Submission of MSc Thesis. A.T. Champion
to the University of Natal

Declaration

I the undersigned, Alfred Timothy Champion, do hereby declare that this dissertation comprises original work and that it has not been submitted to any other university or institution for purposes of obtaining a degree.

signed A.T. Champion.

THE MINERALOGY AND RELATED GEOLOGY OF THE ALBERT SILVER MINE

BRONKHORSTSPRUIT - TRANSVAAL

by ALFRED TIMOTHY CHAMPION

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A B S T R A C T

The Albert Silver Mine is situated on the farm Roodepoortjie, 32 kilometres north of Bronkhorstspruit in the Transvaal.

The deposit forms the largest of a number of sub-parallel quartz-hematite lodes accompanied by sulphide mineralization and is accompanied by an extensive alteration zone along its northern flank.

The trend of emplacement is as vertical bodies along east-west striking shear planes.

This investigation suggests that the intensity of shearing and accompanying mineralization has been influenced by structural dissimilarities in the granite country rock. The major ore assemblage of both hypogene and supergene origin in paragenetic sequence is magnetite, specularite, pitchblende, arsenopyrite, pyrite, sphalerite, galena, chalcopyrite, tetrahedrite, bornite, sulphantimonides, secondary malachite, bornite, azurite, metazeunerite. The hypogene minerals have been introduced into the lode along a number of parallel shear planes developed by a series of successive displacements along the lode.

There is evidence for the local zonation of the ore minerals as well as for the alteration zone which displays a number of characteristic stages of alteration. Mineralogical and chemical evidence support the fact that the western portion of the body has undergone extensive supergene enrichment due to the extensive nature of fracturing in this area as well as the close proximity of the Moos River.

Silver values which are highest in the western sector of the lode are attributable partly to secondary native silver and partly to silver bearing sulphides of low tenor of hypogene origin. Uranium mineralization appears to be related to the quartz-hematite phase of the mineralization and is accompanied by purple fluorite. Uranium anomalies may be related to a high calcium content in the wallrock. The rare secondary uranium mineral metazeunerite has been found in the uppermost portion of the oxidized zone at surface and is described for the first time from South Africa. The ore body has been classified as being of the hydrothermal suite, mesothermal type.

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> "Besides, what we are pleased to call the riches of a mine, are riches relatively to a distinction which nature does not recognize. The spars and veinstones which are thrown out in the rubbish of our mines, may be as precious in the eyes of nature, as conducive to the great object of her economy, and are certainly as characteristic of mineral veins, as the ores of silver or gold, to which we attach so great a value".
>
> John Playfair, 1802.

1. INTRODUCTION.

The Albert Silver Mine is situated approximately 32 kilometres north of Bronkhorstspruit, Transvaal on the farm Roodepoortjie 250 JR (see map). The ore deposit was first discovered in 1885 and was worked intermittently until about 1910. Evidence in the form of old prospecting pits shows that the minor bodies to the north of the Albert lode were also prospected for silver. The old workings took the form of two development drives along the strike of the lode at the 23 metre and 47 metre levels below surface together with a number of raises and winzes which passed into the alteration zone.

In 1952 the Anglo American Corporation drilled four inclined boreholes into the body in an attempt to assess the silver grade at depth. Further work on the body was carried out by J.S. van Zijl who made it the subject of a geophysical and geochemical survey (Geol. Survey Bull 43). His findings established that the body had an eastward extension. Over the period July 1967 to March 1969 the Anglo American Corporation embarked on an intensive investigation of the Albert Lode. Twentysix inclined and deflected boreholes were drilled into the ore body which was also trenched on the surface (see map). Percussion boreholes were also drilled into the lode in an attempt to assess the silver values near the surface. Although the investigation proved that the body contained silver in economic quantities over a limited area, extractive metallurgical tests showed disappointingly low silver recoveries.

The present study was undertaken at the instigation of Dr. H.C.M. Whiteside and Dr. E.S. Antrobus of the Anglo American Corporation in an attempt to resolve the nature of silver and uranium mineralization in the mine. The second most important objective in mind was to determine the nature and distribution of the ore assemblages for the mine and also to try and provide a correlation between ore assemblages and wallrock alteration. In addition a study was made of the supergene enrichment which has taken place in the body in an attempt to provide some information as to its bearing on the concentrations of silver in the body.

The thesis is based on the results of numerous chemical analyses of selected samples of both the ore zone and the alteration zone as well as on the results of the examination of 120 polished as well as a considerable number of thin sections. The samples analysed were selected after all the available borehole cores had been logged and a detailed programme of investigation had been worked out.

Although much of the work is based on samples taken from the 50 and 60 metre levels of intersection of the lode, additional information as to the nature of mineralization as well as of the structure was obtained from the study of samples taken from two borehole deflections which intersected the ore lode at depth of approximately 130 metres.

It is hoped that the sequence of presentation of data as outlined in the table of contents will provide a clear idea of the nature and sequence of events which took place during the formation of the ore body.

It is interesting to record that the occurrence of the secondary uranium mineral metazeunerite has been described for the first time from South Africa. Due to its rarity throughout the world accurate X-ray as well as optical data have been provided for the mineral

2. TOPOGRAPHY AND DRAINAGE.

The mine is situated in mature granite type topography the surface of which consists of rounded slopes separated by the courses of a number of perennial tributaries of the Moos River.

The overall relief of the area is less than 30 metres while the uniformity of the topography can be attributed to the homogeneity of the underlying granite. The soil cover is coarse, loamy and granitic and due to its acidity it is not very well suited to agriculture.

The soil cover is shallow and interspersed by frequent outcrops of granite.

The Moos River crosses the farm Roodepoortjie from south-west to north-east in a series of broad sinuous meanders and is fed by a number of perennial small tributaries which meet it at right angles.

3. GENERAL GEOLOGY./...

3. GENERAL GEOLOGY.

(refer to Map)

The mine lies within the south eastern flank of the granite phase of the Bushveld Igneous Complex.

The granite is mainly a pink porphyritic variety and is either coarse or fine grained, corresponding to the Bobbejaankop and Lease granite phases respectively. The two varieties appear to occur in patches throughout the area and are interbanded in places. In addition a few small patches of a medium grained grey granite were also encountered in the immediate vicinity of the mine.

Quartz-hematite and quartz veins are found throughout the entire area as well as to the south and to the north of Roodepoortjie. All the veins strike roughly east-west and can usually be located as hard red-brown gossan like outcroppings across farm tracks.

A large diabase dike traverses the area from south-east to north-west cutting through both the Albert lode and the minor intermediate lodes north of it. The eastern sector of the Albert lode is displaced north relative to the western sector along the divide formed by the dike which has a number of offshoots into the lode which have only been observed below groundlevel.

The lodes on the farm Roodepoortjie comprise the Albert lode in the south which, for convenience, has been arbitrarily divided into a western and an eastern sector by the line formed by the north-south dike. In addition to the Albert lode are the minor intermediate lodes and Northern lode which has a high uranium-hematite content.

Apart from the Albert lode none of the other bodies possess wallrock alteration zones of any magnitude. The relatively limited alteration zone along the southern flank of the Albert lode considered in conjunction with the pronounced shearing encountered in this lode, suggests that the lode abuts on an east-west fault on its southern flank which resulted in the erosion of part of the alteration zone during and after displacement.

4. STRUCTURE AND MODE OF EMPLACEMENT./...

4. STRUCTURE AND MODE OF EMPLACEMENT.

4.1. Overall Disposition and Structure of the Lodes.

The quartz-hematite ore bodies bounded by the Northern lode in the north and the Albert Lode in the south show a general tendency to strike in a direction ranging from east to south-east.

The bodies are generally continuous throughout the length of strike, parallel to one another, and can be easily followed over the hard rocky surface. The intermediate bodies between the North and Albert Lodes show some branching and are often interconnected with one another (see geological map-.

At the surface very little can be seen of the ore bodies but it can be assumed that the minor lodes conform to the structure which has been proved by drilling for the Northern and Albert Lodes.

The minor, intermediate lodes which appear as slightly raised dark brown gossam cappings or as white quartzose veins due to differential weathering do not stand out with any marked relief but show up best where traversed by farm paths.

The Albert lode crops out most prominently in the immediate vicinity of the Moos River where it stands out as a resistant barrier to erosion when compared with the altered granite along its northern flank. Along the southern flank of the ore body the lode rises only about 0.3 metres above the general surface level, however, on the northern flank overlooking the river, the lode which consists predominantly of quartz and hematite rises to over two metres above the granite of the flanking alteration zone which has been greatly weathered and eroded away by the action of the nearby river.

The lode continues as a prominent, slightly projecting body over a distance of about 150 metres east and 50 metres west of the river. To the west the ore body splits into a number of closely spaced hematite and quartz-hematite veins separated by screens of altered country rock. The western extremity of the body is not very prominently exposed but the minor veins are easily located due to the rocky nature of the steep slope leading down to the river. Some of the many barren cross cutting quartz veins which traverse the area are well exposed in this area. These bodies are coarsely crystalline and

probably./...

probably related to the transverse dislocations which have been proved to have occurred at a stage subsequent to mineralization.

Photo No. 1. View of the outcrop of the Albert lode in the vicinity of the Moos River showing the height of the lode above the surrounding surface due to its resistance to erosion by the river. Foreground - altered granite. View facing south-west, No. 1 Shaft in background.

Photo No. 2. A barren, coarse grained sutured quartz vein~~s~~ crosscutting the western extremities of the Albert lode.

The cross cutting veins consist of successive paired layers of coarse grained quartz which give the rock a sutured appearance. The growth layers terminate at the centre of each vein along an irregular, sometimes partially open median plane. The layers probably represent the sequential stages of crystallization of barren quartz out of solution along the walls of the vein. It is significant that these veins should be very abundant in the western extremities of the lode as this portion of the body becomes progressively more quartz rich.

East of No. 1 shaft the lode continues for 200 metres as a prominent ridge which gradually decreases in height becoming less and less significant further away from the river although it can still be traced on the surface.

Photo No. 3. View of the Albert lode from the river facing south east. No. 2 shaft immediately to the left of the large tree.

Re-orientation of numerous sections of borehole core containing veins of quartz or hematite or quartz and sulphides show that the body possesses a near vertical dip with small variations up to 5 degrees occurring throughout the length of the lodes.

The overall impression gained is that the bodies, including the inner intermediate lodes, are series of subparallel near vertically dipping lodes which vary little in width with depth.

4.2. Localization of Lodes./...

4.2. Localization of Lodes.

4.2.1. Structural Analysis.

Hulin (1948) has pointed out that the most important control mineralization is the necessary presence of permeable channels cutting the rock body. He also points out that these channels are almost entirely of fault origin and that for mineralization of any importance these permeable openings must be maintained lest the process of mineralization ceases due to the sealing at the channels. He quotes the universality of both recurrent fracturing and of brecciation in both barren and ore-bearing veins. The mode of genesis of the Albert ore lode and minor associated bodies bear out all these principles.

The structural analysis of the lode is based upon a detailed log of all the core available. During the logging which also involved detailed sampling, a record was made of the extent of shearing, the extent and nature of mineralization and also of the variations in the type of granite present in each borehole section.

In essence the ore lodes appear to be emplaced along intensely sheared zones in the host granite which has undergone a number of periods of shearing accompanied in each instance by a new period of ore mineralization. The results of a correlation made between the intensity of shearing, extent of mineralization and type of host granite found adjacent to the lodes is presented in figure 5. This data represents an attempt to explain the localization of mineralization in certain portions of the granite with a view to finding out whether the ore bodies have been emplaced in their present positions as the result of any form of textural and hence structural dissimilarities which exist between the two granitic types.

Emmons (1948) cites ore shoot localization as being dependant on many factors such as the presence of zones of brittle, easily fractured rock, faults, etc. etc. However, the localization of mineralization along the zones defined by the Albert and Northern lodes can be shown to be dependant on a more fundamental physical property of the host rock, namely the textural dissimiliarity which exists between masses of the adjoining host rock. The contact acts as a plane of weakness or disjuncture when subjected to severe tectonic forces. The

two./...

two most abundant host rocks are the coarse- and the fine-grained pink porphyritic Bushveld granites which show either gradations or sharp contacts one to another over the entire area. From Fig. 5 the most obvious relationship which imerges is that the heaviest mineralization and greatest extent of shearing coincide with the junctures between granites which are texturally dissimilar. This is most apparent in sections 5, 14, 17, 26 and to a lesser degree in sections 27 and 8 (Northern Lode) (fig. 5). In all these instances the mineralized zone contains bands of massive hematite or sulphide ores.

Both the Albert and Northern Lode are continuous over their lengths and thus also transect areas of homogeneously textured granite. In these localities the ore-body becomes separated into a number of narrow veins alternating with screens of country rock as for example those parts of the body intersected by boreholes 6, 12, 13 and to a lesser degree that in borehole 15 in which mineralization occurs along very numerous sub-parallel shear planes. It appears that the most intense shearing is confined to relatively narrow zones between the two dissimilar granite types. As a consequence of the severity of shearing these areas were the most permeable to mineralization and thus contain massive ores. There exists no zone of preferential weakness in the areas of homogeneous granite. Consequently the relief of stress in these areas was accomplished by the development of a number of non-preferential dislocations separated by screens of country rock which often show extensive microscopic fracturing.

It is to be noted that where the term shearing is used this also implies a degree of tension and hence dilation due to the fact that a component of stress applied to a body can usually be resolved into two components. This will be more fully discussed in the following section and under the section dealing with mode of emplacement.

4.2.2. Nature of the Shearing.

Before the results of a detailed examination of the structural features based on the above analysis is presented, it is felt that it is appropriate at this stage to include a more detailed description of the nature of the shearing in the ore zones.

The country./...

The country rock for some distance from the lodes is fractured along east-west trenching shear planes. The fractures usually take the form of multiple parallel vertical shear planes which visually show a relative displacement of less than 5 mm (measured using the disrupted halves of plagioclase phenocrysts).

As the ore zones are approached the amount of shearing increases and within the actual ore zone it is intense, the movements probably having resulted from shearing, possibly accompanied by a very minor tensional component. Narrow zones of gouge as well as angular brecciated rock are numerous, the brecciated material occasionally being mineralized. Slickensiding is also encountered on many surfaces.

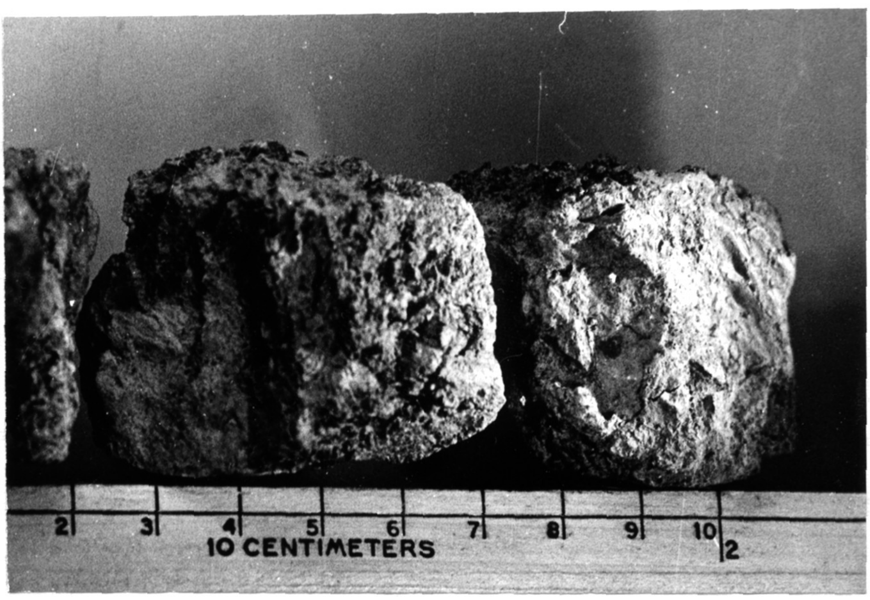


Photo No. 4. Finely comminuted, unmineralized rock gouge whose composition shows it is composed of altered granite.

From the tabulation presented by Farmin (1941) it would appear that the presence of the abovementioned structures indicate that the ore zones were subject to a moderate amount of static load which resulted in a movement along the shear planes in which the component of shear was very much greater than the tensional component. Although the latter component probably did exist, albeit to a minor extent, a radically different mechanism must be called for to explain the great width of hematite emplaced along the lode although it is still possible that the thin sulphide veins were emplaced along open spaces created partially by a tensional component during displacement.

Mechanisms./...

Mechanisms will be more fully discussed in section 4.~~5~~4.

4.2.3. Detailed Structural Analysis.

In the succeeding section the physical structure of the mineralized lode is described in detail. Correlations between mineralization and host rock texture are based on the conclusions arrived at in the analysis presented in Fig. 5.

i) Western Sector of the Lode.

West of the north-south diabase dike the ore zone is relatively massive. From figure 5 it can also be seen that this section of the ore body is bounded dominantly by dissimilar granite types. Concomittant with the heavy mineralization, the wall rock alteration zone of this portion of the body is also widest (fig. 3) attaining a maximum width of 20 metres between boreholes 14 and 6.

Toward the westernmost extremities of the body the host granite consists of bands of coarse and fine-grained granite. The contacts between these bands have acted as parting planes during dislocation and in consequence the lode consists of comparitively narrow veins separated by dissimilarly textured screens of country rock. These ore veins attain a thickness of up to 2 metres and are cut by veins of younger sulphides.

The massive ore often contains a dissemination of finely brecciated granite and for this reason it is possible to speculate that emplacement was in part due to open space filling.

ii) Eastern Sector of the Lode.

Shearing and ore mineralization both decrease in extent eastwards along the ore body (fig. 5) as well as the extent of wallrock alteration (see fig. 3).

The section of the lode intersected in borehole 17 is highly sheared, heavily mineralized, and occurs between two dissimilar granite types, as well as containing a high proportion of sulphide veins. In contrast the deflection borehole which intersected the lode at 160 metres, immediately below the intersection made by borehole 17, shows that the physical structure of the lode varies with depth. At this depth the lode in this section consists of massive sulphide veins along shear zones through veins of earlier hematite.

Further east both the intensity of shearing, the degree of mineralization and the degree of dissimilarity between the granite types decreases.

As a result the ore lode consists of narrow bands of massive ore separated by screens of altered country rock. This deconcentration of shearing with consequent production of a number of minor sheared, mineralized planes could be postulated to have a direct correlation with the host rock texture which in this case is homogeneous and has thus not separated as a major shear along any specific plane of weakness. A striking exception to this generalization is provided by borehole 5 which is highly mineralized by massive sulphides and hematite. The host rock adjoining the lode is intensely sheared and the alteration zone is marginally wider in this section (fig. 3) besides which it is interesting to note that in this section the zone of shearing occupied by the lode lies along the contact between dissimilar bodies of fine grained and coarse grained pink porphyritic granite.

iii) Northern Lode.

The analysis of the Northern Lode is included in figure 5 but as insufficient data could be gathered for this body it serves merely as a comparison with the Albert Lode.

In conclusion it must be stated that it is felt that the correlation which appears to exist between localization of ore and granite types could possibly be applied in the routine geological development if the body were to be exploited.

4.3. Periods and Extent of Displacement-Albert Lode

From a study of the crosscutting relationships of successively younger ore veins accompanied by the data derived from the microscopic study of the ore minerals in polished section it appears that ore mineralization has accompanied a series of successive displacements along the lode. In some cases the resultant shear zones have been infilled with barren quartz.

Using the disrupted and relatively displaced portions of feldspar phenocrysts as markers, the amount of displacement along many of the vertical, mineralized as well as unmineralized, veins was measured and found to be not much more than 0.75 cm. Besides predominantly vertical displacement at least one instance of late stage transverse shear has occurred. This is indicated by the occurrence of irregular slickensided shear planes in which the slickensiding runs transverse to the long axis of borehole core and in doing so also obliquely intersects a number of late stage barren vertical calcite veins at an angle of approximately 30 degrees (see Photo No. 5).

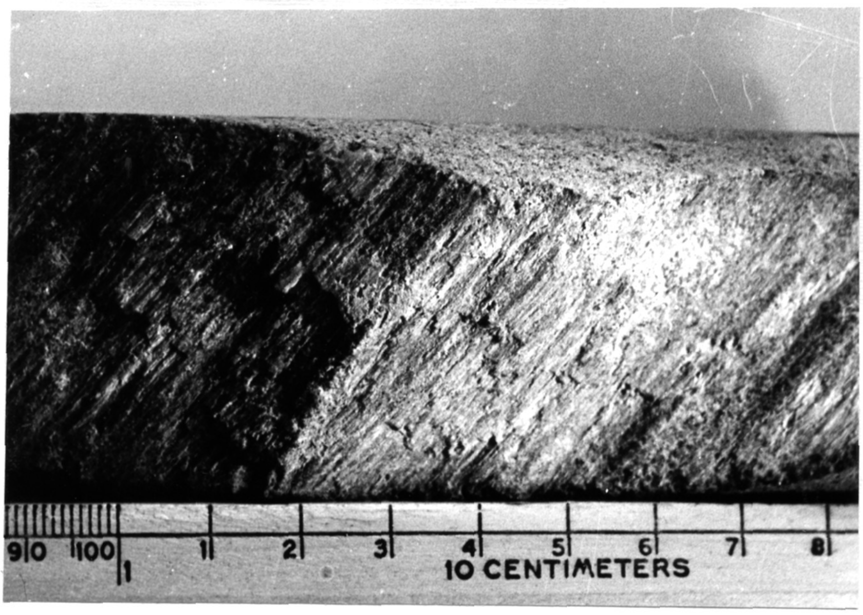


Photo No. 5. Tranversely sheared slickensided granite.

The first major period of shearing was probably followed by the introduction of hematite and quartz which may have been preceded by the introduction of magnetite at depth as is suggested by the abundant instances of martitized magnetite in the central portion of the lode. Renewed dislocation followed along approximately the same zone as that of the first period and disrupted both the hematite and the adjacent altered wallrock. The earliest sulphides arsenopyrite and pyrite were introduced into these fractures. Post hematite movement is also indicated by the occurrence of re-cemented hematite breccia in borehole 7. Veins of later sulphides such as chalcopyrite, sphalerite and galena containing fragments of hematite as well as pyrite and arsenopyrite indicate that a further period of dislocation ensued. A later period of shearing post dating the diabase intrusion has sheared the diabase which appears to be unmineralized except for calcite, quartz and a small quantity of pyrite (see section on intrusives).

The occurrence./...

The occurrence of multiple fractures and unmineralized shear zones, often slickensided, would tend to indicate that movement was still active after discontinuation of the mineralizing epoch.

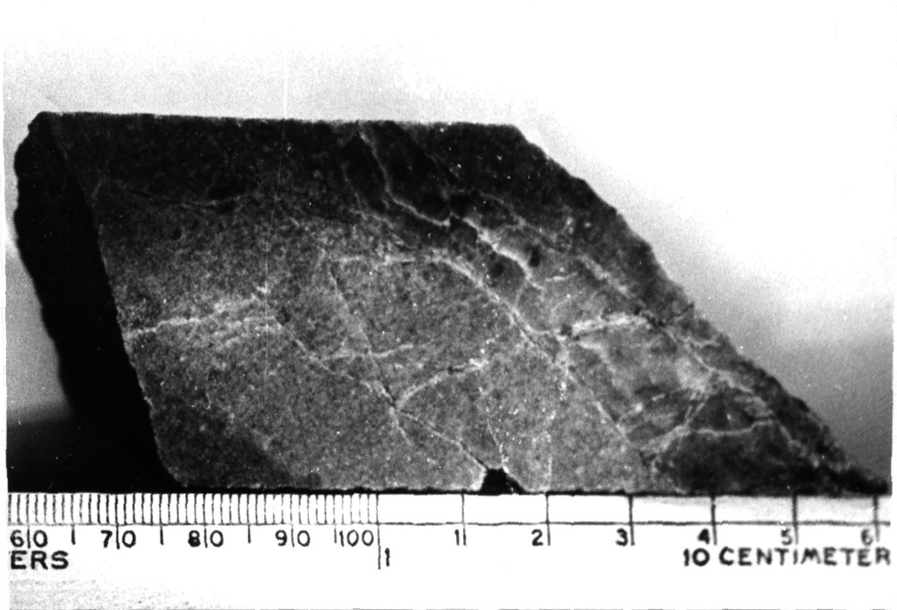


Photo No. 6. A section of altered granite cut by a quartz filled vein showing extensive post mineralization fracturing

4.4. Mode of Emplacement of the Ores.

The purpose of this section is to define the type of emplacement which has taken place in the lodes in the light of the structural evidence presented in the preceding sections.

The extensive width of the hematite in the western sector of the lode makes it speculative that the first period of displacement was possibly a lateral movement which, considered in conjunction with the slight change in strike evident along the body in the region of borehole 15 could have been responsible for an extensive opening in the western sector of the lode. This effect of displacement along a fault which shows a change in strike is discussed by Emmons (1948) who states that the width of the resultant opening would depend on the angle of deflection, i.e. the difference between the bearings of the strike along the lode (in degrees) and the amount of fault movement. The width of the opening which would have been amenable to open space type filling by hematite can be theoretically related to these

measurements./...

measurements by

$$\text{Sin a} = \frac{\text{width of opening}}{\text{displacement along the fault.}}$$

where a = difference in strike angle. Hulin (1929) in his paper on the Sunnyside mine, Silverton, Colorado and Lovering in his paper on Montezuma, Colorado (1955) both cite the effects of changes of strike in forming ore shoots.

More evidence for open space filling is shown by the sulphide minerals which are almost all emplaced along thin vertical shear veins which are seldom greater than 1 cm wide. A slight amount of mineralization by replacement has also occurred in the altered wallrock immediately adjacent to the ore lode where hematite and sulphides are found interstitial to the primary components of the wallrock. In addition a number of sulphide bearing veins were found which were not completely filled with ore but were lined by euhedra of pyrite, galena, chalcopyrite more than likely deposited by open space filling out of the ore solutions flowing along the shear planes.

5. CHEMICAL VARIATIONS.

5.1. Discussion and Methods of Analysis.

The prime objective in carrying out chemical analyses on rock representative of the main ore zone in each borehole has been to provide an accurate picture of the relative distribution of the major elements throughout the orebody. In addition these results have been used in a correlation with the types of ore assemblages present. The results have also been used in conjunction with the results of the ore study to provide a correlation with the wallrock alteration zone. The results which are graphically presented in figure 4 are also to be found in Table No. 4.

For the purposes of this study the main ore zone is defined as being that portion of the lode which consists of massive quartz-hematite ore and sulphides. The main ore zone as defined also contains screens of altered mineralized country rock and is generally highly sheared. Fractions representative of the whole intersection of the ore zone in each particular borehole were obtained for the analysis by splitting the relevant borehole core in two, one half being retained for structural analysis and ore microscopy while

the balance./...

the balance representing the entire intersection of the ore zone was pulverized, coned and quartered in order to obtain a representative fraction for chemical analysis. This material was analysed for copper, lead and zinc using the atomic absorption technique while the silver content was determined by fire assay and fusion. The uranium content was determined by radiometric analysis against an internal standard and has been reported as U_3O_8.

5.2. Interpretation of Results.

Variations of the Major Elements - 60 metre level - Albert Lode.

i) Iron Content.

Although the total iron content was not determined for the various sections of the lode it was felt necessary to include some sort of data so that the distribution of the elements Cu, Zn, Pb, Ag and U_3O_8 could be compared relative to iron. An idea of the relative iron content can be had from figure 2 in which the total width of quartz-hematite has been presented for each section analysed for copper, lead, zinc, silver and uranium. Although figure 2 only gives a comparison of the total iron content relative to the number of sulphide veins the total true width of the ore body at various points along the lode is given later in section 6.3. To further aid in the comparison the number of significant sulphide veins present in the intersection was plotted on the same diagram.

From figure 2 it can be seen that the iron content, in the form of iron oxides, is greatest for the western sector of the lode. The iron content of this sector reaches a maximum in the area between boreholes 14 and 15. In the eastern sector iron decreases radically along the lode while the sulphides show a proportionate increase in percentage.

ii) Uranium.

Uranium values are significantly higher along the western sector of the lode with two maxima (in boreholes 14 and 15 respectively). The decrease in uranium content between boreholes 14 and 26 is thought to be due to the leaching action of the overlying Moos River. The uranium content tails off sharply eastwards along the lode and overall appears to show a correlation with the iron content of the lode which possesses a

similar./...

similar trend. Everhart and Wright (1953) believe hematite to be a definite indication of uranium mineralization in some pitchblende deposits.

At depth the uranium values tend to decrease.

iii) Lead.

Lead in the form of galena appears to be most abundant in the eastern sector of the lode in the vicinity of borehole 18. It is significant that lead and silver mineralization, at least at the 60 metre level, do not show any coincidence.

iv) Copper.

This element shows a similar trend to lead increasing in the eastern sector of the lode. This can be attributed to the abundance of chalcopyrite intergrown with the galena along this section (see fig. 9).

v) Zinc.

Zinc in the form of sphalerite occurs in small but significant quantities throughout the lode. There is accordingly little variation in the zinc content throughout the lode excepting in the extreme eastern portions of the lode where high zinc content in borehole 19 is reflected by the abundant sphalerite found in this section (fig. 11).

vi) Silver.

The highest silver values in the lode at the 60 metre level are those along the western sector of the lode. In a fashion similar to uranium the silver values for this sector are lowest in the sector below the Moos River. This is taken to be evidence that the river has been responsible for the redistribution of soluble sulphides in this area. As far as correlative mineralogy is concerned it is enough at this stage to state that the highest silver values coincide with the occurrence of argentiferous tetrahedrite and tennantite in the body (fig. 9).

Although no analyses were performed due to an initial ignorance of their existence, it must be recorded that bismuth and antimony in the form of sulphantimonides persist from the centre of the eastern sector

into./...

into the western sector as far as borehole 6. These minerals may possibly contain a small amount of silver.

vii) Vertical Variations.

The analyses of samples of the main ore zone at depth which were taken from deflection boreholes numbers 3 and 2 show that the values recorded for copper and uranium do not show any significant increase with depth. Copper values remain more or less constant while uranium actually shows a decrease with depth in the western sector with a corresponding increase in value with depth in the eastern sector of the lode. The values for zinc ore distinctly higher in boreholes 2 and 3 showing that there is just a possibility that some vertical zonation may be present with more abundant sphalerite at depth. Since however the values have been obtained from just two intersections very much more information on values would have to be obtained before such a relationship could be established. Although silver values in borehole 2 are very high, when viewed in the light of later work these can be explained as being due to secondary enrichment.

The above results have also been used in the sections on wallrock alteration and ore assemblages as well as in the section on copper, lead, zinc ratios.

6. ORE MINERALOGY.

6.1. Discussion.

Treatment of this most important section of the investigation has necessitated dividing it into two major sub-sections. The first division deals with descriptions of the major ore minerals and their typical modes of occurrence, distribution and inter-relationships within the orebody as a whole.

In the second section an attempt has been made to compile a fairly comprehensive list of the assemblages present in the different sections through the body. This section is neatly summed up in figure 9 which has been included in the hope that it will give an easily comprehended picture of the distribution of the major primary ore minerals in the lode for the 60 metre level.

Methods./...

Methods.

The mineralogical study of the ores and their identification is to a large extent based on a detailed study of polished sections of the ore minerals. The samples examined were selected from borehole core from a number of boreholes (marked on the map) intersecting the Albert Lode at an average depth of 55 metres below the surface. An idea of the type of mineralization which is to be expected at greater depth is given by the samples obtained from two borehole deflections which intersected the lode at depths of 120 and 160 metres respectively. Most of the polished sections were cut perpendicular to the sulphide veins in order to show up the ore inter-relationships to their best advantage. In all 127 polished sections were examined from 12 borehole intersections along the strike of the Albert Lode.

It is to be born in mind that the distribution of the sulphide ores as given in fig. 9 is not necessarily accurate as the sulphide veins intersected in each borehole may be inconsistent in their distribution. Most of the mineral identifications have been confirmed by either X-ray powder diffraction or by X-ray powder camera photography while many identifications were rapidly verified during the course of the examination by carrying out an elemental analysis on small quantities of material using a Philips X-ray spectrograph.

6.2. The Major Ore Minerals.

In this section the major ore minerals are described in detail giving their typical mode of occurrence, distribution, inter-relationships with other minerals, identificatory characteristics and gangue mineral associations. The relatively minor ore minerals present such as neodigenite, argentite, tennantite are also briefly described.

Hematite - Fe_2O_3.

Specular hematite accompanied by quartz is the predominant ore mineral of the Albert, intermediate and northern lodes. This investigation bears out the fact that the quartz-hematite is of hypogene origin, this conforms to the wide distribution of hydrothermal hematite bodies throughout the Bushveld province. In addition, the fact that the hematite is a massive

unaltered./...

unaltered specular variety at depths of 120 metres, below the zone of supergene alteration further supports a hypogene origin for the hematite. This view was not held by van Zijl who has stated that "specularite and hematite represent the oxidized portions of the lode". He further states that the hematite is an alteration product of pyrite and that hypogene pyrite is rarely found, except as inclusions in chalcopyrite. This view has also proven to be incorrect as many instances of massive pyrite-arsenopyrite-quartz veins are encountered in the lode which often contain an entrainment of earlier brecciated hematite fragments. The ore constitutes an early phase in the paragenesis of the body and subsequent to its emplacement along multiple shear planes in the Bushveld granite it has itself been dislocated and cut through by numerous discrete and compound sulphide veins. At the surface the hematite is extensively altered to red-brown limonite, this effect extending to depth into the body in the vicinity of the Moos River. The distribution of hematite is also responsible for a larger part of the wallrock alteration accompanying the lode and in addition it forms a repository for uranium and secondary silver.

In polished section the ore is platy and consists of tightly intergrown hematite lamellae. The mineral is easily distinguished by its superior hardness, steely blue colour and metallic lustre and often by its bad polishing characteristics and cherry red internal reflections.

