strata could generally be expected at different depths below the Main Marker (figure 5).

A relatively prominent crocidolite zone is found from about 124 feet to 174 feet below the Main Marker. From the vertical distribution of diabase sills in the area this zone may be occupied in part by diabase. This zone has been intersected on Owendale (M2) and Botha (M2). On the latter it represents the No. 1 Reef of the Warrendale Mine. The major portion of this zone falls within the vertical limits below the Main Marker of the Third Lower of the Kuruman area.

The next most persistent zone is located between about 210 and 335 feet below the Main Marker and is present on Owendale and Botha. It could also be expected in structurally favourable localities on farms in the neighbourhood. It is of interest to note that this zone or the upper portion thereof is apparently missing below the present workings in the Ouplaas Mine although the Main Marker at this mine is very well mineralised and a distinct basin structure can be observed at this locality.

In the Warrendale Mine located on Botha (M2) this particular zone is mined as the Nos. 2, 3, 4, 5, 6 and 7 Reefs and its vertical limits still fall mainly within the reach of the Third Lower of the Kuruman area, but its lower portion transgresses into the vertical limits of the Fourth Lower Zone.

Closely below the base of this zone crocidolite-bearing rock is present in places at close intervals from about 350 to 520 feet below the Main Marker, vertical limits which chiefly fall within those of the Fourth and the Fifth Lower Zones of the Kuruman area if measured from the Main Marker. The base of this lowest zone is about 80 feet above the top of the Dolomite Series and should therefore be correlated stratigraphically with the Seventh Lower of the Kuruman area. The very consistent presence of crocidolite-bearing strata about 80 feet above the dolomite in the Kuruman area, the area between Kuruman and Danielskuil and also in the area south of Danielskuil would indicate that the lowermost zone is restricted to a definite stratigraphical horizon and that crocidolite-bearing zones which are found between the Main Marker and the Dolomite cannot, on the basis of the position of the Main Marker only, be correlated as being restricted to the same stratigraphical horizons.

However, for practical purposes the subdivision of the different crocidolite-bearing zones should be based on the position of a characteristic marker-bed higher up in the formation, because these marker-beds form the keys to the prospecting for crocidolite in the entire Northern Region. It is furthermore evident that the Second Lower Zone which represents an important source of crocidolite in the Kuruman area and these immediately adjoining, is completely absent in the area south of Danielskuil.

## 7. The Griquatown Area

The Griquatown area as discussed here includes the entire range of the Asbestos Hills from Lime Acres (M2) in the north to Elandsfontein (P5), about 15 miles south of Griquatown; a length of some 53 miles along strike. The larger portion of this area was mapped during 1938 and 1939 by L.G. Boardman, then a member of the Geological Survey. A number of farms in the northern extremity of the area was mapped by F.C. Truter and co-workers during 1937 and 1938. Visser (1958) who mapped the distribution of the Lower Griquatown Beds in the Matsap Hills, along the western limb of the Ongeluk-Witwater Syncline, compiled a report on the geological features of that area as well as of the area which was mapped by Boardman. During May 1965 the present writer spent a couple of weeks in this area, traced the extension of the Main Marker into the area and concentrated on the distribution of crocidolite-bearing zones in the strata. A number of traverses across the constituent rocks yielded additional information with regard to the facies change apparent in the banded ironstone and the overlying jasper.

### (a) The Banded Ironstone Substage

This substage which attains a thickness of about 1000 feet (Visser, 1958) is exposed southwards as far as the northern boundary of Durandt se Pan 55 (O5), and is separated from the succeeding Jasper Substage, over almost the entire distance, by the Main Marker.
The contact of this substage with the underlying Dolomite, where exposed, shows similar transitional features as in the area farther north. This transitional

contact is characterised by an increase in intercalations of banded chert, some bands of which contain thin laminae of magnetite, in the upper 50 feet of the Dolomite. Visser (1958, p. 13) recorded that, "the transition from dolomite to ferruginous, banded chert and, with an increase in the iron oxide to banded ironstone proper, is usually complete within a few feet".

No deep bore-holes, penetrating into the Dolomite, have been drilled for asbestos in the Griquatown area. The deepest bore-hole in the area, of which the writer is aware, is one recently drilled by the Griqualand West Exploration and Finance Company on the Farm Leeuwvlei 553 (N6). This bore-hole was started just below the Main Marker and was drilled to a depth of 900 feet without reaching the Dolomite (Folder 1). It intersected a thick diabase sill between about 450 and 585 feet below the Main Marker but failed to prove the presence of asbestos-bearing zones in the banded ironstone. According to this bore-hole the minimum thickness of the Banded Ironstone Substage on Leeuwvlei is of the order of 800 feet, which already shows an increase of 200 feet compared with the area immediately south of Danielskuil. A second bore-hole, drilled a couple of hundred yards west of the above, intersected the diabase sill much closer to the Main Marker and therefore indicates the transgressive nature of the sill. The same diabase sill crops out on Jacobsfontein 501 (N6), north of Leeuwvlei 553 and could be followed south of the latter farm to where it disappears underneath surface rubble on 554 (N6), a distance along strike of some ten miles. Farther south on Hopefield 551 (N6) poor outcrops of a diabase sill are found not more than 200 feet above the Dolomite, but it is not certain whether this sill is the same as the one on Leeuwvlei 553 (N6).

Lithologically the banded ironstone in the northern portion of the Griquatown area is very similar to the same rock-type found farther north. However, to the south, beds of yellow-brown jasper, intercalated in the banded ironstone, become much more common and one gets the impression that here this substage contains more layers of jasper than in the area to the north.

(b) The Main Marker and the Jasper Substage

The Main Marker could only be traced with certainty as far south as farm 54 (N5) and perhaps as far as La Provence 51 (N5). The zones of fragmental material in the Main Marker, so characteristic of the Ouplaas-Botha area, do not continue farther south than the vicinity of the northern boundary of Jacobsfontein 501 (N6). The marker-bed decreases rapidly in thickness and attains simultaneously the same characteristics which it displays in the Kuruman area, viz. the presence of warped bedding-planes and the presence of lenses, layers and irregular, elongated bodies of grey-white chert which often resemble "boudinage".

South of the homestead on Jacobsfontein 501 (N6) the Main Marker has an average thickness of approximately 25 feet and is chiefly composed of layers of iron-poor jasper. The oblong-shaped inclusions of grey-white chert in the jasper beds appear coarser-grained than their counterparts in the Kuruman area and are also lighter in colour than in the latter area. The uppermost six to 12 inches of the marker-bed contain partly disorientated, disc-like bodies of white chert and resemble the zones of fragmental material in the Main Marker farther north. On Jacobsfontein 501 (N6) the Main Marker is succeeded by a layer of banded ironstone ap[illegible]mately 60 feet thick, which pinches out rapidly to the south. This layer is still present on Rising Star 528 (N6) but was not observed on Leeuwvlei 553 (N6), immediately south of it. Towards the southern border of Leeuwvlei 553 (N6), the Main Marker decreases in thickness to only 15 feet. It ends aburptly against a diagonal fault running across O.531 (N6), O.532 (N6) and Leeuwvlei 553 (Folder 1). The marker-bed can still be distinguished on O.566 (N6) but farther south the presence of several thin layers which display similar characteristics makes it very difficult to decide which layer actually represents the continuation of the Main Marker. Furthermore, there is an increase in the number and the thickness of jasper intercalations within the upper portion of the Banded Ironstone substage which also makes it more difficult to distinguish the Main Marker.

On Duitseput 53 (N5), Turksvypan 52 (N6) and La Provence 51 (N5) the increase in beds of jasper in the Banded Ironstone Substage is considerably and the distinction between banded ironstone and the overlying jasper becomes less prominent. A diagonal fault, trending across Durandt se Pan 55 (O5) and which probably merges with the strike-fault which runs through the village of Griquatown, caused considerable downfaulting on the west, so much so that only the Jasper Substage crops out from Durandt se Pan 55 to some miles beyond Griquatown.

Visser (1958) noted that in vertical cliffs more than 500 feet high and which are seen south of Griquatown the lowermost strata are composed of remarkably uniform, thinly laminated ferruginous and siliceous bands (p. 14 ). He regards them as belonging to the Banded Ironstone Substage. The strata of which these cliffs are composed show many characteristics similar to the Jasper Substage immediately north of the town. Some two miles south of Griquatown, close to the eastern boundary of the Asbestos Hills and less than 50 feet above the elevation of the flat dolomite plateau to the east, a thin layer showing some characteristics of the Main Marker is found. A bore-hole drilled from this elevation continued in ferruginous layers to a depth of 450 feet without intersecting dolomite. This bore-hole also proved that a strike-fault with considerable downthrow on its west side extends for some distance along the foot of the escarpment between the Dolomite and the banded ironstone-jasper beds.

Traverses across outcrops of the Lower Griquatown Beds immediately north of Griquatown proved that it is composed chiefly of poorly bedded jasper with several thin intercalations of banded ironstone. From approximately due west of Griquatown towards the southern extremity of the Griquatown area a fine-grained, well-bedded chlorite-bearing rock which resembles mudstone makes itss appearance towards the top of the Jasper Substage. The "mudstone" is usually highly ferruginous, fairly siliceous and a fair content of manganese is indicated by encrustations of psilomelane on weathered surfaces and along joint-planes. In the topmost beds of the "mudstone" zone several thin layers of quartzite are developed. They often form low cliffs and prominent ledges. The most prominent quartzite band is found closely below the Tillite Substage.

This particular layer of quartzite first appears as a noticeable feature in the topography on the northern portion of Moos-Fontein (O5) where it lies immediately below the Tillite Substage. A short distance north of this point the Tillite Substage rests directly on the Jasper Substage therefore attaining the same stratigraphical position as in the remainder of the Northern Region. Following the quartzite to the south it becomes more prominent and more layers of quartzite are found on lower horizons until on Taaibosch Fontein (05) they attain their best development and three separate layers are found (Visser 1958). The layers vary in thickness from place to place; on Middelplaats 0.6 the lowermost layer measures 25 feet in thickness. Still farther south the layers gradually decrease in thickness, but two prominent bands are again developed towards the southern border of the Griquatown area. These two bands can be traced for many miles into the Southern Region. The total thickness of the Jasper substage in the Griquatown area is given as 1,000 feet (Visser, 1958, p. 15). This is considerably more than its thickness in the environment of Danielskuil.

It should further be pointed out that because of the general increase in the number of intercalations of jasper in the Banded Ironstone Substage towards the south of the Griquatown area and in the Southern Region this substage can hardly be distinguished from the overlying Jasper Substage. What has been regarded up to the present as the Banded Ironstone Substage in the Southern Region clearly comprises both the Banded Ironstone Substage and the Jasper Substage which form two separate distinguishable zones in the Northern Region and which are separated from each other by the Main Marker in the latter region.

### (c) The Vertical Distribution of Crocidolite-bearing Zones

In the northern portion of the Griquatown area, in the environment of Jacobsfontein 501 (N6), crocidolite-bearing zones are restricted to stratigraphical positions immediately above and below the Main Marker, respectively, and at some 80 to 100 feet above the Dolomite. Prospecting for crocidolite on Jacobsfontein 501 took place at a number of places on poor outcrops of crocidolite seams above and below the Main Marker. In one of these old workings only one fibre-seam, measuring from a ¼ to ½ an inch in width, could be observed along the First Lower Asbestos Zone. Farther south on Leeuwvlei 553 (N6) this zone is better developed as is revealed by a large number of crocidolite seams in the old workings. However, recent drilling at the latter locality has so far not proved a deposit of economic significance.

