THE PARAGENESIS AND ORIGIN OF THE TENNANT CREEK MINERAL DEPOSITS.

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THE ORE DEPOSITS OF TENNANT CREEK.

11. THE RANGE AND DISTRIBUTION OF MINERALISATION.

Although gold and copper are the principal metals of economic value at Tennant Creek, silver, lead, zinc, bismuth and iron, are to be considered with them in discussing mineralisation in the district.

By way of convenience in classification and description, the gold deposits are usually regarded as separate from the copper deposits. There is however, no sharp distinction since nearly all gold lodes contain some sulphides and sulphosalts, and all major copper orebodies contain some gold. Furthermore, with the exception of several minor gold-quartz veins, the gold and the copper deposits are associated with hematite or magnetite, or with both.

Mineralisation is almost entirely confined to the Lower Proterozoic rocks. None occurs in the younger rocks but there is evidence, as outlined in an earlier section, of epigenetic sulphide mineralisation in the Archaean gneisses.

The geologists of the Bureau of Mineral Resources recorded about 700 lens-shaped concentrations of hematite and it is apparent from the aeromagnetic maps that a smaller number of deeper seated, non-outcropping bodies of magnetite also exist. According to Crohn and Oldershaw (1964), approximately 10% of the ironstone lenses are auriferous to a greater or lesser degree, and a very much smaller proportion qualify as copper deposits. Although magnetic anomalies of sufficient intensity to register on the aeromagnetic maps define only one of the principal gold deposits, viz. Eldorado, they do locate the three major copper deposits, each of which is characterised by dominant magnetite.

The Tennant Creek aeromagnetic map exhibits two differently oriented patterns of distribution of anomalies which appear to be related to the location of copper mineralisation. The principal pattern, an east-south-east alignment of anomalies, does not conform to the regional trend of bedding or fold axes in the Lower Proterozoic rocks which contain these orebodies, but probably expresses some feature of the deep-seated Archaean basement, such as faults or basic igneous intrusives. Crohn and Oldershaw (op. cit.), pointed out that this major magnetic trend is parallel to the Mary Lane Shear zone. This Shear contains the Ivanhoe copper orebody and no doubt extends into the underlying basement. The Orlando Shear however, does not conform exactly to this trend, but is nevertheless very close to it.

The second trend in distribution of anomalies strikes north-easterly and more or less parallel to the photolinear and other structural features. The three major copper orebodies, Peko, Orlando and Ivanhoe, as well as a smaller one at Golden Forty, exist on magnetic anomalies located at positions of intersection of these two trends in the distribution of basement magnetic highs.

These observations made by Crohn and Oldershaw (op. cit.), prompt further investigation into the possible relationship between base metal mineralisation and the phenomena which affected the magnetic and structural characteristics of the underlying Archaean basement. There is however, no obvious connection between gold mineralisation and the characteristics of the basement, but as will be shown in the following pages, both gold and copper mineralisation merge in depth and share a common paragenesis. A relationship to the features of the basement may therefore exist also with gold, but it is an indirect one.

Although the gold orebodies are located with concentration of hematite or magnetite, in a similar way to those of copper, their distribution is more closely related to the structure and lithology of the Lower Proterozoic sediments. Structural or other characteristics of the Archaean basement, expressed in regional magnetic trends do not conform to the distribution of gold. While Eldorado may be an exception to this, Noble's Nob and other gold mines show no relation to aeromagnetic trends, and virtually no ground magnetic highs.

In 1954 Ivanac concluded that gold was mainly located at positions where shears intersected shale or mudstone horizons. In 1964 Crohn and Oldershaw added the further observation, that the best of the gold deposits exist adjacent to the thin hematite shale beds which contain as much as 20% iron oxides. These facts relating to the distribution of gold, formed the basis of the concept developed in this thesis, viz. that the occurrence of gold is confined mainly to the Specific Horizon.

Only minor amounts of silver are associated with Tennant Creek gold, but considerable quantities are obtained as a by-product in the treatment of the combined sulphide ores from Peko, Orlando and Ivanhoe. Silver is associated with the lead-zinc sulphides which are marginal to the copper-iron sulphides in the central sections of the Peko lode, and with the galena and sphalerite in the Ivanhoe and Orlando orebodies.

Bismuth, due to its association with both gold and copper ores, has a wide distribution. It occurs in gold deposits mainly as the sulphosalts, wittichenite and emplectite, and in the copper deposits, as bismuthinite and native bismuth. In recent deep drilling on a small magnetic anomaly four miles west of Noble's Nob, GeoPeko Ltd. encountered ore containing the rare bismuth selenide, guanajuatite. This mineral which closely resembles bismuthinite, was identified at the Australian Mineral Development Laboratory by electron probe analysis. It is possible therefore that some bismuthinite in other parts of the field may also have been wrongly identified since by microscope alone, the distinction is scarcely possible.

12. THE GOLD OREBODIES.

There are approximately 90 gold deposits in the Tennant Creek area, but since most of these are in small lode formations they are insignificant from a productive point of view. The analysis, made by Ivanac in 1954, of the size and shape of the gold ore shoots, showed that only in Noble's Nob, Northern Star, Rising Sun and in the upper levels of Peko, did the length exceed 100 feet, reaching a maximum of 325 feet in Noble's Nob.

According to Mines Department records only twenty-two mines have produced more than 1000 ozs. of gold. The majority had little output and little continuity underground. However, to make the investigation as comprehensive as possible, and to facilitate comparisons, between the minor and major gold lodes, ore was collected for study from all accessible deposits.

(1) Noble's Nob Mine.

This deposit, which is the richest gold mine at Tennant Creek, has been the largest producer on the field for nearly 18 years. It is operated by Australian Development N.L.

The current yearly production is about 29,000 tons of ore with an average grade of 33 dwts/ton, but at present the mine retains a reserve of only 57,000 tons at an estimated average grade 24 dwt. per ton.

The original outcrops of this deposit may still be seen on the flat topped hill known as Noble's Nob, elevated some 150 feet above the surrounding plains. This hill, like others in the Tennant Creek district, is a remnant of the uplifted, dissected peneplained Proterozoic land surface.

The structure of Noble's Nob orebody.

The regional environment of the orebody is displayed in Plate 1, the detail of its attitude in respect to the enclosing country rocks is shown in Figs, 54 and 55, and the assay contours which reflect the attitude of the main ore shoots, are illustrated in Plate 3.

Like the other major gold deposits of Tennant Creek, Noble's Nob is situated in one of the drag folds which occur along the southern limb of the main anticline in the southern part of the field. The orebody is located in an area of pitch change within this drag fold, and it is adjacent to an east - west shear of considerable magnitude.

The orebody has two separate surface expressions in hematite-quartz lode formations which form differently oriented outcrops. The larger is 320 feet long and is oriented east-west with a vertical dip, whereas the smaller is 150 feet long and is oriented north-east to south-west with a 50° south-east dip. These separate lode formations merge underground, and at 300 feet depth, the identity of the smaller structure, vanishes. The maximum concentration of gold was near the confluence of these separate lode structures where major steeply plunging pipe-like shoots contained values as high as 300 ozs per ton. The attitude of these rich shoots is comparable with the plunge of the lineations present on the planes of east-west shear.

A prominent zone of east-west shears may be followed on the surface for about two miles east and west of Noble's Nob. This zone does not however pass through the main lode, but exists over a hundred feet to the south of it. Although numerous closely spaced, slickensided shears exist in the orebody itself, there is little evidence of these in the country rocks beyond the extremities of the orebody. Fissile and somewhat sheared country rock along strike to the east of the main lode, and breccia at its western extremity, are surface manifestations of the shears within the orebody.

There is also little expression in the country rocks of the shears within the smaller north-east-trending lode formation. This structure is however, parallel to the subsidiary system of north-east faults which are illustrated in Plate 1.

Detailed mapping, aided by the use of oriented thin sections, showed that the anticlinal drag fold containing the Noble's Nob orebody, was complicated by many smaller drag folds, Fig. 55.

The structure was rendered even more complex by a general pitch reversal of some 60° over a distance of about two miles, and further, by many subsidiary pitch reversals within this interval. The orebody is located somewhat east of the axis of the general pitch reversal, hence the overall lode pitch is about 30° to the east, vide Plate 3.

In common with many other gold deposits at Tennant Creek, the orebody occurs close to a thin, siliceous hematite shale horizon which forms part of the footwall assemblage of tuffaceous sandstones and minor shales, Fig. 54. Immediately east of the orebody, this horizon was repeatedly displaced by a series of transcurrent faults, one of which intersected the orebody in its eastern limits.

The transverse sections, as well as the level plans, indicate that the lode thins rapidly with increasing depth, and that the series of shears within the orebody are very narrow in D.D.Hs. 142 and 143 beneath the deposit.

The structure is much more complex than can be indicated on the inch to the mile scale of Plate 1. The closely spaced folds determined by oriented thin section studies in the Noble's Nob north drive and on the surface, show the degree of contortion on the northern side of the orebody. Smaller scale contortion may be seen in hand specimens of the drag folded and brecciated sericitic-hematite lode material in the underground workings, and microfolding may be observed in polished sections of the ore itself.

It is apparent then, that repeated, closely spaced shears, brecciation, and numerous short pitch changes, developed in a folded zone with an overall pitch reversal of 60°. Both the general and the minor pitch reversals arose out of subsequent folding on north-south axes which were superposed on the principal east-west fold axes. This second folding accentuated the brecciation already present in the relatively competent tuffaceous sandstones and increased the amount of shear and distortion in the interlaminated argillaceous beds.

The country rocks.

A generalised impression of the types of country rock in proximity to Noble's Nob, is given in the surface geological plan, Fig. 54. Most of these are tuffaceous sandstones of different grain sizes, which are in sequence with thinner siltstones, shales and mudstones. All of these rocks contain at least 5% clastic martite, and many contain as much as 10%, Table 15. The common features of this sequence are repeated, short interval facies changes, slumped structures at the interfaces between coarser and finer lamellae, the presence of sporadic interformational conglomeratic bands and thin heavy mineral lamellae, Figs. 56, 57. Such structures were utilised in thin section studies to determine and orient the obscure bedding. Cleavage is clearly marked in almost all of the rocks.

In the vicinity of the lodes the tuffaceous rocks were brecciated, silicified and argillised, especially at the western end of Noble's Nob and at the surface 600 feet north of the main orebody, where a small parallel lode occurs. Some brecciation developed from additional stress on rocks previously folded and most of the fragments retained their original attitudes from the former folds.

Silicification near the surface produced yellow, buff-coloured cryptocrystalline rocks, again preserving in pseudomorph their original structures and attitudes. At the same time, colloform fine grained silica filled the open spaces of the breccias. Hydromicas and primary and secondary kaolin were introduced into the rocks in numerous thin veinlets which may be seen along shears and fractures in the underground workings. The silicification of the country rocks is also manifest underground, in the conversion of sections of the wall rock to banded red jaspers.

Silicification and argillisation were effective mainly in the zones of brecciation, and hence essentially in the siltstones and in the tuffaceous sandstones. Shearing along steeply dipping slickensided surfaces was widespread through the lode formation which exists mainly in the argillaceous rocks.

The dominantly tuffaceous sequence in D.D.H. 165, Fig. 31, provides an example of the type of rocks which constitute the Specific Horizon in this area. The widespread very low grade copper mineralisation encountered in many parts of this drill hole, differs in type from the usual copper mineralisation at Tennant Creek. There were no magnetite or hematite lode formations, but instead, concentrations of chalcopyrite and pyrite were found at positions of sharp facies changes between the coarsely tuffaceous sandstones and the relatively impervious, highly chloritic slate or shale. This mode of occurrence is unusual and is a different type of sulphide mineral accumulation, viz. one of syngenetic origin.

The mineralogy and texture of the country rocks in proximity to mineralised lode formations, changes to varying degrees according to the types of sedimentary facies present. These changes, which may be studied in detail in drill cores and in underground exposures at Noble's Nob Mine, constitute selective wall rock alterations induced in certain types of sediment. These phenomena are not particularly clear in the upper levels of the Mine where oxidation has occurred, but may be examined in detail at deeper levels.

In the oxidised upper levels above 245 feet, red-brown coloured mudstones, siltstones and tuffaceous sandstones are exposed in the drives which extend from the unmineralised country rock through to the contacts with the lode formation. The mudstones and shales have weak bedding and little cleavage and are mainly composed of extremely fine grained sericite.

They contain 5-10% of disseminated clastic martite (0.05-0.5mm diam.), as well as minor zircon and tourmaline. Clastic chlorite is seldom visible in the oxidised rocks since it readily decomposed to secondary limonite and clays.

Near their contacts with the lode the argillites were extensively replaced by primary illite, sericite and kaolin. These formed in isolated clusters at random centres through the rock fabric, in transgressive veinlets, or within specific lamellae. With the incidence, and the progressive increase in the hydromicas and kaolin towards the contacts with ore, the content of magnetite also increased. Finally, in proximity to the lodes, bands of concentrated martite or magnetite crystals, alternating with layers of concentrated hydromicas, kaolin and some muscovite, may be observed parallel to the bedding or cleavage of the shales, Figs. 58 to 61.

At the contact with the lode, the mudstones were frequently completely replaced in pseudomorph by hydromica, kaolin, muscovite and magnetite. The partly replaced country rock and the lode formation itself, were also intersected by thin primary quartz-tourmaline-specularite veins.

In contrast to the easy susceptibility of the argillaceous facies to wall rock alteration, little or no change was affected in the siltstones, or in the tuffaceous sandstones. Not only do these rocks retain their identity up to the contact with lode formations, but quite unaltered residuals are present within the orebody itself. These finer and coarser arenaceous rocks, ranging in grain size from 0.01-0.5mm., consist of irregularly shaped, poorly sorted fragments of quartz phenocrysts and other volcanic and sedimentary rock particles in a medium of sericite, chlorite and clay with accessory martite, zircon and tourmaline.

At depths beyond 245 feet, the red brown colour imposed on the sediments by secondary intergranular limonite disappears and the rocks assume a grey-green colour. In the mine workings down to 450 feet, and in the cores from drill holes beneath the orebody, the rocks may be studied in their original unoxidised condition. Here they contain a proportion of clastic chlorite, usually about 5%.

The fresh unoxidised argillites, composed largely of sericite and chlorite in parallel orientation, are slates rather than shales. The refractory accessory components such as martite, zircon and tourmaline, which were distinguishable with difficulty in the oxidised rocks of the upper levels, are abundant in the fresh rocks.

In the absence of the masking effect of secondary intergranular limonite, the textures and structures of the wall rocks of the primary zone are clearly displayed in thin section. Microbrecciation of the rock fabric was observed to be a widespread feature which provided open space for the accumulation of hydromicas, and for the epigenetic quartz, apatite and tourmaline derived from transgressive veinlets which contain these minerals.

The progressive recrystallisation of sericite and chlorite in the slate, in positions successively closer to the lode formation was observed in crosscuts and in drill cores. This transition is characterised by the progressively increased grain size and quantity of the micaceous minerals, and also by increased quantities of hydromicas, kaolin, magnetite and specularite towards the orebody, Figs. 62 to 65.

The phenomena displayed in the primary zone indicate the transitions which accompanied primary gold mineralisation. These are to be distinguished from secondary and decompositional effects upon silicates, and from the phenomenon of secondary enrichment in gold which occurred in the upper levels.

In the lower levels adjacent to the lode, the slates were rendered more fissile by recrystallisation of indigenous chlorite and sericite. In the wall rock alteration zone, the progressive replacement of recrystallised chlorite by hydromicas, kaolin, muscovite, magnetite and specularite increased towards the orebody. However, the chlorite was not completely replaced in all cases but it persisted in sufficient amount in certain areas, to form the so-called "chloritic hematite" lode rock, Fig. 54. This material is characterised by a much lower gold content than the so-called "sericitic hematite".

While the chloritic hematite lode rock is characteristic of the 300 foot and deeper levels, a little of it survived oxidation and protrudes in a few places as high as the 215 foot level. Above this level, no chlorite is to be found, but only its secondary products, mainly clays.

The process of replacement in the primary zone, which occurred with the formation of magnetite, specularite, hydromicas, kaolin and muscovite both in and across the cleavages of the slate, is illustrated in the series of Figs, 62 to 65. The flakey silicates and the iron oxides commonly grew together forming composite grains which enclosed the original clastic martite or hematite, as well as the other heavy mineral accessories. In extreme replacement these are often the sole remnants of the original slate.

Although recrystallised chlorite formed through dynamic metamorphism in the intergranular matrix of the tuffaceous sandstones and siltstones, there was little other change in these arenaceous rocks in the deeper primary zones. The absence of growths of hydromicas, kaolin, muscovite and iron oxides in these rocks indicates that they were not susceptible to mineralisation, or to the metasomatic wall rock alterations.

The orebody.

Noble's Nob is a unique type of gold orebody and it is essentially of the bonanza type. The extremely high gold values which occur in the lower part of the oxidised zone are in part due to secondary enrichment, as will be explained below. The orebody has three distinct depth zones which are defined by gold tenor, structure and composition.

The upper zone extends from the surface outcrops to a depth of about 100 feet and is characterised by relatively low gold values which seldom exceed 15 dwts per ton. Throughout this zone the mineralogical and structural characteristics of the lode are similar to those of the outcrops at the surface.

The texture and grain size of the lode material is variable, but its structure is essentially massive. In a given sample, the major components exhibit one or other of two contrasting textures which are common throughout the upper section of the orebody.

One major component is prismatic specularite which, by virtue of a criss-crossing arrangement of coarse grained crystals, formed an open textured idiomorphic granular aggregate, Fig. 67. In contrast to this, irregularly granular, finer grained hematite formed dense less permeable allotriomorphic granular aggregates, Fig. 66. In most samples, embayed crystal edges and voids within the aggregates, attest to prolonged leaching of the iron oxides.

In the open spaces in the specularite aggregates, clay minerals and quartz, heavily stained by adsorbed limonite, occur with minor amounts of bismutite and malachite, as well as native copper and gold particles with a maximum size of 0.05mm diameter. On the other hand there is little gold or other minor components in the dense hematite aggregates.

The central zone extends from 100 feet to about 270 feet depth and constitutes the most highly developed and the richest portion of the orebody with lode widths reaching as much as 150 feet. The transition from the upper zone is quite sharp and is characterised not only by greatly increased gold values, but also by significant compositional and structural changes. This central zone is nevertheless, contained entirely within the zone of oxidation and is above normal water table level.

The large increases in the amounts of primary crystallised hydromicas, kaolin, muscovite and magnetite are the main compositional change in this zone. These minerals, associated in most instances with specularite, determine the amount of primary gold in the ore. The tenor of primary gold is however, augmented by secondary gold deposited largely with secondary finely aggregated kaolin within this zone.

The aggregates of hematite and specularite, which are characteristic of the upper portion of the oxidised zone, occur also in the central zone, but are subordinate in amount compared with the so-called "sericitic hematite" in which most of the gold of the central zone occurs, Fig. 68. Sericitic hematite is a banded rock, formed from alternating layers of the crystallised primary flakey alumina silicates, and layers of martite or specularite. This is the end result of the progressive replacement of shale or slate and its banded structure arose out of the control of replacement by the bedding or cleavage planes of the shale. The incidence of wall rock alteration is in fact, greatly accentuated in the slates bordering this wide central zone of the structure and the progression of these conversions can readily be traced in crosscuts, Figs. 62 to 65.

Much of the banded sericitic hematite is contorted or brecciated. These structures, which were imposed upon the country rock before the replacement occurred, provided a highly permeable medium for the solutions which introduced potash and alumina silicates and iron oxides. In the microsections of the banded lode rocks, both the hydromicas and specularite crystals exhibit a decussate texture which indicates that neither folding nor brecciation had any influence on their orientation.

There is a gradually increasing amount of magnetite towards the base of the central zone. This first appears at about 180 feet as minute residual cores within the individual martite grains, Fig. 70. Concurrent with the appearance of incompletely oxidised remnants of magnetite, small amounts of pyrite and chalcopyrite, as well as the sulphosalts, enargite, wittichenite and emplectite, become visible. These are distributed as isolated granules, or as components of thin transgressive quartz veins. The quantity of these minerals then increases in depth, especially towards the eastern end of the orebody where weak copper mineralisation exists in the hanging wall.

The distribution of the richest shoots of gold, was controlled by the superabundance of coarse flakey alumina and potash alumina silicates in the sheared, contorted and brecciated core of the central zone, Figs. 71, 72. While the separate distributions of auriferous sericitic hematite, and low grade allotriomorphic granular hematite reflect the structure of the original country rocks, Fig. 54, the attitude of the rich gold shoots is more closely related to the plunge of the lineations within the planes of the shears. The attitude of these rich shoots is quite clearly demonstrated in Plate 3 and is at an angle to the general pitch of the orebody.

Gold occurs mainly among the intersecting crystals of the flakey silicates, Fig. 69, or in the open spaces between the magnetite euhedra or the specularite prisms. Most of the gold is of very fine grain size, generally not exceeding 0.2mm diameter, but in very rich portions of lode, elongate bodies several cm. in length and several mm. in thickness, may also occur. The gold is a very pure variety with fineness of 960.

The lower zone of the orebody extends from about 270 feet to 400 feet. Between 270 and 300 feet, it thins rapidly and loses its high gold values. The average value of the ore diminishes to one ounce per ton over a maximum lode width of approximately 30 feet, at the 300 foot level, and below this, the gold tenor rapidly falls to only a few pennyweights per ton. At the same time the sulphides and sulphosalts increase in amount and grain size, and in the hanging wall at the eastern end of the lode system, east-west shears were mineralised exclusively by pyrite, enargite and chalcopyrite, Figs. 73, 74.

The vertical depth projections of the lode shears were located by drill holes beneath the orebody at depths of 500 and 600 feet respectively, Fig. 55. These intersections were distinguished by numerous small veinlets of quartz-chlorite-pyrite, or quartz-magnetite-muscovite, in siltstones, sandstones and slates which display interformational slump and brecciated structures.

The lode formation was also followed to 450 feet vertical depth in a winze from the 305 foot level, Fig. 55. The structure was again shown to thin rapidly, but it still retained abundant chlorite and considerable amounts of sulphides and magnetite. Although the gold values almost completely disappeared in this winze, there was a decided increase in sulphides towards the keel of the lode structure.

In this deep part of the lode, the slates are highly chloritic but there is no evidence of their partial replacement by kaolin or hydromicas. Euhedra of magnetite which occur in stressed areas of slate were brecciated, and perhaps also rotated somewhat, Fig. 74. This suggests, that they were either pre-existent clastic components of the slates, or, if formed hydrothermally, slight movement occurred before sulphide mineralisation. The pyrite euhedra, many of which have zoned texture, were not affected by stress but formed in place subsequent to the shearing. The copper sulphides which later entered the sheared slates, replaced mainly the chlorite but also in part, the iron oxides and the pyrite, Fig. 73.

This deep sulphide mineralisation is similar in type to that in the hanging wall at the 305 foot level. However, in the small satellitic magnetite-chlorite lodes in the hanging wall, slight gold mineralisation was accompanied also by replacements by potash alumina silicates.

Vertically below Noble's Nob orebody, mineralisation rapidly diminishes and only weakly mineralised shears, as shown by D.D.Hs. 142, 143 in Fig. 55, exist. However the pitch of the lode structure, as shown in Fig. 54 and in Plate 3, suggest a continuity of mineralisation in depth, in an easterly direction. Copper sulphide mineralisation below 300 feet depth at the eastern end of the orebody, and in the hanging wall of this area, are actual manifestations of this continuity. On these bases, the author advocated a programme of exploratory drilling to test this down pitch extension and this is presently revealing the continuation of lode material in this area.

Secondary enrichment in gold at Noble's Nob.

At about the water table position, and for some distance above it, there is secondarily deposited gold and confused aggregates of primary crystallised hydromicas, kaolin and secondary finer grained clays. The top of the Noble's Nob lode, and in fact of most sizeable gold deposits, is characterised by advanced oxidation and by the leaching of both the primary hydromicas and clays, and by very low gold values.

This secondary gold enrichment at Noble's Nob illustrates an application of the experimental work by Cloke and Kelly (1964) on the solubility of gold in the supergene zone. In this work they arrived at the conclusion that gold will dissolve in acidic chloride solutions in a strongly oxidising environment, and that continuously alternating conditions of transport and deposition of the gold will occur with spasmodic rainfall.

The ground waters of the district contain chlorides, and the requirement for low pH in solutions percolating through the upper oxidised zone, was provided by the oxidation of the small, but widely dispersed quantities of fine grained sulphides and sulphosalts in the lode formations. Furthermore, the abundance of iron oxides in the lodes, provided for the conditions of high Eh through their reaction with acids formed from the oxidising sulphides.

The leaching of gold has been continuous over a long period of time. There is little doubt that the larger lodes, such as Noble's Nob, once extended a 100 feet or more above their present upper limit. Since conditions of peneplanation and flat sluggish drainage have persisted in the district for a long time, there has been little or no rapid erosion, and no formation of alluvial gold from the outcropping lodes.

With the slow erosion of the peneplain, and with the successive rains of the short hot wet seasons and the absence of rains in the longer cooler dry periods, gold has been progressively leached from the outcropping lodes and carried down towards the water table level.

At the beginning of each successive wet season, gold was rendered soluble by the conditions of high Eh and low pH in the first of the chloride-bearing solutions which percolated down the lode channels. A high concentration of rainfall over a short period, is typical of this area. Therefore, shortly after the initial rains and the ensuing solution of gold, there was rapid dilution of these solutions to the stage where, under conditions of increased pH and reduced concentration of chlorides, gold was precipitated. Thus in each wet season, gold may have moved only short distances. Further solution and movement of the gold would not have occurred during each following dry season, but would have, each year, occurred only at the annual wet season.

The ultimate result of these processes was the formation of lode outcrops composed mainly of hematite, limonite and quartz, but containing very little gold, secondary copper, iron or bismuth minerals. By and large, these are the characteristics of the outcropping gold lodes throughout the field down to depths of 80-100 feet.

The leaching processes are still operative and incomplete, and at depths in excess of about 100 feet there are increases in the gold tenor, in the amounts of both primary unleached kaolin and hydromicas, and in secondarily deposited clays, bismutite, secondary copper chloride, silicate and carbonate, as well as in martitised magnetite. Kaolin veins of a secondary type, containing much secondary gold and bismutite permeate all joints, shears and open spaces below 100 feet, but these decrease in abundance at greater depths and vanish at the water table.

Composition variations in relation to structure and depth.

The variation in gold tenor throughout the orebody is depicted in Plate 3, which is a contoured longitudinal assay section, prepared by projecting some thousands of analytical results on to a median plane through the orebody. The assay values utilised to construct this plan were made available by Mr. L. Roach, Chief Chemist of Noble's Nob Mine.

This section illustrates the depth variation in gold content which was discussed in previous pages. It shows also the flat easterly pitch of the orebody and the steeper 60°-70° plunge of the rich shoots within it. There is also an expression of the change to a flat westerly pitch on the left hand side of the assay projection section.

In the central area of the orebody, between the extremities which plunge 10° west and 30° east respectively, the pitch of the structures as seen underground, fluctuate repeatedly at short intervals. These localised and smaller scale pitch reversals had considerable influence on the tenor of the ore and upon the amount of hydromicas, kaolin and magnetite which were introduced. In such areas the greatest amount of sericitic hematite formed. The influence of the pitch reversals upon the composition of the orebody is reflected in the contoured assay section where at least three saddle-like rich shoots may be seen.

Thus, while the locus of ore deposition was broadly controlled by the intersections of the planes of the east-west shears with both the bedding and the argillaceous facies in the folded country rock, the channels of intense mineralisation were more precisely determined by pitch changes and by lineations. The pitch changes arose from the north-south fold axes, and the lineations from the oblique movements within the shears.

The distribution of gold values, the attitude of the ore shoots, and the incidence of copper mineralisation in depth at the eastern end of the deposit, suggest that the source of mineralisation was from a deep centre east of Noble's Nob.

Composite samples were taken across the orebody at various positions in the Mine to provide further data on the compositional variations with respect to increasing depth and distance along the strike of the orebody.

The results obtained are listed in Table 17 in company with those from bulked samples of weakly mineralised, and from completely barren country rocks, Tables 15, 16.

The barren country rock samples were selected representatively from lengths of drill core after thin section examination had established the rock identities, and the absence of mineralisation in them. This series of non-mineralised country rocks were taken from below, and directly down dip from the lode formation and the weakly mineralised rock samples were taken from the wall rock zone of alteration. The metal values of these samples may therefore be compared with those from various parts of the orebody to provide a concept of the chemical changes which resulted from mineralisation.

Since these are only partial analyses, quantitative estimates with respect to the mineralogical changes during mineralisation, are not possible. However, the data is sufficient to qualify the microscopic observations described earlier, and to provide a general concept of the bulk changes in major and minor metals.

The presence of magnesia in the analyses indicates that chlorite or hydromica exists in the rocks. It was shown by X-Ray analyses that illite is the major hydromica in the partially or completely mineralised rocks.

The presence of potash in the analyses indicates that sericite or muscovite, and to a lesser extent hydromicas, may exist in the mineralised rocks. In the case of barren rocks, felspars may also contribute to the potash content.

TABLE 15.

Partial Analyses of barren country rock - Noble's Nob.

Composite Sample of	% Fe_2O_3	% Al_2O_3	% MgO	% K_2O	ppm Cu	ppm Ag	ppm Zn	ppm Bi	ppm Au	estimated % Sericite (felspar)	estimated % Chlorite	Al_2O_3:K_2O
Shale D.D.H. 140* 392'-410'	7.7	18.4	1.8	6.3	6	nil	40	nil	nil	54	5.0	2.9
Tuffac. Sandstone D.D.H. 140* 193'-276'	6.3	14.6	1.6	5.4	8	nil	40	2	nil	40-50 (including felspar)	4.5	2.7
Tuffac. Sandstone D.D.H. 140* 360'-392'	5.6	16.1	1.5	5.3	8	nil	40	nil	nil	40-50 (including felspar)	4.2	3.0
Lithic tuff D.D.H. 140* 620'-700'	4.5	10.7	1.1	3.2	6	nil	50	nil	nil	20-30 (including felspar)	3.1	3.3
Mudstone D.D.H. 151 543'-546'	7.4	18.4	1.3	4.7	1	0.1	30	1	nil	40	3.6	3.9

*D.D.H. 140 is an underground drill hole collared on the 340' level. It penetrated the zone of wall rock alteration (vide Table 16) and passed into barren country rock beyond 150 ft. length.