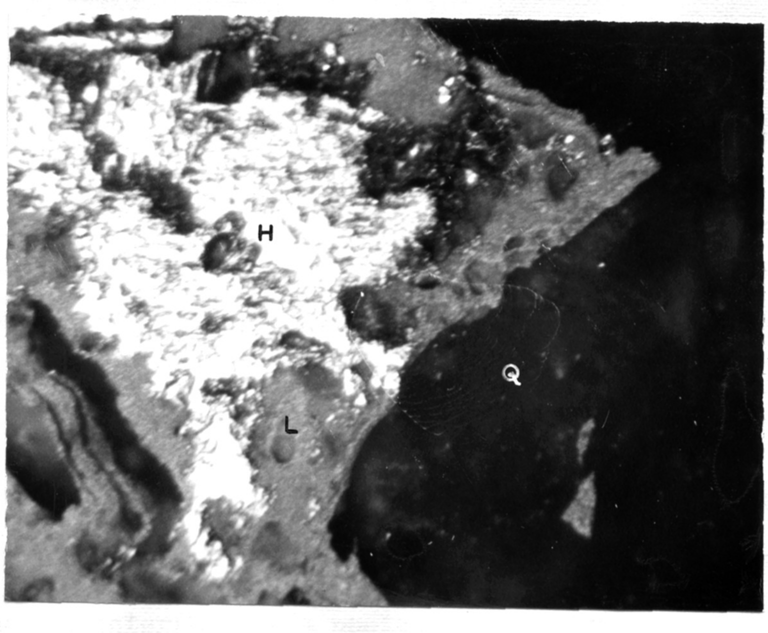


Photo No. 7. Specular hematite (H) intergrown with quartz (Q) and now extensively replaced by secondary limonite (L) which preserves the original outline of the mineral.
Plane polarised light. X 900 magnification.

The hematite./...

The hematite occurs in intimate intergrowth with quartz which usually occurs as large interconnected patches and which possesses a scalloped margin. Quartz also occurs interstitial to the hematite plates.

Due to post-emplacement fracturing the hematite is often irregularly fractured, these fractures are usually limonitized or filled with secondary quartz. While the hematite of the western sector is singularly free of inclusions of earlier formed minerals, abundant subhedral magnetite is found included in the hematite in the eastern sector of the lode. The magnetite is softer than the hematite and is pinkish brown in colour, X-ray spectrography confirming that it is titaniferous in composition. The mineral is often heavily replaced by hematite and is reduced to rows and clusters of small irregular blebs in the hematite while individual grains often have a hematite mantle. This process of replacement of magnetite by hematite is termed martitization. (see photo).

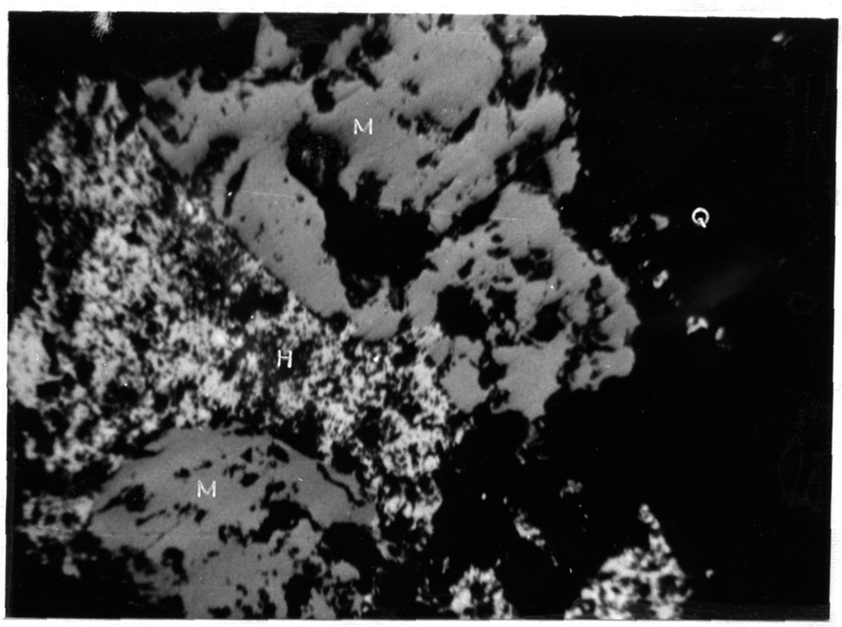


Photo No. 8. The process of martitization showing pleochroic specular hematite (H) and quartz (Q) replacing earlier titano-magnetite in the central sector of the lode. Plane polarized light. X 900 magnification.

Alteration of the hematite to limonite proceeds by the gradual alteration of the hematite aggregates beginning either along fracture planes or at the hematite-quartz interface (see photo).

In the western sector of the lode a second phase of hematite formation is found. This is suggested by a textural variation in the hematite which

proceeds./...

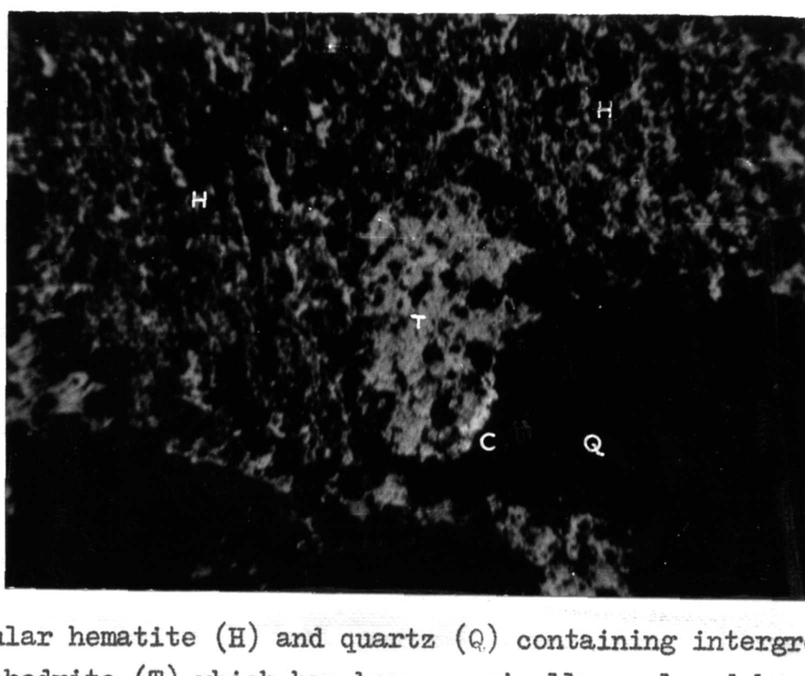
proceeds to develop as coarse grained orbs showing concentric growth structures. This mineral often envelops the earlier specularite marginally.

In the central portion of the body the hematite is frequently replaced by relatively late stage sulphides such as tetrahedrite, bornite and chalcopyrite as well as by pitchblende. The paragenetic position of the latter mineral is unsure although the frequently reported association of hematite and uranium could lead one to believe that the pitchblende phase closely followed hematite emplacement.

<u>Tetrahedrite</u> - Cu_3SbS_3 or $Cu_8Sb_2S_7$.

Tetrahedrite is almost completely confined to the western sector of the Albert Lode where it occurs as highly irregular formless masses up to 2 mm in size interstitial to specular hematite.

The mineral is easily identified by its distinctive light yellow brown colour, moderately high reflectivity and softness. The mineral has not been found in any of the sulphide bearing veins which cut through the hematite so it can be assumed that it was formed early in the paragenesis. With regard to the silver bearing ores it is interesting to consider that the occurrence of tetrahedrite and to a lesser extent, tennantite, correspond to the area of highest silver mineralization in the body. Tetrahedrite is cited as being a frequent silver bearing ore as silver, along with zinc and iron can extensively replace copper in the tetrahedrite structure. (Ramdohr).



<u>Photo No. 9</u>. Specular hematite (H) and quartz (Q) containing intergrown tetrahedrite (T) which has been marginally replaced by chalcopyrite (C) (Note:- Due to the lack of contrast between the three minerals the photograph has been stopped down to make the three phases discernible with a consequent overall darkening of of the print) Plane polarized light 900 X magnification.

Hematite./...

Hematite and tetrahedrite are both marginally replaced by bornite on many occasions and less frequently by chalcopyrite. It is possible that tetrahedrite is one of the primary silver bearing minerals in the ore lode along with tennantite, tetrahedrite-bearing galena and possibly the lead-bismuth sulphides. Although the amount of silver actually present in the body is higher than that which could be ascribed to primary mineralization by one or all of the abovementioned sulphides it has been established that the body has undergone extensive supergene enrichment which would account for the high silver values.

<u>Arsenopyrite</u> - FeAsS.

Arsenopyrite in association with pyrite is ubiquitous throughout the entire sulphide mineralized portion of the lode. The mineral usually occurs in multiple, closely spaced veins of clear quartz which cut through the older hematite.

Due to its early position in the paragenesis the arsenopyrite has been subjected to a number of subsequent periods of dislocation with the result that it is often found as irregular fragments distributed through later sulphide bearing quartz-chlorite veins (see photo). The mineral appears to be particularly abundant between boreholes 15 and 21 while the deflection of borehole 17 shows that the mineral occurs in massive veins associated with pyrite and chalcopyrite at depth.

The ore is easily recognised by its idiomorphic outline, brightly reflectant white colour and strong anisotropism, apart from the fact that it is considerably harder than most of the associated ores. The arsenopyrite also shows faint reflection pleochroism under the most favourable conditions

All variations of grain size up to a maximum of 4 mm are possible.

In most instances the arsenopyrite is found intimately intergrown with subhedral to euhedral pyrite with the two minerals sharing a common idiomorphic outline. Where the mineral has been caught up in younger sulphide veins it is often found enveloped by galena, sphalerite, chalcopyrite, siderite or by bismuth sulphides. These minerals often form veins filling the many fractures in both the arsenopyrite and the pyrite.

Photo No. 10./...

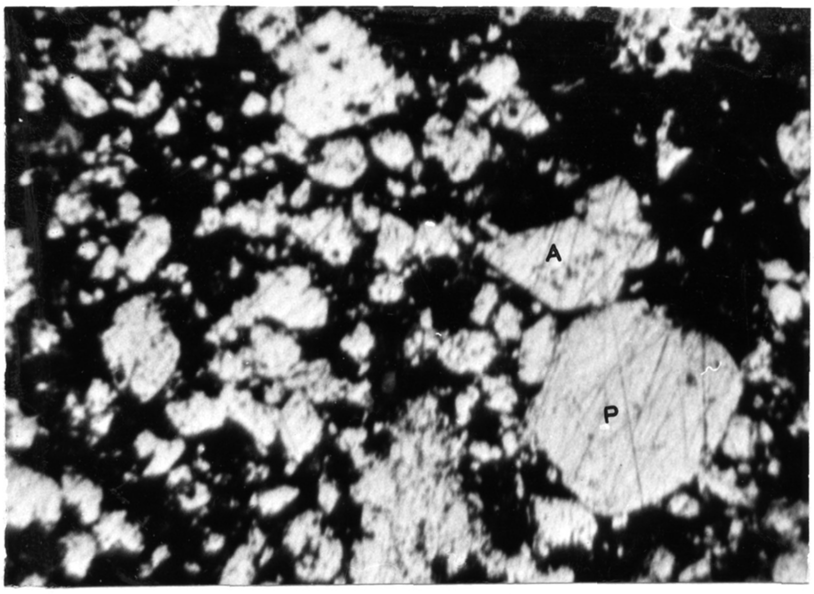


Photo No. 10. Disrupted fragments of pyrite (P) arsenopyrite (A) in a secondary quartz gangue. 900 X magnification.

Pyrite - FeS_2.

The mode of occurrence of pyrite is identical to that of arsenopyrite and the mineral is found throughout the length of the lode although it is most abundant in the central and eastern portions of the orebody where it usually predominates over arsenopyrite in any one vein.

The mineral has a size range between 0.1 mm and 3.5 mm with a typical average size being 3 mm. Like arsenopyrite, pyrite appears to be more massive at depths of 120 to 160 metres as was indicated by samples from deflection boreholes 2 and 3.

High reflectivity, yellow colour and hardness serve to identify the mineral which is often pitted due to imperfect polishing. Although the mineral is usually subhedral with rounded coigns, it shows a strong overall tendency to idiomorphism. The pyrite is associated with a clear quartz gangue occurring in vertical quartz veins cutting through the earlier hematite. Rounded, exsolution bodies which, due to their high reflectivity and intense yellow-green anisotropism were identified as marcasite are distributed through the pyrite and are generally less than 0.01 mm in size. As in the case with arsenopyrite, fractures through the pyrite are either sealed by secondary quartz or are mineralized by later sulphides such as galena,

chalcopyrite./...

chalcopyrite.

At the 120 metre level in the eastern sector of the lode the pyrite is frequently replaced by mutually intergrown bismuth sulphides and galena (see photo). Where the pyrite-arsenopyrite veins have been re-opened to mineralization by subsequent displacement movements, the minerals are found finely comminuted and fractured and accompanied by younger phases of chalcopyrite, sphalerite and galena as well as by younger sideritic gangue which possesses deep red internal reflections. Small inclusions of pyrrhotite in the pyrite have led to the suggestion that the pyrite could possibly be a deuteric alteration product of pyrrhotite.

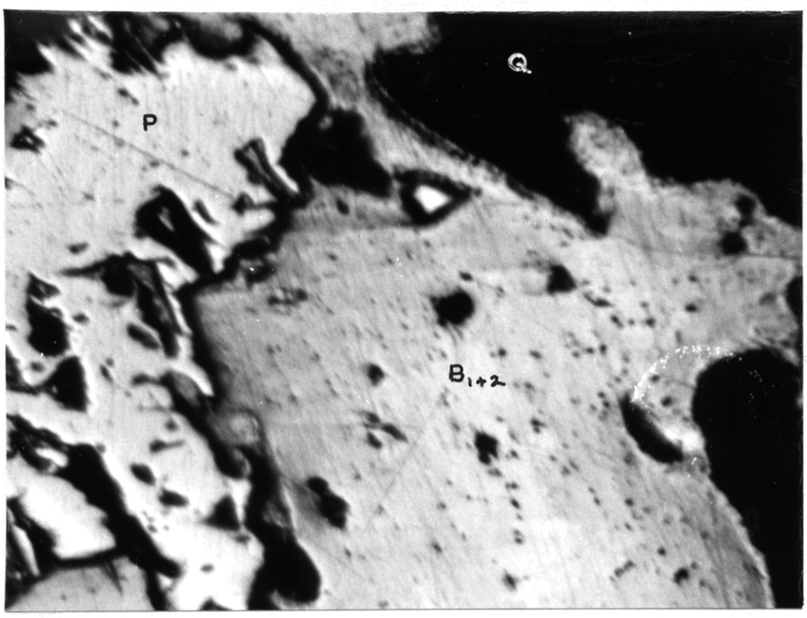


Photo No. 11. Pyrite (P) in the eastern sector of the lode being strongly replaced by softer intergrown bismuth sulphide phases (B) accompanied by quartz gangue (Q). Plane polarized light. 900 X magnification.

Chalcopyrite - $CuFeS_2$.

Varying amounts of chalcopyrite are found throughout the lode, the mineral being most abundant in the central and eastern portions of the lode where it is almost invariably accompanied by galena and sphalerite in narrow veins filled with a quartz-chlorite or quartz-chlorite-siderite gangue. Siderite is a frequent gangue associated with chalcopyrite in the eastern extensions./...

extensions of the lode.

The chalcopyrite occurs in the form of irregular shaped grains up to 3 mm in size which are often intergrown with galena. Chalcopyrite is also found disseminated through disrupted portions of the hematite and to a lesser extent, through screens of altered country rock within the lode.

Identification of the mineral is facilitated by its striking yellow colour which deepens on exposure to the atmosphere due to slight tarnishing. The mineral is relatively soft, highly reflectant and slightly anisotropic. A frequent observation is the marginal alteration of chalcopyrite to deep blue neodigenite. According to Ramdohr (1969) neodigenite formation takes place either as the result of supergene enrichment or as the result of differential pressure on the chalcopyrite where it borders on harder sulphides such as pyrite or arsenopyrite, the latter effect has been observed in specimens from the borehole 3 deflection hole.

Irregular angular inclusions of sphalerite are often found within the chalcopyrite while small elongate exsolution bodies of pyrrhotite are found exsolved out parallel to the 111 plane in the mineral. A few small (0.01 mm) subhedral blebs of cubanite were also observed in the chalcopyrite.

<u>Photo No. 12</u>. Arsenopyrite (A) enclosing older hematite (H) and in turn being replaced by intergrown chalcopyrite (C) and sideritic gangue (F).
Plane polarised light. 900 X magnification.

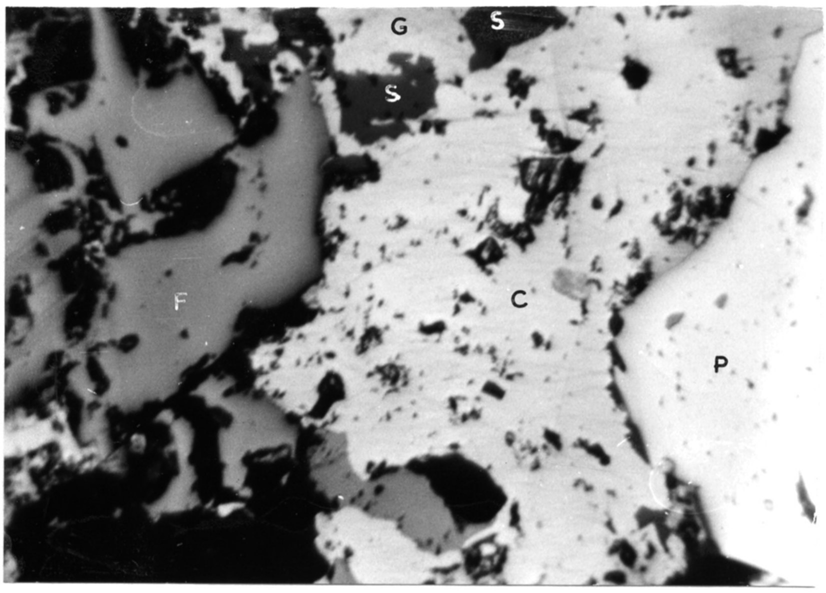


Photo No. 13. A portion of a typically reopened sulphide vein showing subhedral pyrite (P) inclusions enclosed by chalcopyrite (C) intergrown with galena and containing angular inclusions of sphalerite (S). The sulphides are interspersed by veins of quartz (black) and siderite (F).
Plane polarized light 900 X magnification.

Chalcopyrite is also found in the form of exsolution bodies in both sphalerite and bornite.

Galena - PbS.

Galena and chalcopyrite invariably occur as mutual phases in the ore lode although galena also occurs in intergrowth with bismuth sulphides and in the central sector of the lode, with bornite. The mineral is distributed throughout the entire length of the lode but is most abundant in the central sector of the lode.

The mineral is present in smaller quantities than either pyrite or arsenopyrite and has a size distribution from 0.05 to 2 mm in size. A noteable exception is the development of galena as large irregular bodies up to 6 mm in size in quartz-chlorite-calcite veins which traverse the host granite.

In polished section the mineral is easily distinguished by its white grey colour, high reflectivity, softness and characteristic triangularly pitted surface. The mineral is anhedral in shape and occurs as highly irregular bodies intergrown with chalcopyrite in quartz-chlorite gangue veins or

alternatively./.

alternatively the mineral insinuates itself between coarsely crystallized quartz gangue which gives it an irregular scalloped outline. The gangue veins containing the galena are usually cloudy with inclusions of earlier, finely comminuted ores such as hematite, aresenopyrite, pyrite and sphalerite. Purple fluorite and siderite are frequent gangue associates of galena-chalcopyrite phases. Galena often occurs in myrmekitic intergrowth with the chalcopyrite and in earlier veins re-opened to galena-chalcopyrite mineralization the two minerals frequently completely enclose subhedra of pyrite and aresenopyrite insinuating themselves along cracks and partings in these minerals. In many instances galena is found enclosing° angular subhedra of spaherite while in the eastern portion of the lode the mineral is found mutually intergrown with two separate bismuth sulphide phases. Between boreholes 15 and 26 galena is also found in mutual intergrowth with bornite (see photo under bornite).

Particular care was taken in examining occurrences of galena bearing in mind that the mineral could possibly be a silver-bearer. While no inclusions of silver-sulphide minerals could be found a number of x-ray powder diffractograms showed the presence of tetrahedrite which may possibly be an argentiferous variety, within the galena. A small amount of distinctive blue-green boulangerite is also found as rounded grains enclosing galena. This mineral is a frequent associate of silver-bearing sulphide deposits.

<u>Sphalerite</u> - (ZnS)

Sphalerite is found in association with galena, chalcopyrite and siderite along the lode. The mineral becomes increasingly abundant proceeding from west to east along the lode and is accompanied by an increasing proportion of sideritic gangue.

In the western sector of the lode the mineral is usually found as angular inclusions in chalcopyrite but is not very extensively developed as an ore, however, east of borehole 17 the mineral is found in mutual intergrowth with chalcopyrite and galena (see photo). The sphalerite is almost totally confined to sulphide veins and is only rarely encountered in disseminated form in the hematite.

The mineral is identified by its low reflectivity and reddish brown internal reflections. It is also isotropic and invariably contains small

exsolution./...

exsolution bodies of chalcopyrite. In many cases the mineral is distinctly twinned, the twin lamellae being clearly visible without etching.

The exsolution bodies are usually rounded and distributed irregularly through the sphalerite and on occasion are found exsolved parallel to cleavage lamellae in the sphalerite. It is not felt that the presence of the exsolution bodies is indicative of any specific temperature of formation. From the fact that the sphalerite is very often found as angular inclusions in the chalcopyrite and from the fact that the mineral possesses a strong outline onto which the chalcopyrite and galena are moulded it appears that sphalerite was deposited slightly earlier than galena and chalcopyrite in the paragenesis.

In many cases in the eastern part of the lode sphalerite is found replacing and enclosing earlier pyrite and arsenopyrite.

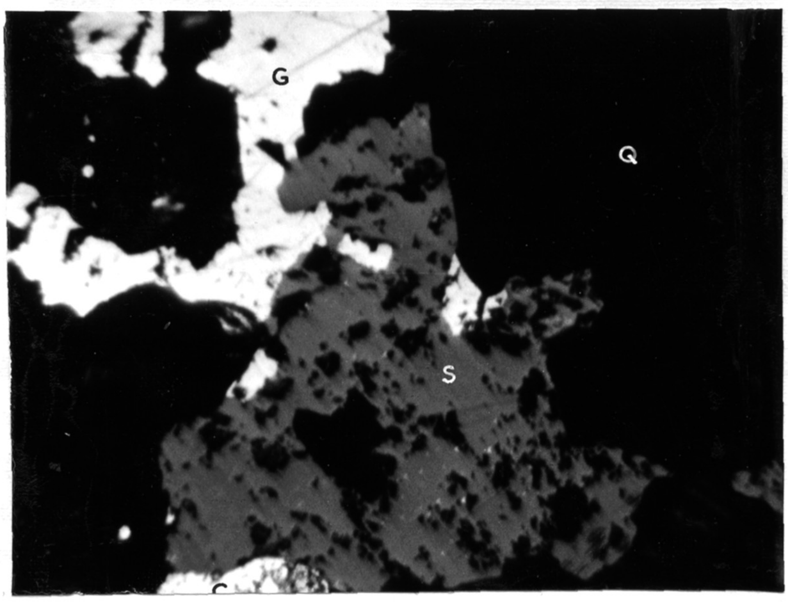


Photo No. 14. Sphalerite (S) containing minute spherical exsolution bodies of chalcopyrite (white spots) and intergrown with slightly later galena (G) and chalcopyrite (C) in a quartz (Q) siderite vein.
Plane polarized light. 900 X magnification.

Bornite - ($Cu_5 Fe S_4$)

Hypogene bornite intergrown with galena is confined to the eastern half of the western sector of the lode. The mineral is most abundant in that sector of the lode represented by borehole 15 where it occurs in association with galena in moderately thick parallel quartz veins up to 11 cm in width. The mineral is also found in disseminated form throughout much of the specularite portion of the

orebody./...

orebody.

The ore is usually brown pink in colour although wide variations in the hues are encountered in any one vein, ranging from brick red to violet red. The bornite is weakly anisotropic, soft and quickly tarnishes when exposed to the atmosphere taking on a wide variety of hues.

The mineral is intimately intergrown with galena with which it forms intricate myrmekitic intergrowths (see photo) and is accompanied by a relatively coarse grained quartz gangue with an average granularity of 1 mm.

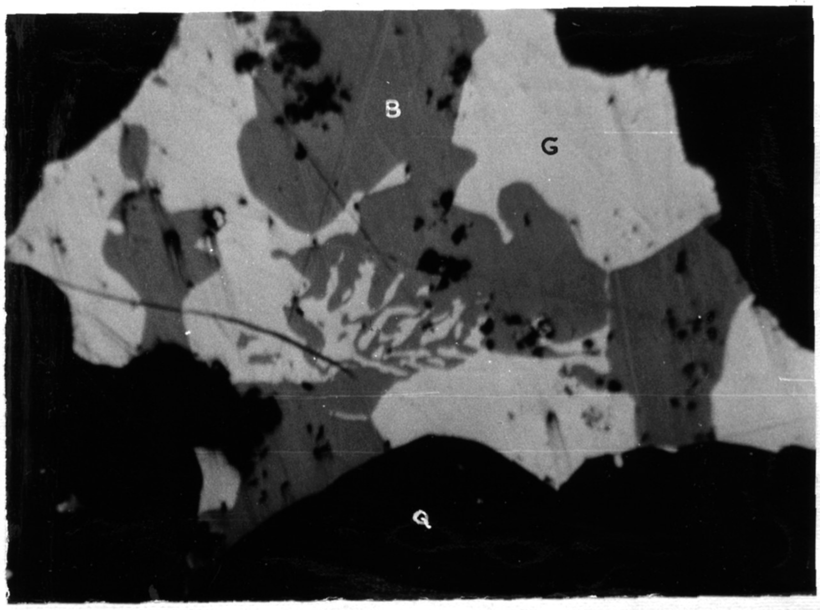


Photo No. 15. A composite aggregate of myrmekitically intergrown bornite (B) and galena (G) occurring interstitial to a coarse grained quartz (Q) gangue. Inclusions of quartz (black) occur within the aggregate.
Plane polarized light. 900 X magnification.

Bornite occurs interstitial to the quartz gangue. In addition to galena a small amount of deep blue anhedral neodigenite less than 0.05 mm in size occurs intergrown with the bornite and would appear to be of hypogene origin.

The bornite is also traversed by thin elongate veinlike exsolution bodies of chalcopyrite. In addition the bornite is marginally replaced by supergene neodigenite ("blue isotropic chalcocite" - Ramdohr). Occasional fragments of arsenopyrite and pyrite are also found in the bornite-galena veins.

Finely disseminated bornite is also found enveloping the margins of platy specular hematite and intergrown tetrahedrite in boreholes 6, 14 and 15 along the western sector of the lode. This bornite is frequently accompanied by very

fine./...

fine elongate bodies of chalcopyrite which may be exsolution bodies.

Pitchblende-(U_3O_8 or UO_2 - UO_3).

Pitchblende was identified in a few samples between boreholes 26 and 17. As distinct from uraninite the mineral is poorly crystalline resulting in ill defined x-ray diffraction peaks. The mineral is found as very dark grey sugary textured veins either marginally replacing hematite (see photo) or, as in one instance, deposited along thin cleavage fractures in a deep purple fluorite and possibly partly replacing it.

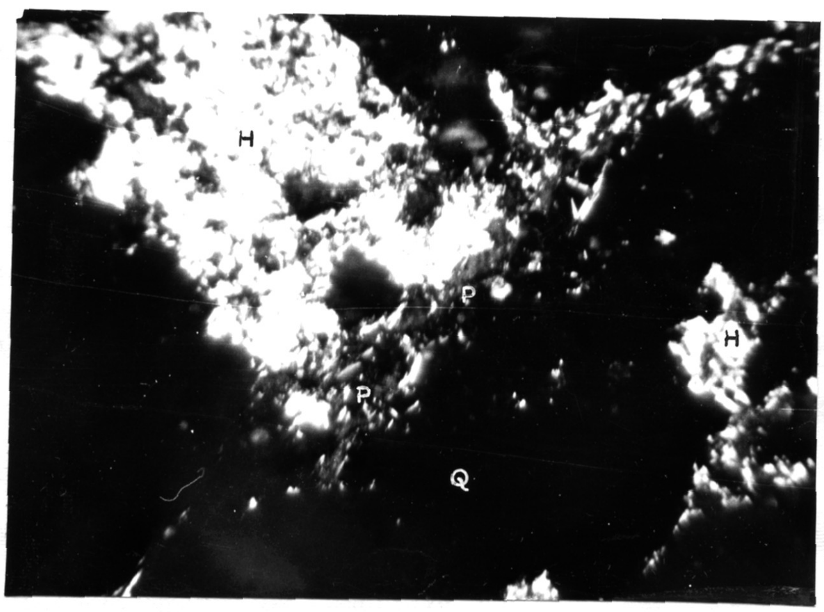


Photo No. 16. Specular hematite (H) replaced by very fine grained dark grey sugary textured pitchblende (P) in a quartz (Q) gangue. Plane polarized light. 900 X magnification.

The mineral possesses moderate to low reflectivity and is dark grey in colour. It is poorly crystalline and contains a small amount of thorium as well as lead.

According to Ramdohr (1969) the association of uranium with silver and bismuth bearing veins is a feature typical of the intrusive hydrothermal ore deposits as is its association with fluorite, calcite, hematite or siderite.

Under section 6.4. further reference has been made to uranium mineralization in connection with the occurrence of uranium-bearing allanite in the mineralized host granite. Here the granite is entirely replaced by quartz with a small quantity of fluorite so it is possible that the gangue minerals directly associated with uranium mineralization are quartz and fluorite. It is speculative

whether./...

whether the pitchblende is an original hydrothermal mineral or whether it has been derived from uraninite by radioactive destruction of the uraninite structure.

Lead-Bismuth Sulphide Mineral.

Between boreholes 17 and 5 a lead-bismuth sulphide mineral, as yet not positively identified, is found accompanied by galena and chalcopyrite.

The mineral contains a small amount of antimony as well and structurally it is similar to many of the more common sulphantimonides. The mineral occurs as irregular anhedral grains mutually intergrown with galena and varies in size from 0.01 to 6 mm. Both the galena and sulph-antimonide mineral are found replacing earlier pyrite and arsenopyrite veins.

The sulphantimonide has a hardness of approximately B+ and has a reflectivity of 39.2%, slightly higher than galena. The mineral has a grey-white lustre and is highly anisotropic with yellow-brown to brown birefringence. It consists of a very fine aggregate mosaic of crystals which are much coarser in the irregular extremities of the aggregate grains. Bismuth occurs as a finely exsolved phase in the mineral, generally as small irregular exsolution bodies smaller than 0.002 mm which account for less than 1% of the mineral. Its presence was established using the Cambridge 5 stereoscan unit which also showed the mineral to contain a small amount of silver in addition to lead, bismuth and antimony.

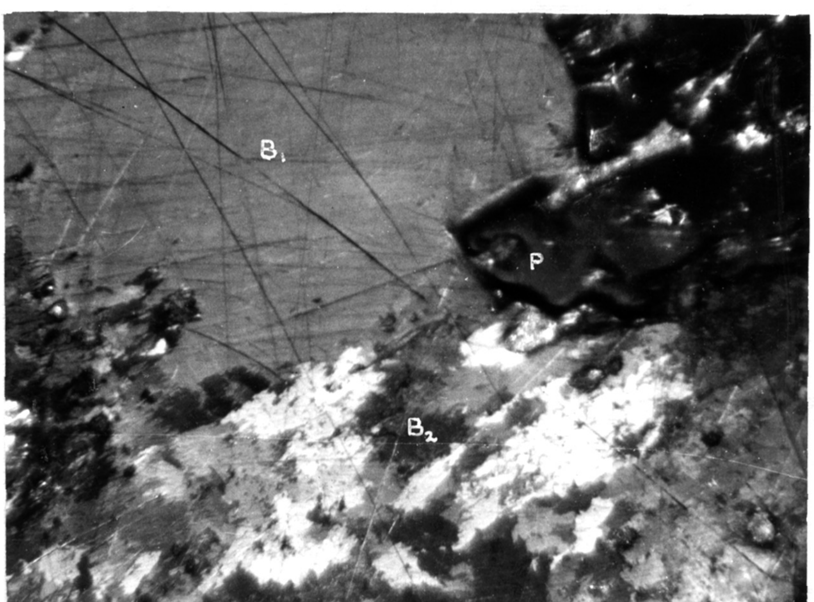


Photo No. 17. Highly anisotropic lead-bismuth sulphide (B_1 and B_2) replacing pyrite (P). B_1 represents the very fine grained mosaic, while B_2 is the coarsely crystalline mosaic aggregate portion of the mineral.

Crossed Nicols 900 X magnification.

6.3. Ore Assemblage Distribution.

Figure 9 is in effect a diagrammatic summary of the distribution and relative abundance of the major hypogene sulphide minerals and the oxides such as hematite, magnetite and pitchblende which occur in the Albert lode at the 60 metre level. It must be emphasized that the relative abundances of the ores could not be accurately determined on the basis of a single intersection of the lode at any specific point along strike. The diagram is thus subject to correction although it is believed that it suffices to show the general trends in ore distribution if the lode is considered in its entirety.

In the ensuing section the ore assemblage distribution is described per borehole from west to east along the body at the 60 metre level. So as to give an idea of the width of the mineralized portion of the body at each intersection the true total width of the lode is given. This is taken to include quartz-hematite veins, sulphide veins, separating screens of country rock and the portion of the alteration zone adjacent to the lode which is most highly mineralized.

