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The geology of the bewaarkloof area : Pietersburg asbestos field

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(e.) Cracks and Joints filled with Cross-Fibre

Figures 35 and 36 indicate cracks and joints filled with cross-fibre, crossing the complete succession. In Figure 35, a fibre band is shown to diverge from a normal fibre band to one crossing the bedding at a high angle. Figure 37 indicates a joint filled with fibre, siderite and graphitic material cutting a normal fibre band at right angles.

The examples mentioned above clearly indicate that amphibole asbestos developed over more than one period and probably over a considerable interval of time. As the plots in Fig. 23a show, these joints filled with asbestos are nearly vertical and trend in a direction 250°. If is further noticeable that the poles of these joints fall on the great circle defined by the poles of the bedding planes (compare with the Figures on Map 5). They are, therefore parallel to the fold axes of the east-west folds and can thus be defined as a - b tensional joints.

The fibre in the joints and tension cracks does not extend over very long distances. In fact, it seldom extends more than two metres across the succession on either side of a fibre horizon. In the area under discussion, this type of vein fibre has only been observed in and near the Tet and 120 Fibre Horizons, which have been responsible for most of the long amosite production in the area.

The cross-cutting bands seldom exceed one centimetre in width. Exceptionally, fibre lengths up to three centimetres can be measured in these joints. It is further observed that the fibres grow or develop at right angles to the joint planes. This must indicate migration and injection of the material producing fibre. The opening of these tension cracks would suggest fibre growth in a tensional direction.

(f.) Bent and Curved Fibre Bands

Quite often fibre bands have a bent or curved nature (Fig. 38). These effects are entirely due to post-fibre shearing and folding (Fig. 39). Curved fibres are usually found associated with shearing or with minute faults in the rock where the fibre is curved and bent in a fashion dependent on the amount and size of the movement (refer to Figures 40 and 41).

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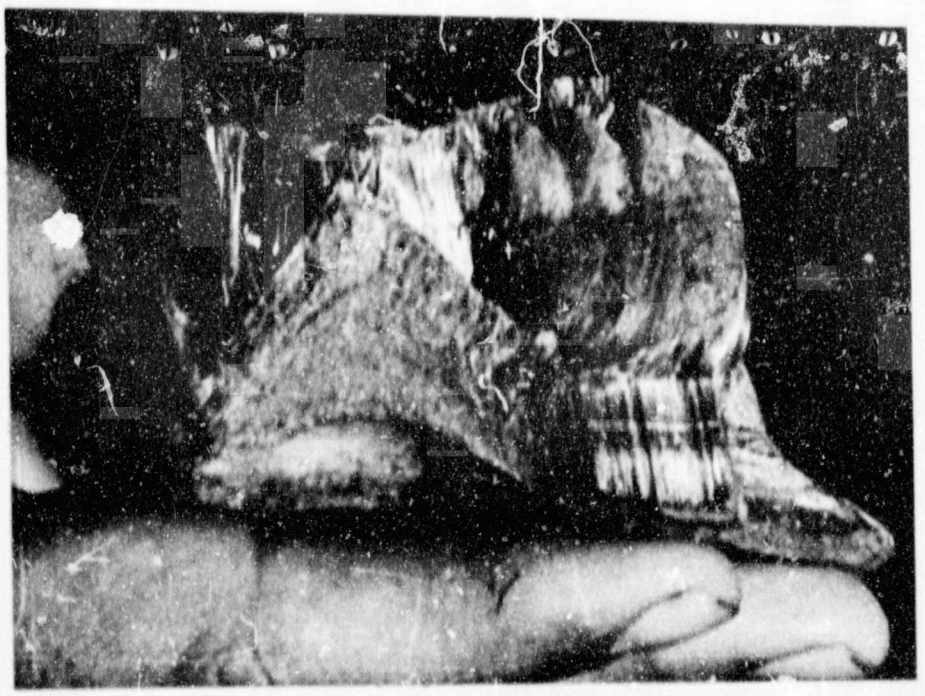


FIGURE 34

EXAMPLE SHOWS A "WASTE CONE" DEVOID OF FIBRE. NOTE THAT THE BEDDING PLANES HAVE BEEN UPFOLDED INTO THIS CONE SHAPE.

