Second Lower Zone

The Second Lower constitutes one of the most important sources of crocidolite in the Kuruman area and south of Kuruman to around the Bretby and the Greyling Mines situated north of Danielskuil. Its upper limit is about 55 feet (Riries Mine I1) to 110 feet (on farm Lambley, I2) below the base of the Main Marker. It attains a maximum recorded width of some 35 feet including several thin partings of waste, as is the case on Hartland (I2) (Figure 2). As a rule, however, the Second Lower, where mined, is less than 30 feet thick. A detailed section of the fibre-bearing banded ironstone in this zone as encountered at the Eldoret and Whitebank Asbestos Mines is shown in figure 3.

In the Eldoret Asbestos Mine (Merencor Group) the upper limit of the Second Lower is found from 56 to 75 feet below the Main Marker and the zone attains a maximum thickness of about 28 feet (Figure 3). It is subdivided into three separate reefs known as the A, B and C-Reefs. The asbestos reefs in the mines are numbered from top to bottom. It is customary to number geological units in ascending order, but to prevent confusion the numbering of reefs as used in the mines will be adhered to. At this locality a black layer, nine inches thick, and composed almost entirely of stilpnomelane is found about nine feet above the hanging wall of the uppermost or A-Reef and constitutes a valuable marker in the succession. In the mine this layer is referred to as the Brecciated Siltstone Marker (Figure 3). In all the bore-holes drilled for asbestos at this mine and in the underground workings this black layer was found to contain appreciable amounts of underground water because of its intensively fractured nature. Microscopic investigation of the stilpnomelane-bearing rock and of several similar layers in the banded ironstone showed that they represent altered tuffs and they will accordingly be referred to as tuffs or tuffaceous layers farther on in the text. A detailed description of the altered tuffs is given on p. 148.

The C-Reef commences immediately above a layer of tuffaceous material, on the average about two feet thick. This layer contains numerous blebs and streaks of pyrite and is known as the Pyritic "Siltstone" Marker. The C-Reef attains a thickness of some 13 feet. The top of the reef is represented by another layer of tuff, two to

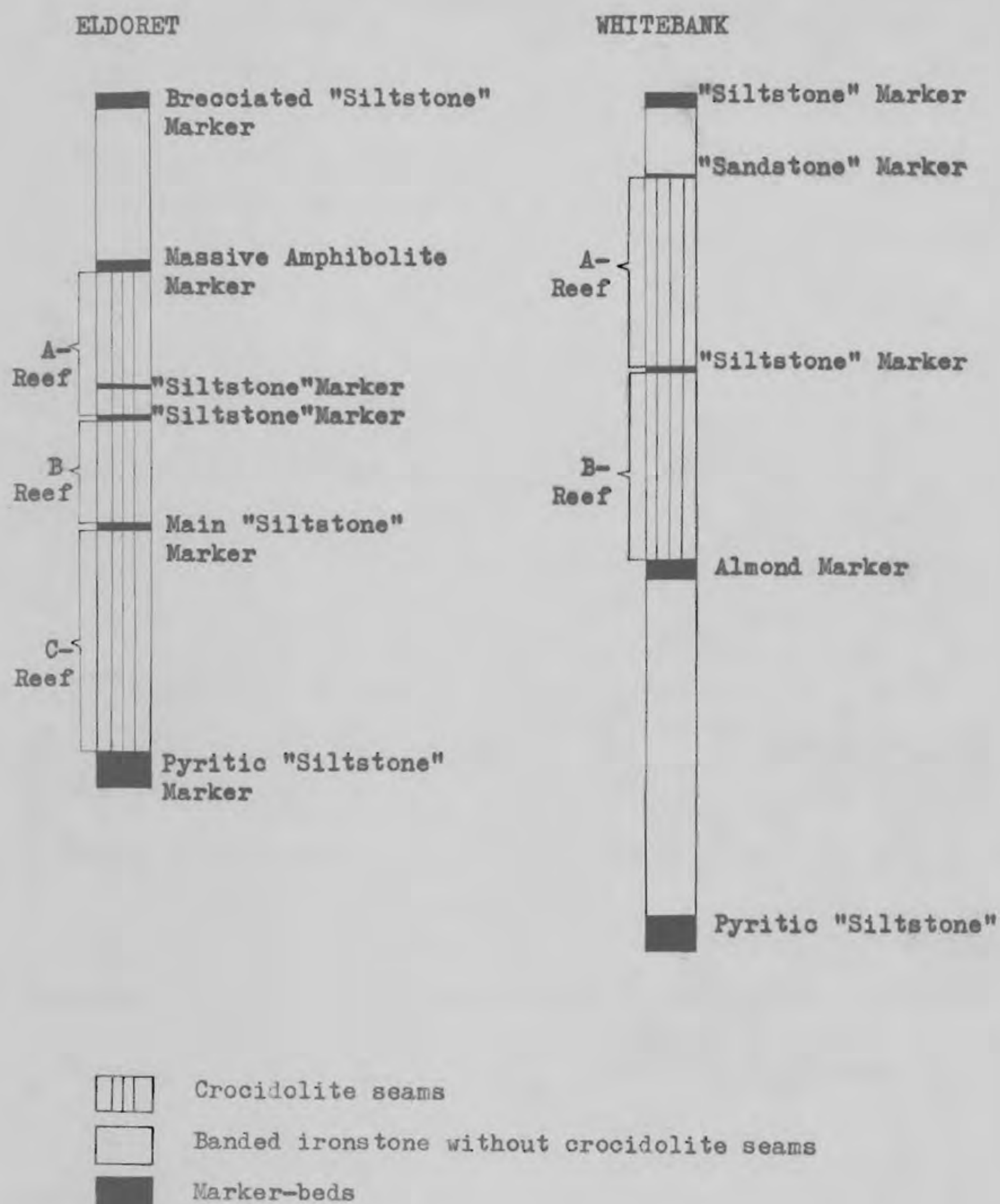

FIGURE 3

THE VERTICAL DISTRIBUTION OF CROCIDOLITE IN THE SECOND LOWER ASBESTOS ZONE IN THE ELDORET AND WHITEBANK MINES(c.a. 20 miles apart) KURUMAN AREA

Scale : 1 Inch = 10 Feet

four inches thick locally called the Main Siltstone Marker (Figure 3).

The B-Reef commences immediately above the Main Siltstone Marker and is about six feet thick. The hanging wall of the reef is represented by another thin layer of tuff, one to two inches thick, which also represents the foot-wall of the A-Reef. This layer is known as the Siltstone Marker.

The A-Reef reaches a thickness of about eight feet. The upper six to seven feet of this reef contain a greater concentration of crocidolite seams than the lower 14 to 24 inches and are separated from the poorer portion by a thin layer of pyroclastic material about 2 inches thick (Siltstone Marker, figure 3). The hanging wall of the A-Reef is characterised by a tough layer of massive riebeckite which is, on the average, five inches thick. This layer, however, increases in thickness to about 20 inches in places.

More layers of tuff than those chosen as "Markers" are found within the range of the Second Lower in the Eldoret Asbestos Mine. Several others, varying in thickness from about a quarter of an inch to just more than one inch, were observed.

Pyrite is a common constituent of many of the tuffaceous layers, but is most abundant in the thick layer which represents the foot-wall marker of the C-Reef. The pyrite is generally found as thin streaks parallel to the bedding or as nodular bodies which are strongly flattened in the plane of the bedding. Streaks and irregular blebs of white quartz are also common in some of these bands, but are most abundant in places where intense fracturing of the lowermost band of pyroclastic material is apparent.

Cross-fibre seams of crocidolite are not equally well developed over the entire width of the Second Lower zone in the Eldoret Asbestos Mine. At this mine the uppermost six to seven feet of the zone (A-Reef) are best developed and contain up to 35 separate seams of crocidolite. The seams vary in width from less than a quarter inch to about one inch, with longer fibre in localised spots. Many of the individual seams are remarkably persistent whereas others again pinch out over short distances. Where a particular crocidolite seam peters out, another may start to develop some distance away along the same bedding plane or it may develop at less than an inch or a few inches above or below the bedding plane in which another seam pinches out. In other places again closely adjacent seams may overlap one another vertically, that is, if one pinches out a second seam can develop closely above or below from a point directly above or some distance away from where the former seam pinches out.

The lowermost 14 to 24 inches of the A-Reef are generally poorly developed in the Eldoret Mine and so also is the B-Reef. The C-Reef is again well developed in places, but nowhere as well as the A-Reef. The best development of crocidolite seams in this mine, no matter in which reef they are located, is restricted to those localities in the mine where folding is most intense.

Another detailed cross-section of the Second Lower zone was obtained in the Whitebank Asbestos Mine which is located about 20 miles south-east of the Eldoret Mine. At this mine the hanging wall of the Second Lower is found at about 80 feet below the Main Marker and the zone consists of two reefs each about 11 feet thick, which are referred to in the mine as the A and the B-Reef respectively.

The B-Reef is about 11 feet thick and its foot-wall is marked by a black cherty layer, six inches to two feet thick. The layer contains stringers, lenses and elongated, flattened, nodular inclusions of light grey to almost white chert, many of which partly resemble amygdales in a lava. This layer is called the "Amandelband" (Eng. Almond band) in the mine (HH 363).

