SECTION II

RESULTS OF THE PRESENT INVESTIGATION

A. TERMINOLOGY

Concerning asbestos fibre the terminologies used in this thesis are based on the common usage in the asbestos industry.
A few definitions are briefly given.

FIBRE SEAM (Fibre Band)

A single asbestos seam generally orientated at right angles to the bedding or fracture planes. Therefore the term fibre seam or fibre band imparts the same meaning and are interchangeable. Fibre seams or bands occurring at an angle less than 90° to the bedding are termed "angled fibre seams" and those orientated parallel to the bedding "slip fibre seams" (see figures 22,25 and 26).

FIBRE REEF OR REEF HORIZON

A group of asbestos seams (bands) occuring close together forming a distinctive unit or pack. These units may be of variable width generally varying between 30 centimetres and 10 metres. The term also implies that the group of fibre seams can be mined as a unit.

Numerous reefs or reef horizons may be developed in one or more stratigraphical units of the ironstone succession and they may be separated from one another by a few metres up to hundreds of metres.

MASS FIBRE BAND

It consists of numerous closely packed spherulites of amphibole defining a distinctive band or layer in the ironstone succession. The spherulites consists of fine crystals of fibrous material radiating out in all directions from a common centre giving a "rosette" type effect. These bands generally do not exceed 7 centimetres in width. Because of their consistency are generally used as marker bands (see Fig. 9).

SHORT FIBRE

A fibre seam (band) generally not exceeding a width of 1 centimetre. The term 'shorts' is also commonly used.

LONG FIBRE

A fibre seam generally exceeding in width of 3 centimetres.

MEDIUM FIBRE

A fibre seam ranging in width between 1 centimetre and 3 centimetres.

DOUBLETS AND TRIPLETS

The terms are only used where both types of fibre (amosite and crocidolite) are in contact with one another and being in crystallographic continuity. At Malips the amosite bands normally cap the longer crocidolite on one side (doublets) or both sides (Triplets).

B. THE BANDED IRONSTONE

1. General

The most typical feature of this rock is its fine and regular banded nature due to alternating layers of light and dark coloured material. The individual bands have sharp and clear cut contacts and vary in thickness from less than 1 mm to several centimetres. These individual bands, even those of a fraction of a millimetre thick can be traced for tens of kilometres without any detectable physical change. At Bewaarkloof, for instance, this remarkable lateral persistence of the individual banding can be precisely correlated in the field over a strike length of at least 8 Kilometres. Two boreholes drilled 4 kilometres apart shows this relation clearly (see Fig. 4). Chemically, the bands appear also to be homogeneous. There is, however, no quantitative evidence to show precisely the chemical behaviour of individual bands and zones within the banded ironstone along strike.

The light coloured bands consist of micro-crystalline quartz and chert with some siderite. The dark bands are silt-like and consist of magnetite, grunerite, riebeckite, soft graphitic material and bands consisting of mixtures of these minerals. Present, also, are soft grey to black coloured non-magnetic shales at definite stratigraphic positions, which may be tens of metres thick. The 'Marker shale' and 'Footwall shale' (Zone B) are the main shale zones present in the succession (see Fig. 6).

Under the microscope these shales show a fine crystalline texture and are mainly composed of siderite, disseminated quartz, chert, flaky apatite. Near the top and bottom contacts of the shales, there are bands, lenses and blobs of chert, and, more rarely, magnesite (see Fig. 5). Mass-fibre bands, three to 6 centimetres thick, and amphibole needles are also present in the shales. The shales have sharply defined contacts with the banded ironstone.