Analyses by Australian Mineral Development Laboratories.

TABLE 16.

Partial Analyses of weakly mineralised country rock - Noble's Nob.

Composite Sample of	% Fe_2O_3	% Al_2O_3	% MgO	% K_2O	ppm Cu	ppm Ag	ppm Zn	ppm Bi	ppm Au	estimated % Chlorite	Al_2O_3 / K_2O
shale D.D.H. 143* 478'-489'	15.9	8.1	2.7	0.3	700	0.1	200	150	0.4	7.5	3.0
Wall rock shale D.D.H. 140** 0-43'	15.9	13.3	7.6	1.2	2000	0.2	120	80	nil	21.1	13.0
argillised shale***	31.1	15.8	1.28	1.55	500	5	120	50	1.5	illite only	10.0

* D.D.H. 143 was collared at the surface in the hanging wall and entered the weakly mineralised sediments immediately beneath the orebody.

** D.D.H. 140 is an underground drill hole collared on the 340' level in the zone of chloritic wall rock alteration and incipient copper mineralisation beneath the orebody.

*** argillised shale - this is a composite sample prepared from a large number of specimens taken from the contact zone of alteration, outside ore limits, on the intermediate levels.

Analyses by Australian Mineral Development Laboratories.

TABLE 17.

Partial Analyses of ore - Noble's Nob Mine.

	% Fe_2O_3	% Al_2O_3	% MgO	% K_2O	ppm Cu	ppm Ag	ppm Zn	ppm Bi	ppm Au	$\frac{Al_2O_3}{K_2O}$
*sericitic hematite	73.5	5.45	0.21	0.56	400	20	150	50000	400	
135' level										
west end	91.6	1.8	0.04	0.10	600	2	200	1500	6	18.0
east end	80.3	6.3	0.06	0.46	250	1	200	400	0.6	
165' level	84.5	5.3	0.06	0.33	120	2.5	180	500	26	16.0
185' level										
west end	87.1	4.1	0.03	0.24	200	3	180	2000	88	17.0
central	77.9	7.8	0.52	0.78	500	7	40	75	272	10.0
215' level										
west end	87.1	3.6	0.07	0.26	150	12	180	700	194	14.0
central	66.2	9.7	1.29	0.8	500	2.5	220	1200	158	12.0
east end	81.5	5.0	3.8	0.4	250	6	180	5000	32	12.0
305' level										
west end	59.3	11.8	4.3	0.8	1500	2	180	400	14	15.0
central	57.2	12.2	3.9	1.2	120	4	250	50	12	10.0

* sericitic hematite - a bulk sample of high tenor gold ore prepared from many samples taken from the intermediate zone of the orebody. The samples were banded magnetite-martite-sericite-kaolin-hydromica rocks.

all other samples - channel samples across the entire orebody including high tenor sericitic hematite and low tenor massive quartz-hematite lode material.

Analyses by Australian Mineral Development Laboratories.

The alumina content is provided by all the above-mentioned minerals. However, where this is very high compared with the potash or magnesia contents, the rock is one which is very rich in the ordinary alumino-silicates, and as indicated by X-Ray analyses, kaolin is the major alumino-silicate present in the samples which were examined.

For the purposes of discussion and comparison with microscopic determinations, the ratio of Al_2O_3: K_2O provides a convenient indication of the relative quantities of potash aluminium silicates and aluminium silicates present in the rocks. This ratio is shown in the tables and may be related in each case to the figure 3.3 which is the ratio for muscovite and sericite. A numerically larger ratio indicates that kaolin is more abundant than the potash micas whereas a numerically lower ratio indicates that felspars are also present in the rocks.

Table 15 indicates that the three main types of sediment present in the Noble's Nob area, are not significantly different from each other in composition. These all contain normal background values for the trace elements listed, and their Al_2O_3: K_2O ratios confirm that clastic felspars as well as some 45% sericite, exist in the rocks. The iron content is derived almost entirely from clastic martite, although some 5% chlorite which also exists in these sediments, contributes to this.

In Table 16 the effects of incipient, and somewhat more advanced mineralisation, as indicated by copper content of the rocks, are demonstrated on shales similar to those in Table 15. In the rocks from drill holes 140 and 143, these early stages of sulphide mineralisation beneath the gold deposit are further manifest in the substantial increases in the magnesia (chlorite), and in the iron (magnetite) content of the rocks. At the same time, the contents of both alumina and potash diminish due to iron and magnesia having replaced the clastic sericitic and felspathic components of the shale.

In the argillised shale which represents the more strongly altered contact zone of the gold orebody, there is some three or four times as much iron as in the barren shales. There is however, little change in the total alumina and magnesia, whereas the potash content is considerably lower. Since chlorite does not exist in the wall rocks of the gold orebodies, the magnesia content represents the quantity of hydromica (illite) formed in them. The high ratio of alumina to potash can be explained on the basis of microscopic observations as due to the formation of abundant primary kaolin, as well as illite, in the wall rock zone, Figs. 58, 59.

In Table 17, the partial analysis of a bulk sample of high grade sericitic-hematite ore is listed for comparison with a series of channel samples taken at various positions across the entire orebody. The sericitic hematite, representing the most advanced stage in mineralisation, consists of martitised magnetite and kaolin with smaller amounts of hydromicas, sericite, bismuth and gold, Figs. 60, 61.

In this series of samples taken at various depths, certain general trends are apparent. Although the total iron values fluctuate somewhat, there is no clearly defined increase or decrease in the intermediate levels. However, in the lower levels of the orebody, there is a definite decrease in total iron which coincides with diminishing gold mineralisation.

The small magnesia content throughout the samples from the intermediate zone is accounted for by the hydromicas, but towards the base of the deposit where copper mineralisation and readily apparent chloritisation exist, the magnesia content is considerably higher.

Throughout the deposit the alumina content is higher than the potash content thus indicating that alumino-silicates (kaolin) are more abundant than the potash micas (sericite). The high alumina : potash ratio on the 305 foot level is due, as in the sericitised argillite of Table 16, to the dominance of primary alumino silicates over potash micas in the area of weak gold mineralisation. At this position, mineralisation in both gold and copper is only in an incipient stage and consequently there is a complex of chloritic, kaolinitic and sericitic alterations.

The fluctuations in bismuth and silver contents, correspond broadly to the variations in gold content. In the richest gold shoots, values as high as 10% bismuth and 30 ppm silver, were found. The high immobility of bismuth and silver, especially in near-surface environments where limonite and secondary clays are abundant, therefore renders these elements useful as pathfinders in the search for gold mineralisation elsewhere in the field. Although zinc is relatively mobile, the amount present in the orebody is probably due to its fixation by co-precipitation with limonite and to its adsorption on the clays.

Copper has a different distribution from gold, bismuth and silver and it is present to a greater extent in the rocks containing chlorite than in those containing hydromicas and sericite.

The bullion from Noble's Nob has for years had a value of 960 fine.

Silver therefore is a minor, but constant associate metal. In the numerous samples of ore which have been examined, no trace of mercury and only slight amounts of tin, chromium, vanadium and cobalt have been found. On the other hand molybdenum values rise to about 150 times background, while tungsten and nickel show only weak increases in the high grade sericitic hematite lode material.

(2) The smaller gold deposits of Tennant Creek.

According to the records of the Bureau of Mineral Resources, about 1,000,000 ozs of gold were produced from Tennant Creek up to the end of 1964. Approximately 65% of this was won from the Noble's Nob Mine and about 10% from each of Peko and Eldorado Mines. In the last year or two, the new copper mines Orlando and Ivanhoe have contributed considerably to this gold production. The remainder was obtained at various periods from numerous small deposits of which only twenty had a recorded production of more than 1000 ozs. Apart from Peko, most gold in the area was obtained from mines which were essentially gold deposits, although at least some sulphides were found in most of these, and minor copper mineralisation was observed in some, e.g. in Eldorado, Noble's Nob, Wheal Doria, Northern Star.

Exclusive of the major producers, the best of the smaller gold deposits were found along the southern limb of the major anticline in the south and along the northern limb of the major syncline in the north, Plate 1. The structural environment of most deposits was determined and described by Ivanac (1954) and his data are incorporated in Plate 1.

Samples from the accessible smaller deposits were examined to establish a comparison with the more detailed study of Noble's Nob. The following brief comments on the mineralogy of the deposits, indicate that most of the smaller gold deposits have the same characteristics, which in turn, are similar to those of Noble's Nob.

Deposits in the southern limb of the main anticline.

Along this structure, the important deposits from west to east are, Westward Ho, Skipper Extended, Mt. Samuel, Hammerjack, Enterprise, Patties, Eldorado, the new Juno, Noble's Nob, Rising Sun, Joker, and New Hope. Each of these was located in sheared or brecciated drag folded minor structures on the south dipping limb of the major anticline and in the major deposits, the structures were further complicated by pitch reversals.

Westward Ho, which produced 150 tons of 7 dwt ore, was located in the brecciated shales of the southern limb of an anticlinal drag fold with 50° westerly pitch. The lode was mainly hematite with interstitial clay, containing isolated gold particles of 0.1-0.5mm diameter. The lode had a massive structure, the clays were pseudomorphs of hydromicas and muscovite, and the allotriomorphic granular hematite, displaying martitisation texture, was developed from magnetite. The barren sections of the lode in depth, were composed mainly of specularite intergrown with hydromicas and muscovite.

The Outlaw lode, which produced several hundred tons of 20 dwt ore, was formed in an anticlinal drag fold characterised by pitch reversal. The ore below 100 feet depth was a highly contorted aggregate of martite, specularite and hydromica. This contained gold and interlaced illite crystals in the open spaces amongst intersecting specularite prisms, as well as wittichenite among the martite aggregates. Hematite which formed upon many of the martite crystals, Fig. 75, is probably related to supergene phenomena and not to mineralisation processes.

The Hammerjack lode occupies brecciated shales and sandstones in the north limb of an anticlinal fold which has 20° east pitch. The productions from open cuts and the shaft were 500 tons of 10 dwt. and 400 tons of 5 dwt. ore respectively. Allotriomorphic granular hematite and idiomorphic granular specularite, intergrown with quartz and hydromicas, formed the lode in massive hydromica impregnated-claystone. Gold particles deposited among the hydromicas, clays and quartz, or in the specularite, whereas wittichenite and enargite, each coated with later secondary covellite, formed mainly in hematite.

One mile further east, the Enterprise lode which produced 6,000 tons of 18 dwt. ore, exists in a breccia in an area of pitch reversal in a minor anticline. The ore shoots formed where the lode structure transected mudstone horizons and according to Ivanac, the values were high where the mudstone was brecciated, and low where it yielded by flow. The ore contained an abundance and variety of hydromicas and clays, as well as muscovite, martite and specularite, but there was little quartz. Gold was observed in the hydromicas and clays, and also in the hematite which contained a little native copper and wittichenite. The richest ore was characterised by an unusual abundance of hydromica, much of which formed in the centres of embayed martitised magnetite euhedra.

Eldorado was a major mine among this group, and it produced

150,000 tons of 15 dwt. ore. In a detailed account of its structure, Ivanac (1954) stated that he observed east, central and west shoots in brecciated and attenuated sediments in the north limb of an anticline pitching 22° east. Gold was deposited with specularite, quartz and hydromicas in brecciated mudstone, whereas the interbedded quartzites and sandstones, which folded competently, were not mineralised. The habit of gold in the lodes is identical with that at Noble's Nob, and in rich shoots its close association with hydromica is always manifest, Fig. 76. Manganese, bismuth and copper minerals were also found in appreciable amounts in the lodes.

Noble's Nob, the major mine on the field is one of this group and because of its importance the previous section was allocated to it.

The Rising Sun lode which produced 10,000 tons of 15 dwt. ore was a shallow orebody in the eastern extremity of the Noble's Nob structure. Its mineralogical characteristics are identical with those of Noble's Nob.

The New Hope Mine, the most easterly of this group, had a small production of only 88 ozs. However, current exploration in this area reveals coincident geochemical and magnetic anomalies which are presently being tested by diamond drilling. Microscopic study of these cores indicates that both gold and copper mineralisation exists below the old workings, in zones where magnetite and talc formed in abundance in stressed chloritic siltstones and slates. Although the typical association of gold, hydromicas and hematite is visible in the surface and near-surface portions of the New Hope lode, this is not apparent in depth. The newly discovered deeper lodes appear therefore to be more closely comparable in mineralogy with the copper deposits of Peko, Pinnacles and Golden Forty.

Deposits in the northern limb of the main anticline.

The main deposits along this horizon include Wheal Doria in the west, Pinnacles in the central area and Peko, Golden Forty and Golden Kangaroo in the east. These follow a general pattern and are located in the minor drag folds on this north-dipping anticlinal limb. Plate 1.

The Wheal Doria was a small mine which produced only 120 tons of 20 dwt. ore. Brecciated sandstones and mudstones contained the lode near a position of pitch reversal in an anticlinal drag fold. The ore shoot was confined to a mudstone horizon in which martite, specularite and hydromicas formed in abundance, the gold being principally associated with hydromicas, clays and specularite. Pyrolusite was also a component of this orebody.

The Pinnacles lode which produced 1,300 tons of 3 dwt. ore, is described in more detail in a later section. It formed in the south limb of a west-pitching anticline where anthophyllite, talc, chlorite and magnetite replaced the sheared country rocks. Both copper and gold were present in the ore. The gold, with secondary bismuth and manganese minerals formed thin plates in the cleavages of chlorite, whereas the copper sulphides concentrated with talc and magnetite in zones of strong metasomatic replacement.

Peko, the largest operating mine on the field is treated in detail in a later section. The quartz-chlorite-magnetite lode formation occupies a brecciated section of a west-pitching fold, Fig. 77. The structure was mineralised only in gold above 200 feet, but below this level copper mineralisation persists to over 1,000 feet depth. The mineralogy of the Peko orebody differs from that of the gold orebodies and is characterised by an abundance of magnesian minerals, magnetite and sulphides. Hydromicas are absent from the assemblages, even in the upper auriferous, copper-free sections.

Golden Forty lode which produced 2,000 tons of 5 dwt. ore, was formed near a number of smaller ironstone bodies in the complexly drag folded area just east of Peko. Both gold and copper shoots formed in the lode with appreciable amounts of bismuth and molybdenum. The gold ore shoots contained mainly martite, specularite and hydromicas, whereas the copper shoots were talc-chlorite-magnetite assemblages similar to those of Peko.

Current exploration in the vicinity of both Golden Forty and Golden Kangaroo Mines reveals the continuity and repetition of the copper orebodies down the pitch of the structures. The mineralogy of the drill core from these newly discovered deep intersections conforms to the talc-chlorite-magnetite-chalcopyrite association, and to the characteristics of the Peko lode. These lodes are miniature examples of Peko and are more characteristic of copper mineralisation.

Along the northern limb of the main syncline.

There are many mines along this limb, and among the few which are significant are Jubilee in the west, Burnt Shirt and Kathleen in the central area and Lone Star, Gigantic and Blue Moon in the east.

The Jubilee Mine, in the sheared southern flank of an east-pitching anticline in proximity to a large porphyry intrusive, produced very little gold. The usual hematite lode formation was absent, hydromica concentrations did not occur, and the gold was mainly in thin flakes in the cleavage planes of the stressed sediments. The deposit was noted mainly for the unusually large amount of bismutite in the lode shear.

Burnt Shirt and Kathleen lodes, which together produced several thousand ounces of gold, formed near an area of pitch change in an anticlinal drag fold. The gold-bearing specularite lodes contained mainly hydromicas at Burnt Shirt, and quartz at Kathleen Mine.

The Lone Star lode produced over 5,000 ozs of gold. It formed in the eastern extension of the Mary Lane Shear, which passes through an east-pitching syncline at this point. The lode contained gold and a small amount of chalcopyrite in an assemblage of hematite, specularite, hydromicas and quartz. Recent drilling has disclosed at greater depth, abundant sulphide below the old workings.

The Blue Moon lode which formed in an overturned east-pitching anticline, yielded more than 12,000 ozs of gold. Abundant fine and coarse gold was found in the clays and hydromicas which filled fractures in the stressed quartz-hematite lode aggregate. The Gigantic, a smaller neighbouring lode in a comparable structural environment, was also a highly stressed quartz-hematite body. This contained gold among the clays, hydromicas and specularite which filled the brecciated quartz-hematite.

<u>The more remote auriferous lodes.</u>

Several gold deposits of considerable significance in former times, were found west and north of the main Tennant Creek area. For the purpose of completeness, samples of ore from these were examined and it was found that the usual association of gold with potash micas, clays and hematite, held in most cases.

For example, Black Angel and Great Western Mines some 20 miles north-west of Tennant Creek, and the Whippet, North Star and others 20 miles north of Tennant Creek, display this typical association of minerals.

A contrasting type of mineralogy was revealed in the examination of the cores obtained from recent deep drilling at the Northern Star Mine. Rich gold intersections at 900-1000 feet depth contain gold only with quartz and specularite, which together penetrated brecciated quartz-chlorite-magnetite lode material. There is no trace of hydromicas or of muscovite in these deeper gold veins. The Northern Star lode is essentially one of low grade copper mineralisation in a medium of quartz, chlorite and magnetite; and the gold, associated with quartz and specularite, is of later origin.

The absence of hydromicas and muscovite with gold in deep environments may be observed in other places, e.g. at Peko, Orlando and Ivanhoe, where again gold is of later generation than its base metal associates. The mica association is characteristic of shallower environments and of those which are dominantly of the gold mineralisation type.

13. THE SULPHIDE OREBODIES.

Minor amounts of sulphides, particularly of pyrite and chalcopyrite, are widespread in the Tennant Creek field. These minerals were noted in minor amounts as clastic components of very coarse grained tuffaceous sediments and as accessory components in the igneous intrusives, particularly in those of intermediate or basic composition.

Sulphides of epigenetic origin are however, much more abundant and widespread. Apart from their concentration in the commercial orebodies such as Peko, Orlando and Ivanhoe, small amounts occur in most gold orebodies, and in many minor transgressive veins which are frequently encountered in otherwise non-mineralised country rock.

Where it is present in considerable amounts, chalcopyrite is usually accompanied by pyrite, pyrrhotite, enargite and minor amounts of bismuth, bismuthinite, wittichenite and emplectite. Sulphide assemblages containing all, or some of these minerals have been discovered in underground workings, or in exploratory drill holes in the following deposits: Northern Star, Lone Star, Shamrock, Pinnacles, Wheal Doria, Eldorado, Cat's Whiskers, Noble's Nob, Golden Forty, Golden Kangaroo, New Hope. In addition to these, there have been more recent, but unpublished finds of sulphides by Geopeko Ltd. in their widespread activities in the Tennant Creek area.

Sulphides of lead and zinc are less widespread and at this stage appreciable quantities have been reported only from Peko, Orlando and Ivanhoe. Minerals such as arsenopyrite, cobaltite and tetrahedrite are presently known mainly from Peko.

In the sections which follow, the mineralogy, textures and structures of the main sulphide orebodies are described in relation to their geological environments, and to the general problem of ore genesis.

1. Peko Mine.

This is the largest ore deposit of Tennant Creek. It has a current annual production of 163,000 tons of ore with a grade of 5.4% copper and 2.4 dwt of gold per ton. At present the reserves are estimated to be 691,000 tons of 4.6% copper ore containing 2.9 dwt of gold per ton. A point of special interest is the increasing silver output from this mine and in recent years, this has risen to 102,000 ounces per year, approximately eight times the quantity of gold produced.

The deposit was opened up in 1935 as a gold mine. During 1936, the Aerial, Geological and Geophysical Survey of Northern Australia revealed a major magnetic anomaly over the site and deep drilling to test this anomaly, was commenced. At a vertical depth of 400 feet, a 35 foot intersection of cupriferous quartz-magnetite rock was encountered, and mining was then extended to reach the copper orebody. As subsequent experience proved, this intersection was in the zone of secondary sulphide enrichment.

These successful circumstances promoted the immediate search in other parts of the field for copper orebodies which might also be associated with magnetite, and the subsequent discovery of the Orlando and Ivanhoe deposits by Geopeko Ltd., showed that this inference was valid.

The Peko lode structure reaches the surface as two merging quartz-hematite masses elongated at 77° and 121° respectively. There are no outcrops of any other type of rock on the flat alluvial plain which surrounds Peko.

More has been written about the Peko ore deposit than about any other geological feature of Tennant Creek. This arose out of its importance, and the accessibility of the sulphide orebody through the extensive underground workings. The main contributors to publish accounts of Peko mineralisation have been Edwards, of C.S.I.R.O. and Elliston, Chief Geologist of Geopeko Ltd.

In papers and in C.S.I.R.O. Mineragraphic Reports, Edwards (1955-1958) outlined a sequence of deposition for the sulphides and other components of the orebody and concluded that deposition commenced at 500°C and finished at 165°C, or lower. Edwards produced evidence to support his concept that the sulphides replaced earlier-formed magnetite and at the same time, showed that the ratio of copper to iron sulphides, and of total sulphides to magnetite, decreased with depth, Table 18.

Since Edwards conducted these investigations, the underground workings have reached greater depths and the knowledge of the environment has been advanced through field and drill hole studies. Access to more recent material was possible through the courtesy of Peko Mines Ltd, and Geopeko Ltd., and the mineragraphic study of the Peko ore deposit was brought up to date in this present work. Since this is the deepest working at Tennant Creek, the data obtained from its study provides a basis for the more complete understanding of copper ore genesis and for planning exploration elsewhere in the field.

In 1960, Elliston stated that the ore deposit provides an example of mineralisation localised by pre-consolidation slump structure. Recently, at a symposium held at Tennant Creek, Elliston (1965) postulated that the mineralisation within the slump was more precisely localised by disturbed greywackes and slates which were slip sheared, folded and brecciated, and in part replaced, and in part intruded, by wedge shaped masses of siliceous magnetite. Subsequent brecciation of the injected siliceous magnetite facilitated sulphide mineralisation, partly as a replacement of the breccia matrix and partly by replacement of the magnetite blocks.

The metallic components introduced into the slumped and brecciated Peko structure were considered by Elliston (1965) to have been mobilised in colloidal phases in connate waters and to have been concentrated from the enclosing and underlying sediments. Apart from heating caused by the crystallisation of this colloidal matter, no significant thermal phenomena are considered by Elliston to have affected the ore deposit.

Thus there are the two contrasting views in respect to the origin of the Peko sulphides - the first, the epigenetic concept of Edwards which invokes hydrothermal phenomena operating within the range of 165°-500°C - and the second, the low temperature colloidal accretion hypothesis of Elliston which implies an essentially syngenetic origin for the metals.

Although evidence of the presence of clastic sulphides at some horizons in the Warramunga sequence was found during the present study, a syngenetic sulphide origin is not proposed for the Peko or the other major copper orebodies. The expression in the aeromagnetic maps of possible basement structures beneath the Warramunga sediments; the intersection of major magnetic trends beneath the sites of the major copper deposits; the evidence of epigenetic sulphide mineralisation in proximity to basic intrusives; and the incidence of wall rock alteration phenomena associated with copper mineralisation at Peko and elsewhere, dictates an epigenetic origin and one with which elevated temperature and juvenile waters, were associated.

<u>The Peko structure and its interpretations</u>.

In the Bureau of Mineral Resources Bulletin 22, Ivanac (1954) stated that the Peko orebody was sited by shears in the north limb of a west plunging anticline. However, the more recent opinion of Elliston (1965), based upon information now available from the deeper workings and from drill holes, is that the lode occurs in slumped sedimentary structures in the south limb of a west plunging syncline.

Crohn and Oldershaw (1964) stated that the controlling influence may be the intersection of a steeply dipping north-east trending shear zone with a zone of favourable beds, or with a shear zone sub-parallel to the bedding which here trends east-west. These trends are reflected in aero-magnetic maps. The north-east trending shear zone, manifest as a distinct photolinear structure, passes through a sheared area in the Cabbage Gum Basin nine miles south-west of Peko.

The structural interpretation plan, Plate 1, places the orebody in a west plunging synclinal drag fold on the northern limb of the main anticline, at a position where it is close to the north-east trending photolinear structure. The position of this photolinear structure is defined on the alluvial plain, by the soil types and the amount of vegetation. It appears as a wide feature on the surface probably through the spread of soils, but underground in the bedrock, it is no doubt a much narrower structure.

The geological sketch plans and section of the Peko Mine, Fig. 77, show no indications of the influence of the photolinear structure which may therefore be assumed to pass a short distance to the west of Peko. These plans and the section, also indicate that the main lode and the minor satellitic lodes exist in the south limb of a syncline.

The orientations of the core zone of brecciated chloritic magnetite, of the sulphide lodes, the quartz-magnetite zones, and the satellitic orebodies, suggest that east-west structures within the folds, localised the ore deposition. These are the structures which are considered by Elliston to have developed in the sediments through interformational slump, prior to their consolidation.

Irrespective of their pre-consolidation, or later tectonic origin, these structures provided the channels and the open space which guided and facilitated later mineralisation.

In contrast to the usual lens-like forms of most orebodies which were caused by the intersection of vertical shears with inclined bedding planes, the Peko lode is a steeply plunging pipe-like body which increases in dimensions towards its base. There are many smaller convolutions which complicate its form, but both in its general shape, and in its intricate detail, it resembles the form of interformational flows, slumps and breccias that are common in the sediments of Tennant Creek, Fig. 20.

These features therefore favour Elliston's hypothesis in as much as pre-consolidation slumping appears to have determined the outline of the deposit. Subsequent tectonic movements, may nevertheless have superposed the structures which guided mineralising solutions into the slumped sediments.

As may be seen in Fig. 77 the orebodies were transected at some period after the completion of mineralisation by north-south faults which offset the lodes as much as 250 feet.

Mineralisation and zoned alteration.

The phenomena which led to the Peko mineralisation are manifest in a series of zoned alterations in the enclosing country rocks, in the wall rocks adjacent to the lodes, and in the textures of the ore minerals within the lodes.

This series of mineralogical transformation, observed in the microscopic study of samples collected throughout the Mine, are summarised under the following headings. Reference to the earlier work of Edwards is made in appropriate places.

(1) The country rocks.

The intercalated slates, siltstones and tuffaceous sandstones of various grain sizes which enclose, or are involved in the Peko ore-bearing structures, were prior to mineralisation, of low grade metamorphic status.

Above the water table level, these rocks are red in colour through the accumulation of limonite in intergranular boundaries. The limonite was derived partly from the oxidation of sulphides in the adjacent lode channel and partly from the hydration of clastic martite present in all of the sediments. Below water table level the rocks retain their natural green colour due to chlorite which, with sericite, clays and fine grained martite, forms the intergranular matrix of the sandy rocks, and the main fabric of the slates.

The partial analysis of some major varieties of sediments in their unaltered state is given in Tables 5 and 15. More complete analyses carried out by the C.S.I.R.O. Mineragraphic Division on rocks specifically from the Peko area, are provided in Table 18. The results from both sources are comparable so far as the limited data in Tables 5 and 15 permit.

The highly tuffaceous nature of the sand and silt grade sediments and their apparent volcanic origin, is manifest in the abundance of clastic volcanic rock particles, euhedral and fragmental magnetite, as well as in shards of isotropic silicate glass. In the shales and slates, the coarser silicate clastic are rare or absent, but magnetite is abundant and the rock fabric consists largely of chlorite, clay and sericite derived from the finer volcanic ash.

Although the general form of the lode structure was defined by the slump breccia, these unstable sediments were further disturbed by tectonic forces which operated after induration. The regional folding which affected the whole field at the end of Lower Proterozoic time and the intrusion of granite and porphyry which followed, caused shearing and further brecciation of the indurated slumped sediments. Thus, in proximity to the mineralised area slates acquired strong cleavage or became schistose, whereas the arenaceous rocks were fractured, but not completely brecciated.

TABLE 18. *

Chemical Composition of Peko Sediments.

	1.	2.	3.	4.
SiO_2	77.10	72.86	62.27	49.67
Al_2O_3	10.76	15.41	19.25	11.75
Fe_2O_3	3.56	3.24	4.19	3.11
FeO	1.01	1.64	1.93	22.66
MgO	1.06	1.34	2.22	7.62
CaO	0.57	0.78	0.84	tr.
Na_2O	0.75	0.45	1.66	tr.
K_2O	1.45	1.74	3.11	tr.
H_2O+	1.81	1.74	2.85	3.80
H_2O-	0.23	0.02	0.11	0.23
CO_2	tr.	tr.	tr.	0.06
TiO_2	0.79	0.91	0.98	0.58
P_2O_5	0.75	0.88	0.58	tr.
MnO	0.06	0.03	0.04	0.33
Cl_2	tr.	tr.	tr.	tr.
SO_2	tr.	tr.	tr.	tr.
	99.90	100.01	100.03	99.81

1. Relatively coarse-grained greywacke, D.D.H. P.1, at 340 feet.
2. Fine-grained greywacke, D.D.H. P.1, at 652 feet.
3. Sericitic slate, D.D.H. P.2, at 820 feet.
4. Chlorite schist, D.D.H. P.1, at 840 feet.

* Table 1, Report 626. C.S.I.R.O. Mineragraphic Investigations 9.9.55.

(2) <u>The zones of wall rock alteration.</u>

The zone defined by Elliston as the zone of disturbed and weakly mineralised sediment, is regarded here, as a one of progressive wall rock alteration, Fig. 77. It is suggested in this thesis, that within this zone, four distinct stages in wall rock alteration may be defined, each of which has specific mineral components indicative of the progressive changes in the country rocks surrounding the orebody.

The zones of wall rock alteration are more apparent in depth than near the surface. In the region above 700-800 feet, a barren enveloping zone of quartz and magnetite, which encloses the central sulphide lode, is in direct contact with virtually unaltered country rocks. At depths greater than this, zones of wall rock alteration and incipient sulphide mineralisation extend laterally from some 100 feet on the flanks of the orebody, and for greater distances at its longitudinal extremities.