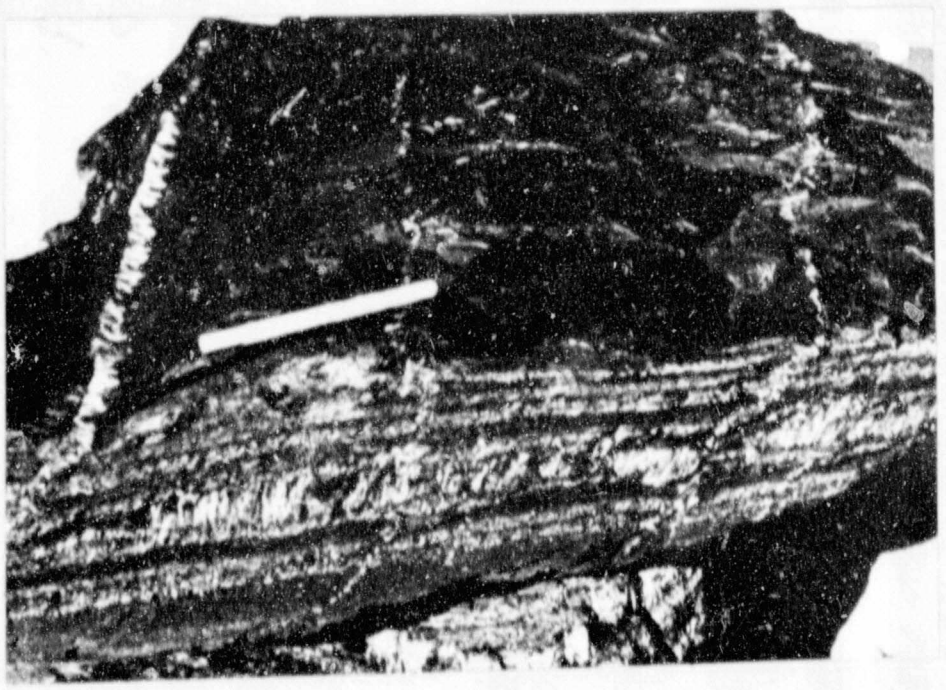


FIGURE 35

PHOTO SHOWS TENSION JOINTS FILLED WITH AMOSITE ASBESTOS. NOTE FIBRE IS DISPOSED AT RIGHT ANGLES TO JOINT PLANES.

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F. THE NATURE AND BEHAVIOUR OF ASBESTOS DEPOSITS

As previously indicated, asbestos horizons occur in certain well defined stratigraphical units in the banded ironstone succession. Economic deposits of fibre, however, do not extend in an even and regular fashion, over long distances along strike or dip, but rather have the tendency to pinch and swell. In fact, the development of asbestos within these horizons in the Pietersburg Asbestos Field, is only found in certain localised areas.

The areas where asbestos horizons show a strong development of fibre have been demarcated on Map 1. The "areas" indicated have either been exploited, or are in the process thereof, and have been responsible for the bulk of the asbestos production in the Pietersburg area. These economic occurrences of fibre, though variable in size and payability, have certain identifiable geological controls and characteristics.

It is noticeable that these "areas" are spaced in a regular "bead-like" fashion, along roughly two sets of lines which appear to conform with the major east-west and north-south fold trends of the area. For instance, the regional geological map clearly indicates that the Montana-Beatrice-Egnep-Pylkop and the Holkloof-Kranskloof amosite deposits are spaced at regular intervals parallel to the east-west fold trend. It is the writer's opinion that large scale, regular folding has been the cause of the regular interval between the "areas".

On closer inspection of these large "areas" of known potential, a similar pattern on a smaller scale can be observed (Map 3). Individual deposits of fibre within these large "areas"

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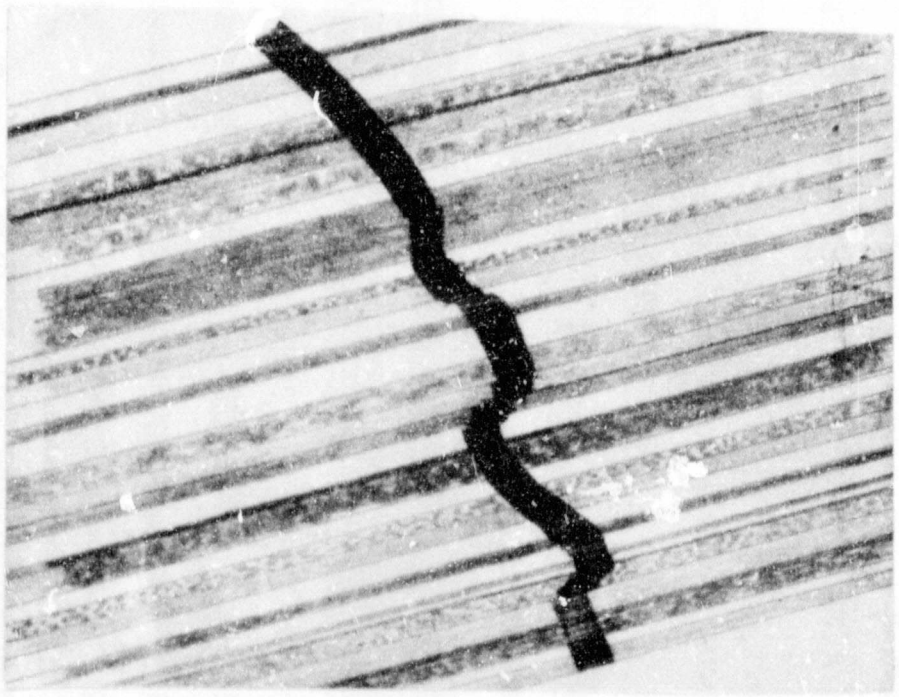