Borehole 27.

The section of the ore lode represented by the intersection of borehole 27 shows that at this point the lode consists predominantly of highly silicified, limonitized hematite. The sulphides of this portion of the body are mainly confined to thick quartz veins cutting vertically through the hematite although the sulphides also occur disseminated through the highly fractured hematite. The true total width of the ore lode at this point is 3.1. metres at the 60 metre level below surface.

Pyrite and arsenopyrite accompanied by quartz gangue occur in numerous veins in the hematite, the pyrite containing numerous inclusions of marcasite. These veins are cut by younger veins of chlorite and quartz which contain anhedral intergrowths of chalcopyrite, sphalerite and lesser quantities of galena. Blebs of deep purple fluorite are frequently found within these veins while it is interesting to note that the sphalerite contains numerous fine chalcopyrite exsolution bodies which are oriented parallel to the cleavage directions of the mineral.

Quartz veins containing sulphides and generally no more than 12 mm wide, also occur in the numerous screens of highly sericitized altered country rock within the main ore zone. These veins contain pyrite enveloped by galena which is in turn marginally replaced by chalcopyrite and small quantities of sphalerite. Hypogene bornite mineralization is very limited in the extreme western end of the body occurring as thin mantles partly enclosing intergrowths of chalcopyrite, sphalerite and galena. While no bismuth sulphides or tetrahedrite were identified in borehole 27, a very small trace quantity of native silver in the form of small highly reflective globules less than 0.01 mm in diameter can sometimes be found between the hematite plates.

Borehole 14.

This section of the orebody is intensely sheared, contains a large volume of primary hematite and is also very heavily oxidized in the top 60 metres. Sulphide veins are relatively scarce, the ores occurring instead in disseminated form through the hematite which is of the platy specularite variety. The true total width of the ore lode at this point has increased to 9.8 metres at the 60 metre level. The hematite occurs as dense irregular patches up to 2 mm in diameter interspersed by patches of clear quartz of a contemporaneous age of deposition in addition to which are found patches of a secondary cloudy quartz containing finely comminuted hematite as well as a fine dispersion of sulphide minerals. These sulphides comprise singular and composite intergrown phases of galena, bornite, chalcopyrite and tennantite with a small amount of neodigenite.

From the highly comminuted nature of the ores in the secondary quartz gangue it could be surmised that post-mineralization shearing of this sector of the lode has been so intense that it has brecciated the sulphide veins in this area with the nett result that their ores have been cemented by a secondary quartz gangue.

Very small quantities of pyrite and arsenopyrite are encountered in this portion of the body but in contrast chalcopyrite is relatively abundant occurring as blebs up to 0.1 mm in size associated with a small amount of sideritic gangue. Sphalerite occurs as occasional irregularly shaped inclusions within the chalcopyrite.

A few highly irregular and minute (0.01 mm) blebs of native silver, most

probably./...

probably of supergene origin, can usually be identified in the limonitized hematite portions of the body.

Borehole 6.

The section of the lode represented by borehole 6 contains two distinct phases of hematite mineralization which in all probability occurred within a relatively short length of time. Platy specularite and quartz constitute the first phase of mineralization while the second phase of hematite formation is present in the form of a fine grained red orbicular structured hematite (described under section 7.2.). The hematite is heavily altered to limonite at the 60 metre level where it is also cut by numerous sulphide bearing quartz veins. In addition the true total width attained by the lode reaches its maximum of 21 metres at this intersection. Small irregular grains of hypogene bornite are disseminated through the quartz interstitial to the specularite which is marginally enclosed by bornite, chalcopyrite and pitchblende.

The sulphide veins containing galena, sphalerite, chalcopyrite and a small quantity of argentite are emplaced along fractures in the altered wallrock in the main ore zone and also along zones of secondary shearing in the hematite itself. Besides galena which is the predominant sulphide, chalcopyrite and bornite are more abundant in this section of the lode than in the preceding sections described. The unaltered nature of much of the bornite and associated galena, chalcopyrite is due to the fact that these minerals occur in many cases in thick unsheared quartz veins. Where these veins have been fractured secondary chalcocite replacing bornite and secondary bornite replacing chalcopyrite are encountered.

Light yellow-brown tetrahedrite is found as irregular bodies up to 1 mm in size interstitial to the hematite while a small amount of tennantite occurs in mutual intergrowth with galena in a few narrow veins through the body.

The occurrence of pyrite and arsenopyrite is limited to the occurrence of numerous fragmental particles included in the galena-chalcopyrite-sphalerite veins while specks of native silver are frequently found occurring interstitially to the specularite plates.

Borehole 15.

The central portion of the lode as represented by borehole 15 narrows to a true total width of 11.2 metres and contains abundant hematite. It also

appears./...

appears that the pulses of sulphide ore introduction which gave rise to bornite, tetrahedrite and uranium are localized in this section of the lode.

The sulphide ores are dominantly confined to thick quartz veins but due to the highly fractured state of the hematite they also occur relatively heavily disseminated through the mass of the hematite. Although quartz is the predominant gangue mineral accompanying the sulphides, purple fluorite is also frequently encountered accompanying the sulphides.

The specularite portion of the lode is less oxidized than that of the western portions of the lode but it differs from them in being fine grained and dense. Tetrahedrite is most abundant in this portion of the lode as far as borehole 6. The mineral occurs as irregular bodies interstitial to the hematite. Thick vertical (20 cm wide) veins of cloudy grey quartz containing abundant bornite associated with galena and a little chalcopyrite and neodigenite (blue chacocite) cut through this section of the body in addition to which are found numerous thin quartz-chlorite-chalcopyrite veins along with a little galena, siderite and bornite. These veins all contain irregular cataclastic inclusions of arsenopyrite and pyrite and, it is interesting to note, very little sphalerite.

Pink brown titano-magnetite in the process of alteration to martite is also frequently encountered in this section of the lode. Bornite also occurs widely disseminated through the hematite where it marginally envelops both the hematite and tetrahedrite as a 'front'. This type of marginal enclosure is also shown by the relatively abundant pitchblende which is found in this section. Trace quantities of bismuth sulphides and tennantite associated with galena were also identified in this borehole.

Borehole 17.

Boreholes 17 and 5 are representative of that portion of the lode most heavily mineralized by sulphide ores. In contrast to the western sector of the lode this portion of the lode contains far less hematite although the true total width of the mineralized zone is the same as in borehole 15 i.e. 11.2 metres at the 60 metre level. The massive quartz-hematite sections of the main ore zone occur as a number of thick bands. The hematite is of the coarse grained specular variety and is only moderately altered to limonite, this alteration generally being confined to the proximity of vertical mineralized and unmineralized shear

planes./...

planes cutting through the ore. Abundant martitized magnetite is found within the hematite which has less associated interstitial quartz gangue than the hematite of the western sector.

The exceptional reflection pleochroism of the hematite in this portion of the lode is due [Randohr (1969)] to its relatively high titanium content which agrees with the high titanium content of the enclosed magnetite. This magnetite also occurs in quartz-veins less than 1 mm wide which traverse the lode along fine vertical shear planes.

Pyrite and arsenopyrite are the abundant sulphide phases of this portion of the lode and often occur in a cataclastically disrupted state in younger veins of chalcopyrite and galena accompanied by sphalerite. These younger sulphides often entirely envelop the pyrite and arsenopyrite and completely fill the narrow fractures and partings in these minerals. Siderite is also found in greater quantities along with the more common quartz-chlorite gangue. Only very small inclusions of bornite and tetrahedrite are found in the hematite while tennantite was only detected on one occasion.

The two bismuth sulphide phases were also detected intergrown with galena and chalcopyrite but they are not as abundant as in borehole 5. No native silver or uranium ore was identified although chemical assaying shows that the uranium content of this portion of the lode is highly relative to many other sections of the lode. However the relatively low percentage of the uranium present minimizes the chances of the mineral being detected in as few as two or three polished sections.

Borehole 5.

Although the overall mineralization of this section of the lode is far less intense than that detected to the west of borehole 5, due to the much lower hematite content of this section, the sulphide ores in contrast appear to be much more abundant. The total true width of the ore lode has however narrowed to 5.1 metres.

The aggregate width of the hematite veins section of the lode is only 2.3 metres wide in comparison with a width of 4 metres in borehole 17. The hematite occurs as irregular aggregates of specularite interspersed by a quartz

gangue./...

gangue which also contains a fine dissemination of subhedral to anhedral fragments of pyrite and arsenopyrite. The ore zone is banded, consisting of alternate layers of hematite and sulphides which occur in massive form in veins up to 14 cm wide.

Pyrite and arsenopyrite are the most abundant sulphides in this section. These minerals occur in quartz-chlorite veins. Numerous separate parallel veins of sulphides occur interspersed between the pyrite-arsenopyrite veins. These veins are usually mineralized by a quartz-chlorite-siderite gangue with some fluorite. The veins contain abundant sphalerite intergrown with lesser quantities of galena and chalcopyrite and from the fact that they often contain irregular fragments of pyrite and arsenopyrite it can be inferred that these veins are younger than the quartz-chlorite-pyrite-arsenopyrite veins. No other sulphides appear to be present in this portion of the body.

Only a small amount of limonitized hematite is found at the 60 metre level and the examination shows that this is probably due to the fact that this section has not been sheared to the extent of those previously described.

Borehole 21.

East of borehole 5 the ore zone becomes progressively more ill defined and resolves into progressively narrower and less frequent sulphide bearing veins. From a width of 5.1 metres in borehole 5 the lode narrows to a width of less than 1 metre in borehole 19.

The ores of this section consist predominantly of a few thin veins of quartz-chlorite gangue containing euhedral crystals of arsenopyrite up to 1 mm in size in addition to which is found a small quantity of sphalerite and siderite. These veins show no evidence of post mineralization shearing and thus bear testimony to the fact that the eastern extremities of the lode represent the physical limits to which the lode extends. Trace quantities of chalcopyrite and galena also occur in the extremities of the lode.

Deflection borehole 3. (120 metre level).

Borehole deflection 3 verifies that the high frequency of sulphide mineralization encountered at the 60 metre level in borehole 17 is persistent to a depth of at least 120 metres.

At./...

At this depth the body consists of massive unaltered specular hematite cut through by relatively massive veins of pyrite and arsenopyrite in a quartose gangue. These minerals are enclosed by lesser quantities of galena, chalcopyrite and the two lead-bismuth sulphides. Veins of the latter three minerals in quartz-chlorite gangue are also observed crosscutting veins of pyrite and arsenopyrite. It is important to note that there are no signs of alteration or supergene effects at this depth which bear out the fact that the ores described are all probably of hypogene origin. This is added testimony to the fact that the hematite is definitely of hypogene origin.

6.4. Minor Mineralization Associated with the Granite.

This short section deals with minor mineralization, genetically related to the Albert Lode but emplaced in vein form some distance from the lode in unaltered granite. Molybdenite and to a lesser degree galena fall within this category. Although a primary constituent of the host granite allanite has been included in this section as it has undergone uranium and thorium substitution directly related to the phase of uranium mineralization of the lode proper. However, the allanite which was examined was found in silicified screens of altered granite within the lode and it is doubtful whether allanite in the unaltered granite at a distance from the lode would contain any uranium or thorium.

a) Radioactive Allanite - (General Formula (Hasegawa, 1960) $(Ca_{2-n}\ Ce_n)$ $(Fe^{+2}_n\ Fe^{+3}_{1-n})\ Fe^{+3}_{1-n})\ Fe^{+3}_m\ Al_{2-m}$ —— $S_{13}O_{12}$ (OH)

During the stages preparatory to the selection of ore sections for analysis the author carried out a qualitative radiometric survey of core from the main ore zone in an attempt to try and establish which were the most highly radioactive sections of the ore zone. The highest levels of radioactivity were recorded in specimens of hematite from boreholes 6, 14, 15 and 17 which subsequent evidence showed could be attributed to the presence of pitchblende. An ultra-violet scan of heavy mineral concentrates prepared from core samples of borehole 15 revealed a highly fluorescent brown mineral later identified as allanite.

Photo./...

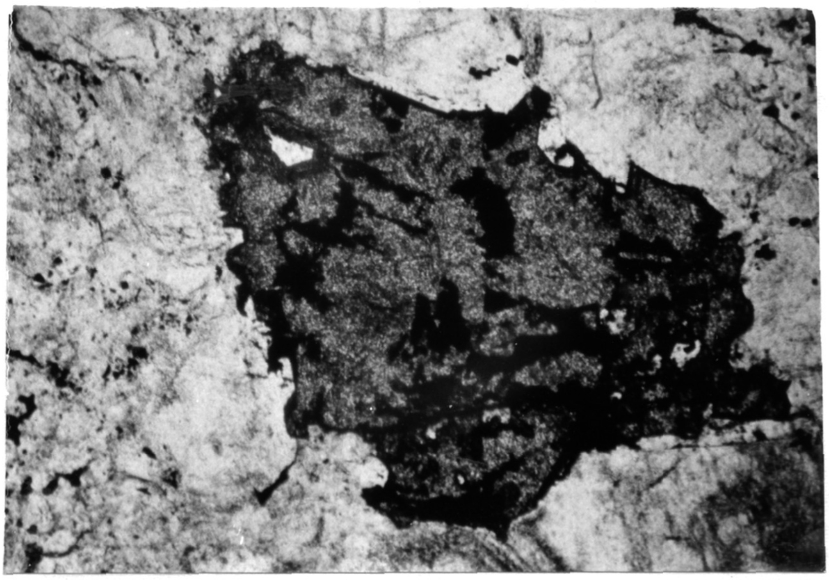


Photo No.18. Radioactive allanite with iron ore inclusions set in highly silicified altered granite containing finely disseminated hematite. (Within the ore lode).
Plane polarized light. 60 X magnification.

Allanite is a member of the epidote group of minerals and Deer, Howie and Zussman cite it as being a characteristic accessory mineral of many granites. In thin section the mineral occurs as anhedral brown crystals up to 0.5 mm in size and is biaxial-ve with a 2V angle greater than 45 . The mineral contains inclusions of iron ore and occurs as a primary component of the pink porphyritic Bushveld granite. The quartz phase of the granite occurs as crystals up to 5 mm in diameter interstitial to which is found fine grained secondary quartz.

A scan of the allanite using the Cambridge 5 electron microscan unit shows that it contains small quantities of uranium and thorium. While thorium may replace Ca in a fashion similar to the rare earths, in which configuration it forms an integral part of the allanite structure, uranium may also substitute itself into the lattice as it has an ionic radius similar to thorium.

From the above evidence it would appear that the altered granite within the main ore zone was pervaded by uraniferous ore fluids which deposited some uranium within the allanite.

b) Molybdenite -

Zones of shearing extend through the unaltered country rock some distance away from both the Albert and intermediate lodes. These fractures are frequently

mineralized./...

mineralized by quartz, calcite and chlorite as well as by molybdenite and galena. Borehole 25 intersected a number of these minor veins. In the photograph a typical infilled shear plane containing discrete aggregates of molybdenite is shown.

Photo No.19. A quartz-fluorite vein (Q) bordered by chlorite. Blebs of molybdenite (arrowed) can be seen scattered through the quartz and chlorite parts of the vein.

The vein is bordered on either side by pink granite lightly kaolinized by weathering. A set of fine shear planes running obliquely through the molydenite vein indicate that the zone was subjected to further shear movement. From the gangue mineral assemblage accompanying the molybdenite it is not clear whether chloritization accompanied the emplacement of the quartz-fluorite-molybdenite or preceded it.

Molybdenite is also found within the wallrock alteration envelope bordering the lode as platy blebs up to 4 mm in size. These blebs occur along 0.1 mm wide fractures through the granite and are similarly associated with a quartz-calcite gangue.

7. THE ALTERATION ZONE.

7.1. Discussion.

Hydrothermal alteration because it is commonly pervasive in the vicinity of certain ore deposits, sometimes furnishes a valuable guide in the exploration of new ore bodies. The object in furnishing comprehensive data on the alteration zone associated with the Albert Lode has been primarily to discover whether the wallrock alteration can be used as a guide to ore.

The methods adopted in the study are broadly based on those used in a number of studies of wallrock alteration, namely those by Schwartz, Sales and Meyer (Butte, Montana), Brown (Mt. Isa, Australia), Kerr (Santa Rita, New Mexico) Morris and Lovering. However, the methods of presentation of results have been modified by the use of new techniques such as the concept of the Barth standard cell and by the use of semi-quantitative mineral analysis determined by x-ray diffractometry based on the use of internal standards for calibration.

The samples selected for the study were chosen as being representative of the most typical alteration encountered along the body. These specimens were taken from roughly equidistant boreholes along the strike of the lode. (see Fig. 7a). Each specimen was split so as to provide a representative fraction for wet chemical analysis as well as a specimen for petrographic analysis and diffractometry.

7.2. Introduction and Methods.

The host rock which is pink Bushveld granite has been altered by sericitization, hematitization, silicification, chloritization and kaolinization. In all causes a small part of the kaolinization is due to natural weathering, in the zone of incipient alteration it is very difficult to tell how much of the alteration is due to weathering and how much is due to hydrothermal alteration but where kaolinization is described in the other zones of alteration bordering the lode this can be taken to be due to hydrothermal alteration probably accompanied by a small amount of kaolinization as a result of natural weathering.

The resultant./..

The resultant altered rock has such indefinite mineral phases that it was judged best to determine the mineralogical proportions by the use of semi-quantitative x-ray diffractometry against internally prepared standards.

The replacement trends have been petrographically described and correlated with the chemical analyses of corresponding sample sections (see Table 7). Quantitative comparisons can be drawn between the analyses for which purpose the results were recalculated according to Barth's standard cell.

Using this method quantitative comparisons can be drawn between any two alteration sequences or individual alteration zones simply by subtracting the Barth cell value of one zone from that of the other to arrive at the relative quantities of any element which have either entered or left a particular zone. This method was used in preference to the older form of representation employed in the classic study of wallrock alteration at Butte, Montana by R. Sales and C. Meyer (1948) where, working on the assumption that the wallrock has not changed in volume, the specific gravity of the rock is used to proportionalize the chemical analyses for each alteration stage.

In the method proposed by Barth it is assumed that on an average rocks contain 160 (O + OH) ions per 100 cations. For weathered rocks the number of O is somewhat higher due to geological oxidation in the upper levels of the lithosphere. However, variations in the number of (O + OH) ions relative to 100 cations are very slight and the method can be used for arriving at equal volume calculation units, this unit being referred to as the Barth standard cell.

The chemical results have been presented in the form of variation diagrams [Figure 7(b)] for ease of comparison. It is to be noted that the diagrams do not show the actual variations through the wallrock but only the general trend which however is statistically meaningful as it is based on a minimum of three points in every case.

Mention must be made of the fact that although the chemical values have been plotted using the Barth cell objections could be raised to its use as some authorities feel that the introduction of SiO_2 into a rock results in a different (O + OH)/cation ratio. However, it is felt that its use is justified as it enables a clearer interpretation of the subject matter to be made. Such is the case for Niggli values, which although often showing a relationship clearly, are not always./...

always based on entirely correct premises.

7.3. Wallrock Alteration of Typical Quartz-Hematite Type Lodes.

As a starting point in the study, the alteration effects accompanying quartz-hematite mineralization were examined. In view of the fact that the Northern and intermediate minor lodes are almost totally quartz-hematite bodies with a very low sulphide content these bodies were taken as being representative of such alteration.

The type alteration and thus sequence of zonation was selected from borehole 7 where the Northern lode has a well developed alteration aureole along its northern flank.

7.3.1. Stages of Alteration.

The characteristic stages of alteration are described starting from the lightly pinitized host granite and continuing through the successive more highly altered zones until the ore lode itself is encountered. Each alteration zone may be imagined to have originated in the vicinity of the ore lode and to have moved outwards into the host granite by displacing earlier stages before it. The most intense zone of alteration is usually situated in highly sheared rock while the least altered zone often shows signs of incipient cataclastic dislocation in the form of subparallel zones of fluid pores traversing the quartz components of the granite.

Stage I. Incipient Alteration. [for location see Fig. 7(a)]

The coarse-grained Bushveld granite is typically pink in colour and has a granularity of approximately 3 to 4 mm with occasional feldspar phenocrysts up to 5 mm in size. The modal composition of the unaltered granite based on point counts is quartz 33%, plagioclase feldspar 29.3%, orthoclase 28.9% chloritized biotite 6.4%, chlorite 1.3%, iron ore 1%, fluorite 0.1%. For comparison the modal composition of the fine-grained pink Bushveld granite is quartz 38.9%, feldspar 55.0%, chlorite 3.1%, iron ore 3.0%.

The quartz is clear, subhedral and intergrown with orthoclase feldspar which is heavily altered to clay. The plagioclase component of the rock often occurs in the form of aggregations of elongate, raggedly terminated lathes intergrown with the major constituents. This mineral is extensively replaced by fine greenish coloured chromiferous sericite 2 M. Large phenocrysts of albite composition and twinned according to the combined albite-carlsbad laws are frequently up to 1 cm in length. At least 40 per cent of the feldspar is also completely kaolinized probably mainly as the result of hydrothermal solutions.

The granite contains an even dissemination of biotite, typically in the form of aggregate booklets, the mica is greenish in colour and commonly altered to magnetite along its peripheries and cleavage lamellae.

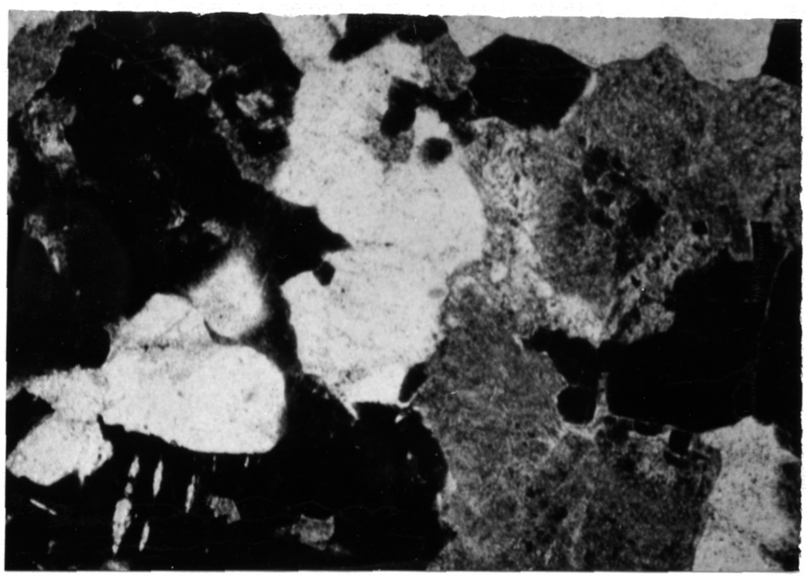


Photo.No.20. Incipient alteration of Bushveld granite by quartz-hematite mineralization. Quartz (white) intergrown with extensively kaolinized potash feldspar (grey) and primary chlorite (black). Stage I.
Plane polarized light. 60 X magnification.

Stage II. Quartz-Sericite Stage. [for location see Fig 7(b)].

Due to local inhomogeneity the granite contains occasional coarse-grained patches which, in the second stage of alteration are extensively sericitized. The abundant sericite gives the rock a light green colour.

The rock consists of coarse grained slightly fractured quartz up to 0.8 cm long set in a groundmass consisting entirely of sericite and fine-grained secondlry quartz with a sprinkling of disseminated hematite.

Photo./...

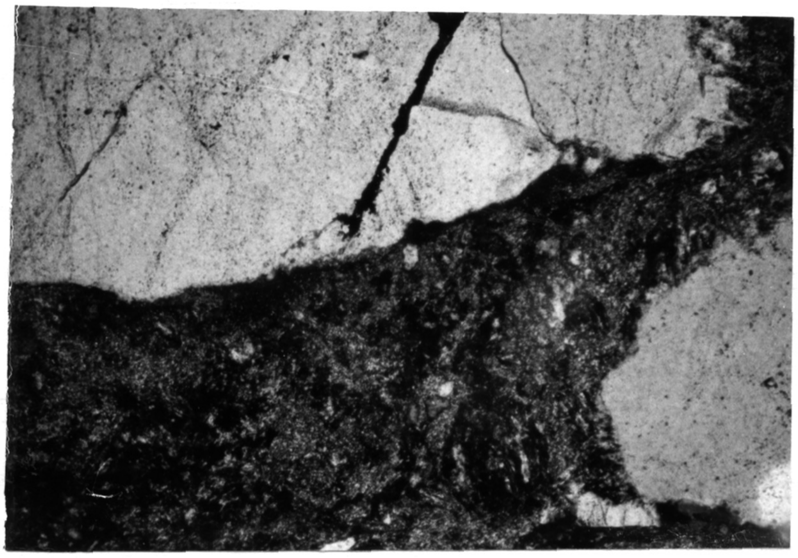


Photo No.21. Coarse-grained primary quartz (white) traversed by fine lines of fluid pores and a vein of hematite and intergrown with secondary sericite and dispersed hematite (grey).

It is clear that the feldspar component of the granite in this zone has been entirely replaced by sericite. Primary mica appears to be unaffected by the more intense alteration and occurs in much the same form as was described for Stage I.

Stage III. Major Quartz Introduction.

Approximately 5 metres from the lode the rock becomes lighter in colour than the preceding stage although it still possesses a distinctly greenish tinge. It is also cut through by occasional fine hematite veins which travel along fractures in the wallrock. The primary quartz aggregates have highly irregular margins and appear to be undergoing deuteric attack by the interstitial sericite component.

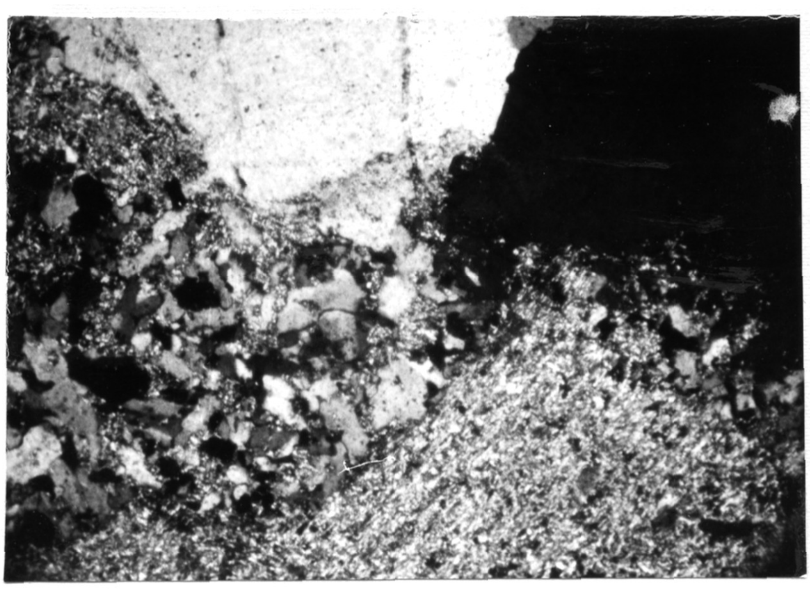


Photo No.22. Stage III alteration showing the introduction of secondary quartz interspersed by sericite (speckled) into altered granite consisting of primary quartz (white/black) and secondary sericite (fine-grained, white). Crossed Nicols. 60 X magnification.

In addition./...

In addition to earlier sericite replacement of the feldspar, fine grained secondary quartz has been introduced into the rock occurring as patches and semi-continuous stringers interstitial to both the primary quartz and sericite. Unlike the preceding zone the mica which was originally probably biotite is darker green in colour and appears to be more heavily chloritized.

Quartz-Hematite Introduction (Stage IV).

In the proximity of the lode the quartz and quartz-hematite content of the wallrock increases at the expense of the sericitized portion of the rock.

The introduction of quartz and hematite into the wallrock has been facilitated by the extensive shearing which the wallrock has undergone in the immediate vicinity of each lode. At this juncture it is well to point out that the complete sequence of alteration stages is always present where wallrock alteration accompanies the quartz-hematite lodes although its extent is mainly dependant on the width of the orebody.

In hand specimen stage 4 rock is speckled red brown by the presence of abundant iron oxides disseminated through the sericitized portions of the rock. Small green flecks are due to knots of dense sericite. The rock is highly fractured and shot through by irregular veins and blebs of limonitized hematite accompanied by secondary quartz. The iron ore is also found as a fine, dense dissemination through the sericite.

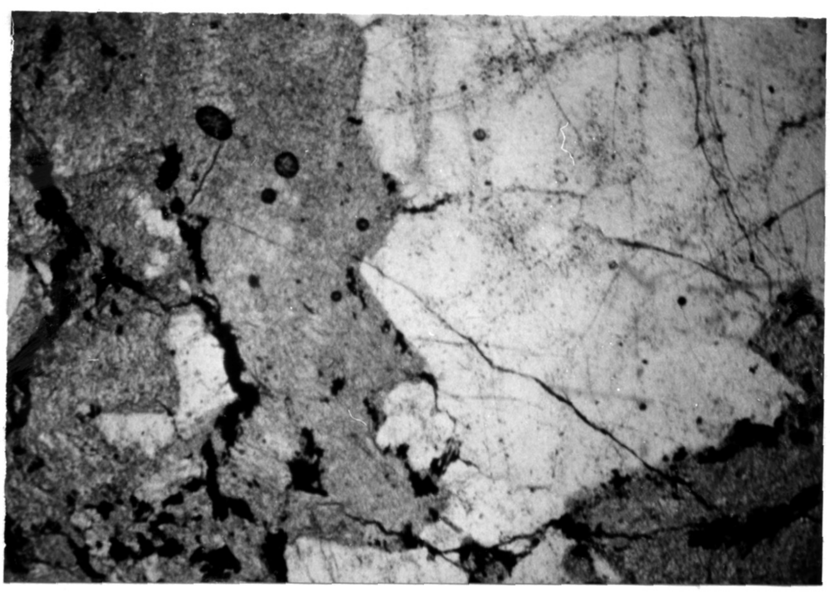


Photo No.23. Stage IV. Alteration showing altered wallrock in the immediate vicinity of the lode consisting of highly fractured quartz (white) sericite (grey) and abundant hematite in the form of veins cutting through the altered rock.

Plane polarized light. 60 X magnification.

The biotite./...

The biotite has been almost completely replaced by hematite and in addition it contains minute euhedral crystals of zircon which were originally present in the mica.

7.3.2. Chemistry of the Alteration Sequence.

The sequence of alteration and replacement has been interpreted in the light of the chemistry of the successive stages in conjunction with the mineralogy. Reference should be made to Figure 7(a) for location of the stages discussed while figure 7(b) shows the chemical analyses presented as variation trends through the different stages of alteration.

Figure 7(b) Section G and Table No. 7 Section 6 give the results of the analysis of the wallrock alteration sequence for the northern lode. Si^{4+} , in the form of secondary quartz increases towards the lode, the content being highest over the 3 metre nearest to the lode where the Si^{4+} content increases by 5 m cations per unit cell. Conversely, the decrease of Al^{3+}, K^{+} and Fe^{2+} toward the lode can be accounted for by the replacement of feldspar by sericite and by the replacement of sericite by secondary quartz. As for silica the greatest change appears over the first 3 metres away from the lode and thus confirms the direct correspondence of silica influx to K^{+} and Fe^{2+} migration outward from the lode.

The introduction of hematite into the wallrock nearest the lode is marked by an increase in Fe^{3+} content of roughly 2 cations per unit cell. Sodium as Na^{+} has been radically reduced in the vicinity of the lode due to the replacement of sericite by secondary quartz.

Mg^{2+} is present in small amounts but is nevertheless constant throughout the alteration zone and thus is probably correlative with the green mica. Ti^{4+} shows a decrease in the vicinity of the lode which may be due to the element having undergone outward migration from the lode. This would have been made possible if the titanium was originally present as a trace constituent in either the mica or magnetite which has been oxidized to hematite. The slight increase in Ca^{2+} content is interesting when it is considered that high Ca^{2+} values are present in the wallrock adjacent to the most highly uraniferous section of the Albert Lode. This factor may be of some interest in the exploration for uranium bearing quartz-hematite bodies (see work done under Section C, Albert Lode alteration mineralogy). H^{+}, which goes to form the hydration radical of the micas shows a small increase in stages 2 to 3 which corresponds to the most highly sericitized zones in the wallrock.

In conclusion the sequence of alteration and element migration can be summed up as follows. The introduction of hematite and quartz into the wallrock adjacent to the lode displace the elements Na^+, K^+ and H^+ which migrate outwards resulting in extreme sericitization of the next zone while the incipient alteration of the host granite is indicated by a zone of heavy kaolinization.

7.4. Wallrock Alteration - Albert Lode.

7.4.1. Discussion.

Reference to Figure 3 shows that the alteration zone accompanying the Albert orebody is most extensive along the eastern sector of the lode. By comparing this diagram with Figure 5, which features the results of a structural analysis of the lode, it can be seen that the western sector of the orebody is highly sheared and consequently heavily mineralized by quartz-hematite ore. Analyses of sections through the alteration zone from west to east show that a clear correlation exists between the type of alteration sequence and the mineralogy of the orebody itself. The ore lode varies from being broadly quartz-hematite in its western extremities through predominantly massive hematite in the central section to prominently sulphide rich in the eastern sector. Similar changes are reflected in the type of alteration accompanying the lode. For ease of correlation the mineralogic composition of the stages of alteration along the strike have been determined by semi-quantitative x-ray diffractometry, the results of which are presented in Figure 8. The modal compositions arrived at have been partially verified by a normal modal analysis based on point counting which is deemed to be of little value in itself apart from serving as a check on the accuracy of the diffractometric analysis due to the highly altered nature of most of the rock. A feature of the alteration zone which can not be readily explained is why the alteration zone along the northern flank of the ore lode should be so much more extensive than that along the southern flank where the alteration is much less extensive, although the full sequence of alteration does occur outward from the lode. The nature of the wallrocks is the same on both flanks. A possible explanation is that minor shear zones parallel to the main

ore./...

ore zone are more prominent north of the lode. These planes are an indication that the alteration zone along the northern flank of the ore lode lies along a more highly fractured portion of the wallrock than is encountered in the southern flank. These fractures which are very extensive on a microscopic scale probably made the area north of the lode more permeable to hydrothermal solutions with the nett result that alteration has extended further into the host granite.