The Almond Band does not everywhere contain almond-shaped cherty bodies from top to bottom. The upper portion of this layer is often characterised by the presence of discontinuous streaks or lenses of the light-grey, cherty material which are set in a ground-mass of dark-grey to black chert. Where the discontinuous layers of chert are present the almond-shaped bodies are developed only towards the base of the layer. Where these discontinuous stringers of grey chert are present in the upper portion of the Almond Band, it usually reaches its maximum thickness of some 24 inches. If, however, the almond-shaped bodies are present throughout the entire thickness of this band its thickness is only some six to nine inches. Furthermore, the Almond Band appears to thicken in the troughs of local small synclinal folds as well as in the crests of similar small anticlinal folds whereas in the limbs of these folds the layer thins out. A thin layer of black tuffaceous material is present about three feet below the top of the Almond Band and this distance remains remarkably consistent whatever the thickness of the Almond Band may be.

It is important to note that the almond-shaped bodies of grey chert in the Almond Band are most abundant where the layer becomes very thin. In those places where the Almond Band reaches its maximum thickness the almond-shaped bodies are sporadically developed. This relation between the thickness of the Almond Band and the varying amount of almond-shaped bodies in it indicates that these bodies represent a form of "boundinage" formed during the folding of the beds.

Immediately overlying the Almond Band is a layer, generally some two inches thick, which displays a yellow-grey colour resembling the colour of khaki material. For this reason it is called the "Kakieband" (Eng. Khaki Band (HH363A). Wide variations in the thickness of the Khaki Band are found in several places in the mine, where it sometimes reaches a maximum of about nine inches. This band displays perfect conchoidal fracturing similar to the bands of black tuffaceous material which are so abundant in the Banded Ironstone Substage.

The rock which constitutes the "Kakieband" is composed mainly of ferristilpnomelane which displays a yellow-brown to olive-brown colour under the microscope and is accompanied by carbonate and magnetite as essential mineral constituents. The carbonate is present as irregular grains, but often it attains crystal outlines and encloses numerous round specks of hematite. Hematite was nowhere observed outside the carbonate, but magnetite is present in relatively large quantities in the remainder of the rock. The hematite grains included in the carbonate grains and in the xenoblastic crystals are generally arranged in linear fashion parallel to the stratification. Under low magnification numerous lense-like bodies which are lighter in colour than the green-brown matrix, are found with their major axes parallel to the bedding. These small lenses vary in length from a fraction of a millimetre to a maximum of about 4.2 mm and is seldom wider than about 1 mm. They are composed of fine flakes resembling a colourless mica accompanied by ferrostilpnomelane, which is slightly coloured in tints of yellow and green, and carbonate. Accessory amounts of microcrystalline quartz are present in some of the small lenses.

The B-Reef in the Whitebank Asbestos Mine can be subdivided into three separate sections of approximately equal thickness, based on the toughness of the rock in each of the sections. The layered rocks of the middle section are the softest, with the upper section slightly harder and the lower section extremely hard. This variation in toughness of the rocks is experienced especially during underground drilling operations. A close inspection of the B-Reef revealed the fact that the toughness of each section depends on the abundance of seams of massive riebeckite intercalated with the banded ironstone. The middle section contains almost no seams of massive riebeckite, the upper section contains only a few thin seams of this material, but the lower section is composed almost completely of rather thick seams of massive riebeckite (Specimen HH 368). The general impression one gets when studying the B-Reef is that seams of crocidolite fibre decrease in width in those sections containing the most seams of massive riebeckite. The top of the B-Reef is marked by a tuffaceous layer, about two inches thick.

The A-Reef commences immediately above this layer of tuffaceous material and reaches a thickness of 11 feet. The top of the A-Reef is formed by a layer of grey chert and massive riebeckite which in the mine is called the "Sandstone Marker". This band varies in thickness from about 9 to 15 inches and is composed of lenses or thin, discontinuous layers of "quartzitic" or "sandy"-looking grey-white chert embedded in hard, blue, massive riebeckite. The band of massive riebeckite is similar to the one constituting the hanging wall marker of the Second Lower in the Eldoret Mine, except for the presence of the chert bodies in it. The lenses and thin, discontinuous layers of grey-white chert in the layer of massive riebeckite are generally restricted to three separate horizons within the layer. A single crocidolite seam is present immediately above the uppermost layer of grey-white chert and is well developed in places, but is not very persistent in its areal distribution. In places where this crocidolite seam is well developed it is not mined even when present, as in some places, a foot or less above the highest seam in the A-Reef. The reason for this is because the tough layer of massive riebeckite forms an excellent, strong hanging in the stopes.

A tuffaceous layer, ten inches thick, which is present about four to five feet above the hanging wall marker of the A-Reef in the Whitebank Mine, could well be regarded as the counterpart of the fractured layer of tuffaceous material which is present some nine feet above the top of the Second Lower zone in the Eldoret Mine. If this is the case the stratigraphical position of this layer is remarkably persistent seeing that the two mines are located at least 20 miles apart.

A tuffaceous layer two feet thick, which contains abundant pyrite and also irregular bodies of white quartz is found about 20 feet below the base of the B-Reef. This layer may correspond with a similar layer which constitutes the foot-wall marker of the C-Reef in the Eldoret Asbestos Mine. Should this be the case the vertical thickness between the uppermost layer of tuff ("siltstone") and the lowermost layer of tuff ("siltstone") found within the reach of the Second Lower increases from some 37 feet in the Eldoret Mine to about 47 feet in the Whitebank Mine, located 20 miles south of the former. Furthermore the C-Reef of the Eldoret Mine, or part of it, is not developed in the Whitebank Mine.

Third Lower Zone

Together with the Second Lower the Third Lower represents the most important source of crocidolite in the Kuruman area. This zone generally consists of a series of fibre-bearing beds the uppermost of which is found from about 35 to 100 feet below the base of the Second Lower. In those localities where the Third Lower is best developed its top generally occurs between 35 and 65 feet below the base of the Second Lower. In certain mines the fibre-bearing beds constituting this zone are so widely spaced that it is locally subdivided into a Third and a Fourth Lower, which is naturally incorrect because barren beds at one locality may be fibre-bearing in another as is shown in figure 2. The Third Lower reaches a maximum thickness of about 140 feet, including the narrow waste partings in between fibre-bearing beds and is especially well developed in the Riries Asbestos Mine and also in the Whitebank Asbestos Mine. The vertical distribution of crocidolite in this zone varies quite remarkably from one locality to another. In some the most persistent development of fibre is towards the upper part of the zone, in others the best development is towards the centre of the zone, whereas in others again the most persistent development is towards the base of the zone.

A detailed section of the Third Lower Zone as represented in the Whitebank Mine is given in figure 4. In the mine the different fibre-bearing sections are referred to as the C, C_1, C_2, D and D_1 Reefs in successive order from top to bottom.

The D_1-reef represents the lowermost reef in the Third Lower Zone and commences immediately above a layer of chocolate-brown chert about one foot thick (Chert Marker, fig. 4). The reef attains a thickness of 10 feet and is succeeded by barren banded ironstone, about 10 feet thick.

The D-Reef is about 12 feet thick and succeeds the barren banded ironstone above the D_1-Reef. The foot-wall of the D-Reef is formed by a layer of chocolate-brown chert (Chert Marker, Fig. 4), which is similar in appearance to the foot-wall marker of the D_1-Reef. The top of the D-Reef is marked by a layer of massive riebeckite, about three feet thick (Massive Riebeckite Marker, fig. 4). Subordinate, thin intercalations of banded ironstone are present in the layer of massive riebeckite.

The Massive Riebeckite Marker is succeeded by a layer of banded ironstone, 14 feet thick, barren of crocidolite seams, before the base of the succeeding C_2 Reef is reached. The C_2-Reef has a thickness of some eight feet and terminates at its base against a layer of finely laminated, banded ironstone which contains a few laminae of red-coloured chert. This layer is known as the Rainbow Marker in the mine and forms the foot-wall of the C_2-Reef.

The foot-wall of the C_1-Reef is a layer of tuffaceous material, 6-12 inches thick, which is found about two feet above the top of the C_2-Reef. This layer is known as the Siltstone Marker in the mine. Plastic flow of the tuffaceous material which constitutes this layer has been observed in places.