The best development of fibre is seen on Hopefield M115 (N6), about 14 miles north of Griquatown. Here there are three separate reefs at about 15 to 20 feet intervals, which are found from about 80 to 130 feet above the massive Dolomite. This stratigraphical position corresponds with that of the Seventh Lower Zone in the area to the north and its constant presence over many miles to the north indicates that this fibre zone is the most persistent of all fibre zones.

The asbestos deposit on Hopefield M115 is associated with a brachyanticline, trending north-south, the axis of which pitches to the north. A large number of narrow, tight anticlines and synclines with axes parallel to that of the major structure is present and they are invariably overfolded to the east. The western limbs of the narrow anticlinal folds dip at angles of approximately 45 degrees to the west whereas the eastern limbs dip at angles exceeding 55 degrees. Duplication of the deposit is caused by faulting.

Within the area of local intensification of folding there is generally a stronger concentration of asbestos fibre than in the less folded portion of the brachyanticline. As a rule the fibre attains its maximum development and greatest length in the crests of the narrow anticlines and in the troughs of the synclines. Individual seams of fibre in these small folds display a pronounced pinch-and-swell structure; a single seam about 1½ inches wide commonly thins out to less than ⅛ of an inch and may even pinch out completely over relatively short distances, measured in inches, along strike. Many of the tight folds in this locality are intimately associated with the faulting, which would tend to indicate that fibre formation took place well after the consolidation of the host-rock or that fibre formation took place at more than one period.

South of Hopefield (N6) prospecting for crocidolite took place on Duitseput 53 (N5), Durandt se Pan 55 (O5) and the adjoining portion of the Griquatown Townlands. All of these occurrences are restricted to one asbestos-bearing zone only, which, judged by the composition of the host-rock, represents the Fourth Upper Zone of the Kuruman area. The characteristic marker-beds, i.e. the Magnetite-chert and the Potsherd Marker which are respectively associated with the Third and the Fourth

Upper Zones in the Kuruman area are not represented in the immediate vicinity of Griquatown; the Potsherd Marker was not traced farther south than Clifton 468 (M2) which is located near the northern boundary of the Griquatown area. Owing to the absence of these Markers the actual stratigraphical position of the asbestos-bearing zone immediately north and west of Griquatown, found on the farms mentioned above, cannot be determined accurately and definite correlation with the asbestos-bearing zones of the Kuruman area is therefore not possible. However, seams of massive, hard, blue amphibole are constantly associated with the asbestos seams along this zone, and point to the possibility that this zone represents the Fourth Upper or uppermost development of fibre in the Lower Griquatown Beds of the Northern Region.

The maximum number of fibre seams observed in this zone is four. Of these seams only the uppermost contains fibre exceeding $\frac{1}{4}$ inch in length. The four seams which are exposed in old excavations on the Griquatown Townlands, west-north-west of the town, are distributed over a vertical width of about one foot. The uppermost seam varies in width from less than a quarter inch to $\frac{3}{4}$ inch and is found six, nine and eleven inches respectively above three very thin seams, all of which seldom exceed $\frac{1}{8}$ inch in width. All of these seams pinch out abruptly over short distances to develop again on the same stratigraphical horizon. The seams are generally spaced the same distances apart. An old prospecting shaft, about 50 feet deep, revealed no fibre seams within this distance below the four seams mentioned above.

The seams of crocidolite at this locality is associated with a gentle monoclinal fold which trends north-south. The angle of dip increases from about 10 degrees (regional dip) to 45 degrees over a short distance perpendicular to the strike and then reverts to 10 degrees again. The best development of fibre is along the limb of the fold and towards the synclinal flexure where the angle of dip returns to the normal regional dip of approximately 10 degrees. Seams of massive riebeckite, up to about nine inches thick and often almost completely chertified near surface, are associated with the fibre seams.

Prospecting along the same crocidolite-bearing zone took place on Pannetjie (O5) south-west of Griquatown.

At this locality two separate reefs 30 feet apart were opened up at a few places. The lower reef contains only one seam which varies in width from $\frac{1}{8}$ inch to a maximum observed width of $1\frac{1}{2}$ inches. The upper reef also contains only one seam which varies in width from $\frac{1}{8}$ to about $\frac{3}{4}$ inch. The development of these seams appears to be very sporadic and the chances to find a payable asbestos deposit along this zone appears to be remote. Like its counterpart to the immediate north this zone is associated with several seams of massive blue riebeckite. Small-scale prospecting on the same two reefs also took place on Merwehoop (Portion of Middelplaats, O5) and Doradale (O5), located south of Pannetjie, but without any success.

In the southernmost portion of the area quite large-scale mining of crocidolite took place on Elandsfontein (P5). Several reefs were opened up and extensive mining took place on some five different reefs. This asbestos-bearing zone is correlated with the Intermediate Asbestos Zone of the Southern Region discussed on p. 115. The number of reefs in this particular asbestos zone varies much from one locality to another.

From the distribution and the quality of the asbestos-bearing zones in the entire Griquatown area it appears unlikely that any large crocidolite deposit will be found in it. As pointed out (p. 92-94), deposits of crocidolite are found only in four separate zones viz. the Seventh Lower (approx. 80-100 feet above the Dolomite), the First Lower, Second Upper and possibly the Fourth Upper. The latter zone is tentatively correlated with the Intermediate Zone of the Southern Region. Of these zones only the Seventh Lower appears to be capable of producing significant deposits of crocidolite within local areas of structural disturbance. Owing to faulting and the gradual thickening of the banded ironstone succession to the south this zone will be comparatively deep below surface in the area at and south of Griquatown. The lack of outcrops of promising fibre deposits in the Griquatown area has so far retarded the exploitation of the mineral in this area. Future prospecting should be based on detailed mapping of localised areas in which favourable structural features can be observed. Even if such areas could be found it is still doubtful whether deposits of payable fibre would be intersected on any other horizon than in the lowermost asbestos-bearing zone. This zone would probably be so deep below surface that, at the ruling prices of crocidolite, only very high-grade deposits, if any, would lend themselves to economic exploitation.

As a whole the Griquatown area appears to be very unpromising as far as the finding of new and large deposits of fibre are concerned.

## C. The Southern Region

The Southern Region comprises outcrops of banded ironstone and associated rock-types from about 15 miles south of Griquatown to beyond Prieska in the south and Koegas in the west. In this section the outcrops forming the Matsap Hills along the western limb of the Ongeluk-Witwater Syncline will also be discussed.

The constituent rocks of the Lower Griquatown Stage display a remarkable facies change from south of Griquatown towards Prieska and Koegas and the thickness of this stage increases considerably. In the field no distinction between separate Banded Ironstone and Jasper Substage is possible over the greater portion of the region, and all the highly ferruginous and siliceous rocks are accordingly grouped with the Banded Ironstone Substage. The siliceous "mudstones" which are present in the upper portion of the Lower Griquatown Stage in the vicinity of Griquatown also increase considerably in thickness towards the south, while slaty rocks, quartzite and dolomitic limestone constitute prominent layers.

Leube (1964) mapped an area around Koegas in the south-west and included the Banded Ironstone Substage in the Dolomite Series. He draws the line of subdivision between the Dolomite and overlying Pretoria Series at the base of a cherty or jaspery layer which immediately succeeds the Westerberg Beds and which underlies slate in which separate, almost pure, riebeckite layers are present in profusion.

The subdivision of the Dolomite and the Pretoria Series in the Southern Region as suggested by Leube (1964) is given in Table 10.

Leube (1964) reports that the Pretoria Series as subdivided in Table 10, follows conformably on the Banded Ironstone Stage and its base is characterised by dark-brown and red jasper or highly siliceous shale. The author notes that the dark-brown jasper is well bedded,

Table 10. - Subdivision of Dolomite and Pretoria Series in the Southern Region

(After Leube, 1964)

| Thickness in Feet | Lava Zone | |
|---|---|---|
| 130 | Tillite Horizon ( 30 ft.) Tillite Zone<br>Limestone Horizon ( 80 ft.) | Pretoria Series |
| 800-1000 | Upper Green Shale Zone | Pretoria Series |
| 250- 300 | Upper Black Shale Zone | Pretoria Series |
| 40 | Conglomerate and Upper Asbestos Zone | Pretoria Series |
| 90- 200 | Lower Green Shale Zone | Pretoria Series |
| 350- 400 | Lower Black Shale Zone | Pretoria Series |
| 50- 150 | Jasper Zone | Pretoria Series |
| ? | Upper Banded Ironstone Stage | Dolomite Series |
| ? | Diabase Sill | Dolomite Series |
| 2,000 | Lower Banded Ironstone Stage | Dolomite Series |
| 40- 70 | Transition-shale | Dolomite Series |
| | Dolomite Stage | Dolomite Series |

but the banded structure is missing altogether and can only be distinguished under the microscope. He notes further the complete lack of any interbedded bands of magnetite and the concomitant, abrupt disappearance of magnetic properties, so characteristic of the underlying banded ironstone.

The change in the lithological and the physical (magnetic) characteristics of his Jasper Zone which succeeds the Westerberg Beds appears to be the chief criterion on which Leube based this subdivision between the Dolomite and the Pretoria Series. However, he also pointed out that the Jasper Zone which attains a thickness of about 150 feet on Koegas (Q2) and Westerberg (Q2) is completely absent in other localities so that the succeeding "Lower Black Shale Zone" (Riebeckite Slate) follows immediately above the banded ironstone. He is accordingly of opinion that the Jasper Zone was eroded away prior to the deposition of the "Lower Black Shale Zone" or that the black shales represent a facies change of the jasper in places.

Both Cilliers (1961) and Leube (1964) proposed a slightly different subdivision for the lithological rock-types which constitute the Dolomite Series and the Lower Griquatown Stage in this area. The nomenclature used by the two authors for the same rock-type is different in certain localities and the thicknesses for individual lithological zones are also different in some cases. The subdivisions used by them are shown in Tables 10 and 11.

Table 11. - The Subdivision of the Lower Griquatown Stage (After Cilliers 1961)

| Thickness in Feet | Ongeluk Volcanics | | Middle Griquatown Stage | | |
|---|---|---|---|---|---|
| 50 | Tillite Beds | Tillite Zone | Lower Griquatown Stage | Pretoria Series | TRANSVAAL SYSTEM |
| 1300 | Upper Mudstone Beds | Mudstone Zone | | | |
| 300 | Upper Shale Beds | | | | |
| 20 | Chert layer with Upper Asbestos Horizon | | | | |
| 400 | Lower Mudstone Beds | | | | |
| 500 | Lower Shale Beds | | | | |
| 300 | Westerberg Beds with Westerberg Asbestos Horizon | Banded Ironstone Zone | | | |
| 400 | Upper Banded Ironstone Beds with Prieskaite Horizon | | | | |
| 300 | Diabase Sill | | | | |
| 1300 | Lower Banded Ironstone Beds with Intermediate Asbestos Horizon and Basal Asbestos Horizon | | | | |
| 50 | White Shale | Transition zone | | | |
| Dolomite, Limestone and Chert | | | | Dolomite series | |

In Table 12 the present writer gives a subdivision of the Lower Griquatown Stage based on the observations of the previous authors and from detailed measurements and observations carried out by the writer in the field and in the laboratory.

