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THESIS.

CROCIDOLITE IN THE DISTRICTS OF PRIESKA AND HAY.

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Crocidolite in the Districts of Prieska and Hay.

The belt of hilly country extending from the southern extremity of the Doornbergen, through Prieska, Niekerkshoop, Griquatown and Kuruman, to a point far north of the latter, constitutes a region of great scientific and economic interest. Spoken of generally as the "Blue Asbestos Belt", it has ramifications stretching in north, and north-westerly directions from Prieska. In the south it is known as the Doornbergen, passing into the "Asbestos Mountains" north of the Orange River, while farther north it becomes the Kuruman Hills.

This large area is unique in that enormous deposits of fibrous crocidolite or "blue asbestos" are known to occur scattered more or less irregularly over the entire belt. The mineral, often accompanied by some or all of its variations and alteration products, has been reported from nearly every farm, excepting only that portion covered by Ongeluk Volcanics, and the UPPER BEDS OF THE LOWER GRIQUATOWN SERIES, which thus form the only interruption to an otherwise unbroken extension of crocidolite bearing strata.

The physiographical features and general geology of the area have been so ably and exhaustively treated by Dr. A.L. Hall in his memoir on "Asbestos in the Union of S. Africa", that very little remains to be added here, and a detailed discussion of these would thus become mere repetition. While attempting then only a short summary, stress will be laid on those features which appear to have an important bearing on the crocidolite occurrences.

In the south the asbestos formation rises to a considerable elevation above the Dwyka-covered flats. Here intense denudation has resulted in an almost complete removal of the overlying lavas, and fairly deep valleys have been exposed, giving rise to very hilly, almost mountainous, scenic effects. Passing northwards this strong relief is replaced gradually by low, undulating and rounded hills, typical of the middle member of the Griquatown Series.

The eastern margin of the asbestos formation is a well defined ridge, striking in a north-north-easterly direction, where it becomes a dominant feature commanding the vast Kaap Plateau region.

Along this eastern margin the Lower Griquatown beds, conforming to the underlying Dolomite of the Campbell Rand Series, dip at gentle angles westwards, forming a wide shallow synclinal basin, still retaining remnants of a former widespread covering of lavas. These lavas have their fullest development in the middle zone of the basin from south of Witwater to slightly north of Ongeluk.

From Griquatown southwards, the junction of the Lower Griquatown beds with the Dolomite is obscured by a thin unconformable covering of Dwyka Conglomerate, which is represented on the western margin of the belt by a few scattered outliers. The significance of the Dwyka as a probable agent for supplying the siliceous solutions which have caused such extensive surface alteration will be discussed later.

The asbestos horizons are confined to the lower portion of the Lower Griquatown Series, extending from very near the base upwards. These beds are made up of hard yellow and brown jaspery rocks, dark magnetic ironstones and soft yellow ferruginous phases resembling a shale. M. A. Peacock describes these rocks as cryptocrystalline cherts, and finegrained magnetite quartzites, in which detrital grains cannot be detected, and crystalline structure appears to be secondary. More normal rock types comprising quartzites, sandstones, shales, limestones, and a boulder bed, are described by Hall and du Toit as occurring near the top of the Series. These, however, do not carry crocidolite deposits.

Dr. Hall puts the total length of the asbestos belt at not less than 240 miles with a variable width not exceeding 30 miles, but narrowing down in places to a few miles. There is very little doubt that a considerable further extension northward will yet be proved. The mineral is mined at numerous points along the belt, and although the economic possibilities of the area brought into prominence by the keen demand for asbestos, have aroused considerable interest lately, only a fraction of this enormous area is being systematically mined.

Although rich local concentrations of crocidolite are comparatively rare, and then of relatively small dimensions,, large deposits of low grade fibre are fairly common. The fibre reserves on the most conservative cal~~c~~culation must be exceptionally large, and the real economic importance of the belt is thus largely potential a legacy for the future, when conditions may permit a fuller exploitation.

For convenience in description it is proposed to treat the asbestos belt under four divisional sections, which to some extent show varying and characteristic features. They are:-

1. The South, or Doornberg Section.
2. The North-west, or Koegas Section.
3. The North, or Blackridge Section.
4. The North-east, or Main Section.

The South Section embraces that portion situated south of the Orange River, extending from Vergeetmyniet, and Lovedale, through Prieska to Westerberg in the North-west..Crocidolite occurs throughout the whole of this section, due to the duplication of crocidolite horizons by folding, and to the fact that denudation has frequently cut down to the lower beds. Folding is pronounced following the Doornberg system. The country rock is often very hard consisting of dark magnetic ironstones, and yellow and brownish jaspers, which are less thinly bedded at times than is the case farther north. The softer phases show a distinctly limited development, being confined to thin bands up to a few feet wide, situated in close proximity to the crocidolite seams.At Keikam's Poort, Glen Allen, and Kalkgat the lower fibre horizons occur very near to the Dolomite, which at Glen Allen is distinctly folded into the banded ironstones.

The North-west Section is that arm following the north bank of the Orange River, and include the well known workings of Kliphuis, Klein Naauwte, Koegas, Leelykstaat, and Stilverlaat. The physiography is very similar to that of the South Section showing strong relief, but a fuller development of Lower Griquatown beds is seen, with occasional outliers of lavas, and there is thus a more sporadic distribution of crocidolite outcrops.

The North Section extends almost due north from Prieska, and forms the western limb of the Witwater-Ongeluk basin. Here the hills are low and undulating with wide sandy valleys in between. The ironstones have been subjected to severe local folding, but have a general easterly dip, and often consist of soft yellow and thinly bedded shaly phases, alternating with yellowish jaspers, and siliceous fine grained types approaching a quartzite. The section has yielded only one mine of economic importance thus far, due no doubt to the paucity of outcrops, much of which are covered by red sand. Judging from the mode of occurrence elsewhere one would expect a tendency to local concentrations of fibre in this section, with its usual accompanyment of large barren stretches.

The Main Section strikes in a north-north-easterly direction from Prieska, passing through Niekerkshoop, Griquatown, and Kuruman. Near the Groenwater Location, north east of Postmasburg, it forms a junction with ~~with~~ the north arm, and ends up with a gradual sweep to the north-north-west. Towards the southern end the section is disturbed by undulating folds, and the country is hilly with deep narrow valleys, which gradually die out towards Niekerkshoop and Griquatown. In this middle zone the asbestos formation is much less disturbed, denudation following lines reminiscent of the Karroo.

A change becomes noticeable in the rock types of this section or zone, due perhaps to the lesser degree of folding. Thus in the folded and contorted area round Prieska the hard yellow and brown jaspers predominate, while in the Niekerkshoop-Griquatown area the soft yellowish shaly varieties become increasingly common, and are generally confined to the crocidolite horizons. Here the higher beds, forming krantz-like ledges, consist of hard yellow jaspers and fine grained quartzitic rocks. Throughout the whole of this section alteration, particularly silicification, of crocidolite seams are extremely common, and the process of alteration can be traced through nearly all its stages.

VARIETIES OF CROCIDOLITE.

Three varieties are commonly met with, differing mainly in their physical properties. A fourth variety has recently been described by Peacock.

1. Cross Fibre.

This is the much prized commercial variety, in which the fibrous structure isx perfectly developed, the fibres being placed at approximately right angles to the containing walls. Although the actual development is probably always truly normal to the bedding planes, the fibres often show an inclination to the norma -1. An inclination of 50° was measured in a specimen from Leelykstaat The general assumption, based on observation, is that the greater the angle of inclination the more closely does cross fibre approach slip fibre in properties. In the specimen from Leelykstaat, however, the perfect cross fibre characteristics were unimpaired. As a general rule a slight or pronounced inclination is seen in all the k longer lengths even in undisturbed country, this inclination often increasing in folded areas. In narrow seams the fibres are frequently orientated normal to the bedding planes. Sometimes the upper or lower portions of the seams, or both, are curved or curled. This inclination of the fibres is undoubtedly due to movement after crystallisation.