It took place especially in the crests of the localised, steep anticlinal to isoclinal folds, and is characterised by the exploitation of irregular fractures in the banded ironstone by material squeezed out from the pyroclastic material. These fractures may cut vertically across the adjacent layers of banded ironstone. In many of these filled-up fractures the pyroclastic material recrystallised to form shiny black, acicular

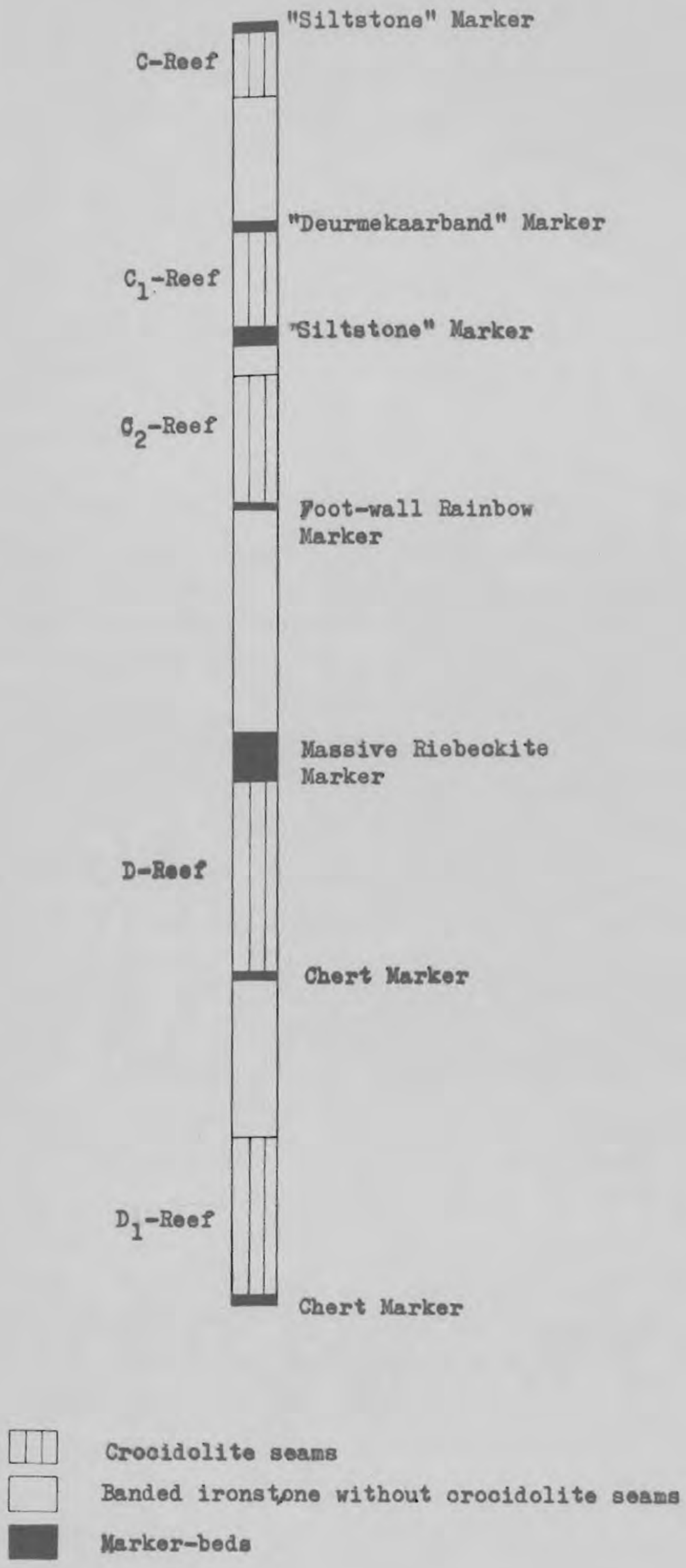

FIGURE 4

THE VERTICAL DISTRIBUTION OF CROCIDOLITE IN THE THIRD LOWER ASBESTOS ZONE, WHITEBANK MINE, KURUMAN AREA

Scale: 1 Inch = 10 Feet

crystals of ferristilpnomelane which are commonly orientated with their long axes perpendicular to the edges of the fractures. Irregular fractures within the main body of tuff are also occupied by similar black, acicular crystals of ferristilpnomelane.

Under the microscope the crystals appear as acicular to plume-like crystals orientated at right angles to the walls of the fractures. They are distinctly pleochroic in pale-yellow to green-brown, elongation positive and uniaxial negative. The longest crystals, observed within fractures of the tuffaceous rock itself, approach 0.25 mm. In some of the fractures it can clearly be seen that the crystals grew from the opposite walls of the fractures, and meet more or less in the centre of the fracture. Along the line where they meet there appears to be a very thin line of disorientated flaky crystals of the same mineral (HH 364). The remainder of the tuffaceous rock is composed, almost completely, of tiny, intricately interwoven flakes of the same mineral. The C_1-Reef is about six feet thick and terminates at its top against a layer of brown chert which contains nodular inclusions of grey-white chert. This layer is called the "Deurmekaarband" in the mine and resembles the Almond Band in the Second Lower, discussed on p. 50.

The C_1-Reef is succeeded by a layer of barren banded ironstone, eight feet thick, before the base of the C-Reef is reached. This reef attains a thickness of about four feet. A thin layer of tuffaceous material, one to six inches thick, is found 15 inches above the top of the reef and represents the hanging-wall marker known as the Siltstone Marker (Fig. 4). The tuffaceous material varies in colour from greenish-black to black and displays strong conchoidal fracturing.

Asbestos-bearing zones below the Third Lower Zone

Intersections in bore-holes of crocidolite-bearing strata below the Third Lower are not many because to date the First, Second and Third Lower Zones have received the most attention by mining concerns. Only a small number of bore-holes have been drilled to well below the Third Lower in the Kuruman area and only one is known to have penetrated the entire Banded Ironstone Substage.

Information on the vertical distribution of crocidolite-bearing zones below the Third Lower is therefore incomplete and is based mainly on field-observations. In addition to a few intersections in bore-holes these observations tend to indicate that crocidolite-bearing zones below the Third Lower are generally less well developed than the upper ones in the Banded Ironstone Substage. It indicates further that the distribution of separate, and with a few exceptions, fairly thin, intersections of crocidolite-bearing strata in the lowermost portion of the Banded Ironstone Substage are not very persistent. This is particularly the case with those fibre-bearing beds which can be grouped into the Fourth and Fifth Lower Zones. The Sixth Lower and especially the Seventh Lower, which is the lowermost crocidolite-bearing zone in the banded ironstones, is quite persistent, but not very well developed.

The Fourth and Fifth Lower Zones are actually difficult to define with certainty from the available evidence, but are present in a number of localities, as is shown in figure 2.

The Sixth Lower is found about 180 to 190 feet above the dolomite and although less persistent that the Seventh Lower it also enjoys quite a wide areal distribution.

The Seventh Lower Zone is usually found about 80 feet above the contact between the Banded Ironstone Substage and the underlying massive dolomite. Its development is fairly persistent not only in the Kuruman area, but also in the area towards Danielskuil and beyond where it remains around 80 feet above the dolomite.

(ii) The Stratigraphical Position of Asbestos Zones in the Banded Ironstone Substage

A series of generalised columnar sections showing the vertical depths at which fibre-bearing beds in the separate crocidolite-bearing zones in the Banded Ironstone Substage could be expected is given in figure 2. According to the subdivision used in this figure the Second Lower Asbestos Zone can be expected from about 55 feet to 135 feet below the Main Marker. Mineralised sections belonging to the Third Lower fall between 150 and 315 feet below this point. The upper portion of the Fourth Lower, as tentatively subdivided, may overlap with the lowermost portion of the Third Lower and could be expected between 295 and 400 feet below the Main Marker. The Fifth Lower may again overlap the Fourth Lower and may range in vertical position from 395 to 480 feet below the Main Marker. Fibre-bearing beds in both the Fourth and the Fifth Lower Zones are generally thin and could be expected at relatively large intervals within the vertical ranges given above.

Separate thin fibre-bearing beds which could be included in the Sixth Lower may range from 540 to 620 feet below the Main Marker whereas separate fibre-bearing beds of the Seventh Lower may range between 635 and 720 feet below the Main Marker. The foot-wall of the latter zone as pointed out, is quite consistently found about 80 feet above the dolomite.

(iii) The Upper Asbestos Zones

First Upper Zone

As pointed out (p. 45) all the upper zones are located within the Jasper Substage. The First Upper is found within the thin layer of banded ironstone immediately overlying the Main Marker and the fibre seams in this zone are generally restricted to the lowermost portion of this layer of banded ironstone. There are localities where fibre seams transgress the top of the Main Marker and may be found in interbedded layers of banded ironstone within this marker-bed; this is especially the case in the area around Danielskuil, but seldom in the Kuruman area, except on Ettrick (Il). The First Upper is in general poorly developed in the Kuruman area and to date no mining has been carried out on this zone. Old prospecting pits and opencast workings are located along this zone on a number of farms in the area, but none of them disclosed a deposit of economic value.

A shaft which was recently sunk on Ettrick penetrated several fibre-bearing beds. They vary in width from less than a foot to a maximum of seven feet within the banded ironstone layer immediately overlying the Main Marker and within intercalated layers of banded ironstone in the Main Marker. No additional information with regard to the lateral distribution of these fibre zones is available, but the width of some of the fibre-bearing beds is such that it may lead to the exploitation of this zone at the locality mentioned above. These intersections were obtained at depths below the zone of oxidation. Should additional exploration prove this zone to be profitable, it would be the only locality in the Kuruman area where crocidolite concentrations of economic importance have so far been found in the First Upper. The First Upper, in addition to the upper portion of the Main Marker, proved to be an important crocidolite-bearing zone in the area around Danielskuil and should structural conditions be favourable, there is no reason why this zone should not also yield good deposits of crocidolite in the Kuruman area.

Second Upper Zone

The Second Upper is found from 80 to 100 feet above the top of the Main Marker. It is found in close proximity to the Speckled Marker and fibre seams may be developed within the layers of banded ironstone or the strongly ferruginous jasper immediately below and above this marker-bed. Fibre development within this zone is seldom encountered and nowhere is there a concentration of crocidolite of suitable extent to be exploited. One of the few known localities where crocidolite fibre of good length has been found in this zone is in the mine shaft at the Koretsi South Mine (H1) which is located in the Lower Kuruman Native Reserve. In this shaft crocidolite seams which measure some one and a half to two inches have been intersected.