Table 12. - Suggested Subdivision of the Lower Griquatown Stage in the Southern Region

| Thickness in Feet | | | | |
|---|---|---|---|---|
| | Ongeluk Lava | | | |
| 90 | Tillite-limestone and Jasper Zone | Tillite Sub-Stage | Pretoria Series | TRANSVAAL SYSTEM |
| 1200 | Quartz-Chloritefels Zone | Kwakwas Sub-stage | | |
| 300 | Riebeckite Slate Zone | | | |
| 30 | Jasper Zone and associated Upper Asbestos Reef | Middelwater substage | | |
| 300 | Quartz-Chloritefels Zone | | | |
| 500 | Riebeckite Slate Zone | | | |
| 300-400 | Westerberg Beds and associated Westerberg Asbestos Zone | | | |
| 400-500 | Upper Banded Ironstone Beds | Banded Ironstone Sub-stage | | |
| 300-600 | Diabase Sill (Impersistent) | | | |
| 2300 | Lower Banded, Ironstone Beds and associated Lower Asbestos Zone | | | |
| 300-400 | Transition-zone | | | |
| | Dolomite, Limestone and Chert | | Dolomite Series | |

1. The Transition-zone

A shale band which reaches a maximum observed thickness of 400 feet on Buisvlei (R3) and Orange View (R3) follows conformably upon the Dolomite. The shale band is found consistently below the banded ironstone throughout the entire Prieska-Koegas area, but is not exposed north of Prieska towards Griquatown. The shale varies in colour from white to grey or grey-green and occasionally contains pink to reddish intercalations.

In many exposures of the shale irregular streaks parallel as well as inclined to the bedding display light- to dark-red colours due to staining by iron oxide derived from the overlying banded ironstone. The shale is very thinly laminated and commonly shows strong slaty cleavage. The slaty cleavage is not always parallel to the bedding but is often slightly inclined to it in places.

Cilliers (1961, p. 32) noted that the shale bed has a thickness of only 50 feet whereas Leube (1964, p. 24) recorded a thickness ranging from 40 to 70 feet. These figures appear to be on the conservative side. Reconnaissance work in the Prieska and Koegas areas and detailed measurements carried out on the farms Buisvlei (R3) and Orange View (R3) showed that the average thickness of the shale is in excess of 300 feet.

The contact between the shale and the underlying Dolomite is characterised by the frequent occurrence of thin intercalations of shale in the uppermost portion of the Dolomite. The intercalations of shale gradually increase in number and in thickness until shale is the dominant rock-type, with intercalations of dolomite. The dolomite bands gradually fade out upwards and shale becomes the dominant rock-type in this zone. In places the shale also contains thin intercalations of chert or jasper and even intercalations of well-bedded, banded ironstone.

The contact between the shale and the banded ironstone displays a similar gradation. Several intercalations of chert and banded ironstone are found towards the top of the shale, ever increasing in number and in thickness as the banded ironstone proper is approached. At the very base of the banded ironstone thin intercalations of shale are closely distributed over a relatively small thickness. A detailed section from above the main Dolomite to the Banded Ironstone Substage as measured on Orange View (R3) is shown in Table 13.

Table 13. - The Transition-zone on Orange View

| | |
|---|---|
| Buisvlei Asbestos Reef | = 6 feet |
| Banded Ironstone | = 485 feet |
| Green-yellow Shale | = 410 feet |
| Banded Ironstone | = 11 feet |
| Dolomitic Limestone | = 36 feet |
| Blue Chert | = 7 feet |
| Dolomitic Limestone | = 13 feet |
| Banded ironstone and thin intercalations of blue chert and dolomitic limestone (2 inches and less) | = 4 feet |
| Massive Dolomite | |

At the locality where the contact relations shown in Table 13 were measured the contact between shale and banded ironstone is sharp, with no intercalations of shale in the banded ironstone or vice versa. On Buisvlei (R3), located a few miles south of Orange View seven thin intercalations of banded ironstone, measuring from about three inches to two feet were observed in the uppermost portion of the shale, whereas a few thin intercalations of shale are present in the basal portion of the banded ironstone.

The presence of intercalations of banded ironstone, jaspery chert and shale in the upper portion of the dolomite and again the presence of intercalations of shale in the basal portion of the banded ironstone indicate abrupt changes in the conditions of deposition. This is especially true with regard to the intercalations of banded ironstone in dolomite which indicates that pH conditions in the basin of deposition must have changed from fairly alkaline to pronouncedly acid to cause the intermittent precipitation of the carbonate minerals.

## 2. The Banded Ironstone Substage

The Banded Ironstone Substage of the Southern Region is the representative of both the Banded Ironstone and the Jasper Substages of the Northern Region and attains a thickness of about 3,000 feet (p. 92, Profile A-B). This indicates a considerable increase in the thickness of this succession from north to south. This maximum thickness is probably only attained in the Prieska-Koegas area. The thickness of this substage could not be measured between Prieska and Griquatown because the contact between Dolomite and Banded Ironstone is nowhere exposed in this stretch of country. The contact is chiefly obscured by a thick cover of Dwyka shale and other recent deposits of windblown sand and surface rubble.

In the area between Prieska and Koegas this substage is intruded by a diabase varying in thickness from about 300 to 600 feet. This sill could be traced as far east as Kameelfontein 338 (Q3) in which direction it gradually thins out and eventually disappears completely. Intermittent outcrops of a diabase sill are found also along a fault trending north-south on Kloof 143 (P4), Kameelpoort 368 and Kromaar 355 (Q4), northeast and south of Niekerkshoop. These outcrops appear to be on the same stratigraphical horizon as those of the sill in the Prieska-

Koegas area.

The diabase sill is generally concordant with relation to the banded ironstone, but Leube (1964) pointed out that the sill transgresses upwards in a number of places.

The rocks composing the Banded Ironstone Substage are remarkably uniform in character over almost the entire succession. Only towards the top of this stage a gradual lithological change is apparent.

Cilliers (1961) has divided the Banded Ironstone Substage into three subdivisions:-

Westerberg Beds
Upper Banded Ironstone Beds
Lower Banded Ironstone Beds

The line of division between the Lower and the Upper Beds is drawn above the diabase sill referred to earlier (p. 101). This subdivision is therefore not based on lithological grounds, but is merely done for practical purposes. There is, however, a gradual change in the composition and in the macroscopic appearance of the rocks from well below the diabase sill. From the base of the Banded Ironstone Substage to about 250 to 300 feet above the top of the Lower Asbestos Zone the constituent rocks are characterised by the frequent occurrence of thin intercalations and layers of yellow-brown jasper. The jasper beds display poor and uneven bedding-planes, have a conchoidal fracture and are therefore very similar to the beds of the Jasper Substage of the Northern Region.

From well below the diabase sill the layers of jaspery rock are found less frequently and the rocks acquire a dark-brown to almost black colour on weathered surfaces. Bedding becomes pronounced throughout the entire succession and the beds even tend to become phyllitic in texture on certain stratigraphical horizons. Microscopical investigation shows that free silica in the form of separate laminae of chert is less abundant than in the lower portion of the Substage. The beds which follow above the diabase sill are essentially the same as those immediately underlying the sill with the exception that chert becomes even less conspicuous higher up in the succession with the result that they are more susceptible to weathering. These chert-poor rocks which attain a thickness of some 700 to 900 feet display distinct yellow colours on some weathered surfaces.

## 3. The Middelwater Substage

### (a) The Westerberg Beds

The uppermost 300 to 400 feet of the Banded Ironstone Substage as indicated on Folder 1 contain the Westerberg Asbestos Zone and represent the Westerberg Beds as subdivided by Cilliers (1961).

The contact between the Upper Banded Ironstone Beds and the Westerberg Beds which succeed it is gradational and is characterised by a gradual decrease in the amount of magnetite. In the banded ironstone magnetite is present in separate laminae but in the Westerberg Beds the magnetite is restricted to the asbestos-bearing zones only, whereas in the rest of the succession the mineral is completely lacking or is present in accessory amounts only. The rock which constitutes the Westerberg Beds is composed chiefly of a micro- to cryptocrystalline mass of needles of minnesotaite which form the matrix in which irregular grains of riebeckite are distributed haphazardly (HH204). In some places the riebeckite tends to be concentrated within particular laminae. Microcrystalline quartz is present in accessory amounts only and is dispersed throughout the ground-mass of minnesotaite.

In places the rock displays perfect slaty cleavage, but contains separate thin layers which have a particular massive appearance. A thin section (HH209) cut from a bore-hole core from a depth of approximately 10 feet below the lowermost (Second Outer) asbestos reef in the Westerberg Asbestos Zone revealed peculiar radial textures in transparent light. Under crossed nicols the radial textures become vague or are completely obliterated. An X-ray analysis of the rock revealed the presence of amphibole (riebeckite), siderite, quartz and kaolinite. According to its mineralogical composition and its structure the rock which composes the Westerberg Beds could best be described as a minnesotaite slate. The mineralogical composition, and the chemical composition of the slate (Table 32, Analysis I & II) differ from those of banded ironstone. This rock-type can therefore not be grouped with the Banded Ironstone Substage as suggested by Cilliers (1961) and Leube (1964). It should rather be grouped with the succeeding Riebeckite Slate Zone of the Middelwater Substage.

## (b) Riebeckite Slate Zone

As pointed out on p. 96, Leube (1964) recognised a layer of jasper which succeeds the Westerberg Beds on Koegas and Westerberg. He regards this jasper as the base of the Pretoria Series. Cilliers (1961) did not distinguish a jasper zone immediately above the Westerberg Beds, but mentioned (p. 47) a succession of approximately 100 feet of shale which follows immediately above the asbestos-bearing strata (generally the lowermost 120 feet of the Westerberg Beds) and which is somewhat more resistant to weathering than the underlying strata.

The present writer investigated numerous thin sections cut from bore-hole cores obtained from a bore-hole (W2) drilled on Westerberg (Q2). The bore-hole commenced about 500 feet above the uppermost asbestos reef (Inner) in the Westerberg Asbestos Zone but did not intersect any rock-type which qualifies as a jasper. The microscopical investigation showed that there is practically no change in the mineralogical composition of the rock which constitutes the beds over at least 300 feet above the top of the Westerberg Asbestos Zone. The rock remains largely composed of minnesotaite and riebeckite with accessory amounts of magnetite and quartz (HH179, 182).

Riebeckite gradually becomes a more important constituent of the rock until higher up in the succession the mineral constitutes separate bands six and more inches thick. The riebeckite is often accompanied by a second amphibole which displays almost the same pleochroism as riebeckite. This second amphibole has, however, positive elongation and an extinction angle of 28 degrees. These properties indicate an affinity with katophorite. Owing to the fineness of the material and its intimate association with the other constituents it could not be separated for positive determination (HH543).

In specimens taken from surface exposures the riebeckite is accompanied by minnesotaite, stilpnomelane and chloritic material as well as disseminated crystals of goethite and hematite; quartz is indicated by X-ray analysis. On weathered surfaces the rock acquires a thin black coating which lends an outstanding black colour to outcrops of this zone. The layers composed chiefly of massive riebeckite, are strongly resistant to weathering compared with the intercalated layers of minnesotaite, stilpnomelane and siderite, which weather quite easily. The result is that oucrops of the riebeckite slate are generally poor and are usually covered with loose, flat slabs of the massive riebeckite rock.

The presence of cherty or jaspery beds closely above the Westerberg Beds could be attributed to secondary silicification or chertification in local areas. Examples of the results of these processes are often found in the field. Layers of massive riebeckite are sometimes partly or even completely silicified to form a yellow-brown or brown and blue, mottled chert. Another example of secondary silicification is supplied by the complete alteration of the upper portion of the Transition Shale (immediately below the Banded Ironstone Substage) into a multicoloured opal at certain localities. The process of silicification of this usually soft and friable shale is so complete in places that the rock is being mined as a semi-precious stone.

On the accompanying map (Folder 1) the riebeckite slate zone is shown to end abruptly against a fault which trends north-west— south-east on Riet Vontein 134 (P4). Outcrops to the east of this fault are poor, but a few narrow seams of massive riebeckite were observed in the otherwise sand-covered flats, which indicate that the zone probably extends still farther to the north-east. However, there is little doubt that the rocks of this zone thin out rapidly in this direction.

(b) Quartz-chloritefels Zone

Following on the Riebeckite Slate Zone is a succession of greenish-coloured rocks which resembles mudstone and which reaches a thickness of some 300 feet in the Koegas area.