7.4.2. Comparitive Mineralogy and Petrology.

Western Extremities.

The alteration sequence encountered in borehole 27 (Figure 7(a), 7(b) Section A) is representative of the type of alteration accompanying the western extremity of the lode. Examination shows that the sequence closely resembles that established for the minor intermediate and northern lodes which are of quartz-hematite composition. It is well to note that in Figure 7(a) while the positions of the samples analysed and described are numerically indicated, the approximate limits of the various zones of alteration in each section are represented by a set of dashed lines. These limits have been established by thin section analysis and indicate that the alteration effects extend further away from the lode. This stage is indicated by Figure 3 which depicts the limit of alteration visible in hand specimen. I of section A falls in the zone furthest away from the lode and the position of the sample representative of that part of the alteration zone is given by the number 1.

Stage I - Incipient Alteration.

In hand specimen the granite north of the lode is lightly flecked by green sericite probably of hydrothermal origin. Petrographically the rock resembles resembles that of Stage I described under section 7.3.

The potash feldspar components of the rock are highly altered to a kaolinite-like mineral probably mostly due to hydrothermal solution and to a lesser extent due to weathering while the minor plagioclase component of the granite is replaced by very fine grained light green chromiferous sericite of the 2 M type. Sericitization proceeds preferentially along twin lamellae, cleavage planes and along fractures through the feldspar which is of albite-oligoclase composition. The quartz component of the granite shows signs of incipient cataclastic disruption by the development of sub-parallel lines of fluid pores aligned at right angles to the direction of shearing stress in the rock. It would appear that a small quantity of potassium has been introduced into the margin o of the alteration aureole where it manifests itself as fine veins of sericite which run through the rock interstitial to the quartz and feldspar components. The granite contains a small amount (1%) of lightly chloritized mica which contains a fine dissemination of secondary hematite. Trace quantities of apatite are also found in the granite.

Stage II Quartz-Sericite Stage.

Nearer the ore lode the granite becomes more highly altered. The feldspar components are entirely made over to sericite and are interspersed by clusters of coarse-grained quartz. The biotite is chloritized and in hand specimen the rock closely resembles Stage II described under section 8.3., being light coloured, coarse-grained and flecked with green sericite.

Stage III Quartz Stage.

Mapping of the western extremity of the body shows that the granite in this area is inhomogeneous and contains coarse-grained, quartz-rich bands which, have suffered secondary silicification nearer the lode. These bands consist of coarse-grained granular quartz up to 7 mm in size which is aggregated together in a groundmass composed of fine-grained secondary quartz and sericite. A small quantity of bleached biotite which has been altered to chlorite and a little primary magnetite is also present.

Stage IV Quartz-Hematite Introduction.

The coarse granular green rock of stage III becomes red-brown in colour in the proximity of the lode due to the introduction of hematite into the wallrock. The hematite occurs as a mass of fine, densely disseminated particles and small veins running through the sericite and interstitial to the fine-grained secondary quartz portions of the rock. The hematite also occurs as dense segregations in the chloritized mica where it forms layers interstitial to the mica lamellae.

In common with the alteration accompanying the minor quartz-hematite type lodes, the alteration form in the western extremities of the Albert lode appears./...

appears to be due to the hydrothermal effects accompanying an entirely quartz-hematite mineralization.

Mid-Western Sector.

The mid-western sector of the lode is represented by Figure 7(b) Section B (for location see Fig. 7(a). The alteration zone is most extensive at this point and from Figure 3 it can be seen that it accompanies that portion of the lode which is most heavily mineralized by hematite. This sector of the ore-body also contains the highest payeable silver values which is however purely incidental as there is no correlation between the silver sulphide mineralization and the characteristic alteration forms which are entirely due to hematite mineralization. The wallrock along the northern flank is banded into coarse and fine grained portions at this point. The coarse-grained granite is older and highly porphyritic, containing heavily kaolinized phenocrysts of potash feldspar up to 1.3 cm in length.

The samples chosen as representative of the successive alteration stages at this point were selected from sections of the medium to coarse-grained granite. Minor folding encountered within the granite is attributed to movements within the granite prior to its final consolidation. The individual fold bands are preferentially replaced by successive alternating bands of hematite, quartz-sericite and quartz.

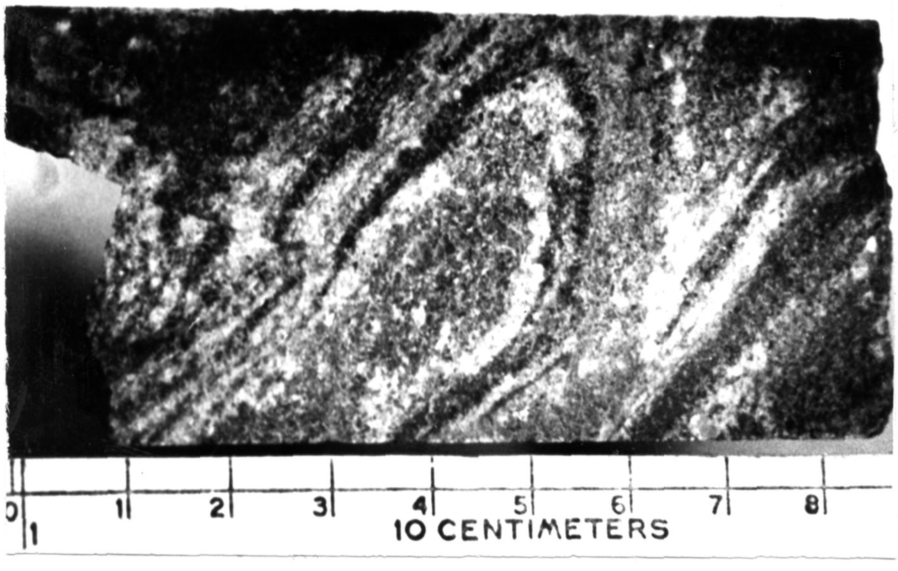


Photo No. 24. Minor fold in fine-grained granite strikingly accentuated by the preferential replacement of alternate fold bands by sericite (grey), hematite (black) and quartz (white).

Stage I./...

Stage I Incipient Alteration.

The granite is highly fractured up to 15 metres north of the lode and in consequence besides kaolinization which is probably due in part to weathering and initial sericitization of the feldspathic constituents of the rock, traces of hematite are encountered along fractures extending to the northernmost limit of the alteration zone. Sericitization is a highly developed feature of the zone and extensively replaces both the sodic and potash feldspar constituents of the rock.

Stage II Quartz-Sericite Stage.

Nearer the lode the rock is coarse-grained and consists of aggregates of irregular, intergrown primary quartz up to 1.5 mm in diameter dispersed through a groundmass of sericite and fine-grained secondary quartz interspersed with sericite. The sericite forms elongate clusters and clearly preserves the outlines of the earlier feldspar components of the rock.

Stage III Hematite Introduction.

The wallrock alteration zone adjacent to the central section of the western sector of the lode is highly sheared and fractured up to 15 metres from the lode. The entire zone is extensively hematitized. The hematite occurs as small irregular blebs and stringers through the rock. The biotite is extensively bleached and replaced by elongate lensoids of hematite along its cleavage traces. In the immediate vicinity of the lode the groundmass is largely replaced by fine-grained hematite which gives the rock a mottled red-brown appearance.

Central Sector.

In section C [Fig. 7(a)] the alteration zone is appreciably narrower than in section B (see Figure 3).

The alteration sequence is characterized by an increase in chlorite content which is a direct consequence of the quartz-chlorite-sulphide mineralization which is more extensively developed along this sector.

Chlorite Stage I.

The persistent development of an aphrosideritic chlorite throughout the entire alteration envelope is characteristic of this sector of the lode. The granite along the northern periphery of the alteration zone is medium to fine grained with a granularity of from 0.9 to 1.2 mm. It is also rich in biotite mica (± 4%). The rock is pinkish in hand specimen and contains small green-black flecks of chlorite. The potash feldspar constituents of the rock are heavily kaolinized while the

plagioclase./...

plagioclase component is heavily sericitized.

Unlike the mica of the central and western extremities of the alteration zone, which is bleached, the mica in this sector of the alteration zone is completely replaced by dark green, highly pleochroic chlorite accompanied by a small quantity (<2%) of iron ore (see photo).

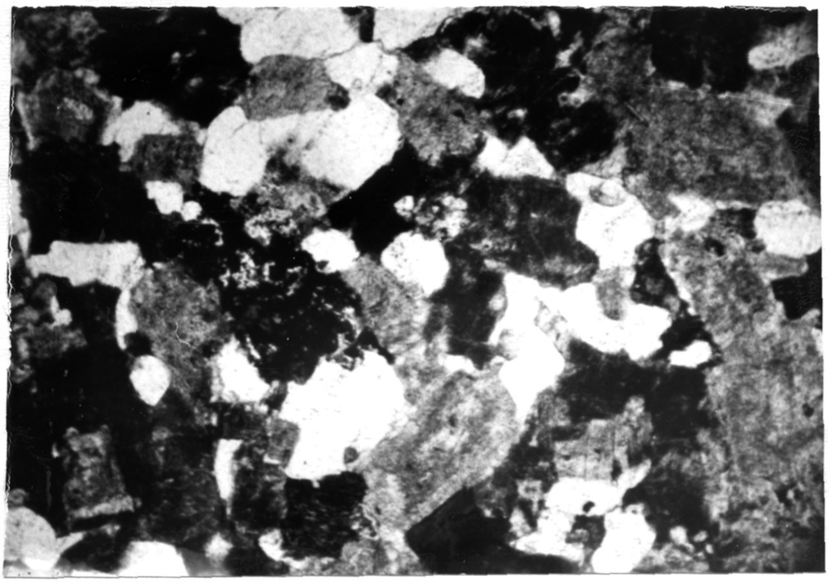


Photo No.25. Medium grained pink granite in the process of incipient alteration showing the heavy kaolinization of potash feldspar (v. dark grey), the sericitization of orthoclase and plagioclase (grey) and the presence of abundant chloritized mica (black).
Plane polarized light. 60 X magnification.

Chlorite-Hematite Stage II.

The rock shows no increase in granularity towards the lode although it becomes progressively darker in colour due to an increasing hematite content. At least 50% of the feldspar is sericitized although this form of alteration is markedly less significant than is the case in Stage II alteration associated with the quartz-hematite portion of the lode to the west of section C. Flakes of a secondary green chlorite, and clusters of densely disseminated hematite particles are distributed through the rock while it is of interest to note that some of the feldspar is extensively replaced by hematite which preserves the outline of the lathes in relict form.

By a progressive increase in the hematite content which is accompanied by a sympathetic decrease in the amount of chlorite present in the rock, the wall-rock becomes dark purplish in colour in the immediate proximity of the orebody.

Photo./...

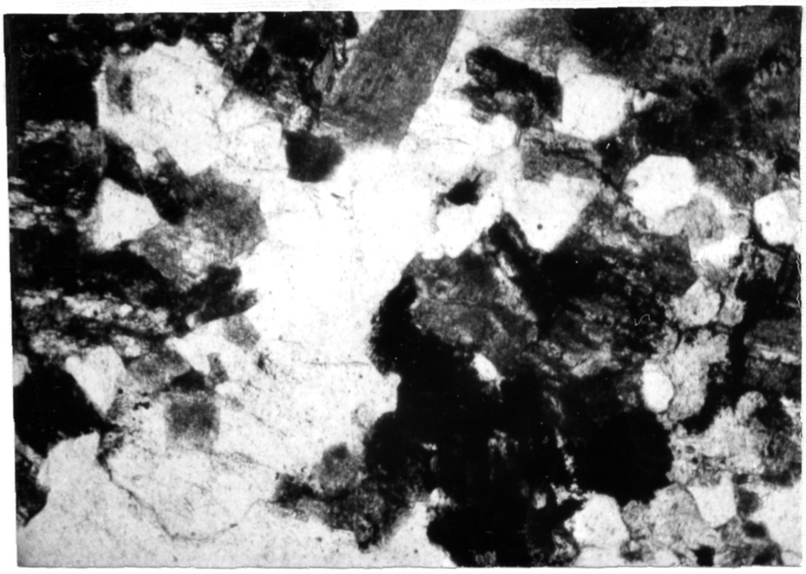


Photo No.26. Altered granite from the chlorite-hematite zone showing partially sericitized feldspar (grey), large flakes of secondary chlorite (black), occasional fine black stringers and disseminations of hematite and quartz (white).
Plane polarized light. 60 X magnification.

Stage III Hematite Rich Zone.

The granite in the immediate vicinity of the lode is completely sericitized and extensively replaced by large blebs of hematite up to 0.6 mm in size. The remainder of the rock is riddled by a dense dissemination of fine-grained hematite while the mica is extensively bleached and replaced by hematite. In marked contrast to the modes of alteration described in the preceding sections, no silicification of the wallrock has occurred which may possibly be related to the structure of the lode. Fig. 5 shows that the lode consists of a number of alternating bands of highly mineralized material separated by screens of highly silicified altered wallrock (borehole 15 - section C). It is possible that these screens were silicified during a mineralization phase subsequent to the introduction of a relatively massive quartz deficient hematite which resulted in extensive hematitization but little silicification of the adjacent wallrock.

Photo./...

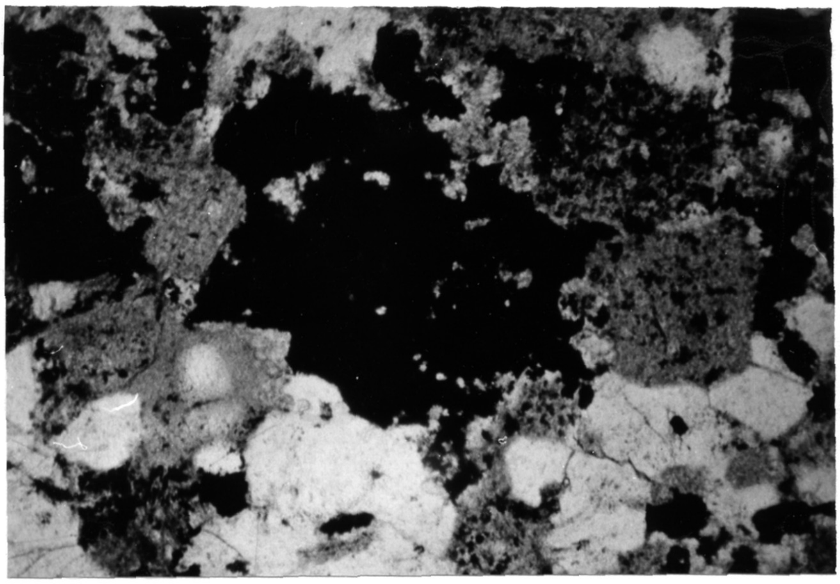


Photo No.27. Intensively hematitized and relatively unfractured wallrock showing quartz (white) intergrown with completely sericitized feldspar (grey) which has been strongly replaced by large blebs and finely disseminated hematite (black).
Plane polarized light 60 X magnification.

Mid-Eastern Sector.

The mid-eastern sector of the lode decreases in width and is accompanied by a concommittantly narrower alteration zone (see borehole 5 - Figure 3). This portion of the body is represented by section D in Figures 7a,b. Chlorite and quartz become the dominant replacement minerals in the wallrock adjacent to the lode while in the lode itself sulphide ores in a predominantly quartz-chlorite gangue assume a more dominant role in the ore assemblage when considered relative to other sections of the lode.

Incipient Alteration Stage I.

In the vicinity of borehole 5, north of the lode the granite is a grey, fine-grained porphyritic variety. Initial alteration of the granite on the margin of the alteration zone begins with the incipient sericitization of the zoned plagioclase component. The small (3%) quantity of mica present is almost completely chloritized while apatite and magnetite, which are original constituents of the granite, occur in trace amounts.

Chlorite- ./...

Chlorite-Quartz-Sericite Stage II.

Nearer the lode the wallrock becomes pinkish in colour due to extensive kaolinization most probably produced as a result of hydrothermal alteration. It is also flecked by patches of greenish chloritized feldspar.

In this the intermediate zone of alteration, orthoclase is almost completely kaolinized while the plagioclase component is extensively sericitized (up to 25%). An unusual form of alteration characteristic of this zone is the marginal replacement of the sericitized plagioclase feldspar by fine-grained chlorite which accounts for its greenish colour in hand specimen. The rock is also traversed by fine veins of secondary quartz.

Chlorite-Quartz Stage III.

In the immediate proximity of the lode the rock is mottled by the development of large dark green flakes of chlorite. The rock is relatively unfractured and more extensively chloritized than in the preceding zone. The chlorite is accompanied by fine-grained secondary quartz.

Eastern Extremities.

East of borehole 24 (see sections E, F) the lode and attendant alteration zone are very much narrower and hematite ceases to be the predominant ore mineral in the body. The ore zone proper consists of a fine-grained quartz-chlorite gangue containing a few thin sulphide veins and very little hematite. It is thus possible to correlate the attendant alteration sequence with vein sulphide mineralization, an important factor if alteration zone effects are to be used in locating similar sulphide bodies in the Bushveld. The following analysis will make it clearer that the alterational sequence described for section D is also predominantly the result of quartz-chlorite-sulphide mineralization.

Incipient Alteration Stage I.

The granite on the margin of the alteration zone 9 metres from the lode is of the medium-grained pink porphyritic variety with a granularity of 1.4 to 1.7 mm. Both the potash and sodic feldspar components are heavily altered to clay which could be due partly to the influence of weathering as the specimen described was./...

was located only 6 metres below surface level. Chloritized mica is present in trace amounts, and in addition the rock is traversed by numerous fine veins of secondary chlorite.

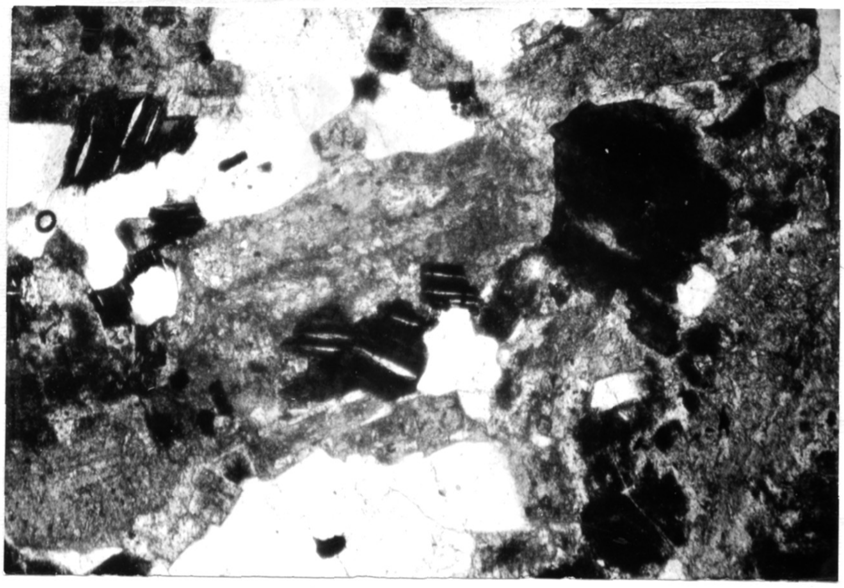


Photo No.28. Medium-grained pink porphyritic granite from the zone of incipient alteration showing quartz (white) intergrown with highly chloritized feldspar (light grey) and booklets of mica completely altered to aphrosideritic chlorite (black).
Plane polarised light. 60 X magnification.

Chlorite-Quartz-Sericite Stage II.

Approximately 4 metres from the lode the rock shows clear signs of alteration and replacement with 90% of the feldspar being sericitized (see Fig. 8). Fracturing is more intense than in the equivalent zone in section D, these fissures being completely filled with secondary chlorite which also occurs in the form of ragged flakes up to 0.2 mm in size interstitial to the quartz and sericitized feldspar. A small amount of fine-grained secondary quartz occurs interstitial to the sericite and it is interesting to note that apatite persists as a trace constituent of the rock (see photo overleaf).

Photo./...

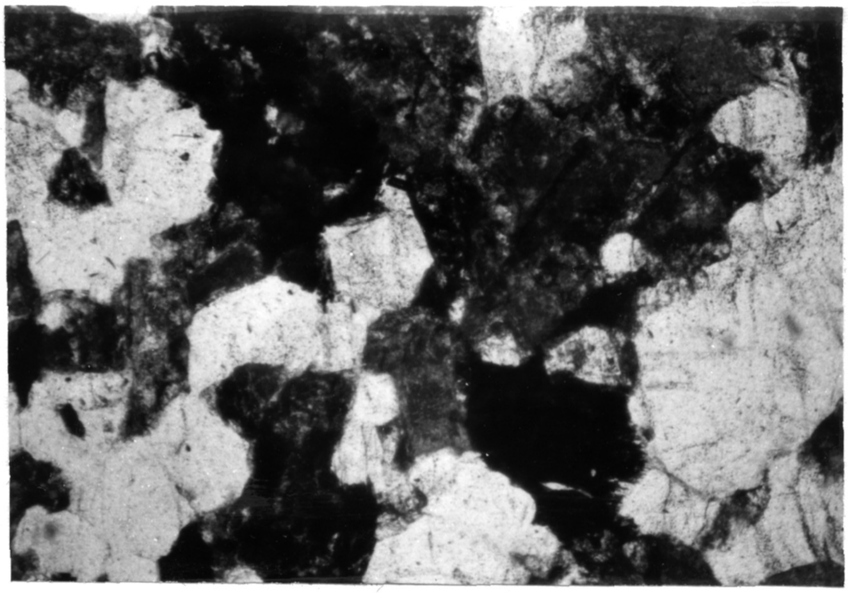
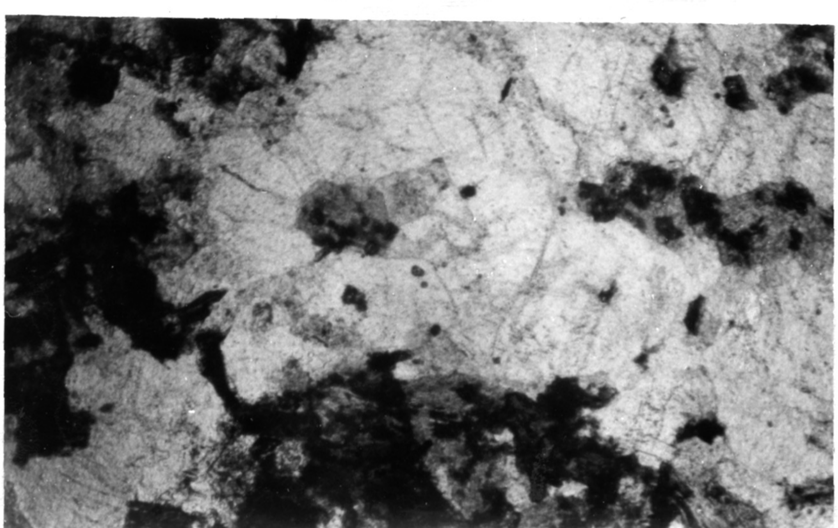


Photo No.29. Highly chloritized granite in the chlorite-quartz-sericite zone. The rock consists of quartz (white) intergrown with highly sericitized and kaolinized feldspar (dark grey) and chlorite (black) which has also been introduced into the rock along numerous fractures (top right hand corner). Plane polarized light. 60 X magnification.

Chlorite-Quartz Stage III.

In the proximity of the lode the wallrock is dark green and coarser grained than in the preceding section. This is due in the first instance to the abundant secondary chlorite which has been introduced into the granite and secondaly to the recrystallization of the quartz component. Chloritic replacement also extends to the sericitized feldspar where it is developed as a light green border to the crystals. It is interesting to note that kaolinization of the feldspar persists right up to the lode (see photo below).



In the./...

In the far eastern extremities of the ore lode, intersected by borehole 21 (Figure 7a, sections E,F) the lode consists of a few weakly mineralized chlorite-quartz veins flanked by a narrow highly chloritic alteration zone on both the northern and southern sides. The alteration envelope at this point was not deemed to be significant enough to zone.

CONCLUSIONS.

The detailed mineralogical analysis of the forms and sequence of alterations encountered along the northern flank of the Albert Lode show that a marked difference exists in the mode of alteration from east to west. It is also apparent that the alteration stages described under sections A to F bear a direct correlation to the predominant form of ore mineralization encountered along the lode (viz. quartz-hematite, hematite, hematite plus sulphides or sulphides. From the preceding section it is also apparent that while the intensity of alteration increases progressively toward the lode, that it is possible to divide the alteration envelope into a number of distinctive zones on a mineralogical basis. Such a zonation might be used to good effect were the body to achieve economic importance as it would provide an efficient means of providing easily delimited 'cuff-offs' if a study was made relating payeable ore values in the wallrock to the alteration zones.

7.4.3. Semi-Quantitative Mineralogical Zonation - Albert Lode.

The sequence and extent of wallrock alteration of the host granite, which consists essentially of quartz and feldspar, can best be appreciated by reference to Figure 8 in which the modal composition of the sections described in the previous chapter are plotted in semi-quantitative form . This diagram is briefly described in the section below (for further reference see Comparative Chemistry of the Wallrock).

Variations in Wallrock Mineralogy Outwards from the Lode.

Each stage of replacement described under 'mineralogy' enables the wallrock to be zoned into a number of distinctive areas. In each case Stage I represents the peripheral zone characterized by incipient alteration. Similarly Stages II and III are zones characterized by more intense alteration as the

lode./...

lode itself is approached.

Figure 8 makes it apparent that the primary changes brought about in the granite in the incipient stages of alteration (Stage I) are hydrothermal kaolinization and sericitization and some chloritization of the ferromagnesian constituents. Hematite which is found as a replacement mineral in the alteration zone does not occur in quantities great enough to be estimated in semi-quantitative x-ray diffractometric patterns and as a result hematite has not been plotted on the diagram.

In the zone intermediate to the lode (Stage II), the characteristic changes in the granite are intense sericitization which may be accompanied by the introduction of secondary silica and a little sericite. In addition, chlorite is the dominant alteration mineral of this zone in some parts of the lode while the proportion of clay minerals is considerably decreased due to their alteration to sericite. This zone grades into that of Stage III where the alteration effects are most severe. The change is accompanied by the appearance of abundant secondary quartz, the almost complete disappearance of kaolinized feldspar in favour of sericite and the introduction of either abundant hematite or chlorite into the wallrock dependant on whether the alteration sequence lies in the western or the eastern sectors of the lode. This zone is usually fractured to varying degrees.

Mineralogical Variations West-East.

While hematite-quartz, accompanied by later sulphides is the predominant ore of the western sector, sulphide mineralization increases eastwards along the lode. The type of wallrock alteration encountered shows a corresponding variation from west to east and might thus be used as a guide to the characteristic types of ore mineralization. Little west-east variation is apparent in Stage I (see Fig. 8) but in Stage II the intensity of alteration and replacement decreases from west to east. This factor is directly attributable to the intensity of mineralization which shows a similar decrease along the lode from west to east (Fig. 5). The persistence of heavy hydrothermally induced kaolinization into the intermediate zone adjacent to the western sector of the ore lode is also indicative of a less intense form of alteration which is in part due to the lower development of quartz-hematite accompanying this section of the lode.

The alteration./....

The alteration zone in the immediate proximity of the orebody is characterized by heavy hematitic replacement in the west (not indicated) and by chloritic replacement in the east, sericitization appears to be an effect directly attributable to heavy quartz-hematite mineralization. In the eastern sector of the alteration zone where alteration is largely attributable to quartz-chlorite-sulphide mineralization, the feldspar is usually incompletely sericitized.

7.4.4. Comparitive Chemistry of Replacement.

This section correlates the mineralogy of alteration described under section 7.4.2. with the chemistry of the same sections. Reference is made to Table No. 7 and Figures 7(a), (b).

Western Sector.

The western sector of the lode is represented by Figure 7, sections A and B. A comparison of the chemistry and mineralogy of this section of the lode shows that it is similar in all respects to the alteration sequence accompanying the minor and northern quartz-hematite type lodes.

Figure 7(b), sections A and B make it clear that the relative Si^{4+} content of Stage III is greater than 68 cations per unit cell which is attributable to the introduction of abundant secondary quartz into this part of the lode at the expense of sericite. The displacement of sericite in the minor zone of alteration is accompanied by a concomitant decrease in Al^{3+}, $Na^{+}$and K^{+} toward the lode. The outward migration of these elements as secondary sericite is attested to by the increase in Al^{3+}, Na^{+} and K^{+} reflected in the intermediate alteration zone. While an increase in Fe^{3+} content nearest the lode is borne out by hematitic replacement in section A, a similar increase is not shown by section B which is equally highly hematitized. This anomalous effect reflects the fact that besides straight replacement which involves no volumetric increase, the rock has also undergone extensive fracturing in section B with the result that the cationic ratio of the wallrock has been decreased from an average 95:160 to 89:160. Fe^{2+} shows no determinate trend while Mg^{2+} decreases toward the lode.

In the outer zones of alteration Mg^{2+} is mineralogically present as chlorite, its decrease toward the lode being due to the substitution of iron for

magnesium./...

magnesium Ca^{2+} is present in minor quantities and shows no increase or decrease through the alteration zone.

Ti^{4+} is also present in small quantities, however it displays a definite tendency to decrease towards the lode which stands in direct contrast to Si^{4+} and Fe^{3+} which, due to quartz-hematite introduction increase sharply in the proximity of the lode.

H^{+} in the form of hydroxonium ion tends to increase in the highly sericitized intermediate zone (Stage II) and to decrease in the proximity of the lode where the hydrous constituents of the granite such as micas, clay and sericite are replaced by hematite and quartz.

Central Sector.

It is interesting to note that the wallrock alteration accompanying the central sector of the lode appears to be due to hematitization unaccompanied by silicification. In consequence the chemistry and mode of wallrock alteration as shown by sections C, D, differs radically to that accompanying sections A and B.

Toward the lode there is a marked decrease in Si^{4+} accompanied by a corresponding increase in Fe^{3+} which, mineralogically can be interpreted as being due to the extreme replacement of the wallrock by hematite. Al^{3+} shows an anomalous increase towards the lode while Fe^{2+} shows a small decrease in the most intense zone of alteration which could be due to replacement of the minor ferro-magnesian constituents and iron ore by hematite as Fe^{3+} Neither sodium nor potassium show any significant change in cell content which can be accounted for mineralogically bu the fact that there has been no replacement of the sericitized portion of the rock.

None of the remaining elements show any significant trends apart from Ca^{2+} which shows a large increase in the proximity of the lode. A prime motive behind an examination of the zone of wallrock alteration has been to try and find correlations between the mineralogy of the ore lode and the type of alteration present, it is interesting to note that this increase in Ca^{2+} co-incides with that portion of the lode possessing the highest uranium values (see Fig. 4). This relationship is also borne out by the analyses of the northern lode where a similar

correlation./...

correlation appears to hold true. It is unsure whether the Ca^{2+} could in part be attributed to the presence of relatively abundant fluorite (CaF_2) in the lode.

Mid-Eastern Sector.

Section D reflects the hematite-poor nature of the altered rock adjacent to the mid-eastern sector of the lode which is relatively narrow at this point and consists of banded hematite and massive sulphides.

Silicification of the wallrock extends up to 10 metres away from the lode increasing the proportion of Si^{4+} per standard cell unit by 4 cations relative to that of the unaltered granite. The tendency towards silicic replacement in Stage III is accompanied by a corresponding decrease in Al^{3+} and Na^{+} toward the lode while Fe^{3+}, Mg^{2+} and K^{+} all show an overall decrease towards the lode. The latter three elements show a slight increase in the intermediate zone of alteration (Stage II) where they are probably related to the abundant secondary sericite and chlorite which occur in this zone.

In contrast to the preceeding sequences of replacement in which hematite has played a dominant role, being manifest as Fe^{3+}, there is no increase in Fe^{3+} content toward the lode.

H^{+} representing the hyroxonium ion shows an increase toward the lode which is also apparent in sections E and F, this can be directly attributed to the abundance of chlorite found both in the alteration zone and associated with the abundant sulphides of this portion of the orebody.

Eastern Sector.

The mineralogy and chemistry of sections E and F [Fig. 7(b), (a)] reflect that the dominant replacement minerals of this section of the wallrock namely chlorite and quartz are apparently related to the sulphide phase of mineralization of the body.

While there is little increase in the proportion of the Si^{4+} toward the lode the Fe^{2+} content of the wallrock increases by 0.52 cations per cell unit, a similar trend being followed by Fe^{3+}, Mg^{2+} which both attain maximum values in the second, intermediate alteration stage where they occur in the form of secondary

chlorite./...

chlorite. The increase in chlorite content is also reflected by an increase in H^+ toward the lode.

Chemical Zonation of the Alteration Zone and Conclusions.

The chemical analyses of the successive stages of replacement support the apparent mineralogical zonation of the wallrock in that the salient trends are silica and iron introduction with a corresponding outward migration of aluminium, sodium and potassium into the outer zones of alteration (Stages I and II). While the western sector is characterized by increases in Fe^{3+} and decreases in H^+ toward the lode, the eastern sector shows increases in Fe^{2+} as well as H^+ towards the lode.

By comparison Schwartz (1939) records that silicification is a common but by no means universal form of hydrothermal alteration, citing the Climax Molybdenum deposit U.S.A. as a typical example of this process. Ransome (1919) lends further support to the fact that silicification is often accompanied by sericitization as can be seen in sections A, B.