(a) <u>The chloritic zone.</u>

The increased development of cleavage and in places, the adoption of a schistose structure in the argillaceous rocks, was accompanied in the outer limits of this zone by the formation of coarse penninite in stress shadows adjacent to the larger clastic magnetites. The recrystallisation of some of the disseminated clastic quartz is manifest in parallel growths which formed with the chlorite as composite tails extending from magnetites along the rock cleavage, Fig. 78. There were no changes in the tuffaceous sandstones other than irregular fracturing and an increase in the degree of orientation of the chlorite and sericite of the intergranular matrix.

The inner parts of this zone contain rocks in which chlorite is much more abundant than either sericite or clays. This compositional change in the slates, and in the sericite, chlorite and clay components of the matrix of the sandstones, indicates the incipient stage of alteration. Spent hydrothermal solutions from the adjoining lode zone may also have introduced some magnesium and removed alkalies and some alumina from the rocks of this zone.

Parallel oriented flakes of penninite are the major component of the chloritised rocks, but small amounts of stilpnomelane occur in crystals which do not conform to the rock cleavage. The matrix of the intercalated tuffaceous sandstones is often completely chloritic, but the coarser siliceous volcanic rock clastics are retained in unaltered condition, Fig. 79. Veinlets composed of ankerite or of subidiomorphic quartz, frequently occur in the inner portion of the chlorite zone where they transect the rock structures, following irregular lines of fracture. The chloritisation of the tuffaceous sandstones was not uniform and is usually absent in rocks which were not fractured. This suggests that hydrothermal phenomena may have assisted in the transformations..

Thin transgressive quartz-chlorite-sulphide veinlets extending from the inner sulphide zone, appear frequently in the chloritised wall rocks, thus marking the outermost limits of travel by metal-bearing solutions.

(b) <u>The silicic zone.</u>

The upper part of the lode structure is separated from the chloritised sediments by fine grained, red coloured, highly silicified sediments, or jaspers. This zone of silicification fades in depth and appears to be a characteristic only of the upper reaches of the lode structure, where the succeeding zones of talc and anthophyllite, are absent. Further comment on the relation between the silicic zone and the weakly sulphidic quartz-magnetite lode zone, is made in the section dealing with the orebody.

Silicification of sediments and the formation of red jasperised rocks, occurs in the higher level marginal zones of other major orebodies, such as Noble's Nob.

(c) The anthophyllite-talc zone.

The minerals which characterise this zone appear in the main lode at depths beyond 900 feet. They were observed also in marginal areas where isolated east-west shears containing sulphides, exist outside the limits of the main orebody. The incidence of magnesian silicate minerals in rocks which were already chloritised, is irregular. It depended upon the extent of fracturing, access to metasomatising solutions, and upon the presence of rocks physically and chemically favourable to alteration. The changes in the attitude of bedding resulting from small scale folding, brought argillaceous and arenaceous rocks into successive and alternating coincidence with the shears and brecciated zones. The consequent variable access to the mineralising solutions, gave rise to different degrees of alteration.

Anthophyllite first appears in the chloritised rocks as minute, widely disseminated knots sited in the planes of cleavage. These are very fine fibrous aggregates which, with increasing intensity of alteration, develop into radial growths from which other minerals such as quartz and relict chlorite, were eliminated. The presence of carbonate veins in some parts of the chloritic rocks, as noted earlier, probably led to the simultaneous formation of small amounts of actinolite in addition to anthophyllite.

The change from chlorite to anthophyllite requires that the hydrothermal solutions added further magnesia and silica to the rocks, but requires no significant addition of iron beyond that already present. The alumina content of rocks in this zone was reduced by this change, and its removal by the solutions may be postulated.

Although talc and anthophyllite commonly occur together in the same environment, they usually occupy separate areas within a given altered rock. This segregation was due partly to the difference in their crystalloblastic capacities, but in most cases, anthophyllite formed first while talc developed with more advanced alteration.

It would appear therefore, that advanced wall rock alteration followed upon a continuing influx of hydrothermally transported magnesia and silica. The iron released by these mineralogical transformations remained in place and contributed to the general build-up of magnetite in the mineralised structure. In the highly talcose rocks, minute granules of chemically separated magnetite formed ring-like structures which progressively assumed isometric outlines. The granules coalesced at centres and finally produced idiomorphic magnetite individuals of greatly increased size, Figs, 80 to 83. Thus, chemically formed magnetite, added to that originally present as a clastic component of the sediments, contributed to the large masses of magnetite concentrated in the lode structure.

The inner parts of the anthophyllite-talc zone are extensively brecciated, and in many places, penetrated by sulphides from the adjoining orebody. Elongate, and parallel oriented rafts of relict chloritic sediment, particularly of siltstones and sandstones, are common in the talcose and anthophyllitic rocks. These relicts persist into the ore zone and ultimately become part of the gangue assemblage of the sulphides, Figs. 84, 85.

Small aggregates, as well as individual idiomorphs of magnetite, are prominent in sections of the rocks which were altered to talc and anthophyllite. Since the slate horizons of interlaminated sequences were preferentially metasomatised, the magnetite is commonly distributed along talcose foliae between bands of relatively unaltered arenaceous rocks. The magnetite was in many places fractured, and the matching edges of the fractures indicate that the crystals were pulled apart and spread along the foliae, while the enclosing magnesian silicate minerals continued to form in the openings so formed, Figs, 86, 87. The origin of these structures may be attributed to one of the two following causes:

In the first place, the manner in which some of the magnetite formed during the progressive transformation of chloritic rock to talc-anthophyllite rock, allows for the retention of some magnesian silicate inclusions in the magnetite. Under the continued influence of the environment, the progressive growth of the silicate inclusions to greater dimensions, may have forced the magnetites apart.

In the second place, a state of tension directed along the ore-body structure, may have produced a condition of attenuation in the sediments. Under these conditions the magnetite would fracture transversely to the rock cleavage forming open spaces in which the oriented silicates would continue to develop. The brecciation of the intercalated siltstones and sandstones supports this latter view.

(d) <u>The pneumatolytic tourmaline zone</u>.

In parts of the deepest levels of the Mine the effects of pneumatolysis were superposed on the mineralogical changes discussed above. This was a later and more localised form of wall rock alteration, marked by concentrations of tourmaline and pyrite which replaced portions of the chlorite-anthophyllite-talc rocks, Figs. 88, 97. In areas of intense pneumatolysis, coarsely idiomorphic pyrite intergrown with radial clusters of tourmaline, replaced almost the entire rock. Sheaf-like clusters of orthite, as well as long prisms of apatite are prominent amongst the tourmaline aggregates, thus suggesting that gases or fluids, charged with the rarer and more volatile elements, were active in the wall rock zones.

Unreplaced relicts of the magnesian silicate minerals exist both in the tourmaline and in the pyrite, while sulphides of later origin, mainly chalcopyrite and sphalerite, penetrated the tourmalinised rock in thin veinlets. The pneumatolysis is related to the hydrothermal phenomena responsible for wall rock alteration and may be regarded as a late phase of this.

(e) The biotite-zircon contact zone.

This zone is confined to the contacts of some chalcopyrite veins with highly altered relict rafts of wall rocks, in or close to the orebody. These sulphide vein contacts are characterised by thin selvedges of red-green biotite (possibly phlogopite) and abundant zircons, Fig. 86. As in the case of tourmalinisation, these phenomena are superposed on rocks already extensively altered to talc and anthophyllite. These contact effects were not seen in relation to tourmalinisation hence their period of incidence, relative to pneumatolytic action, cannot be stated. However, the phenomena is late in the sequence of mineralisation and closely associated with the influx of copper sulphide.

The various mineralogical changes described above, all of which decrease in intensity away from the sulphide lodes, took place in advance of the main sulphide mineralisation. Only the thin extremities of far-reaching sulphide veinlets from the inner highly mineralised core, penetrated these outer zones. This is therefore a normal sequence in which wall rock alteration was followed by ore emplaced in physically and chemically conditioned country rocks.

The nature of the wall rock alteration phenomena indicate the initial influx of magnesia-bearing hydrothermal solutions followed by pneumatolytic fluids, and ultimately by siliceous ore-bearing solutions which deposited quartz and sulphides in the lode structure.

The orebody.

The Peko orebody differs in shape from those of Ivanhoe, Orlando and many other deposits of Tennant Creek. Elliston (1960, 1965), considered this shape to have been determined by the configuration of a pre-consolidation slump breccia.

The orebody is lenticular in its east-west longitudinal projection, but it has a distinct pear shape, thickening with depth, in its north-south section, Fig. 77. In longitudinal projection the lode structure pitches 70° westerly in conformity with the plunge of the syncline in which it exists.

The elongate quartz-hematite outcrop, 200 feet long and 80 feet wide, is oriented approximately east-west in conformity with the strike of the rocks on the south limb of the syncline. Although the dip of the lode is steep, in the underground workings no appreciable disconformity with the sediments is apparent. Since little of the sulphide lode extended above water table level, no boxworks structures, or other manifestations of the presence of sulphides are visible in the outcrop.

The three zones defined by Elliston together comprise the entire lode structure, Fig. 77. It will be shown in the discussion which follows, that each is distinct in its mineralogy and structure, as well as in its position in space. The comparative study of these contrasting portions of the lode structure, and their relation to the successive zones of wall rock alteration, indicate that mineralisation commenced in depth through the central brecciated core and spread upwards, and outwards, through fissile and fractured rocks.

(1) The quartz-magnetite zone.

Banded or massive quartz-magnetite, largely altered to quartz-hematite, occupies the upper portion of the lode structure and is directly in contact with wall rock sediments which attained only the chlorite stage of alteration. This upper portion of the quartz-hematite zone contains disseminated fine grained gold associated with sericite, bismite, bismutite, manganese and iron oxides, but secondary copper minerals are absent.

The peak of the narrow inner zone of oxidised copper minerals which is the altered upper limits of the centrally situated core of sulphides, was encountered at 200 feet depth. Below the water table level unoxidised quartz-magnetite appeared and the inner sulphide core thickened. Quartz-magnetite formed a continuous envelope around the sulphide core to a depth of about 1000 feet, beyond which it thinned rapidly, lost its identity and did not appear at 1130 feet, the deepest working level of the Mine.

Throughout most of its vertical extent the quartz-magnetite zone has a layered, often contorted, or brecciated structure which is the bedding of the country rocks in pseudomorph. Although layered quartz and magnetite constitute the main components of the envelope zone, irregularly replaced, ragged relicts of very fine grained red jasper appear in places. In addition, most of the coarse quartz bands and some of the magnetite, contain disseminated flakes of chlorite.

These jasperised and chloritic relicts are portions of the earlier-formed zones of wall rock alteration which were later penetrated by quartz and magnetite from the centre of the lode structure. The contact of epigenetic, subidiomorphic quartz veins and aggregates against the jasperised sediments, is characterised by marginal layers of magnetite, Fig. 89. The centres of these quartz-magnetite veins which penetrate jasperised rock, commonly contain pyrite, pyrrhotite, biotite, apatite and tourmaline, an assemblage which can be regarded as compatible with fluids of a primary nature evolved from igneous sources.

Jasperised sediments commonly occur along the contact edges of the porphyries and are generally considered to have resulted from marginal silicification affected by siliceous fluids expelled from the intrusives. The jasper along the contact of the lode structure also resulted from silicification, but in this environment from hydrothermal solutions.

Jasper formation was therefore an expression of wall rock alteration in the higher level, lower temperature limits of mineralisation. The lower temperature status of jasperisation is further exemplified by its association only with the chlorite zone of wall rock alteration. In depth, where talc-anthophyllite and pneumatolytic alteration exist, jasper is less common and occurs only in the outer chloritic zone of wall rock alteration some 100 feet from the orebody.

In the deeper levels of the Mine skeletal remnants of zoned euhedra of cobaltite occur in quartz-magnetite and among the chalcopyrite, pyrrhotite, or galena which replaced this, Fig. 103. The textures suggest that cobaltite may have been intergrown with, or replaced by the quartz-magnetite. Cobaltite therefore appears to have been introduced with quartz-magnetite rather than with the later sulphides.

(2) The sulphide core section.

The shape of the inner zone of sulphide ore is similar to that of the entire mineralised lode structure, Fig. 77, and in keeping with the changing compositional pattern of the zones of wall rock alteration, the sulphide ore assemblage also varies with depth.

Although the sulphide zone did not reach the surface to form a gossan, the tapering upper extremity reaches above water table level and is completely oxidised. Mining operations have depressed the water table level in proximity to the orebody and oxidation has now extended to an abnormal depth of about 260 feet, i.e. some 100 feet below the normal level for this area.

(a) The oxidised zone.

The oxidised portion of the lode is characterised by an abundance of cuprite and native copper in the cavernous leached quartz-hematite, but other minerals are also present, including limonite, tenorite, copper silicates, siderite and gold in complex colloform and crustified open space fillings, Fig. 90. Magnetite and primary sulphides which were fully enclosed by unfractured quartz gangue, were protected from oxidation and persist among these oxidised minerals.

(b) The secondary enrichment zone.

Gold was leached from the oxidised zone by the acidic chloride solutions which were formed as pyrite oxidised in the chloride-bearing ground waters. Subsequent redeposition of gold as sporadic concentrations in deeper parts of the oxidised zone, occurred where these solutions hydrolysed upon dilution and increased pH, to form limonite.

Prior to the removal of much of the orebody by stoping, Edwards observed near water table level, the transition of the assemblage native copper-cuprous-cupric-oxides, to the assemblage copper carbonate-cupric sulphide. This change marked the upper limit of the zone of secondary sulphide enrichment and was accompanied by an abrupt rise in the copper tenor to some 40%, and in gold tenor, to 30 dwt per ton. The enriched zone extended down for some 50 feet with characteristically decreasing metal values, finally merging into unaltered hypogene ore at 310 feet. A normal metal value profile, typical of secondarily enriched copper lodes, therefore existed in the original Peko orebody. The average content of copper and gold throughout the entire secondarily enriched zone was estimated at 15% Cu. and 4 dwts Au. per ton, (Edwards 1955).

The creation of underground openings in the chalcocite zone promoted chemical changes in the secondary sulphides, hence the active oxidation of chalcocite and covellite renders mine air dangerous through elevated temperatures and a high content of sulphur-di-oxide. The walls of drives and stopes rapidly crumble with the expansion of the ore during its fast oxidation and the formation of highly acidic mine waters. These waters attack the siderite gangue and the final products are pulverulent masses of jarosite and chalcanthite which enclose relicts of the sulphides and gangue.

Secondary copper sulphide enrichment may be observed in specimens from the upper limits of the hypogene zone. The reactions between hypogene pyrite, pyrrhotite and chalcopyrite, and the copper sulphate solutions derived from the oxidised zone, are manifest in the chalcocite veins in the intergranular boundaries and in fractures in the primary minerals. Some of the original pyrite was leached and subsequently replaced by colloform secondary gel-pyrite, while the pyrrhotite was converted to lamellar aggregates of melnikovite-pyrite and marcasite, Fig. 91. Cobaltite, bismuthinite, gold and other minor inclusions in pyrite or chalcopyrite did not react with copper sulphate solutions and were retained as inclusions in the secondary chalcocite.

Although a proportion of the acidic chloride solutions hydrolysed and formed both limonite and gold concentrations in parts of the oxidised zone, conditions of low pH were maintained in some areas and a larger amount of gold was transported through the lode channel into the hypogene zone. The ensuing secondary enrichment reactions between these solutions, the solutions of metal sulphates and the hypogene sulphides, led to strong accumulations of gold in the zone immediately below water table level. The distribution of secondary gold in respect to depth is thus different from that at Noble's Nob. The abundance of sulphides and the consequent differences in chemistry, account for this.

(c) The hypogene zone.

Edwards (1955) stated that hypogene ore extended to within 310 feet of the surface, and that at a depth of 400 feet from the surface, the natural unchanged hypogene assemblage of pyrite and chalcopyrite in quartz and magnetite, contained 7-11% Cu. and 3-4 dwt Au. per ton.

Although the thickness of the orebody and the bulk of magnetite and pyrrhotite increase with depth, the total amount of chalcopyrite appears to remain unchanged, with the result that there is a steady decrease in actual copper and gold grades with depth. In 1958, the C.S.I.R.O. Mineragraphic Section made a quantitative examination of this apparent trend, using samples collected from the workings to a depth of 980 feet. Included in the report of this survey was Table 19, which shows the changing ratios of the three main minerals.

The underground workings have since been extended to 1130 feet and many deeper drill holes have been completed. Some of this more recent material was studied during this present investigation.

The mineralogy and texture of the ore to a depth of 980 feet, as originally described by Edwards in the period 1955-1958, was re-examined by using samples from more recent openings on these upper levels. No opaque minerals other than those listed by Edwards were found, but a number of extra silicates were detected in the gangue and wall rocks. The following summaries outline the mineralogy and the textural characteristics of the hypogene ore in the successive levels down to the present working level of 1130 feet.

On the 400 and 530 foot levels, the major sulphides are chalcopyrite and pyrite. Pyrite is the more abundant sulphide, particularly in the footwall area of the lode where, with quartz and magnetite, it formed banded ore. In these areas chalcopyrite displays its later origin in veins which entered along the banding in the footwall ore replacing the pyrite in preference to quartz and magnetite. On these levels pyrrhotite, bismuthinite, cobaltite and other sulphides are minor ore components.

The lode thickens on the 680 foot level and contains several varieties of ore which are distinct in their structure and mineralogy.

TABLE 19.

Variations in major ore components with depth - Peko Mine.

530 foot Level – $\dfrac{\text{chalcopyrite}}{\text{pyrrhotite}} = \dfrac{44}{1}$: $\dfrac{\text{chalcopyrite} + \text{pyrrhotite}}{\text{magnetite}} = \dfrac{1.09}{1}$

680 foot Level – $\dfrac{\text{chalcopyrite}}{\text{pyrrhotite}} = \dfrac{5}{1}$: $\dfrac{\text{chalcopyrite} + \text{pyrrhotite}}{\text{magnetite}} = \dfrac{0.83}{1}$

830 foot Level – $\dfrac{\text{chalcopyrite}}{\text{pyrrhotite}} = \dfrac{2.8}{1}$: $\dfrac{\text{chalcopyrite} + \text{pyrrhotite}}{\text{magnetite}} = \dfrac{0.6}{1}$

980 foot Level – $\dfrac{\text{chalcopyrite}}{\text{pyrrhotite}} = \dfrac{1.2}{1}$: $\dfrac{\text{chalcopyrite} + \text{pyrrhotite}}{\text{magnetite}} = \dfrac{0.3}{1}$

(After Edwards 1958.)

The highest grades of copper ore are commonly banded. Relict silicates in parallel disposition, are contained in continuous bands of chalcopyrite which alternate with layers of magnetite and of pyrite, Fig. 92. The chalcopyrite contains also many bismuthinite inclusions and along specific bands, these sulphides together, almost completely replaced the host rock. In other parts of the lode where the copper grade is lower, pyrrhotite as well as chalcopyrite and bismuthinite, replaced sections of the host rock and produced more complexly banded ore.

Sections of the footwall of the lode on this level consist of brecciated quartz-magnetite-pyrite rock containing abundant galena in composite veins, Figs. 93, 94, 95. There are two main types of composite galena veins each of which followed the trend of the previously emplaced pyrrhotite veins, or the trend of the fractures which intersect these, as well as the quartz-pyrite-magnetite rock. In one type, galena is associated with ankerite and with a later generation of pyrite, whereas in the other type, galena is associated with chalcopyrite, sphalerite, tetrahedrite and bismuth in a quartz gangue. Some of the pyrrhotite was converted to lamellar marcasite and during its replacement, the later sulphides lodged between the lamellae.

The sulphide lode attains a thickness of 200 feet on the 830 foot level and is appreciably richer in magnetite. Most of the ore contains intersecting lattice-works of strings of minute magnetite granules, with silicates remaining in the intergranular spaces, Fig. 96. Since the polarity of the magnetite granules may have determined their linear arrangement, this texture suggests that the formation of the quartz-magnetite rock at this depth may have occurred in a medium of low viscosity. This texture was not observed in shallower levels where magnetite pseudomorphed the laminated structures of the brecciated sediments.

Pyrite, pyrrhotite and chalcopyrite entered the magnetite-rich lode structure along closely spaced parallel shears and the oblique tension fractures which exist between them. Silicates, rather than the magnetite were replaced, with the result that the strings of granules persist in their original orientation in the sulphide metasome. The shears in the magnetite medium indicate also that the lode formation was affected by stress after the formation of quartz and magnetite in it.

The ore on the 830 foot level contains a lower percentage of sulphides than that at the shallower levels. The sulphides are finer grained and formed thinner veins in the quartz-magnetite of the lode structure. The footwall section of the lode, in conformity with that on the 680 foot level, contains much galena and displays similar mineral assemblages and controls for the emplacement of the later complex of galena-bearing sulphide veins.

Small satellitic ore shoots appear for the first time on the 830 foot level in the altered, anthophyllite-bearing wall rock sediments. Residual radial clusters of anthophyllite were retained among the magnetite, and in the chalcopyrite which replaced the magnetite, and in the pyrite and pyrrhotite associated with chalcopyrite. In these shoots tourmaline was introduced in places with chalcopyrite and sphalerite, thus indicating the local concurrence of pneumatolysis and sulphide mineralisation. Such areas within the wall rock zone are marked by ore of mottled appearance, composed of coarse idiomorphic pyrite dispersed among rosettes of radiating black tourmaline crystals, both of which replaced the pre-existent quartz, magnesian silicates and magnetite, Fig. 97. While the pyrite is in coarse granular intergrowth with entire aggregates of tourmaline, the chalcopyrite and sphalerite are in finer grained parallel growth with the individual prisms of tourmaline. There was however, little time disparity between the emplacements of these minerals since all are involved in mutual intergrowths produced in a single period of pneumatolysis.

A series of north-south vertical faults intersected the orebody and displaced sections of it laterally as much as 250 feet. These major transgressive structures occurred subsequent to all mineralisation, Fig. 77.

The main lode retains its thickness of 200 feet on the 980 foot level where it is again repeatedly offset by the north-south faults which extend from the 830 foot level. The common variety of ore on this level is also rich in magnetite and it contains relatively low percentages of sulphides, quartz and silicate mineral gangue.

The fabric of the magnetite displays two common forms, one of which is the lattice-texture noted in the massive magnetite on the 830 foot level, while the other is a graphic intergrowth of granular magnetite with coarse idiomorphic quartz which is common in areas of severe brecciation, Fig. 98. These two minerals, together with pyrite form the bulk of the lode zone.

Subsequently, sulphides with quartz, ankerite and phlogopite, entered the quartz-magnetite as composite veins, filling systems of fine parallel fractures with crustified deposits of chalcopyrite, bismuthinite, native bismuth, gold and gangue minerals. These mineral assemblages also penetrated beyond the walls of the fractures, into the quartz-magnetite in a series of lateral replacement veinlets.

Some portions of the ore which are unusually rich in copper contain also very high bismuth and gold values. The gold is very fine grained, usually less than 0.1 mm in size and is located in chalcopyrite or in bismuthinite, but not in the associated native bismuth, Fig. 102.

This type of ore commonly contains skeletal cobaltite crystals which, even though they are contained mainly in the later sulphides, appear to be confined to certain narrow layers within the quartz-magnetite rock which was replaced by the sulphides. The idiomorphs of cobaltite were zoned crystals and most of them exhibit selective internal, or core replacement by quartz, pyrrhotite, chalcopyrite or bismuthinite. Some textures, such as that in Fig. 103, indicate the probability that cobaltite existed in the lode before quartz and magnetite, in which case it suggests an earlier, deeper-seated, higher temperature phase of mineralisation which preceded the formation of quartz and magnetite.

In the central part of the main orebody on the 980 foot level, there is the first evidence of a relatively barren core zone of massive quartz-magnetite containing residuals of red jasperised sediment. This resembles the outer quartz-magnetite envelope zone of the upper limits of the orebody and it is mineralised to about the same extent by weak veinlets of sulphides.

Satellitic ore shoots within the wall-rock zone are more abundant and more fully developed on this level than on the 830 foot level. The sketch section of the 980 foot level, Fig. 77, shows that the orientation of these shoots differs little from that of the orebody in the main structure, although their mineralogy and texture contrasts with that of the main orebody. The main difference lies in their content of galena, chalcopyrite, arsenopyrite, marcasite and sphalerite, and in the strong lineation preserved through the pseudomorphous replacement of the original rock structures, Fig. 99.

The early stages of mineralisation in the satellitic ore shoots are manifest in the replacement of magnetite and chlorite, by arsenopyrite and by marcasite, Figs. 100, 101. Galena and chalcopyrite, which exhibit no time disparity in their mutual textural relations, filled fractures in marcasite, arsenopyrite, magnetite and chlorite and may therefore be regarded as later in the sequence. In the rocks as a whole, galena and chalcopyrite preferentially replaced the sheared anthophyllite-rich zones and avoided pyrite and magnetite, which persist in the ore aggregate. However, the incipient replacement of both marcasite and arsenopyrite by galena and chalcopyrite, occurred in places.

These lead-rich shoots containing small amounts of sphalerite and tetrahedrite, although present in the wall rock zone on the 980 foot level, are probably directly related to the lead-zinc mineralisation in the footwall of the main orebody on the 830 foot and 680 foot levels. Silver is contained in these areas, both in tetrahedrite and in solid solution in galena.

The common ore of the 1130 foot level is again massive magnetite with less than 20% of its bulk taken up by quartz, magnesian silicates and sulphides. The progressive reduction in ore grade with increasing depth, already noted in the levels above, is even more apparent at 1130 feet near the base of the orebody. The structures and textures are comparable with those on the levels immediately above, Figs. 104, 105, and in keeping with this, pyrrhotite, chalcopyrite, bismuthinite and minor molybdenite followed fractures, first as open space fillings, and subsequently as lateral replacement veins. Two well-defined sets of fractures are generally apparent and the sulphides in these retain unreplaced portions of the silicate minerals, Fig. 104.

Similar sets of intersecting fractures, which clearly guided sulphide mineralisation, are also present in the magnetite of the Orlando orebody. In most cases the sulphides filling these fractures exhibit slickensided surfaces caused by movement which occurred along these lines of weakness after sulphide mineralisation.

In many parts of the 1130 foot level there are areas of banded, dominantly pyritic ore which consists of closely spaced zoned pyrite euhedra in a quartz medium. Felspar, magnetite and chlorite together replaced the pyritic bands in thin parallel veinlets. At the contacts, the silicates and the magnetite penetrated the surrounding pyritic aggregates along their intergranular boundaries and along specific zones within individual pyrites, replacing the quartz and producing pseudomorphs in magnetite after zoned pyrite, Figs. 106, 107.

In other parts of the orebody on this level the weakly mineralised rock consists of alternating bands of pyrite, magnetite and idiomorphic quartz. Pseudomorphous replacement of the slumped and crenulated bedding of the original sediments is manifest in the structures exhibited by the magnetite bands. Pyrite is confined to layers on either side of the magnetite-replaced slumped horizons and may be regarded as having replaced the less crumpled arenaceous intercalations, Fig. 116. These banded rocks were fractured and brecciated in the same manner as the more massive, magnetite-rich rocks and were penetrated by chalcopyrite, pyrrhotite and bismuthinite, but not to the same degree.

There is also on this level a poorly mineralised central core zone composed mainly of brecciated siltstones and tuffaceous sandstones. This is similar to, and continuous with that of the 980 foot level, and in spite of widespread silicification and chloritisation, it contains only sporadic centres of magnetite and sulphide mineralisation. In these centres, much of the pyrrhotite was converted to marcasite and where magnetite and pyrite are concentrated, chalcopyrite exists in thin veins with bismuthinite, galena and molybdenite.

The general decrease in the intensity of mineralisation in this deep level is further accentuated by the absence of both sulphide veins and the satellitic ore shoots in the wall rock zone.

2. <u>The Pinnacles Mine</u>.

The Pinnacles orebody and its immediate environment present in miniature, the structural and mineralogical changes attending both gold and copper mineralisation. The lodes are clearly visible within a strong axial plane shear in rocks, which according to Ivanac (1954), were contorted into a west-pitching fold. However, according to the interpretation prepared in the present study, the Pinnacles occupies a position of neutral pitch in this fold, Plate 1.

The country rock is mainly weakly bedded sericitic siltstone with a few shale intercalations. In the outer portion of the hanging wall one of the shale horizons was bleached almost white and amorphous green-grey allophane formed in it as granules of about 10 microns diameter, Fig. 108.

Closer to the orebody and to the zone of intense shear, both the shale and the sericitic siltstone were recrystallised. The high content of chlorite in the black slate contrasts with the pale colour of the sericitic shale and suggests that there was an enrichment in magnesia in proximity to the orebody. The chloritic slate contains both oriented muscovite and ovate lenticles of quartz and zoisite which probably formed at the time of shear. These survived chloritisation of the sheared country rock, Fig. 109.

The lode itself, which consists of coarse grained chlorite, tremolite, martite and specularite, contains also irregularly dispersed remnant fragments of granulose clastic quartz. The martite is coarsely euhedral, while the specularite is finer, tabular and formed within the cleavages of the chlorite flakes, Fig. 110. The chalcopyrite, which in depth is associated with chlorite and magnetite, was completely changed in the surface samples to colloform secondary copper silicates.

In the inner zone of alteration in the footwall rocks there is an abundance of talc and anthophyllite. This schistose rock contains at intervals, thin bands of martite which enclose minor, partly oxidised copper sulphides, Fig. 111. The outer zone of alteration in the footwall is, like the hanging wall, heavily chloritised, and grades outwards into unaltered siltstone and shales.

The country rocks in proximity to the Pinnacles Mine are composed mainly of clastic quartz, sericite and clays with some 5% clastic martite. Chlorite is not a prominent constituent in the surface rocks although below the zone of oxidation it is present in the rocks to a greater or lesser degree. The great abundance of chlorite, talc and anthophyllite in the contact zones, as well as in the ore itself, clearly indicates that there was a decided influx of magnesia into the lode structure. There is also a much greater content of iron oxide minerals in the lode and in the enclosing wall rock zones than in the surrounding country rocks.

Mineralisation in the Pinnacles shear appears therefore to have been accompanied by both magnesium and iron metasomatism and since potash micas are preserved only in the less metasomatically modified wall rocks, alumina and alkalies were probably removed from the lode itself.