The rocks of this zone are very fine-grained and display no or only slight traces of bedding. They are composed chiefly of quartz, chlorite and siderite.

A similar rock-type is found in the Kwakwas Substage immediately below the Tillite Substage. It was called mudstone (Cilliers, 1961) and shale (Leube, 1964) by previous investigators. Thin sections of this rock-type indicate that the chief constituents chlorite and quartz vary considerably in transverse profiles. Chlorite is often the major mineral constituent, accompanied by accessory quartz and carbonate. On certain stratigraphical horizons quartz becomes prominent and the rock is composed of approximately equal amounts of chlorite and quartz. In other places an increase in the amount of quartz leads to the presence of intercalations of chlorite-bearing quartzite. The less siliceous variety is tentatively referred to as quartz-chloritefels (HH 382).

Although superficial deposits of wind-blown sand largely obscure outcrops of this zone towards the north-east it appears as if this zone either fades out rapidly in that direction or merges with the Quartz-chloritefels Zone of the Kwakwas Substage. The latter appears to be most likely because the Riebeckite Slate Zone of the Kwakwas Substage thins out appreciably to the north and the east before it finally disappears underneath a blanket of wind-blown sand.

Leube (1964) p. 32 reports the presence of ripple-marks in "shaly" varieties of this zone on Middelwater (Q3) and Kwakwas (P2).

(d) Jaspery Banded Ironstone and associated asbestos seams.

Immediately above the Quartz-chloritefels Zone of the Middelwater Substage is a layer, a few inches to some nine feet thick, which in some places resembles a conglomerate and in others a breccia. Exposures of the layer commonly display a pitted surface which is due to holes of various sizes caused by the removal of rounded and angular fragments. The rock is similar to the zones of fragmental material found above and within the Main Marker of the Northern Region except for the greater degree of roundness displayed by the inclusions in it. The inclusions are composed of chert and vary in size from mere fragments to large elongated bodies measuring up to five inches along their major axes. The proportion of inclusions to the flinty ground-mass varies considerably. In some exposures the inclusions are sporadically distributed whereas in other exposures the layer carries a profusion of inclusions of comparatively large size, closely sp- and cemented by a minimum of ferruginous chert as binding material. The origin of this layer is probably similar to that of the Main Marker and the Potsherd Marker of the Northern Region.

The layer is followed by beds of light-brown chert or jasper which grade into banded ironstone in places. It measures about 30 feet in thickness and contains th Upper Asbestos Zone.

## 4. The Kwakwas Substage

### (a) Riebeckite Slate Zone

This zone succeeds the jasper conformably, although the contact between the two is sharp, and differs only slightly from the rocks of the Riebeckite Slate Zone found in the Middelwater Substage. The rock is less siliceous and more opaque minerals, chiefly goethite and hematite in weathered material, make their appearance. The thickness of this zone in the western portion of the Southern Region is of the order of 300 feet, but it thins out towards the east and the north until it apparently pinches out on Hoogansi 337 (Q3) where large areas are completely covered with wind-blown sand.

### (b) Quartz-chloritefels Zone

The rocks of the Riebeckite Slate Zone gradually make way for a thick succession of rocks very similar to that of the Quartz-chloritefels Zone which belongs to the Middelwater Substage. Angular fragments of quartz and clastic feldspar, showing polysynthetic twinning, are present in the rocks of this zone. The fragments are embedded in a matrix composed of chlorite and carbonate. Flakes of biotite are present in some thin sections (HH383-387).

This zone reaches a thickness of from 800 to 1,000 feet in the Koegas-Prieska area (Leube, 1964), but increases in thickness to the north and the east where on the farms Kruispad 135, Pan 124 and Vaalwater 123 (Folder 1, P4) the minimum thickness is in the order of 1200 feet.

An important feature of this zone is the increase in silica- and iron-content towards its top. This feature is especially well displayed in the area north of Kwakwas 318 and Paardevlei 151 (P2) along the western limb of the Abrams Dam syncline and towards Kameelfontein 338 (Q3) and Diepfontein 147 (P3) located on the eastern limb of the Abrams Dam syncline. Clastic quartz and feldspar become abundant towards the top of this zone where some layers display a sandy character in places and the degree of silicification varies appreciably even within localised areas.

In the western portion of the area, Leube (1964) reports the presence of intercalated beds of shale, argillaceous quartzite, chert and an intraformational conglomerate in this zone. He also noted the abundance of calcareous components especially in the greenish coloured "mudstones" and "shales"; thin laminae of dolomite and calcite alternate with fine-grained clastic bands composed of tiny angular to subangular grains of quartz which frequently show secondary growth. Feldspar, probably albite and white mica accompany the quartz.

A layer of impure quartzite is intercalated with the chloritic rocks in the area north and north-east of Niekerkshoop (HH545, 546). In the latter areas the layers of quartzite are found in the upper portion of the zone. Two separate layers, the uppermost of which is the most conspicuous, outcrop intermittently on the farms Kruispad 135 (P4), Pan 124 (P4), Dam 125 (P4), Dunmore 131 (P5), Punt 128 (P5), and Kievietskloof 15 (P5). They extend into the Griquatown area as decribed on p. 92. On Dunmore 131 (P5) the two layers are found about 100 to 200 feet below the top and at the top of the Zone respectively. Cross-bedding was observed in the lower layer. Specimens of impure quartzite from outcrops are composed of grains of clastic quartz accompanied by plagioclase feldspar (albite?) hematite and goethite and interstitial chloritic material. Flakes of biotite are also present. (HH545, 546).

The rocks belonging to the Quartz-chloritefels Zone of the Kwakwas Substage extend into the Griquatown area where they immediately succeed the Jasper Substage of the Northern area. At the same time this Zone decreases considerably in thickness (Folder 1).

The western limb of the Ongeluk-Witwater Syncline represented by the Matsap Hills is largely formed by rocks belonging to this Quartz-chloritefels Zone of the Kwakwas Substage. Visser (1956, p. 16) noted that rocks essentially similar to the well-bedded "mudstones" and fine-grained ferruginous quartzites that are found towards the top of the Jasper Substage in the southern extremity of the Griquatown area, are found in the Matsap Hills. The Matsap Hills represent a low brachyanticline which plunges gently towards the north with the result that only the uppermost portion of the Quartz-chloritefels Zone outcrops in this area. Jaspery beds are also found in the Matsap Hills and could be either part of the Jasper Substage or they may represent the uppermost siliceous beds of the chloritefels which become siliceous and ferruginous northwards to such an extent that they resemble jasper in many places.

In the Matsap Hills seams of dark-blue massive amphibole are found near the top of the jaspery and siliceous beds and in some places crocidolite is associated with these seams.

### 5. The Tillite Zone

This Zone can be subdivided into Limestone-jasper Beds and Tillite Beds.

#### (a) Limestone and Jasper Beds

In the Koegas area a discontinuous layer of limestone immediately succeeds the Kwakwas Substage. The limestone reaches a maximum thickness of 150 feet on the farm Koegasputs 325 (Q2) and an average thickness of 80 feet on Kwakwas 318 (P2) and the immediately surrounding farms (Leube, 1964). Thin intercalations of chert are found sporadically within the limestone. Leube (1964) also reported three beds of tillite, each of them up to 10 feet thick, which are intercalated in the limestone on Swart Pan 329 (Q2). Apart from these intercalations of tillite he also noted the sporadic occurrence of pebbles in the limestone on the northern portion of the same farm. Stromatolites up to 10 inches long are reported along the bedding planes in the upper portion of the limestone about 10 feet below the contact with the overlying tillite (Leube, 1964). Towards the north, along the flanks of the Abrams Dam syncline and along the edges of the narrow southward extension of the Ongeluk-Witwater Syncline the layer of limestone becomes less prominent. In the latter areas the Quartz-chloritefels Zone of the Kwakwas Substage contains a calcareous and siliceous layer, 20 feet thick, near its top. Manganese staining is a common feature in this layer. This layer is succeeded by beds of green quartz-chloritefels which are about 50 feet thick. These beds are immediately succeeded by four separate layers of calcareous quartzite, 10 to 20 feet thick, each of which contains thin intercalations of limestone. These intercalations are from 3 to 10 feet thick.

The calcareous beds are succeeded by poorly bedded jasper which attains a thickness of 100 feet in places.

This layer of jasper immediately underlies the Ongeluk Tillite.

The thin intercalations of limestone in the Limestone Beds gradually fade out to the north until shortly beyond Kama 158 (P3) the entire zone is occupied by black-coloured manganiferous jasper. Irregular yellowish spots of limestone in the jasper are frequently seen but it becomes less conspicuous farther north.

On Grassmead 336 (Q3), Koodoos Kop 159 (P3) and the surrounding farms this manganiferous jasper outcrops prominently along a narrow anticline and the underlying Kwakwas Substage only crops out along and near to the anticlinal axis. Where these rocks outcrop they are appreciably more siliceous than in the areas farther south. It would, therefore, appear as if the rocks in the upper portion of the Kwakwas Substage become gradually more siliceous towards the Matsap Hills.

Towards the east, around the southern edge of the Ongeluk-Witwater Syncline, and along its eastern limb the Limestone Zone is not present and the prominent layer of jasper which overlies it in the south and west has decreased considerably in thickness. On Dunmore 131 (P5) and adjacent farms the Kwakwas Substage is separated from the Ongeluk Tillite by a thin layer of jasper measuring only about 10 to 15 feet in thickness.

(b) Tillite Beds

In the Southern Region these beds have an average thickness of about 50 feet, which is almost the same as in the Northern Region. Locally, however, as for example on Dam 125 (P4) the thickness increases to well over 100 feet. The tillite is, composed of dark-coloured conglomeratic and/or gritty rocks. It decomposes quite rapidly with the result that outcrops are found sporadically along strike. The tillite commonly contains small angular fragments of bluish chert and brown jasper, enclosed in a reddish-brown to black, gritty matrix. Occasional fragments of dolomitic limestone, grey quartzite and white vein-quartz are found. Striated pebbles are rare.

On Dunmore 131 (P5) the tillite attains a thickness of about 90 feet, and this includes an intercalation of quartzite which is about 10 to 15 feet thick. The quartzite is found some 30 feet above the base of the tillite.

The characteristics of the tillite are generally the same over the greater part of the Southern Region, but Leube (1964) distinguished between two types in the Koegas area, viz. a fine-grained and a coarse-grained tillite. The coarse-grained variety contains pebbles ranging from 0.5 to 6 inches in diameter and is cemented with fine-grained material of which the grain-size varies from 0.05 to 0.20 inches. Pebbles and fragments of chert make up about 90 per cent of the components and are accompanied by pebbles and fragments of banded ironstone, quartzite and limestone distributed sporadically.

The fine-grained variety is less abundant. Where found it succeeds the coarse-grained variety, for example on Kwakwas 318 and Klein Witberg 315 (P2). In a few places the entire tillite zone is built of the fine-grained type. According to Leube (1964) this variety consists almost entirely of an arkose of greywacke, and in places of quartzite. It is generally intensely sheared, even in areas of comparatively little tectonic disturbance.

The fine-grained variety is composed of small fragments of quartz, feldspar, chert and other rock-types set in a fine-grained matrix. The fragments and grains measure up to 0.5 inches in length and the larger ones are flattened parallel to the direction of cleavage in the tillite. The matrix contains a fair amount of sericite and hematite and subordinate amounts of magnetite.

## 6. The Vertical Distribution of the Asbestos-bearing Zones in the Southern Region

Four separate zones are distinguished, viz.:-

d. The Upper Asbestos Zone
c. The Westerberg Asbestos Zone
b. The Intermediate Asbestos Zone
a. The Lower Asbestos Zone

The lowermost two zones are restricted to the Banded Ironstone Substage, the third to the Westerberg Beds and the Upper Zone is found in a layer of ferruginous jasper which is intercalated between the Middelwater Substage and the Kwakwas Substage.