Discoloured fibre is the result of partial alteration produced in cross fibre, whereby the original lavender blue is replaced by yellows and reds, or lighter shades of blue, owing to either a varying degree of oxidation of the iron content, or to infiltration of iron oxides derived from the country rock. Very often it is caused by a limonitic band lining the inner walls of the containing rock.

2. Slip Fibre.

In this variety the fibrous structure is very poorly developed, the orientation being parallel or very nearly parallel to the bedding planes. It represents the final stage after movement, and should perhaps be regarded as an alteration product of cross fibre. The fibres have lost their highly individualised character, and cannot be worked up between the fingers. In those cases where a high degree of parallelism to the containing walls is attained, very unusual lengths, up to a few feet long, may be reached. It has lost all those properties on which the value of asbestos depend, and is generally lighter in colour than cross fibre. It occurs commonly in disturbed or folded areas, in the vicinity of shear planes, or associated with small quartz veins.

3. Mass Fibre.

In mass fibre no fibrous structure is obvious to the naked eye. It is represented by a finegrained, apparently amorphous rock, commonly pale to dark blue in colour, sometimes assuming a green or greenish blue shade. While quite soft, it is usually very tough, and then becomes a distinct barrier in mining, when, as so ofte happens, it occurs closely associated with cross fibre. Dr. Hall has applied the name "Potential Crocidolite" to the rock, and describes it as "consisting of a mass of microscopic fibres, haphazardly orientated, sometimes scattered irregularly through the rock, or again this arrangement may be accompanied by nests or groups of small radiating needles"

Mass fibre occurs in interbedded layers, seams, or bands, from mere films ~~up~~ to 18 inches or more in width. At Blaauwboschkuil, north east of Niekerkshoop, such a band continues unchanged along its strike for a measured distance of 800 yards, a length of strike quite unknown to cross fibre. In a similar seam at Naauwpoort a gradual development of cross fibre seams within it are seen. Elsewhere on the same horizon cross fibre seams replace potential crocidolite, although the transition is not well defined. The reverse is more common. Very often potential crocidolite is replaced by thinly bedded ironstones.

4. Acicular Crocidolite.

This variety is described by M. A. Peacock in the "American Mineralogist" for July 1928, Vol. 13, page 245 as occurring in bands of acicular brown amphibole, arranged in the cross fibre manner typical of the blue fibres, but coarser in structure. It is from this material that he derived the fuller optical data so urgently required.

MODE OF OCCURRENCE AND DISTRIBUTION.

Crocidolite occurs as interbedded cross fibre seams or veins, always conforming perfectly to the bedding planes of the countr rock. Iron in the form of the three oxides, ranged as parallel layers or thin bands, sometimes distributed irregularly through the rock, is very often associated with crocidolite in the harder rock types, while in the softer phases limonite is often dominantly present.

The occurrences are confined to certain horizons in the Lower Griquatown Series, commencing from very near the base upwards. At Zeekoebaart, the most extreme north west farm in the Koegas Section, the first set of crocidolite seams occur not more than 40 feet above a thin band of Dolomite. While no accurate figures are available it would appear that all the crocidolite horizons are contained within the lower 1000 feet of strata.

In connection with the surface distribution of crocidolite outcrops, it is noticeable that all those farms situated at or near the base of the series carry fibre deposits. Conversely a belt of farms bordering on the Ongeluk Volcanics are barren of crocidolite, and this is the case on several farms situated in the middle of the belt,(egg. Martlowe) where denudation has not yet cut down to the lower beds.

A remarkable feature of the asbestos belt is the consistency in distribution of crocidolite outcrops over the belt as a whole. The same cannot be said, however, in the case of individual seams and seam-groups.

Normally crocidolite occurs in fibre areas or patches showing the utmost marginal irregularity, and these vary in size between very wide limits. They resemble lenses elongated in every direction, subject along the line of outcrop to all the vagaries of erosion. Moreover, they appear to be placed haphazardly with reference to one another, and it is thus very difficult, if not impossible, to lay down any rule as to the localities likely to be crocidolite bearing.

A series of such fibre areas, more or less irregularly distributed over a given locality, sometimes forms a well defined group, which may be regarded as a "fibre zone". At Elandsfontein, south west of Griquatown, an exceptional case is seen where the zone consists of one large and continuous fibre area, with several small barren enclosures. Outside such a zone crocidolite may occur in isolated patches or be absent over very large distances along the same horizons.

These zones are subject to so many variations in their arrangement that the following classification may serve as a condensed illustration of the types met with over the belt as a whole.

1. Lateral Zones.

A fibre zone may be confined entirely to one horizon, upper or lower horizons being barren in the vicinity. It may consist of one or more fibre areas, which in turn may be composed of one or more seams of crocidolite. The Elandsfontein mine is an example of a zone comprising a single fibre area with only one seam averaging about 1 inch in width. Kaffirkrantz, north east of Niekerkshoop, is an example of a multi-seam, multi-patch lateral fibre zone.

2. Vertical Zones.

More often fibre areas are developed at two or three horizons simultaneously, these being placed at vertical intervals of from 10 feet to 80 feet. At Blackridge Mine two reefs in close proximity, carry in the case of the "upper reef" two consistent seams, while the "lower reef" may show as many as twelve seams. At Keikam's Poort three such horizons, roughly equidistant vertically, u show a sim~~i~~ltaneous fibre development, which~~m~~ reach es a maximum in the "lower reef".

3. Alternating or Step Zones.

This is a rather rare combination of vertical and lateral zones, the fibre areas being placed at intervals along several horizons, in such a way that the barren areas in one horizon correspond with fibre areas in an upper or lower horizon. At Naauwpoort Mine, four large fibre areas have been located each on a separate horizon, and at widespaced lateral intervals. Numerous smaller fibre areas show the same arrangement. The fibre zone at Naauwpoort has an enormous extension of approximately 1½ miles with an unknown width. Mining operations consequently take the form of numerous small centres of activity spread over the entire length of the zone.

Nature of the Seams..

Consisting of an infinite number of highly individualised though densely-packed bluish-grey to lavender-blue fibres, the seams may vary in width from mere films to about 4 inches. A specimen from Westerberg Mine measured 3⅞ inches, and another from Hopefield 4 inches. Such lengths pepresent the maximum, however, and are very rare even in the northern portion of the belt where the longer lengths are more common. Lehgths up to 2 inches occur often enough to form a small portion of the output, but the great bulk of the fibre produced ranges between ½ inch and ¾ inch in width.

Seam formation presents many peculiar and striking characteristics, which could be grouped under two broad divisions according ~~as~~ to whether the seams show;-

either 1. A regular or normal structure.

or 2. An intermittent or wavy structure.

There is no well defined line of demarcation between these two groups. A seam belonging to one group may gradually pass into the other along a dip slope and vice versa. Both types are common and may occur as separate seams in the same "reef", one or more of the seams maintaining a regular or even width along strike and dip, until it "pinches" gradually all round, while others follow a wavy and irregular course. They vary in width every few inches, sometimes "pinching" abruptly, and as suddenly widening out again. Another characteristic peculiar to intermittent seams is the tendency to overlapping or step structure. Such seams continue for short distances and at the point of "pinch" appear again a few inches above or below.

Other variations in seam structure often met with are the following:-

a. Dual-seam structure.
b. Composite-seam structure.
c. Cone and corrugated structure.

The relation between these and the two groups discussed above will be best seen by taking typical examples derived from various parts of the belt. Thus at Naauwpoort a dual-seam, falling definitely under group 1, is made up of two intermittent seams, such that the crests in one of the unit seams correspond with the troughs of the other. Separation is caused by a thin wavy parting of country rock, which disappears at times when the two combine to form a single normal seam. This seam is one of the upper members in the horizon known locally as the Main Reef. About 11 inches below it another dual-seam, known as the "tweeling" (twin) consists of two normal seams, with a regular parting plane so minute that the fibre extremities appear to be touching at the junction, which is placed in such a way that the lower unit is approximately half the width of the upper one. This seam retains these characteristics over several miles along the strike, and never shows any perceptible variation except in width, serving thus as an excellent local marker.