Schwartz' work also confirms that the nett result of hydrothermal alteration is a loss in Mg^{2+}, this change is reflected throughout the alteration zone of the Albert Mine. Reference to Figure 7(b) confirms too that the trend along the lode, especially in the western sector, is toward a decrease in potassium which according to Schwartz is fairly uncommon in hydrothermal alteration but is to be expected where silicification has taken place. In this instance he cites Ely, Nevada as an example of a deposit where the wallrock has been enriched in iron and silica with a corresponding decrease in potassium.

7.4.5. Fields of Formation of Alteration Minerals.

The data published by Stringham (1952) give a very limited and not necessarily accurate idea of the temperatures involved in the formation of the more characteristic alteration minerals such as kaolinite, sericite and chlorite.

Kaolinite occurs in the outermost zone of alteration but persists into the intermediate zone (Stage II) along the Albert Lode. From Stringham's data it is only possible to conclude that the mineral precludes temperatures of formation much higher than 350°C at the time and that its formation is indicative

of the./...

of the existence of an alkaline environment at the time.

The field of formation of sericite, which is a highly characteristic mineral of the intermediate alteration zone (Stage II) along the western sector of the lode, lies above 200°C but the mineral forms at temperatures higher than 350°C if an acid environment is present. However, if potassium is present, sericite may still form above 350°C even if conditions of low pH prevail. As no evidence exists that an acid environment prevailed it is most probable that sericite formed at a temperature below 300°C.

Although no idea is given of the pressures involved in wallrock alteration it can be imagined that these are considerable if temperatures of over 300°C have been attained by the wallrock during hydrothermal alteration. The fields of formation of chlorite are not given but it is interesting to note that it forms under pH conditions closely approaching neutrality.

8. SUPERGENE ENRICHMENT.

8.1. Discussion.

A survey of the literature reveals that many examples of supergene enriched silver deposits can be given, these include the famous bonanza deposits of the western hemisphere which extend through the United States, Mexico, Central America and along the western slopes of the South American Andes.

From an extensive examination of the ore assemblage of the Albert Mine it appears that the silver-bearing sulphides by themselves would be incapable of providing silver values as high as those encountered. In addition, the discovery of argentite and native silver suggest that the silver values encountered partly owe their existence to supergene enrichment. Proof of this is given in the following chapter showing that the course of mineralization of the Albert Mine has closely followed those described for the more famous supergene enriched silver deposits of the western hemisphere such as Zacatecas (Bastin 1941) and Chañarcillo - Chile (Whitehead 1919). Structurally the Albert Mine has followed the same sequence of events as Chañarcillo in that the ore bearing veins of hypogene origin have been reopened during periods of displacement subsequent to hypogene mineralization thus permitting erosion and weathering to redistribute the silver minerals in the lode.

The evidence presented in this section bears out the statement by Park and McDiarmid (1963) that the best examples of supergene leaching and enrichment are to be found in pyrite bearing silver and copper deposits.

8.2. Factors Favouring Enrichment.

Structure.

The downward percolation of supergene enriched solutions through the ore-body has been greatly facilitated by the periods of shearing which followed hypogene mineralization of the lode. This post mineralization movement has resulted in heavy fracturing of the ore both in the form of fracturing which has displaced the rock along previously sheared and mineralized planes as well as fractures which bear no relation to former zones of mineralization. Post mineralization displacement is most intense along the western sector of the lode, here numerous examples of supergene enrichment along the resultant shear planes and in solution cavities in this area are found.

Borehole 6 can be cited as a typical example as numerous solution cavities occur within the lode in this borehole. These often follow the path of veins mineralized by chalcopyrite and galena. The cavities in this section contain re-crystallized stacked galena cubes and covellite and bornite replacing chalcopyrite.

Hypogene Ore Assemblage and the Process of Enrichment.

A desirable condition for the process of supergene enrichment in silver deposits is that the ore assemblage present should contain either pyrite, chalcopyrite, marcasite or pyrrhotite. These minerals are necessary to the process of supergene enrichment by virtue of the fact that their oxidation yields sulphuric acid and ferric sulphate which are necessary for the leaching of copper, zinc and silver from the associated sulphide mineral assemblage.

Pyrite, arsenopyrite and chalcopyrite are all reasonably abundant in the lode and coincide in their distribution with the silver bearing ores tennantite, tetrahedrite and the sulphantimonides (see Fig. 9).

Examination of the surface zone of the mine as well as of samples derived from borehole intersections with the body at depths of 50 to 60 metres shows that minerals and salts corresponding to the various stages of supergene enrichment are all present.

In this investigation the supergene minerals are treated in order of their relationship to the process of supergene enrichment, namely from those present in the upper leached zone, through those occurring in the lower oxidation zone, to those present in the supergene sulphide zone. The latter zone includes secondary native silver.

Meteoric Water Supply and Water Table Level.

The extent to which supergene enrichment will take place is partially governed by the presence of oxidising sulphides and also by the necessary presence of meteoric waters capable of downward migration to the phreatic zone. By virtue of its location across the Moos river the western sector of the lode satisfies the latter condition perfectly. As the rock of the neighbouring environment especially the lode, is highly fractured, every opportunity is afforded to the solutions of downward migration.

As the deposition of secondary sulphides from supergene solutions depends on the solutions being neutralized it can be expected that deposition will take place immediately below the watertable where, due to reaction with carbonates and silicate minerals, the groundwaters will become alkaline.

Exploration of the three shafts sunk into the western sector of the lode showed that they are all flooded and thus provide an indication of the level of the watertable in the mine. This is about 20 metres below ground level. It is possible however that the oxidized zone has been carried to considerably greater depths by fluctuations in the level of the watertable which could be expected to accompany the not infrequent periods of drought which occur in the area. This is confirmed by the fact that on dewatering the mine minerals common to the oxidation zone, such as malachite, were found down to the 47 metre level. Due to its narrowness and distance away from the immediate vicinity of the river and also due to the fact that it is bounded on both sides by relatively impermeable granite, it is to be expected that the extent of supergene enrichment in the eastern sector of the lode should be considerably less than that in the western half.

It is interesting to consider that it is entirely fortuitous that the area of maximum shearing and lode width should coincide with the intersection of the lode with the Moos river which has thus played the role of an active agent in the process of enrichment.

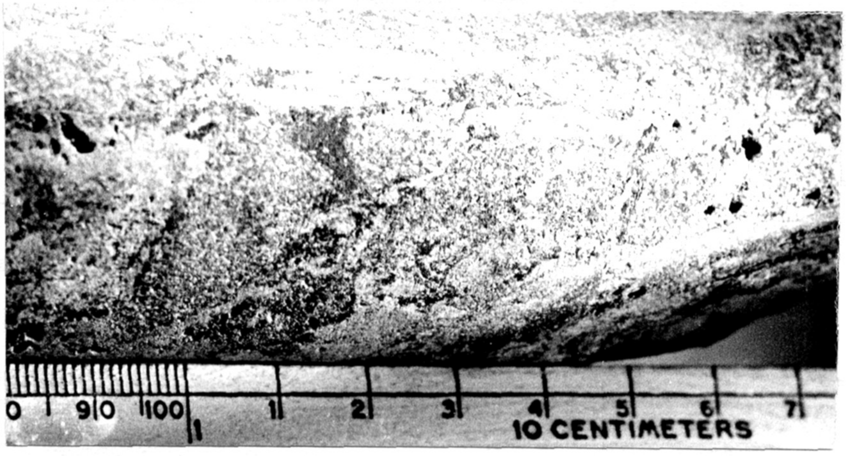


Photo No.30. Altered granite traversed by mineralized veins of quartz, calcite and chlorite riddled with dissolution cavities and vugs, some containing secondary quartz or bornite.

8.3. Secondary Minerals.

8.3.1. Supergene Oxide Zone.

Residual Oxides and their Formation.

Limonite.

The massive hematite portion of the lode has played the role of a passive host to the processes of oxidation and supergene enrichment which have affected the sulphide minerals within the body. At the same time the hematite has itself been very extensively altered to massive red brown limonite by oxidation. In the numerous smaller lodes in the area this limonite forms a typical crusty gossan which, relative to the granite, remains as a slightly raised hump on the surface.

Within./.....

Within the Albert Lode the massive hematite portions of the lodes contain much interstitial quartz and have not been as badly affected by alteration as those sections which consist of altered granite replaced by disseminated hematite, these portions are often entirely limonitized.

The surface of the lode is rough and consists of the typical boxwork structure common to deposits of this nature. The surface is divided up into many small irregular compartments formed by crosscutting veins of quartz running through the rock. These have resisted erosion better than the limonite. Limonitization of the lode is at its most intense in the proximity of the Moos river. Here the limonite is softer at the surface and more reddish in colour, drilling in boreholes 6, 26 and 14 shows that the process has almost completely replaced the hematite to depths greater than 30 metres

Photo No. 31. View of the lode on the west bank of the Moos river showing crumbly extensively altered limonitized hematite stained by residual oxides of As, Sb and Bi and cut by planes containing secondary growths of metazeunerite.

At this juncture it is well to mention that all the sulphides with the possible exception of galena have been leached out of the surface portion of the lode. Their former presence within the surface portion of the lode is indicated by cavities in quartz veins in the hematite which are often filled with bright red limonite. The oxidation of pyrite, arsenopyrite within the body probably proceeded according to the equation:-

$$2\ FeS + \frac{15}{2} O + 4H_2O = Fe_2O_3 + 4SO_4^{-2} + {}_8H^+$$

(pyrite) $4SO + 8H$

$$2\ FeS + \frac{15}{2} O_2 + H_2O + H_2O = Fe\ (SO_4)_2 + SO_4^{-2} + 2H^+$$

$SO + 2H$.

The resultant solutions contain sulphuric acid and ferric sulphate which would then have proceeded to leach out the elements copper, zinc and silver according to the following reactions (Park and McDiarmid p.419).

Chalcopyrite $2\ CuFeS_2 + \frac{17}{2} O_2 + 2H_2O = Fe_2O_3 + 2\ Cu^{2+} + 4SO_4^{-2} + 4H^+$

or, if an acid solution is already present,

$$CuFeS_2 + 4Fe^{+3} + 2H_2O + 3O_2 = Cu^{+2} + 5Fe^{+2} + 2SO_4^{-2} + 4H^+$$

Sphalerite $ZnS + 2Fe^{+3} + 3SO_4^{-2} + H_2O + \frac{3}{2} O_2 =$

$$Zn^{+2} + 2Fe^{+2} + 2H^+ + 4SO_4^{-2}$$

Silver bearing sulphides are dissolved in a similar fashion while the sulphantimonides go to form complex residual oxides.

Complex Bi, As, Sb, Pb Oxides.

Lead, bismuth and antimony are elements generally regarded as being relatively stable in the presence of ferric sulphate solutions in the oxidation zone. In the oxidation zone the breakdown of sulphide minerals containing these elements leaves them behind as stable oxides. By comparison the arsenates are relatively uncommon in the oxidation zone due to their relative insolubility.

Bands of yellow powdery oxides occur as veins through the hematite portions of the lode at the surface. These bands are most commonly found where the lode intersects the west bank of the Moos river. Analysis of this material shows that it consists of oxides of lead, bismuth, antimony and arsenic left behind after the removal of sulphur as sulphate ions, and the soluble cation components, of minerals such as tetrahedrite, tennantite and the sulphantimonides. Semi-quantitative X-ray spectrographic analysis shows that the oxides consist mainly of lead and bismuth ($\pm$ 60%) with a fair amount of antimony ($\pm$ 30%) and small quantities of arsenic and uranium ($\pm$ 10%).

Photo No. 32. Vein (light grey) of complex, poorly crystalline Pb, Bi, As, Sb oxides in limonitized hematite (banks of Moos river).

If these veins formerly contained silver bearing sulphides it is apparent that the silver would have been removed in solution by sulphuric acid and ferric sulphate solutions to be re-deposited at depth. This process, where present, is facilitated by the presence of abundant ferrous sulphate which reduces the silver ion according to the following exchange reaction.

$$2Ag^{+} + 2Fe^{+2} = 2Ag + 2Fe^{+3}$$

In its new form the silver is deposited in its native form as is supported by the ore microscopic study of the body. (Further work on silver enrichment see section 8.3.2.

Lindackerite-type Mineral $Cu_5 As_4 O_{15} . 9H_2O$.

Under 'Mode of Emplacement' it was pointed out that the sulphide minerals are frequently distributed as discrete bodies through the sheared hematite ore. The discovery of a hydrated copper arsenite phase tends to show that the ferric arsenic sulphide, arsenopyrite, is not always completely oxidized but can form complex hydrated oxides of copper and arsenic where the right conditions exist in the orebody, it would appear that the isolated discrete particles of arsenopyrite are prone to this form of oxidation.

The lindackerite./...

Photo No. 32. Vein (light grey) of complex, poorly crystalline Pb, Bi, As, Sb oxides in limonitized hematite (banks of Moos river).

If these veins formerly contained silver bearing sulphides it is apparent that the silver would have been removed in solution by sulphuric acid and ferric sulphate solutions to be re-deposited at depth. This process, where present, is facilitated by the presence of abundant ferrous sulphate which reduces the silver ion according to the following exchange reaction.

$$2Ag^{+} + 2Fe^{+2} = 2Ag + 2Fe^{+3}$$

In its new form the silver is deposited in its native form as is supported by the ore microscopic study of the body. (Further work on silver enrichment see section 8.3.2.

Lindackerite-type Mineral $Cu_5 As_4 O_{15}. 9H_2O$.

Under 'Mode of Emplacement' it was pointed out that the sulphide minerals are frequently distributed as discrete bodies through the sheared hematite ore. The discovery of a hydrated copper arsenite phase tends to show that the ferric arsenic sulphide, arsenopyrite, is not always completely oxidized but can form complex hydrated oxides of copper and arsenic where the right conditions exist in the orebody, it would appear that the isolated discrete particles of arsenopyrite are prone to this form of oxidation.

The lindackerite./...

The lindackerite is turquoise blue in colour and at magnifications of X10 show that it is reniform in habit occurring as an overgrowth and lining to subhedral cavities in the hematite. Heating to temperatures in excess of 100°C turns the mineral white due to dehydration.

X-ray powder diffraction shows that the mineral is highly crystalline and that it possesses a structure closely parallel to that of lindackerite possessing the same d spacings for its strongest intensity lines. Qualitative X-ray spectrographic analysis shows that the major components of the mineral are copper and arsenic with a small amount of iron.

<u>Metazeunerite</u> $Cu(UO_2)_2\ (AsO_4)_2.8H_2O$.

From the ore mineralogical study of the body at the 60 metre level it is apparent that the high uranium values along the western sector of the lode can be attributed to the presence of pitchblende which probably bears some relation to the hematite.

Subsequent radiometric traverses along the surface of the lode revealed extremely high superficial radioactivity within the lode for a distance of 70 metres west of the Moos river. This high radioactivity is due to the presence of the secondary uranium mineral metazeunerite, which is described for the first time from South Africa.

The mineral is found in the form of small leek green flakes along parting planes in both the massive specularite and in quartz-hematite veins. The flakes have probably formed as the result of the reaction of copper and arsenic-bearing solutions with accumulations of uranium-bearing solutions leached out of the hematite into partings and fissures. The flakes have a mica-like appearance and are fairly soft.

The mineral occurs as individual crystals and in the form of rosette-like clusters of square, tabular flakes. When weathered the metazeunerite becomes amorphous and resolves itself into a light yellow-green powdery uranium oxide.

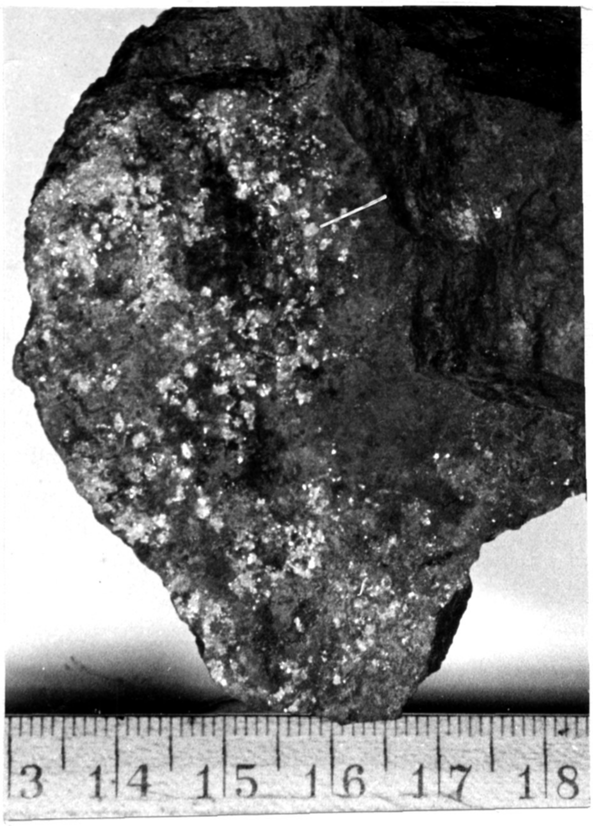


Photo No. 33. Clusters of metazeunerite flakes (white arrow) on a cleavage plane through hematite. (scale cms).

The mineral occasionally occurs as a dense composite layer of crystals up to 0.7 mm thick on the cleavage planes. X-ray spectrographic analysis reveals that the major components of the mineral are copper, arsenic and uranium with a trace amount of lead which is probably due to radioactive decay.

X-ray Analytical and Optical Data.

A pure fraction of the mineral, hand picked from a metazeunerite concentrate, was used to determine the X-ray and optical parameters of the mineral. The mineral was X-rayed in a 9 cm Debye Scherrer camera using the Straumanis position of projection after which the resultant photographs were stabilized in an airconditioned room prior to measurement. All measurements were carried out with the aid of a vernier scale and were subsequently corrected for shrinkage. Line intensities given are visual approximations. The resultant data is presented in Table No. 8 with the d spacings recorded for metazeunerite from the Anton Mine, Germany for comparison (Card 17 - 146 of the Kwic X-ray Powder Data File). The optical characteristics recorded for the mineral are presented in the same table.

Malachite./...

Malachite $CuCO_3.Cu(OH)_2$.

Secondary malachite is a common occurrence within the western sector of the orebody from the vicinity of the dolerite dyke to borehole 26. The mineral occurs abundantly at the surface as thin green layers along cleavage planes and faults in the outcrop of the lode. The mineral has probably been formed from cupric sulphate solutions derived from the chalcopyrite in the body which have reacted with the abundant carbonate veins which cut through the ore lode according to the equation

$$2Cu\ SO_4 + Ca\ CO_3 + H_2O = CuCO_3.Cu(OH)_2 + Ca^+ + 2SO_4^{-2}$$

(copper solution) (carbonate vein)

In some of the wider cavities in the lode the mineral assumes its characteristic growth structure and can be found as botryoidal overgrowths on the hematite. The individual lumps consist of concentric depositional shells of malachite.

Azurite $2CuCO_3.Cu(OH)_2$.

A small amount of this deep azure blue mineral is found at the surface of the lode in association with malachite and was undoubtedly formed in a like manner.

Copper Sulphate Penta Hydrate $CuSO_4.5H_2O$.

Copper sulphate salts are found within the oxidation zone and as coatings on pieces of sulphide ore lying in the moist ground in the vicinity of the Moos river. Copper sulphate pentahydrate is formed by the crystallization of copper bearing solutions and can thus be taken to be evidence that supergene enrichment is still active and in the process of leaching copper out of the oxide zone of the orebody. In the normal course of events the copper sulphate solutions would go to form secondary chalcocite, covellite and bornite in the supergene sulphide zone below the water table. The mineral (salt) also forms as a pale

blue-white./...

blue-white crust over the surface of exposed ore. The mineral is triclinic, optically -ve and highly crystalline and was identified from X-ray data.

Photo No. 34. A crusty overgrowth of copper sulphate penta hydrate (grey-white) over sulphide rich hematite ore.

8.3.2. Supergene Sulphide Zone.

The supergene sulphide zone extends from approximately the 20 metre level in the body downwards. As is to be expected from the foregoing sections it is apparent that this zone is more extensive and probably extends to a greater depth in the western sector of the lode than in the eastern sector. This conclusion is borne out to a certain extent by the chemical analyses and graphs plotted for copper, lead and silver distribution in the lode at the surface, 50 metre, 120 metre and 160 metre levels (Table Nos. 3, 5, Fig. No. 6). These results are dealt with under silver mineralization.

Secondary Minerals of the Supergene Sulphide Zone.

Covellite, Chalcocite, Bornite.

Very small quantities of covellite, bornite and chalcocite were detected within the supergene sulphide zone. These minerals all replace chalcopyrite.

Native Silver./...

Native Silver.

a) Discussion.

From the section on ore mineralization it is clear that native silver occurs within the main ore zone at the supergene sulphide level. The occurrence of silver as minute blebs disseminated through the hematite tends to support the theory that it is of secondary origin. In an attempt to provide proof that the deposit definitely has undergone supergene silver enrichment chemical analyses for silver and lead were carried out on numerous samples representative of various levels within the body. This work forms the basis of the following sub-section.

b) Variations in Lead/Silver Ratios.

This exercise is based on the fact that silver sulphides are soluble in acid solution and are thus relatively easily leached out of the oxidation zone. Lead in contrast is relatively unsoluble and thus tends to remain within the oxidation zone. It is therefore obvious that silver:lead values should be higher in the zone of supergene enrichment if silver has been leached out of the oxidation zone and redeposited below the watertable.

Samples representative of the main ore zone in each borehole were analysed for silver, lead and copper (Table No. 4). The results have been combined to arrive at mean values for silver, lead and copper for both the western and eastern sectors of the lode. This was done for the values representative of the oxidation as well as supergene sulphide zones. The ratios of silver to lead and lead to copper are presented in Table No. 3. In Figure No. 6 the ratios have been plotted in graphical form for ease of interpretation.

Figure 6 makes it clear that there is a definite relative increase in silver over lead with depth in both the eastern and western sectors of the orebody. Although the relative increase in silver over lead is greater for the eastern sector the actual silver content is greater in the western sector (Table 4). When it is borne in mind that the actual lead content of the western sector of the lode is far greater than in the eastern sector, the relative increase in the ratio of silver to lead from 0.01 to 0.13 in the eastern sector of the lode is the more spectacular and provides graphic proof that the supergene sulphide zone has been considerably enriched in silver.

The values provided by the deflection boreholes show that the silver/lead ratio for the western sector increases down to the 120 metre level where it is 2.6:1. Within the eastern sector of the lode the ratio of silver to lead tends to decrease from the 60 to the 160 metre level. This can be interpreted to mean that the zone of supergene enrichment extends to a greater depth within the western sector of the Albert Lode than in the eastern sector. The relative increase in silver content with depth is greater in both boreholes when it is considered that the actual percentage of lead present at the 120 and 160 metre levels is higher (Fig. 4) at 0.65% in borehole 1 and 0.59% in borehole 3 (17), than at the 60 metre level.

In conclusion it is felt that the exercise shows that the economic silver content of the orebody is the direct result of supergene enrichment and that at depth the silver bearing sulphides probably have a relatively low silver tenor. Factors such as intense post mineralization shearing, proximity to the Moos river and size of the lode in the western sector have all contributed to the extent of supergene enrichment which appears to extend to below the 120 metre level in this section. In contrast it would appear that supergene enrichment of the eastern sector of the lode does not extend deeper than the 160 metre level where the silver content is indicative of a relatively silver poor protore.

A consideration of the lead/copper ratios in Table 3 shows that a trend similar to that for silver/lead holds true for copper mineralization as well. At the 60 metre level there is an increase in the ratio of copper to lead in both sectors of the lode. At greater depths the trends followed by lead/copper ratios show that the relative copper content increases in the western sector and decreases in the eastern sector in a fashion exactly similar to the trends recorded for silver/lead. This appears to be further proof that the zone of supergene sulphide enrichment extends to a greater depth in the western sector of the lode than in the eastern half.

Photo No. 35./...

Photo No. 35.

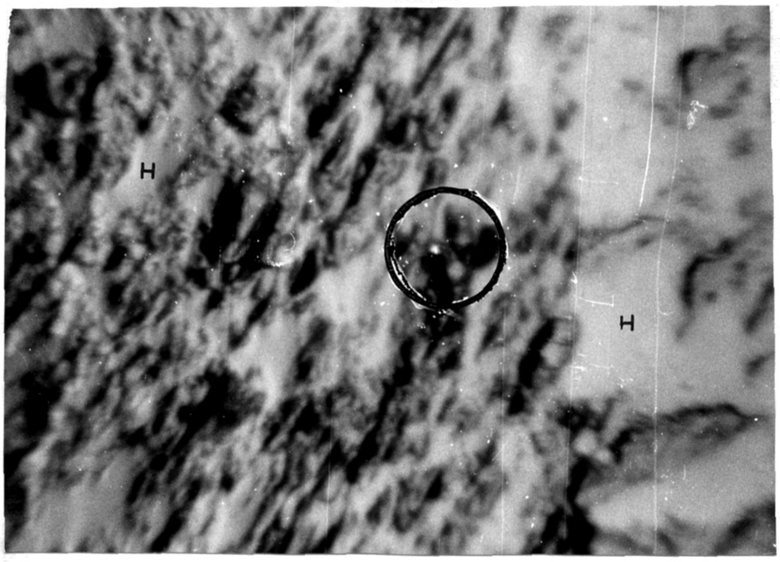


Photo No. 35. A minute speck of native silver (ringed) contained within the specular hematite (H). 3000 X magnification.

8.3.3. The Mutual Behaviour of Copper, Lead, Zinc.

Discussion.

The mutual behaviour of copper, lead and zinc in the orebody have been examined in the light of chemical and mineralogical affinities, supergene enrichment and ore mineral assemblage of the body. Although this sort of treatment is common practice in normal petrology very few studies of sulphide mineral assemblages have included such a treatment. A noteable exception is the study made by Stanton (1958) of the mutual behaviour of the three elements from sedimentary sulphide deposits. The three elements are considered together and plotted, as molecular percentages on triangular diagrams (see Table No. 6 and Figs. 1a, b, c).

Interpretation of Results.

Leaching and differential solubility have strongly influenced the ratios of copper, lead and zinc found in the supergene oxidation and supergene sulphide zones of the ore lode. In addition it can be seen from Figures 1a, b, c, that the proportion of zinc to lead and copper is relatively insignificant with the result that the copper, lead, zinc values are clustered along a line between copper and lead.

Comparison of figures 1b and 1c show that the copper/lead ratio increases with depth in the western sector, represented by cluster 'A' for the oxidation zone and by the indicated values for the supergene sulphide zone. Zinc shows no significant change relative to lead and copper although it appears that the ratio zinc:copper and lead decreases with depth possibly as the result of leaching and transport of zinc out of the body by supergene solutions.

The values recorded for the supergene oxidation zone are based on representative samples obtained from percussion drill holes evenly spaced from west to east along the surface of the lode. These holes were drilled to an average depth of 15 metres. On the triangular diagram (Figure 1b) these values cluster around three points designated as A, B and C. Cluster A represents samples along the western sector of the lode, the high lead:copper and zinc values probably being the result of supergene leaching as is shown in the comparison of these results with those of the supergene sulphide zone. The ore assemblages present in the supergene sulphide zone confirm that galena and chalcopyrite are both present in this section although higher copper values than were recorded could have been expected as this portion of the body has also undergone mineralization by primary bornite (Fig. No. 1a) This tends to confirm that the western sector of the zone has undergone a high degree of supergene enrichment.

Clustering C represents samples along the western sector in the immediate vicinity of the Moos river. Their high copper values appear to be completely anomalous when considered in the light of the preceding evidence which tends to support the theory that the western sector has suffered severe supergene alteration. The values can most likely be attributed to the presence of abundant malachite and azurite which are distributed through the oxidation zone at this point.

Copper/lead/zinc values falling in Cluster C represent samples from the eastern and western extremities of the lode. Their copper/lead/zinc ratios correspond closely to those recorded for the lode in the supergene sulphide zone.

Although zinc shows no significant trend in either the oxidation or supergene sulphide zone, a noteable exception is provided by Analysis 5 representative of the 160 metre level in the ore lode. This high zinc value is directly attributable to the increased sphalerite content of the lode with

depth./...

depth and towards the eastern end of the orebody.

In Figure 1(c) the copper/lead/zinc values obtained from a series of percussion holes along the length of the northern lode have been plotted. The resultant diagram indicates that the values show a grouping between the limits Cu:Pb:Zn = 84.4:14.4:1.2 and 66.0:33.7:0.3. This localization occurs around a point entirely dissimilar to any plotted for the supergene oxidation zone of the Albert Lode where the three clusterings in Figure 1(b) indicate dissimilar conditions of supergene activity at the surface of the lode. Considering the clustering of values for the northern lode in conjunction with the relatively high ratio of copper to lead and zinc it would appear that supergene enrichment has not taken place to any extent in the body.

Although the northern lode has not been studied in any detail, the localization of molecular percentage values for the length of the body may be an indication that the small quantity of sulphides contained in the orebody are evenly distributed throughout its length.

9. POST MINERALIZATION INTRUSIVES.

9.1. Discussion.

Roodepoortjie and its surrounding environs are situated in an area of the Bushveld granite which has been subject to post mineralization intrusion by diabase dikes. The intrusives are emplaced along north-south trending fractures and are post Bushveld in age and possibly pre-Waterberg.

9.2. Distribution.

The only diabase outcrop in the vicinity of the Albert Mine is that of the large dike shown on the map which trends north north-west to south south-east and which transects both the Albert and minor intermediate lodes. This body appears to have been vertically emplaced and crops out as dark grey, rounded outcrops which stand only slightly higher than the level of the surrounding country. It is cut by the Moos river north of the eastern sector of the Albert Lode where numerous outcrops are exposed in the partially dry river bed. The western sector of the Albert Lode is displaced 30 metres to the south relative to the eastern half along a north-south line formed by the dike, this displacement is also noticeable where the dike cuts the intermediate lodes but to a lesser degree.

Horizontal drilling in the old workings revealed that the main dike has a number of tonguelike offshoots which have intruded along vertical fissures in the lode. These tongues extend to depth, the offshoot along the western sector of the lode being intersected by borehole 4 at 60 metres and by the deflection of borehole 1 at a depth of 115 metres.

Accurate plotting of the points of intersection of the boreholes with this minor body shows that the offshoot is sinuous in the vertical sense. It deviates from a position immediately north of the main lode at the 60 metre level, to a position within the southern flank of the main ore zone at 115 metres. The offshoots are constant in width and it can be expected that the ore zone has undergone a number of minor displacements as a result of their intrusion. The offshoot along the western sector of the lode has insinuated itself along the centre of the ore zone in the vicinity of borehole 28 but it swings north of the lode in the vicinity of borehole 14 where it cuts through the alteration zone to a point 6 metres south of the collar of borehole 14. The tongue maintains a constant width of from 1.5 to 2 metres throughout its length.

Along the eastern sector a vertical tongue-like offshoot intersects the lode in the vicinity of borehole 5 which may mean that it has its point of origin in the main dike either north or south of the lode. This body is forked and cuts the lode as two minor shoots 0.3 and 1.5 metres in width respectively.

9.3. Petrography.

Petrographic examination shows that the north-south dike is a diabase which has been lightly altered. A prominent feature of the dike is the development of blackish-green chilled margins up to 0.3 metres in width along the flanks. The dike becomes coarse-grained and highly porphyritic towards the centre.

In hand specimen the rock varies in colour from light to dark grey and consists of grey-white feldspar crystals set in a blackish-green matrix of pyroxene, iron ore and a little chlorite. The chilled margins of the diabase are

often./...

often porphyritic and contain clusters of feldspar crystals up to 1.5 cm in length set in a dark, fine-grained groundmass.

Microscopically the diabase is holocrystalline with an average granularity of approximately 2 mm. The rock possesses a sub-ophitic texture and is composed of an intermeshed field of feldspar laths set in a matrix of augite and pigeonitic pyroxene.

Generally the pyroxene only partially encloses individual feldspar crystals but occasionally it is found in ophitic intergrowth with the pyroxene. The feldspar as optically determined using the Michel Levy method is of labradorite An_{59} composition and occurs both as phenocrysts and in the groundmass. The laths are usually regularly terminated and are twinned according to the carlsbad, albite and pericline laws. Zonary extinction is a feature of many of the crystals. This effect is well developed in the phenocrysts where the individual compository layers are clearly defined.

The phenocrysts usually occur as sub-radial aggregates and are often slightly sericitized along their borders. In the groundmass the feldspar is lightly altered to sericite which occurs as fine-grained overgrowths on the crystals.

Augite and pigeonite are both present in the rock and have ZV angles of 49° and 22° respectively, the minerals occur as short stumpy zoned crystals from 0.1 to 0.5 mm in size. Small anhedral crystals of olivine less than one millimetre in diameter make up less than 3% of the rock. The olivine is extensively altered to a brown-green chlorite along its margins.

Accessory minerals are limited to trace quantities of magnetite and apatite. The marginal chilled zones have a granularity of less than 0.2 mm and contain abundant finely disseminated magnetite. Fine fissures filled by calcite and quartz form an extensive network through the rock. These minerals have pervaded late stage shear zones which have dislocated both the ore lode and the alteration zone.

9.4. Chemistry.

Owing to the fact that cost restricted the number of chemical analyses which could be performed, only one analysis of the diabase was carried out. The sample selected was purposely chosen from the offshoot along the western sector of the lode so as to illustrate the effect of post intrusive weathering on the diabase. The sample analysed was sheared and contained fine veins of calcite together with a little quartz. The results of the analysis appear in Table No. 2.

9.5. Contact and Post-Intrusive Effects.

The diabase offshoots provide a convenient index to the weathering effects and dislocatory movements which followed their emplacement and which have affected the ore lode. In addition the diabase contains two types of inclusions of the host rock, these are described below as they illustrate the type of alteration undergone by ordinary granite and granite altered by hydrothermal solution when it is assimilated by diabase.

Inclusions.