FIGURE 36

SKETCH INDICATES A JOINT FRACTURE FILLED WITH AMOSITE. IT WOULD APPEAR THAT BEDDING PLANE DIFFERENTIAL MOVEMENT WAS RESPONSIBLE FOR THE EFFECT ON THE JOINT, AS THE SKETCH INDICATES. [NORMAL SCALE].

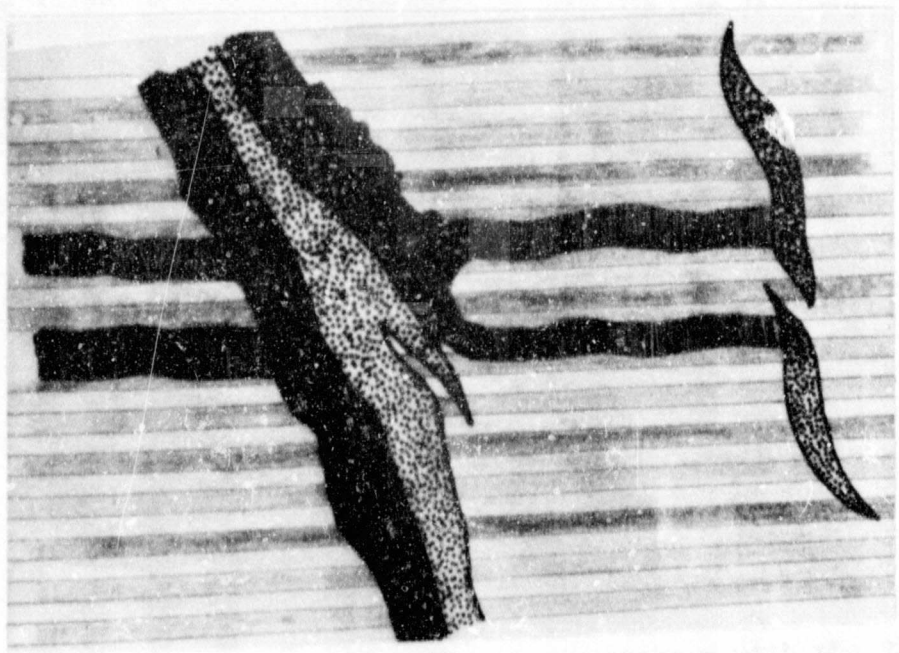


FIGURE 37

SKETCH SHOWS GENERAL BEHAVIOUR OF TENSION JOINTS FILLED WITH ASBESTOS, SIDERITE AND BLACK MASSIVE MATERIAL. (THE LIGHT STIPPLED LAYER IS SIDERITE AND THE DARK ZONES REPRESENTING BLACK GRAPHITIC MATERIAL (NORMAL SCALE).

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are again separated from one another by apparent barren stretches of ironstone. These deposits of fibre are found in the form of lenticular bodies, situated in the crests and troughs of elongated dome and basin-like anticlinal and synclinal fold structures. The elongated fold structures appear to be the result of cross-folding, as previously described.

The size of each of these deposits can directly be related to the size of the fold in which it occurs. (Map 3). As the geological and structural map of Bewaarskloof indicates, the largest amosite deposit in the area is situated in a syncline (Tet Syncline) with an east-west trend (see Maps 2 and 3). This is also the largest structure in Bewaarkloof. A quite remarkable feature is that individual deposits are parallel to one another and to the east-west fold trend.

It is therefore concluded that asbestos development is intimately related to structure both on a regional and minor scale, and it would appear that in the Pietersburg field asbestos deposits are located only where folds cross at high angles to form dome and basinlike structures.

G. GENESIS OF AMOSITE AND CROCIDOLITE

Any theory of genesis of amosite and crocidolite must be compatible and account for the following observations :-

1.) The invariable association of amphibole asbestos and banded ironstone.