(a) The Lower Asbestos Zone

Both Leube (1964) and Cilliers (1961) reported that the lowest crocidolite seam in this Zone is found about 50 feet above the top of the Transition-zone or the base of the Banded Ironstone Substage, and that the Zone extends over a vertical thickness of 200 feet. Both these figures are apparently conservative.

The Lower Asbestos Zone contains a maximum of ten separate asbestos reefs and the only locality where these reefs are developed to such a degree that all of them could be mined is on Klein Naauwte 346. Detailed measurement of the individual thickness and the vertical distribution of the reefs at the latter locality shows that the reefs are distributed over a vertical thickness of rock of just over 300 feet.

On Orange View (Q3), directly opposite the Orange River from Klein Naauwte 346 (Q3), both the base of the Banded Ironstone Substage and the No. 8 or Buisvlei Reef are well exposed. A survey carried out at this locality proved that the lowermost asbestos reef in this Zone is not less than 300 feet above the base of the Banded Ironstone Substage. The Transition-zone, underlying the banded ironstone, reaches a thickness of 400 feet at this locality so that the lowest reef in the Lower Asbestos Zone is found fully 700 feet above the top of the Dolomite. The widths and the vertical distribution of the reefs of the Lower Asbestos Zone are shown in Table 14.

The Lower Asbestos Zone corresponds roughly to those asbestos-bearing zones of the Northern Region which are found below the Main Marker. Owing to the thick succession of shale between the Dolomite and the Banded Ironstone Substage in the Southern Region compared with the Northern Region and the complete absence of a marker-bed which may be correlated with the Main Marker, no direct correlation between the asbestos-bearing zones of the two regions is possible.

The Lower Asbestos-bearing Zone crops out on several farms within a radius of some 16 miles from Prieska. North of the Orange River, in the vicinity of Koegas, this zone crops out along the Doringberg fault-scarp on Schalksdrift 322 (Q2), Pypwater 321, Leelykstaat 320 and Stilverlaat 314 (P2).

Table 14. - The distribution of asbestos reefs in the Lower Asbestos Zone on Klein Naauwte 346 and Erfrus (Ptn. Naauwte 339), Hay District, Southern Region

| No. of reef | Name of reef | Width in Feet | Width of barren rock between reefs in Feet | Remarks |
|---|---|---|---|---|
| 10 | Sinai Reef | 3.5 | | Bands of massive blue riebeckite immediately above and below reef. |
| | | | 61 | |
| 9 | Reef X | 4.0 | | |
| | | | 61 | |
| 8 | Buisvlei Reef | 5.0 | | |
| | | | 68 | |
| 7 | Kliphuis Reef | 4.0 | | Tuffaceous band (one to two feet thick) along foot-wall of reef. |
| | | | 6 | |
| 6 | "Blouband" Reef | 4.0 | | |
| | | | 8 | |
| 5 | Greef Reef | 6.0 | | |
| | | | 26 | |
| 4 | "Bloutonnel" Reef | 5.0 | | Tuffaceous band, 6 to 12 inches thick, along hanging wall of reef. |
| | | | 5 | |
| 3 | "Blom" Reef | 3.0 | | Tuffaceous band 6 to 12 inches thick, along foot-wall of reef. |
| | | | 8 | |
| 2 | "Waband" (also "Karband") Reef | 6.5 | | |
| | | | 20 | |
| 1 | "Piet Bok" Reef | 4.0 | | Tuffaceous band, one to two inches thick, along hanging wall of reef. |
| | | | 312 | Banded ironstone below No. 1 Reef. |
| | | | 400 | Transition-zone below Banded Ironstone |
| | | | | Dolomite below Shale. |

In the area immediately around Prieska the most promising crocidolite deposits in this zone are located on Glen Allen (R3), Buisvlei (R3), Klein Naauwte 346 (Q3), Erfrus (Ptn. of Naauwte 339) (Q3), Kliphuis 359 (R3), Wilgeboomsdam 348 (R3), Stofbakkies 360 (R4) and at Cairn Brae (Keikams Poort) (S4). At present the Glen Allen deposit is the only one being mined; mining at the other centres was suspended owing to the depletion of the deposits or owing to poor marketing conditions.

Except for Klein Naauwte 346 (Q3) where all of the ten reefs in the Lower Zone have been explored to some extent, only a few and often only one of the reefs contains workable concentrations of fibre at the other localities mentioned above. Small-scale mining and prospecting in this zone were also carried out on Orange View (Q3), Kranzfontein (R4), Asbestos Reefs (S4) (Ptn. Keikams Poort) and Prieska Poort (S3), but the results were not promising. The Lower Asbestos Zone is characterized by its extreme patchiness with regard to the development of economic deposits of crocidolite.

Cilliers (1961, p. 41), who visited several of the mines located on the Lower Zone while they were still in operation, reported that fibre in payable quantities is developed only in small areas which are roughly circular or elliptical in outline, and which seldom exceed 1000 feet in diameter or along their major axes. Such areas of greater concentration of fibre in a reef are referred to as "pockets".

The Glen Allen Mine, at present the only operating mine located on the Lower Zone, is found in a basin, trending north-south. The distribution of the reefs in this mine is given in Table 15.

If the thickness of each reef and that of the waste partings in between them are compared with those on Klein Naauwte (Table 14) it is clear that correlation becomes exceedingly difficult.

Table 15. - Distribution of asbestos reefs in

Glen Allen Mine, Prieska District

| Waste Parting (Feet) | Reef | Reef Width (Inches) | Remarks |
|---|---|---|---|
| | Upper Hanging wall | 12 | |
| 15 | | | |
| | Hanging-wall Main | 96-120 | Actually two reefs with only 18 inches of waste parting |
| 6 | | | |
| | Foot-wall | 48-60 | Patchy, black tuffaceous marker-band at approximately 48 inches above hanging-wall of reef |
| 4 | | | |
| | Outer No. 1 | 48-60 | Fibre development good. Band of hard blue riebeckite (+48") immediately above reef |
| 6 | | | |
| | Outer Reef No. 1A | 12 | Only one to three seams, never workable |
| 40 | | | |
| | Outer No. 2 | 30-36 | Very patchy |
| 40 | | | |
| | Outer No. 3 | 60-96 | Very patchy |

(b) The Intermediate Asbestos Zone

This zone is found approximately 1300 feet above the top of the Lower Asbestos Zone and about 400 feet below a thick diabase sill which is intrusive in the Banded Ironstone Substage. On Orange View, located north-west of Prieska, this zone includes seven reefs distributed over a vertical thickness of about 125 feet. (Table 16).

Mining on the Intermediate Asbestos Zone has been carried out in the past on Geduld (R3), Orange View (Q3), Erfrus (Ptn. Naauwte 339, Q3), Naauwte 339 (Q3), Rooipan (Ptn. Kameelfontein 338)(Q3), Kameelfontein 338 (Q3), Blaauwputs 340 (Q3), Rooisand 345 (Q3), Blaauwbosch Poort 349 (Q4), Sandfontein 356 (Q4), Kameel Poort 368 (Q4), Kloof 143 (P4), Naauw Poort 144 (P4), Blaauwbosch Kuile 380 (P4), Kaffir Krants 379 (Q4), Klipfontein 381 (Q5) and Elandsfontein 395 (P5). These farms are located along a line from north of Prieska towards Niekerkshoop and Griquatown, Elandsfontein 395 being located about 15 miles south of Griquatown.

Table 16. - Distribution of asbestos reefs in the Intermediate Asbestos Zone on Orange View, Prieska District

| Waste Parting Feet | Reef | Reef Width (Inches) | Remarks |
|---|---|---|---|
| | No. 7 or Upper | 36 | Fibre development poor, Fibre displays a greyish colour and is usually of the slip-fibre type |
| 21 | | | |
| | No. 6 | 24 | ditto |
| 38 | | | |
| | No. 5 | 18 | Fibre grey in colour, development good |
| 4 | | | |
| | No. 4 | 24 | ditto |
| 14 | | | |
| | No. 3 | 24 | ditto |
| 15 | | | |
| | No. 2 | 24 | Fibre grey in colour; development usually poor |
| 22 | | | |
| | No. 1 or Lower | 12 | Fibre dark blue-black in colour; development usually poor |

Relatively large-scale mining of crocidolite on this zone took place on Geduld (R3), Naauw Poort 144 (P4), Kloof 143 (P4) and Elandsfontein (P5) only. On Orange View (Q3) all of the seven reefs were prospected to some extent but actual mining took place on three of them only, viz. No's. 3, 4 and 5 (Table 16).

The lowermost reef in the Intermediate Zone (No. 1) contains seams of dark-blue to dark-coloured fibre, very similar to that obtainable from the Lower and Westerberg Zones. Fibre from the upper six reefs, however, has a distinct greyish-blue colour and is often of the slip-fibre type. The No. 6 reef, where exposed, contains chiefly slip-fibre. Fibres in individual seams of the latter reef are often distinctly inclined to the bedding and in some seams the fibres are practically elongated parallel to the bedding of the banded ironstone. In such localities fibre bundles measuring from 1½ to 2 inches in length are found in seams less than a quarter inch wide.

On Erfrus (Ptn. Naauwte 339, Q3 ), located north-east of Orange View, on the opposite bank of the Orange

River, slip-fibre is common in the places where the reefs have been opened up. On this farm three narrow asbestos reefs, distributed over a vertical distance of 30 feet are found closely above the diabase sill which succeeds the Intermediate Zone. The lowermost reef is found about 60 feet above the sill. The vertical distribution of the reefs is shown in Table 17.

Table 17. - Distribution of Asbestos Reefs Immediately above the Intrusive Diabase Sill on Erfrus (Ptn. Naauwte 339), Hay District

| Waste Parting (Feet) | Reef | Channel Width (Inches) |
|---|---|---|
| | Upper | 30 |
| 15 | | |
| | Middle | 30 |
| 14 | | |
| | Lower | 36 |

Prospecting on a small scale took place on these reefs both on Erfrus (Ptn. Naauwte 339) and on the neighbouring farm Kameelfontein 338 (Q3). On the latter farm the reefs were opened up close to the main road between Koegas and Prieska. The colour of the fibre in these reefs is conspicuously different from that of crocidolite. The colour is ash-grey and the fibre is brittle in places. Asbestos fibres from this zone will be discussed in more detail on p. 144.

Along the extension of the Intermediate Asbestos Zone to the north-east, that is towards Niekerkshoop and Griquatown, crocidolite has been mined intermittently on a number of farms mentioned on page 115 . The most extensive workings are located on Kloof 143 (P4), Kaffir Krantz 379 (Q4), Naauw Poort 144 (P4), Blaauwbosch Kuile 380 (P4) and Elandsfontein (P5). Mining of crocidolite on these farms has been suspended several years ago, but the Intermediate Zone still enjoys attention on some farms owing to the good quality of "tiger's-eye" (silicified crocidolite) which is found in the Niekerkshoop area.

Mining for "tigers-eye" is carried out on Blaauwbosch Kuile 380 where seams of silicified crocidolite are found separately or in closely-spaced groups or reefs.

The distribution of the silicified crocidolite seams are given in Table 18.