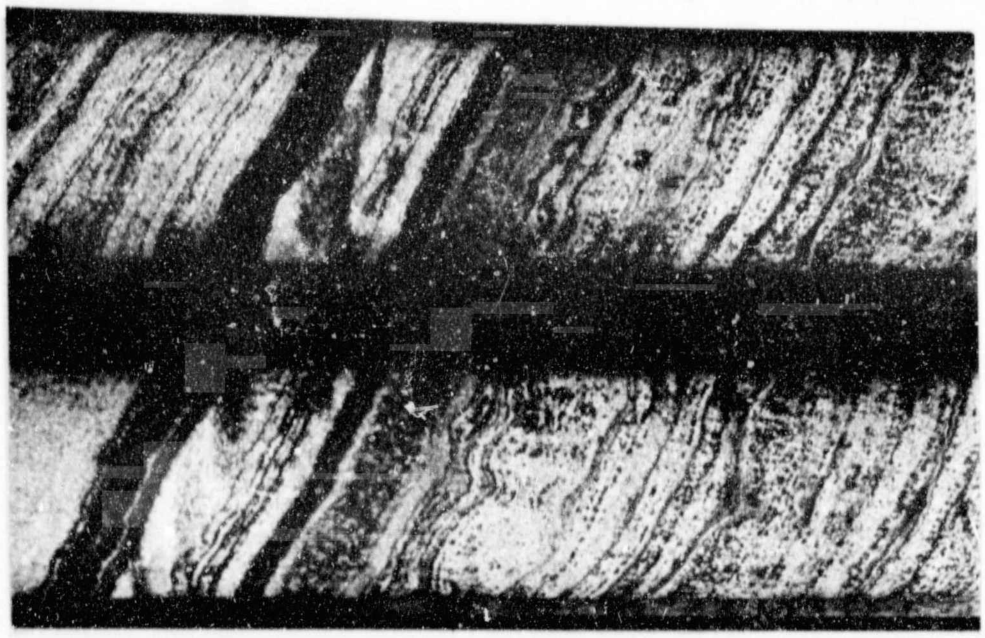

FIGURE 4

PHOTO OF TWO CORES SHOWING THE FINE CORRELATION POSSIBLE IN THE BANDED IRONSTONE. CORES ARE FROM BOREHOLE MP1 AND MP2 APPROX. 4 KILOMETRES APART (CORES HAVE A 3.5 CM DIAMETER).

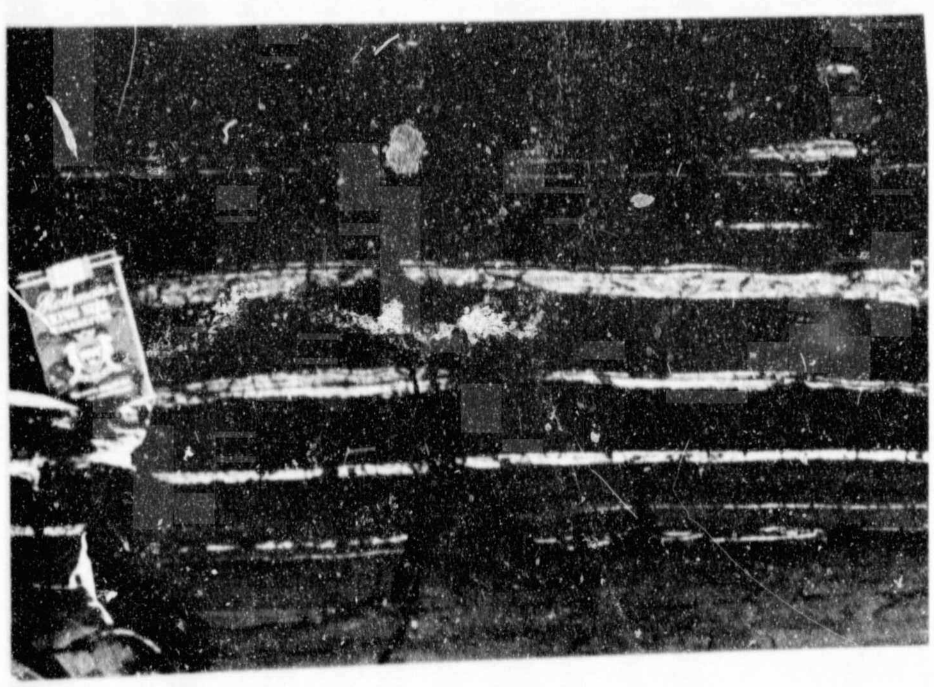

FIGURE 5

MARKER SHALE. NOTE THE CONSPICUOUS INTER-BEDDED CHERT BANDS.

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2. Detailed Succession of the Banded Ironstone Formation

Only the lower portion of the banded ironstone formation is present on Bewaarkloof, i.e. from the dolomite to a diabase sill above the main fibre seams (Fig. 6). This portion of the banded ironstone succession has been investigated in detail and has been subdivided into five distinct zones(see Fig. 6). The banded ironstone succession above the diabase sill, contains another 3 zones (Zones F,G and H) and is only briefly described(see Fig.7).

(a) Transition Zone (Zone A)

This zone forms the transition phase from the dolomite to the siliceous cherty ironstone formation. It consists of alternating bands and lenses of dolomite and broad irregular banded cherty formation, the chert bands varying in thickness from one to more than five centimetres. There is no asbestos fibre developed in this zone(see Fig. 6).

(b) Footwall Shale Zone (Zone B)

This zone is a 24 metre thick, soft friable, very finely laminated shale. Near the top and bottom contacts there are conspicuous bands and lenses of glassy white chert. Bands of mass-fibre and scattered amphibole needles are also present in this zone, giving it an overall speckled appearance. It persists throughout the region from near Chuniespoort to Kromellenboog, north of the Steelpoort River. There is no asbestos fibre developed in this zone.