2.) The interbedded and occasional cross-cutting nature of the fibre seams, as well as joints and tension fractures filled with asbestos.

3.) The regular and persistent nature of the individual members of the banded ironstone as compared with the discontinous behaviour and distribution of the fibre horizons and individual fibre seams.

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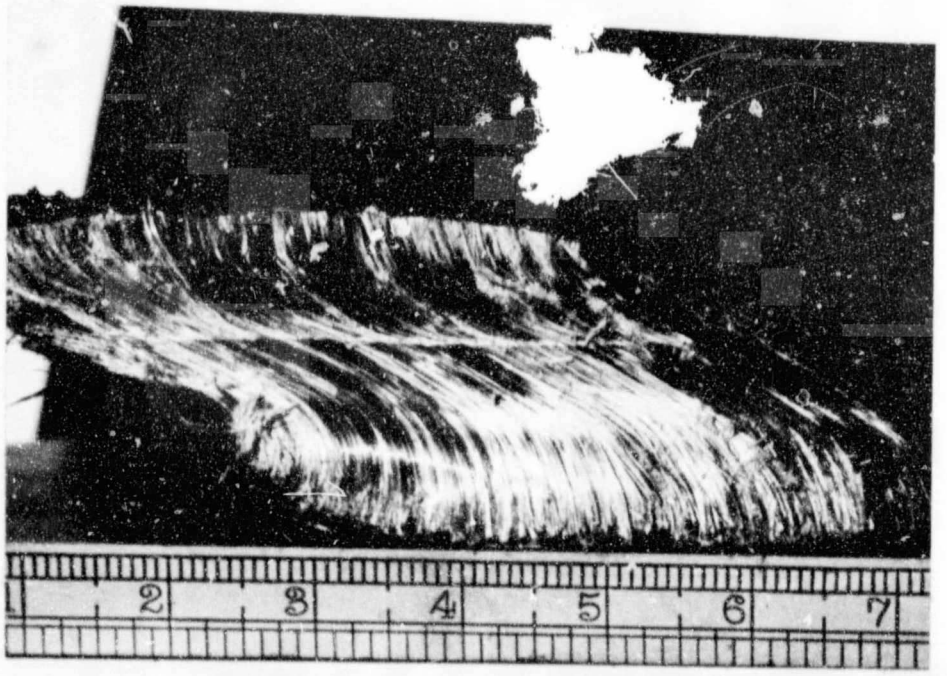


FIGURE 38

EXAMPLE OF A CURVED AND BENT FIBRE BAND, CAUSED BY POST FIBRE BEDDING PLANE MOVEMENT AND SHEARING.