In the shaft on Ettrick several crocidolite seams which apparently fall within the vertical range of the Second Upper have been intersected over a width of some 10 feet. About 12 feet below the base of these fibre-bearing beds a single seam, 1 - 1¾ inches wide, which contains completely silicified, dark-blue crocidolite has been penetrated. This silicified material is found some 237 feet below surface within completely fresh, i.e. unoxidized, host-rock. As far as the writer is aware this is one of the very few examples in which completely silicified asbestos has been found below the zone of oxidation and the occurrence provides a reason for reconsidering the process of silicification to yield the blue variety of the semi-precious stone known as blue "tiger's-eye" or "cat's-eye".

Third Upper Zone

This zone is found about 50 to 60 feet above the Second Upper and is associated with the Magnetite-chert Marker. Asbestos fibre in this zone is generally restricted to the marker-bed only. In outcrops the fibre is commonly well silicified and is represented by yellow and yellow-brown "Tiger's eye". The seams generally have a limited extent in the direction of strike and more often contain bundles of silicified fibre which are slightly inclined to the bedding of the rocks. Because fibre seams are developed only in the marker-bed itself, this zone is seldom more than two feet thick. No commercial deposits of crocidolite are known to occur in this zone in the Kuruman area and such deposits are not expected because of the very localised development of fibre in the zone.

Fourth Upper Zone

The Fourth Upper stretches from about 220 to 240 feet above the Magnetite-chert Marker or the Third Upper and represents the uppermost limit of crocidolite development in the Lower Griquatown Stage in the area. Crocidolite seams in this zone are associated with layers of hard blue, massive riebeckite which are present almost immediately below the Potsherd Marker. The seams are seldom developed over long distances and individual seams are quite thin as a rule. One of the few localities where prospecting for asbestos in this zone took place is on Ettrick where a number of shallow excavations and adits were made in the past. This zone is present some 360 to 390 feet above the top of the Main Marker.

2. The Severn Area

With the description of the different substages of the Lower Griquatown Beds, the associated marker-beds and the vertical distribution of the crocidolite-bearing zones in the succession in mind, we may now proceed with the discussion of these rocks in the remainder of the Northern Region. For this purpose the rest of the region will be subdivided into smaller areas like the Severn, the Heuningvlei and the Pomfret areas located to the north of Kuruman and the Carrington-Derbi, the Ouplaas-Botha and the Griquatown areas south of Kuruman.

The Severn area is represented by the stretch of country between Tsineng in the south and the immediate surroundings of Severn in the north. Lithologically the rocks of the Lower Griquatown Stage in this area are very much the same as in the Kuruman area. The total thickness of the succession also remains approximately the same, being about 1600 feet in all. The

Tillite Substage is about 110 feet thick (De Villiers, S.B., 1961a, p. 6) which is a little more than the thickness of this substage in the Kuruman area. It also contains a layer of conglomerate which is apparently not developed in the Kuruman area. The upper portion of the Jasper Substage is more calcareous than in the Kuruman area and contains separate, recognisable intercalations of dolomitic limestone approximately 250 feet below its top.

(a) The Banded Ironstone Substage

This substage reaches a thickness of some 800 feet which corresponds with its thickness in the Kuruman area. In places it is characterised by apparently more ferruginous layers near the base. They display a deep-red colour on weathered surfaces and contain several intercalated layers of brown jasper and thin layers of white to grey chert. A quite conspicuous layer of white chert is found approximately 250 feet above the base of the banded ironstone whereas a series of relatively thick, poorly bedded layers of jasper are encountered between 300 and 400 feet above the contact between the dolomite and the banded ironstone (De Villiers, 1961a, p. 5).

Characteristic of the area is the occurrence of a layer of yellow-brown jasper, 20 feet thick, closely below the Main Marker. Immediately below this layer of jasper particular beds of banded ironstone display peculiar, warped bedding-planes and contain thin, white to grey, lens-like inclusions of chert. These characteristics are much the same as those of the Main Marker.

Asbestos-bearing zones occur at five different stratigraphical horizons below the Main Marker. Compared with those in the Kuruman area these zones correspond with the First Lower, Second Lower, Third Lower, Sixth Lower and Seventh Lower crocidolite-bearing zones in the latter area. The vertical distribution of these zones are shown in Figure 1.

The First Lower Zone which is found immediately below the Main Marker, has fibre seams developed over a vertical distance of some 20 feet. The Second Lower is found about 80 feet below the Main Marker and attains a maximum thickness of about 50 feet. The Third Lower commences some 30 feet below the Second Lower and has an average thickness of about 40 feet. The next crocidolite-bearing zone is present from 570 to 590 feet below the Main Marker and corresponds quite well with the Sixth Lower Zone of the Kuruman area. The lowermost crocidolite-bearing zone occurs 80 to 90 feet above the contact between the Banded Ironstone Substage and the underlying dolomite, and therefore corresponds very well with the stratigraphical position of the Seventh Lower in the Kuruman area.

(b) The Jasper Substage

According to De Villiers (1961a, p. 5) the average thickness of the Main Marker in the Severn area is between 20 and 30 feet which is considerably less than in the Kuruman area. In the field it would actually appear as if there is a gradual, although slight decrease in the total thickness of the Main Marker in a northerly direction along the strike. Except for the difference in thickness, the Main Marker retains its lithological characteristics in this area and may contain occasional thin seams of fibre, generally located towards its base. It is succeeded by a layer of banded ironstone, approximately 20 feet thick, which in places contains thin seams of crocidolite towards its top.

The layer of banded ironstone is succeeded by yellow-brown to dark-brown jasper which continues for some 60 feet before the Speckled Marker is encountered. A second "speckled" band almost similar to the Speckled Marker, except for the greater diameters of the "speckles", is present from 20 to 30 feet above this marker-bed. The second "speckled" band is, however, very impersistent. The Speckled Marker is succeeded by more jaspery layers intercalated with numerous bands of hard blue, massive riebeckite until the Potsherd Marker is reached. The Magnetite-chert Marker is still recognisable as far north as Amy's Hope but beyond this point it becomes very impersistent. The sediments between the Speckled and the Potsherd Markers are similar to those in the Kuruman area and concretionary structures are also common in some of the layers of siliceous mudstone. The uppermost 250 feet of strata of the Jasper Substage are quite calcareous and well-defined lenses and intercalations of dolomitic limestone are found in places e.g. in the bed of the Kgokgole River, not far north of Severn.

(c) The Tillite Substage

This substage is well displayed in a number of outcrops in the area, and attains a maximum recorded thickness of about 110 feet. The composition of the fragments, the pebbles and the cobbles in the tillite is generally the same as in the Kuruman area. The constituents are poorly sorted, but some degree of sorting is apparent through the over-all decrease in the size of the pebbles towards the top of the substage. The finer-grained, topmost portion contains angular and rounded fragments which are generally not more than half an inch in diameter. The cementing material of the tillite is gritty or sandy (De Villiers, 1961a, p. 6).

Layers of soft purple-brown sandstone, displaying cross-bedding, and hard, grey, felspathic grit are present as lenticular intercalations within the tillite on Amy's Hope (De Villiers, 1961a, p. 6). A conglomerate band, referred to earlier (p. 44), occurs within the tillite near to the common border of Amy's Hope (F1) and Ventersrus (F2), while bands and lenses of purple-brown quartzite have been reported from a number of localities (De Villiers, 1961a).

3. The Heuningvlei Area

This area covers the stretch of country between Tay (D1) in the south and Campden (C3) in the north, a distance of some 34 miles (Folder 1). The mining township at Heuningvlei is located in the approximate centre of the area. Only one asbestos mine is at present in operation and it is situated on Bute (C2). Mining for asbestos was previously also carried out on Hove (C2), where the possibility of locating new deposits of crocidolite is not excluded.

(a) The Banded Ironstone Substage and the distribution of associated crocidolite-bearing zones

The thickness of this substage is considerably more than in the Kuruman area. From available information it exceeds 1200 feet, which is 400 feet more than in the Kuruman area. Because of the extensive cover of talus and windblown sand along the eastern edge of the range of hills in which the Lower Griquatown Beds outcrop, the contact with the underlying dolomite is nowhere exposed, but drilling for water in the area has supplied valuable information which renders it possible to determine the thickness of the Banded Ironstone Substage.

The bore-hole results indicate that the basal portion of this substage is represented by a series of alternating layers of black, siliceous shale, banded ironstone and banded chert, of which the black shales are the most abundant. Individual layers in which intercalations of black shale are most abundant vary in thickness from about 15 to 65 feet. Some of these layers of shale contain pyrite, and they are usually intercalated with relatively thin bands of chert. Towards the basal portion of the Banded Ironstone Substage the shaly beds become calcareous and may contain frequent separate intercalations of dolomitic material. Near the base of this substage layers of dolomite become even more pronounced and are intercalated with thin layers of shale and chert. None of the bore-holes reached the massive dolomite, but those which intersected rocks in which dolomite layers are predominant certainly approached the top of the massive dolomite.

Most of the bore-holes, drilled by the Department of Water Affairs, intersected one or two sills of diabase located on different stratigraphical horizons in the banded ironstone. The heights above the dolomite at which these sills were intersected are recorded as 100, 220, 250, 420 and 520 feet. The thicknesses of the diabase sills vary from 20 feet to a maximum of 170 feet. The thick sill (170 feet) was intersected in a bore-hole on Bute and is found between 420 and 590 feet above the Dolomite.