(c) Footwall Cherty Zone (Zone C)

This zone is 38 metres thick and has been subdivided into five sub-zones (see Fig. 6):-

(i) Sub-Zone C1

This is an uneven banded cherty formation, with a thickness of 15 metres. The thickness of the chert bands

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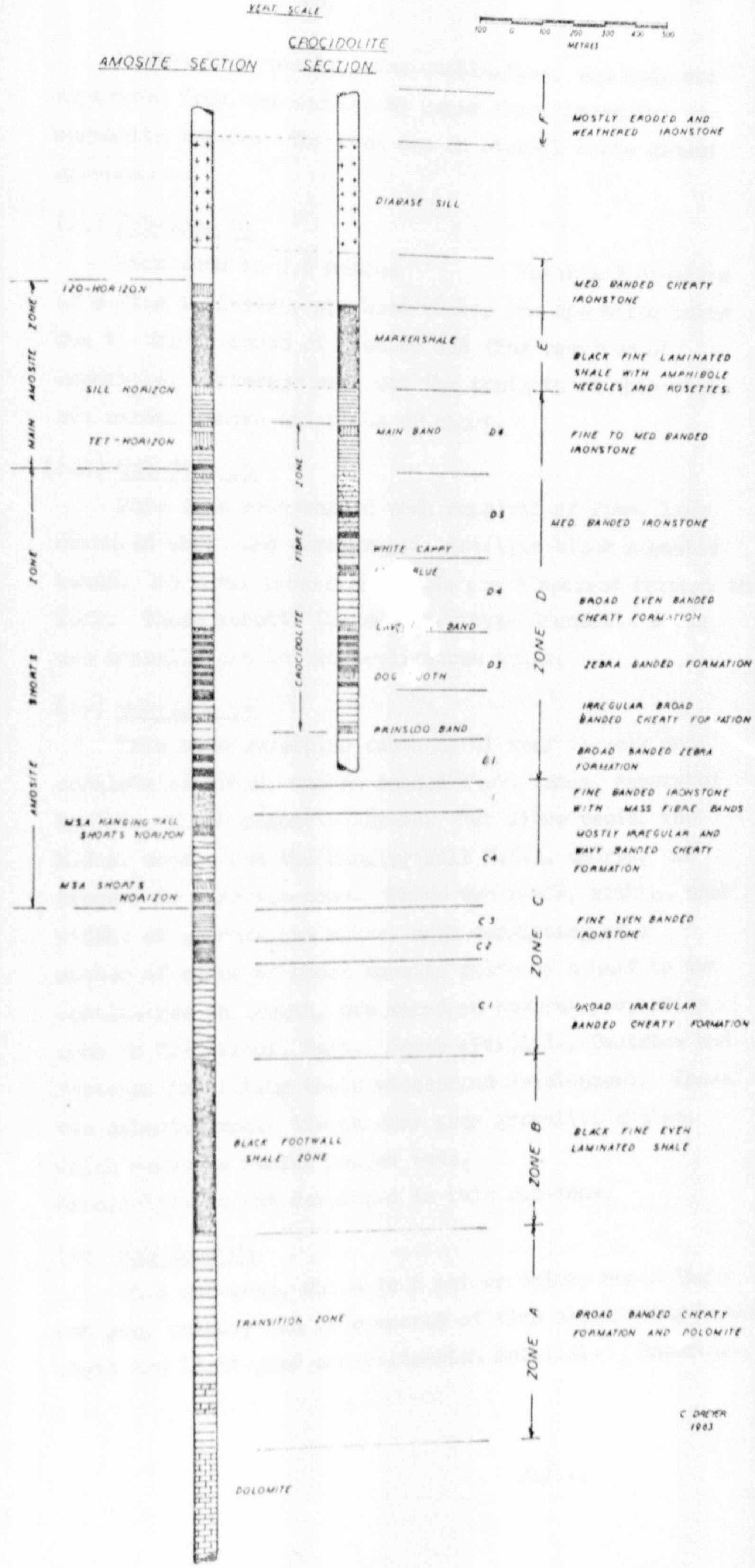
BEWAARKLOOF STRATIGRAPHIC COLUMN

FIG 6



varies from one to three centimetres, and they are separated from one another by paper thin, irregular magnetite layers. The rock has an overall white glassy appearance.

(ii) <u>Sub-Zone C2</u>

This zone is 3,6 metres thick and consists of a fine laminated, speckled shale, the speckling being due to the presence of needles and fine rosettes of amphibole. Interspersed near the contacts of this shale are bands, lenses and blobs of chert.

(iii) <u>Sub-Zone C3</u>

This fine even-banded rock consists of fine, light coloured chert and dark grey to metallic black magnetic bands. Numerous mass-fibre bands are dispersed through this rock. These rosette (mass-fibre) type Grunerite bands are normally one to two centimetres thick.

(iv) <u>Sub-Zone C4</u>

This zone resembles sub-zone C1 very closely and consists of broad, uneven banded chert bands, separated by thin, black magnetic layers. Two fibre reefs, the M.S.A. shorts and the Hanging Wall M.S.A. shorts, are present in this sub-zone. These two reefs, with channel widths of approx. one metre, each consisting of a number of seams of short amosite fibre of a half to two centimetres in length, are mined on several properties such as Kranskloof, Selix, Egnep (Pty)Ltd., Beatrice and Montana, indicating their widespread development. These two asbestos reefs lie on dark grey graphitic shales, which serve as useful marker beds.
Crocidolite is not developed in this sub-zone.