3. The Orlando Mine.

Some 18 miles north-west of Tennant Creek, Peko Mines Ltd. operates a small copper mine known as the Orlando. The development of this orebody followed upon the discovery of a magnetic anomaly by the Aerial, Geological and Geophysical Survey of Northern Australia during the period 1935-1937. The former Orlando and Orlando East Mines which were small gold prospects, lie some distance south-east of the present Mine. All three orebodies are located on a common shear, known as the Orlando Shear.

At the end of the period of exploratory development and drilling the reserves of ore were estimated at 150,000 tons of 1.5% copper ore, containing 11.0 dwt Au. per ton. Mining commenced in 1963 during which year, 37,134 tons of ore containing 0.85% Cu. and 12.2 dwt Au. per ton, were produced. Continued drilling revealed extensions to the orebody and at the end of 1963, the reserves stood at 230,000 tons of 1.2% copper ore containing 11.7 dwt Au. per ton. During 1964, 52,833 tons of ore containing 1.05% Cu. and 8.02 dwt Au. per ton were produced, but since no further ore has been found, the current reserves are approximately 180,000 tons with an estimated grade of 1.0% Cu. and 9.0 dwt Au. per ton.

Geological and structural environment.

The structure of the area which includes the Orlando orebody is regarded by Elliston (1965) to have derived its characteristics from gravity sliding of partly consolidated sediments during the development of the Warramunga Geosyncline. In support of this, Elliston cited evidence of soft sediment deformation, fluidal type folds, brecciation and the development of pelletoid conglomerates.

The geological environment as depicted in Fig. 112, indicates that the Orlando orebody is located in a shear which is parallel to the attitude of both the bedding and the cleavage of the surrounding country rocks and also to the strike of the major north-west-trending 14-Mile Fault.

The orebody is a flat lenticular structure 400 feet long and 28 feet thick at its centre, with a steep southerly dip and a plunge of 25° to the north-west. The orebody lies in the plane of cleavage of the country rocks and apparently also within that of the Orlando Shear.

The wide zone of brecciation which exists in the hanging wall of the shear, dips at a somewhat flatter angle and intersects the shear near the surface. The breccia therefore post-dates the shear, and appears to be a purely tectonic feature. The characteristics of the fabric of the wall rocks seem contrary to Elliston's concept of the development of these structures contemporaneously with sedimentation.

The country rock environment consists mainly of shale and slate in which there are subordinate, thin intercalations of siltstone and tuffaceous sandstone. However, these rocks do not outcrop on the site of the orebody which is obscured by transported alluvium and sands, but appear with concentrations of hematite, along the shear south-east of the Mine.

The wall rocks.

The zone of brecciation in the hanging wall of the Orlando Shear dips at a shallower angle than the shear and in depth, it trends further into the hanging wall. The breccia consists mainly of fragments of fissile chloritic slates, but there is also a proportion of the intercalated tuffaceous sandstones and siltstones. The sandy rocks retain a strong lineation, which was imposed prior to brecciation, and this is manifest in the parallel alignment of the inequidimensional clastic particles in the rock fabric. All fragmentary rocks in the brecciated zone above the 550 foot level are thoroughly oxidised and transected by systems of quartz-filled and limonite-impregnated fractures. The brecciated, fissile chloritic slates are commonly talcose and enclose within the cleavages, lenticular segregations, or continuous foliae of talc.

In the deeper levels of the Mine, Elliston recorded the presence of dolomite in the inner section of the main breccia zone. At the contact of this dolomite against the shear, a thin shoot of lead-zinc sulphides occurs in talcose gangue. This is quite separate from the main copper-gold orebody, but probably occupies a minor shear parallel to the main Orlando Shear.

There is much less oxidation on the footwall side of the shear since this is not brecciated but consists of compact, impermeable, fissile chloritic slates, as well as augen and flaser schistose and gneissic rocks. These highly sheared chloritic rocks are regarded by Elliston (op. cit.) as "pelletoid conglomerates" derived from interformational breccias and conglomerates which formed during the movement of the original unconsolidated sediments on the geosynclinal shelf.

Thin section studies of the "pelletoids" showed that the larger lenticular, and the smaller augen-type bodies, enwrapped in chlorite and strung out in the cleavage of the schistose rocks, are detached, elongated fragments of siltstone, or of fine grained tuffaceous sandstone, Fig. 114. They may therefore be equally well regarded as fragmented portions of the thin arenaceous intercalations which are common in the shales of this area. The "pelletoids" might therefore be regarded as tectonic in origin and formed simultaneously with the Orlando Shear.

The orebody.

In addition to the copper-gold orebody which is associated with chloritic rocks, a lead-zinc ore shoot of small dimensions and similar attitude, was recently discovered by drilling into the hanging wall of the shear. It is associated with brecciated dolomite and talcose country rock.

The main copper-gold orebody does not reach the surface but it extends some distance above water table level where it is completely oxidised and extensively leached. The lead-zinc shoot exists only in the deeper levels below 800 feet.

In the mine workings above the 550 foot level, the access of air and moisture promoted the rapid oxidation of the coarser sulphides in the upper limits of the lode, as well as the finer sulphides disseminated in small quantities throughout the wide breccia zone. Large quantities of heat and sulphur-di-oxide are continuously evolved and special ventilation procedures are necessary.

On the 550 foot level, open spaces contain crustified aggregates of secondary minerals which include sulphides, Fig. 113. The orebody merges with the hanging wall breccia in the upper levels and since in this environment most of the hypogene sulphides were fully oxidised, the open space fillings contain only secondary sulphides such as marcasite and melnikovite pyrite. The outer portions of these open spaces were lined with alternating layers of quartz or calcite crystals, while the sulphides occupied the central sections.

At greater depths, where the lode is not influenced by the breccia, both the magnetite and the sulphides occur together in repeated sheet-like veins, or in elongate segregations, oriented in the cleavage structure of a chloritic slate host rock, Figs. 114, 117. The grade of this hypogene ore depends upon the thicknesses, and upon the number of these veins within a given section of the sheared lode formation.

Most of the ore consists of chloritic slate injected by numerous relatively thin sheeted veins, which pinch and swell in accordance with the plications of the host rock cleavage. At intervals there are thicker and more continuous masses of ore which constitute substantial conformable shoots in which little or no remnant of the chloritic slate exists, Fig. 115.

Individual veins range in mineralogical composition from simple pyrite or magnetite veins to more complex ones containing magnetite, pyrite, chalcopyrite and bismuthinite with minor amounts of hematite and gold. In most of these, the gangue assemblage consists of dolomite and quartz, often with coarse grained random oriented chlorite of much coarser grain size than the chlorite which constitutes the host rock slates.

The magnetite in the mineralised lode rock commonly displays two contrasting grain sizes, each of which is confined to specific, often adjacent bands, Fig. 117. The finer grained magnetite which exists in thin parallel bands in the slate, displays irregular shapes and may be a clastic component of original thin heavy mineral lamellae. The coarser magnetite is commonly subhedral and intergrown with much coarser grained chlorite, but may also contain relicts of the original chloritic components of the slate, Fig. 119. It is probable that the coarse grained magnetite and chlorite grew in place in the slate by replacement and might be regarded as the first minerals formed by the mineralising solutions.

Coarsely crystalline magnetite and chlorite were widely distributed in the sheared chloritic slates. Pyrite, on the other hand, is more commonly found in the highly schistose, talcose sections of the shear. The pyrite euhedra, like the coarse magnetites, transect the rock cleavage without distorting it, thus suggesting their formation by progressive replacement of the host rock.

Epigenetic magnetite was introduced into the slates during the stage of incipient magnesium metasomatism which is manifest in the growth of very coarse grained, random oriented chlorite. Epigenetic pyrite was introduced somewhat later, accompanied by more complete magnesium metasomatism, and it therefore occurs mainly with talc in the sheared zone.

Chalcopyrite, bismuthinite and gold entered the lode structure after the crystallisation of coarse magnetite, chlorite, pyrite and talc. In the incipient stage of copper mineralisation, such as that depicted in Fig. 117, the sulphide was confined to the bands of coarse magnetite and chlorite which had already formed in the slate. The sulphides therefore followed the same relatively permeable foliae within the sheared slate as the solutions which promoted the growth of coarse magnetite and chlorite.

Chalcopyrite and bismuthinite, as well as the gold which accompanied it, preferentially replaced the coarse chlorite by entry along its cleavage planes, Figs. 118, 120, but for most part did not attack the magnetite. Even in examples of very strong copper mineralisation, as shown in Fig. 115, magnetite, as well as the earlier-formed pyrite, survived while chlorite was extensively replaced.

Gold is a minor component of the ore found mainly in the chalcopyrite, particularly in areas where this contains an unusual abundance of bismuthinite.

The lead-zinc ore shoot in the hanging wall is associated with talcose and dolomitic host rocks which are regarded as products of metasomatism. There is no surface evidence at Orlando of a calcareous sedimentary horizon and sediments of this type are unknown at Tennant Creek. Since carbonates have been noted in many places as components, or as associates of epigenetic sulphide veins, it is probable that the dolomite at Orlando is also of metasomatic origin.

Although the Orlando orebodies are conformable with the country rocks, the field and microscopic evidences favour an epigenetic origin for most of the magnetite and all of the sulphides. The orebodies were located in positions in the Orlando Shear where adequate permeability facilitated the movements of mineralising solutions which left their mark in mild wall rock alteration.

The formation of magnesian minerals in rocks which do not normally contain these, provides evidence of the influx of magnesium in hydrothermal fluids. These fluids appear to have emerged from a subterranean source, since there is no lateral manifestations of their passage through the rocks. This source may be in the basement rocks since the Orlando Shear is parallel to the magnetic lineaments which exist in depth in this area.

4. Ivanhoe Mine.

This is the most recent copper mine on the Tennant Creek field and at present it is in the stage of development rather than production. In 1964 the reserves were estimated at 240,000 tons of ore containing 5% Cu. and 4 dwt Au. per ton. Exploratory drilling continues beyond the reaches of the present workings and Elliston (1965) reports an ore thickness of 24 feet at 1100 feet vertical depth.

The orebody occurs beneath an area obscured by alluvium and the nearest rock outcrops are about one and a half miles away. The strong magnetic anomaly which exists at the site led to its discovery although it is now known, through experimental geochemical prospecting, that this would also have revealed the presence of the underlying orebody.

The alluvial cover is of the transported type, thus geochemical investigation required auger drilling to the underlying bedrock, where residual anomalies in copper, bismuth and molybdenum were obtained from the preserved, weathered surfaces.

Geological and structural environment.

The outcropping country rock beyond the alluvial plain which surrounds the Ivanhoe Mine, consists mainly of shales and slate with minor intercalated tuffaceous sandstones and siltstones. There are no outcrops immediately to the south, while to the west, north and east, outcrops are at least one and a half miles distant, Fig. 121.

It is apparent underground that the deposit lies in a shear which is continuous with the Mary Ann - Mary Lane Shear. This structure is oriented at approximately 300° magnetic and is parallel to the series of regional magnetic highs in the underlying basement. A second series of basement magnetic highs is oriented at 30° magnetic, and at the position of the Ivanhoe Mine, lines of magnetic highs from each of these trends, intersect.

The position of the orebody not only marks the magnetic intersections, but it is also the point at which the large fault on the western side of Station Hill, oriented at 60° magnetic, meets the Mary Lane - Mary Ann Shear. Evidence in the underground workings shows however, that this fault occurred after mineralisation and is responsible only for the repeated lateral offsetting of the orebody.

The wall rocks.

In the hypogene zone, the wall rocks are green fissile chloritic slates and tuffaceous sandstones with vertically inclined cleavage and steeply plunging lineations. The influence of the movement within the Mary Lane Shear is manifest in the arenaceous rocks in the fractured, attenuated and lenticular forms of the aggregates of coarser clastic particles of volcanic rock. Parallel growths of both quartz and chlorite, directed along the lineation, are common in the stress shadows adjacent to the coarser clastic components of all rocks.

Actinolite and tremolite, and in places also talc, occupy transgressive joints and fractures in the sheared or brecciated slates. Crystals of these minerals are, within the fractures, oriented approximately parallel to the lineations of the host rock. Remnants of dolomite in these veins indicate that some of the calc-magnesian silicate minerals formed from carbonate with the aid of siliceous mineralising solutions.

The rocks are essentially chloritic and contain very little sericite. In addition to the usual clastic quartz and volcanic rock fragments, the sandstones contain some 5% clastic martite and the slates about 3%.

The orebody.

The orebody is enclosed within the brecciated and stressed rocks of the Mary Lane - Mary Ann Shear. It is a flat lenticular body of about ten feet average thickness dipping almost vertically within the shear, and plunging steeply to the east. The present workings extend to about 800 feet depth at which level mineralisation weakens, but as reported by Elliston (1965), a further shoot may be present beyond 1000 feet depth.

Lineation and foliation structures were preserved in the ore and are parallel with those present in the wall rocks. Drag folding produced by differential movement along the main shear and subsequently pseudomorphed in the ore, is expressed in both the vertical and horizontal cross sections by northerly "rolls" and by the pinch and swell form of the shoots, Fig. 121.

The oxidised zone of the orebody extends below the 220 foot level, but does not reach the 390 foot level. The lode consists of massive hematite and limonite, which is leached, cavernous and stained by secondary copper silicates. Native copper occurs in thin sheets in both joint and cleavage planes of the wall rocks and pyromorphite coats the inner surfaces of leached cavities in the hematite. The abundance of pyromorphite indicates the presence of small amounts of arsenic and phosphorus in the ore assemblage which during oxidation, reacted with the chlorides in the ground waters.

The first opening into primary ore is on the 390 foot level. This is not far below the water table, hence secondary sulphide enrichment by covellite and chalcocite is widespread through the hypogene sulphide assemblage on this level. However, the replacements were far from complete and the characteristics of the higher level primary ore aggregate can be observed in detail.

Three contrasting assemblages of ore and gangue minerals were distinguished and although these may form separate shoots within the lode structure, they are also transitional into each other.

One of these assemblages, a rhythmically banded sulphide-oxide ore, represents the incipient stage of mineralisation and its structure is the scarcely modified pseudomorph of the rocks within the Shear.

This ore consists of alternating parallel bands, respectively rich in gangue minerals, in magnetite, or in pyrite, Fig. 122. The banding stands vertically and is parallel to the wall rock surfaces and its cleavage. The bands or foliae are generally continuous for many yards, but at intervals they taper to form disconnected oriented lenticles. This foliated structure is in places, complicated by complex folding which reflects the drag folding of the original slates and tuffaceous sandstones in the Mary Lane Shear.

Both magnetite and pyrite formed subhedra or euhedra of 0.1-3.0mm grain size in the argillaceous facies rather than in the interbedded arenaceous lamellae. The arenites therefore persist in the ore as quartzose bands among the chloritic host rock which was heavily impregnated by pyrite, or magnetite. The unreplaced, fine grained clastic quartz components of the chloritic slates, remain in the pyrite or in the magnetite-enriched foliae of the slates.

Hypogene hematite is common in the magnetite-bearing foliae and it occasionally replaced the outer surfaces of magnetite crystals, Fig. 123. This hematite was not derived from magnetite by oxidation for it is not of the martite type, but was emplaced by hydrothermal fluids, the Eh - pH conditions of which varied with the progress of mineralisation such that the deposition of iron oxide as hematite occurred in the later stages.

The form of the aggregates of magnetite crystals in the magnetite-bearing foliae gave rise to a texture in which there was considerable space. This was occupied only by chlorite and was therefore available for further mineralisation, Fig. 123.

In the early stages of copper mineralisation chalcopyrite formed in the interstitial chloritic areas among the magnetite aggregates, with the result that little replacement of the magnetite or the pyrite occurred in the low grade, magnetite-rich copper ores. Pyrite crystals have a more complicated form, and less interstitial chloritic area was available for replacement in the pyrite-rich foliae. Possibly through this crystallographic control, chalcopyrite was located preferentially in the magnetite-rich foliae.

The advanced stage of sulphide mineralisation is revealed in the second type of assemblage which is of massive structure. Ore of this type occurs in the central sections of shoots which occupy the swell positions in the lode structure, and may contain up to 50% chalcopyrite.

In these high grade copper ores all the intergranular chloritic areas were taken up by chalcopyrite, and there was almost complete replacement of the slates. However, the actinolite, tremolite and talc which filled the fractures in the slates, as well as a proportion of the clastic quartz, sericite and chlorite of the slates, frequently persist in the chalcopyrite, Fig. 124. Magnetite which formed earlier in the slates was not completely replaced, but remained in the chalcopyrite with its embayed crystal edges. Pyrite which also formed earlier, was seldom replaced except in the case of zoned crystals which underwent selective internal replacement.

Minor components of the high grade ore include hematite, bismuthinite, sphalerite and gold. The hypogene hematite is usually associated with magnetite and the bismuthinite with chalcopyrite. Granular sphalerite which is also contained in the chalcopyrite, incorporates minute oriented chalcopyrite exsolution blebs. Bismuthinite, with which fine grained gold occurs, formed in irregularly shaped areas and veinlets in the chalcopyrite and may have crystallised late in the paragenetic sequence.

The exsolution relationship between chalcopyrite and sphalerite suggests that the granular sphalerite containing oriented chalcopyrite blebs formed at about 350-400°C. However, it is also probable that the granular sphalerite itself, represents segregated exsolved individuals formed from chalcopyrite at temperatures as high as 550°C. This implies that the ore cooled slowly enough to permit coalescence of the exsolved sphalerite particles (Edwards 1960).

The third assemblage is a complex sulphide ore which contains in addition to the usual chalcopyrite, pyrite, magnetite and quartz, considerable amounts of galena and sphalerite. Much of the galena is very coarse grained and displays evidence of stress in contorted cleavage planes. The galena enclosed embayed relict crystals of magnetite and pyrite and it penetrated the aggregates of granular sphalerite and chalcopyrite, Fig. 127. Galena was a lower temperature mineral emplaced under conditions of stress after the unmixing and segregation of copper and zinc sulphides. As in other orebodies such as Peko and Orlando it is not widespread, but occurs in localised concentrations.

In another variety of the complex sulphide ore, thin veinlets of chalcopyrite and specularite with subordinate pyrrhotite, pyrite, bismuthinite, galena, wittichenite, gold and quartz, penetrated either the dominant pyrite, or the dominant magnetite in the lode zone. The gold which often exhibits perfect isometric form, is closely associated with both wittichenite and specularite in these veinlets. Two sets of fractures, which intersect at a steep angle may be seen in the massive magnetite which usually constitutes about 90% of these complex sulphide ores. It was these structures which controlled the initial movement of specularite, chalcopyrite and other sulphides into the massive magnetite-rich lode, giving rise first to fracture fillings, and subsequently to replacement veins as the mineralisation progressed, Fig. 126.

Fractures of this type are not apparent in the richly pyritic complex ore where the later components entered along the intergranular boundaries before penetrating the individual pyrites along systems of very thin veinlets.

The deepest level opened up at present is the 590 foot level. It is occupied mainly by the complex types of ore in which massive, or banded magnetite-pyrite aggregates, are the major components. In the banded sections of the lode, the minutely folded forms of the original sheared rocks are well preserved and in the pyritic foliae, thin lines of inclusions mark either cleavage or bedding planes. Fig. 125.

The foliated magnetite-pyrite lode was transected by chalcopyrite-specularite veins which contain most of the subordinate metallic components mentioned for the level above. There is no clear evidence of the order of deposition of the lesser components in respect to chalcopyrite and specularite, but since the specularite is generally euhedral, it may have crystallised before the chalcopyrite which usually encloses it. Pyrrhotite and bismuthinite which are in mutual granular intergrowths with the chalcopyrite probably formed simultaneously with it. These veins generally follow the two intersecting systems of fractures in the lode rock, as mentioned above.

Taking all factors into account it would appear that the location of ore at Ivanhoe was controlled by the tectonic structures expressed in the Mary Lane Shear and that the mineralisation occurred in two major stages, and was of hydrothermal origin. There was however, no significant wall rock alteration.

The evidence suggests that during the first stage of mineralisation, pyrite and magnetite were introduced by an iron-rich siliceous medium into the sheared structure. These two minerals formed massive or banded aggregates, the configuration of which was controlled by bedding, cleavage and the minor folded structures. While there was little rock alteration, dolomite veins were changed to calc-magnesian silicate veins by the siliceous hydrothermal medium.

Subsequent movements fractured the pyrite-magnetite lode formation and these openings, as well as the intergranular areas between pyrite and magnetite crystals, facilitated the entry of the sulphides during the second stage of mineralisation.

The medium was again siliceous but was in this case copper-rich and contained zinc and subordinate lead. The minor phase of lead mineralisation which succeeded the principal phase of copper and zinc deposition, is manifest in local concentrations of galena among the granular sphalerite, chalcopyrite or magnetite. Assuming sphalerite separated from chalcopyrite initially, as finer grained exsolution bodies, which then segregated to form coarser granules, a temperature of no less than 550°C might be assigned to the stage at which copper and zinc entered the lode formation. During the stage of chalcopyrite crystallisation, minor elements such as bismuth and gold precipitated in mutual granular intergrowth with it.

14. THE ORIGIN AND PARAGENESIS OF MINERALISATION.

(1) Summary.

The most probable period of mineralisation in relation to the chronological sequence of geological events in the Tennant Creek area, is depicted in Fig. 128. In this diagram, two distinct cycles of igneous activity are shown; the granites and porphyries which were injected towards the close of the main period of folding when they acquired some fabric distortion; and the basic rocks which were injected after the completion of folding. The basic rocks consequently intruded the granites and are massive in structure.

The principal controlling structures for the location of ore, were developed during, and closely following upon the intrusion of the acidic igneous rocks, thus any mineralisation related to the granites and porphyries, would have late magmatic affiliations. Evidence of hydrothermal activity along the borders of both the granite and porphyry intrusives has been cited and examined, and was shown to have had no expression of metallisation. The different phases of the granite itself, while showing distinct fractionation of the rarer accessory silicate components, display no evidence of enrichment in trace heavy metal components.

However, most previous workers concluded that the porphyries or the granites appeared to be the most likely source of mineralisation at Tennant Creek, with the exception of Elliston who advocated a syngenetic origin for the metals in what he calls the porphyroidal sediments. These however, are considered to be intrusive porphyries by most workers in the area. Elliston also maintains, that through colloidal processes the

metals were subsequently transferred to, and concentrated in pre-consolidation slump structures within these porphyroidal sediments, to form the copper orebodies.

The results of this present investigation, have revealed metasomatic changes in the country rocks in proximity to both the gold and copper-rich orebodies. These manifestations of wall rock alteration provide sufficient evidence of the action of heated, chemically active waters during mineralisation, to invalidate a concept of low temperature colloidal transfer and accumulation of the metallic minerals. Thus the syngenetic origin, held by Elliston, appears untenable.

Evidence of country rock alteration which has not been previously brought forward, constitutes new data to apply to the problem of mineralisation. This data may now be considered in the light of the discovery of gabbros in the Archaean basement south-west of Tennant Creek, to determine whether the basic or acidic intrusives are the more feasible source of mineralisation.

It may be deduced from their undisturbed fabric that the basic intrusives are of later generation than the mineralised folded structures throughout Tennant Creek. In view of the sulphide, magnetite and trace metal contents of the gabbro, its magnetic characteristics and related marginal mineralisation, the source for the metasomatising and mineralising solutions may be in this, or in similar, widerspread basic igneous rocks. Features such as these, which are relevant to a genetic relationship with mineralisation, do not occur with the acidic intrusives.

Although copper and gold usually occur together in the ore deposits of Tennant Creek, these are individually, either predominantly auriferous, or mainly cupriferous.

Copper and other metallic sulphides occur with magnetite, magnesian silicates and quartz in relatively deep structures located on major shears and distinguished by strong magnetic anomalies. These are superimposed upon the deeper-seated magnetic lineaments, which are thought to originate within the underlying Archaean basement.

On the other hand, the gold deposits with little or no magnetic expression, occur at shallow depth. Gold occurs in, or adjacent to the hematite lode formations and is directly associated with oxidised magnetite, sericite, kaolin and hydromicas and with higher concentrations of bismuth minerals, than is copper. The gold deposits show no relationship to the deep-seated magnetic lineaments, and in contrast to most of the copper deposits, they are located in relatively shallow structures in the Specific Horizon. The gold deposits are therefore distinct from copper deposits mainly in their sericite-kaolin-hydromica association which in turn, implies a lesser degree of wall rock alteration, and consequently a milder temperature of formation at a greater distance from a common source.

Many of the gold deposits, especially the larger ones, are transitional to incipient sulphide mineralisation in their deep levels. This change develops as both the gold tenor and the sericitisation decrease and it is accompanied by increased chloritisation and magnetite impregnation of the wall rocks. Although such transitions have not been found so far to develop into useful copper lodes, they indicate that depth zoning applies in this field.

It is apparent therefore, that gold and copper, as well as the other base metal sulphides, have a common origin which is linked with the hydrolytic activity responsible for both the argillic (sericite, kaolin, hydromica) and the phyllic (chlorite anthophyllite, talc) alteration phenomena. The order and depth of deposition of the metals, and the different degrees of rock alteration, indicate a common paragenesis from one source located at greater depth than the sulphide ores. This source is clearly a primary one related to the later basic intrusives, rather than to the earlier acidic ones.

While there exists a diversity of opinion about the source of mineralisation, there is general agreement on the nature of the loci of metal accumulation. The views of Elliston and Ivanac are complementary in that pre-consolidation slumping and brecciation led in certain horizons within the sediments, to both initial high permeability, and to subsequent mechanical weakness. Through preferential susceptibility to failure during later tectonic activity, these areas of the Lower Proterozoic rocks were further conditioned to receive mineralisation.

The sites for mineralisation may be accounted for on these bases, but may also be more precisely defined by several additional factors. The more important of these are the pitch reversals which produced the closed, or partially closed structures which contain the major gold deposits; the incidence within a given favourable structure, of chemically susceptible argillaceous beds capable of reaction with hydrothermal media; and the presence of porous, commonly fractured coarse grained tuffaceous beds adjacent to these.

(2) <u>The base metals and the magnetite lode formation.</u>

The textural relationships between the various sulphides and magnetite in all the deposits studied, indicate comparable paragenesis. In each deposit, magnesium-bearing silicates and magnetite formed ahead of the main sulphides in both the lode structures and in the contiguous country rocks. Since it is mined to greater depth, the most complete paragenesis is displayed in the Peko Orebody, whereas in the Orlando and Ivanhoe Mines, only part of the sequences are presently apparent. The data from Peko are therefore used to illustrate the complete paragenesis of base metal sulphides, Fig. 129. Observations from the lesser copper deposits are compatible with this.

Much of the chlorite-magnetite of the sulphide lodes exhibits a brecciated structure which is somewhat akin to that shown by the banded sericite-magnetite in many of the gold deposits. This is a pseudomorphous structure preserved from the brecciated, highly permeable sediments which were replaced. However, in the intermediate and deeper levels of Peko, the lattice-works of intersecting strings of magnetite euhedra with interstitial chlorite, present a texture of a different type which is not pseudomorphous, but one which resulted from crystallisation in a fluid medium. Magnetite also occurs with quartz in graphic intergrowths which again are not pseudomorphous after sedimentary structures, but which are similar to those in crystalline igneous rocks.

The mineragraphic evidence indicates that small amounts of both cobaltite and pyrite formed in the deepest part of the lodes before the entry of magnetite, chlorite, and the bulk of pyrite, pyrrhotite and other sulphides.

The spatial distribution of the various zones of wall rock alteration suggest that the first changes in the rocks were chloritisation and silicification. Chloritisation is preserved in the outer zones at depth, and silicification in the jasperised sediments at shallower levels.

The initial stages of magnetite introduction commenced during the early phase of wall rock alteration and are manifest in the Peko Mine in the quartz-magnetite envelope zone which extends from the surface to 1000 feet depth. Small amounts of pyrite and pyrrhotite exist throughout the quartz-magnetite and are accompanied by biotite, apatite and tourmaline. Such minerals, containing fluorine, phosphorous and boron as well as sulphur, again point to a primary source for the agents of rock alteration.

The introduction of the main mass of pyrite and pyrrhotite commenced in the interior of the structure and as mineralisation progressed, thin veinlets of these minerals penetrated into the enclosing envelope of altered sediments.

Concurrent with the main sulphide mineralisation, larger amounts of magnesia were carried into the structure by the hydrothermal fluids, and in the more intense rock alteration which ensued, anthophyllite and talc were formed. These, as has been shown, forced apart some of the crystals of magnetite which had formed earlier.

Tourmaline and orthite formed at certain centres with pyrite where they replaced the chlorite, anthophyllite and talc-impregnated rock of the lode structure. This phase, marked by pneumatolytic rather than by hydrolytic action, followed upon the main iron sulphide-magnesium stage of metasomatism.

The main mass of chalcopyrite was introduced at about this time and was in some places, accompanied by a peculiar green biotite or phlogopite, and by abundant zircon where it transgressed the talcose magnetite and pyrite-bearing lode material.

In most places the ore textures suggest that bismuth, bismuthinite and gold formed at the same time as chalcopyrite, There are also occasional transgressive veinlets of bismuthinite and gold in the chalcopyrite which indicate that the emplacement of bismuth and gold continued beyond the period during which most of the copper was deposited.

In the lead-zinc orebodies which appear to be confined to intermediate depths, chalcopyrite, sphalerite and tetrahedrite appear in textural aggregates which indicate contemporaneity amongst them. However, these minerals all replaced earlier crystallised arsenopyrite and marcasite. Marcasite may represent former pyrite or pyrrhotite. Galena in these ore complexes was a later mineral which, with carbonate gangue, replaced the earlier-formed iron, copper and zinc sulphides.

The various carbonate gangue minerals appear to have formed throughout the whole period of sulphide emplacement. There are also minor amounts of gold and tourmaline in the lead-zinc associations. Silver, which is not present as a discrete mineral, occurs in solid solution in both galena and tetrahedrite.

The total of all sulphides decreases very little with increasing depth although they become progressively finer grained and less apparent amongst the magnetite. There is however, a progressive change in the relative proportions of the iron and copper sulphides. In the deeper levels the copper grade diminishes and pyrite and pyrrhotite become more abundant.