Layers of white, brown and almost black chert are found at several elevations in the banded ironstone. In the field some of them, especially the layers of white chert are quite persistent and serve as good marker-beds. A prominent layer of white chert, about 8 feet thick, is found about 280 feet above the top of the dolomite.

A layer of ferruginous jasper approximately five feet thick, which displays peculiar warped bedding-planes is present about 630 feet above the base of the banded ironstone or 540 feet when the total width of intrusive sills is excluded. This layer is quite persistent and proved a valuable marker in the field. It is well exposed on Hove (C2) and the adjacent farms. It displays a yellow-brown colour, is fairly well bedded and intensely contorted (Plates VI and VII). The warped or contorted nature of the layer is best observed where a single bedding-plane is exposed over a couple of square feet. This band often contains silicified crocidolite, the fibres of which are generally orientated at an angle to the bedding-plane. Folds on a small scale, measuring only a fraction of an inch in height, are present in abundance along the bedding-planes. Most of the small folds are accompanied by fractures or faults oriented parallel or nearly parallel to the axes of the folds, with vertical displacement of individual laminae showing on opposite sides of these structures (Plate VII). De Villiers (1961b) who first mapped this area in detail referred to this marker-bed as the "Kronkel Merker" (Eng. Contorted Marker). Two marker-beds of this type are present in the Heuningvlei area and the lower one just described will be referred to as the Lower Contorted Marker.

Crocidolite seams are found in the layers of banded ironstone immediately above the Lower Contorted Marker and reappear at intervals over a vertical thickness of about 70 feet. Information obtained from bore-holes also indicates the occasional presence of crocidolite seams from about 30 to 75 feet below this marker-bed. Except for the intersection of two thin crocidolite seams in one bore-hole about 330 feet below the Lower Contorted Marker, the fibre-bearing zone closely below this marker appears to be the lowermost crocidolite zone in the Heuningvlei area.

The crocidolite seams immediately below the Lower Contorted Marker are distributed at random between 620 and 670 feet below the Main Marker and therefore correspond roughly in vertical position with the Seventh Lower Zone of the Kuruman area. The fibre seams found immediately above the Lower Contorted Marker are located between 520 and 590 feet below the Main Marker and can therefor be correlated with the Sixth Lower Zone of the Kuruman area (Figure 1).

The second layer of contorted, ferruginous jasper referred to above, has the same characteristics as the Lower Contorted Marker. It is found about 130 feet above the Lower Contorted Marker and is referred to as the Upper Contorted Marker. Because of a similarity in characteristics it is not possible to distinguish without doubt between these two contorted beds in the field. A guide thereto is offered by the layers of banded ironstone immediately overlying them. Those beds immediately overlying the upper layer display the usual dark-brown to black colours on weathered surfaces, but the layers of banded ironstone immediately overlying the Lower Contorted Marker are usually characterised by extremely vivid colours. Apart from the usual brown, dark-brown and black colours these beds often display red-brown and deep vermillion-red colours on their bedding-planes. The material displaying these reddish colours forms very smooth, shiny surfaces on the bedding-planes and is composed of thin veneers of silica and iron oxide.

The Upper Contorted Marker is generally slightly thicker than the Lower and silicified crocidolite is also more common above, within and below this layer. Fibre seams within the Upper Contorted Marker attain a thickness generally less than a quarter inch and the fibres are invariably inclined to the bedding-planes or may even approach the slip-fibre type. The fibre-bearing zone associated with the Upper Contorted Marker is found between 420 and 470 feet below the Main Marker and therefore corresponds with the Fifth Lower Zone of the Kuruman area (Figure 1).

About 180 feet above the Upper Contorted Marker another crocidolite-bearing zone is present over a vertical width of some 40 feet. The fibre seams in this zone are found in layers of banded ironstone which are intensely folded over the entire width of the zone. Folding fades out rapidly below and above the zone, apparently indicating that the fibre formed only within a certain layer of incompetent material. Lithologically the banded ironstone in these folded layers is similar to the strata which are present below and above them and which are not folded. It is concluded that the material from which the crocidolite crystallised, was composed of material softer than the enclosing beds of banded ironstone and that because of this the entire zone behaved as more incompetent. The best development of crocidolite is found in the crests of the small folds. This zone is present between 200 and 240 feet below the Main Marker and therefore corresponds with the Third Lower Zone of the Kuruman area (Fig. 1). From the available information it will therefore appear as if the Fourth Lower Zone is not represented in the Heuningvlei area.

The zone of folded asbestos-bearing beds is succeeded by a succession of banded ironstone, 180 to 200 feet thick, with subordinate layers of jasper which display quite regular bedding. The topmost portion of this succession of banded ironstone contains crocidolite seams distributed over a vertical distance of about 20 feet. This asbestos zone is immediately succeeded by the Main Marker, where recognisable as such, or by jaspery layers and therefore represents the First Lower Zone.

(b) The Jasper Substage

The Main Marker which represents the base of the Jasper Substage is rather poorly developed in the Heuningvlei area. In the southernmost portion it may still be distinguished from the succeeding layers of jasper because it still contains lense-like bodies of grey chert and displays warped bedding-planes as in the Kuruman area. Towards the northern extremity of the area the lens-like inclusions become less numerous and the bedding-planes of the jasper constituting the Main Marker are more even and similar to the bedding in the overlying Jasper Substage. Where recognisable, the Main Marker is much thinner than in the Kuruman and the southern portion of the Severn areas, and measures only some 20 feet. Oxidised and silicified crocidolite is found in a few places in discontinuous seams interbedded with the more ferruginous layers in the marker-bed.

Although the Main Marker, or that portion of it which retains the characteristics of the true Main Marker, becomes thinner quite rapidly towards the northern extremity of the Heuningvlei area it is still recognisable as far as the centre of the area. At a point due west of the settlement at Heuningvlei a layer of fragmental rocks, about one foot thick, immediately succeeds the Main Marker thus indicating its top as in the Kuruman area. This zone of fragmental rock is succeeded by a layer of banded ironstone, 15 feet thick, which displays intense folding in quite a number of places. The folds in this layer are generally isoclinal and their axial planes which have a north-south strike are commonly overfolded to the east.

The Jasper Substage reaches a thickness of about 500 feet in the Heuningvlei area. The lowermost portion of this succession is well exposed over the greater part of the area, but theupper portion is generally poorly exposed owing to the presence of talus and wind-blown sand along the western edge of the hilly tract formed by the Lower Griquatown Beds. The northern portion of the area is especially characterised by the paucity of outcrops and the abundance of large areas covered by wind-blown sand.

The lower portion of the Jasper Substage is similar to that in the Kuruman area and the rocks generally display yellow-brown to brown colours on weathered surfaces. The Speckled Marker is found about 200 feet above the Main Marker. It attains a thickness of two feet and displays the same characteristics as in the Kuruman Area.

The sediments above the Speckled Marker gradually change into more sandy types and are intercalated with thin bands of massive riebeckite. Septarian nodules similar to those found in the Kuruman area are associated with some of the **siliceous layers** of mudstone in this succession.

(c) The Tillite Substage

The Tillite Substage is poorly represented in the Heuningvlei area. It ourcrops only at the corner beacon of the farms Tay (D1) and Berwick (D2) where the rock is composed mainly of rounded and angular fragments of jasper, chert and quartzite, cemented by red-brown to purple-brown gritty material.

4. The Pomfret Area

In this area rocks of the Lower Griquatown Stage crop out sporadically; suboutcrops are generally obscured by recent Kalahari sand. As far as could be ascertained, the Jasper Substage crops out only in a few places and no outcrops of the tillite could be traced. This area was, however, not mapped in detail, only reconnaissance work having been carried out, so that detailed mapping of the area in future may disclose additional outcrops of the upper two substages. However, the majority of outcrops belong to the Banded Ironstone Substage

The Banded Ironstone Substage

Although the total thickness of this substage could not be determined accurately in the field, field observations, in addition to bore-hole results, tend to indicate that the thickness of the banded ironstone in this area is the same as in the Heuningvlei area, i.e. around 1200 feet. Drilling showed that the Banded Ironstone Substage is composed of alternating layers of banded ironstone and banded chert in which the former predominates. The basal portion of this substage is represented by a layer of banded chert, approximately 50 feet thick, which succeeds the underlying dolomite conformably. Bore-hole results indicate that shaly beds are far less common than in the Heuningvlei area and that this rock-type is represented by a few thin layers, generally less than one foot thick.

Two diabase sills, 30 and 75 feet thick respectively, were penetrated by a bore-hole drilled by diamond-drill which intersected the major portion of the Banded Ironstone Substage and which reached into the underlying dolomite. These sills are found about 250 and 440 feet respectively, above the dolomite. These vertical distances above the dolomite correspond well with those distances above the dolomite at which bore-holes intersected diabase sills in the Heuningvlei area so that the sills can be regarded as underlying a large area (Bore-hole G14084 on Hove (C2), Vryburg District).