(v) <u>Sub-Zone C5</u>

This sub-zone, which is 6 metres thick, has a light ash grey colour, and is composed of fine alternating bands of chert and light grey magnetite-rich material. Numerous consistent mass-fibre bands, at roughly 4.5 centimetre intervals, are present within the sub-zone.

There is no fibre development in this sub-zone.

(d) Main Amosite and Crocidolite Zone (Zone D)

This zone, about 60 metres thick, is composed of white chert bands and dark grey to black bands of magnetite and haematite. The bands are from 5 millimetres to 2 centimetres thick. It is subdivided into six sub-zones, as shown in Figure 6.

(i) Sub-Zone D1

This sub-zone consists of one to two centimetres thick white chert and black magnetite bands. The banding is conspicuous, so the term "Zebra Banding" is used. There is no fibre developed in this sub-zone.

(ii) Sub-Zone D2

Irregular broad chert bands, separated by thin magnetite bands, characterise this sub-zone. There are scattered magnetite crystals throughout the rock. Where it is much weathered, brown and yellow colours prevail. Siderite and Goethite are common constituents. The "Prinsloo" crocidolite reef horizon is developed in this zone.

(iii) Sub-Zone D3

This zone consists of "zebra rock", similar to sub-zone D1. The individual magnetite and chert bands are, however, mainly half to one centimetre thick. No fibre is developed in this sub-zone.

(iv) Sub-Zone D4

This thick cherty formation resembles sub-zone D2, the main difference is its marked even banding. The chert bands are finely laminated with thin "slender" inclusions of amphibole. There are six thin, dark grey speckled shale beds, thirty to sixty centimetres thick, in this sub-zone, which serve as marker horizons.

One seam of amosite shorts and two seams of "blue" asbestos are present in this sub-zone.

(v) Sub-Zone D5

There are two, 60 centimetre thick, shale beds in this even medium banded ironstone. The banding is more clear-cut than in sub-zone D4. The "White Cappy" crocidolite reef horizon, as well as a few seams of amosite are developed in this sub-zone (see Fig. 6).

(vi) Sub-Zone D6

A fine to medium banded ironstone with two shale beds. The fibre seams in this sub-zone are the two main long fibre amosite seams "Tet" and "Sill", and the crocidolite "Main Band".

It is significant to note that in this main zone, amosite is only developed north of the main east-west valley. To the south are the crocidolite seams. Although the crocidolite is found in the same zone as the amosite, it is not developed in exactly the same stratigraphic positions as the amosite seams(see Fig.8). Between the two there is a zone of transition in which doubtlets and Triplets are found. This transition zone is indicated on Map 3. A similar condition, although less noticeable, is found throughout the Pietersburg Asbestos Field and is suggestive of compositional facies changes in this northern area.

(e) Main Marker Shale (Zone E)

This is a finely laminated black, 7,5 metres thick shale, with conspicuous white bands, lenses and blobs of chert (see Fig.5). It is the main marker horison and is easily identified on surface. The "120" amosite seam is 1,5 metres above this shale.

(f) Hanging Wall Diabase Sill

This sill maintains a uniform thickness of 15 metres and occurs at a constant distance above the main marker shale. The intervening banded ironstone is a cherty formation, with fine to coarse banding.