One of the four seams at the Blaauwboschkuil Mine consists of four unit seams with three minute partings of potential crocidolite. Here the parent seam is regular while two of the unit seams are regular and two intermittent. In a mine on the north section a single normal seam about 2 inches wide at the surface and for some distance down the dip (35°), assumes at depth the nature of a composite seam, which on cobbing yield unit seams falling under grade "X", that is, up to ¼ inch wide, although in situ it never loses its identity as an individual seam.

Composite structure is perhaps due to slight movement under pressure, such as would result in the vicinity of folds, or it may also be due to variations in fibre growth. At Naauwpoort, folds of the kneebend type are always associated with crocidolite seams showing curves or curls at one or both of the extremities. This bending of the fibres resulted in lines of weakness, which by reflected light can be seen running parallel to the containing walls. It often happens that in the folds such lines of weakness show a transition into a plane of fracture, thus giving rise to dual or composite structure. As a general rule, however, composite structure is caused by uneven crystallisation over interrupted intervals, fibre growth commencing at the top, middle, or base of a seam either simultaneously or otherwise.

Cone and corrugated structures are very well described by Hall. These are the natural structures resulting from the wavy, irregular, and undulating margins of intermittent seams. At Naauwpoort a peculiar variation is seen where conical structures connected with a regular seam, only occur at, and are enclosed within, the upper margin of the seam. The bedding planes do not conform to these cones, the axes of which are inclined at an angle, corresponding to a curve in the upper extremity of the seam. When the fibre is removed these peculiarly shaped cones appear as irregularly placed protuberances having some resemblance to certain species of lamellibranch~~s~~. The cones often consist of very thin layers of country rock alternating with minute seams of crocidolite or potential crocidolite.

The kneebend folds of Naauwpoort are always heralded by parallel undulations, or corrugations which gradually increase in wave length and amplitude as they approach the fold. A regular seam traversing these undulations gives a perfect illustration of
contained in

corrugated structure, widening slightly at the crests and troughs, and narrowing in the limbs of these minute folds.

Grouping of Seams.

Crocidolite seams generally show a group arrangement or aggregation of two or more seams, the whole being confined to a definite horizon. The number of seams to a given horizon may vary from one to twenty five, spread over a varying extent of country rock. Sometimes they are sandwiched closely together over a few inches, or again they may be evenly distributed over as much as 20 feet of ironstones. At Hppefield Estate 25 seams were counted at roughly even intervals over 20 feet of country rock. More often from three to five seams occur at irregularly spaced intervals over four to six feet of rock. A common occurrence is for four, five, or six seams, when short, to be spaced over as many inches of rock. In the main reef at Naauwpoort the maximum number of seams never exceeds nine distributed over six feet of rock.

Relation of Seam-groups to Individual Seams.

The group characteristics bear a close similarity to those of individual seams; in fact what is applicable to the seam can also be applied to the horizon in which it occurs, and the same relation may be said to hold between the seam-group and the group of minor horizons of which the former is a member. Thus individual horizons or seam-groups are subject to the same structural peculiarities discussed above as pertaining to single seams. They may be intermittent or regular. Alternating or step zones represent the group equivalent of step structure common to intermittent seams. Lateral zones are merely the group duplication of characteristics attributed to a single, normal and consistent seam. Vertical zones find a counterpart in the horizon containing the average three seams more or less evenly spaced apart.

The Identity and Correlation of the Various Crocidolite Horizons.

The characteristics peculiar to a group of seams and the nature of the country rock in which they occur, are generally very local. These are subject to continual modification and change, not only in the degree of fibre development, but also in the number of seams, and in their arrangement relative to one another.

When to this is added the absence of any stratigraphical marker, and the slight value of dip readings due to the presence of numerous anticlinal and synclinal rolls, or undulating folds, it will be seen that the correlation of the crocidolite horizons becomes a matter of considerable difficulty and uncertainty when applied over large areas.

These horizons are invariably clustered closely together, the total thickness of strata involved comprising a comparatively thin section of banded ironstones, seldom exceeding 100 feet in width. In trying to reconcile this with the fact that crocidolite seams occur over a maximum of approximately 1000 feet of the series the following conclusions are suggested.

1. The crocidolite bearing beds are arranged such that two, and perhaps even three major horizons separated by some hundreds of feet of barren country rock, could be recognised.

2. The beds are potentially crocidolite-bearing over the whole sequence of approximately 1000 feet, but that a full development is never attained at any one locality, crocidolitisation following the laws applicable to individual seams and minor horizons. Thus barren sections at a given locality may show a development of crocidolite elsewhere.

The latter assumption appears to accord more nearly with the facts derived from field evidence, and it explains the difficulty experienced in correlating the crocidolite horizons.

At Naauwpoort and Leelykstaat an unusual number of minor horizons developed over great lateral distances yields an interesting field of study. These two localities, including as they do a maximum of exposed crocidolite bearing strata, are typical of a large number of occurrences. At Naauwpoort crocidolite has been exploited along seven well established minor horizons, a wide gap of apparently barren country rock occurring between the Bottom Reef and the New Mine Reef. The Top Reef marks the highest crocidolite horizon, but seams of "tigereye" occur still higher in the succession, thus corresponding to at least three upper minor horizons now completely silicified. A sketch of the Naauwpoort horizons drawn to scale is appended.

Tendency to Uniformity in Process of Crocidolitisation.

The generalisation expressed above is based on the assumption that the amount of crocidolite present as such, or in the form of any of its variations and alteration products, tends to be constant when calculated over any complete section of the asbestos bearing beds.

It has been remarked that the greatest consistency is seen in the distribution of crocidolite outcrops over the belt as a whole, although this does not hold in the case of individual seams and minor horizons. It implies a continuity in the process of crocidolitisation which is not negatived by the intermittency of seams and seam-groups, but rather that these are merely variable members, indicating in their arrangement a larger process which tends to uniformity in distribution.

The principle has been applied to local fibre areas and it was found that the amount of crocidolite to any given horizon often remained remarkably constant, even though the seams varied in number and width; and diminished gradually towards the edges of the group of seams comprising the horizon. At Naauwpoort the idea of continuity to the group of horizons, has had a practical application, and it was found that at any locality where both Bosman's Reef and the Lower Reef were barren or very poor, the Main Reef or some other horizon carried payable deposits of crocidolite. It was also established that a simultaneous development of crocidolite on all the local horizons, resulted in no single horizon yielding payable deposits. Elsewhere the same tendency was noted following, however, along different lines. At Elandsfontein crocidolitisation exhausted itself in a consistent lateral development of fibre along a single horizon.

At Hopefield Estate the abnormal development of 25 seams over 20 feet of country rock is compensated by an absence of upper and lower horizons. Numerous other cases could be cited illustrating the same principle.

FOLDING AND ITS RELATION TO CROCIDOLITISATION.

The Lower Griquatown beds have everywhere been subjected to a greater or lesser degree of folding, which is severe in the south and north west section, and merges into gentle, undulating synclinal and anticlinal rolls farther north towards Niekerkshoop and Griquatown. In this comparatively undisturbed area a striking feature is the occurrence of small parallel monoclinal folds or kneebends, always dipping steeply to the west. They vary indepth from mere corrugations to about 100 feet, and at Naauwpoort occur some 50 yards to 200 yards apart. The downthrow is compensated by a slight easterly dip between the folds.

These folds represent an unusual phase of the minor disturbances, described first by Stow, then by Rogers and later by Hall, who takes the view that such local disturbances were caused by the subsidence of overlying beds into solution chambers in the Dolomite. Stow explained their presence as being due to pressure acting from the west. At first sight this view appears to fit the facts very well. At Naauwpoort the two most consistent seams in the Main Reef always show an eastward curve to their upper portions, while the bases of the seams are curved to the west. Bearing in mind the parallel structure of these folds, and their common westerly dip, there is much to support Stow's view. Yet the fact that these disturbances tend to die out higher up in the succession, finds no adequate explanation in that case.