Table 18. - Distribution of Seams of Silicified Crocidolite in the Intermediate Asbestos Zone on Blaauwbosch Kuil, 380, Hay District

| Waste Parting (Feet) | Reef | Reef Width (Ins.) | No. of Seams | Fibre Length (Ins.) | Remarks |
|---|---|---|---|---|---|
| | Upper or No. 16 | 1 | 1 | $\frac{3}{4}$ - 1 | Composite seam |
| 27 | | | | | |
| | No. 15 | 17 | 2 | $\frac{3}{4}$ - $1\frac{1}{2}$ | |
| 6 | | | | | |
| | No. 14 | $\frac{1}{2}$ | 1 | $\frac{1}{2}$ | |
| 12 | | | | | |
| | No. 13 | 24 | 4 | $\frac{1}{4}$ - $\frac{3}{4}$ | |
| 8 | | | | | |
| | No. 12 | 8 | 2 | $\frac{1}{2}$ - 1 | |
| 21 | | | | | |
| | No. 11 | 1 | 1 | $\frac{3}{4}$ - 1 | |
| 10 | | | | | |
| | No. 10 | 1 | 1 | $\frac{3}{4}$ - 1 | |
| 42 | | | | | |
| | No. 9 | 1 | 1 | $\frac{1}{4}$ - $\frac{1}{2}$ | |
| 34 | | | | | |
| | No. 8 | 1 | 1 | $\frac{3}{4}$ - 1 | |
| 21 | | | | | |
| | No. 7 | 13 | 2 | $\frac{1}{4}$ - $\frac{1}{2}$ | |
| 28 | | | | | |
| | No. 6 | 36 | 2 | $\frac{1}{4}$ - $\frac{1}{2}$ | |
| 16 | | | | | |
| | No. 5 | 60 | 3 | $\frac{1}{4}$ - $1\frac{1}{4}$ | |
| 21 | | | | | |
| | No. 4 | 96 | 5 | $\frac{1}{4}$ - $1\frac{1}{2}$ | |
| 11 | | | | | |
| | No. 3 | 1 | 1 | $\frac{3}{4}$ - 1 | Impersistent |
| 48 | | | | | |
| | No. 2 | 18 | 2 | $1\frac{1}{4}$ - 2 | |
| 30 | | | | | |
| | Lower or No. 1 | 24 | 2 | 1 - 6 | |

Total vertical distance over which crocidolite seams are found = 360 ft.

From Table 18 it may be concluded that only Reefs 1, 2 and 4 would have been mineable propositions for crocidolite. It is also seen that the total width of 360 feet over which asbestos seams are distributed is much in excess of the vertical distribution of about 125 feet in the same Zone on Orange View (Table 16).

(c) The Westerberg Asbestos Zone

As a rule this Zone is restricted to the lowermost 120 feet of the Westerberg Beds. A diabase sill, about 40 feet thick, is found approximately 35 feet above the highest asbestos seam in the Westerberg Mine and is generally referred to as the Marker Sill. According to

Cilliers (1961, p. 47) this sill extends to Hounslow 323 (Q2) and Koegas 324 (Q2) on the northern bank of the Orange River where it is found in places only about five feet above the uppermost reef in this Zone.

Mining on this Zone takes place at Westerberg (Q2) and Koegas 324 (Q2) only. Drilling has indicated that the Zone extends towards Kwakwas 318 (P2), located adjacent to Koegas 324, but mineralization appears to be less promising. The distribution of the reefs in the Westerberg Asbestos-bearing Zone is shown in Table 19.

Table 19. - Distribution of crocidolite reefs in the Westerberg Asbestos-bearing Zone, Southern Region

| Waste Parting (Feet) | Reef | Reef Channel-Width (Inches) | Average Number of Fibre seams over $\frac{1}{8}$" | Average Fibre Length (Inches) | Maximum Fibre Length (Inches) |
|---|---|---|---|---|---|
| | Inner | 10-40 | 5-15 | $\frac{1}{8} - \frac{3}{4}$ | 2 |
| 6 | | | | | |
| | Main | 6-48 | 5-15 | $\frac{1}{8} - 2\frac{1}{4}$ | 4 |
| 4 | | | | | |
| | Bottom Main | 24-40 | 5-15 | $\frac{1}{8} - 1$ | 1 |
| 8.5 | | | | | |
| | Visser | 48-82 | 5-18 | $\frac{1}{8} - \frac{1}{2}$ | $1\frac{1}{4}$ |
| 4.5 | | | | | |
| | Bottom Visser | 6-12 | 3-18 | $\frac{1}{8} - \frac{1}{4}$ | $\frac{3}{4}$ |
| 35 | | | | | |
| | Intermediate | 5-32 | 2-10 | $\frac{1}{8} - \frac{1}{4}$ | $\frac{1}{2}$ |
| 12 | | | | | |
| | Outer | 9-48 | 5-18 | $\frac{1}{8} - \frac{3}{4}$ | 1 |
| 7 | | | | | |
| | Second Outer | 3-27 | 2- 6 | $\frac{1}{8} - \frac{1}{2}$ | 2 |
| 14 | | | | | |
| | Third Outer | 3-24 | 2- 6 | $\frac{1}{8} - \frac{1}{2}$ | $\frac{3}{4}$ |

After Cilliers, 1961, p. 48.

### (d) The Upper Asbestos Zone

As mentioned earlier (p. 106) this Zone is found in the upper portion of a layer of ferruginous jasper approximately 30 to 35 feet thick which separates the Middelwater and the Kwakwas Substages. The asbestos is generally concentrated in a number of fibre seams grouped together so as to form a single reef. The maximum length of fibre in these seams is two inches.

The development of the fibre seams in this Zone is sporadic. It is locally developed on Koegas 324 (Q2) and Kwakwas 318 (Q2) where a little prospecting has been carried out, but the reef could not be traced on the neighbouring farms. Owing to the relatively rapid thinning out of the various substages of the Lower Griquatown Beds towards the north it cannot be said with certainty whether the Upper Zone corresponds with the asbestos being worked on Blackridge 193 (O3) in the Matsap Hills. This does not appear to be the case because at the latter locality the crocidolite is found in thinly laminated ironstone which occupies a position near the top of the Jasper Substage of the Northern Region.

Workable asbestos is found in two reefs at Blackridge 193 (O3) which are only 6 feet apart. The lower reef is about 18 inches wide and contains a maximum of 8 seams. The upper reef has an average width of 24 inches and contains up to 13 seams. The fibre lengths in these seams vary from less than $\frac{1}{8}$ inch to about $1\frac{3}{4}$ inch in places. According to Visser (1958, p. 47) the stratigraphical position of the asbestos reefs on Blackridge and the adjacent farm Breckenridge 192 (O3) corresponds with that on Pannetjie (Ptn. Naauwhoek 45) (O5), Merwehoop (Ptn. Middelplaats 6) (O5), and Doradale 9 (O5) to the west of Griquatown which is tentatively correlated with the Fourth Upper Zone of the Northern Region.

## D. Intrusive Rocks

The rocks of the Lower Griquatown Stage are intruded by sill-like, pipe-like and dyke-like intrusions of which diabase dykes are the most abundant. Because the present investigation was chiefly restricted to the Lower Griquatown Beds it is not possible to date the intrusive rocks with certainty. However, it is felt that the intrusives represent several periods of intrusion, ranging from Ongeluk lava times to post-Karroo times. The post-Karroo emplacements are represented by Kimberlite pipes as for instance on Brits (M2), Postmasburg District.

Truter, et al (1938, pp. 46-49) and Visser (1944, pp. 215-217) who have also discussed the area beyond that covered by the Lower Griquatown beds recognised igneous rocks of at least four different periods of emplacement viz.:-

Table 20. - Chemical composition of Diabase Intrusive as Sills and Dykes in the Lower Griquatown Stage, Karroo Dolerite and Ongeluk Lava with Corresponding Niggli Values and Norms

A. Chemical Analysis

| Sample number | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | FeO | MgO | CaO | $Na_2O$ | $K_2O$ | $H_2O^+$ | $H_2O^-$ | $CO_2$ | $TiO_2$ | $P_2O_5$ | Cl | F | MnO | Minus O=Cl, F | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| I | 45.71 | 11.32 | 3.20 | 9.76 | 12.60 | 8.30 | 1.65 | 2.45 | 2.11 | 0.13 | 1.53 | 0.80 | 0.13 | 0.17 | 0.05 | 0.19 | 0.06 | 100.04 |
| II | 46.20 | 16.63 | 0.63 | 9.22 | 15.00 | 5.49 | 0.55 | 3.00 | 1.29 | 0.11 | 1.68 | 0.30 | 0.05 | 0.19 | 0.00 | 0.14 | 0.04 | 100.44 |
| III | 49.35 | 11.26 | 3.01 | 9.93 | 6.97 | 9.57 | 3.70 | 2.41 | 1.27 | 0.10 | 1.13 | 0.58 | 0.14 | 0.27 | 0.02 | 0.21 | 0.07 | 99.85 |
| IV | 54.16 | 14.57 | 0.96 | 8.99 | 6.47 | 7.50 | 2.16 | 2.24 | 2.14 | 0.10 | - | 0.61 | - | - | - | 0.18 | - | 100.08 |
| V | 51.04 | 13.83 | 1.20 | 9.08 | 10.23 | 9.88 | 1.84 | 0.84 | 1.35 | 0.08 | - | 0.69 | - | - | - | 0.16 | - | 100.22 |
| Average I - V | 49.29 | 13.52 | 1.80 | 9.40 | 10.25 | 8.15 | 1.98 | 2.19 | 1.63 | 0.10 | 1.45 | 0.60 | 0.11 | 0.21 | - | 0.18 | 0.17 | 100.12 |
| VI | 42.75 | 7.03 | 7.03 | 12.60 | 15.32 | 9.01 | 0.83 | 1.01 | 2.40 | 0.30 | 1.70 | 2.14 | 0.35 | 0.21 | 0.05 | 0.28 | 0.07 | 99.96 |
| VII | 51.15 | 15.09 | 2.435 | 8.05 | 6.96 | 10.60 | 2.07 | 0.88 | 1.04 | 0.25 | - | 1.22 | 0.17 | - | - | 0.18 | - | 100.09 |
| VIII | 54.35 | 14.38 | 0.88 | 9.14 | 6.40 | 7.53 | 2.31 | 2.12 | 2.19 | 0.14 | - | 0.59 | - | - | - | 0.19 | - | 100.22 |

B. Niggli Values

| Sample number | si | al | fm | c | alk | mg | k | p | ti | $co_2$ | h+ | cl | f |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| I | 95.0 | 14.0 | 61.0 | 18.5 | 6.5 | 0.64 | 0.49 | 0.1 | 1.3 | 4.3 | 14.5 | 0.60 | 0.3 |
| II | 94.5 | 20.1 | 63.0 | 12.1 | 5.0 | 0.73 | 0.78 | 0.0 | 0.5 | 4.7 | 9.0 | 0.7 | |
| III | 114.5 | 15.5 | 49.0 | 23.5 | 12.0 | 0.49 | 0.30 | 0.1 | 1.0 | 3.6 | 10.0 | 1.1 | 0.2 |
| IV | 142.0 | 22.5 | 47.5 | 21.0 | 9.0 | 0.53 | 0.41 | - | 1.2 | - | 18.5 | - | - |
| V | 113.5 | 18.0 | 53.0 | 24.0 | 5.0 | 0.64 | 0.23 | - | 1.2 | - | 10.0 | - | - |
| Average I - V | 110.5 | 18.0 | 55.0 | 20.0 | 7.0 | 0.62 | 0.42 | 0.2 | 1.0 | 4.4 | 12.0 | 0.9 | - |
| VI | 82.5 | 8.0 | 70.5 | 18.5 | 3.0 | 0.62 | 0.44 | 0.3 | 3.1 | 4.5 | 15.5 | 0.7 | 0.3 |
| VII | 122.0 | 21.0 | 46.0 | 27.0 | 6.0 | 0.54 | 0.22 | 0.3 | 2.2 | - | 8.5 | - | - |
| VIII | 142.5 | 22.0 | 47.0 | 21.5 | 9.5 | 0.53 | 0.38 | - | 1.2 | - | 19.0 | - | - |

I Diabase from uppermost sill in banded ironstone, Pomfret, Vryburg District. Analysts, E.C. Haumann and J.F. Dry, Soil Research Institute. New analysis.