Crocidolite-bearing Zones

Information obtained from bore-holes (G14084 on Hove C2 and DW 19A on Pomfret B4), from mines (Bute and Pomfret) and from field observations indicates that crocidolite-bearing zones are present at several stratigraphical elevations above the dolomite. The vertical positions of these zones were compared with those in the Heuningvlei and the Kuruman areas and the correlation is shown in Table 6 (Also Figure 1).

In the Pomfret area the lowermost crocidolite-bearing zone is present between 570 and 600 feet above the top of the Dolomite Series. If the combined thickness of the two diabase sills intersected in this succession is subtracted this zone is found between 480 and 525 feet above the dolomite or alternatively approximately

Table 6. - Vertical distribution of Crocidolite-bearing Zones with respect to the Dolomite and the Main Marker in the Heuningvlei and Pomfret Areas

Crocidolite-bearing Zone	Height in feet above dolomite*		Depth in feet below Main Marker	
	Heuningvlei area	Pomfret area	Heuningvlei area	Pomfret area
First Lower Zone	1110-1130	1130-1140	0-20	0-10
Second Lower Zone	Not present	1045-1055	Not present	75-85
Third Lower Zone	890-930	865-880	200-240	250-265
Fourth Lower Zone	Not present	700-775	Not present	355-430
Fifth Lower Zone	660-710	655-675	420-470	455-475
Sixth Lower Zone	540-610	595-615	520-590	515-535
Seventh Lower Zone	465-510	480-525	620-670	605-650

* Thickness of diabase sills excluded

605 and 650 feet below the Main Merker. This position vertically below the Main Marker corresponds fairly well with that of the Seventh Lower in the Heuningvlei area (620 to 670 feet below the Main Marker), but overlaps the vertical position of the Sixth and the Seventh Lower of the Kuruman area slightly (Figure 1). The larger part of this zone does, however, fall within the range of the Seventh Lower of the Kuruman area with the result that it can be correlated with this zone.

This particular zone is mined in the Pomfret Asbestos Mine where it is represented by two separate reefs referred to in the mine as the "Blue Horizon" (Upper Reef) and the "Violet Horizon" (Lower Reef). The two reefs are generally separated by barren banded ironstone varying in width from 8 to 10 feet, but in places they merge into each other because of the development of mineable fibre seams in between these two reefs. In the Pomfret Mine the development of crocidolite in this zone is associated with an asymmetrical synclinal fold the fold-axis of which trends in an approximately east-west direction. The Lower Reef (Violet Horizon) reaches a maximum thickness of some 14 feet in the trough of the syncline and thins out towards the limbs of the fold. Those fibre seams which are present in the upper six feet of the Lower Reef are most persistent and are often the only seams which are developed towards the limbs of the fold. This fading out of the fibre seams is best observed in Block D24/25 of the Pomfret No. 2 Mine where the lower seams of crocidolite in the reef gradually thin out and eventually fade out as either the northern or the southern limb of the syncline is approached.

In those layers of banded ironstone in which the fibre seams fade out the rock is composed of alternating laminae of magnetite and greenish-yellow chert. This rock is referred to in the mine as "Zebra" rock. It is also characterised by the irregular thickness of individual laminae of magnetite and chert, which resemble pinch-and-swell structures. (Plate VIII). Crocidolite is occasionally developed within the "Zebra" rock, commonly between adjacent laminae of magnetite and chert but not within either of them. The general absence of crocidolite in this rock would indicate that the parent-material from which crocidolite crystallised was squeezed out of the rock in the limbs of the fold towards the trough of the syncline.

In the Upper Reef (Blue Horizon) those fibre seams located near the middle of the reef are the most persistent and the uppermost and lowermost seams in the reef generally fade out first toward the limbs of the fold. It is further of interest to note that cone-in-cone structures, often observed in crocidolite seams and discussed fully on p. 171, are restricted mainly to the Upper Reef in the Seventh Lower at Pomfret.

Towards the trough of the syncline, where both the upper and the lower reefs are best developed, the usual waste parting of some 8 to 10 feet between these two reefs generally carry so many fibre seams that this thickness of strata separating the two reefs becomes of economic value and is mined out, i.e. the entire thickness of banded ferruginous rock in the trough of the syncline becomes fibre-bearing.

At the Pomfret Mine the foot-wall of the succeeding crocidolite zone is found some 70 feet above the hanging of the Seventh Lower. It reaches a maximum width of from 18 to 20 feet and is located roughly between 515 and 535 feet below the Main Marker. In the mine this zone is referred to as the "Red Horizon" and its vertical distance below the Main Marker coincides roughly with that of the Sixth Lower in the Heuningvlei area (Figure 1).

Five separate crocidolite-bearing subzones are developed within the vertical range of 40 to 160 feet above the hanging wall of the Sixth Lower at Pomfret. These subzones are separated from one another by barren rock varying in width from about 10 to 25 feet. Only the uppermost subzone contains crocidolite in sufficient quantity as to be of economic value. This zone, which is found between 355 and 475 feet below the Main Marker, overlaps the vertical boundary between the Fourth and Fifth Lower Zones of the Kuruman area. As only the uppermost portion of it is of economic importance this zone can be correlated with the Fourth Lower of the Kuruman area (Figure 1).

The succeeding crocidolite-bearing zone is present at about 90 feet above the hanging wall of the Fourth Lower and reaches a thickness of 12 to 15 feet. It is found some 250 to 265 feet below the Main Marker and corresponds with the Third Lower of the Kuruman area.

The First Lower and the Second Lower Zones are found immediately below, and about 70 feet respectively below the Main Marker and were observed at the north-eastern corner of Pomfret only. Fibre development in these two zones does not appear to be very good. The Main Marker itself is rather poorly developed and is not much more than 10 feet thick. The zone of fragmental material which usually overlies the Main Marker was not observed.

5. The area between Kuruman and Danielskuil

The lithological characteristics of the rocks belonging to the Lower Griquatown Stage in this area are much the same as those described in the area around Kuruman. The main differences are found in the thicknesses of the lower two substages, the stratigraphical positions and the persistence of the different marker-beds described in the Kuruman area and, lastly, the vertical distribution of crocidolite-bearing zones in the Banded Ironstone Substage. Only those localities in which operating asbestos mines are located were investigated by the author, but additional information about the areas in between was obtained from bore-hole results and from

Mr. P.D. Fockema (personal communication), geologist of the Griqualand West Exploration and Finance Company, who kindly also supplied geological maps of the farms Schietfontein (L2), Hurley K3, and Bretby (K2).

(a) The Banded Ironstone Substage

This substage decreases in thickness quite rapidly between the Kuruman area and a point immediately north of Danielskuil. From the latter point southwards there is again a steady increase in the thickness of this substage. On Carrington (J2), about 5 miles south of the southernmost asbestos mine in the Kuruman area (Asbes Mine), the banded ironstones attain a thickness of about 650 feet, which is 150 feet less than in the Kuruman area. In the Gathlose Block immediately east of Repton (K2) the thickness remains about 650 feet, but not far south of this point, immediately east of Hurley it decreases to only 450 feet. On Derbi (K2), 6 to 7 miles south of the latter point drilling proved the thickness of the banded ironstones to be of the order of 580 feet, and another bore-hole located not far from the one on Derbi indicated a thickness of 530 feet. Immediately north of Danielskuil the total thickness of the entire succession of Griquqtown Beds is but 900 feet, thus indicating not only a decrease in the thickness of the Banded Ironstone Substage, which remains of the order of 500 feet, but also of the Jasper Substage and the overlying Tillite Substage. On Lemoenkloof (M2) and Botha (M2), about 12 miles south-south-west of Danielskuil, the thickness of the Banded Ironstone Substage again increases to 600 feet and from hereon southwards it increases steadily to some 1000 feet (Visser, 1958, p. 13) in the environment of Griquatown.

A bore-hole drilled by diamond-drill on Derbi, about 12 miles north of Danielskuil, penetrated the entire Banded Ironstone Substage and proved it to be composed chiefly of well-bedded, banded ironstone. Layers of jasper and chert are seldom found and, where present, are usually thin, measuring only a couple of feet. Layers of black shale are often encountered, especially between 80 and 170 feet and again between 320 and 350 feet above the top of the dolomite. These layers of shale vary in thickness from less than two inches to a maximum of some 3 feet. Layers of massive riebeckite which vary in thickness from mere partings to more than one foot are also quite frequent, generally more so on certain stratigraphical horizons in the banded ironstone. These layers of massive riebeckite are found at unequal intervals and are most abundant between 220 feet and 510 feet above the top of the Dolomite Series. Very thin seams of crocidolite are occasionally developed within the thicker layers of massive riebeckite.

Thin layers of grey dolomite intercalated with chert and black shale are present from about 45 to a hundred feet above the top of the main body of dolomite. The bore-hole referred to earlier proved that the contact between the dolomite and the banded ironstone is transitional, similar to that in the Kuruman area and the areas farther north. The detailed section between the top of the Main Marker and the Dolomite, as gathered from the bore-hole on the farm Derbi is provided in Table 7.

Table 7. - Detailed section of the Banded Ironstone Substage as intersected in bore-holes on Derbi, located between Kuruman and Danielskuil

(Drilled by Kuruman Cape Blue (Pty.) Ltd.)