There canbe no doubt that folding was subsequent to fibre growth and, thus no relationship can exist. Everywhere the crocidolite seams follow the folds, and generally exhibit the effects consequent on such disturbances. In sharply compressed folds the seams are often contorted, and the fibres become inclined to the bedding planes, the complete change to slip fibre, however, is comparatively rare. The development of dual and composite structure in the folds at Naauwpoort is an illustration of the remarkable results of folding on crocidolite seams.

Among asbestos workers it is commonly accepted that fibre growth is often concentrated either in folded areas or in folds, and it cannot be gainsaid that a large number of the best known workings are so situated, a fact which can hardly be attributed purely to coincidence. Further it is noticeable that the effetcs of ~~of~~ folding are not equally distributed over all the seams contained in the fold. Thus in the Main Reef at Naauwpoort only two two seams show the curvature of fibres referred to , the remaining seams being quite normal.

An explanation may be found in the assumption that crocidolitisation, although commencing at a time long prior to the folding, continued up to, and during the period of disturbance, such disturbed areas yielding conditions favourable to fibre growth.

ALTERATION.

The physical and chemical changes to which crocidolite is liable, range in ~~in~~ progressive order from a slight variation in colour shades to complete replacement by silica, iron oxide, or calcite.

(a). Colour Changes.

This marks the first stage in alteration, the deep lavender blue of the unaltered mineral going into paler shades of blue, or greyish blue, the change being accompanied by a decrease in specific gravity, and the usual stringiness of the fibre is lost. An appearance is assumed which gives the impression of greater woolliness, the fibres being finer and more fleecy. At this stage the economic value of the fibre is still retained but it is less highly prized than the blue, stringy, unaltered mineral, being appreciatively inferior in spinnability and tensile strength.

(b) Oxidation.

In the next stage of alteration colour changes become pronounced. The characteristic lavender blue is partially or wholly replaced by yellows or reds, sometimes mixed with lighter shades of blue. Two distinct products of oxidation can be recognised.

1. Discoloured Fibre, indicating the incomplete process of limonitic or haematitic replacement. Very often alteration attacks the extremities of the fibres first, which can then be powdered between the fingers, while the middle portion remains unaffected. Discolouration is frequently caused by infiltration of ferric oxide derived either from the country rock, or from thin bands of iron oxides adjoining the seams of crocidolite.

2. A soft yellow or red fibrous substances, probably identical with what Hall terms griqualandite. The fibrous structure is very marked, but the material powders very readily and consists almost wholly of limonite. At Elandsfontein a seam from 1½ inches to 2 inches wide has been completely altered in this way for a considerable distance along the outcrop. A drive carried in for some 50 feet along the dip showed no signs of a change to blue fibre.

(c). Silicification.

This is by far the most common and extensive form of alteration, but is more pronounced in the southern portion of the asbestos belt. Towards the north it is less intense, where the products of oxidation are widespread. In an optical and chemical study of the asbestos bearing ironstones, M. A. Peacock[@] describes three modes of occurrence of the siliceous element. Secondary quartz appears as mosaic bands which he says are recrystallised from the more siliceous components of the original sediment. He arrived at the interesting conclusion that the third and latest phase of quartz represented by "tigereye", although regarded as a replacement product of crocidolite, grew concurrently with the latter. This view fits in none too well with the facts derived from field work. At Blackridge, Hopefield, and many other workings, seams of "tigereye" passed into asbestos at no great depth from the surface. At Naauwpoort and nearly all the surrounding workings the silicified seams are confined either

[@] American Mineralogist, July 1928.

to the upper horizons or to certain areas, where the conditions were exceptionally favourable to alteration. On the whole the ironstones are everywhere highly altered at the surface by this later phase of silicification, which never continues for any great distance along the dip, when it passes into a soft yellow ferruginous and thinly bedded rock. Occasionally the latter is again replaced by the hard brown or yellow jaspers, which occur then in bands or streaks always coinciding with open, fissure-like vertical cracks. Even in the relatively shallow asbestos workings it has been found that in the lower levels alteration is reduced to a minimum. This leads to the conclusion that alteration, and particularly silicification must have a direct connection with physio~~topo~~graphical conditions, and that its influence became pronounced long after crocidolitisation commenced.

The asbestos belt could be divided into a southern, dominantly silicified region, and into a northern portion where alteration of crocidolite seams is mainly in the form of oxidation. The boundary is somewhere in the vicinity of Griquatown, thus roughly coinciding with the northern margin of the Dwyka. Proceeding southwards along the eastern margin of the asbestos mountains, silicification becomes gradually more marked until in places even the lower horizons are affected. Hence it may be said that silicification is more intense in Dwyka-bordered ironstones, and the inference thatk the Dwyka may have been partly responsible in supplying the later silica, is worth consideration.

A common result of silicification is the formation of either a pure white or bluish pseudomorph after crocidolite. The fibrous structure is more perfect in the bluish variety, which is widely distributed. All stages in the process of alteration can be seen, from a slight hardening of the extremities, through a semi-fibrous brittle stage, to the finished pseudomorph. Curiously enough this form of silicification is remarkably continuous along the dip, and by asbestos workers is regarded as the least likely tp pass into asbestos at a depth which will justify prospecting drives. As a result information on this point is very meagre.

(d). Oxidation and Silicification Combined.

When both forms of alteration proceed simultaneously the product is often a beautifully coloured, highly siliceous pseudomorph, occurring more often in shades of gold, yellow, and brown. Some specimens exhibit a wide range of colours, gold, yellows, mauves, pinks, greens, blues, and white appearing with peculiar iridescent shot effect in a single stone. The finely fibrous forms of highly coloured "tigereye" have a limited application in the jewellery trade, and have been used for making ornaments, table tops, penholders and handles for cutlery etc.

(e). Replacement by Calcite.

On the Prieska Commonage, and on Rooisand, crocidolite occurs on the surface in limestone, which appears to have replaced the country rock, for only a few feet in, the crocidolite seams are quite normally interbedded in ironstones. Mr E. G. Bryant of Prieska is in possession of a specimen of fibrous calcite inter-bedded in ironstones, and it probably represents a rather rare case of calcite replacing crocidolite.

Properties of Crocidolite.

It is on the physical and chemical properties of crocidolite that its economic value depends, and these are best discussed by a comparison with chrysotile and amosite. Recently Peacock added considerably to the chemical and optical data available, deriving his results from what he terms the "acicular" variety of crocidolite, a material better suited to determinative work. Previously the finely fibrous form had been used, the great divisibility of which naturally made for inaccuracy in optical work. The table of optical properties given below is taken from his paper published in the "American Mineralogist", July 1928, page 255.

Table of Optical Constants of Crocidolite.

Mineral & locality.	α	β	γ	Pleochroism.			Orientn.	Ref.
				X.	Y.	Z.		
Crocidolite ex. Kliphuis.	1.698. $(\gamma - \alpha) = 0.008.$	1.699.	1.706.	Indigo.	Yellow.	Indigo.	$X\ c \wedge 0^\circ$ $Z = b.$	New data.
Croc. ex. Orange. R.	..... $(\gamma - \alpha) = 0.005.$	1.70.	.....	Bluish green.	Bluish grey.	Bluish grey.	$X\ c = low$ $Z = b.$	Gordon 1927.
Croc. ex. Quincy, Mass,	..... $(\gamma - \alpha) = 0.005.$	1.699.	.....	Deep bluish green.	Bluish yellow.	Bluish grey.	X near c $Z = b.$	"
Croc. ex Narsarsuk, Greenland.	..... $(\gamma - \alpha) = 0.005.$	1.701.	.....	Methyl blue.	Straw yellow.	Pale blue.	$X\ c = 0^\circ.$ $Z = b.$	"

Peacock adds that observations on a basal section of the acicular phase showed intersecting prismatic cleavages less clearly than is usual in amphiboles. No optical figure could be obtained owing to strong absorption and weak birefringence; also the extreme closeness of α and β rendered the directions of X and Y indistinguishable. He states that the pleochroism scheme and orientation given above are the more probable of two possibilities, X and Y may, however, require to be interchanged. He further adds the following:-

Colour in ordinary light.	Lavender.
Absorptiom.	Parallel to c - indigo; perpendicular to c - pale grey blue.
Extinction.	Sensibly parallel to c.