II Diabase from Hanging-wall marker-sill in Westerberg Mine, Westerberg, Prieska District. Analysts, E.C. Haumann and J.F. Dry, Soil Research Institute. New analysis.

III Diabase from Foot-wall marker-sill in Westerberg Mine, Westerberg, Prieska District. Analysts, E.C. Haumann and J.F. Dry, Soil Research Institute. New analysis.

IV Diabase, Ouplaas 304, Postmasburg District. (J.N.J. Visser, 1964, p. 101).

V Diabase, Taaibosch Puts 499, Postmasburg District. (J.N.J. Visser, 1964, p. 101).

VI "Dolerite" from dyke intersected by bore-hole W2, Westerberg, Prieska District. Analysts, E.C. Haumann and J.F. Dry, Soil Research Institute. New analysis.

VII Average of seven analyses of Karroo dolerite. (J.N.J. Visser, 1964, p. 85-87).

VIII Andesite, Ongeluk lava, Goede Hoop 547, Postmasburg District. (J.N.J. Visser, 1964, p. 133).

C. Equivalent Norms

| Sample number | Cp | Cc | Kp | Ne | Cal | Cs | Sp | Fs | Fo | Fa | Ru | Q | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| I | 0.3 | 3.9 | 8.8 | 9.0 | 9.9 | 4.4 | - | 3.4 | 26.4 | 11.7 | 0.6 | 21.6 | 100.0 |
| II | 0.1 | 4.2 | 10.5 | 2.9 | 9.6 | - | 10.5 | 0.6 | 25.3 | 10.7 | 0.2 | 25.4 | 100.0 |
| III | 0.3 | 2.9 | 8.7 | 20.2 | 4.3 | 9.9 | - | 3.2 | 14.6 | 12.0 | 0.4 | 23.5 | 100.0 |
| IV | - | - | 8.2 | 12.0 | 14.5 | 4.2 | - | 1.0 | 13.8 | 11.0 | 0.4 | 34.9 | 100.0 |
| V | - | - | 3.0 | 10.0 | 16.3 | 6.7 | - | 1.3 | 2.4 | 10.8 | 0.5 | 30.0 | 100.0 |
| Average I - V | 0.2 | 3.7 | 7.8 | 10.7 | 12.9 | 2.7 | - | 1.9 | 21.3 | 11.2 | 0.4 | 27.2 | 100.0 |
| VI | 0.7 | 4.4 | 3.7 | 4.6 | 7.8 | 6.0 | - | 4.4 | 32.8 | 15.5 | 1.5 | 18.6 | 100.0 |
| VII | 0.3 | - | 3.2 | 11.4 | 18.0 | 6.8 | - | 2.6 | 14.7 | 9.8 | 0.9 | 32.3 | 100.0 |
| VIII | - | - | 7.7 | 12.8 | 13.9 | 4.6 | - | 0.9 | 13.6 | 11.2 | 0.4 | 34.9 | 100.0 |

D. Standard Katanorms

| Sample number | Q | Or | Ab | An | Cord | Wo | Cs | Hy | Fa | En | Fo | Mt | Ru | Cp | Cc | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| I | - | 14.7 | 15.0 | 16.5 | - | 5.9 | - | 13.4 | - | - | 26.4 | 3.4 | 0.6 | 0.3 | 4.0 | 100.0 |
| II | - | 17.2 | 4.8 | 16.0 | 19.5 | - | - | 6.4 | 5.6 | - | 25.4 | 0.6 | 0.2 | 0.1 | 4.2 | 100.0 |
| III | - | 14.5 | 33.6 | 7.2 | - | 11.5 | 1.2 | - | 10.7 | - | 14.5 | 3.2 | 0.4 | 0.3 | 2.9 | 100.0 |
| IV | 2.7 | 13.7 | 20.0 | 24.1 | - | 5.6 | - | 14.0 | - | 18.5 | - | 1.0 | 0.4 | - | - | 100.0 |
| V | - | 5.0 | 27.2 | 16.8 | - | 8.9 | - | 13.6 | - | 21.6 | 5.1 | 1.3 | 0.5 | - | - | 100.0 |
| Average I - V | - | 13.0 | 17.8 | 21.5 | - | 3.6 | - | 13.7 | - | 11.6 | 12.6 | 1.9 | 0.4 | 0.2 | 3.7 | 100.0 |
| VI | - | 6.2 | 7.7 | 12.8 | - | 8.0 | - | 17.7 | - | 15.2 | 21.4 | 4.4 | 1.5 | 0.7 | 4.4 | 100.0 |
| VII | 1.9 | 5.3 | 19.0 | 30.0 | - | 9.1 | - | 11.3 | - | 19.6 | - | 2.6 | 0.9 | 0.3 | - | 100.0 |
| VIII | 3.2 | 12.8 | 21.3 | 23.1 | - | 6.1 | - | 14.2 | - | 18.0 | - | 0.9 | 0.4 | - | - | 100.0 |

4. Post-Karroo emplacement of kimberlite.
3. Dolerites of Karroo-type and related noritic rocks.
2. Mafic rocks of post-Upper Matsap and probably pre-Karroo age.
1. Diabasic rocks related to the Ongeluk lavas.

A microscopical investigation of thin sections from several mafic sills and dykes intrusive into the Lower Griquatown Stage revealed that the rocks are as a rule much decomposed. The feldspar is generally represented by small irregular skeleton crystals and occasionally by stout laths which show subophitic to ophitic intergrowth with altered pyroxene. The plagioclase is commonly heavily kaolinised or altered to aggregates of zoisite and secondary epidote. The pyroxene is seldom fresh, uralitization commonly commencing from the edges of the crystals. Irregular grains and occasional well-formed crystals of titanite are usually present, but even this mineral is often subjected to severe alteration which resulted in the concomitant crystallization of small amounts of magnetite. Other accessory minerals are calcite and occasionally a little quartz.

Chemical analyses, Niggli values, molecular and katanorms of five separate diabase sills intrusive into the Lower Griquatown Beds are given in Table 20. For comparative purposes the average chemical composition of material derived from seven Karroo dolerite dykes, and a chemical analysis of the Ongeluk lava and the corresponding Niggli values are also given in Table 20.

The si value differs remarkably in the various diabases which are intrusive as sills into the rocks of the Lower Griquatown Stage (Table 20). The value for si varies from 95 to 142 and in the corresponding katanorm (Table 20) it is shown that free quartz could only be expected in one of the five analysis given in Table 20, viz. analysis IV (si = 142). The chemical analysis of material derived from a diabase dyke which is intrusive into the Lower Griquatown Beds on Westerberg also shows a low Niggli value for si and according to the katanorm (Table 20D, VI) no free quartz is present.

Niggli values calculated from the chemical analysis of material derived from Karroo dolerite and andesite of the Ongeluk lava show higher si values (122-142.5) except for analysis IV, Table 20. The corresponding katanorms (Table 20D VII and VIII) shows that free quartz could be expected in the mineralogical composition of the intrusive rocks of Ongeluk lava and Karroo age.

In this respect it is of interest to note that analysis IV, Table 20, which shows the presence of free quartz in the Katanorm is that of diabase which intruded as a sill on Ouplaas 304 (L2) and caused intense thermal metamorphism of crocidolite in the banded ironstone.

The variation in the total content of iron, magnesium and the alkalis in the chemical composition of mafic rocks intrusive into the Lower Griquatown Stage is compared with that in dolerite of Karroo Age in Figure 8. The respective values obtained from seven analyses of Karroo dolerite (Visser, 1964, Analyses 607, 609, 617, 620, 621, 622 and 625) plotted as filled in circles on figure 8 fall within a comparatively small field.

The respective values derived from analyses of diabase which intruded the Lower Griquatown Stage, when plotted, are appreciably scattered. That of diabase from sill intrusions are roughly restricted to three different fields; analyses III, IV and VIII, analyses I and V and analysis II.

Analyses III, IV and VIII and also VI have approximately the same iron-content (Fe'' + Fe''') as that of Karroo dolerite (VII), but the first three contain less magnesium and slightly more alkalis (Na + K). Analysis VI contains more magnesium than the former three mentioned analyses as well as the Karroo dolerite, but contains appreciably less alkalis.

Analyses I and V are of diabase from sills at Pomfret and Taaibosch Puts, respectively and correspond closely in iron-, magnesium- and alkali-content. They differ from the Karroo dolerite in that they have slightly less iron and alkali and a higher magnesium-content.

Analysis II is of diabase from the hanging-wall sill at the Westerberg Asbestos Mine. It differs remarkably from the Karroo dolerite and also from the other analyses. It contains much less iron, more magnesia and about the same amount of alkalis.

Figure 8 shows that diabase from intrusive sills in the Lower Griquatown Stage could roughly be divided into three different groups; those which correspond closely in chemical composition with Karroo dolerite