Elevation in feet above the Dolomite	Thickness in feet	Description of rock type
590-597	7	White and grey chert with intercalated laminae of magnetite and subrounded inclusions of chert.
537-590	53	Poorly bedded, jaspery chert, magnetite-bearing in places. Laminae of reddish chert and seams of massive riebeckite in places. Subordinate seams of crocidolite at 543, 547 and 589 feet.
533-537	4	Dark greenish, black "shale".
528-533	5	Yellow-green chert.
512-528	16	Finely laminated, banded ironstone with seams of massive riebeckite and

Elevation in feet above the Dolomite	Thickness in feet	Description of rock type
		crocidolite. Thin layers of black shale at 520 ft. Crocidolite from 512 to 519 ft.
510-512	2	White-green chert.
441-510	69	Finely laminated, banded ironstone and several thin layers of intercalated black shale and seams of massive riebeckite and crocidolite. Crocidolite at intervals from 481 to 506 ft.
431-441	10	Medium, thickly laminated, banded ironstone. Width of individual cherty laminae varying from a quarter to half an inch.
420-431	11	Thinly laminated banded ironstone; width of cherty laminae from 1/16 to 1/8 inch; crocidolite at 425 and massive riebeckite and 424 and 426 ft.
407-420	13	Thickly laminated banded ironstone and a few seams of massive riebeckite. (Cherty laminae display pinch-and-swell structures).
352-407	55	Thickly laminated banded ironstone and numerous seams of massive riebeckite.
274-352	78	Thickly laminated banded ironstone; width of cherty laminae a ¼ to one inch; numerous layers of black shale and massive riebeckite.
228-274	46	Finely laminated banded ironstone and occasional seams of massive riebeckite.
223-228	5	Banded ironstone. Cherty laminae display pinch-and-swell structures.

Elevation in feet above the Dolomite	Thickness in feet	Description of rock type
124-223	99	Medium, thickly laminated banded ironstone and layers of intercalated black shale, as well as numerous seams of massive riebeckite in some of which crocidolite is developed. A layer of dolomitic limestone, 6 inches thick, is present at 141 feet. Seams of crocidolite sparingly developed between 160 and 222.
65-124	58	Thinly laminated banded iron-stone; brecciated material at 65 ft.; numerous inter-calations of black shale, a few inches to two feet thick, usually pyritic. Banded ironstone, calcareous, es-pecially between 65 and 113 ft.; cherty laminae grey, greenish and reddish in colour.
62- 65	3	Pyrite-bearing, black shale.
58-62	4	Banded ironstone.
44-58	14	Alternating thin layers of black shale and dolomite and subordinate layers of chert.
21-44	23	White-grey, poorly banded chert and intercalations of khaki-coloured shale $\frac{1}{2}$ to $\frac{3}{4}$ inch thick.
16-21	5	Grey dolomite displaying white specks.
13-16	3	White, banded chert.
8-13	5	Grey dolomite with white specks.
0-8	8	Thin, alternating layers of banded ironstone, shaly material and chert. Two

Elevation in feet above the Dolomite	Thickness in feet	Description of rock type
		thin layers of dolomite are present towards bottom of section.
zero	17	Massive grey dolomite (Logged by B. Free)

Although no diabase sill was intersected in the borehole on the farm Derbi (K2), two diabase sills are found in the Banded Ironstone Substage in the environment of Bretby (K2) and Schietfontein (L2). These sills are about 180 feet above the top of the Dolomite Series and closely above the Main Marker respectively. The sill which is found above the Main Marker on the farm Bretby (K2) is transgressive and farther south it is present in the Main Marker and in other places below the Marker-bed.

Crocidolite-bearing Zones

In the area between Kuruman and Danielskuil crocidolite-bearing zones which are of economic importance appear to be restricted chiefly to the horizons of the First Lower and the Second Lower of the Kuruman area. Separate crocidolite-bearing zones are developed in the Main Marker and at several elevations between 10 and 115 feet below the Main Marker. The upper portion of these zones falls within the range of the First Lower whereas the lower portion thereof falls within the range of the Second Lower. That portion corresponding to the Second Lower is best developed and is mined on Bretby (K2) and Greyling (portion of Bolham, K2). On Alphen (J2), Mapperley (J2) and Cubbie (J2) a maximum of five separate crocidolite-bearing reefs occurs within the first 80 feet below the Main Marker. Of these the second and the third reefs below the Main Marker are generally best developed, and reach thicknesses of some five feet. On Happy Valley (portion of Cubbie, J2) the lowermost of the five reefs is again the best developed.

Drilling on Derbi (K2) indicated six thin reefs within the first 115 feet below the Main Marker in which crocidolite seams are present. The uppermost three reefs which are found between 10 and 50 feet below the Main Marker are better developed than the lower ones and in the drill-core reach maximum widths of about four feet. Another crocidolite-bearing zone is present between 315 to 410 feet below the Main Marker. In this zone groups of crocidolite seams were intersected at intervals of 8 to 25 feet. In the drill-core the seams are usually very thin. Compared with the zones in the Kuruman area this zone corresponds stratigraphically with the Fourth Lower. The lowermost crocidolite-bearing material in this zone was intersected about 170 feet above the top of the Dolomite Series, but in neighbouring localities a still lower crocidolite-bearing zone is present about 80 feet above the main Dolomite.

From the above correlation it is evident that because of the thinning out of the Banded Ironstone Substage towards Danielskuil some of the crocidolite zones between the Main Marker and the Dolomite are not developed over the entire distance between Kuruman and Danielskuil. This statement is based on the fact that the First Lower remains prominent and so does the lowermost zone, found about 80 feet above the Dolomite in both the Kuruman and the Kuruman-Danielskuil areas, but in between there is a decrease in the number of separate crocidolite-bearing zones. The Second Lower which is a prominent and important crocidolite-bearing zone in the Kuruman area and also on Bretby (K2) and Greyling (portion of Bolham, K2) extends not much farther south than Garingkloof (portion of Schietfontein L2) and is completely absent on Ouplaas (L2), Owendale (M2) and Botha (M2) south-west of Danielskuil.

(b) <u>The Jasper Substage</u>

(i) <u>The Main Marker</u>

The Main Marker undergoes a gradual change towards the south especially with respect to the width of the zone of fragmental material which constitutes the uppermost portion of the marker-bed. On Carrington (J2), located not far south of the Kuruman area the Main Marker still displays the same warped bedding-planes and elongated inclusions of yellow-grey chert and retains its over-all thickness of about 40 feet, but the zone of fragmental material at its top becomes thicker and therefore more prominent. Still farther south, for example on Alphen (J2) and Happy Valley (portion of Cubbie, J2) the zone of fragmental material above the Main Marker reaches a maximum thickness of about five feet. Where this thickness is approached it often displays a conspicuous gradation in the size of the fragments from bottom to top.

The fragments in the lower portion are angular, subangular and in some places almost rounded. They generally measure about three inches along their major axes. Towards the top of the zone the fragments decreases gradually in size to dimensions of less than half an inch measured along their major axes. The fragments are mainly composed of white, grey and brownish chert set in a ferruginous ground-mass composed of smaller fragments of chert, cemented by ferruginous and siliceous material.

The fact that the zone of fragmental material is remarkably persistent over long distances, that is presumably retains the same stratigraphical position and that some degree of sorting is evident, points to the possibility that the fragmental material may represent an intraformational sedimentary breccia.

(ii) The succession above the Main Marker

The Jasper Substage and the underlying Banded Ironstone Substage decrease in thickness from Kuruman towards Danielskuil. A couple of miles south of the Kuruman area they measure about 600 feet in thickness. They are about 650 feet thick in the environment of Bretby (K2) and about 400 feet or less immediately north of Danielskuil.

The rock-types composing the Jasper Substage are the same as in the Kuruman area, but the Speckled and the Magnetite-chert Markers become difficult to distinguish from other similar bands in close proximity of one another. This is particularly the case in the area around Carrington where Stulting (1964) recognised at least five different layers displaying the characteristics of the Speckled Marker. These "speckled" layers are found about 50, 85, 115, 120 and 130 feet above the Main Marker. Most of them are impersistent, except for the one nearest to the Main Marker and the one found some 120 feet above it. The latter is the most persistent and has an average thickness of one foot. It is immediately underlain by a layer, approximately three feet thick, which resembles the Magnetite-chert Marker and which contains silicified crocidolite (tiger's-eye) in places.

Several other layers resembling the Magnetite-chert Marker are also found, but none of them is as persistent as the one immediately below the speckled band 120 feet above the Main Marker. If this marker-band is traced to the south, it becomes much thicker and very conspicuous because of the frequent development of crocidolite closely below, within or above it. Towards Daniëlskuil and beyond it attains a thickness of about six to eight feet and is easily recognised as the Magnetite-chert Marker. A detailed description of its characteristics around Danielskuil is given in the discussion of the Ouplaas-Botha area (M2), south-west of Danielskuil (p.84).

The Potsherd Marker, which is the lowermost of a series of usually three similar layers in the area is found about 100 feet above the Magnetite-chert Marker on Carrington and in the immediate neighbourhood, which is about 220 feet above the Main Marker. In the Kuruman area the stratigraphical interval between the Main Marker and the Potsherd Marker varies from around 370 to 390 feet, thus showing a decrease of about 150 to 170 feet in the area around Carrington.