Chemical Properties.

Considerable disagreement exists in the available analytical data. Dana, Iddings and Larsen accept the simplified formula, $Na_2O.2FeO.\ Fe_2O_3.\ 6SiO_2$. Gordon regards crocidolite as a variety of riebeckite, with the ideal formula $R_2O.R_2O_3.4SiO_2$, R_2O being soda with some water, and R_2O_3 chiefly ferric oxide.

Physical Properties.

The following table, taken from the S. African Mining and Engineering Journal, gives an interesting comparison of the physical properties of chrysoltile, crocidolite and amosite.

Properties.	Chrysotile.	Crocidolite.	Amosite.
Max. fibre length.	1½ to 2 in.	@ 1½ to 4 in.	7 inches.
Tensile strength.	High.	Highest.	High.
Fibre fineness.	Very fine.	Fine.	Fine.
Heat Resistance.	Good, but becomes brittle.	Poor - fuses to a glass.	Good but becomes brittle.
Acid resistance.	Poor.	Good.	Good.
Insulating value.	Fair to good.	Good.	Fair
Heat insul. value.	Good.	Moderate.	Good.
Spinnability.	Excellent.	Fair.	Fair.

Uses.

It will be seen from the above comparison that each of the three true asbestos minerals will be specially adapted for particular uses. Thus the extreme fineness of chrysotile fibres gives it exceptional value when required for spinning purposes. Crocidolite on the other hand is particulaly suited for the manufacture of insulating material in electric ware, for coarsely woven textile products, and for many marine uses. The long fibre lengths of amosite, and the large percentage of spinning lengths in the available supplies, give it a decided economic advantage.

The uses of asbestos may be briefly summarised as follows:-

1. Heat and Fire Resisting Textile Products.

Fire curtains, incombustible cloth, fireman's suits, brake linings, gaskets for machinery, blanket linings, aprons, gloves, leggings, helmets, tapes, wicks, rope, and clutch facings.

Only the higher grades and longer lengths are used for the above purposes. The shorter and less valuable grades have almost innumerable adaptations, chiefly in the production of :-

2. Paper Goods for Building Purposes, Millboard, and Asbestos Shingles.

Shingles are utilised in heat and electrical insulation ware. Sheeting paper is used between floors, in stove linings, heaters, cabinets, and helmets etc. Also for filtration purposes, and in the manufacture of paper for chemical purposes. Shingles are also finding an important application in the production of asbestos cement. Millboard is used for making asbestos wall boards, roofing boards, and joint packings for steam pipes and machinery.

These are the old and established uses and do not by any means represent the full list, yet new uses are being found for asbestos almost daily. A paint has recently been prepared, asbestos forming a primary ingredient, which is said to resist the action of sea water. Asbestos fibre combined with wood pulp derivatives are said to be used in the manufacture of hose, and socks.

GENESIS.

Although the problem of asbestos genesis has occupied the attention of several mineralogists for a considerable time it still remains an admittedly unsettled and vexed question. Several theories have been postulated to explain the origin of crocidolite and the banded ironstones in which the former occurs.

The country rock is supposed to have been formed under deep sea conditions, as a result of chemical precipitation in an extensive ocean basin. Peacock argues that the action of hot submarine fumaroles yielding hydrochloric acid gas, would result in the formation of alkali chlorides, ferric chloride, and gelatinous silica, ammonium solutions and soluble alkali silicates reacting to yield ferric hydrate. The rock so formed should after dehydration and induration be similar to typical phases of banded ironstones. Peacock bases his conclusions on the non-detrital character of the grains, and simple chemical composition, of the ironstones.

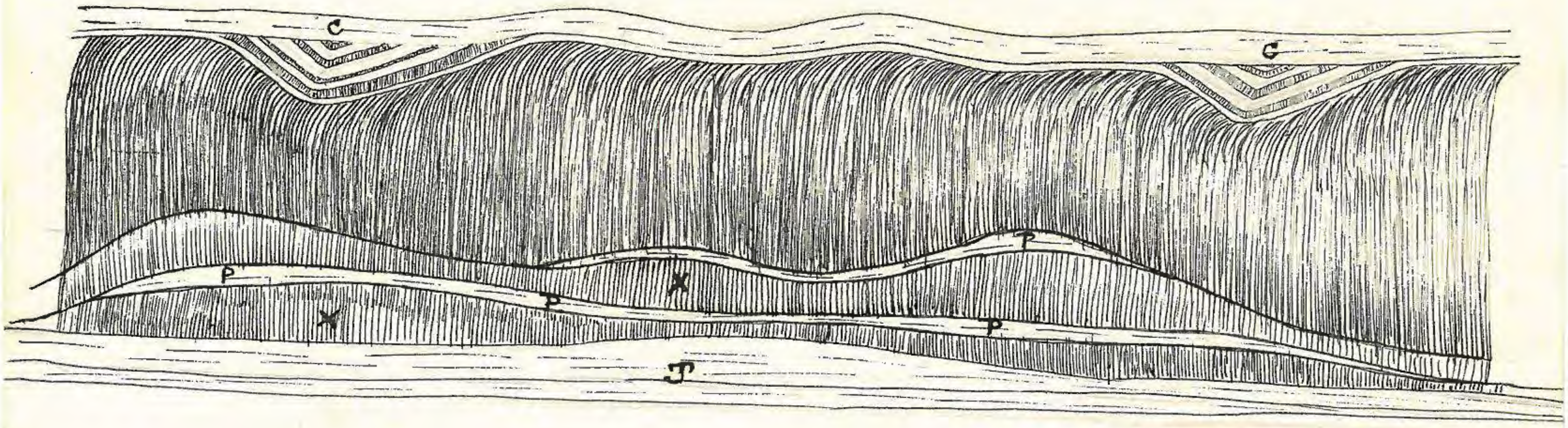
The country rock so formed can be shown to contain all the constituent elements of crocidolite with the exception of soda. This led to the view adopted by Hall,and supported by Peacock, that fibre growth took place along bedding planes, marking the existence of pre-existing soda-rich bands.

Hall explains the presence of magnesia in crocidolite as being directly connected with the underlying Dolomite. Peacock finds some difficulty in accepting this view, believing it unlikely that such solutions would be capable of traversing the ironstones, and instead adopts the assumption that as crocidolite only contains four times the quantity of magnesia present in the country rock, which, he states, often shows a leached appearance, the magnesia was probably concentrated near the present position of the seams. This view appears to be the more acceptable of the two.

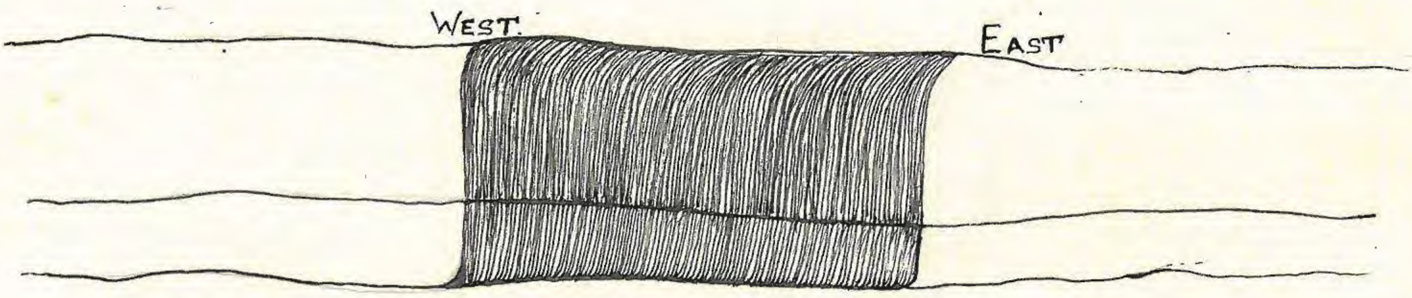
In summarising Peacock describes crocidolitisation as a mild metamorphic process, occurring along soda bearing strata, facilitated by the presence of interstitial water, and by a moderate temperature and pressure such as would result from the weight of superincumbent beds.