Stratigraphic Column of the Banded Ironstone Succession in the Malipsdrift Area

SCALE 1:4000

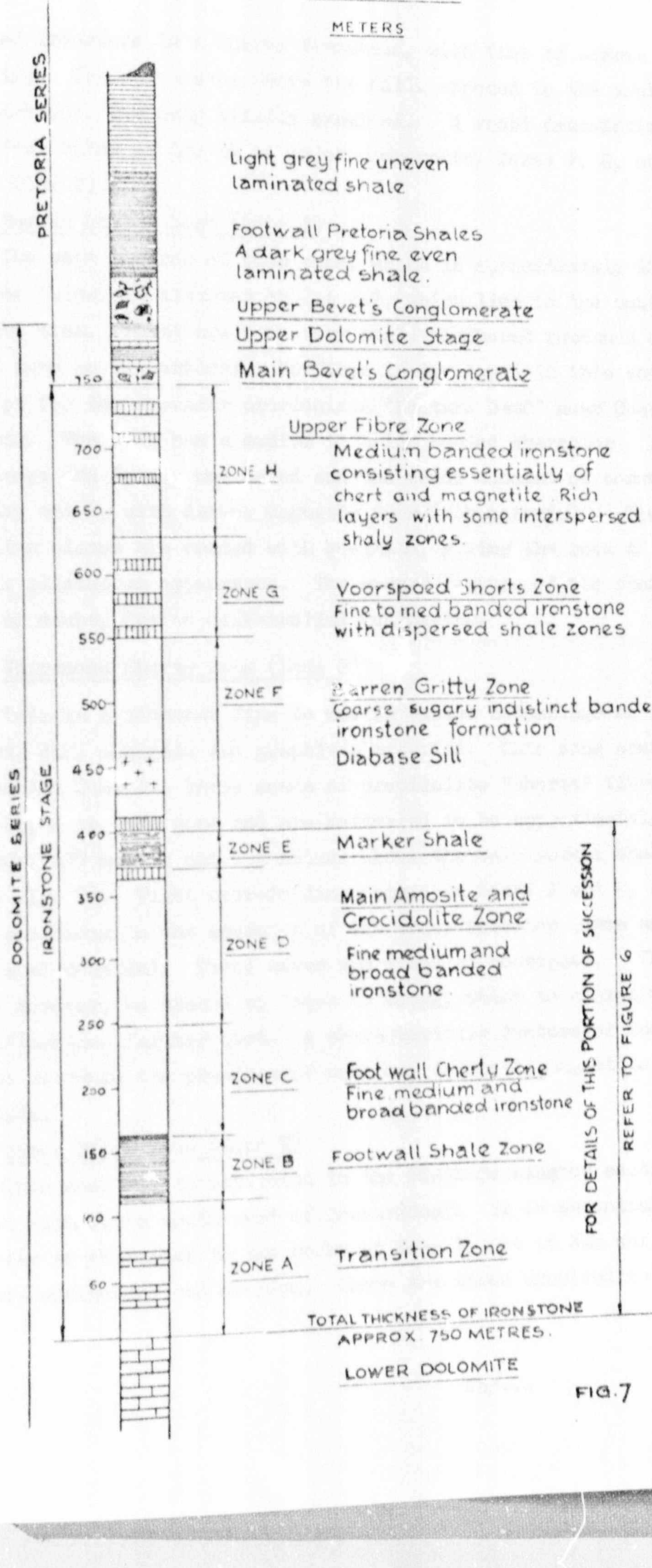


FIG. 7

banded ironstone is a cherty formation, with fine to coarse banding. The succession above the sill, exposed to the south of Bewaarkloof, was only briefly examined. A short description is given below of the three major components, Zones F, G, and H (see Fig. 7).

(g) Barren Gritty Zone (Zone F)

The main outcrop of this zone, which is approximately 120 metres thick, is situated on Lot 247, which lies to the south of the area. There are some very small weathered remnants of this zone on Bewaarkloof. No fibre is developed in this zone, except for the sporadic crocidolite "Bastard Band" near Cowan's Claims. The rock has a medium to thick banded character. The outcrops are deeply weathered and the bands consist of coarse, sugary chert, with darker magnetic iron-rich material. The bedding planes are coated with goethite, giving the rock a black glistening appearance. The sugary texture of the chert is, no doubt, due to differential weathering.

(h) Voorspoed Shorts Zone (Zone G)

This is a distinct fine to medium banded assemblage of light chert, dark magnetic and graphitic material. This zone somewhat resembles Zone D. Three seams of crocidolite "shorts" fibre are developed in this zone and are estimated to be approximately 152 metres, 179 metres and 204 metres above the main marker shale (see Fig. 7). Tight over-folding occurs in Zones F and G, so the positions in the sequence of the three asbestos seams are somewhat doubtful. These seams are mined on Voorspoed. They can, however, be traced to Leopards Cragg, which is approximately 24 kilometres farther east. A characteristic feature of the fibre seams is the presence of numerous scattered magnetite cystals.

(j) Upper Fibre Zone (Zone H)

This zone was investigated in the Pisga-Heuningkop section, eight kilometres south-west of Bewaarkloof. It is essentially similar in character to the rocks of Zone F, but it has suffered deeper weathering and erosion. There are three crocidolite