Rounded, highly digested inclusions up to 3 cm in size are found within the chilled margins of the offshoots. These inclusions are of a xenolithic nature and display shadowy remnants of granitic texture although they are now highly chloritized. These inclusions are probably fragments of the Bushveld granite.

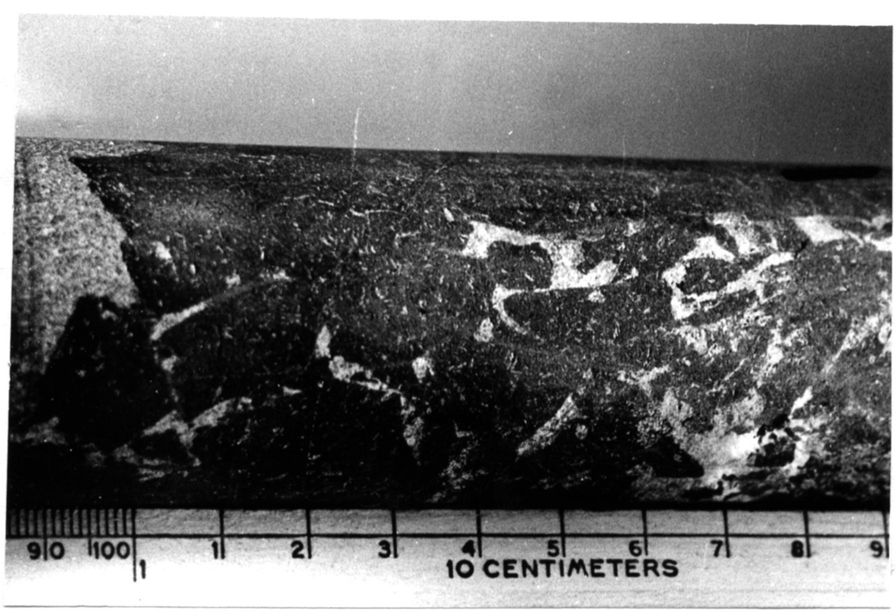


Photo No. 35. Chilled zone of a diabase offshoot along the Albert Lode showing an inclusion of altered wallrock (extreme left) and abundant calcification along post intrusive shear planes.

Irregular,/...

Irregular, jagged inclusions of rock derived from the alteration zone are also found included in the chilled margins. This rock consists of quartz and sericite and has suffered very little in the way of further alteration apart from mild chloritization.

Brecciated Contacts.

In borehole 10 a thick vertical diabase dike was encountered striking parallel to the Albert Lode. The body has a fine-grained chilled margin and is bordered by a zone of highly brecciated altered granite consisting of disaggregated quartz fragments set in a brown, highly chilled and chloritized diabasic groundmass. This zone is about 4 cm wide and grades into heavily silicified altered granite.

10. PARAGENESIS.

The postulated time sequence of hypogene mineral deposition in the Albert Mine is given in tabular form below, followed by a summary of the evidence favouring such a paragenesis.

	Ore Minerals	Associated Gangue
Youngest		
	Galena, chalcopyrite,	
	sulphantimonides.	Quartz, siderite
	Galena, bornite.	chlorite, calcite
	Sphalerite.	fluorite.
	Tennantite, tetrahedrite.	
	Molybdenite	Quartz, fluorite, chlorite.
	Arsenopyrite, pyrite.	Quartz.
Oldest	Pitchblende.	Quartz, fluorite.
	Hematite	Quartz.
	Magnetite	

That the above paragenetic sequence is related to a succession of dislocations which disrupted the ore lode is strongly supported by the frequent occurrence of cataclastic fragments of the older ore minerals entrained in veins of younger sulphides which cut through the hematite portion of the body.

Magnetite is the oldest mineral found being replaced by specular hematite accompanied by an intergrown quartz gangue. It also appears possible that

pitchblende./...

pitchblende, accompanied by quartz and fluorite, was deposited soon after hematite with which it appears to enjoy a ubiquitous relationship both spatially and chemically. Pyrite and arsenopyrite are clearly younger than hematite occurring as they do in multiple vertical veins which cut through the hematite. Besides showing clear crosscutting relationships with hematite, fragments of hematite and magnetite are also found entrained in quartz veins containing euhedral pyrite and arsenopyrite. From the intergrown nature of the two minerals it would appear that they are contemporaneous, almost simultaneous phases in the paragenesis. Fluorite and chlorite gangue first appears accompanying molybdenite which is clearly younger than hematite as it occurs in thin veins cutting through the altered wallrock where the alteration is definitely the result of hematite introduction. As no definite relationships could be established between pyrite, arsenopyrite and molybdenite, molybdenite has been placed in the paragenetic position suggested by Lindgren, namely later than arsenopyrite and pyrite.

Tetrahedrite and minor tennantite probably occupy a position in the paragenetic sequence between older pyrite and arsenopyrite and younger sphalerite, bornite and chalcopyrite. In polished section the only relationships which could actually be proved were that the tetrahedrite was younger than bornite and chalcopyrite, both of which occurred replacing it. Although it could not be definitely proved it is in all probability likely that the next mineral to be deposited was sphalerite followed closely by the simultaneous deposition of galena and chalcopyrite in the eastern sector and by bornite and galena in the central sector of the lode. It would appear that bornite was deposited slightly before chalcopyrite as bornite being enclosed by chalcopyrite is found in the western sector of the lode. In addition to quartz, chlorite, calcite and fluorite, abundant sideritic gangue accompanies the deposition of galena, chalcopyrite and sphalerite in the eastern sector of the lode.

Deposition of the lead bismuth sulphide mineral appears to have been contemporaneous with chalcopyrite and galena, with which it is found intergrown in the eastern sector of the lode. Owing to their scarcity it is not possible to assign a definite position to argentite or tennantite short of stating that they were probably deposited late in the paragenesis. It is also most probable that argentite is not hypogene but supergene.

Short./...

Short of providing a list of the supergene minerals that occur in the lode it is not possible to submit a relative age relationship between them as these minerals were never found in quantities great enough for relative determinations. It therefore suffices to say that malachite, azurite, bornite, covellite, lindackerite, limonite, metazeunerite and possibly argentite are all minerals of secondary origin derived from the hypogene ore minerals.

11. CLASSIFICATION.

Discussion.

It is singularly appropriate in a study of this nature that the classification should be one of the last portions of the work to be dealt with as it is in essence based on conclusions which could only be arrived at on completion of the work. Each chapter has contributed a number of facts which, when taken together, provide a useful means of classifying the orebody.

Classification.

The salient facts on which the classification is based are metallogenetic province, mode and type of emplacement, characteristic ore assemblage, associated gangue minerals, characteristic wallrock alteration and temperature of formation.

Structurally the lode is centered on a highly sheared zone containing both breccia and rock gouge. Mineral emplacement took place mainly by open space filling during a number of successive periods of movement which re-opened new mineralization channels through the lode. Mineralization also occurred to a minor extent by replacement of the wallrock. Park and McDiarmid cite these features as being characteristic of the mesothermal environment.

The process of emplacement outlined above furthermore explains the occurrence within the Albert Lode of some minerals more typical of the hypothermal zone which are found in the early stages of the paragenesis of the body. These minerals are magnetite, specularite and molybdenite. In contrast the occurrence of pyrite and arsenopyrite is cited by Park and McDiarmid (p.269) as being a feature common to both the hypo and mesothermal environment. The occurrence of bornite, tennantite and tetrahedrite are firmly indicative of mesothermal

conditions./...

conditions while argentite is more commonly associated with epithermal conditions. This range of minerals, when taken as a whole, are indicative of typically mesothermal conditions, the mesothermal zone being an intermediate rather than a distinctive zone. The gangue mineral assemblage is also consistent with the theory that the orebody should be regarded as being of the mesothermal type. Quartz and a limited amount of fluorite are the only gangue minerals found accompanying the early phases of mineralization and by themselves do not afford much indication of the early temperatures or pressures of formation undergone by the body. However, chlorite and siderite in association with quartz and minor quantities of fluorite and calcite are the predominant gangue minerals accompanying the intermediate to late stage sulphides. These minerals form a gangue mineral assemblage which is typical of the mesothermal type of deposit.

Both structurally and mineralogically the body shows numerous similarities to some of the more famous silver bearing mines such as those found in the Coeur d'Alene district, Mexico, e.g., the Polaris Mine. (McKinstry 1942, Sorenson 1947). The deposits of this area are cited by Park and McDiarmid as being typical examples of ore emplacement in the mesothermal environment. Wallrock alteration accompanying the early stages of mineralization is predominantly by silicification and sericitization while chloritization and silicification accompany the later stages of mineralization. The known fields of formation of sericite and kaolinite (Stringham 1952) support the idea that the environmental temperature at the time of formation of the body was in the order of approximately 250°C. Park and McDiarmid p.289 state that the ores of the mesothermal environment are deposited at about 200 - 300°C.

12. CONCLUSIONS.

A definite age cannot be assigned to the ore bodies, it is only possible to say that they are post Bushveld in age and that they are transected by a younger diabase dike of post-Bushveld age.

During the period following on the consolidation of the Bushveld granite the area was subjected to a series of displacements which resulted in a set of east-west trending shear planes which were to a certain extent localized by the structural dissimilarities which exist between the older coarse-grained and

younger./...

younger fine-grained phases of the granite. This localization of shearing has come about as a result of the difference in texture and hence physical properties of the two granite types at their contact. The nett effect has been the production of zone of potential shearing in adjustment to any stress which has been imposed on the granite. Strauss and Truter (1954) cite the occurrence of similar quartz-hematite bodies along contacts between the Bobbejaankop and main granites in the Potgieterus tinfield area. These disjunctures acted as access channels to the post-magmatic ore fluids of the granite which must initially have been rich in iron and silica giving rise to specularite with a small amount of magnetite and accompanied by quartz.

This hematite-quartz phase of mineralization resulted in the characteristic quartz-sericite form of alteration zone accompanying the larger lodes and it is possible that uranium mineralization occurred either simultaneously with, or very closely after hematite introduction.

It is interesting at this point to speculate on the probable mechanism whereby the ore fluids were formed and which resulted in their emplacement. If the collector mechanism outlined by A.B. Edwards (1956) is to be accepted it is possible that the sulphides of the common metals are stripped out of the ore chamber and concentrated in granitic masses, such as the Bushveld granite, by gases at very high pressure. Subsequent to the initial concentration of the volatile substances a state of tension is believed to have developed into the solidified portion (Hood-Emmons 1924) of the granite which eventually led to fracturing in the roof of the granite with the escape of the volatile sulphide bearing concentrations upwards. This theory was first proposed by Emmons in 1924.

In the Albert Mine deposition of hematite was followed by a further series of dislocations at which time the sulphide ores were deposited. These later dislocations resulted in the extension of the lode eastward of the earliest section which had been mineralized by hematite. This accounts for the persistence of sulphide ores unaccompanied by much hematite in the eastern extremities of the lode.

Deposition of the ore minerals has largely followed the accepted paragenetic sequence and in addition the body appears to show a slight amount of local zonation from east to west with high zinc values in the east, high copper in the centre and high silver in the west.

The ore assemblages described include a number of potential silver-bearing base minerals which however are insufficient in themselves to account for the quantities of silver found to be present in the body. After deposition of the ore minerals the body was subjected to further shearing movements unaccompanied by mineralization. The body has also been dislocated by a north south fault movement which is probably related to the intrusion of a vertical diabase dike along the resultant plane of dislocation.

At at much later stage lowering of the overall topography by erosion resulted in exposure of the ore bearing granite and superimposed a younger drainage pattern on the area. The resultant abundant meteoric water as well as the many fractures in the ore lode itself have resulted in a large amount of supergene enrichment of the body, particularly in the western sector where a small but economic concentration of secondary silver has been produced. This extends to a depth of at least 120 metres in the western sector.

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T A B L E S.

TABLE NO. 1.

CHEMICAL COMPOSITION OF FINE AND COARSE GRAINED BUSHVELD GRANITE.

%	1	2	3	4
SiO_2	73.56	76.54	72.76	71.90
Al_2O_3	12.50	10.99	15.11	13.84
Fe_2O_3	0.78	0.53	1.41	2.59
FeO	1.97	1.82	0.96	1.31
MnO	0.06	0.03	0.06	0.06
MgO	0.40	0.23	0.32	0.44
CaO	0.63	0.49	0.01	0.01
Na_2O	3.79	2.93	1.55	3.56
K_2O	4.94	5.07	6.09	4.08
TiO_2	0.49	0.32	0.43	0.60
P_2O_5	0.09	0.18	0.28	0.21
CO_2	0.20	0.23	0.11	0.35
$\pm H_2O$	0.56	0.49	0.83	1.01
Cu	0.01	0.03	0.01	0.01
Pb	0.01	0.10	0.04	0.01
Zn	0.01	0.02	0.03	0.02

Specimen No.	Location	Granite type
1	Borehole 5	Fine, even grained. Lightly sericitized.
2	Borehole 7	Medium to coarse grained,
3	Borehole 27	Fine grained. Slightly decomposed.
4	Borehole 25	Medium grained, porphyritic.

N.B. All analyses recalculated to 100 per cent.

Analyst: N. Bailey.

TABLE NO. 2./.

TABLE NO. 2.

CHEMICAL COMPOSITION OF A TYPICAL MINERALIZED DIABASE OFFSHOOT.

Element	Percentage
SiO_2	37.19
Al_2O_3	18.03
Fe_2O_3	3.75
FeO	15.42
MnO	0.82
MgO	5.03
CaO	5.41
Na_2O	3.33
K_2O	1.03
TiO_2	2.31
P_2O_5	0.30
CO_2	4.11
$\pm H_2O$	3.11
Cu	0.02
Pb	0.08
Zn	0.06
TOTAL:	100.01

Analyst: N.H. Bailey.

NOTE: Sample location - Borehole 5.

Chilled, calcified diabase.

TABLE NO. 3./...

TABLE NO. 3.

MEAN Lead:Silver and Lead:Copper Ratios.
(Supergene Oxide, Sulphide and Protore Levels)

		Ag %	Pb %	Cu %	Ag:Pb	Pb:Cu
WESTERN SECTOR	Supergene Oxide Zone (0-20 metre level)	0.011	0.25	0.26	0.04	0.96
	Supergene Sulphide Zone (50-60 metres)	0.011	0.23	0.29	0.05	0.79
	120 metre level	0.026	0.10	0.96	0.26	0.10
EASTERN SECTOR	Supergene Oxide Zone (0-20 metre level)	0.005	0.62	0.30	0.01	2.06
	Supergene Sulphide Zone (50-60 metres)	0.03	0.23	0.92	0.13	0.25
	160 metre level	0.04	0.66	0.30	0.06	2.20

NOTE: Supergene Oxide Zone - 36 analyses.
Supergene Sulphide Zone -

Western Sector - Mean of 7 analyses.
Eastern Sector - Mean of 6 analyses.

Protore Zone - Two analyses only.

Analyst: N. Bailey.

TABLE 4./...

TABLE NO. 4.

CHEMICAL ANALYSES - Ag, Pb, Cu, Zn and U_3O_8 - Main Ore Zone - 60 m level

Borehole Number	Ag %	Pb %	Cu %	Zn %	U_3O_8
27	0.009	0.16	0.19	0.02	0.004
14	0.015'	0.04	0.12	0.04	0.018
26	0.003	0.09	0.03	0.05	0.031
6	0.010	0.05	0.13	0.03	0.011
1 (120 m level)	0.025	0.10	0.96	-	0.009
15	0.007	0.04	0.48	0.04	0.018
17	0.005	0.10	3.39	0.43	0.006
18	0.006	0.38	0.66	0.04	0.003
5	0.002	0.17	0.15	0.59	0.001
19	0.002	0.28	0.35	0.06	0.002

Analyst: C. van Zyl.

TABLE NO. 5./...

TABLE NO. 5.

CHEMICAL ANALYSES - Cu, Pb, Zn - PERCUSSION BOREHOLE SAMPLES.

	Hole No.	Cu %	Pb %	Zn %
WESTERN SECTOR	C 3	0.46	2.24	0.05
	4	0.97	0.51	0.09
	5	0.03	0.11	0.02
	6	0.04	0.04	0.04
	7	0.01	0.02	0.02
	9	0.27	0.33	0.04
	10	0.38	0.30	0.05
	11	0.58	0.12	0.07
	12	0.23	0.07	0.04
	14	0.02	0.10	0.02
	15	0.20	0.02	0.02
	16	0.26	0.04	0.04
	17	0.35	0.06	0.06
EASTERN SECTOR	22	0.09	0.50	0.01
	24	0.71	0.24	0.06
	26	0.05	0.22	0.05
	27	0.05	0.89	0.12
	28	0.16	1.75	0.05
	29	0.45	0.27	0.03
	30	0.33	0.56	0.19
NORTHERN LODE	1	6.29	3.21	0.61
	3	4.72	1.53	0.03
	5	4.72	1.22	0.01
	7	6.29	2.14	0.02
	9	6.29	1.68	0.03
	11	6.29	1.68	0.02
	13	7.9	1.68	
	15	1.4	1.22	0.10
	17	4.7	9.18	0.10
	19	6.3	2.29	0.02
	21	3.1	6.12	0.10
	23	6.3	1.07	0.10

Analyst: C. van Zyl.

TABLE NO. 6./...

TABLE NO. 6.

MOLECULAR WEIGHT PERCENTAGES.

Cu:Pb:Zn.

Zone	Borehole No.	Eastern Sector Cu %	Eastern Sector Pb %	Eastern Sector Zn %	Borehole No.	Western Sector Cu %	Western Sector Pb %	Western Sector Zn %
SUPERGENE OXIDE ZONE	3	17.3	82.1	0.57	22	15.6	84.0	0.5
	4	65.0	33.0	1.8	24	23.23	76.1	0.6
	5	20.9	75.0	4.5	25	66.5	32.9	0.6
	6	44.0	42.7	13.3	26	66.6	28.5	4.9
	7	28.6	55.3	17.9	27	85.1	14.7	0.2
	10	55.3	42.5	2.2	28	48.4	51.4	0.2
	11	80.2	16.7	3.1	29	58.4	34.0	7.5
	12	92.6	2.8	4.9	30	31.1	51.3	17.6
	14	16.1	79.2	5.2				
	15	88.7	8.7	2.8				
	16	83.6	12.5	3.9				
SUPERGENE SULPHIDE ZONE	3	28.4	60.8	10.8	6	69.3	25.9	4.9
	5	30.2	33.3	36.5	14	70.1	22.7	7.1
	17	54.7	42.5	0.29	15	90.4	7.3	2.2
	18	63.3	35.5	1.2	26	22.6	65.8	11.5
					27	54.0	44.3	0.16
					1	90.8	9.1	-
					28	42.5	55.4	0.19
SUPERGENE OXIDE ZONE NORTHERN LODE	1	66.0	33.7	0.3				
	3	75.5	24.3	0.2				
	5	79.2	20.5	0.2				
	77	74.3	25.3	0.4				
	9	78.7	21.0	0.3				
	11	78.0	20.8	1.2				
	13	82.2	17.6	0.2				
	15	53.4	45.9	0.7				
	17	33.9	66.0	1.0				
	19	73.1	26.0	0.3				
	21	33.6	65.3	1.1				
	23	84.4	14.4	1.2				

TABLE NO. 7./...

TABLE NO. 7.

CHEMICAL ANALYSES AND BARTH STANDARD CELL VALUES - ALTERATION ZONE - ALBERT. AND NORTHERN LODES.

(ref. Figures 7a, 7b)

SECTION A.

		Stage 1		Stage 2		Stage 3		Stage 4	
		(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
SiO_2	Si^{4+}	72.76	62.96	74.51	63.73	72.83	62.30	81.37	68.81
Al_2O_3	Al^{3+}	15.11	15.16	13.98	13.85	16.65	16.53	10.81	9.92
FeO	Fe^{2+}	1.47	1.10	2.71	1.97	1.22	0.88	1.57	1.06
Fe_2O_3	Fe^{3+}	0.96	0.62	1.27	0.82	1.56	1.03	1.31	0.79
MgO	Mg^{2+}	0.32	0.42	0.45	0.57	0.40	0.52	0.01	0.05
Na_2O	Na^+	1.55	2.62	0.16	0.32	0.22	0.42	0.08	0.10
K_2O	K^+	6.09	7.02	4.62	5.28	5.33	6.12	3.08	4.22
CaO	Ca^{2+}	0.01	0.05	0.01	0.05	0.01	0.05	0.01	0.05
TiO_2	Ti^{4+}	0.43	0.29	0.47	0.31	0.35	0.28	0.24	0.15
P_2O_5	P^{5+}	0.28	0.21	0.06	0.04	0.06	0.04	0.25	0.17
CO_2	C^{4+}	0.15	0.13	0.14	0.03	0.14	0.16	0.19	0.22
H_2O	H^+	0.84	4.82	1.48	6.30	1.13	6.22	0.82	4.32
TOTAL:		99.97	95.40	99.86	95.27	99.90	94.55	99.74	89.86

SECTION B.

		Stage 1		Stage 2		Stage 3	
SiO_2	Si^{4+}	79.97	67.45	76.42	64.78	73.22	62.94
Al_2O_3	Al^{3+}	12.18	11.91	13.99	13.83	15.37	15.34
FeO	Fe^{2+}	1.21	0.87	1.55	1.08	1.08	0.78
Fe_2O_3	Fe^{3+}	0.66	0.44	2.00	1.29	4.00	2.61
MgO	Mg^{2+}	0.06	0.10	0.06	0.10	0.10	0.16
Na_2O	Na^+	0.08	0.10	0.08	0.10	0.09	0.10
K_2O	K^+	4.56	5.12	4.53	5.16	4.38	5.00
CaO	Ca^{2+}	0.01	0.05	0.01	0.05	0.29	0.26
TiO_2	Ti^{4+}	0.27	0.18	0.27	0.18	0.35	0.24
P_2O_5	P^{5+}	0.03	0.02	0.04	0.02	0.05	0.04
CO_2	C^{4+}	0.18	0.22	0.20	0.23	0.20	0.24
H_2O	H^+	0.69	3.88	0.78	4.44	0.75	4.28
TOTAL:		99.90	90.34	99.93	91.26	99.88	91.99

Analyst: N. Bailey.

SECTION C./...

SECTION C.

		Stage 1		Stage 2		Stage 3	
		(a)	(b)	(a)	(b)	(a)	(b)
SiO_2	Si^{4+}	71.90	62.36	76.44	65.74	76.24	65.23
Al_2O_3	Al^{3+}	13.84	13.91	10.74	10.70	12.48	12.40
FeO	Fe^{2+}	2.65	1.94	2.71	1.98	2.40	1.76
Fe_2O_3	Fe^{3+}	1.31	0.86	0.54	0.34	2.53	1.64
MgO	Mg^{2+}	0.44	0.58	0.33	0.42	0.31	0.41
Na_2O	Na^{+}	3.56	6.00	2.84	4.70	0.09	0.10
K_2O	K^{+}	4.08	4.74	4.20	4.80	3.90	4.46
CaO	Ca^{2+}	0.01	0.05	0.01	0.05	0.01	0.05
TiO_2	Ti^{4+}	0.60	0.04	0.48	0.32	0.40	0.26
P_2O_5	P^{5+}	0.21	0.15	0.15	0.10	0.17	0.20
CO_2	C^{4+}	0.35	0.42	0.68	0.81	0.48	0.57
H_2O	H^{+}	1.01	5.88	0.73	4.18	0.64	3.62
TOTAL		99.96	97.29	99.85	94.14	99.65	90.70

SECTION D.

		Stage 1		Stage 2		Stage 3	
SiO_2	Si^{4+}	73.56	64.24	72.24	63.30	80.54	67.00
Al_2O_3	Al^{3+}	12.50	12.67	13.52	13.74	11.09	10.71
FeO	Fe^{2+}	2.03	1.44	2.50	1.86	0.99	0.71
Fe_2O_3	Fe^{3+}	0.78	0.53	0.75	0.49	0.79	0.50
MgO	Mg^{2+}	0.40	0.48	0.65	0.85	0.08	0.10
Na_2O	Na^{+}	3.79	6.40	3.31	5.62	0.12	0.20
K_2O	K^{+}	4.94	5.44	5.04	5.84	3.58	3.94
CaO	Ca^{2+}	0.63	0.64	0.62	0.58	0.36	0.30
TiO_2	Ti^{4+}	0.49	0.32	0.52	0.35	0.38	0.25
P_2O_5	P^{5+}	0.09	0.06	0.09	0.06	0.06	0.04
CO_2	C^{4+}	0.20	0.24	0.21	0.24	0.30	0.36
H_2O	H^{+}	0.56	3.20	0.51	2.98	1.64	9.08
TOTAL		99.97	95.65	99.96	96.40	99.93	93.01

Analyst: N. Bailey.

SECTIONS E to F./...

TABLE NO. 7. (continued)

SECTION E.

		Stage 1		Stage 2		Stage 3	
		(a)	(b)	(a)	(b)	(a)	(b)
SiO_2	Si^{4+}	76.32	65.85	72.84	63.64	77.06	66.20
Al_2O_3	Al^{3+}	12.05	12.05	13.46	13.63	12.36	12.30
FeO	Fe^{2+}	1.69	1.20	3.67	2.70	2.35	1.72
Fe_2O_3	Fe^{3+}	0.24	0.17	1.19	0.81	0.65	0.31
MgO	Mg^{2+}	0.45	0.57	0.99	1.32	0.72	0.73
Na_2O	Na^{+}	3.12	5.22	0.07	0.10	0.04	0.10
K_2O	K^{+}	4.53	5.22	6.17	7.20	5.27	6.04
CaO	Ca^{2+}	0.46	0.42	0.25	0.26	0.25	0.26
TiO_2	Ti^{4+}	0.42	0.29	0.43	0.27	0.35	0.24
P_2O_5	P^{5+}	0.12	0.08	0.10	0.08	0.18	0.12
CO_2	C^{4+}	0.14	0.16	0.21	0.24	0.15	0.18
H_2O	H^{+}	0.42	2.40	0.58	3.38	0.58	3.32
TOTAL		99.96	93.63	99.96	93.63	99.96	91.52

SECTION F.

		Stage 1		Stage 2		Stage 3	
SiO_2	Si^{4+}	73.53	61.14	73.69	63.72	71.04	66.79
Al_2O_3	Al^{3+}	13.63	13.78	14.20	14.26	14.74	14.86
FeO	Fe^{2+}	2.79	2.06	3.04	2.20	6.15	4.53
Fe_2O_3	Fe^{3+}	0.20	0.14	0.90	0.59	1.09	0.73
MgO	Mg^{2+}	0.37	0.48	0.78	1.05	0.54	0.74
Na_2O	Na^{+}	2.71	4.54	0.12	0.20	0.12	0.20
K_2O	K^{+}	5.15	6.04	5.54	6.28	3.69	4.32
CaO	Ca^{2+}	0.40	0.37	0.31	0.31	0.49	0.47
TiO_2	Ti^{4+}	0.40	0.19	0.42	0.29	0.47	0.32
P_2O_5	P^{5+}	0.08	0.04	0.10	0.08	0.14	0.10
CO_2	C^{4+}	0.16	0.19	0.14	0.16	0.10	0.13
H_2O	H^{+}	0.55	3.18	0.74	4.30	1.25	7.28
TOTAL		100.00	95.15	99.98	93.44	99.82	100.47

Analyst: N. Bailey.

SECTION G./...

TABLE NO. 7 (continued)

NORTHERN LODE - SECTION G.

		Stage 1		Stage 2		Stage 3	
		(a)	(b)	(a)	(b)	(a)	(b)
SiO_2	Si	76.54	66.26	81.22	68.24	89.12	73.34
Al_2O_3	Al	10.99	11.04	10.45	10.18	4.41	4.24
FeO	Fe	1.85	1.36	0.87	0.61	0.60	0.40
Fe_2O_3	Fe	0.53	0.34	2.53	1.61	2.06	1.29
MgO	Mg	0.23	0.31	0.02	0.05	0.22	0.30
Na_2O	Na	2.93	4.94	0.08	0.10	0.04	0.10
K_2O	K	5.07	5.88	3.54	3.98	1.70	1.90
CaO	Ca	0.49	0.47	0.01	0.05	0.62	0.55
TiO_2	Ti	0.32	0.21	0.33	0.21	0.12	0.08
P_2O_5	P	0.18	0.12	0.08	0.06	0.14	0.10
CO_2	C	0.23	0.26	0.10	0.03	0.51	0.58
H_2O	H	0.49	2.84	0.74	4.18	0.42	2.30
TOTAL		99.85	94.03	99.97	89.29	99.96	85.18

N.B. The above silicate analyses originally included Cu, Zn, Pb and are shown re-calculated to 100 per cent, however, for the purposes of the unit cell calculations Cu, Zn, Pb have been left out of the totals as they come to less than one per cent.

(a) = Chemical Analyses.

(b) = Cationic Proportions of the Elements Calculated to the Barth Standard Cell.

TABLE NO. 8.

X-RAY ANALYTICAL DATA - METAZEUNERITE.

Albert Mine		A.S.T.M. Ref. 17-146 Anton Mine Germany		
d Å	I_o	d Å	I/I_2	nkl
8.77	100	8.86	100	002
6.85	25	6.63	5	101
5.62	25	5.57	80	102
5.14	20	5.10	60	110
4.366	5	4.38	30	112,004
3.74	100	3.73	100	104
3.57	100	3.57	70	200
3.31	75	3.30	80	202,114
3.15	5	3.13	56	211,105
2.99	65	2.98	40	212
2.75	4	2.77	10	204
2.69	3	2.69	20	106
2.57	30	2.57	40	214
2.52	40	2.51	40	220,116
2.42	45	2.41	30	222
2.22	55	2.29	10	302
2.19	3	2.24	20	310,206
2.17	20	2.18	20	312,224
2.14	3	2.14	5	216
2.08	60	2.08	30	304,108
1.994	2	1.993	40	314,118
1.987	15			
1.924	10	1.925	56	322
1.848	6	1.857	56	208
		1.833	5	306
1.811	60	1.796	30	324,118
1.784	4	1.776	30	400,316
1.744	5	1.742	5	402,0010
1.734	45	1.643	30	30
1.602	35	1.602	20	20

TABLE CONTINUED./...

TABLE NO. 8. (continued)

Albert Mine		A.S.T.M. Ref. 17-146 Anton Mine Germany		
d Å	I_o	d Å	I/I_2	
1.565	55	1.586	20	
1.491	4	1.561	60	
1.428	4	1.422	20	
1.403	4	1.395	5	
1.377	30	1.377	30	
1.355	25	1.352	10	

I_o = Relative Intensities estimated visually.

Powder Diffractogram   Co Radiation   90 mm Debye-Scherrer camera.
                        Fe Filter   Philips X-ray Generator.

Optical Data.

Formula - $Cu(UO_2)_2 (AsO_4)_2 . 8H_2O$ (System - Tetragonal

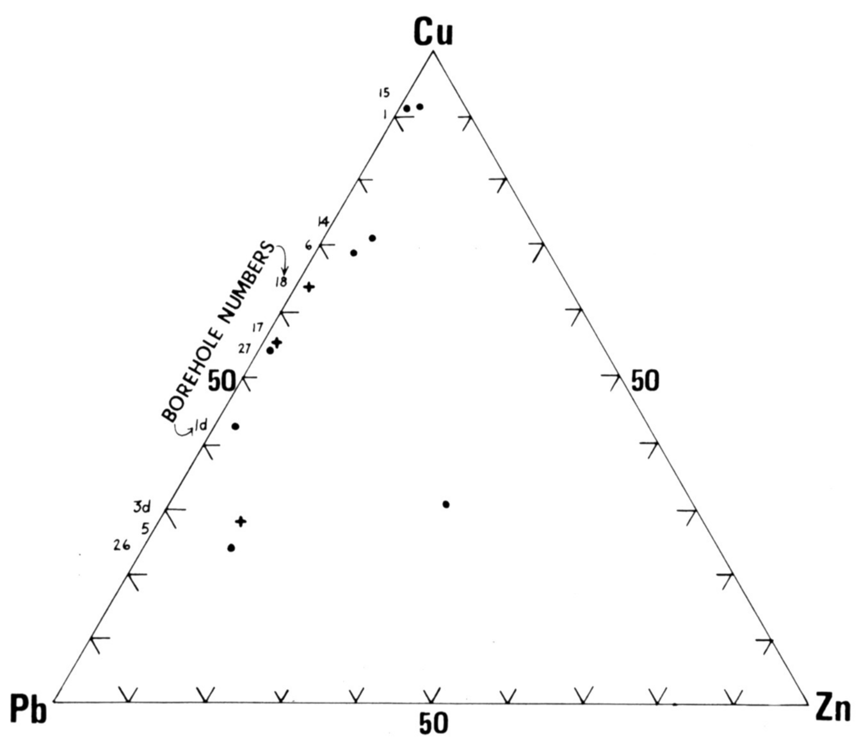
nw = 1.647

n = 1.625

opt. (-)

Colour: Pale green in thin section.

F I G U R E S.