The cross fibre structure is attributed by Hall to the mutual interference of growing crystals, volume changes, unequal supply of solutions, and the tendency in amphiboles to prismatic habit. Peacock considers it due to the control which bounding surfaces exercise on the orientation of fibrous minerals.

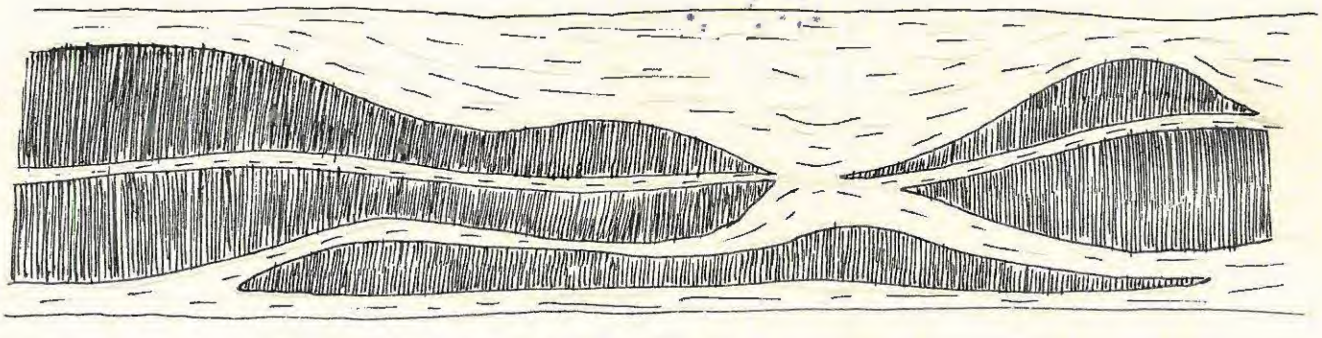
Both agree that potential crocidolite is the primary metamorphic product, followed by cross fibre, the end product being, according to Peacock,the acicular variety.



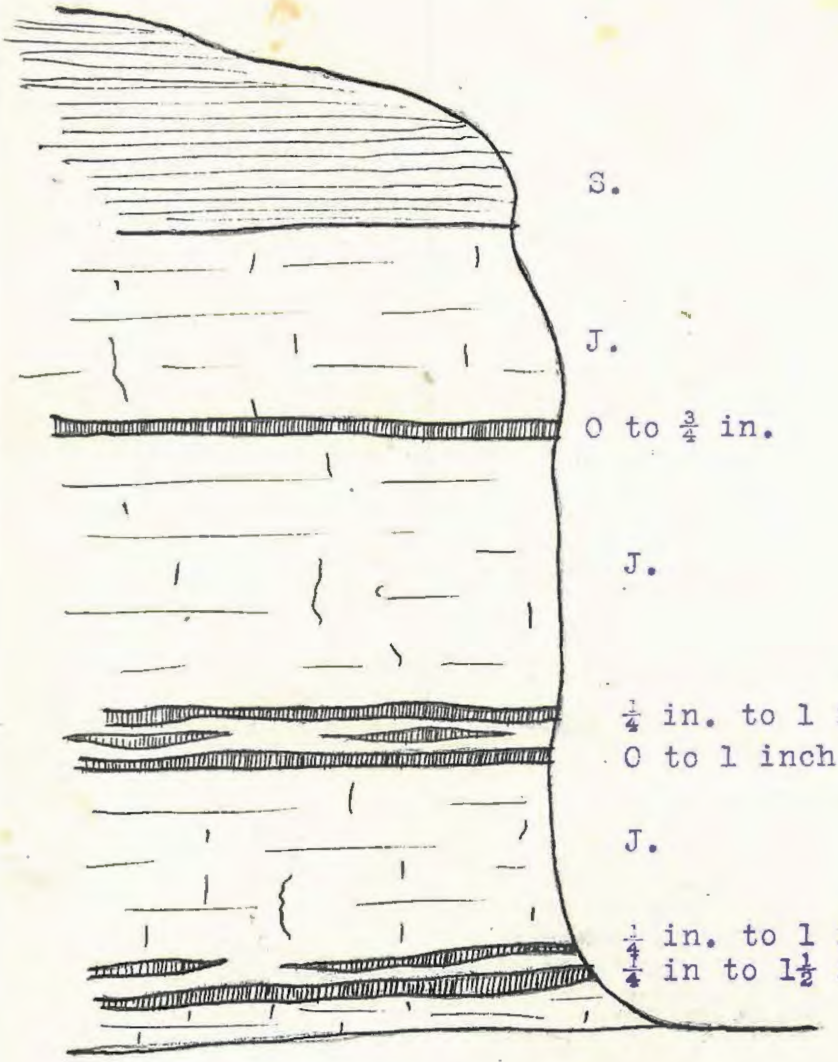
Regular, composite seam, Main Reef, Naauwpoort, showing unit intermittent seams, separated by a parting plane of country rock. Two typical cone structures (c) above, not conforming to bedding planes.



Regular dual seam (tweeling) Naauwpoort, Main Reef, showing east and west curvature to fibre extremities.

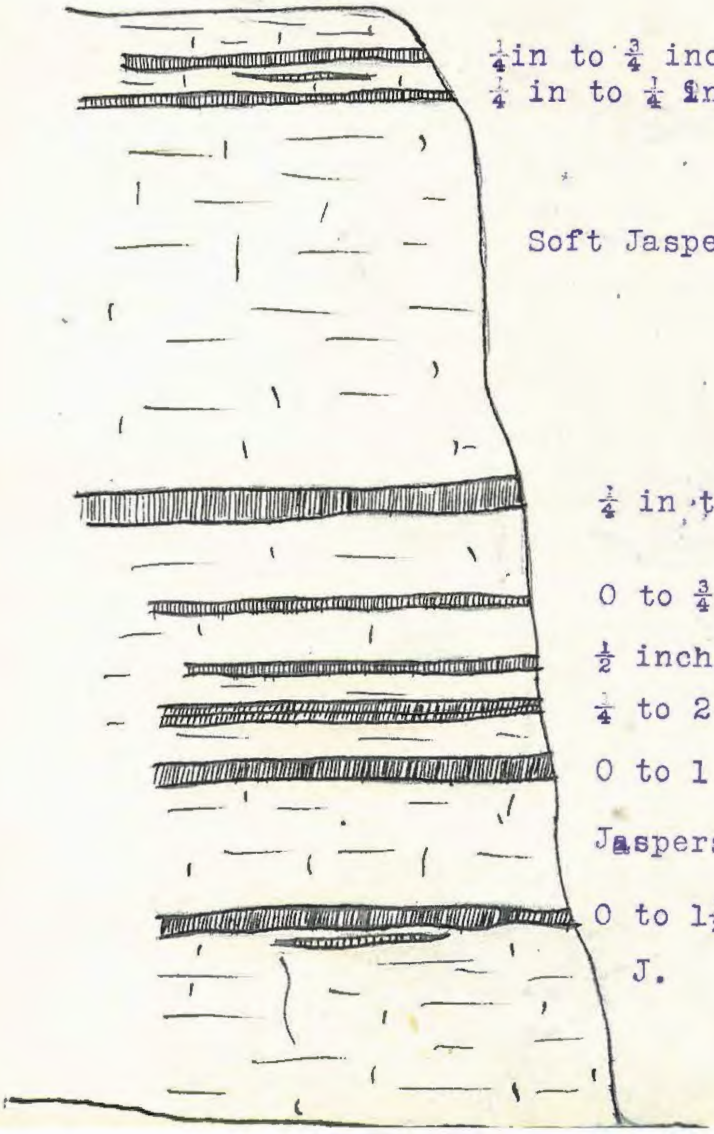


Intermittent seam, Bosman's Reef, Naauwpoort.