Thus further depth zoning exists within the copper orebodies themselves. In this, sulphides of increasingly higher temperatures of formation, greater amounts of magnetite, and silicate minerals resulting from more intense rock alteration, become more abundant in depth.

Edwards (1955) stated that mineralisation commenced at about 500°C and was completed at about 165°C. The highest temperature was probably attained some time after mineralisation commenced, when the strongest alteration, manifest in talc and anthophyllite, was developed, and pyrite, pyrrhotite and chalcopyrite were emplaced.

(3) <u>The gold and the ironstone lode formation</u>.

The mineralogy of the gold deposits is simpler than that of the copper deposits, and the degree of wall rock alteration, although quite as widely manifest, is much less intense.

Silicification and kaolinisation are characteristic alteration phenomena in the upper and outer limits of the deposits. In depth, and towards the contact with the orebodies, increased amounts of illite, kaolin and sericite, as well as magnetite were developed in the argillaceous facies of the country rock. In all phases of rock alteration, the highly tuffaceous and arenaceous rocks display almost complete resistance to the metasomatic changes.

The most advanced alteration, in which the argillite was extensively replaced by sericite, kaolin, illite and magnetite, occurs in depth, and at, or within the contact with the actual lodes. At a later stage, a minor pneumatolytic phase ensued during which quartz-tourmaline-specularite veins penetrated both the ore and wall rock zones in the Noble's Nob orebody.

Towards the base of the largest of the gold deposits, the intensity of sericitic-type alteration decreases as the gold values decrease and the continuation in depth of the structure is marked by incipient chloritisation, continued magnetite impregnation and sulphide mineralisation.

The zonal arrangement of the silicates which was produced in wall rock alteration, has its counterpart in the distribution of the metals brought into the structures. Discounting for the moment the effects of leaching and secondary enrichment on the distribution of gold, the values for immobile silver and bismuth which represent the amount of primary gold, are relatively low in the upper levels, reach a maximum at intermediate levels and dwindle towards the base of the lodes. Small amounts of pyrite and chalcopyrite and of enargite, wittichenite and emplectite, are distributed throughout the gold orebodies. Below the areas where gold values and sericitisation decrease, pyrite, enargite and chalcopyrite increase in conformity with incipient chloritisation, either within the main lode structure, or in the parallel satellitic shoots within the wall rocks.

An important factor relevant to the origin of primary gold is its distribution which is virtually exclusive to the Specific Horizon, except in so far as low gold values exist also in the sulphide ores. The main feature of the structural interpretation is the definition of the Specific Horizon which is a rapidly deposited, shallow water facies characterised by large accumulations of heavy minerals, especially martite and hematite.

Trace element analyses of all types of sediments throughout the field showed higher than average values for copper, lead, silver, zinc, bismuth, etc., only in proximity to ore deposits and in certain parts of the Specific Horizon where minor clastic sulphides were found to be present.

Apart from these small and localised amounts of clastic sulphides, the main heavy mineral accumulations consist of martite, zircon and apatite but even in these, clastic gold has never been observed. It is unlikely therefore, that either sulphides or gold were sufficiently abundant, even in the heavy mineral-bearing sediments to provide a syngenetic source for any of the orebodies.

Practically all gold deposits are located in the Specific Horizon at positions where there were extraordinarily large accumulations of clastic iron oxides. The low temperature transport of a small proportion of the iron oxides through permeable coarse grained tuffaceous rocks, to structures in which they recrystallised to form the ironstone lode formations, has been discussed.

These ironstone lode formations have been forming progressively within the zone above water table level, over a long period of time.

Their development may have commenced in Middle Proterozoic, following upon the formation of the localising structures in Lower Proterozoic times. The growth of the ironstone bodies was interrupted during the period of accumulation of Upper Proterozoic and Cambrian sediments. However, after the removal of the overlain Upper Proterozoic and Cambrian sediments, the iron-rich Lower Proterozoic rocks were again brought into the influence of the zone of oxidation. The processes of erosion and weathering, and the continuation of the solution, circulation and redeposition of iron oxides and silica in the oxidised zone, caused the further development of the ironstone formations in near-surface environments.

It is generally agreed, and it has in fact been stated by Crohn and Oldershaw (1964), that both siliceous and ferruginous duricrusts have formed continuously with progressive base levelling from the evaporation of vadose waters at the surface. A small proportion of these vadose waters, residing temporarily in closed and sheared structures within the zone of oxidation, has during the same time, gradually built up the ironstone lode formations.

The hydrothermal solutions introduced gold, potash and alumina silicates, magnetite and a limited amount of iron, copper and bismuth sulphides into approximately 10% of the structures which are also occupied in part, by the syngenetic ironstone lode formations. The allotriomorphic granular hematite aggregates of which these ironstone lodes are principally composed, are either barren, or contain relatively small amounts of gold and other epigenetic minerals, such as the sulphides and sulphosalts of copper, iron and bismuth.

By virtue of their origin the ironstone lodes are in part older, and in part younger than the primary components of the gold orebodies, hence their irregular and generally low gold tenor and their separate position within a given deposit, Figs. 54, 55. In the Noble's Nob orebody for example, at least 95% of the gold and almost all of potash and alumina silicates exist in the banded sericitic hematite lode rock. The contiguous massive hematite lode formation is comparatively barren.

(4) The source of base metal sulphides and gold.

It has been shown that sulphide deposits contain minor gold, that gold deposits contain minor sulphides, and that the characteristics of wall rock alteration are comparable in both types of ore. It is apparent that the two types of mineralisation are related, gradational, and specific to different depth zones, Fig. 129. A common origin for both the sulphides and the gold is the natural conclusion.

The results of this investigation favour basic intrusives of the type that are known to exist in the Archaean basement, as a source for both the agents of rock alteration and the metals. It is required now to examine the mineralising potential of basic igneous rock which consolidated adjacent to deeply penetrating structures which lead to the surface.

Two fundamental geochemical factors are important in this respect, viz. the relative solubilities of sulphur or sulphides in basic and acidic magmas, and the control of the primary distribution of metals through the size and valence of their ions, and through the configuration of their electron shell structures.

Molten basic magmas, like basic slags, may contain in solution several percent of base metal sulphides, whereas acidic magmas cannot. Consequently, if the basic rock chills without differentiation, the sulphides will crystallise out and probably segregate the thiophile elements of low atomic radius. If, due to differentiation, the higher temperature silicates separate, the remaining more acidic liquid is unable to contain in solution the quantity of sulphur or sulphides originally held. Thus, upon rapid cooling accompanied by partial or complete differentiation, both the sulphides if originally present, and the iron-magnesium-rich silicates are bound to separate.

The geochemical and mineralogical characteristics of the gabbroic intrusive in the basement indicate that it contained an abundance of sulphur as well as base, and other metals. The values in Table 20 show that copper, lead, zinc, cobalt and vanadium are well represented in the quartz dolerite. In polished sections of this rock there are always abundant pyrite, and magnetite, as well as considerable amounts of pyrrhotite, chalcopyrite and ilmenite. Minerals containing lead, zinc, cobalt and vanadium have not been observed, but of these, lead is in too small an amount for normal observation and zinc and cobalt may be partly or completely concealed in pyrrhotite, magnetite or ilmenite. The vanadium may also be concealed through substitution in magnetite, apatite or sphene, (Rankama and Sahama, op.cit.).

TABLE 20.

Minor metal contents of quartz dolerite.

metal:-	Cu	Pb	Zn	Ni	Co	Cr	V	Ti
*Av. gabbroic rock	150	10	90	160	80	340	50-320	**
quartz-dolerite	250	18	400	45	140	180	500	20,000

* Compiled from Rankama and Sahama, (1949)

** no reliable average known.

Analyses by Australian Mineral Development Laboratories.

The low values for nickel and chromium suggest that these separated earlier and segregated deeper within the gabbro or, that the gabbro is a differentiate lying above a more basic parent magma.

The iron oxide minerals are generally the first minerals to separate from a magma, and although this is not certain, the separation may occur before the magma consolidates, (Turner and Verhoogen, 1951).

Sulphur may therefore have remained in solution in the liquid magma until the iron oxides had separated. Upon subsequent consolidation of the magma, sulphides containing mainly iron and copper, as well as minor cobalt, could have separated to form pyrite, pyrrhotite, chalcopyrite and minor cobaltite.

At that stage it is feasible that the immiscible sulphides were still molten since their melting points were lower than those of the first silicates to separate. Under the high confining pressure which would have existed in the deep environment, the movement of the liquid sulphides in heated tenuous waters to higher levels of pressure relief, would have been possible in areas where structures penetrated to great depths. In the absence of shears or faults, the sulphides would have entered the cleavages and intergranular boundaries of the contiguous country rocks.

The phenomena observed in the Archaean south-west of Tennant Creek are compatible with a postulation of this nature, especially in view of the disseminated sulphides and magnetite in the gneisses in contact with the basic rocks. Major shears or faults have not been observed in this locality, hence the magmatic separates may, for this reason, have been confined to the immediate surroundings.

The mineralisation in this area of the Archaean was not accompanied by magnesian metasomatism and therefore differs from the sulphide mineralisation in the overlying Proterozoic rocks. This difference may be attributed to the lithological characteristics of the Archaean gneisses which are similar to those of the resistant tuffaceous sandstones, and quite different from those of the susceptible argillaceous facies in the mineralised Warramunga sediments.

Since the first silicates which separate from a basic magma are strongly enriched in magnesium, it is feasible that the media responsible for the formation of chlorite and talc in the lode structures were also generated at the early magmatic stage. The work has shown that magnesia was introduced into the structures with magnetite, ahead of the main sulphides, and presumably in a phase mobile enough to permit considerable penetration into the rocks surrounding the lode structures.

The presence in the district of less basic and intermediate intrusives, which by virtue of their field relationships are also of later origin than the granites and the folded Warramunga rocks, indicates that partial differentiation of basic magma did occur. The widespread distribution of these differentiates further suggest that the parent basic magma is not confined to the area in which it is presently known.

Lamprophyre dykes are prominent in the northern part of the field where they are closely associated with diorite dykes, and they occur also in the south close to the intermediate and basic rocks which penetrated the Southern Granites. Recent drilling in the western areas near Red Bluff has again disclosed the presence of scapolite-bearing diorites, lamprophyric rocks and associated incipient vein-type sulphides in the Warramunga rocks.

According to Wilson (1953), zinc and lead may associate with the early immiscible sulphides to some extent, but they reach their maximum concentration at a later stage in the cooling process of the magma when the tenuous hydrothermal phases develop more completely. Geochemical principles dictate that zinc will predominate if differentiation has progressed to intermediate stages, whereas lead and silver will predominate at more acidic stages.

These metals occur in minerals which are late in the paragenetic sequences in all deposits, and their origin may correspond in time with the generation of the dioritic and lamprophyric intrusives which are prominent along the line of the main copper deposits in which all lead-zinc sulphides occur.

Small amounts of gold, representing that in excess of the amount which the early mineralising solutions could contain, were deposited with chalcopyrite, bismuthinite, galena and sphalerite. However, the bulk of the gold and the bismuth apparently remained in the intrusives to the stage where, having become depleted in magnesia, they produced hydrothermal emanations which contained mainly potash, alumina and silica. Sericite, various hydromicas and kaolin were therefore concentrated with gold in lode formations at higher levels than were the sulphides. Finally, solutions depleted in potash, formed the alumino-silicates in the wall rocks enclosing the gold lodes, while the residual siliceous waters produced the outermost and uppermost manifestations of wall rock alteration in jaspers and in chalcedonic pseudomorphs of the brecciated and folded country rocks.

15. CONCLUSION.

It has been shown that the geological, mineralogical and geophysical observations may be considered in terms of fundamental geochemical theory to explain the sequence in mineralisation, the depth zoning of the metals and the manifestations of country rock alteration.

An external source for the metals was the ultimate conclusion since the evidence suggests they are not indigenous in the sediments and that the orebodies are not syngenetic. Furthermore, the mineralogy indicates that the orebodies were formed in an environment characterised by elevated temperatures, and by the presence of aqueous fluids capable of promoting chemical reactions with the host rocks.

The results from the examination of all types of igneous intrusives in the district favours the basic, rather than the acidic rocks, as a source for the metals, and for the hydrothermal solutions.

Conditions of coincidental sulphide mineralisation, basic intrusion and anomalously high magnetism were found in the shallow area of Archaean. Within the environs of Ivanhoe and at Red Bluff, basic differentiates occur and relatively shallow magnetite bodies exist superposed upon deeper magnetic lineaments. At Orlando and Peko, magnesium metasomatism occurs with sulphide mineralisation in magnetite-enriched lode formations situated above the deeper magnetic lineaments.

It is apparent that the deep magnetic lineaments are in some way related to deep seated basic intrusives and that where structures penetrated deeply enough to intersect these, mineralisation was possible. It is therefore concluded that basic magma crystallised at depth in proximity to such structures and that some of the oxides, sulphides and early formed magnesian silicates migrated surfacewards in chemically active waters to the receptive structures in which ore was formed.

The distance between the postulated source and the ore deposits is not excessive for it is generally accepted that many hydrothermal copper-lead-zinc ores have travelled considerable distances from their point of origin. Experience in other areas has shown, that where the source for ores of this type can be traced, it is often found to be in intermediate or basic intrusive rock.

Gold deposits are mainly in the shallower levels where the lode formations, by virtue of oxidation, show little magnetic expression. Further gold deposits will be found in the Specific Horizon not only where syngenetic ironstone bodies exist, but in drag folded positions, particularly where there are pitch reversals, transgressive east-west structures and surface manifestations of silicification and kaolinisation.

Since gold extends to considerable depth in the base metal deposits it may also be expected, of its own accord, to form a limited number of somewhat deeper-seated deposits associated with rather less magnetite than are the base metal ores. Weak magnetic anomalies in favourable structures in the Specific Horizon, should therefore be examined, and in fact, the recent discovery of the Juno gold orebody at 600 feet depth, demonstrates this possibility.

The future discovery of base metal deposits will follow upon deeper drilling than has been practised in the past. Exploration in the southern, relatively shallow section of the basement complex, has already revealed the presence of disseminated sulphides. Further investigations in a northerly direction where, although the basement is deeper, known major structures occur, may lead to the discovery of other ore deposits.

A more comprehensive investigation of the cause of the basement magnetic lineaments could prove rewarding not only in the discovery of deeper copper-lead-zinc ores, but perhaps also in leads towards segregated masses of copper-nickel, cobalt and even platinoids.

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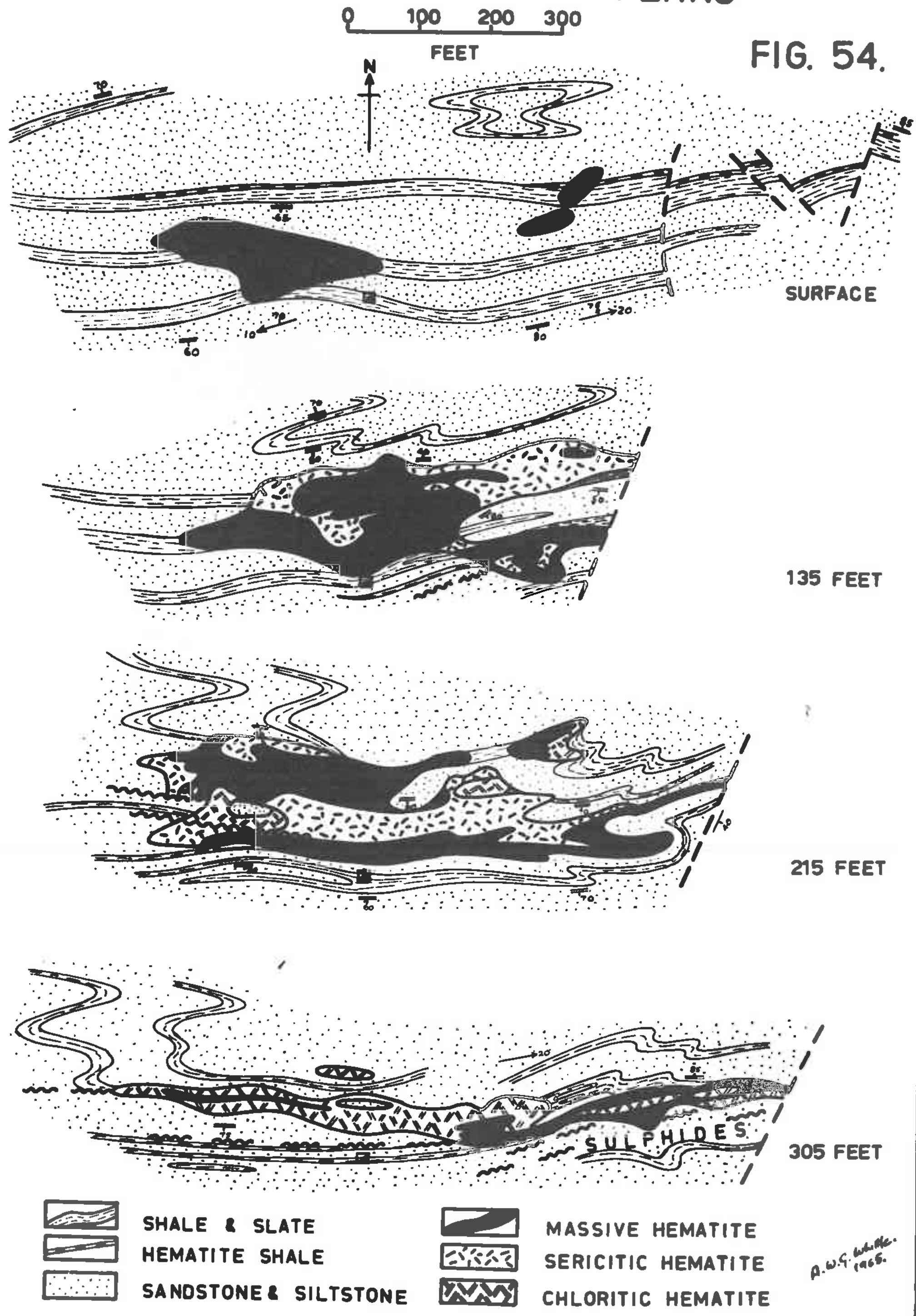
NOBLE'S NOB MINE PLANS

FIG. 54.



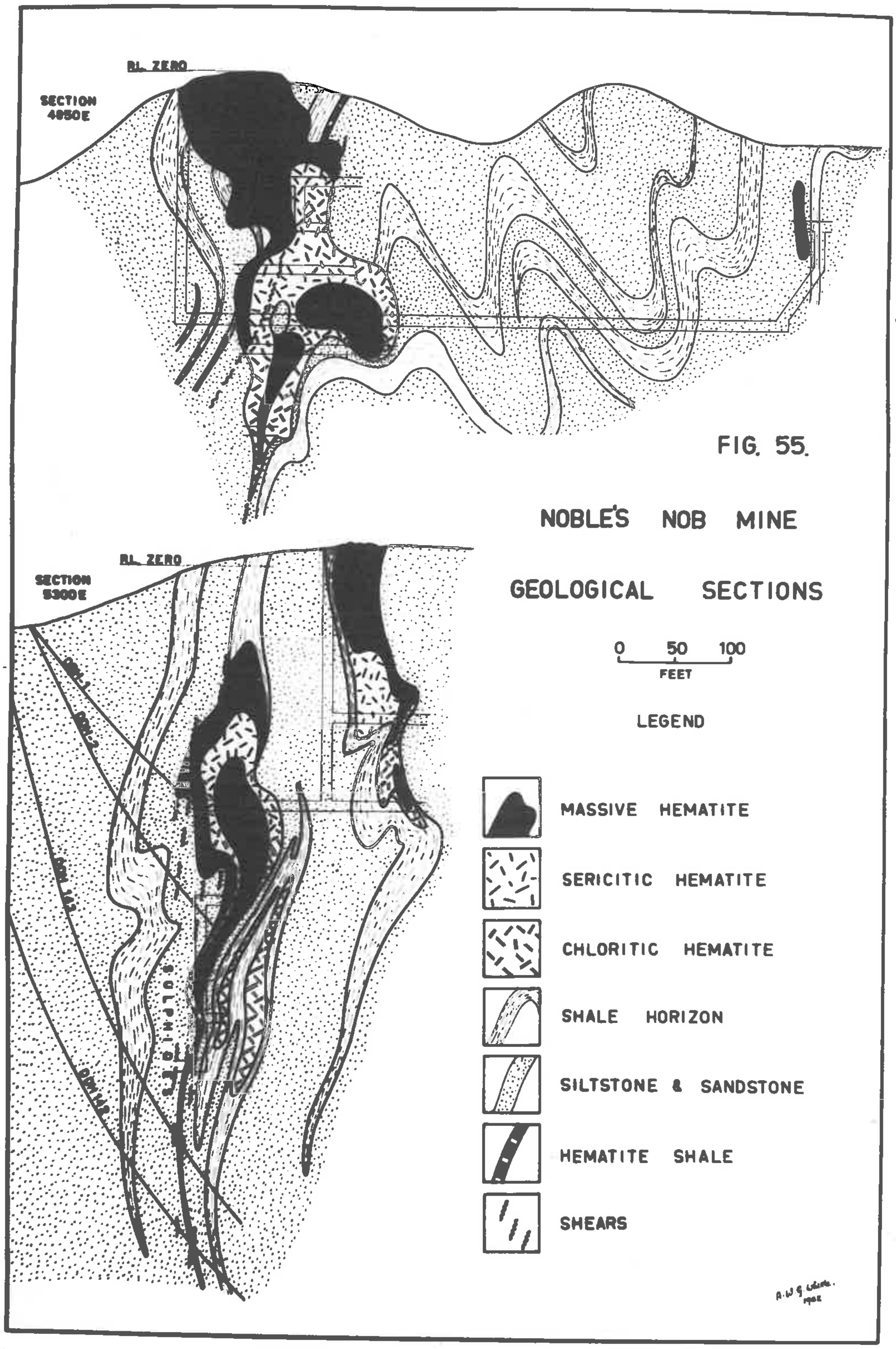


FIG. 55.

NOBLE'S NOB MINE

GEOLOGICAL SECTIONS

Fig. 56.

Country rock.

thin section x 70.

A section of intercalated siltstone and shale which illustrates the sharp and short interval facies changes. Clastic martite (black granules) exist in both rock varieties.

near Noble's Nob.

Fig. 57.

Country rock.

thin section x 25.

This section of siltstone illustrates thin heavy mineral lamellae in which the clastic martite (black granules), is concentrated.

near Noble's Nob.

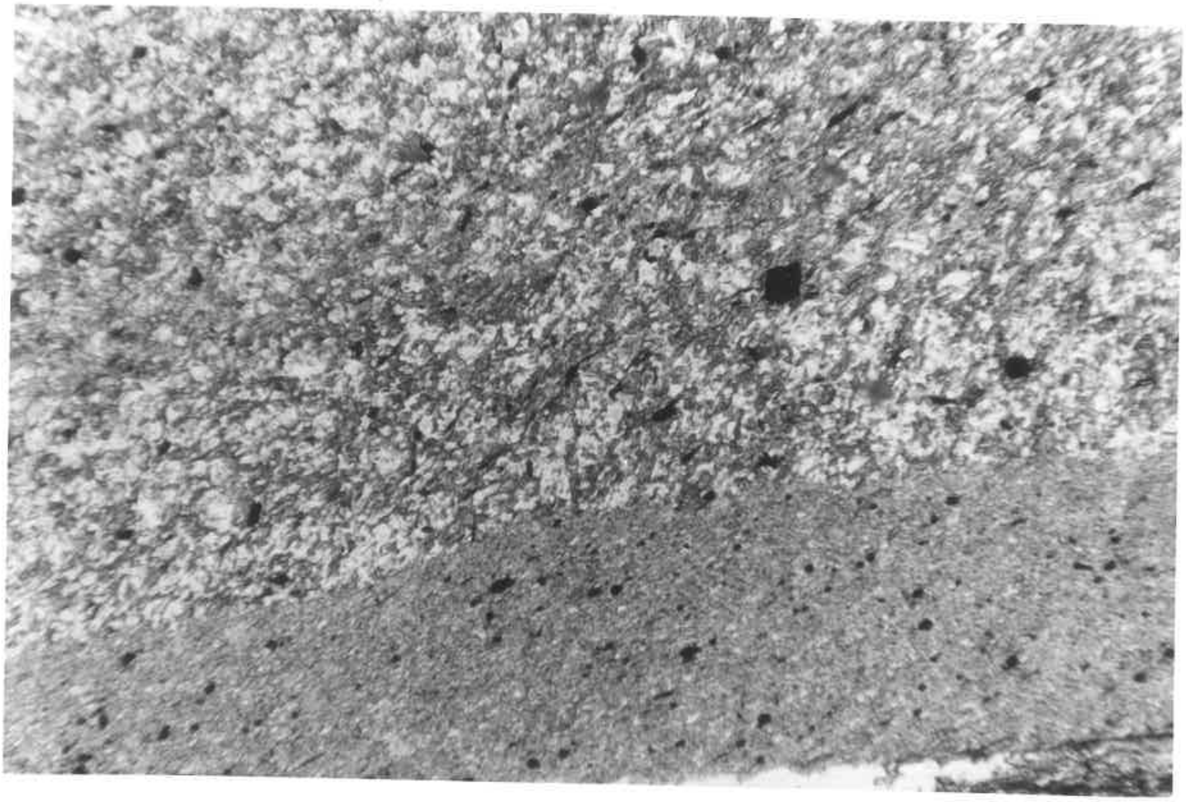


Fig. 58.

Wall rock alteration.

thin section x 70.

The section of red, limonite-impregnated shale in the oxidised zone of the footwall shows the early stage of its replacement by hydromicas and kaolin. These minerals formed in parallel bands disposed approximately along the bedding. The cleavages of these flakey minerals within the bands, is oblique to the bedding.

215 foot level, Noble's Nob.

Fig. 59.

Contact zone.

thin section x 70.

This section of shale at the plane of contact with ore shows its almost complete replacement by euhedra of magnetite (black - now martitised) and crystals of muscovite, kaolin and hydromicas (white). The kaolin crystals display typical curved cleavages.

215 foot level, Noble's Nob.

Fig. 60.

Banded "sericitic hematite" ore.

thin section x 25.

This section illustrates the banded structure present in the ore after the complete replacement of shale by magnetite (black), and by muscovite, kaolin and hydromicas (white). Gold is located principally in the light coloured bands.

183 foot level, Noble's Nob.

Fig. 61.

"Sericitic hematite" ore.

polished section x 110.

The section was taken from banded sericitic hematite lode material. Gold particles (bright white) occur in the extensively replaced argillite (mottled pale grey) adjacent to hydromica crystals (dark grey).

215 foot level, Noble's Nob.

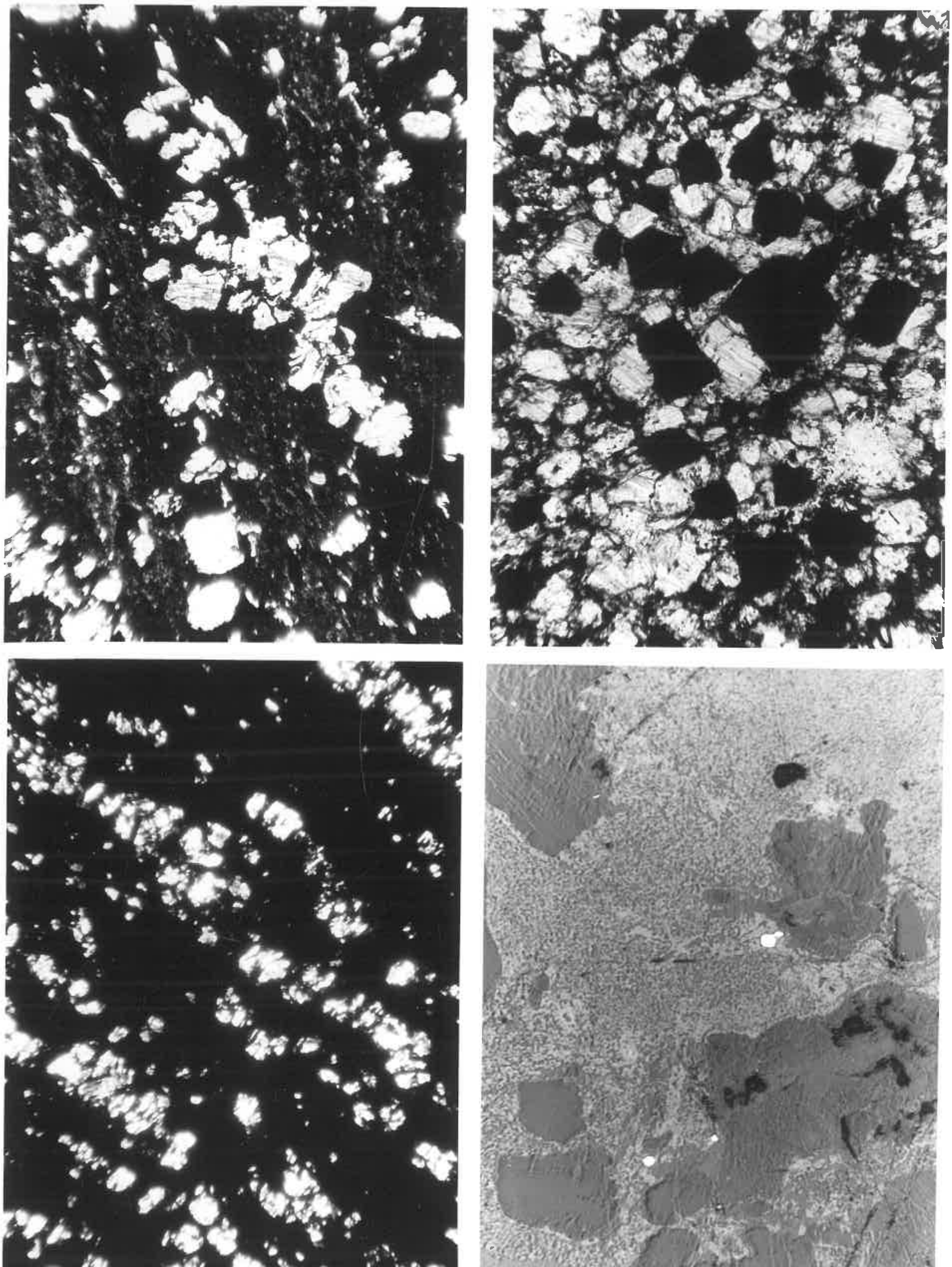


Fig. 62.