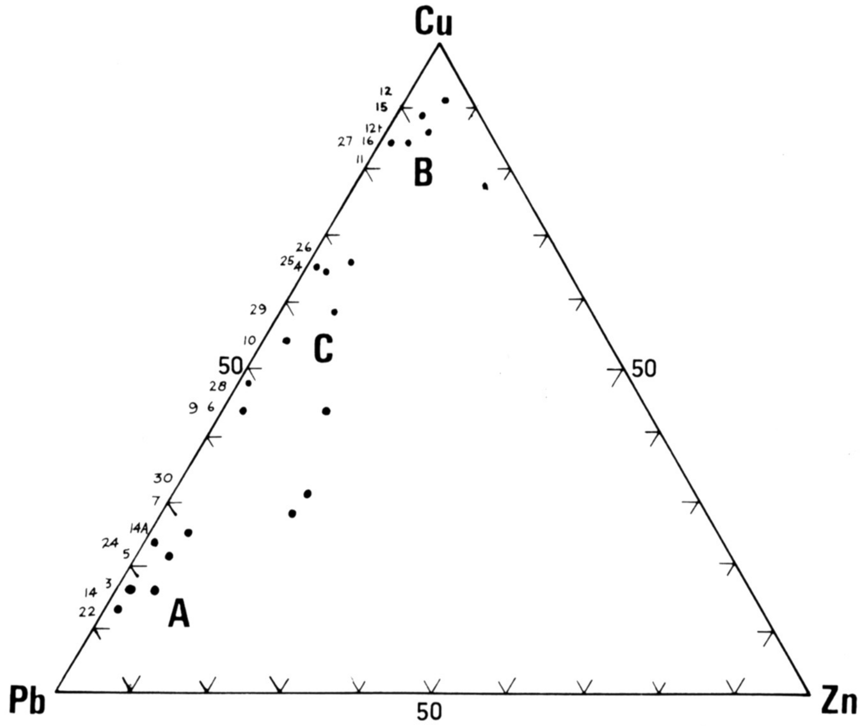


KEY

DEPTH		
50M	•	Western Sector
60M	+	Eastern Sector

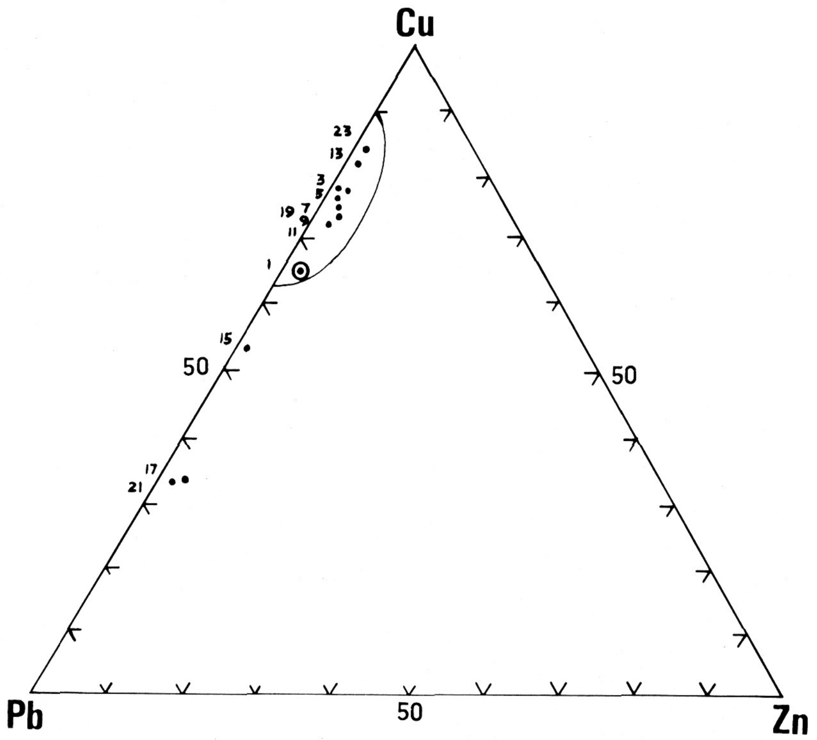
Cu. Pb. & Zn. RATIOS FOR ALBERT LODE SUPERGENE SULPHIDE ZONE.

FIG. 1a



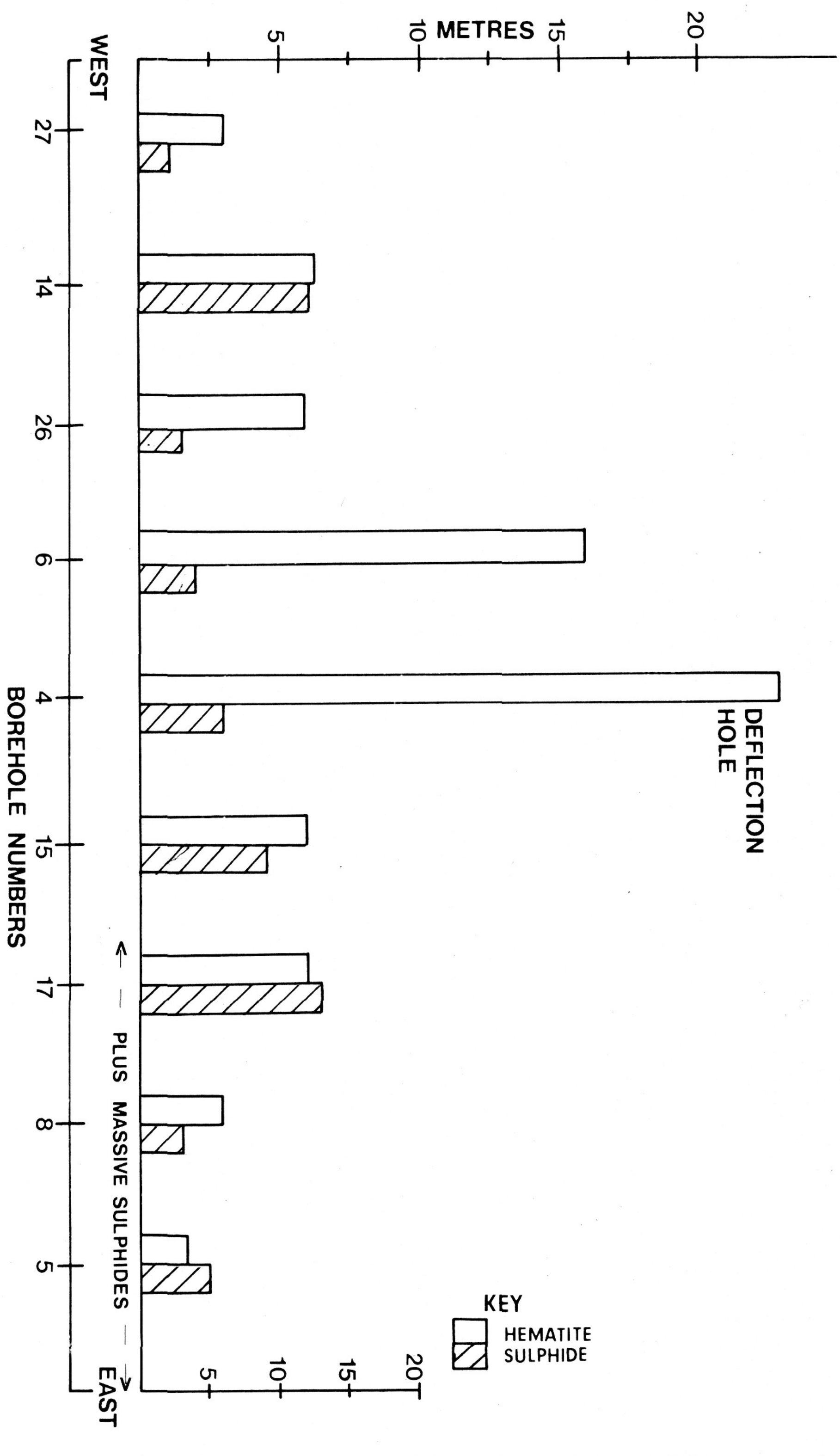
ALBERT LODE
SUPERGENE OXIDE ZONE

FIG.1b



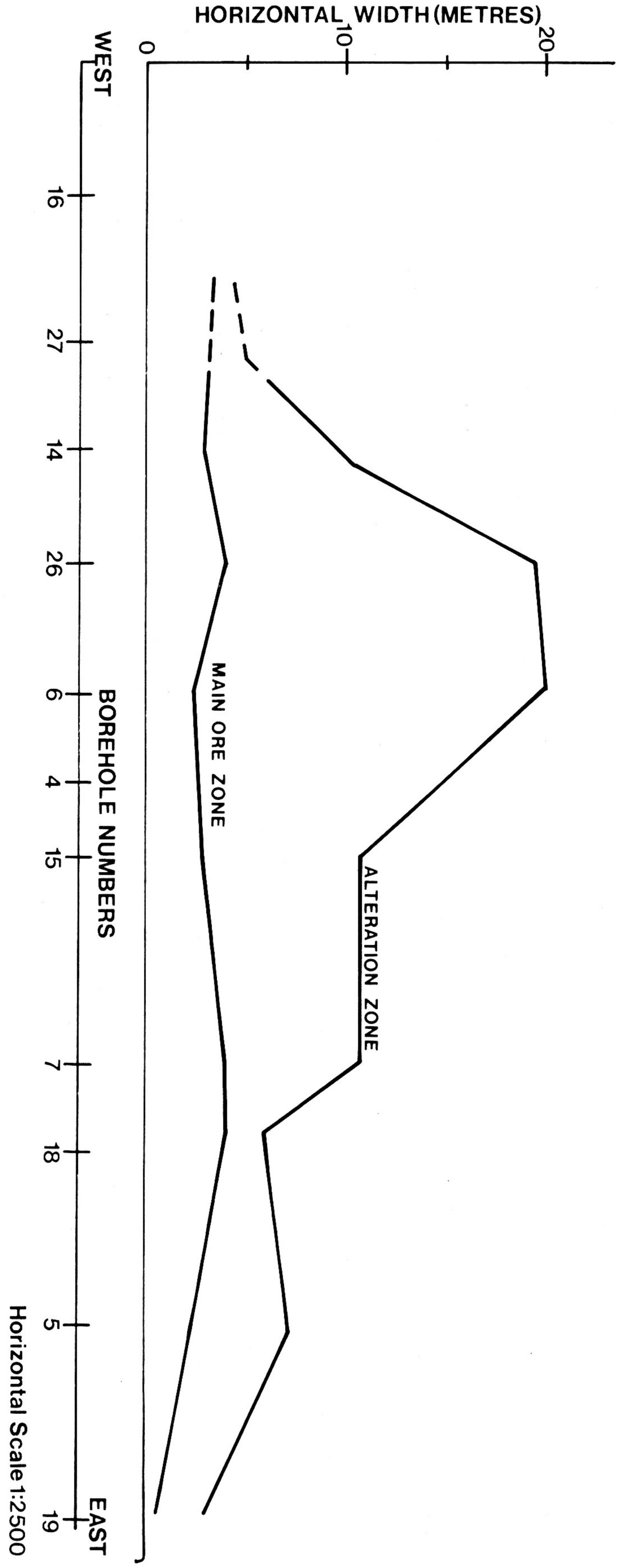
NORTHERN LODE
SUPERGENE OXIDE ZONE

FIG.1c



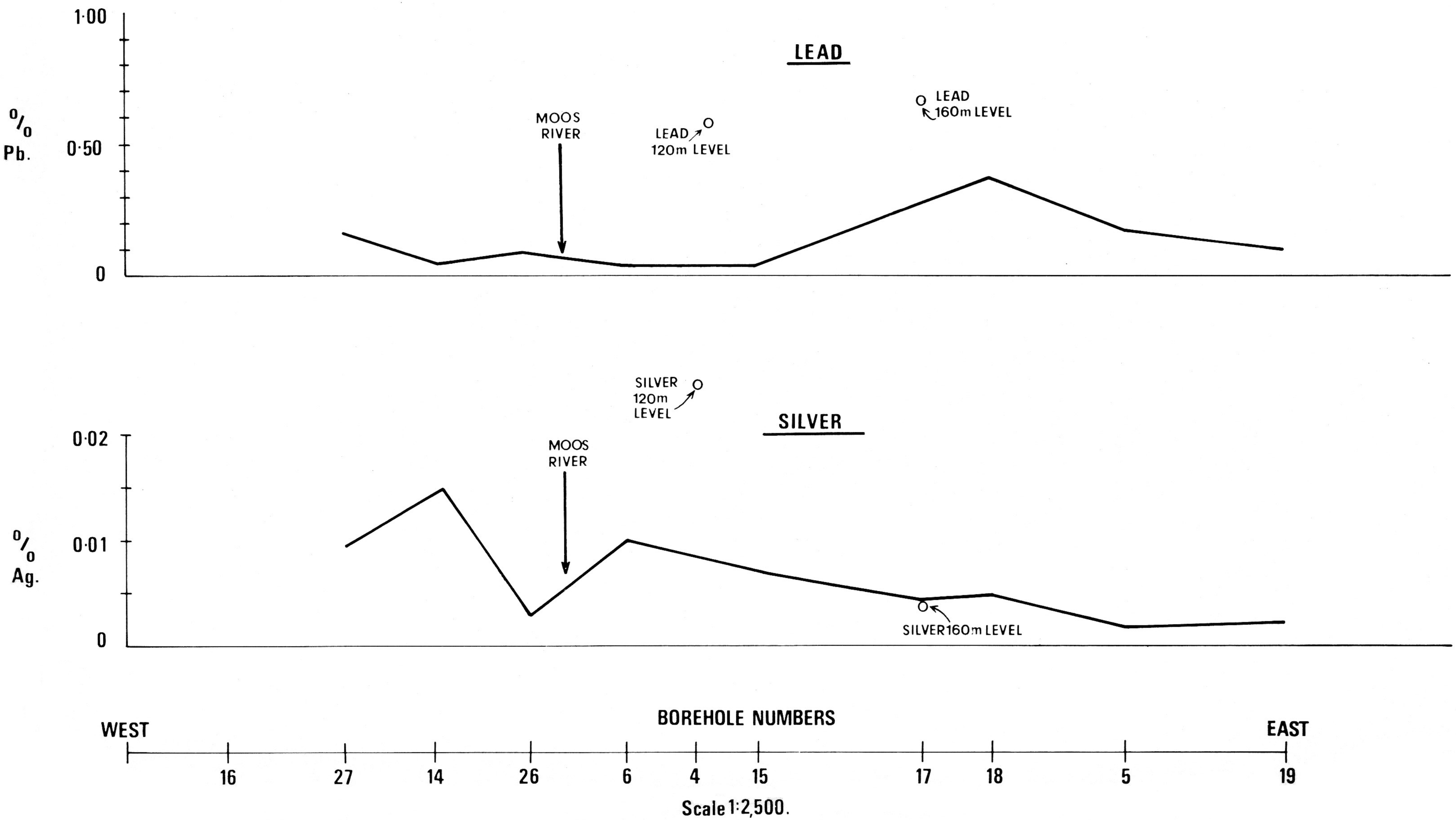
NUMBER OF SULPHIDE VEINS RELATIVE TO HEMATITE

FIG. 2

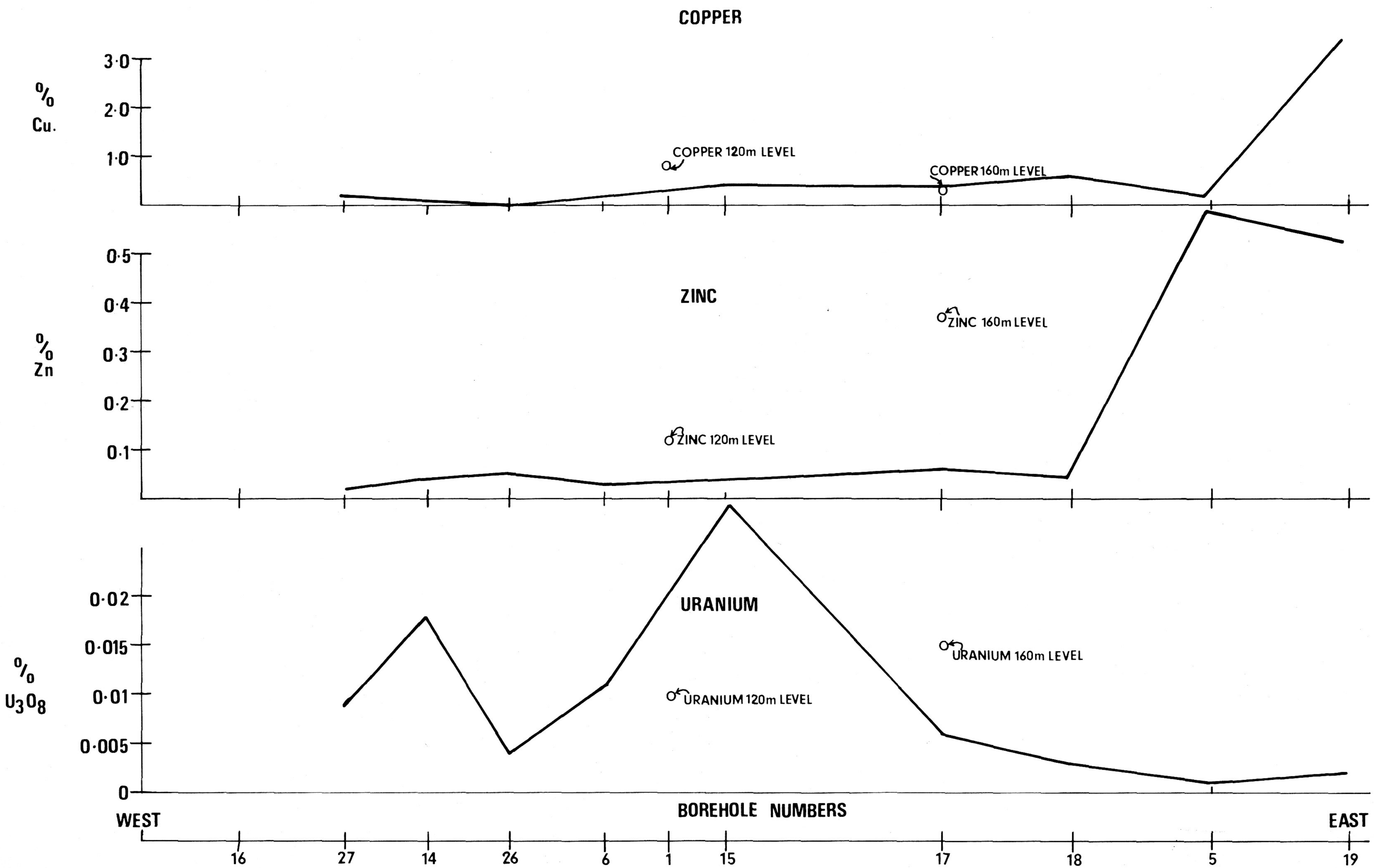


WIDTHS OF MAIN ORE BODY COMPARED WITH THE ALTERATION ZONE

FIG.3

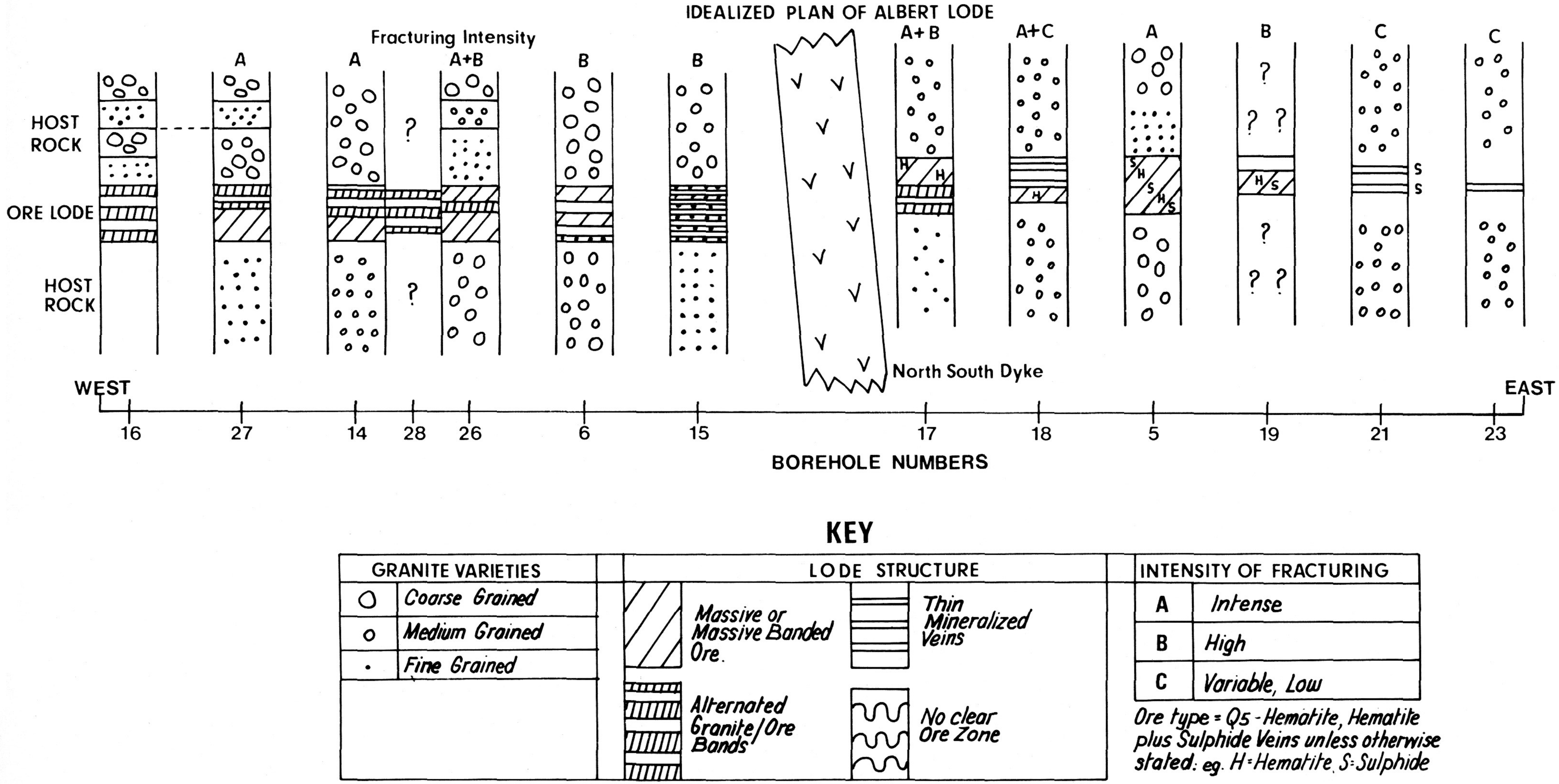


DISTRIBUTION OF Ag. Pb. Cu. Zn. & U_3O_8 IN THE MAIN ORE ZONE
ALBERT LODE
[50 to 60m. LEVEL]



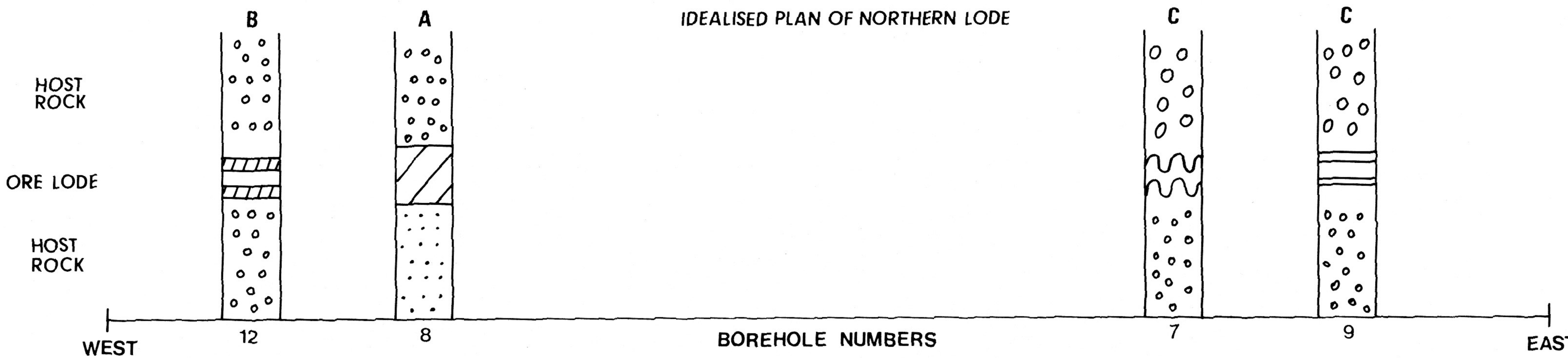
COPPER
%
Cu.
3·0
2·0
1·0
COPPER 120m LEVEL
COPPER 160m LEVEL
ZINC
%
Zn
0·5
0·4
0·3
0·2
0·1
ZINC 160m LEVEL
ZINC 120m LEVEL
URANIUM
%
U_3O_8
0·02
0·015
0·01
0·005
0
URANIUM 160m LEVEL
URANIUM 120m LEVEL
BOREHOLE NUMBERS
WEST
EAST
16
27
14
26
6
1
15
17
18
5
19

FIG 4 (cont.)

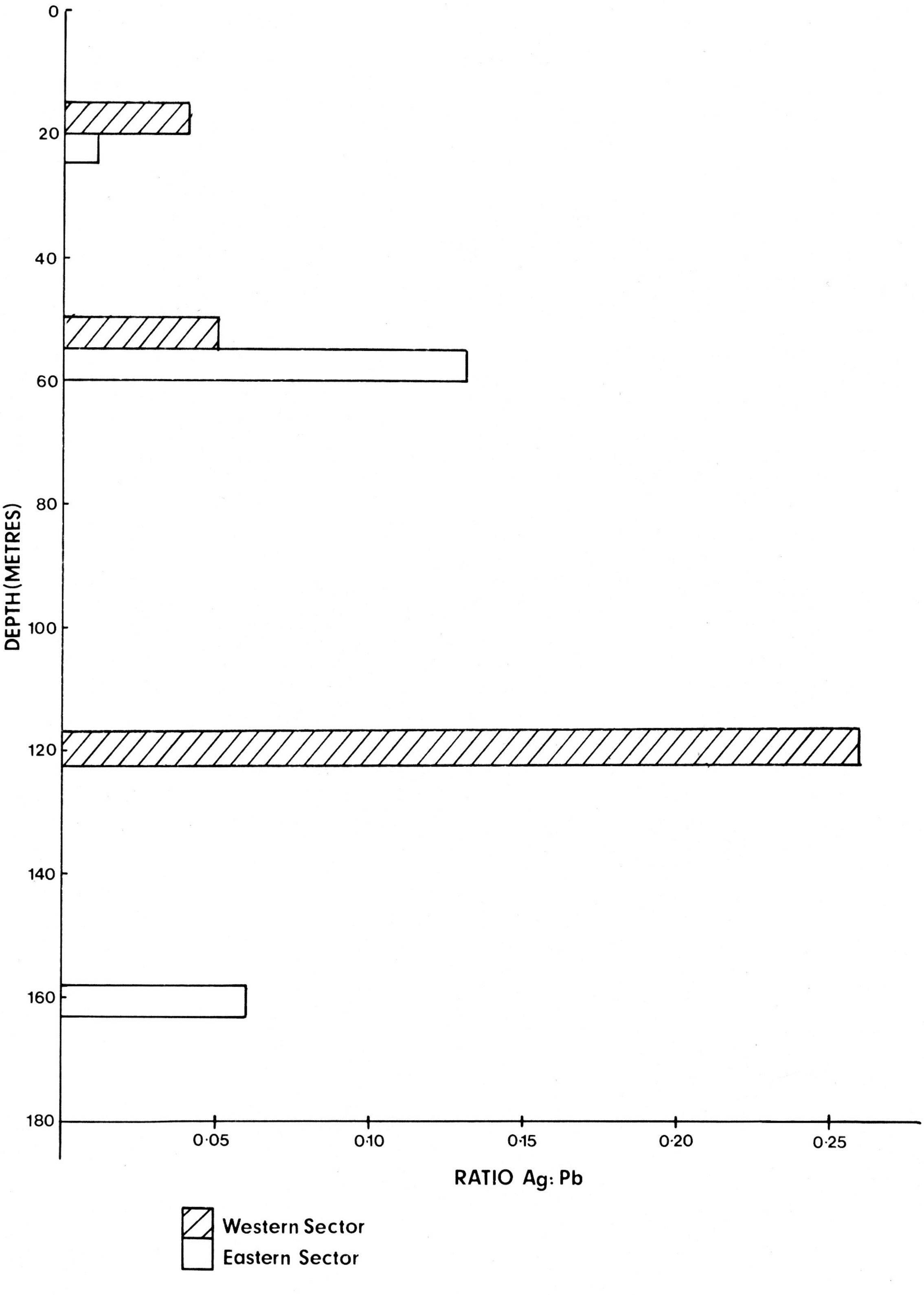


STRUCTURAL ANALYSIS
ALBERT LODE — HOST ROCK

FIG 5

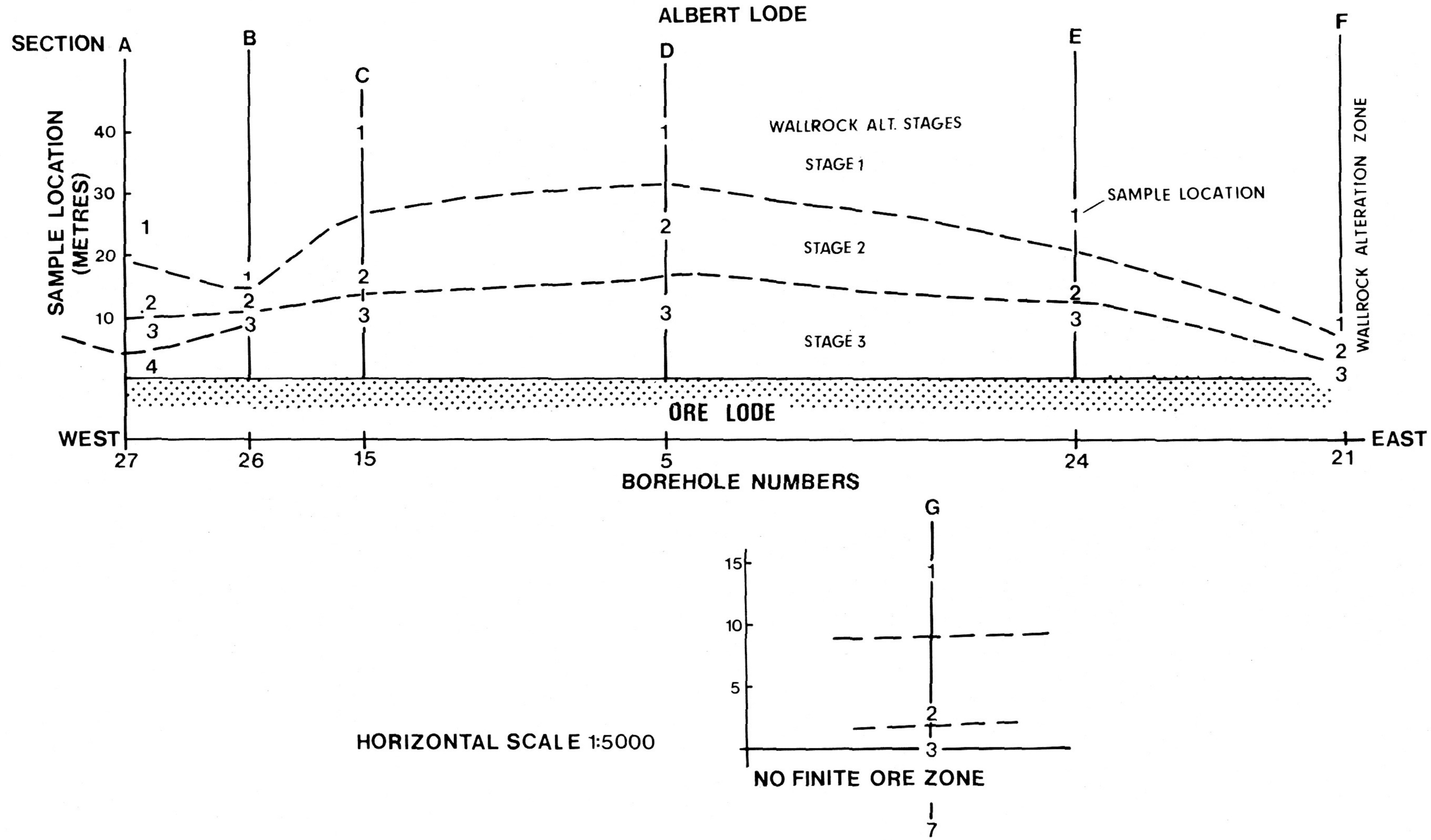

IDEALISED PLAN OF NORTHERN LODE
B
A
C
C
HOST ROCK
ORE LODE
HOST ROCK
WEST
12
8
BOREHOLE NUMBERS
7
9
EAST

Key see fig. 5



VERTICAL VARIATION IN THE Ag: Pb RATIO
WITH DEPTH

FIG.6



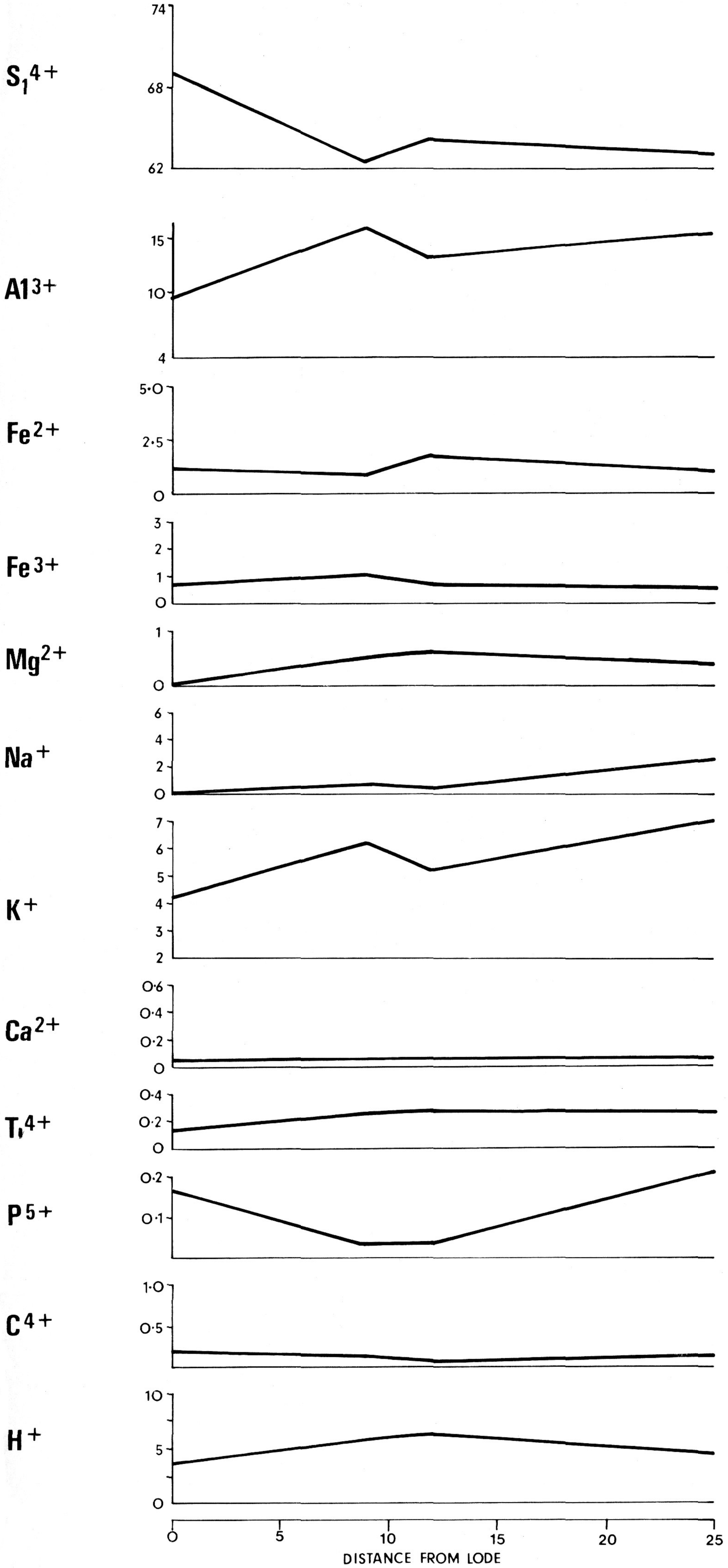
PLAN SHOWING LOCALITY OF THE ANALYSED WALLROCK SAMPLES

FIG 7A

Note- Figure 7(b)

The curves in some of the diagrams end short of the lode as they are of a quantitative nature and represent the joins of accurate compositional plots. As such the curves have not been extrapolated so as to intersect the lode. The alteration zone between the lode and the analysis representative of Stage 3 was very uniform in each case, closely resembling the last analysis in composition.