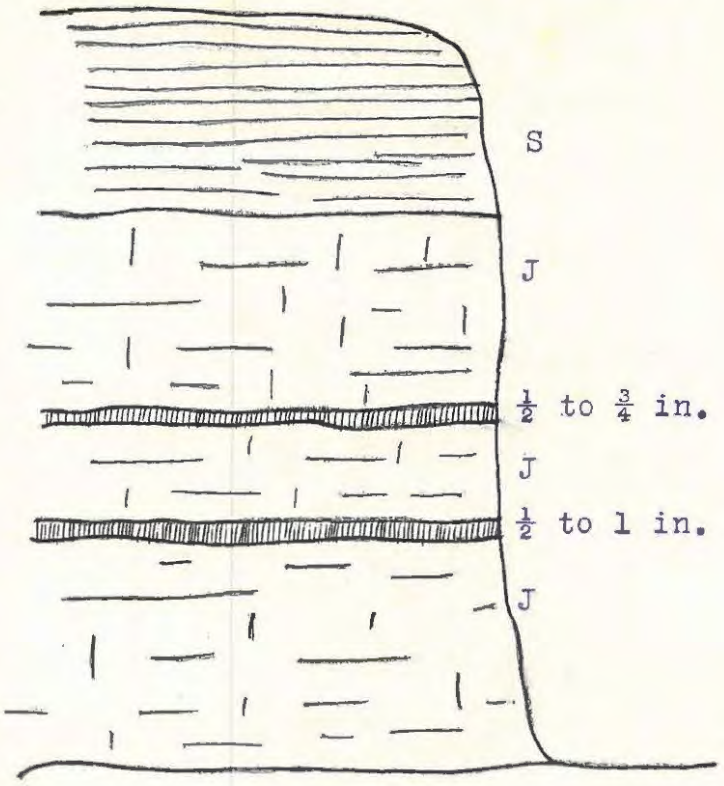
BOSMAN'S REEF. NAAUWPOORT.

(Intermittent).



MAIN REEF. NAAUWPOORT.

(Regular).



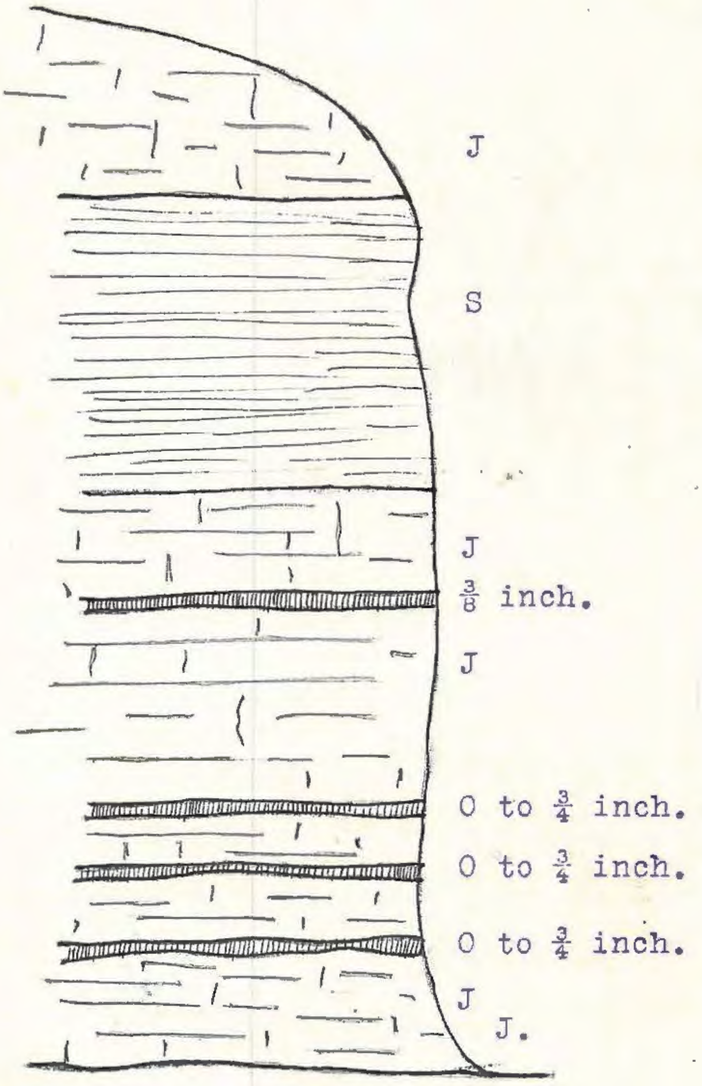
TOP REEF. NAAUWPOORT.

(Intermittent)

S - Very soft band of shales.
J - Hard brown jaspers.

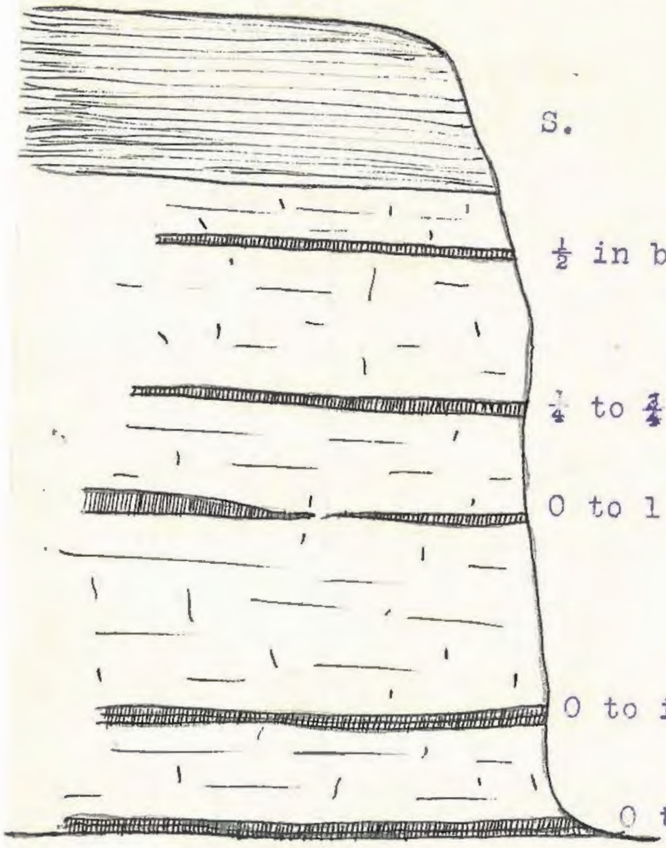
Seams of crocidolite in inches.

Scale...... 1 inch equals 1 foot.



UPPER REEF. NAAUWPOORT.

(Intermittent).



LOWER REEF. NAAUWPOORT.

(Intermittent).