Wall rock alteration zone.

thin section x 70.

Fissile slate which consists of chlorite flakes in optical continuity, (dark grey). Numerous crystals of sericite (white) and euhedra of magnetite (black) formed in the cleavage planes of the chloritic fabric.

270 foot level, Noble's Nob Mine.

Fig. 63.

Wall rock contact against ore.

thin section x 70.

This chloritic slate in contact with an ore shoot, has changed to auriferous "sericitic hematite." Poorly formed wispy chlorite (grey), replaced most of the original argillite. Thin blades of specularite (black), equidimensional magnetite euhedra (black), and sericite crystals (white) formed in, and across the chlorite, by replacement.

270 foot level, Noble's Nob Mine.

Fig. 64.

Wall rock contact against ore.

thin section x 70.

Chloritised slate located near the contact with the chloritic hematite lode. The fissile rock composed of optically continuous chlorite (grey), was extensively replaced across its cleavage by veins of sericite (light grey), by individual sericite crystals mainly oriented in the cleavage and by numerous specularites (basal sections - black).

270 foot level, Noble's Nob Mine.

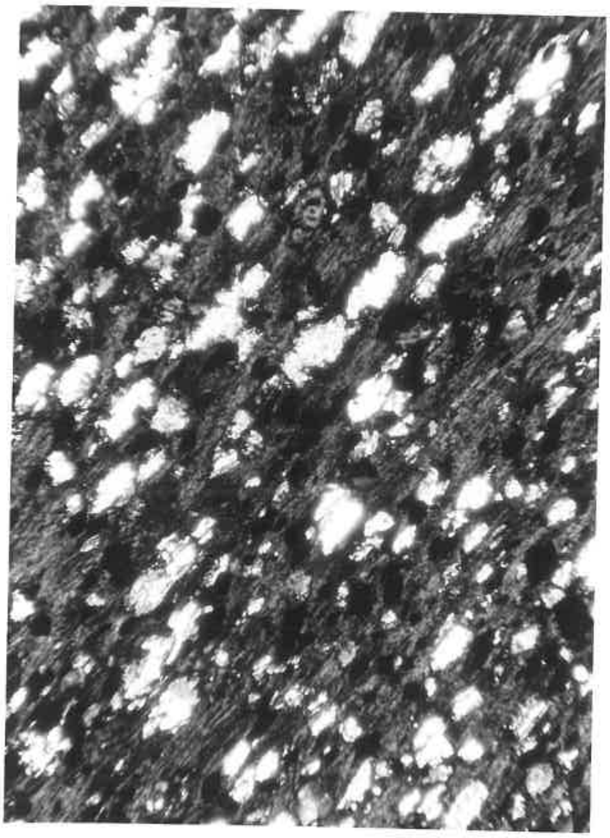
Fig. 65.

Wall rock contact against ore.

thin section x 70.

Chloritised slate which is in process of replacement by specularite plates (black) in the cleavage, and by sericite (white), across the cleavage.

270 foot level, Noble's Nob Mine.



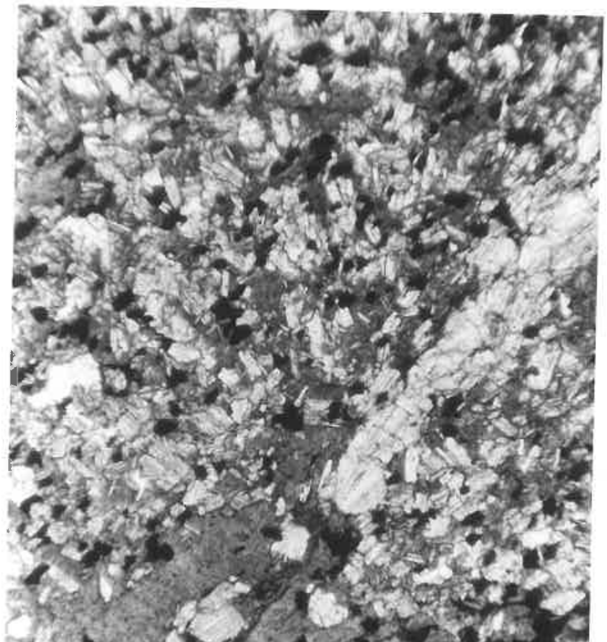



Fig. 66.

Allotriomorphic granular hematite.

polished section x 330 - crossed nicols.

This section illustrates the interlocked texture of allotriomorphic hematite grains (shades of grey), and the irregularly shaped leached cavities (black).

Surface outcrop, Noble's Nob Mine.

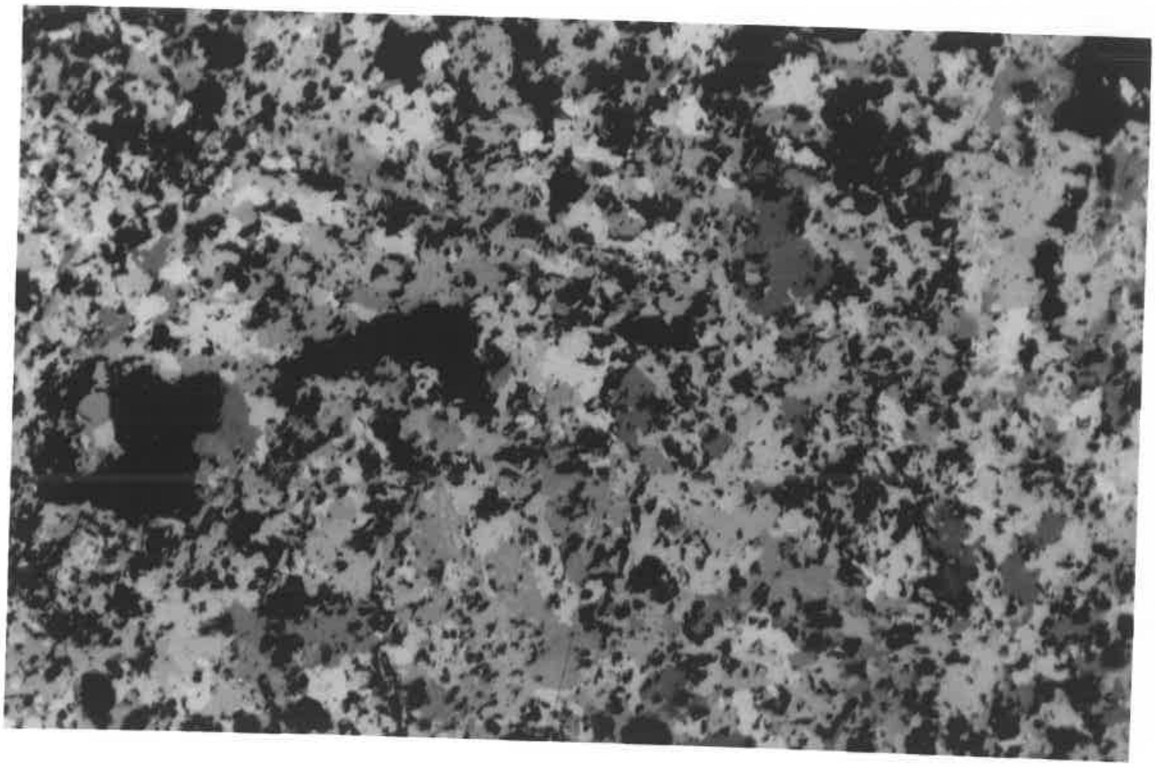
Fig. 67.

Idiomorphic granular hematite.

polished section x 330.

This section illustrates the criss-crossing disposition of specularite euhedra (white), which are intergrown with a small amount of quartz (grey).

Surface outcrop, Noble's Nob Mine.



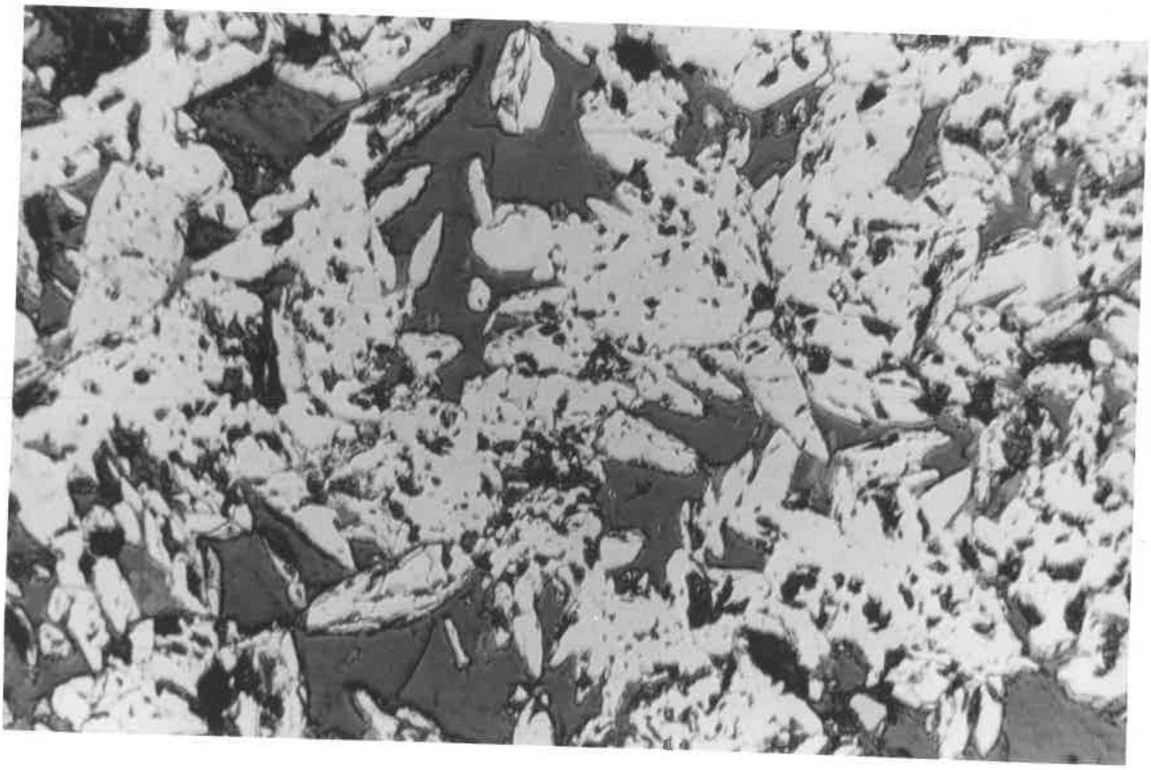


Fig. 68.

Bonanza gold shoot.

thin section x 70.

Thin section of richly auriferous sericitic-hematite ore showing primary hydromicas and kaolin (light grey), gold (numerous irregularly shaped black masses) and euhedral martite (black crystals with straight line edges).

215 foot level, Noble's Nob Mine.

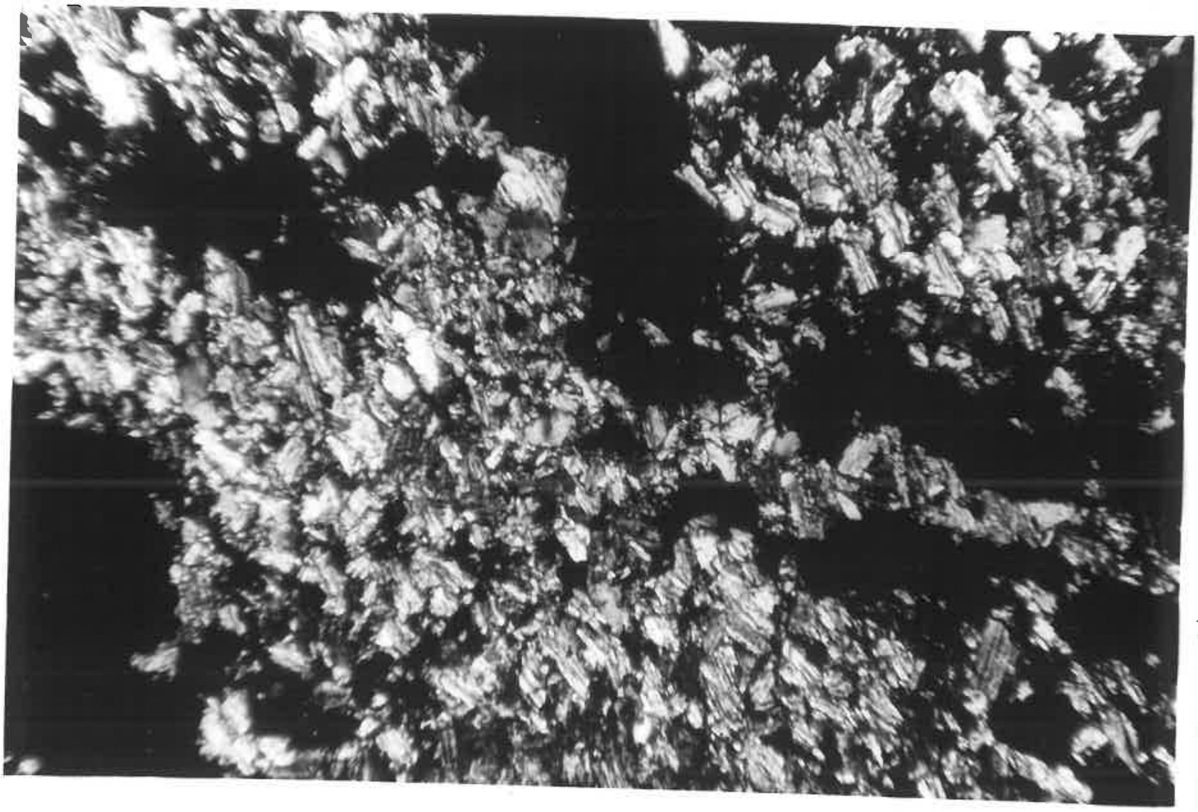
Fig. 69.

Bonanza gold shoot.

thin section x 200.

Thin section of an assemblage of gold (black) and clusters of hydromica, sericite and kaolin crystals (light grey). Some gold fills the spaces between the intersecting crystals, and some is formed in the boundaries between adjacent radiating clusters.

215 foot level, Noble's Nob Mine.



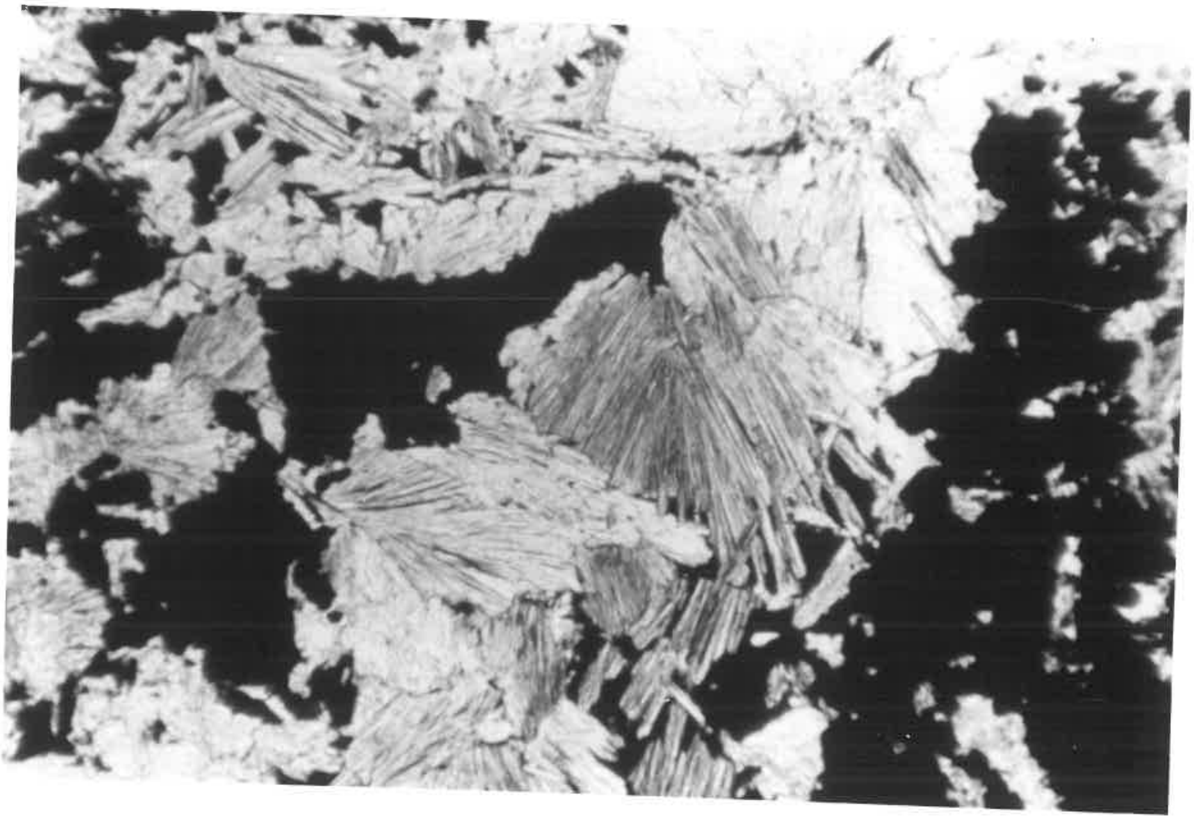


Fig. 70.

Martitised magnetite.

polished section x 300.

Partially oxidised magnetite euhedra (white) in a medium of intersecting potash-alumina silicates. Unoxidised residuals of the original magnetite crystals are preserved in the outer martitised rim.

185 foot level, Noble's Nob Mine.

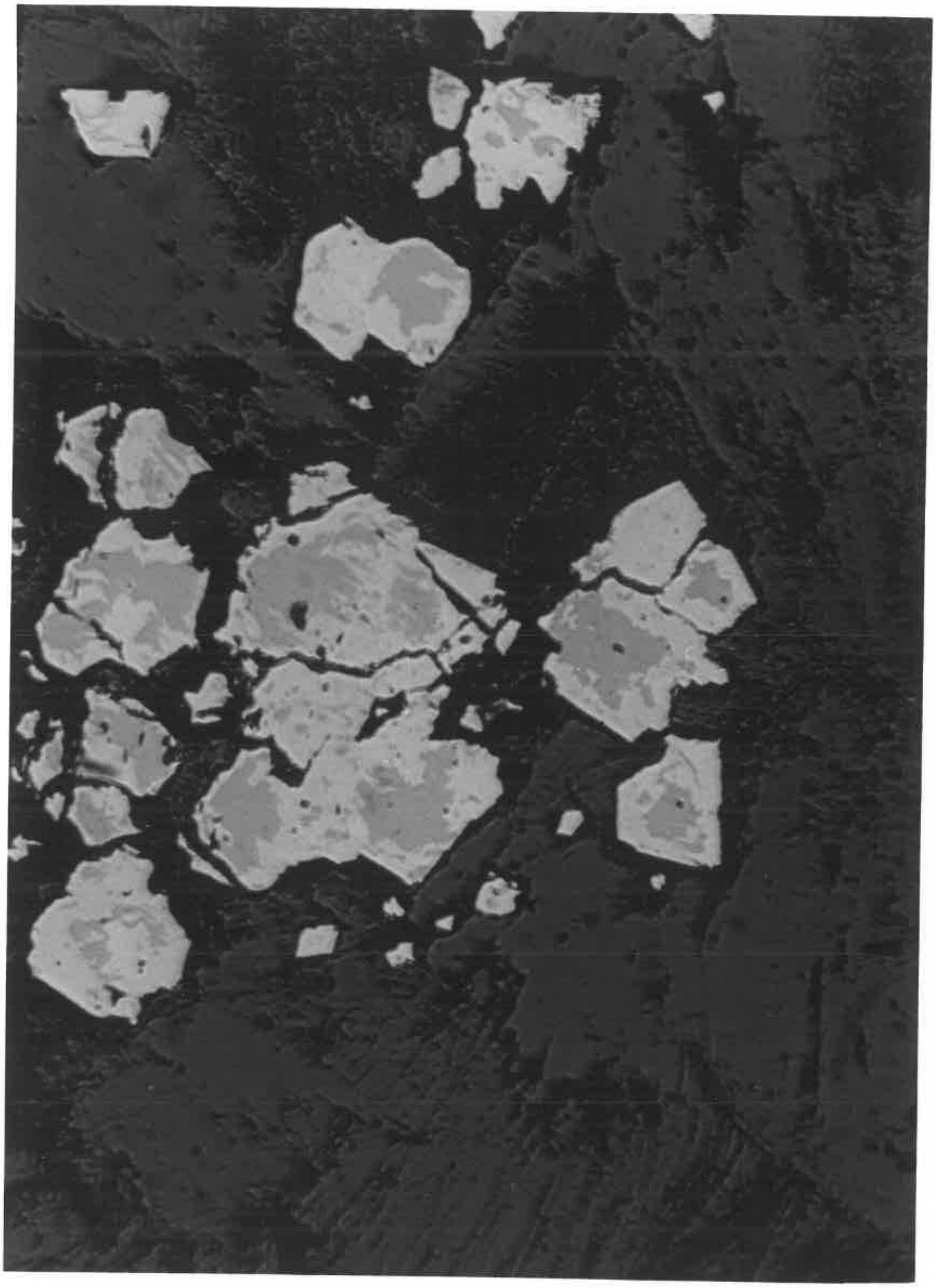


Fig. 71.

Banded sericitic hematite ore.

polished section x 110.

The section is made up of :-

(a) bands containing subhedral martitised magnetite (light grey with dispersed residuals of magnetite of slightly darker colour) and euhedra of specularite (light grey prisms), crystallised around the magnetites. Minor amounts of fine grained gold (white) occur in the martite.

(b) bands of illite and kaolin (medium and darker greys criss-crossing crystals) which enclose abundant gold (white) as open space fillings. The unfilled open spaces are black.

(c) bands of sericite or muscovite (very dark grey flakes) enclosing minor gold as partial fillings in open spaces.

215 foot level, Noble's Nob Mine.

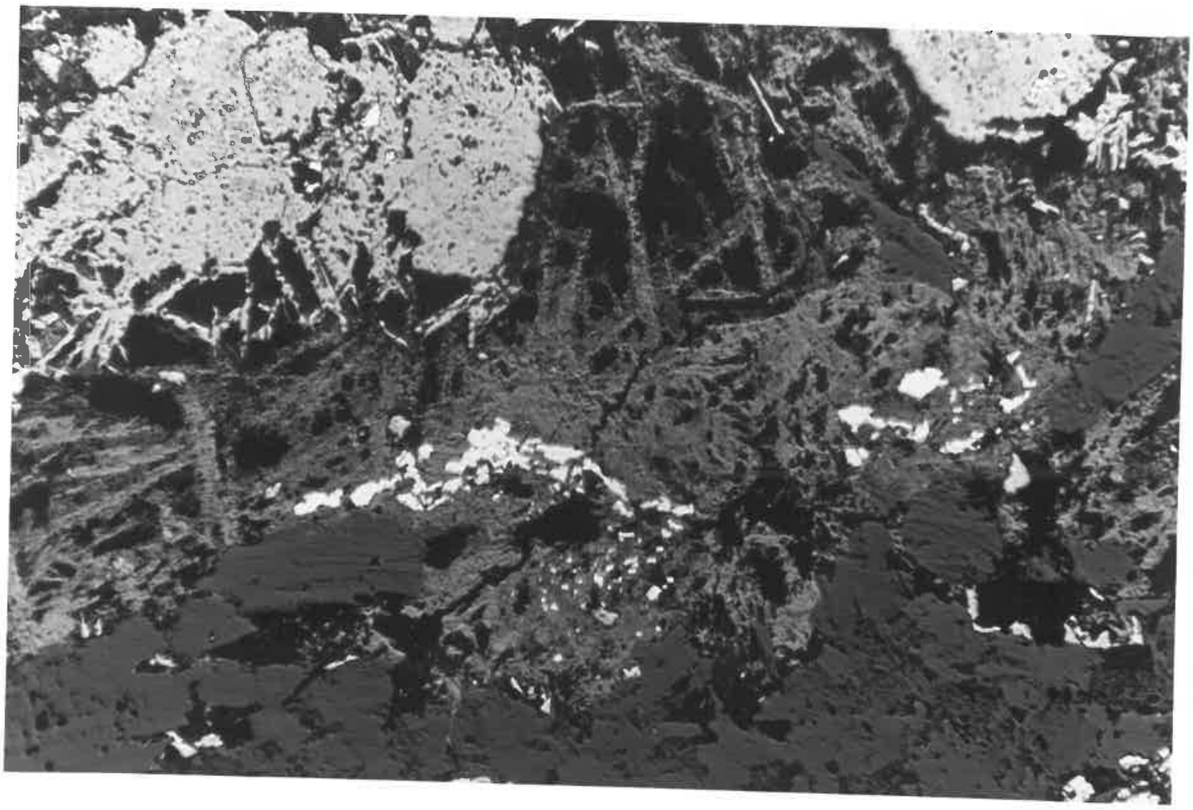
Fig. 72.

Contorted sericitic hematite ore.

polished section x 110.

The section reveals a more irregular intergrowth of martite (light grey) and sericite (dark grey) which contains a great abundance of gold (white). The groups of granules of martite are contained within separate rectilinear areas, which suggest the euhedral form of magnetite prior to contortion and brecciation. The sericite crystals have partial alignment and enclose much open space, in some of which, gold was deposited. Gold also deposited in the open textured areas of brecciated magnetite.

215 foot level, Noble's Nob Mine.



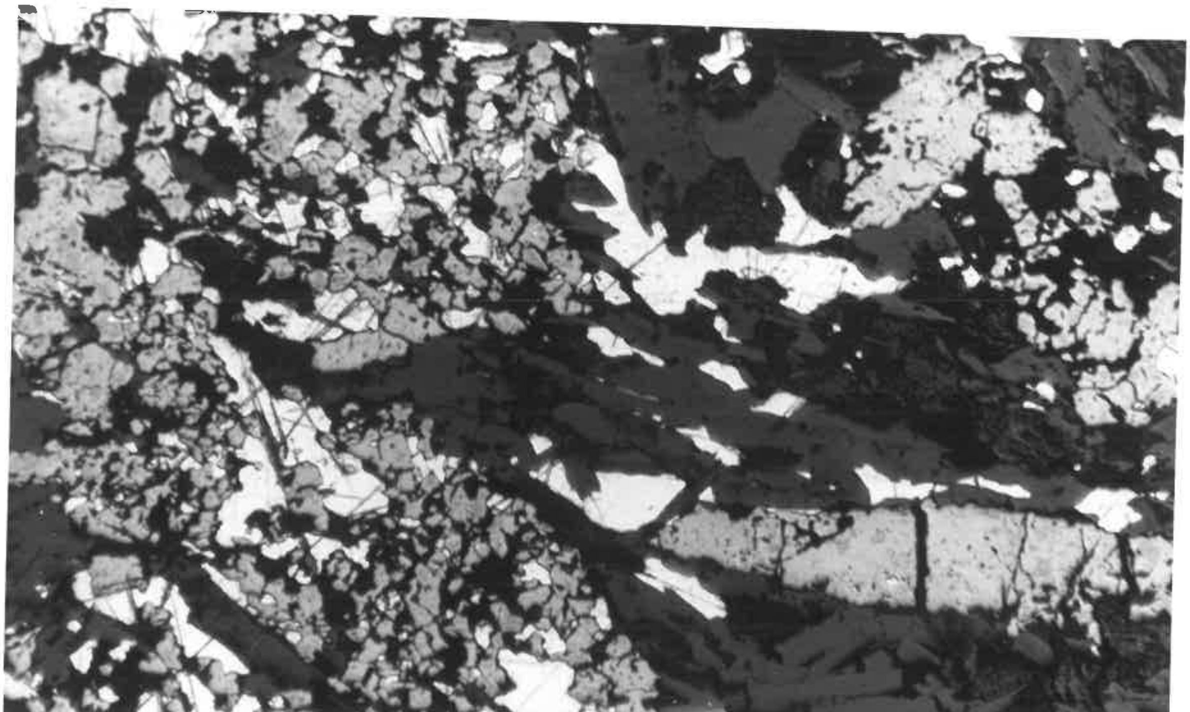


Fig. 73.

Copper mineralisation.

polished section x 330.

The section shows zoned euhedra of pyrite (off white), penetrated by enargite (light grey), which encloses specularite and chlorite (grey and black). Pyrite and enargite exist in slate (dark grey) against which there is a contact rim of chlorite crystals (slightly darker grey).

450 foot level, Noble's Nob Mine.

Fig. 74.