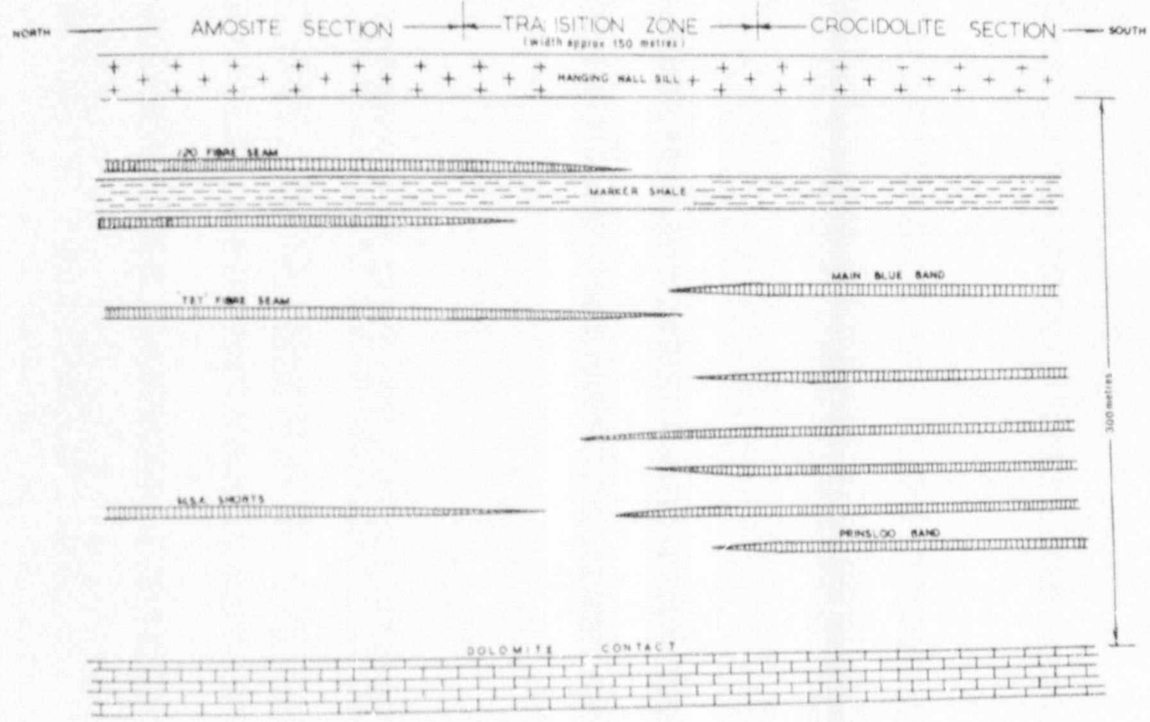


Figure 8

Schematic presentation of transition zone in the main amosite and crocidolite fibre zone.

fibre horizons developed in this zone, of which the lower two are best developed. They outcrop on Heuningkop, Benauwdheid, Pisga, Tweekloof and Middelrand, but do not appear to have developed east of the Malips River.

3. Metamorphism

The ironstone has been metamorphosed thermally(presumably by the Bushveld Igneous Complex) and dynamically with the subsequent formation of amphibole minerals. The amphibole minerals are found in three main types :-

(i) Cross-Fibre Amosite and Crocidolite

The behaviour and characteristics of cross-fibre asbestos is fully discussed in a later section (see Page 54).

(ii) Mass-Fibre Grunerite and Riebeckite

These mass-fibrous seams consist of numerous closely packed spherulites of amphibole. The spherulites consist of fine crystals of fibrous material radiating out in all directions from common centres(see Fig. 9). The diameters of these spherulites range in size from infinitely small to approximately six millimetres.

Mass-fibre is found to occur in a definite stratigraphical position in the form of individual bands, ranging in thickness from one millimetre to eight centimetres. They are persistent over tens of kilometres along strike and can be used as marker beds. They, furthermore, show no detectable physical change and in no instance throughout the Transvaal Field could a transition phase be found between the unorientated mass-fibre bands and the cross-fibre asbestos seams. There is a sharp distinction and the one cannot be confused with the other.

The fact that these bands of mass-fibre are found only in certain stratigraphic beds or units suggests an original chemical control.

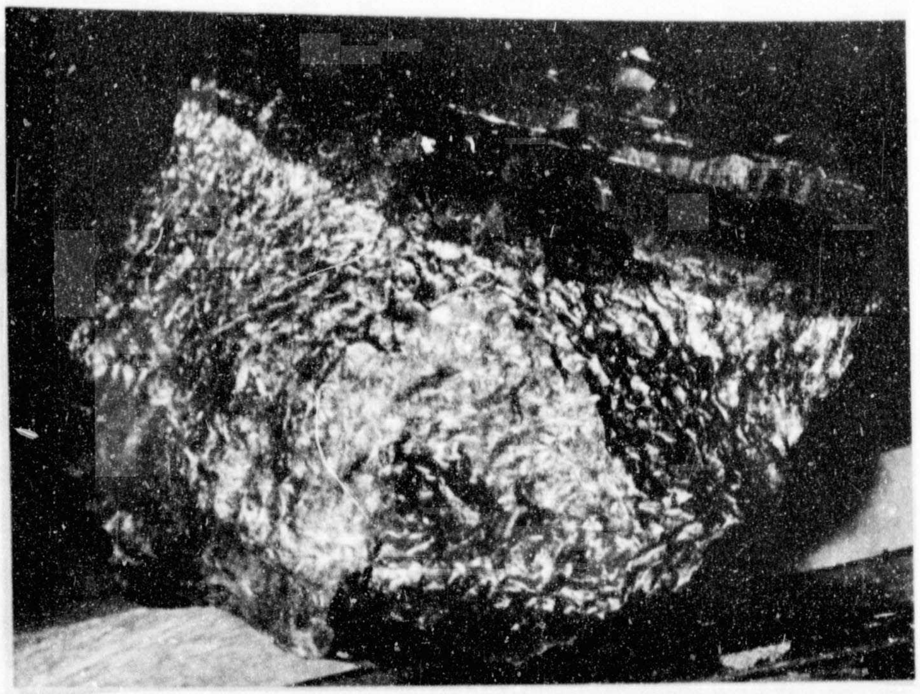


Figure 9

Photo shows a two inch thick "mass-fibre" band of grunerite. Note radiating nature of fibrous material.