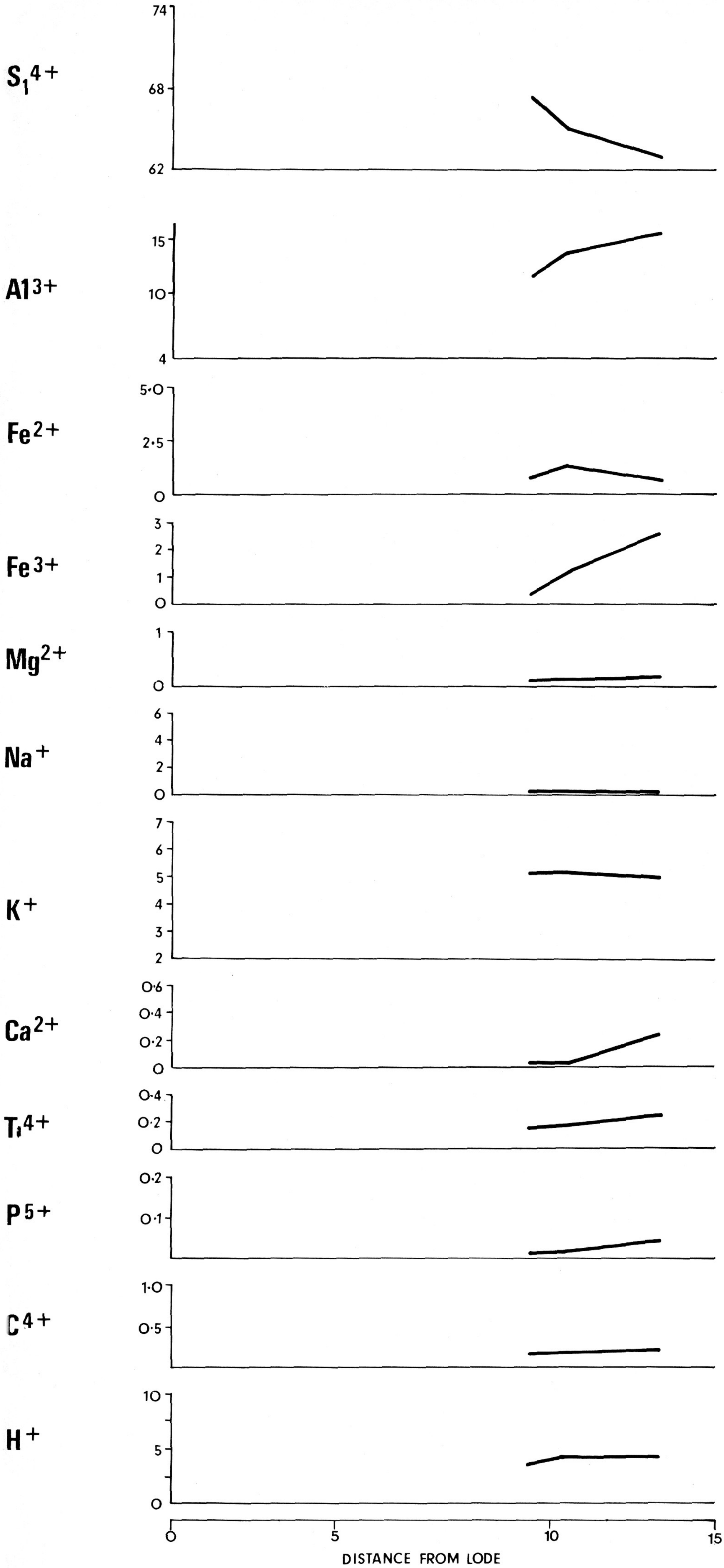
ALBERT LODE **SECTION A** (ref. see table 7 a)



VARIATION DIAGRAMS SHOWING THE ADDITION OR SUBTRACTION OF ELEMENTS THROUGH PROGRESSIVE STAGES OF WALLROCK ALTERATION AND REPLACEMENT [Cationic Proportions according to the Barth Standard Cell]

FIG.7b

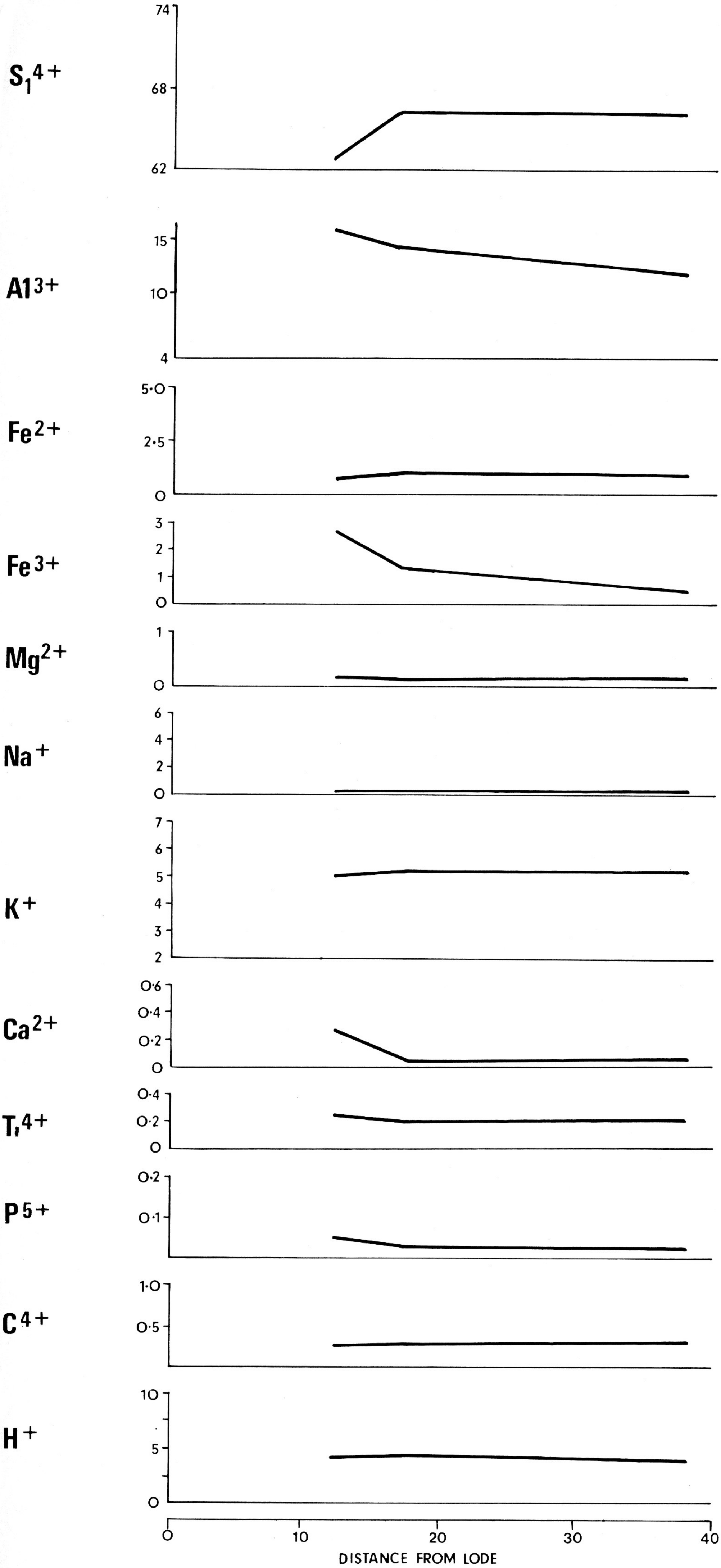
ALBERT LODE **SECTION B** (ref. see table 7 a)



VARIATION DIAGRAMS SHOWING THE ADDITION OR SUBTRACTION OF ELEMENTS THROUGH PROGRESSIVE STAGES OF WALLROCK ALTERATION AND REPLACEMENT [Cationic Proportions according to the Barth Standard Cell]

FIG.7b

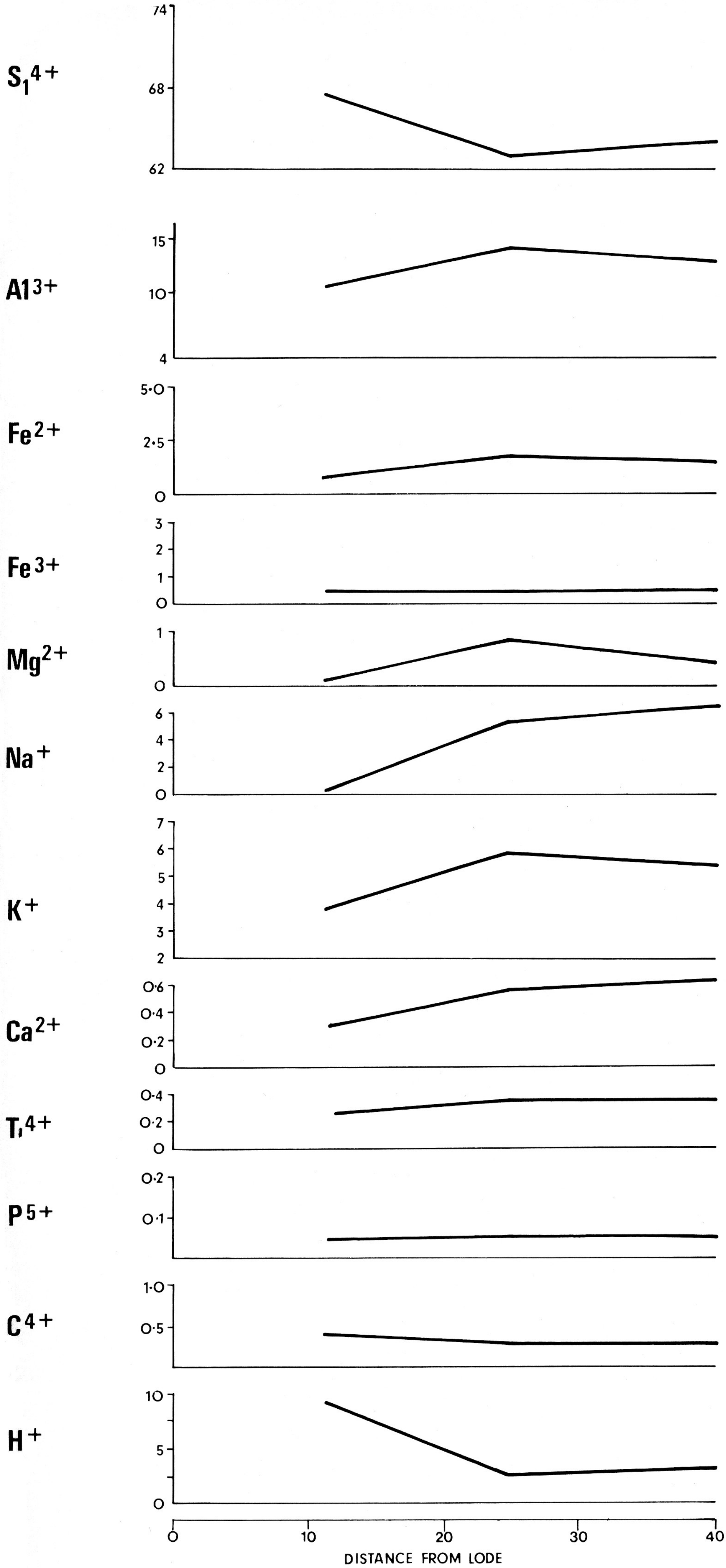
ALBERT LODE **SECTION C** (ref. see table 7 a)



VARIATION DIAGRAMS SHOWING THE ADDITION OR SUBTRACTION OF ELEMENTS THROUGH PROGRESSIVE STAGES OF WALLROCK ALTERATION AND REPLACEMENT [Cationic Proportions according to the Barth Standard Cell]

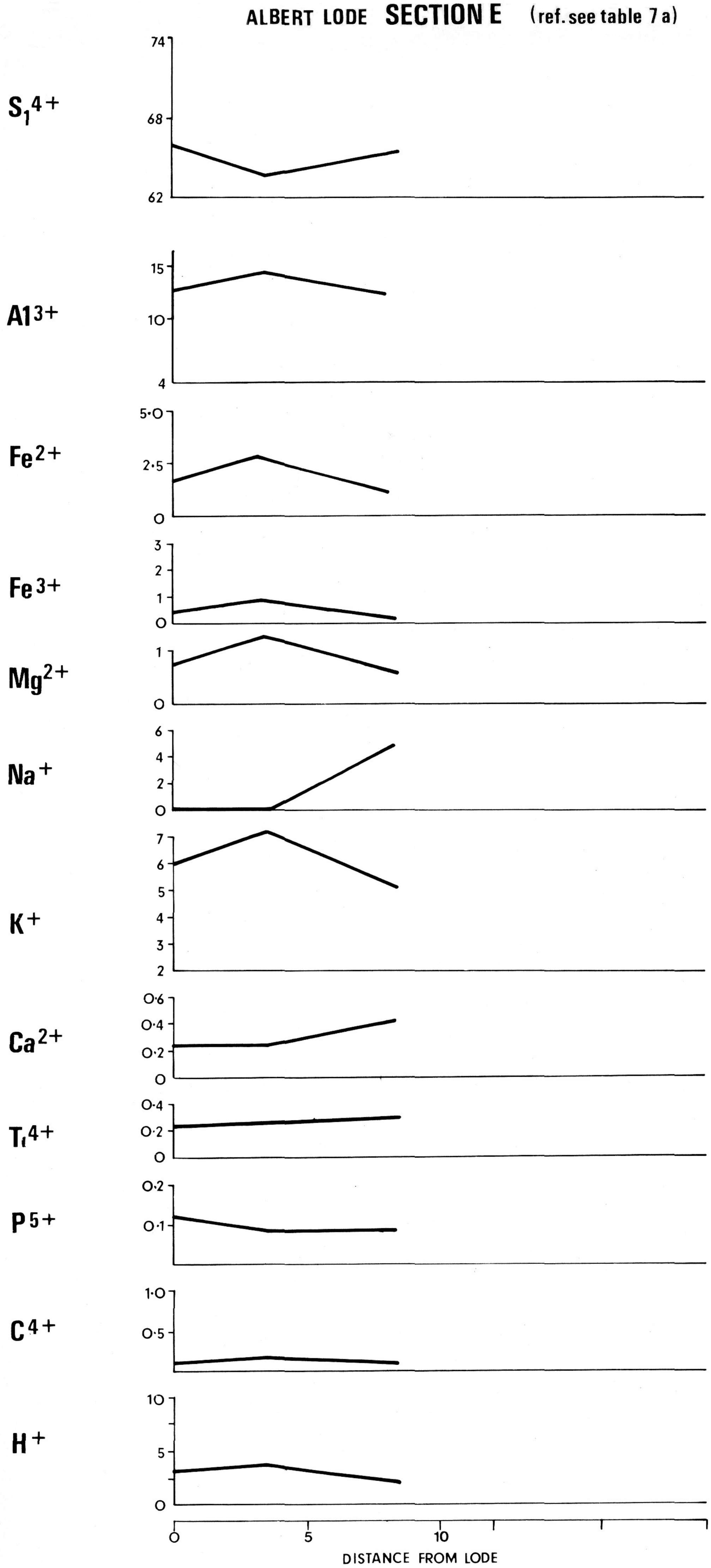
FIG.7b

ALBERT LODE **SECTION D** (ref. see table 7a)



VARIATION DIAGRAMS SHOWING THE ADDITION OR SUBTRACTION OF ELEMENTS THROUGH PROGRESSIVE STAGES OF WALLROCK ALTERATION AND REPLACEMENT [Cationic Proportions according to the Barth Standard Cell]

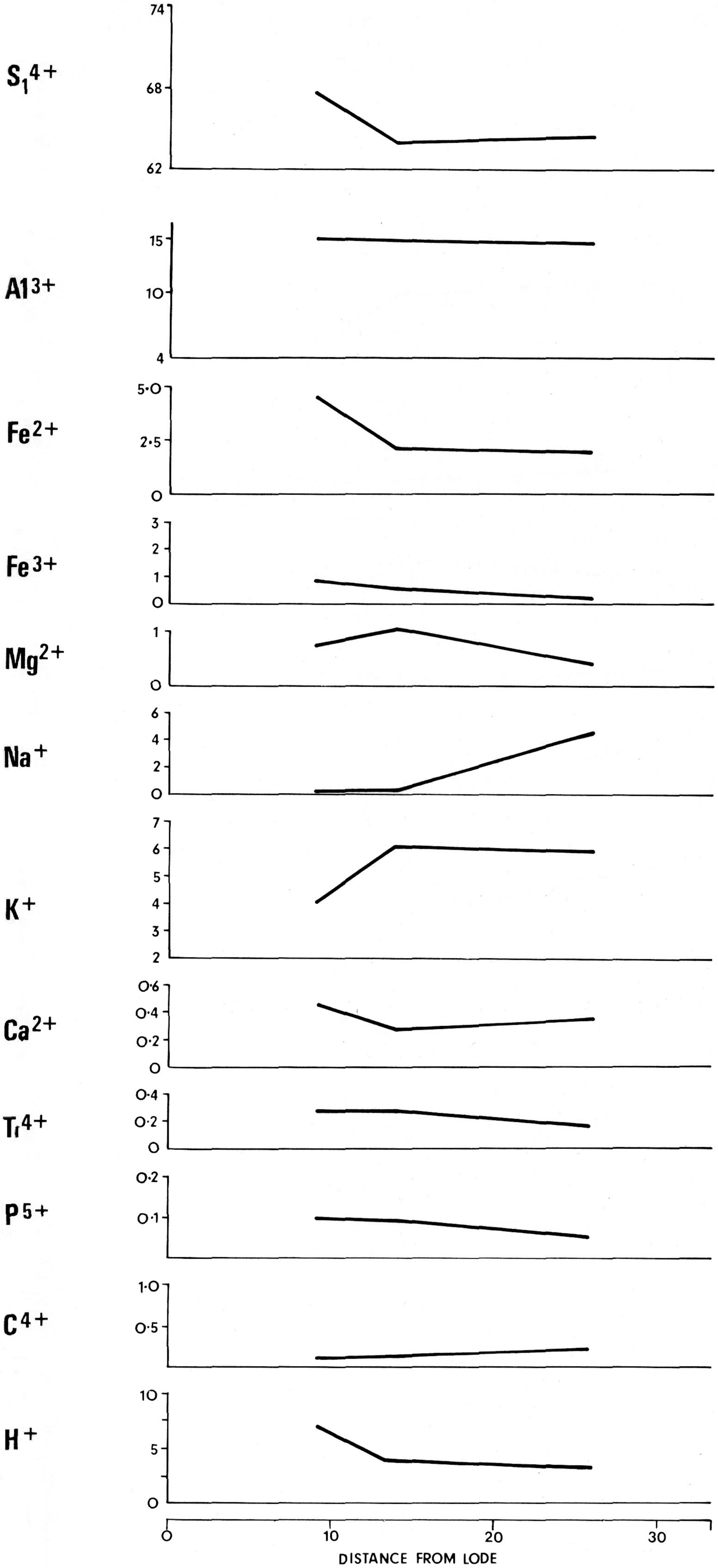
FIG.7b



VARIATION DIAGRAMS SHOWING THE ADDITION OR SUBTRACTION OF ELEMENTS THROUGH PROGRESSIVE STAGES OF WALLROCK ALTERATION AND REPLACEMENT [Cationic Proportions according to the Barth Standard Cell]

FIG.7b

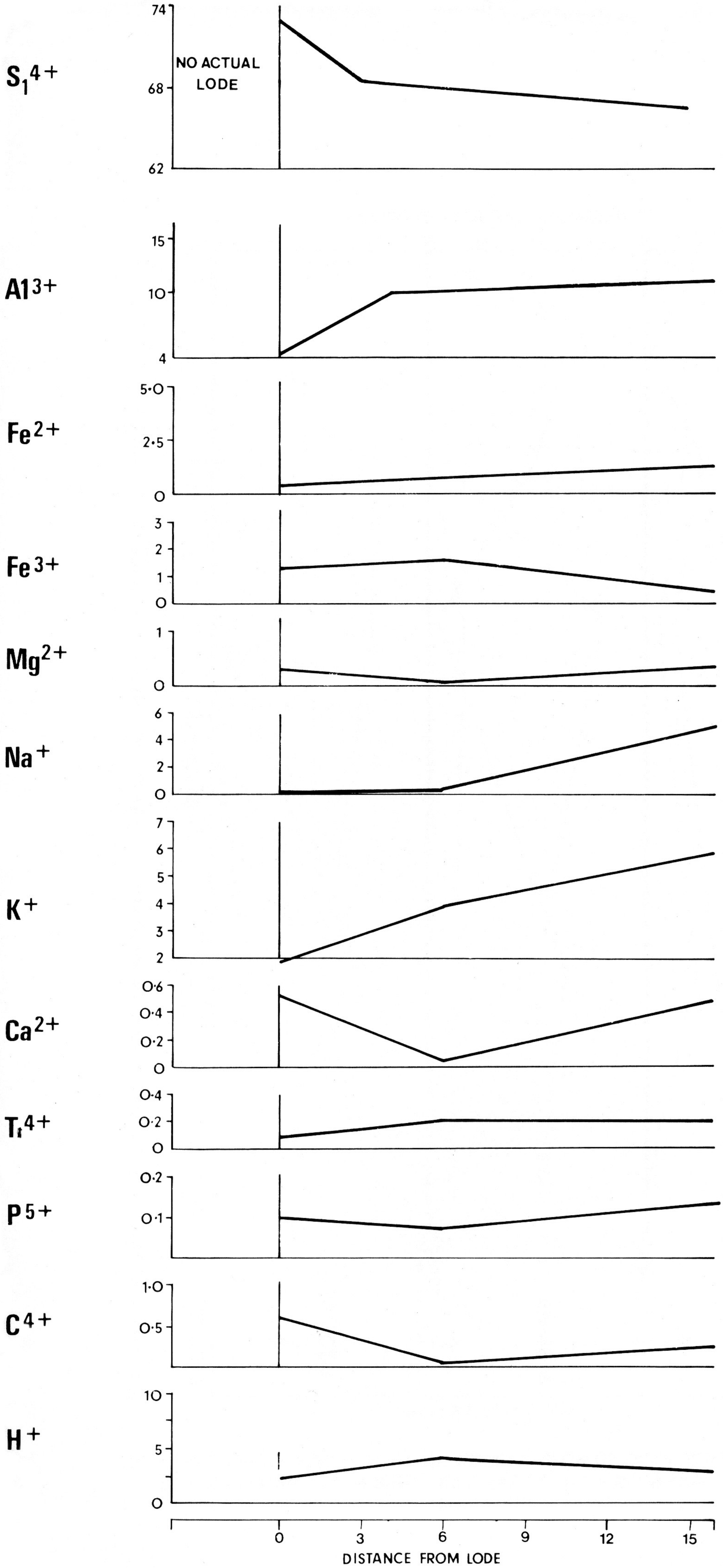
ALBERT LODE **SECTION F** (ref. see table 7 a)



VARIATION DIAGRAMS SHOWING THE ADDITION OR SUBTRACTION OF ELEMENTS THROUGH PROGRESSIVE STAGES OF WALLROCK ALTERATION AND REPLACEMENT [Cationic Proportions according to the Barth Standard Cell]

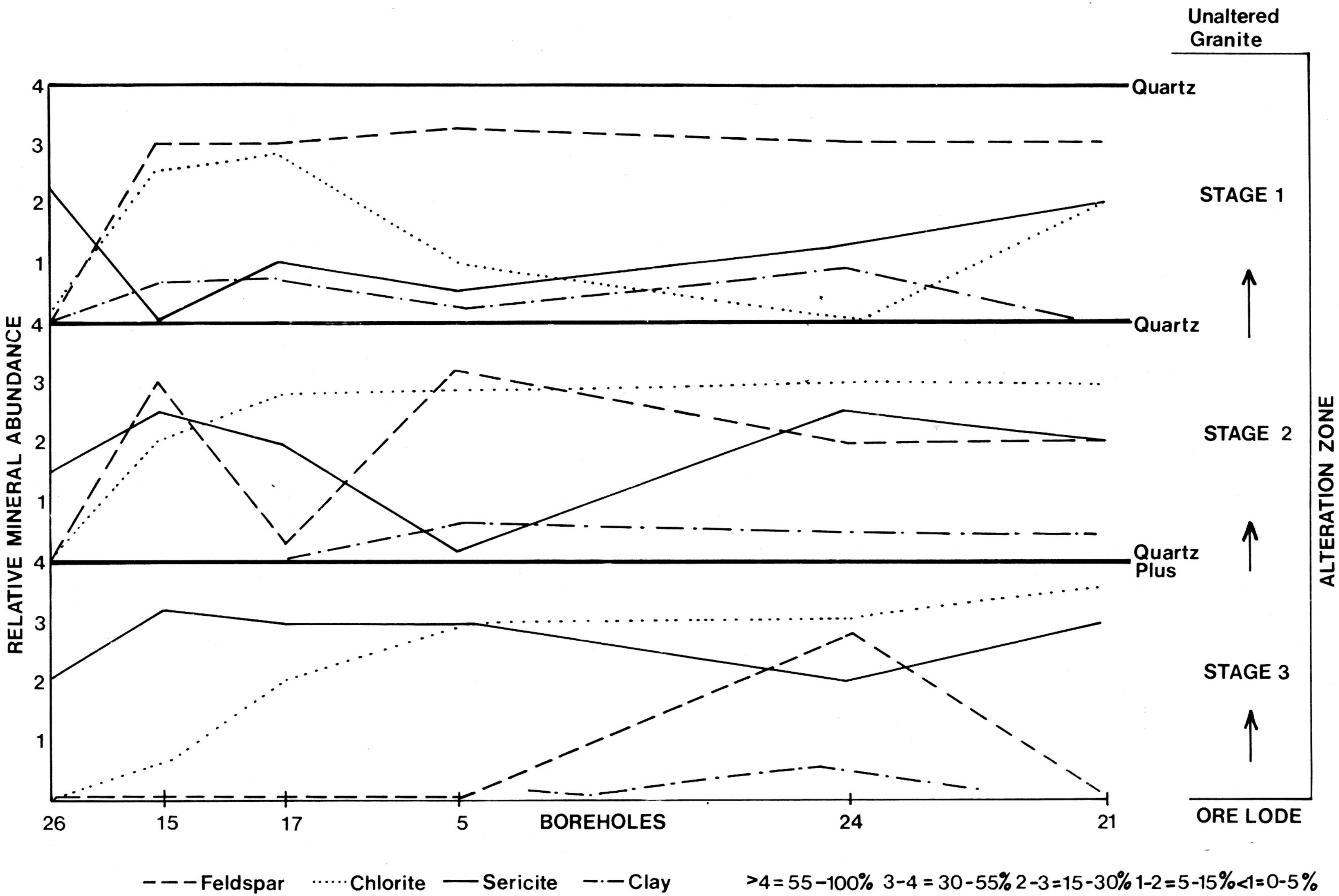
FIG.7b

ALBERT LODE **SECTION G** (ref. see table 7a)



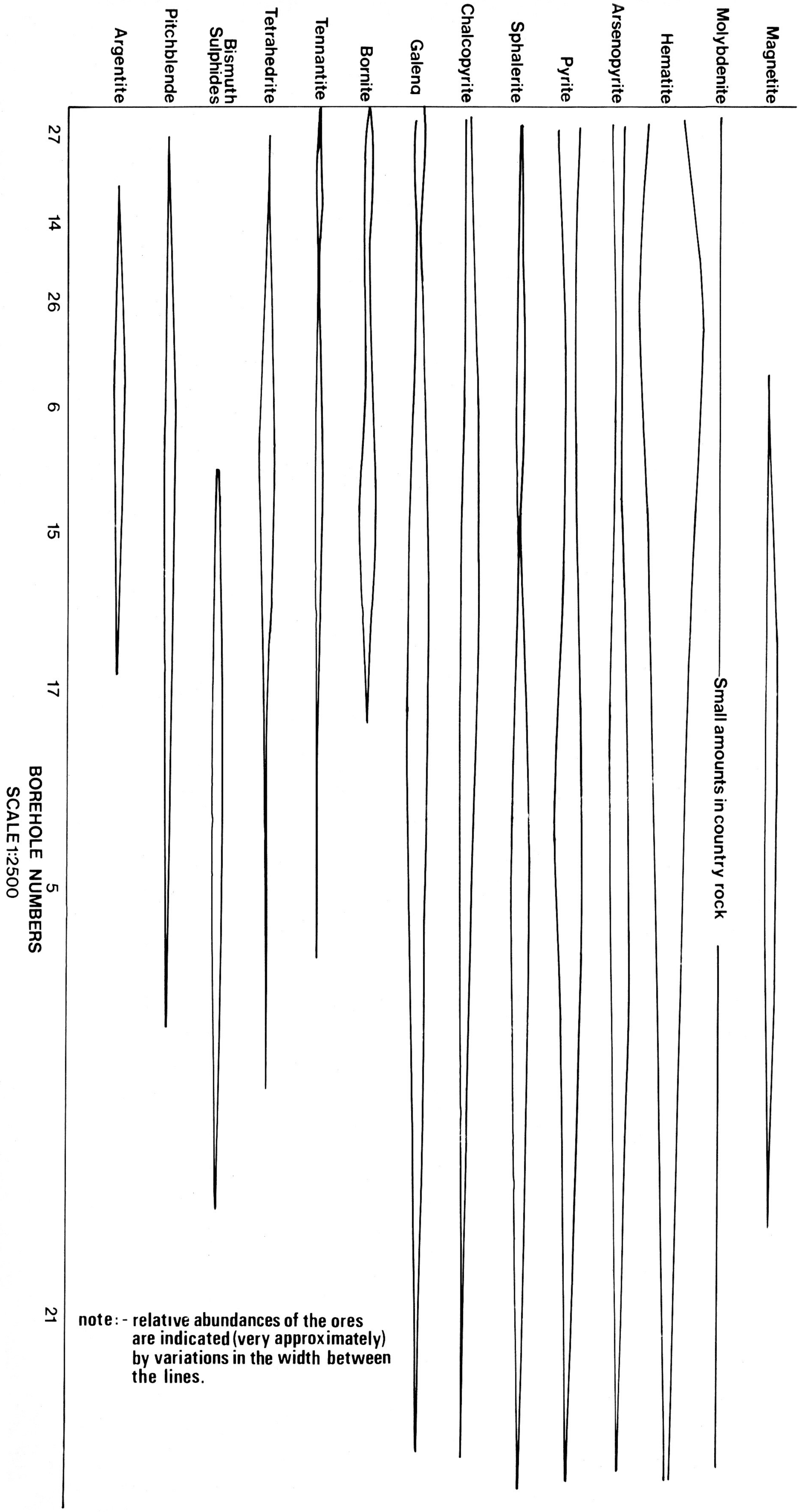
VARIATION DIAGRAMS SHOWING THE ADDITION OR SUBTRACTION OF ELEMENTS THROUGH PROGRESSIVE STAGES OF WALLROCK ALTERATION AND REPLACEMENT [Cationic Proportions according to the Barth Standard Cell]

FIG. 7b



THE APPROXIMATE MINERALOGICAL COMPOSITION OF DIFFERENT WALLROCK STAGES ALONG THE ALBERT LODE BASED ON X-RAY DIFFRACTOMETRIC ANALYSIS

FIG.8



APPROXIMATE DISTRIBUTION OF THE MAJOR PRIMARY ORES
(60 METRE LEVEL)

FIG.9