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Bosman. Reef
27 ft.
Main Reef.
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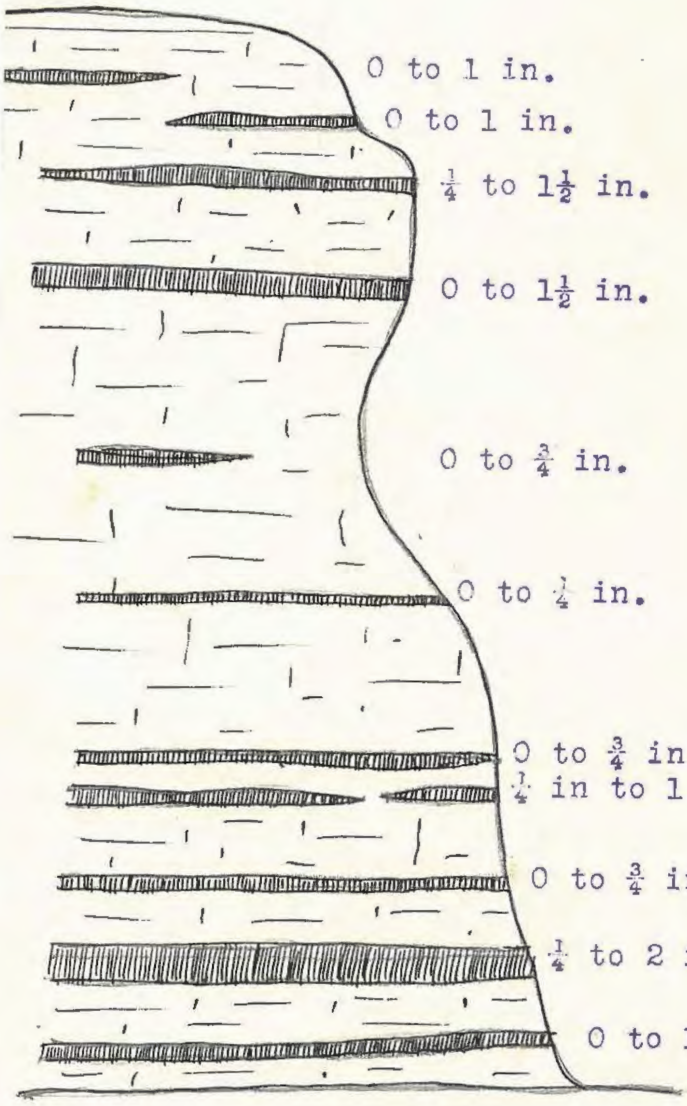
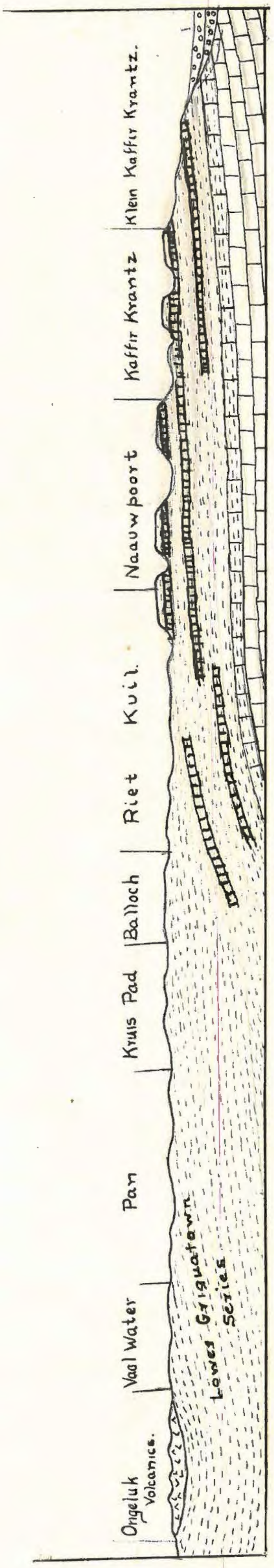
New Mine Reef.
105 ft.
Bottom Reef.



NEW MINE REEF. NAAUWPOORT.

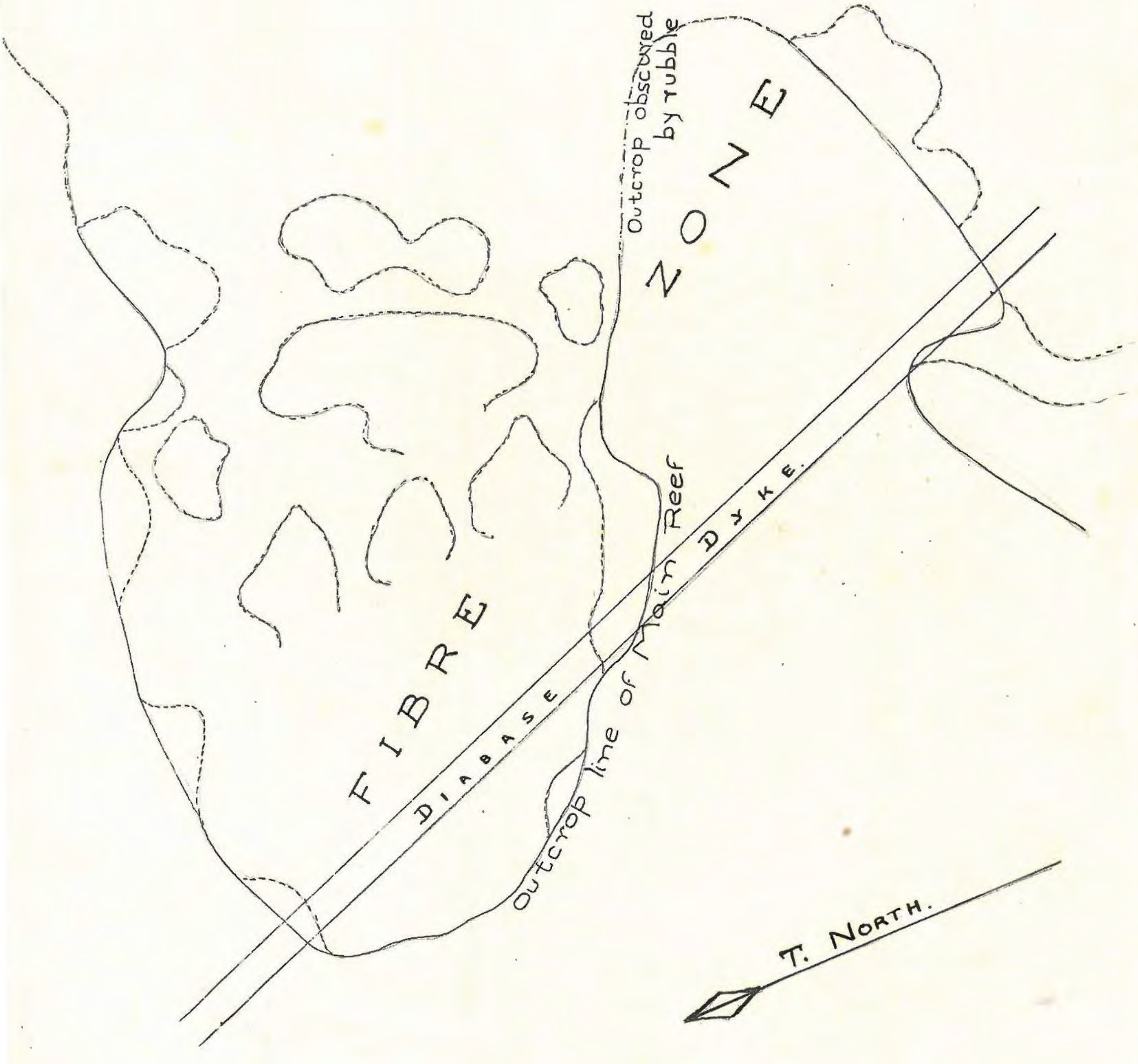


Section through asbestos bearing beds, showing horizontal bedding and peculiar karroo like weathering effects.

The asbestos horizons are roughly indicated.

Vertical scale $2\frac{1}{2}$ times horizontal.

Portion of Naauwpoort Mine, showing outcrop of Main Reef, and probable marginal outlines of a portion of the old workings. This would correspond rpughly to the shape of the fibre areas. West of the diabase dyke all crocidolite seams are highly silicified, although these are proved extensions of the horizons worked east of the dyke.



Scale........ 1 inch = 200 feet.