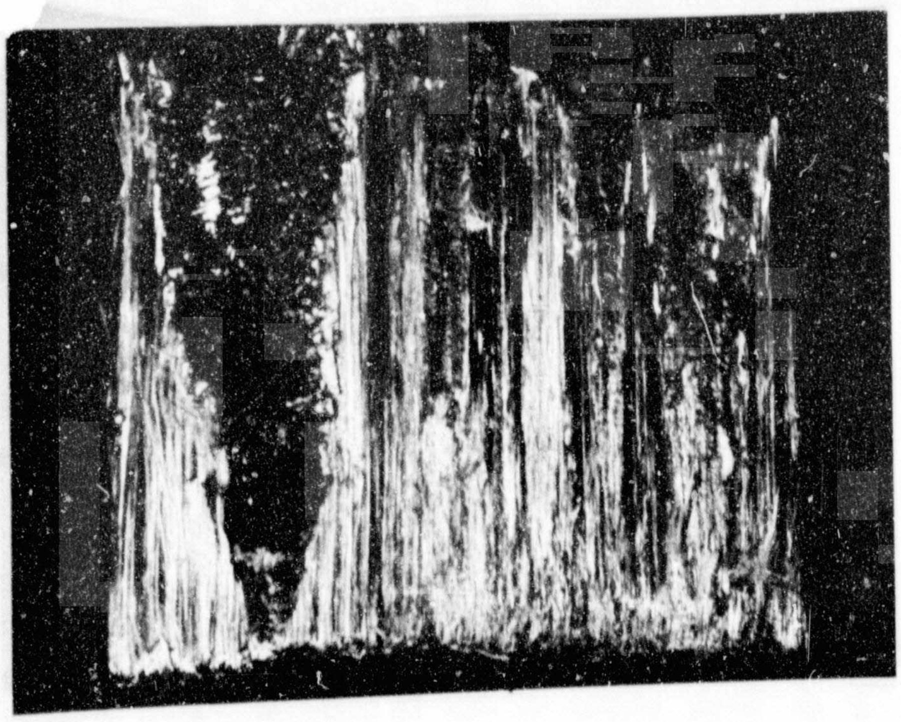


Figure 10

Scattered fine grunerite needles in a dark cone shaped material within an amosite band. Note needles show a cross-cutting relationship with the amosite fibre(half normal size).

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(iii) Needlelike Crystals of Grunerite and Riebeckite

These thin slender amphibole crystals developed throughout the ironstone succession. The crystals have lengths generally ranging from microscopically small to two centimetres and appear not to have any preferred orientation. They are found to cross-cut, at various angles, the individual bands of chert and magnetite in the ironstone. In fact they even show a cross-cutting relationship with the amosite and crocidolite asbestos seams (see Fig.10). In the Penge Mine Area, this cross-cutting relationship with the fibre is very conspicuously displayed.

If, as postulated by Cilliers and Genis (1964), pp 64-74) the amphibole formed during diagenesis when the rock was still in a relatively plastic state, and is not a metamorphic mineral surely asbestos and crystals of grunerite and riebeckite will not show cross-cutting relationships with the ironstone. From the above, the writer is forced to conclude that the amphibole present in the ironstone was developed during various periods of metamorphism. Vermaas (1952), after an intensive study of the various amphiboles, concluded that a process of thermal metamorphism has formed grunerite and riebeckite, and that a process of shearing caused the actual growth of fibre.

No other effects of metamorphism are visible in the rock. It is only around the major dislocations and diabase sill contacts where metamorphic minerals have developed.

4. The Origin of the Banded Ironstone

A number of theories have been advanced on the origin of banded iron formations and although there is still no completely acceptable theory it is generally accepted that Pre-Cambrian banded ironstones were formed by chemical precipitation in a sedimentary environment.

In any theory on the formation of banded iron formations, the following features must be considered:-

(i) The rhythmic banding, band thicknesses and thickness variation of single and composite bands.

(ii) The extraordinary lateral persistence of these individual rock units on a macro, meso and microscale and the extreme vertical heterogeneity of the banded ironstone formations.

(iii) Mineral constitution of individual bands.

(iv) The chemical compositions with the predominance of iron and silica and rare alumina; the presence of K_2O in the "shales" of the Transvaal region; the lateral changes in Na_2O and MgO content of the asbestos seams.

(v) General absence of detrital material and of clastic sedimentary features.

(vi) "Shale" bands - some possibly consisting of tuffaceous material.

(vii) Evidence of the presence of organisms, organic material and carbon

(viii) The conformable transition from the underlying carbonate formations (Dolomite and Dolomitic Limestone)

(ix) The association of carbonate rocks and general similarity in the geological successions of formations of similar age in various par' · of the world.

(x) The presence of breccias within the iron formations.

(xi) The source of the banded ironstone material.