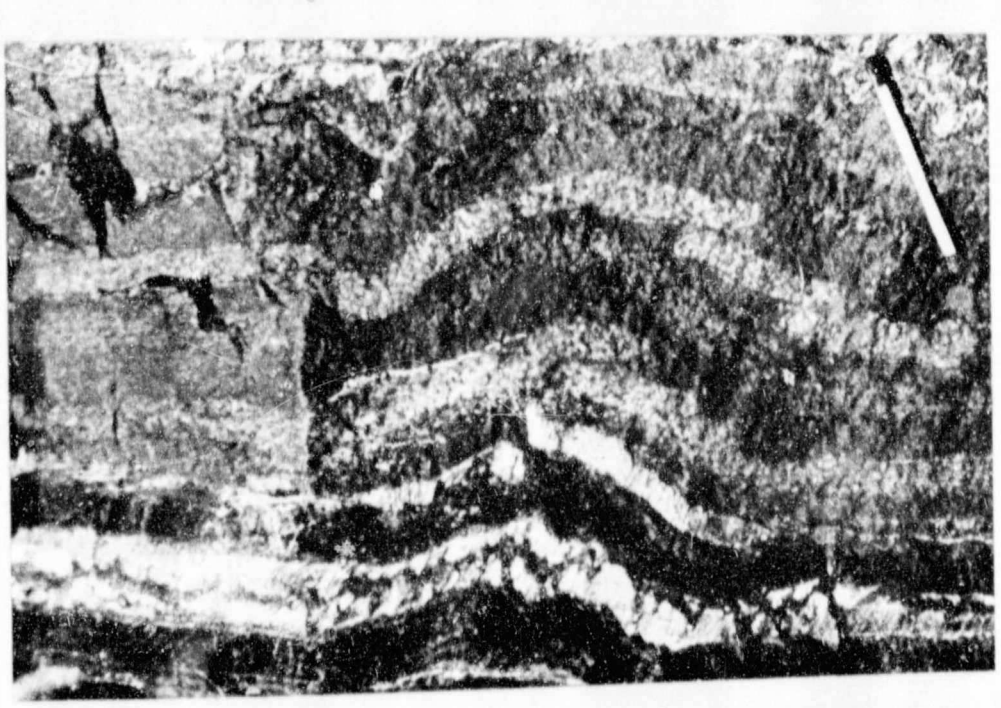


FIGURE 39

SPECIMEN SHOWS THREE DISTINCT BANDS OF CHERT AT THE TOP OF THE PHOTO AND TWO SEAMS OF CROCIDOLITE ASBESTOS. NOTE SIMILAR MANNER IN WHICH BOTH THE CHERT AND FIBRE HAVE BEEN SHEARED AND DISPLACED.

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4.) The fact that the fibres are sometimes normal to the bedding planes and other instances oblique.

5.) The irregular nature of waste partings in the fibre bands and the presence of gentle curves and the "cone" effects displayed by the fibre.

6.) Some fibrous amphiboles do not have the other physical characteristics of asbestos.

7. The close association of magnetite with crocidolite fibre on the one hand and the general absence of magnetite in the shaly formations bearing amosite fibre on the other hand.

8.) The persistent orientation of cross fibre and the fact that the fibre appears to be orientated parallel to the minimum a-stress direction of the east-west folds, which according to Schwellnus et al.(1962) is of Post Waterberg age.

9.) The occurrence of "pay-shoots" within deposits and also the fact that asbestos deposits invariably have a lenticular nature, with a common orientation of the lenses.

10.) The regular interval between economic areas on a regional scale.

From the above it is obvious that the problem is quite a complex one, involving not only the chemistry of the rocks and the crystallography of asbestos, but also the geology and structure of the area. Numerous attempts have been made by various authors to offer a suitable explanation for the origin of cross-fibre amphibole, none of which has ever met with general acceptance. From a study of the work and theories of the more recent investigators of amosite and crocidolite asbestos, two main schools of thought appear to have developed. The one school advocates burial and compaction of the ironstone during the early stages of ironstone formation resulting in a sort of thermal and load metamorphism; the other school of thought postulates a dynamic and structural control for the development of cross-fibre amosite and crocidolite

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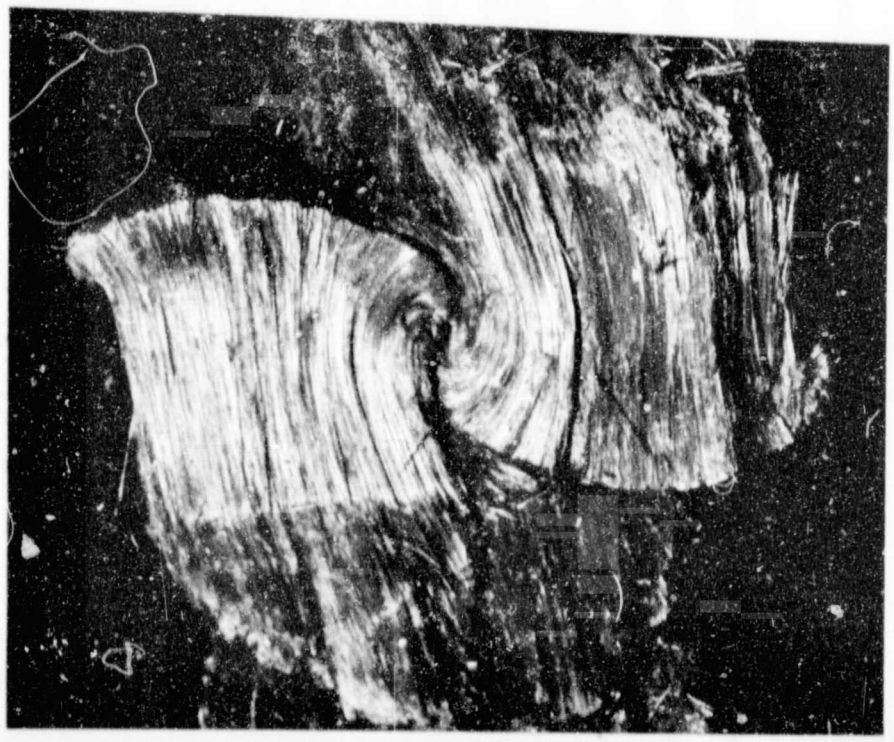


FIGURE 40

EXAMPLE SHOWS A DOME-LIKE STRUCTURE OF FIBRE PRODUCED BY SHEAR CLEAVAGE. NOTE WRENCHING OF THE FIBRE AS THE RESULT OF THIS SHEARING (HALF NATURAL SCALE).