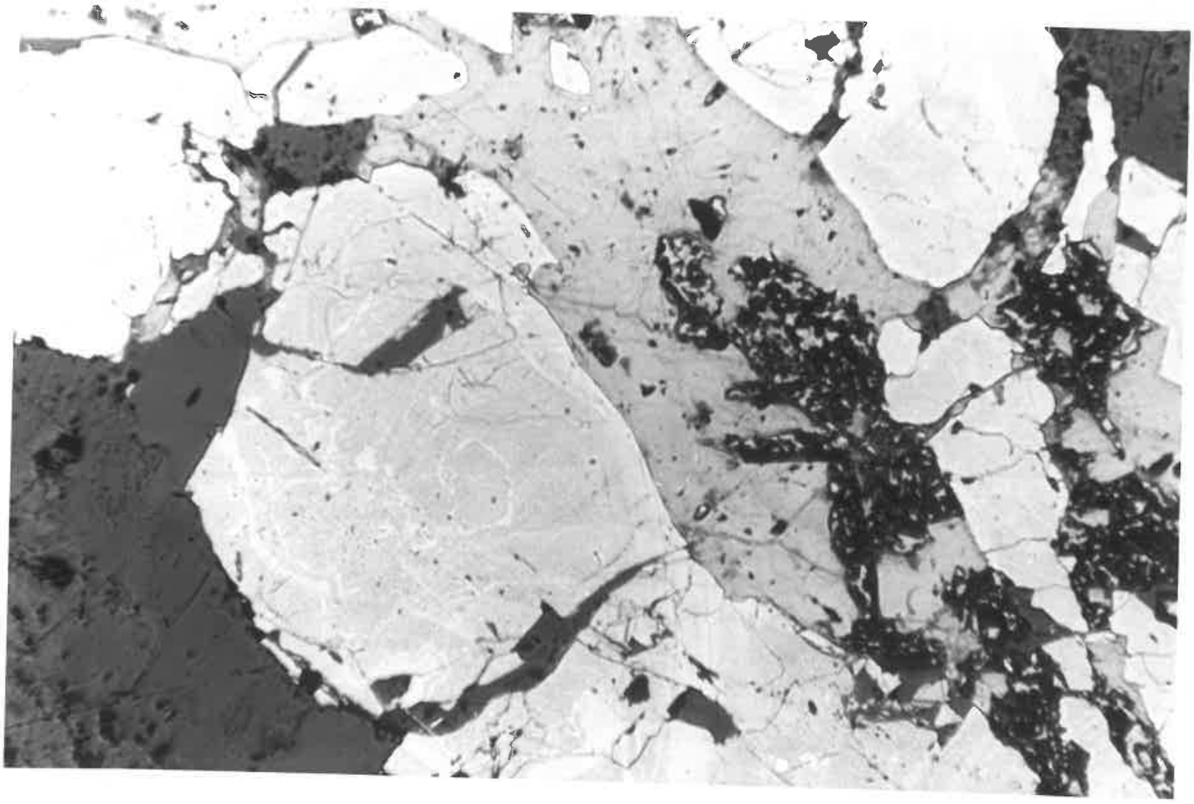
Copper mineralisation.

polished section x 110.

The section of chloritic slate (dark grey with lines of cleavage), contains and enwraps a large magnetite crystal (light grey) which was rotated and fractured during shearing movements. The smaller crystals of pyrite (white) were not rotated or fractured but formed across the cleavage by replacement.

Covellite (mottled lighter and darker grey) which occurs in parts of the slate and in and around the fractures in the magnetite, is a secondary sulphide impregnation.

450 foot level, Noble's Nob Mine.



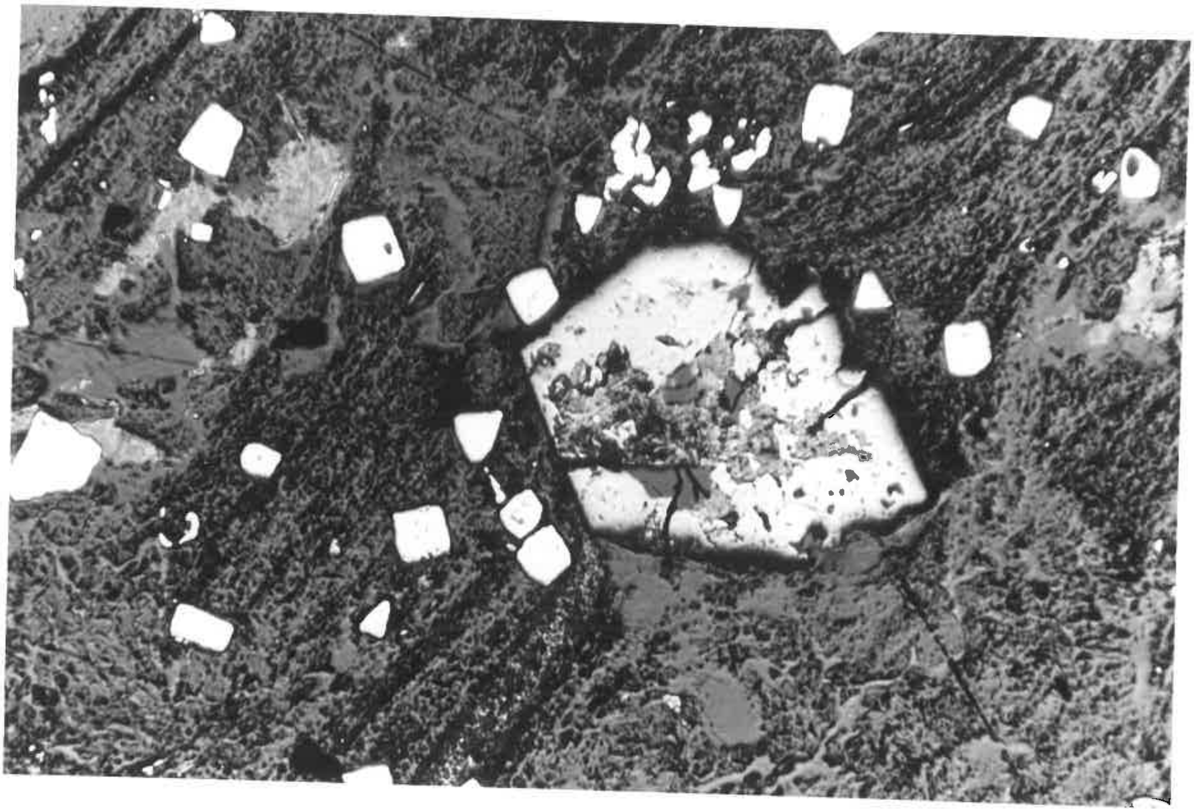


Fig. 75.

Gold ore.

polished section x 330.

The section shows hematite (grey) of probable supergene origin, moulded upon martitised magnetite (cross hatched structure). The martite is enclosed in fine grained hydromica aggregate (dark grey).

135 foot level, Outlaw West Mine.

Fig. 76.

Gold ore.

polished section x 110.

The typical habit of gold is illustrated by this section in which gold and hydromicas fill the open spaces in a lattice-like structure formed by intersecting specularite prisms.

Gold (white). Specularite (medium grey).

Hydromicas (dark grey). Open spaces (black).

Eldorado Mine.

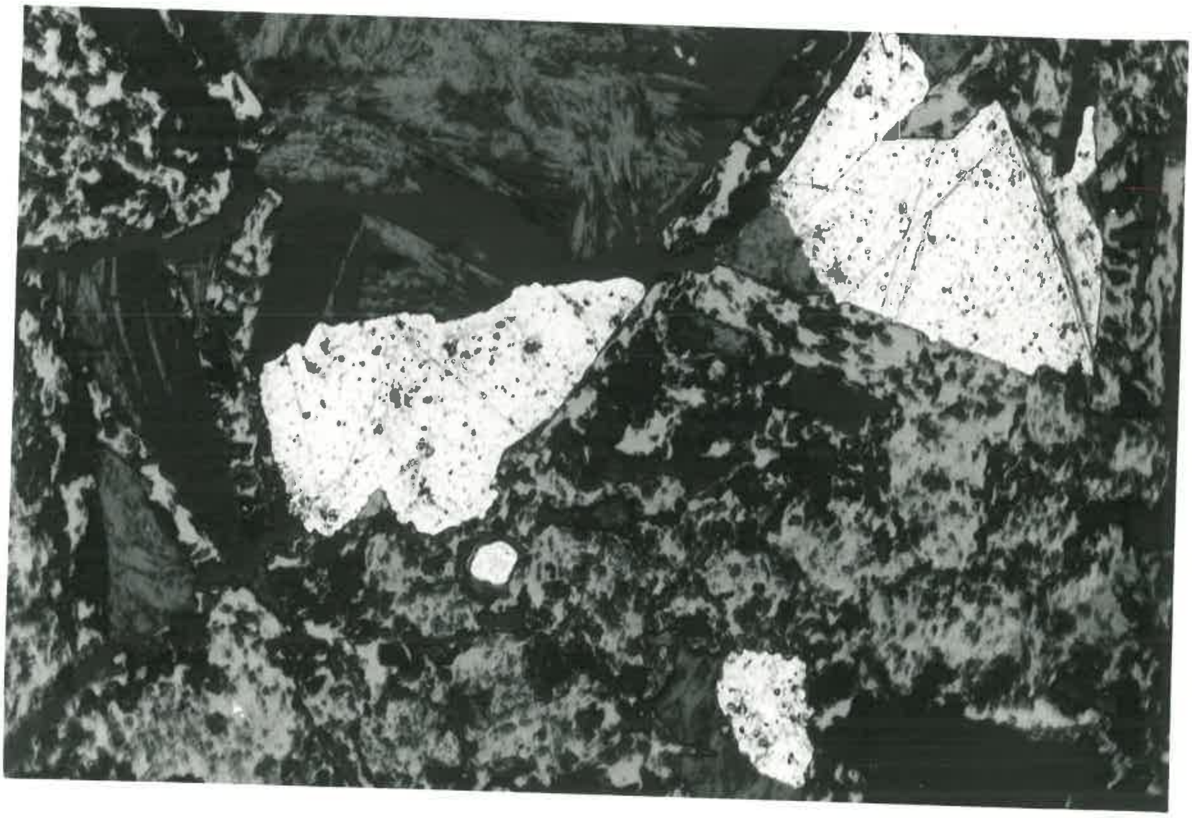
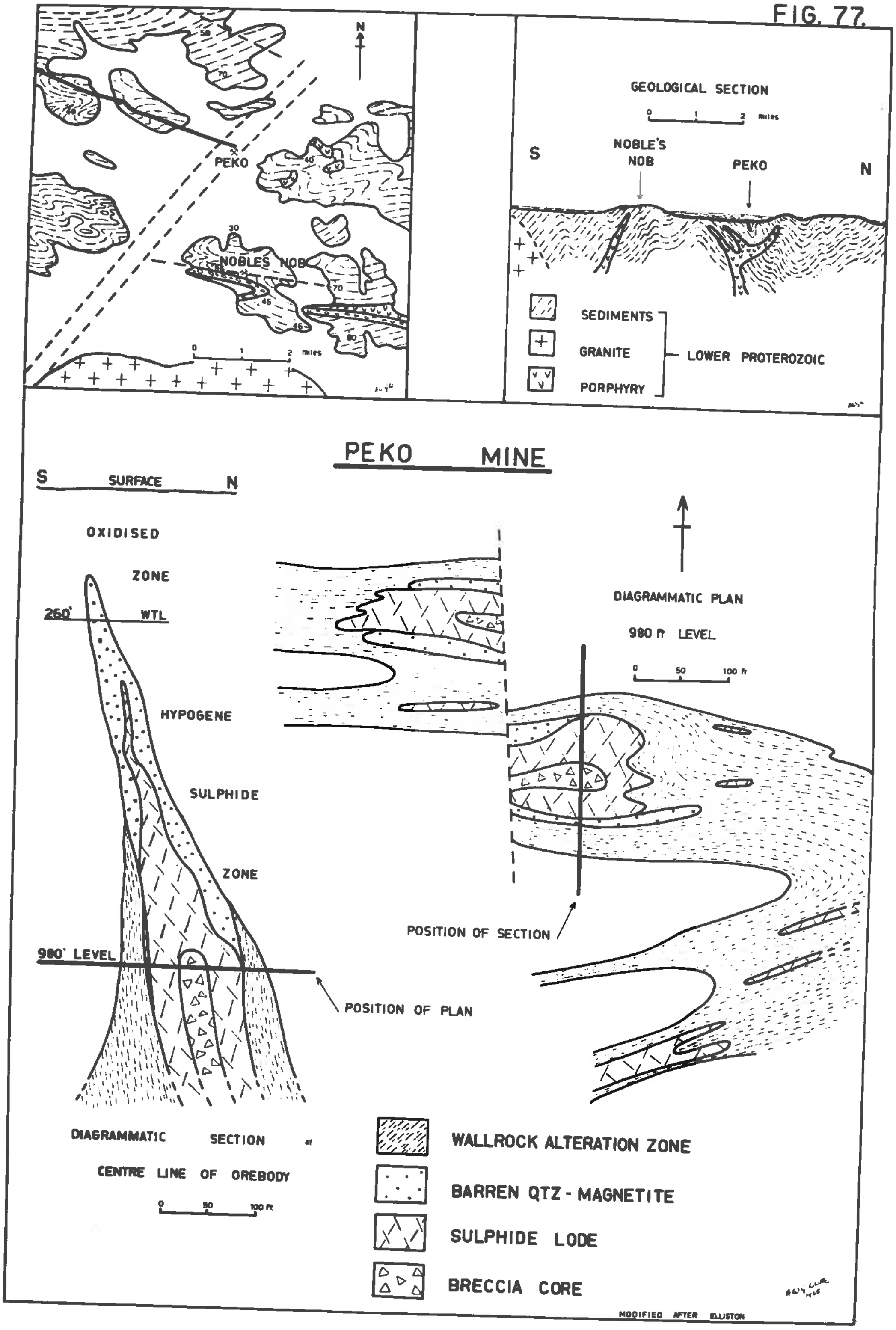


FIG. 77.



PEKO
NOBLES NOB
0 1 2 miles
GEOLOGICAL SECTION
0 1 2 miles
S
NOBLE'S NOB
PEKO
N
SEDIMENTS
GRANITE
PORPHYRY
LOWER PROTEROZOIC
PEKO MINE
S SURFACE N
OXIDISED ZONE
260' WTL
HYPOGENE SULPHIDE ZONE
980' LEVEL
POSITION OF PLAN
DIAGRAMMATIC SECTION at CENTRE LINE OF OREBODY
0 50 100 ft
DIAGRAMMATIC PLAN
980 ft LEVEL
0 50 100 ft
POSITION OF SECTION
WALLROCK ALTERATION ZONE
BARREN QTZ - MAGNETITE
SULPHIDE LODE
BRECCIA CORE
MODIFIED AFTER ELLISTON

Fig. 78.

Country rock.

thin section x 70.

Country rock near the Main Shaft recrystallised to fissile chlorite schist. Recrystallised chlorite and quartz formed parallel growths in stress shadows behind the faces of clastic magnetite crystals and fragments.

1130 foot level, Peko Mine.

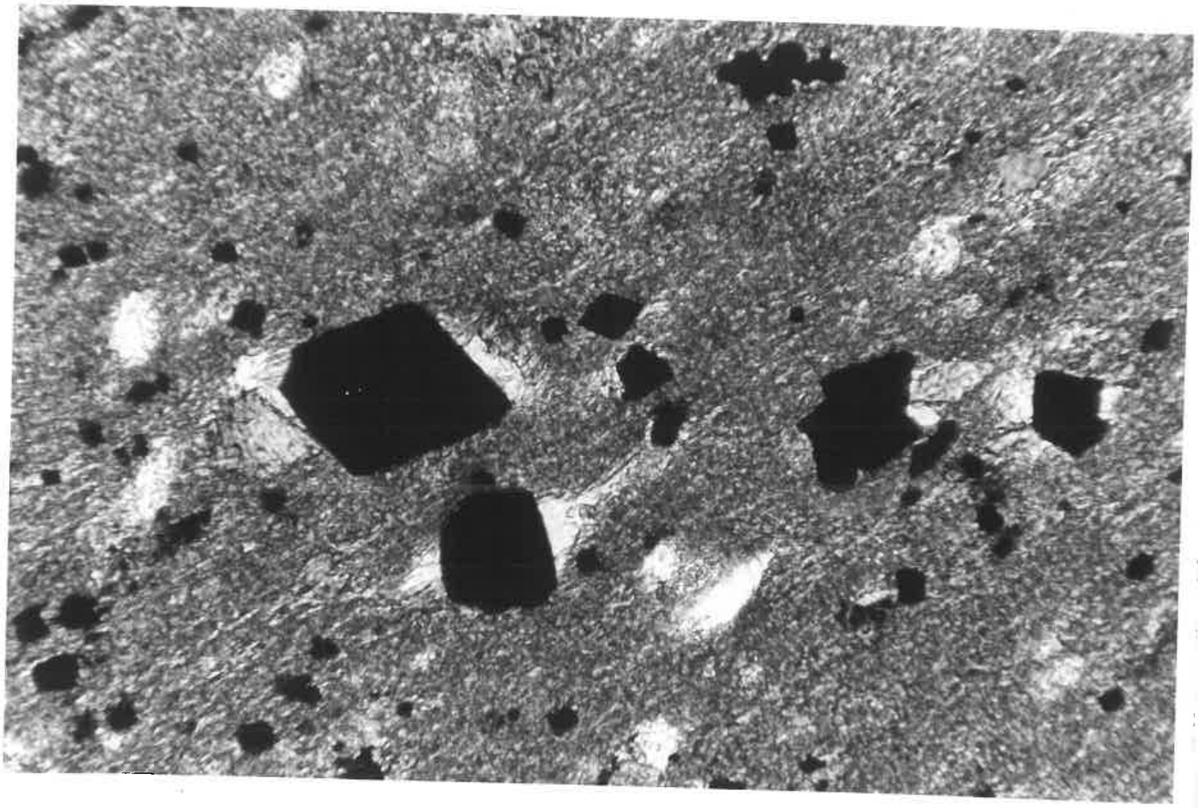
Fig. 79.

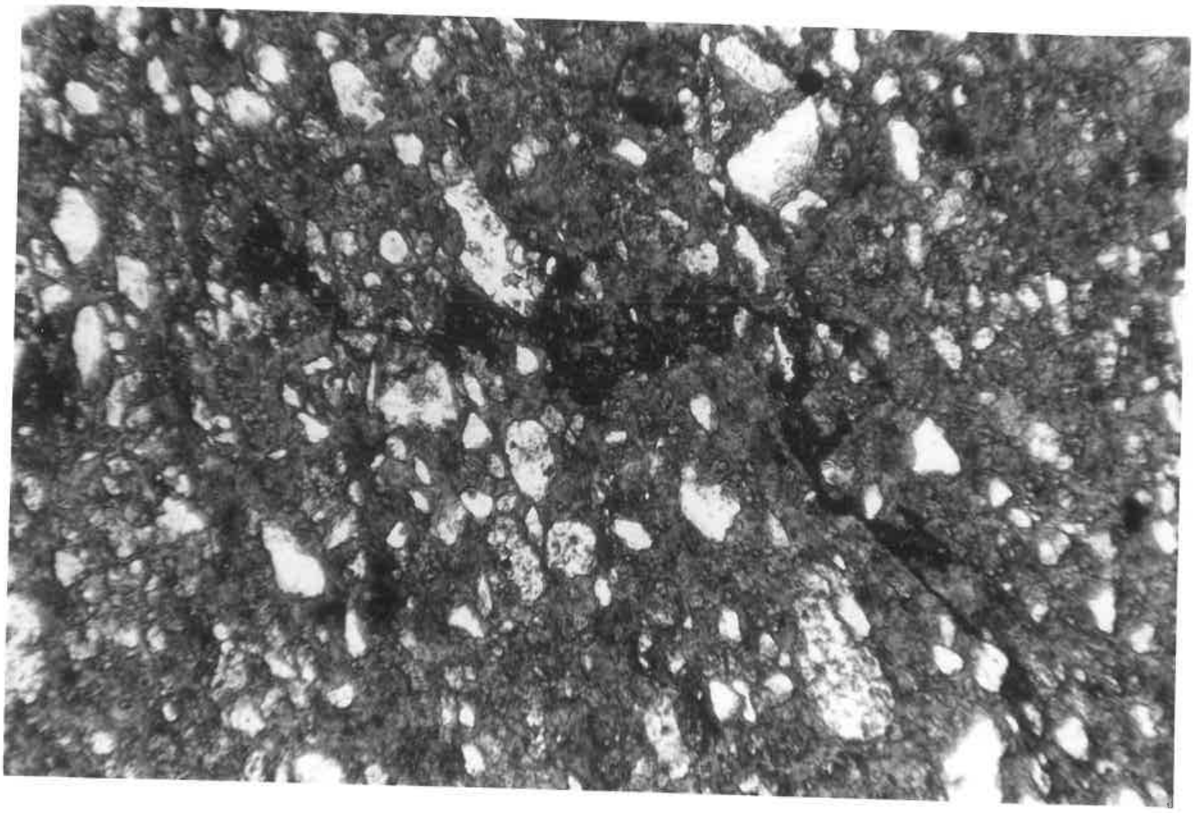
Country rock.

thin section x 70.

Hanging wall tuffaceous sandstone in which the entire matrix was converted to chlorite while detrital quartz and rock fragments remained unaltered. The dark coloured veinlet is ankerite.

400 foot level, Peko Mine.





Figs. 80-83.

Wall rock alteration.

thin section x 35.

This series of four photomicrographs was taken from samples in the zone of talc-anthophyllite wall rock alteration. They illustrate the progressive formation of magnetite euhedra from fine grained magnetite granules which separated from chlorite during its conversion to anthophyllite and talc.

The initial linkage of granules into ring-like structures, was followed by the progressive segregation into clusters to form approximate isometric outlines, and finally into isometric crystals.

Magnetite (black), talc-anthophyllite (grey).

980 foot level, Peko Mine.

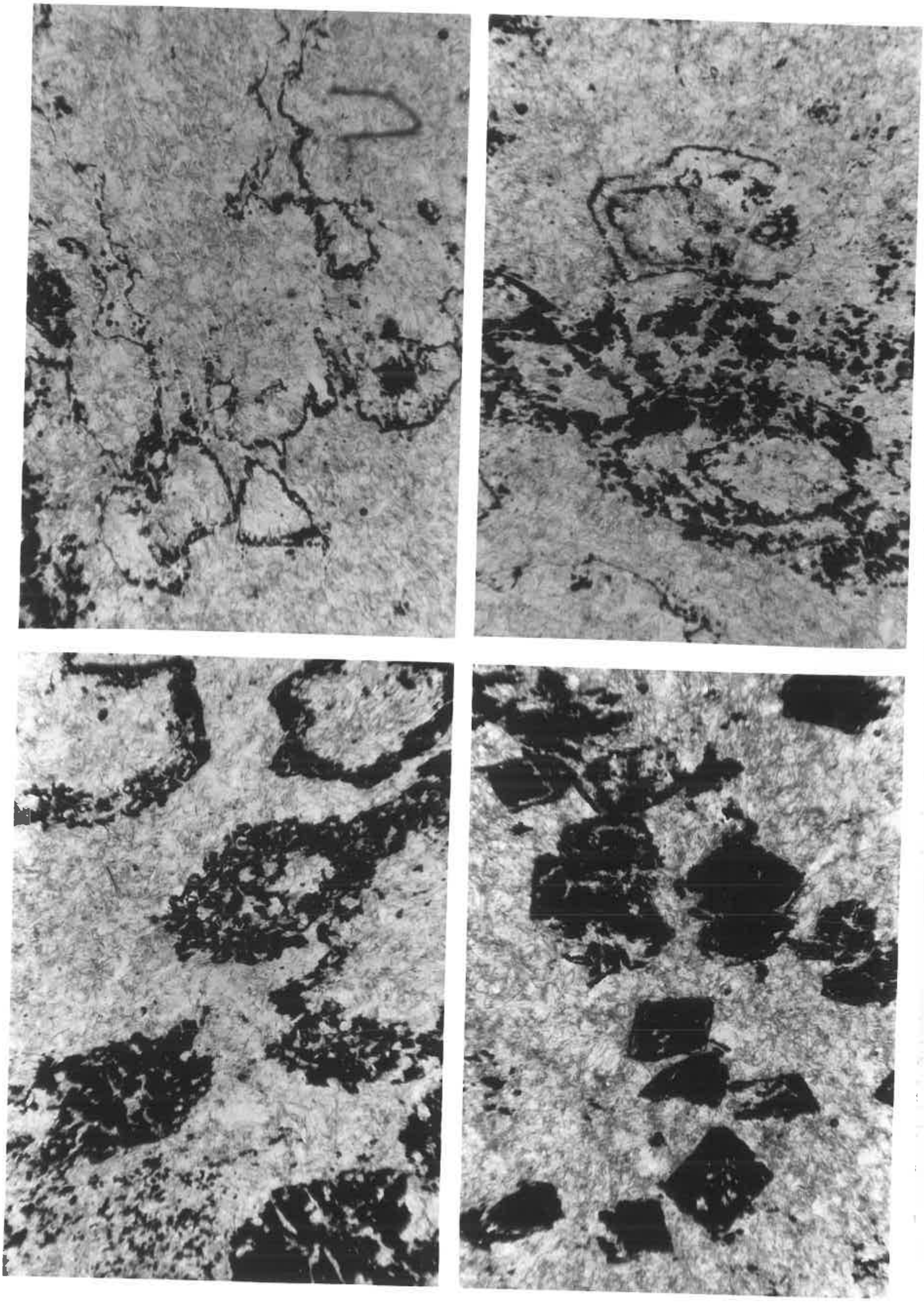


Fig. 84.

Peko ore.

polished section x 110.

Unreplaced needles of anthophyllite contained in sulphides and quartz in ore near its contact with wall rock (compare section below).

Components are:-

quartz and anthophyllite, (dark grey).

magnetite, (medium grey).

galena and chalcopyrite, (light grey).

pyrite euhedra, (white).

980 foot level, Peko Mine.

Fig. 85.

Wall rock alteration.

thin section x 70.

Advanced wall rock alteration which exists at the contact of the orebody. The wall rock on the left consists of talc and anthophyllite crowded with fine grained magnetite and sulphides (black). On the right, radial clusters of fibrous anthophyllite are dispersed through the aggregate of quartz gangue, (white) and ore, (black).

980 foot level, Peko Mine.

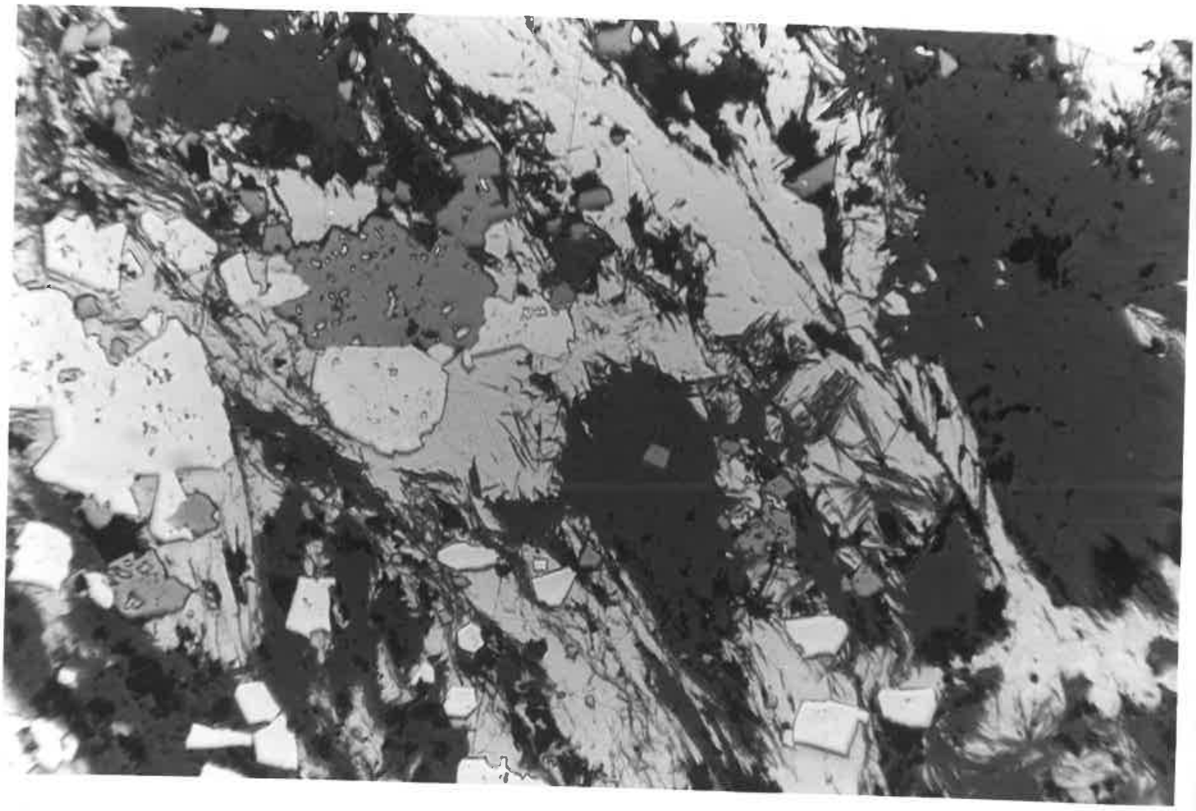


Fig. 86.

Wall rock alteration.

thin section x 70.

This section of the contact of a chalcopyrite vein (Cu - centre of photo), against chloritic argillaceous siltstone (C.S. - left hand side), and against magnetite-chlorite rock (M and C - right hand side), shows contact alteration phenomena. The vein contact against the siltstone is marked by the progressive loss of interstitial clay from the siltstone (C.S. - mottled dark grey portion) and by the growth of abundant chlorite against the vein (C.Z. - light grey area). On the right hand side of the vein is a narrow zone of red-green biotite (or phlogopite) and zircon (B.Z.) which separates the chalcopyrite from the quartz-magnetite.

Peko Mine.