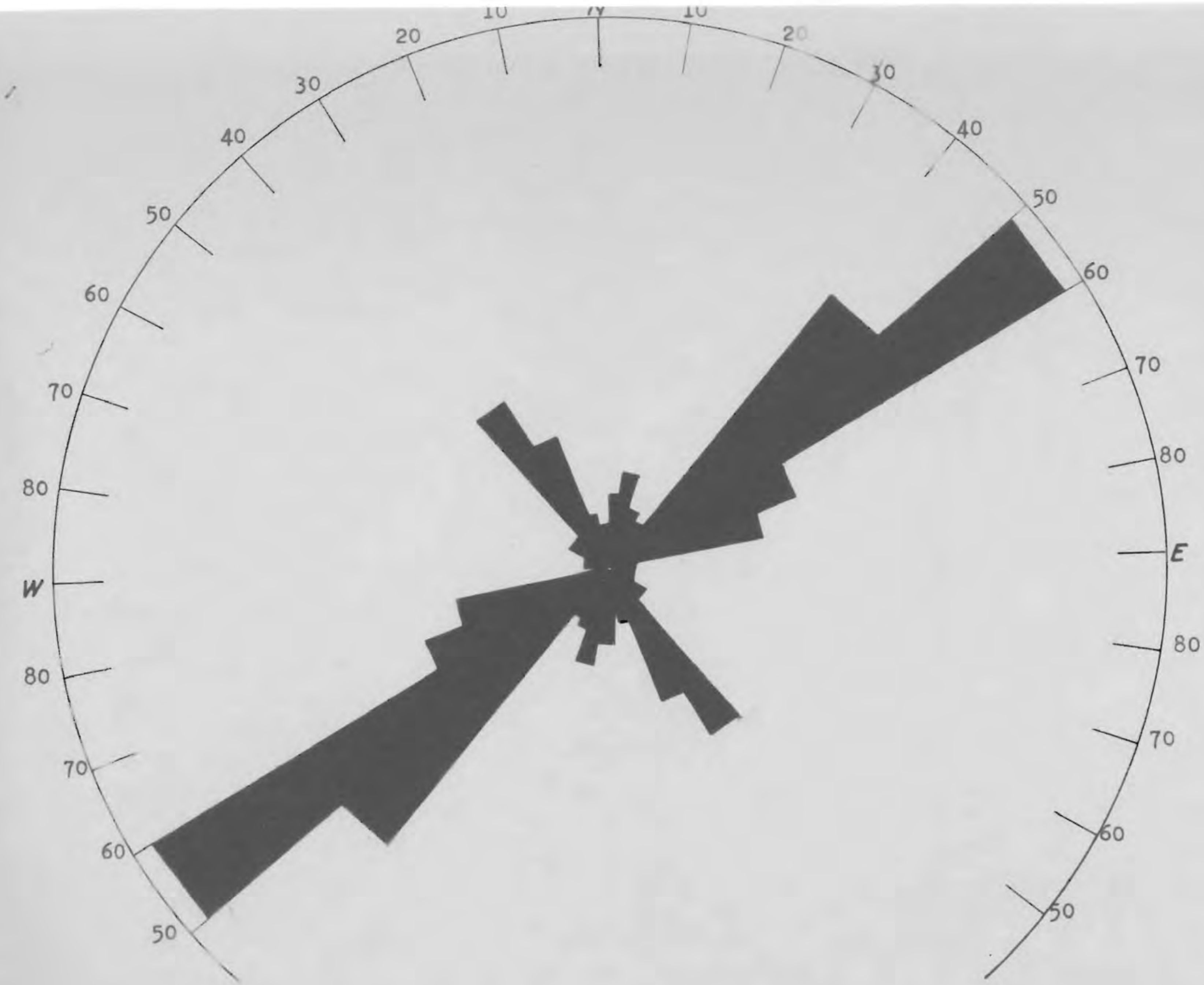


FIGURE 6

DIAGRAM SHOWING THE PREFERRED STRIKE OF MAFIC DYKES IN THE LOWER GRIQUATOWN STAGE

Scale: 1cm = 5 Dykes

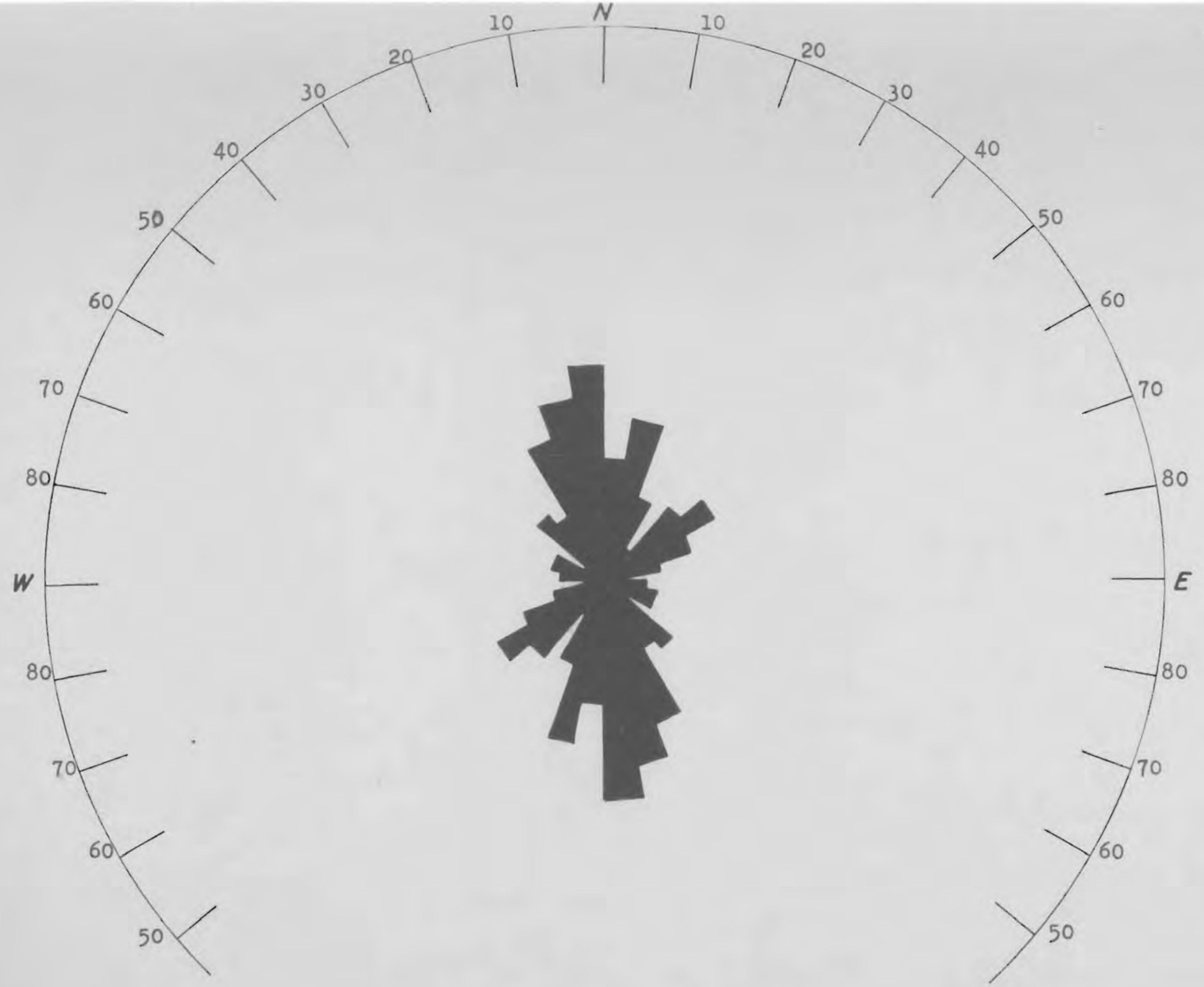


FIGURE 7

DIAGRAM SHOWING THE TREND OF FAULTS IN THE LOWER GRIQUATOWN STAGE

Scale: 1cm = 5 Faults

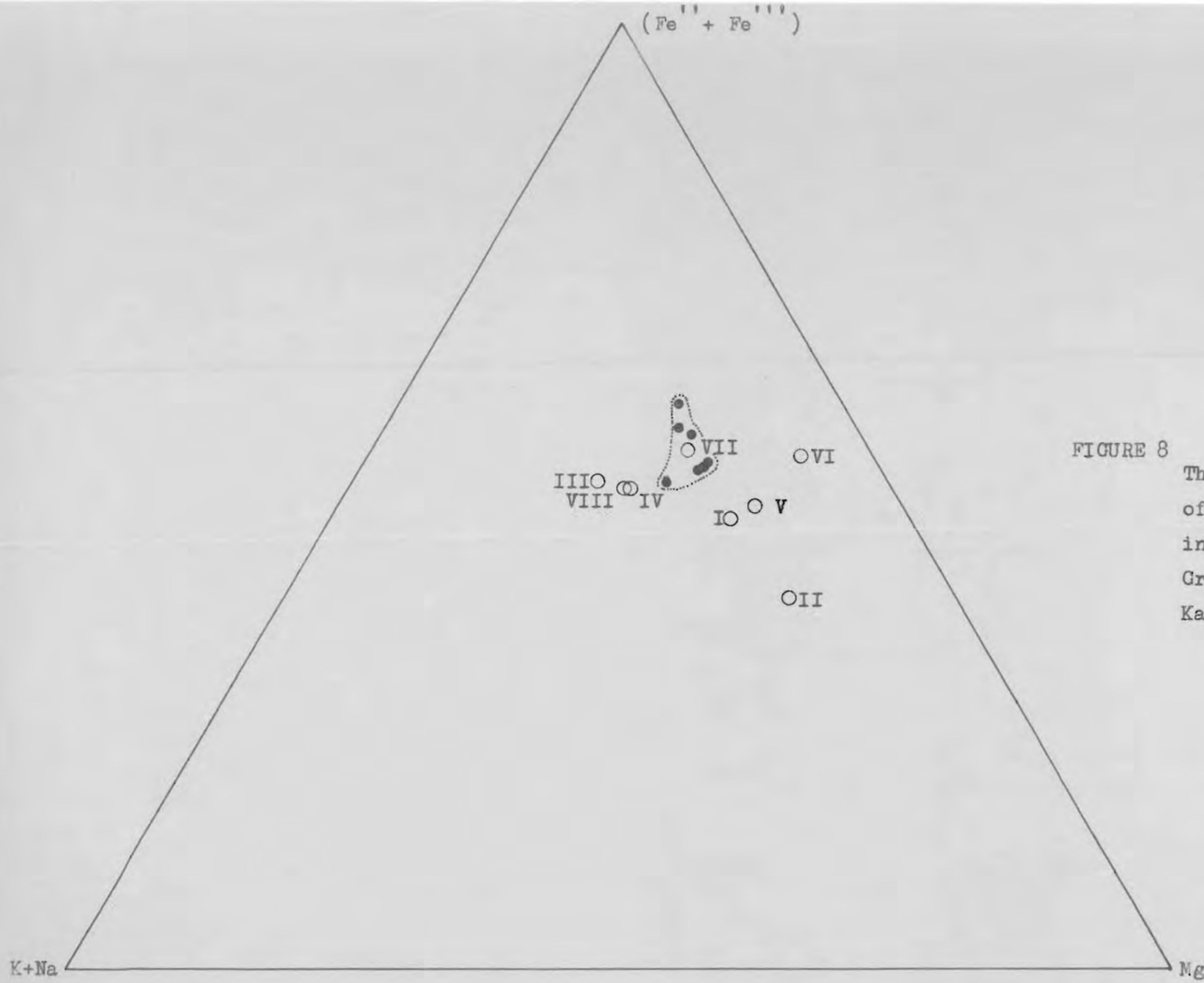


FIGURE 8

The variation in the total content of iron, magnesium, and the alkalis in diabase intrusive into the Lower Griquatown Stage and in dolerite of Karroo Age. (Compare Table 20).

and Ongeluk lava (No's. III, IV and VIII), a second group which contains less iron but more magnesium (No's. I and V) and a third group, represented by one analysis only, which contains considerably less iron, and more magnesium (II).

The diabase sills vary remarkably in thickness. Most sills attain a thickness of less than 100 feet, generally varying between 30 and 50 feet and they may be found on any stratigraphical horizon in the succession, from closely above the Dolomite (Taaibosch Puts 499, Postmasburg District) to near the top of the Banded Ironstone Substage (Hanging-wall sill, Westerberg, Prieska District). The thickest and most persistent diabase sill observed is present closely above the Intermediate Asbestos Zone in the Southern Region (p. 101). Some sills are concordant over long distances whereas others are only slightly transgressive e.g. the sill on Ouplaas 304.

Dykes are extremely abundant especially in the Northern Region. The most favoured directions along which the dykes are intruded are shown in figure 6. In this figure the strike directions of about 200 dykes were plotted and it shows that the majority of the dykes strike in a direction between N50E and N60E. The next most favoured direction is between N40E and N50E, so that about 40 per cent of all dykes in the area strike between N40E and N60E. Approximately 15 per cent of the dykes in the region strike between N60E and N80E bringing the total NE and ENE trending dykes up to 55 per cent of all dykes intrusive into the Lower Griquatown Stage.

Only about 20 per cent of the dykes strike in a north-westerly direction and almost all the dykes trending in this direction are found in the Southern Region and practically none in the Northern Region. A very small proportion of the dykes strike north-south.

Many of the mafic dykes were intruded along faults, but the majority of the dykes which trend north-east are not associated with faulting. Most prominent faults in the entire area are thrust- and normal faults and commonly strike between 20$^{o}$ west and 20$^{o}$ east of north, directions in which diabasic dykes seldom strike. Figure 7 shows that only a very small number of the dykes strike in the same direction as that in which most faults are trending and further illustrates that only a few of the dykes with the prominent north-eastern trend are associated with faults. The prominent northerly direction in which most faults strike coincides with the strike of the major thrust faults in the Postmasburg area and are of post-Matsap age. Most of the mafic dykes which strike northeast are displaced to some degree by faults which trend more towards the north, which indicates that these dykes were emplaced before faulting took place during the post-Matsap period of crustal deformation. It therefore appears as if most of the mafic dykes and sills were emplaced prior to or during the early stages of post-Matsap deformation but some, especially those occupying fault-zones which trend north-south are of post-Matsap age. Some of the dykes and sills caused thermal metamorphism of the crocidolite viz. on Ouplaas 304 (L2) and Koretsi (H1), showing them to be emplaced contemporaneous with or after the formation of the crocidolite.