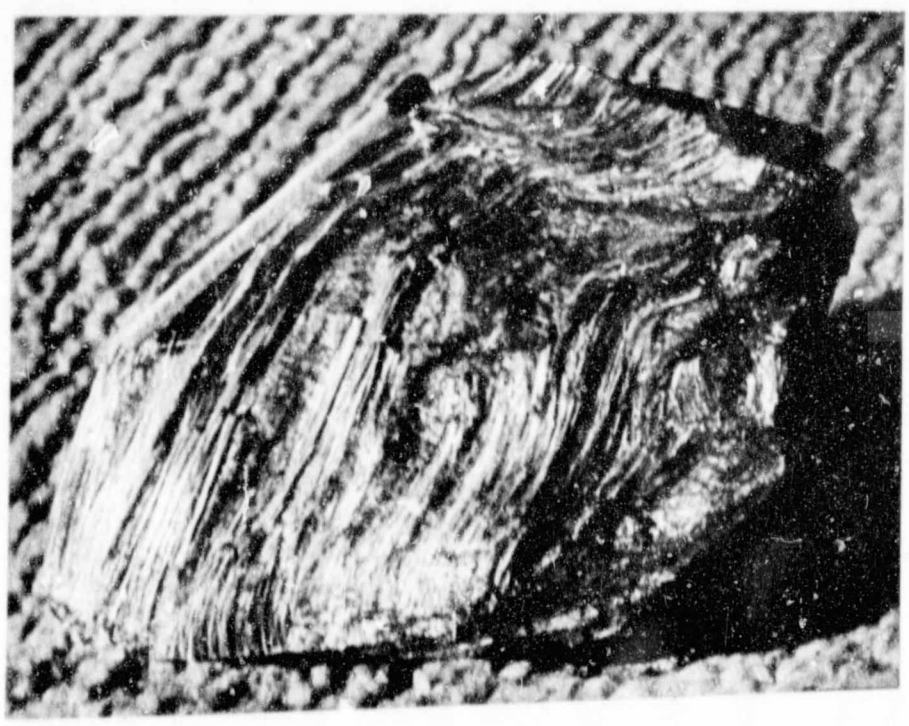


FIGURE 41

SPECIMEN SHOWS A CURVED FIBRE SEAM. SOFT BLACK GRAPHITIC MATERIAL ARE DEVELOPED IN BETWEEN THE FIBRES.

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1. Thermal and Load Metamorphism

This theory has been advocated by various authors, notably Peacock (1928), Hall (1930) and Cilliers and Genis (1963).

Peacock (1928) arrives at the following conclusions :- "Crocidolisation is thus conceived as a mild, static, non-additive metamorphic process, resulting in the chemical union, along soda-rich bedding planes of the necessary constituents in situ. The process is described as a "sweating action" facilitated by interstitial rock moisture, and a moderate rise of temperatue and pressure such as would result from simple burial of the ironstone to moderate depths".

Hall (1930) remarked as follows :-

"Doubtless the above conception of load metamorphism contains some speculative element, but it represents, in the writer's opinion, the nearest approach to an intelligent working hypothesis that seems possible in the present state of our knowledge".

Cilliers and Genis (1964) came to the conclusion:-

"That crocidolite was formed by the transformation of proto-riebeckite during the lithification of the banded ironstone, and that the fibrous nature of the crocidolite resulted from the orientating effect of layers of magnetite".

The main, and serious, objection to this theory of thermal and load metamorphism is the fact that it fails to explain the following features in the Pietersburg field:

(a.) Lens-like deposits of fibre separated by barren stretches of ground and the common trend of the lenses parallel to the younger folds.

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(b.) The close association with folding. For instance, the size of a deposit is directly related to the size of the fold in which it occurs.

(c.) The common orientation of fibre and the fact that it appears to be parallel to the direction of maximum stress release of the younger folds.

(d.) Cone in cone structures.

In the Pietersburg field the banded iron formation is composed of bands of varied thickness and composition, with the individual bands retaining uniform features over very large areas. It is possible to correlate individual bands for miles along strike, with no detectable difference at all. Obviously, the parent material from which asbestos was developed must have behaved in a very similar fashion.

Bearing the abovementioned in mind, it is impossible to account for the formation of asbestos as the result of load metamorphism. If this were the case, asbestos deposits would surely have shown a very widespread development. Fibre bands would not have shown sharp "cut-off" effects or been localised in lenticular bodies in anticlines or synclines.