Several other layers, displaying the same characteristics as the Potsherd Marker, have been recorded at odd intervals above this marker-bed (Stulting, 1964). The "potsherd" layers are quite persistent, but any individual layer is not restricted to the same stratigraphical horizon over long distances. If one of these layers is traced along strike it is found that it retains its stratigraphical position over distances of the order of 150 feet, then fades out gradually along strike to reappear at an elevation slightly below or slightly (2 to 5 feet) above its former stratigraphical position. Away from the point where it starts to develop again it will gradually become thicker attaining a width of about two feet and again decreasing in width farther on. Because these layers are found closely together the narrow zone in which they are present remains conspicuous and persistent and serves as a good marker-horizon.

Farther south towards Danielskuil three major "potsherd" bands are present. On the farm Derbi (K2) and the immediate vicinity the lower one is found at about 300 feet above the Main Marker. A diabase sill is present within the Jasper Substage, about 100 feet above the Main Marker.

6. The Ouplaas-Botha Area

This area which is situated south-west of Danielskuil covers the farms Ouplaas (L2), Barker (M2), Owendale (M2), Lemoenkloof (M2), Botha (M2) and Warrendale (M2) which are located from about six to twelve miles south-west of the village. During the time of investigation four asbestos mines were in operation on some of the farms with the result that detailed information on the vertical distribution of asbestos-bearing zones could be obtained from underground workings and from bore-holes drilled for prospecting purposes. Core samples from a bore-hole on Botha (M2) also supplied valuable information with regard to the lithological variation in the major portion of the banded ironstone succession.

The total thickness of the Lower Griquatown Stage increases from 900 feet immediately north of Danielskuil to about 1100 to 1200 feet in the Ouplaas-Botha area. Of this total the Banded Ironstone Substage represents about 600 feet as measured between the Main Marker and the Dolomite. It should be pointed out that whereas in the Kuruman area a thin layer of banded ironstone, about 30 feet thick immediately succeeds the Main Marker, this particular banded ironstone zone increases in thickness to about 160 feet in the area under discussion. Should this portion be included in the Banded Ironstone Substage its thickness increases to about 800 feet.

(a) The Banded Ironstone Substage

Since the upper limit of this substage had been set at the Main Marker in the region north of Danielskuil the same subdivision will be adhered to in the area south of the village although there is an increase in the thickness of the banded ironstone zone succeeding the Main Marker. The thickness of the banded ironstone intersected by drilling below the Main Marker varies from about 550 feet on Lemoenkloof (M2) to 600 feet on Botha. This Substage is composed chiefly of well-bedded ironstone with subordinate intercalations of jasper and banded chert. In both bore-holes referred to, black, shaly layers were intersected towards the base of the banded ironstone as well as thin beds of tuffaceous material at odd intervals.

In the bore-hole drilled on Lemoenkloof a layer of black shale, 30 feet thick, was penetrated immediately above a series of alternating layers of dolomite and chert. This zone represents the transitional contact between the Banded Ironstone Substage and the Dolomite Series and corresponds with that found in localities towards the north of the present area. This transitional zone is also proved by bore-hole results on Botha. This bore-hole was collared at about 20 feet below the Main Marker and intersected chiefly banded ironstone to a depth of 434 feet below surface. The upper 200 feet of the banded ironstone were oxidised to varying degrees, the intensity of oxidation decreasing with an increase in depth below surface.

The detailed section penetrated by this bore-hole is given in Table 8.

Table No. 8 - Detailed Section of the Banded Ironstone Substage as intersected in bore-hole DM12A on Botha (M2), Postmasburg District (Drilled by Cape Blue Mines (Pty.) Ltd.)

Elevation in feet above the Dolomite	Thickness in feet	Description
170-590*	420	Banded ironstone.
168-170	2	Dolomitic limestone.
156-168	12	Thinly laminated banded ironstone.
115-156	41	Banded chert and thin intercalations of dolomitic limestone at 139 and 156 feet.
98-115	17	Black to grey shale.
94- 98	4	Dolomitic limestone.
66- 94	28	Light-grey, banded chert and occasional thin intercalations of dolomitic limestone.
59- 66	7	Dolomitic limestone.
15- 59	44	Banded ironstone and subsidiary intercalations of dolomitic limestone and banded chert.

Elevation in feet above the Dolomite	Thickness in feet	Description
0-15	15	Banded chert and intercalations of limestone.
Zero	(13)	Massive dolomite

* Collar of bore-hole about 20 feet below base of Main Marker. (Logged by J.J. Mayer).

This bore-hole (Table 8) intersected no diabase sills, but other bore-holes on the same farm and also on the near-by farms Lemoenkloof (M2), Owendale (M2) and Ouplaas (L2) intersected one or two sills within the Banded Ironstone Substage. On the adjacent farms Ouplaas (L2) and Barker (M2) a diabase sill about 100 feet thick is present closely below the Main Marker. This sill crops out over a length of strike of some 2,000 feet and is terminated in the north against a fault striking north-south, with downthrow on the east side. The same sill is found immediately north of Danielskuil, just below the Main Marker (Folder 1).

Drilling at the Ouplaas Mine proved the presence of a diabase sill at an average depth of 200 feet below the Main Marker. The top of this sill was intersected by a number of bore-holes close together and indicated that it varies from 175 to 230 feet below the Main Marker over a short distance. The average thickness of the sill is 70 feet and varies from 56 to 157 feet from east to west. This is apparently the same sill which crops out approximately 20 feet below the Main Marker on Barker (M2), located just over a mile east of the Ouplaas Mine. This sill is therefore slightly transgressive at a low angle.

Drilling on Owendale (M2), south-west of the Ouplaas Mine indicated the presence of one, or in places two sills below the Main Marker. Where only one sill was intersected it is found about 120 feet below the Main Marker and has an average thickness of 20 feet. In bore-holes near by a second diabase sill was intersected at some 45 feet below the upper sill. The average thickness of the lower sill as obtained from ten different bore-hole sections is 23 feet, and varies from 15 to 45 feet. In some of the bore-holes in which only the upper sill was encountered its thickness increased to 50 or even to 80 feet in places. The fact that the upper sill increases remarkably in thickness where the lower sill is absent points to the possibility that the two represent a single injection of magma which in places gave rise to two separate sills, which merge into each other again in other localities. A deep borehole on Lemoenkloof (M2), west of Owendale (M2), intersected one diabase sill only at a depth of 150 feet below the Main Marker. This sill is 95 feet thick. On Owendale (M2) where one of the sills intruded into a crocidolite-bearing zone the mineral is highly metamorphosed. The thermal metamorphic effects are discussed on p. 144.

(b) The Main Marker and the Jasper Substage

The Main Marker is a very conspicuous marker-bed in the Ouplaas-Botha area, even more so than in the Kuruman area. The main difference from its counterpart in the Kuruman area is the general presence of two, and in some places three, well-defined zones of fragmental material at its top, towards its middle and at its base.

Where three separate zones of fragmental material are present, as for example on Owendale (M2), Botha (M2) and other farms in the vicinity, the vertical distribution of rock-types in the Main Marker from base to top is as follows:-

51-61 feet	:	Zone of fragmental material. Top.
36-51 feet	:	Ferruginous jasper and intercalations of banded ironstone.
34-36 feet	:	Zone of fragmental material.
4-34 feet	:	Ferruginous jasper and intercalations of banded ironstone.
0-4 feet	:	Zone of fragmental material. Base.

The uppermost and lowermost zones of fragmental material are the most persistent and are often the only zones of their kind present in the Main Marker. At a number of localities not far north of the area under discussion a well-defined zone of fragmental material is found about 100 feet below the Main Marker. This particular zone thins out to a few inches and is completely absent in many places.

The Main Marker is succeeded by a layer of banded ironstone which attains a thickness of some 160 feet compared with about 30 feet in the Kuruman area. It is succeeded by yellow to yellow-brown jasper. A thin layer at the base of this jasper zone displays many features characteristic of the Speckled Marker. All the concretions or "speckles" in this band have a thin outer rim composed of iron oxides which form a distinct contrast with the enveloping jaspery matrix.

A layer, approximately three feet thick and which displays all the characteristics of the Magnetite-chert Marker of the Kuruman area is found about 190 feet above the Main Marker. Crocidolite, oxidised and partially silicified where exposed, is associated with this layer in a few places. The proper Magnetite-chert Marker is found, however, about 30 to 40 feet above this thin layer.

The Magnetite-chert Marker in this area attains a thickness of from six to eight feet and generally forms a conspicuous ledge. It is composed mainly of yellow-grey chert, with thick ($\frac{1}{2}$-1 inch) laminae of magnetite. Immediately above and below the Marker-bed a thin bed, measuring from 6 to 12 inches and containing cherty nodules, is present in places. Some of the nodules are subrounded and the beds are accordingly referred to by some prospectors as "conglomerate". Crocidolite is associated with the Magnetite-chert Marker in many places. In this particular area the crocidolite seams are generally found above the marker-bed. North of Danielskuil in the vicinity of Schietfontein (L2) and the neighbouring farms the best development of crocidolite seams is a short distance below the marker-bed. Cross-fibre is also developed in places within the marker-bed, as for instance on Warrendale (M2). At the latter locality oxidised crocidolite fibres, more than four inches in length, are exposed in old working-places (Plate XVIII). This crocidolite zone represents the Third Upper and is the upper limit of crocidolite development in the area.

The marker-bed is followed by more jaspery layers and the Potsherd Marker is found about 100 feet above the Magnetite-chert Marker. The vertical distribution of the marker-beds in this area is given in Table 9.