From the accumulated evidence, a few deductions on the conditions under which banded ironstone was formed can be drawn:-

Persistence of individual bands within the ironstone throughout extensive areas indicates stable conditions of deposition. The presence of oolites and stromatolites in the underlying dolomite and intra-formational breccias within the ironstone formations suggests shallow water conditions during precipitation of the dolomite as well as the banded ironstone.

The changes in the composition of the individual rock units appear to be due to several changes of conditions under which the material was precipitated and also possibly due to variations in the material at source. Minute quantities of hydrocarbons (Genis 1961) and micro-fossils(Harrington and Cilliers, 1963, p.411-417) suggest that precipitation was influenced by chemical and bio-chemical activity. There are numerous papers describing iron formations in detail. A paper by James (1966) dealing with the chemistry of iron rich sedimentary rocks, contains a comprehensive list of references. The reader is referred to this paper.

C. INTRUSIVE ROCKS

One diabase sill has intruded into the ironstone formation in the Bewaarkloof and surrounding area. The sill has an average thickness of 15 metres and is found to occur 18 metres above the Main Shale Marker and shows no transgression.

Numerous veins of quartz, siderite and calcite up to several inches thick are present in the ironstone. These veins are formed along joints, faults and tension fractures, and occassionally are found developed in cymoid curve fashion and as lenticular layers parallel to the bedding planes.

D. STRUCTURAL GEOLOGY

1. General

The structural investigation was based on outcrops and underground work, and measurements were plotted on a topographical map with 25 feet (7,5 metre) contour intervals, to a scale of 1 inch to 300 feet (approx. 1.0 cm to 36 metres). An attempt was made to analyse the overall structure of the area. The terminology used in this thesis is based on that used by De Sitter (1956, 1964), Weiss (1958) and Ramsay (1958, 1962 a and b).

For the purpose of structural analyses, the area was sub-divided into 21 squares, each being 2000 x 2000 feet in extent (approx. 610 x 610 metres) and each treated separately. This method makes it possible to obtain a clear picture of the orientation of the various structural elements in each small area, and to determine their variation from area to area.

2. Bedding

In the banded ironstone the compositional banding is very well developed, giving the rock a "striped" appearance.

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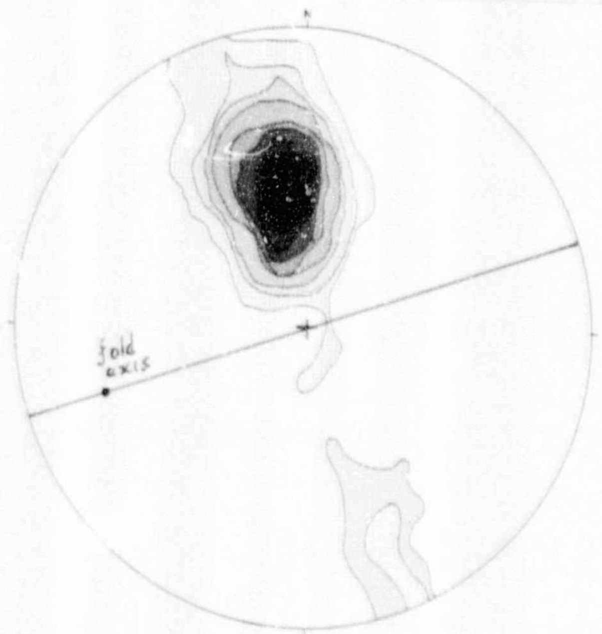
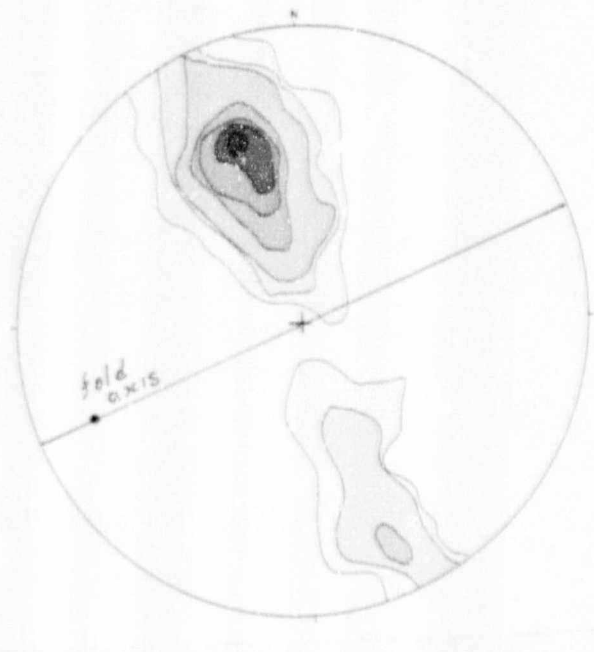


Western Section Synoptic diagram of Pye bedding plane plots. Total of 250 measurements at 1%, 2%, 3% 4%, 6%, 8%, 10%, 12% and 14% intervals.



Eastern Section Synoptic diagram of Pye bedding plane plots. Total 260 measurements at 1%, 2%, 3%, 6%, 8%, 10% and 12% intervals.

Fig. 11