Load metamorphism cannot account for the fact that these lenticular bodies are parallel to the younger folds of the area.

If, as postulated by Cilliers and Genis (1963), these lenses of fibre were formed by slumping and the wavy bands were formed by a continued downward pressure during compaction, as further postulated, then one would expect a random orientation of both features in question. This is, however, not the case. The writer is, therefore, forced to conclude that "load metamorphism" does not appear to be the cause of asbestos formation in the Pietersburg Field.

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2. Thermal Dynamic Theory

The main supporters of this theory are Vermaas (1952) Du Toit (1945), Gevers (unpublished report, 1945) and Fockema (1967).

Vermaas (1952) considers : ".....that a process of thermal metamorphism has formed grunerite and riebeckite (the lamellar amphiboles) and a subsequent process of shearing caused the actual fibre growth from both or one side of a seam upwards".

Du Toit (1945) postulated his theory as follows :- "Asbestos was generated in several phases under crustal deformation of Post-Matsap/Post-Waterberg age".

Fockema (1967) concluded: "that crystallization of crocidolite was initiated during periods of deformation and only took place in those areas that were in a tensional state or where the proto-asbestos was subjected to shearing stresses".

The writer of this paper lends his full support to the above statements.

These investigators are nevertheless in agreement that the morphological display of amosite and crocidolite differs completely from hydrothermal injected cross-fibre veins. On this aspect, the writer is in full support of the general conclusions arrived at by Hall (1930), Peacock (1928) and others, that these minerals represent the recrystallisation in situ of Na and Mg rich layers and bands of material originally present in the ironstone formation. The invariable association of these minerals with the banded ironstone, as well as the occurrence of asbestos in certain well defined stratigraphical units only, are the main points in favour of this postulation. Furthermore, the overall morphological display of the fibre is strongly suggestive of crystallisation in situ, with no large scale introduction and transportation of material, except in the case of cross-cutting veins. Regarding the Na and Mg rich layering, it will suffice to mention the "doublets" and "triplets" of Bewaarkloof, which clearly indicate an original Na and Mg rich layering.

In all the work published prior to 1960, it was generally accepted that cross-fibre amosite and crocidolite were derived from mass-fibre grunerite and riebeckite, and that these mass-fibre

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bands represent some intermediate stage between the original parent material and the final cross-fibre seams. There is not one known example in the Northern Cape and Northern Transvaal in which an intermediate stage could be found between mass-fibre and cross-fibre or, for that matter, could a cross-fibre seam be found to pass into an unorientated mass-fibre seam. Regarding their genesis, the writer is forced to conclude that there is no common link between these two amphibole minerals, except for normal metamorphism.

Cilliers (1964) reaches the following conclusion :

"The most serious objection is that they (previous authors) fail to explain how layers of mass-fibre riebeckite came to be preserved between and even adjacent to layers of crocidolite".

Apart from the above statements, Peacock (1928), Hall (1930), Miles (1942) and Du Toit (1945) further considered that the growth of amosite and crocidolite began on a divisional plane between suitable and unsuitable strata and was propagated through the former until an unsuitable layer or band was encountered. The writer is in full support of the general conclusion drawn on this aspect. Cilliers and Genis (1964) are, however, of the opinion that this process took place only when the divisional plane was occupied by a layer of magnetite.

Cilliers (1961) expressed the opinion : "The writer has, therefore, come to the conclusion that crocidolite asbestos was formed as the result of the growth from a colloidal solution of extremely fine riebeckite needles perpendicular to an initiating surface of already crystallised magnetite. Where growth was obstructed in the direction away from the magnetite, the growing crystals made room for themselves, where possible, by pushing back the magnetite layer into a more plastic adjacent layer. Where magnetite was absent, there was no control over the orientation of the riebeckite crystals forming

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in the parent material, which crystallised finally into layers consisting of a homogeneous mass of non-orientated, interlocking riebeckite laths and needles".

Cilliers and Genis" theory centres on the presence or absence of a magnetite adjacent to the parent rock to form cross fibre or mass-fibre riebeckite. Where it is present, cross-fibre developed during the lithification of the ironstone; where absent mass-fibre developed.

There are serious objections to this view. For instance, most amosite fibre seams do not contain associated layers or bands of magnetite. Amosite is mostly found in the soft "amosite" slates, which are entirely non-magnetic. This theory further fails to give an explanation for the fractures and joints filled with cross-fibre when cutting across chert, shale and magnetite bands. One would also expect that were these magnetite bands the controlling factor for the development of cross-fibre, the fibre would be orientated at right angles to the banding. This, however, is not the case.

Magnetite can occur either as perfectly crystallised octahedrons as sheets or plates or as irregular bands. Under the microscope these sheets and bands consist of highly irregular aggregates of variable size and interconnected one with the other. Octahedrons of magnetite quite often are found within a fibre seam (Voorspoed Shorts Horizon); they show a very clear cross-cutting relationship with fibre. The fibres have been cut and pushed apart during the growth and development of these cubes of magnetite. This, to the writer, indicates rest liquid entrapped during fibre growth with the eventual crystallisation of euhedral crystals of magnetite. Furthermore, sheets and layers of impurities, pushed ahead of the growing fibre crystals, crystallised out as a residue of magnetite and haematite. This might also account for the fact that, since amosite required more iron for its formation than crocidolite, most of the iron present was used up in the formation of amosite. The crocidolite, not needing all the iron, expelled it as a rest

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product which crystallised out as irregular bands of magnetite at the contacts of the fibre.

The hypothesis favoured is that the amosite and crocidolite developed from the transformation of certain stratigraphical units or layers (in the banded ironstone formation) of pure or almost pure parent material into cross-fibre amphibole and that no new material was metasomatically introduced or that any large scale migration of the parent material took place. Whether amosite or crocidolite or both formed, depended on the exact composition of the original parent material. The sodium rich protoamphibole gave rise to crocidolite, whereas the magnesium rich protoamphibole gave rise to amosite. These units or layers were, however, transformed into asbestos in certain localised areas only, with large apparent barren stretches of ground in between. The barren stretches show no detectable mineralogical difference from the rocks in which the asbestos developed.

It is further postulated that fibre developed only in the areas where synclines and anticlines of two different sets of folding crossed to produce a "double system" of folding. In other words, the units or beds suitable to form asbestos, were only converted into asbestos in the basins and domes produced by the cross-folding. The size of the structurally suitable areas, ranging a few centimetres to hundreds of metres in diameter, are entirely dependent on the size, shape and intensity of the interfering folds. Within these structurally suitable areas, all layers chemically suited were transformed into asbestos as a result of the stress associated with the folds.

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Depending on whether the asbestos developed in a synclinal basin or anticlinal dome, the bottom fibre horizons would either be developed over a smaller or larger area than the upper fibre horizons, thus resulting in superimposed development of fibre. Furthermore, it would appear that the growth of asbestos was initiated during the final stages of the earlier north-south trending fold system and the initial stages of the later east-west trending fold system when maximum interference took place. The process ceased after these later folds reached a peak period of development.

The nature and character of the divisional plane played no dominant role in orientating the growing fibre. This is clearly the result of the later east-west folds(Post-Waterberg) and thus resulted in the fibres growing parallel to the axial plane.During this period of fibre growth, the excess and residual materials were continually pushed ahead(in waves) of the growing crystals, producing as a final result, screens of magnetite, quartz and siderite. The entrapped rest products crystallised out as massive magnetic material, euhedralmagnetite crystals and quartz. Cessation of the fibre growth only took place when the stress responsible for the growth became "excessive" or died out resulting in a partially crystallised layer of asbestos, with irregular and jagged "ends". Where the process was completed, normal and regular seams of asbestos developed.

It would appear that during the period of maximum intensity of the east-west trending folds (when little asbestos developed due mainly to the excessive stress), bedding plane slip,fracture planes, shear and tension joints acted and interfered with the cross-fibre seams of asbestos. The asbestos seams were sheared, cut, fractured and faulted. During this stage original parent material could have mobilized into a solution that was squeezed into the tension fractures and joints, where it crystallised out as cross-fibre amphibole asbestos veins.

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The re-crystallisation of parent material and in some instances, already developed cross-fibre, took place during the final and end stages of this east west period of deformation, when conditions once more appear to have become structurally suited to asbestos formation. It is also during these end stages of this deformation that because of a slight change in the stress-field and subsequent folding on a very much smaller scale, en echelon folds were produced. It is quite possible that a subsequent period of fibre development on a very minor scale took place at this time, as is borne out by minor developments of fibre arranged in an en echelon fashion.

The ideas expressed in this section are the result not only of field investigation, examination and measurement of specimens in the Bewaarkloof area, but also a study of other areas in the Northern Cape and in the North Eastern Transvaal. This, as well as a study of the work of previous investigators, all contribute to the general conclusion that certain units (parent material) within the ironstone succession become unstable and transformed into asbestos as the result of stress developed and associated with cross folding of Post-Waterberg/Post-Matsap age.

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A special note of thanks to Prof. W.J. van Biljon and Dr. C. Roering under whose guidance the work was done.

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