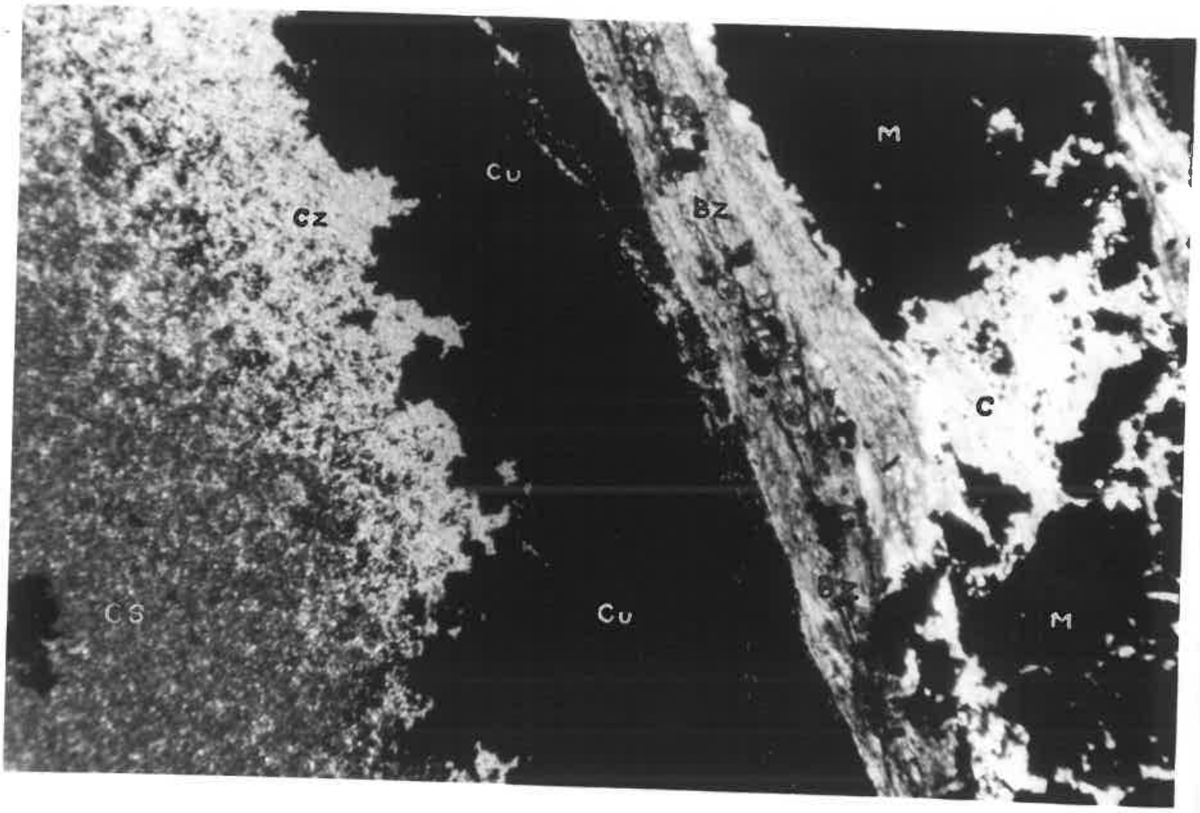
Fig. 87.

Wall rock alteration.

thin section x 70.

This section of magnetite-talc-anthophyllite rock in the contact zone illustrates the attenuation of large magnetites (M - black) which are sited mainly in the areas of anthophyllite (A - lighter grey). The talcose areas (T - darker grey) form separate bands in the rock.

Peko Mine.


Cz
Cu
BZ
M
C
CS
Cu
BZ
M

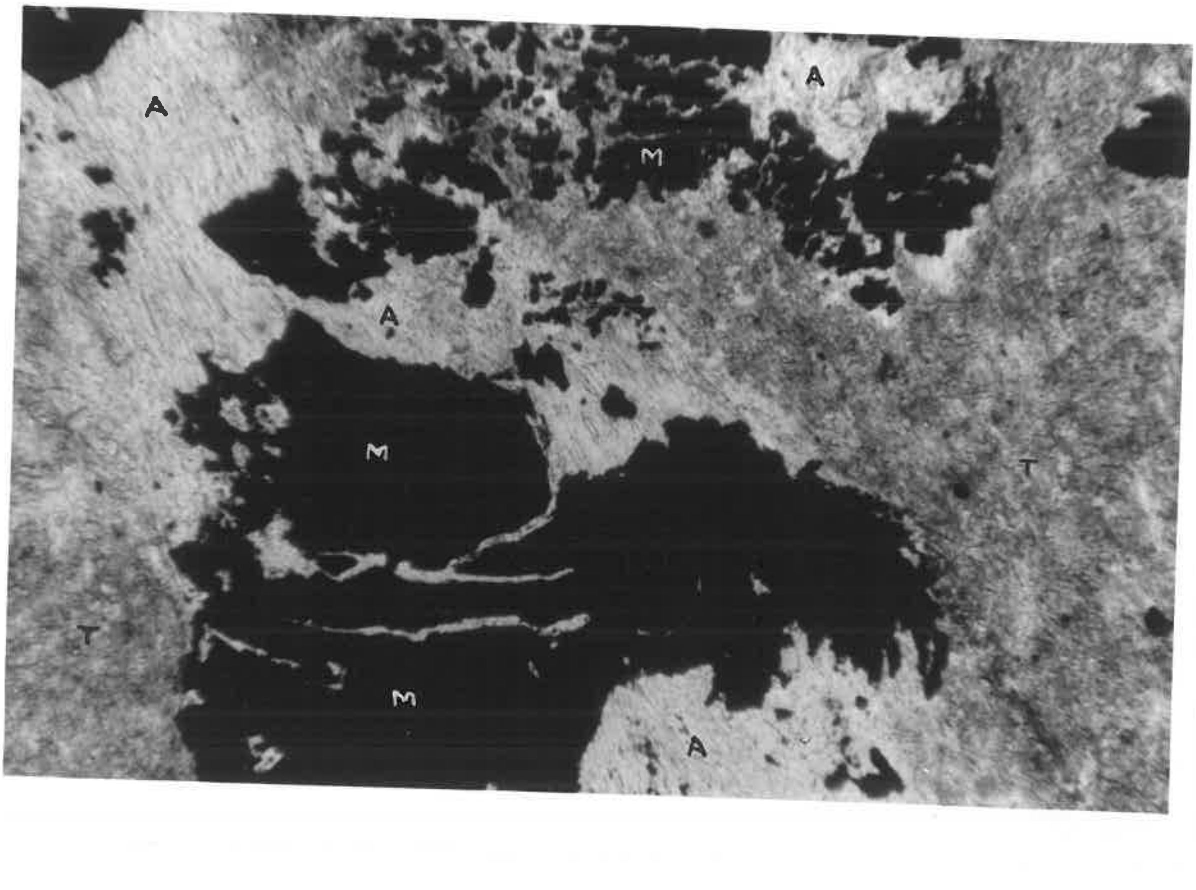

A
A
M
A
M
T
T
M
A

Fig. 88.

Wall rock alteration.

thin section x 70.

Pneumatolytic wall rock alteration which exists close to the ore-body contact. Pyrite, P (black), is intergrown with chlorite and anthophyllite (light coloured) and with tourmaline (light grey, marked T) and with columnar aggregates of orthite (dark grey, marked O).

1130 foot level, Peko Mine.

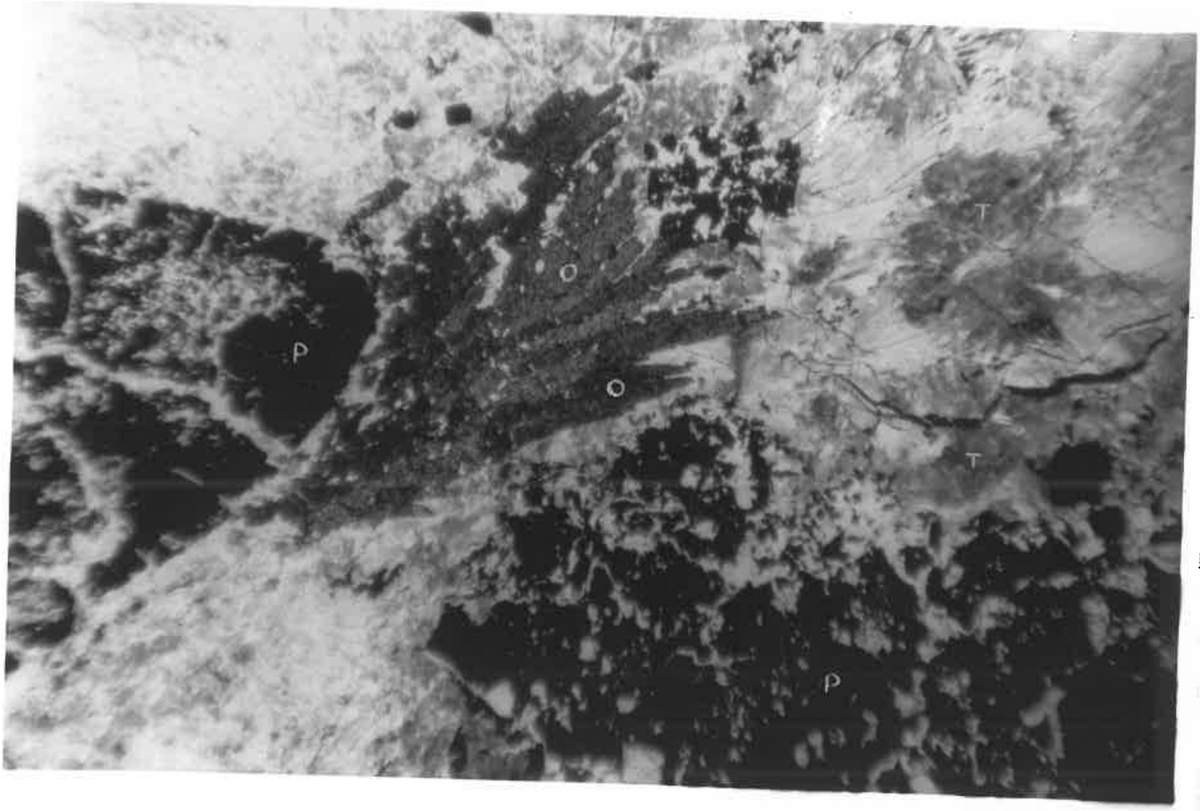
Fig. 89.

Wall rock alteration.

thin section x 70.

Fine grained silica aggregates, typical of jasperised country rock, irregularly replaced by coarse grained epigenetic quartz, (light grey) and by magnetite, (black). The irregular veins and aggregates of quartz and magnetite emerge from an inner envelope zone which encloses the sulphide core of the lode structure.

680 foot level, Peko Mine.


O
O
P
P
T
T

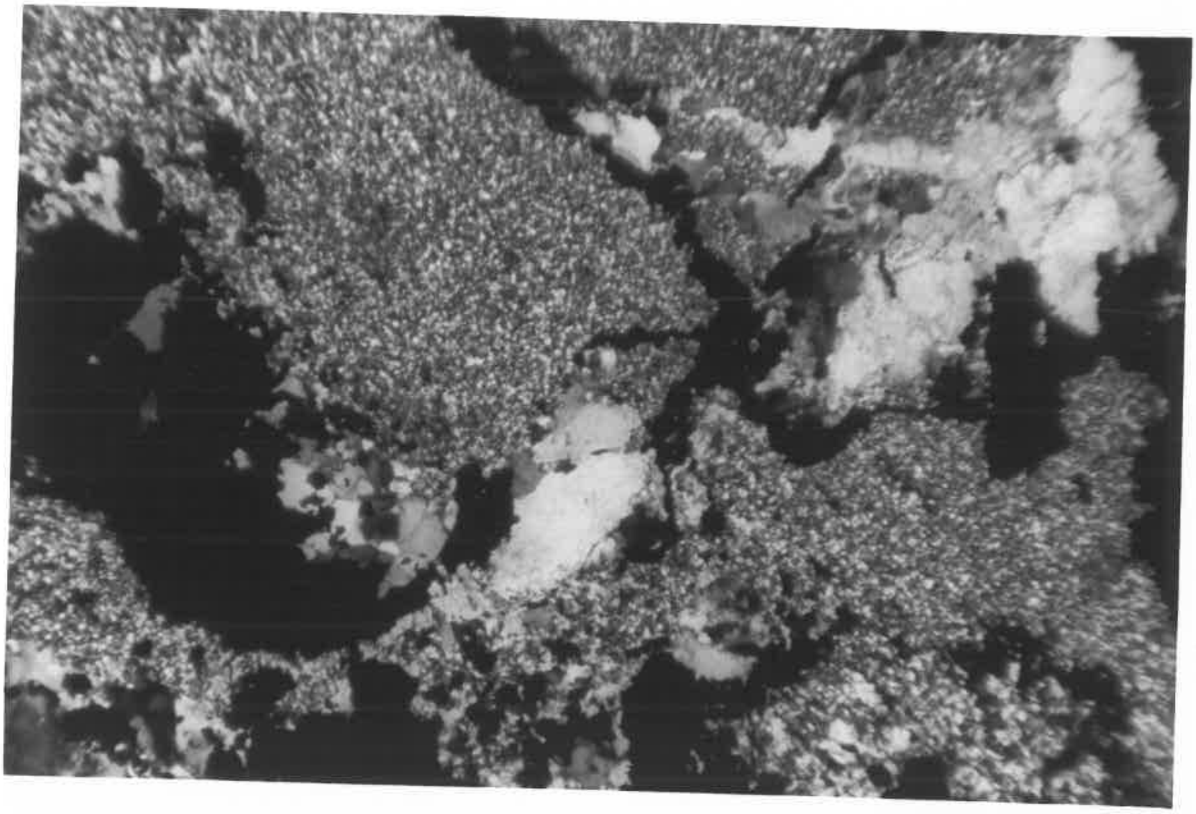


Fig. 90.

Oxidised ore.

polished section x 330.

An aggregate of isometric euhedra of cuprite, (light grey) and siderite, (dark grey) which occupies open spaces formed through the leaching of quartz and magnetite. Native copper (bright white) is contained in the cuprite.

No. 2 level, Peko Mine.

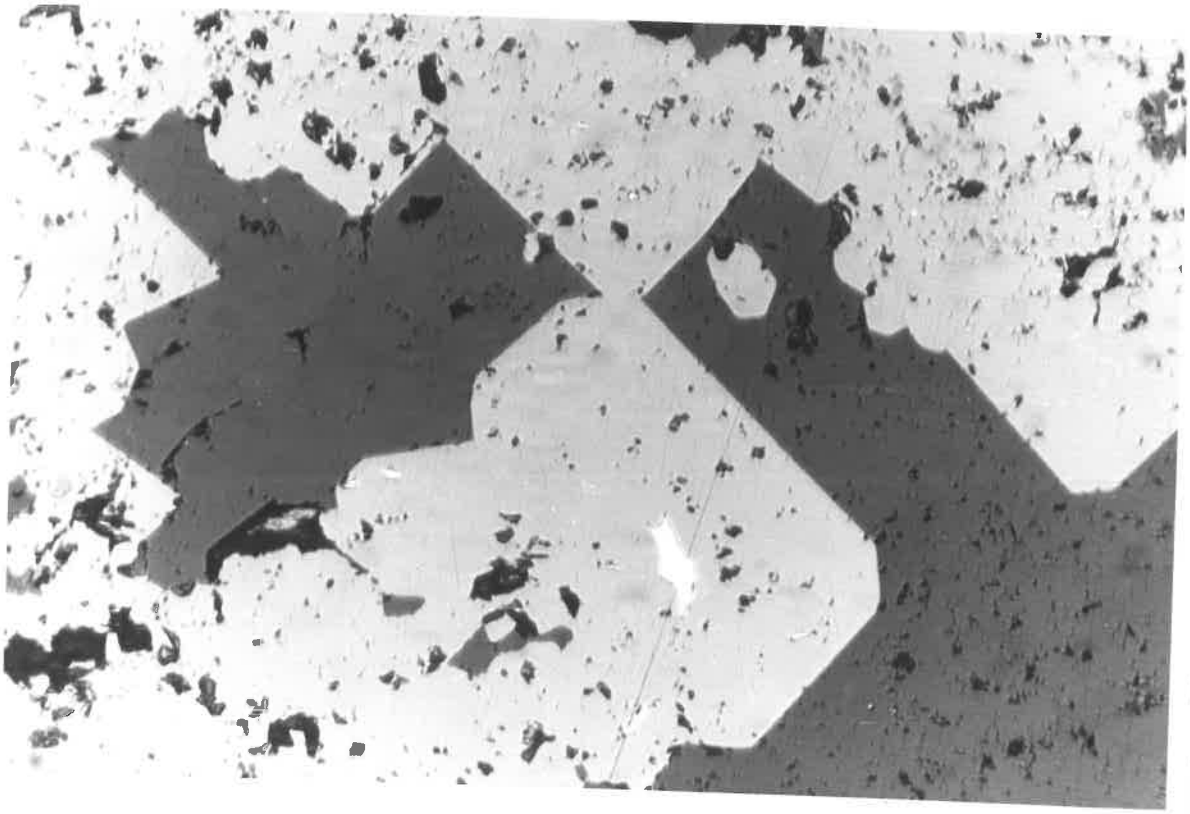
Fig. 91.

Secondary sulphides.

polished section x 330.

Chalcopyrite, C, extensively replaced by chalcocite, CH; and pyrrhotite completely transformed to colloform melnikovite-type pyrite, M; and magnetite almost completely replaced by siderite, S. Small portions of magnetite, (light grey) remain amongst the siderite.

No. 3 level, Peko Mine.



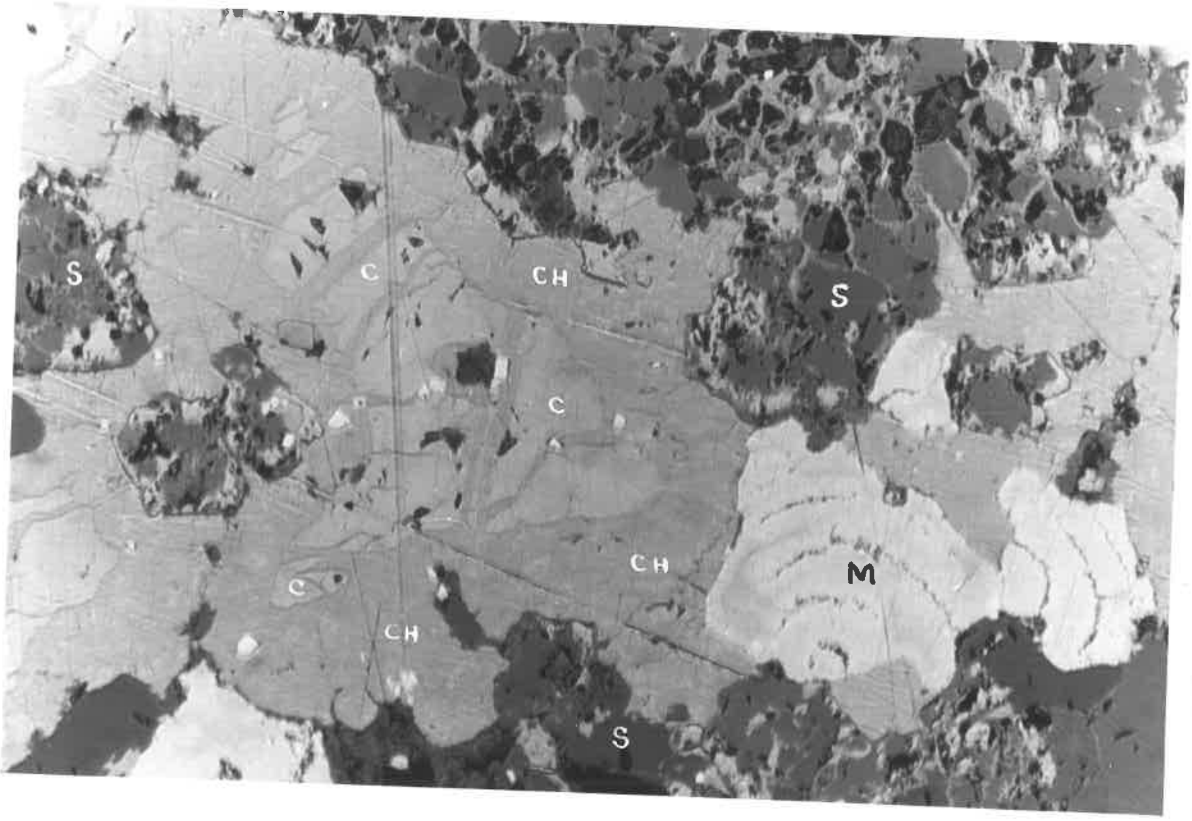

S
C
CH
S
C
CH
M
C
CH
S

Fig. 92.

Peko ore.

polished section x 330.

Banded copper ore in which there was preferential replacement of silicates by chalcopyrite. Magnetite (dark grey), contains little chalcopyrite, while pyrite (white), was replaced mainly along the boundaries of its crystal aggregates. The bands composed mainly of anthophyllite (black), and very little magnetite (dark grey), were extensively replaced by chalcopyrite (light grey).

680 foot level, Peko Mine.

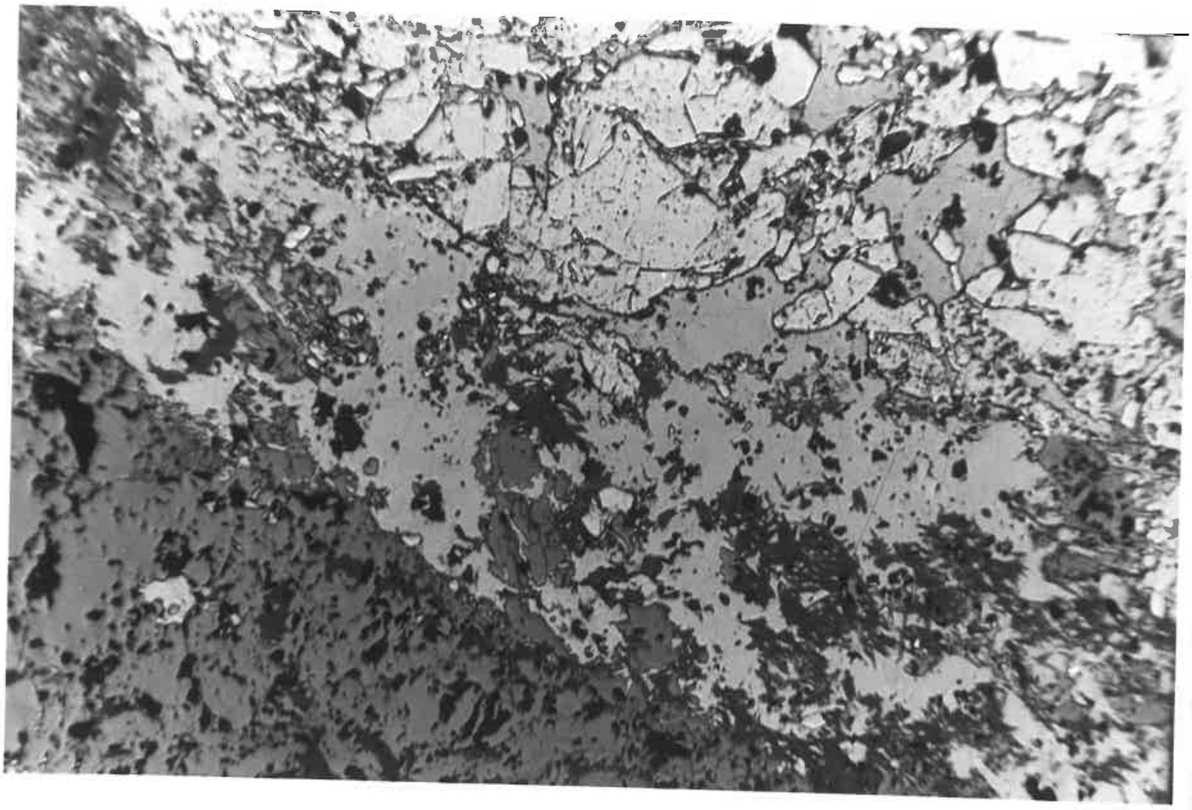
Fig. 93.

Peko ore.

polished section x 330.

Lode rock composed of magnetite, quartz and chlorite (medium, dark grey and black respectively), replaced by sulphides (light coloured), which followed fractures in the lode rock. Pyrrhotite-chalcopyrite veins (oriented SW-NE), were offset by micro-faults oriented SE-NW. Subsequently galena (white), and quartz (dark grey), entered along the microfaults.

680 foot level, Peko Mine.



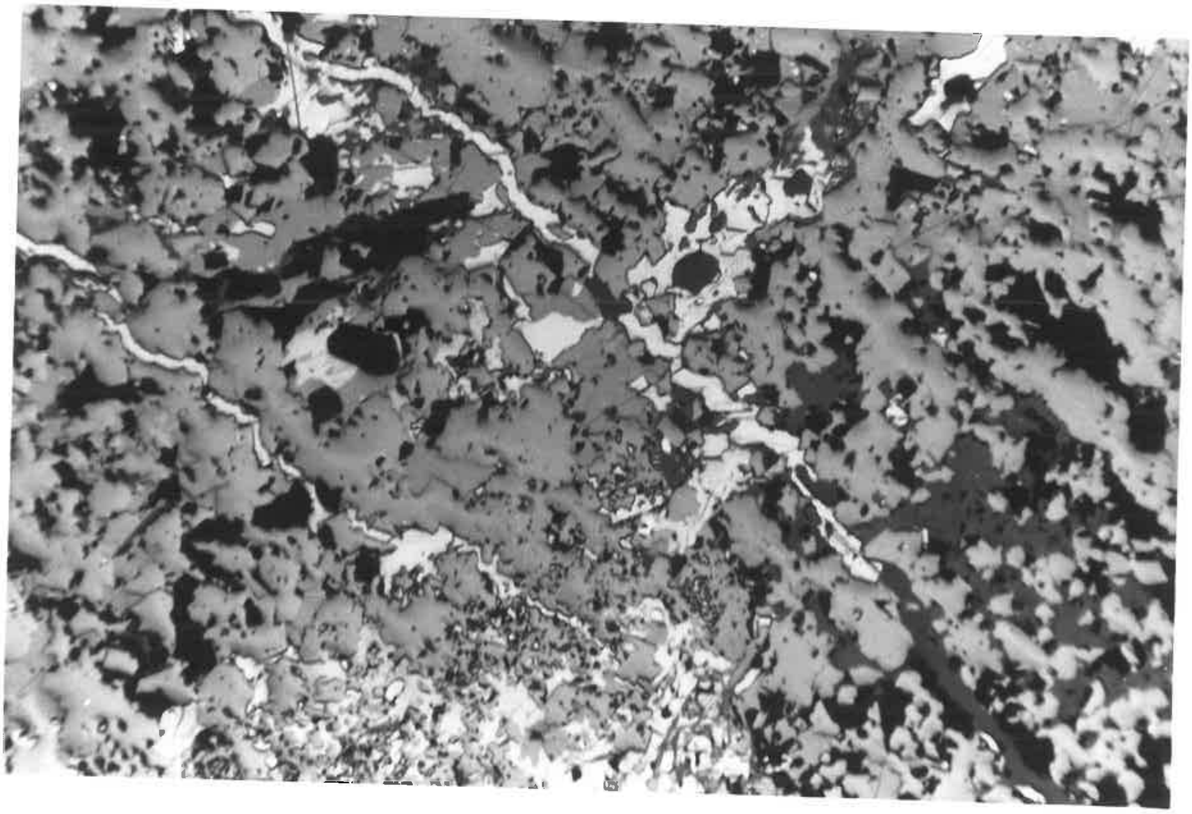


Fig. 94.

Peko ore.

polished section x 330.

The lead-rich footwall section of orebody in which there was the replacement of pyrite (white) by galena (light grey); and of magnetite rock (medium grey) by ankerite (dark grey). The replacement of pyrite was controlled by its crystallographic planes; and of magnetite by its irregular fractures.

680 foot level, Peko Mine.

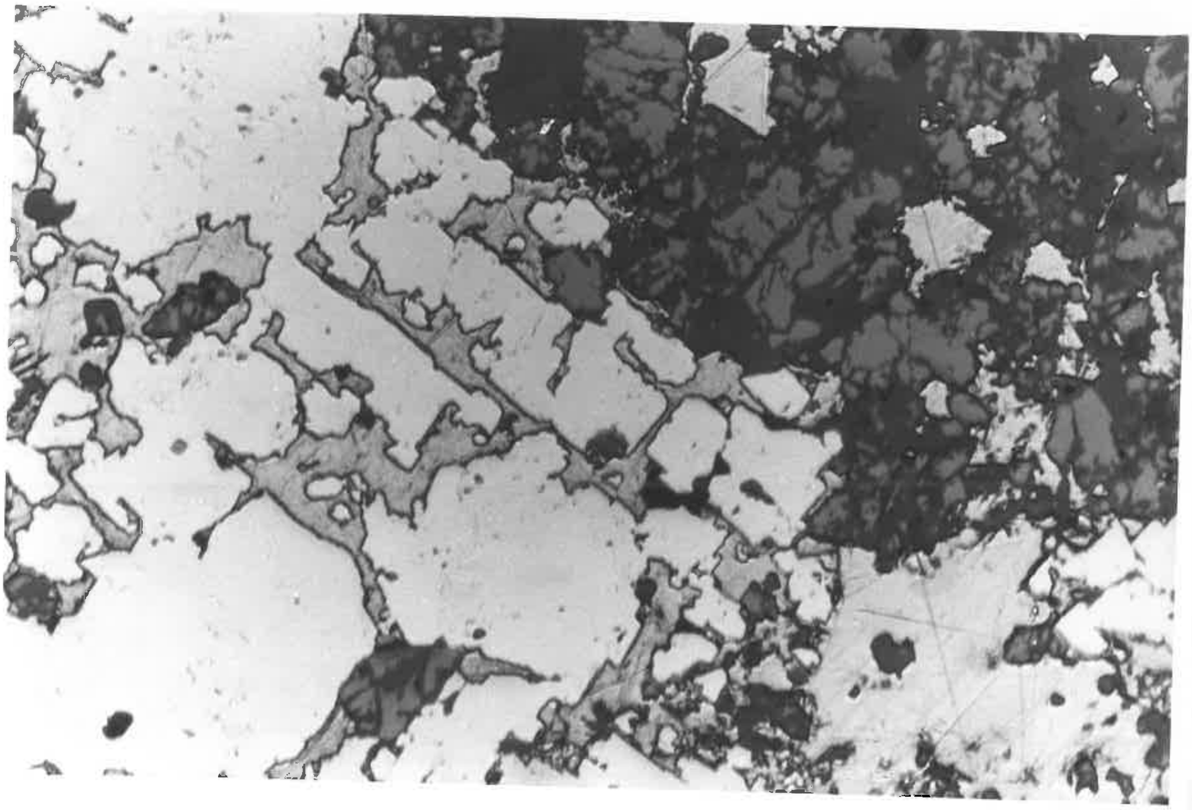
Fig. 95.

Peko ore.

polished section x 70.

A composite vein of pyrite (white with dusty inclusions), galena (light grey), and ankerite (very dark grey), which transects rock composed of magnetite (medium grey) and of pyrite (white without inclusions). Some of the galena and ankerite penetrated beyond the vein into the enclosing magnetite-pyrite rock. The vein pyrite (with inclusions) intersects the earlier-formed clear pyrite associated with magnetite.

680 foot level, Peko Mine.



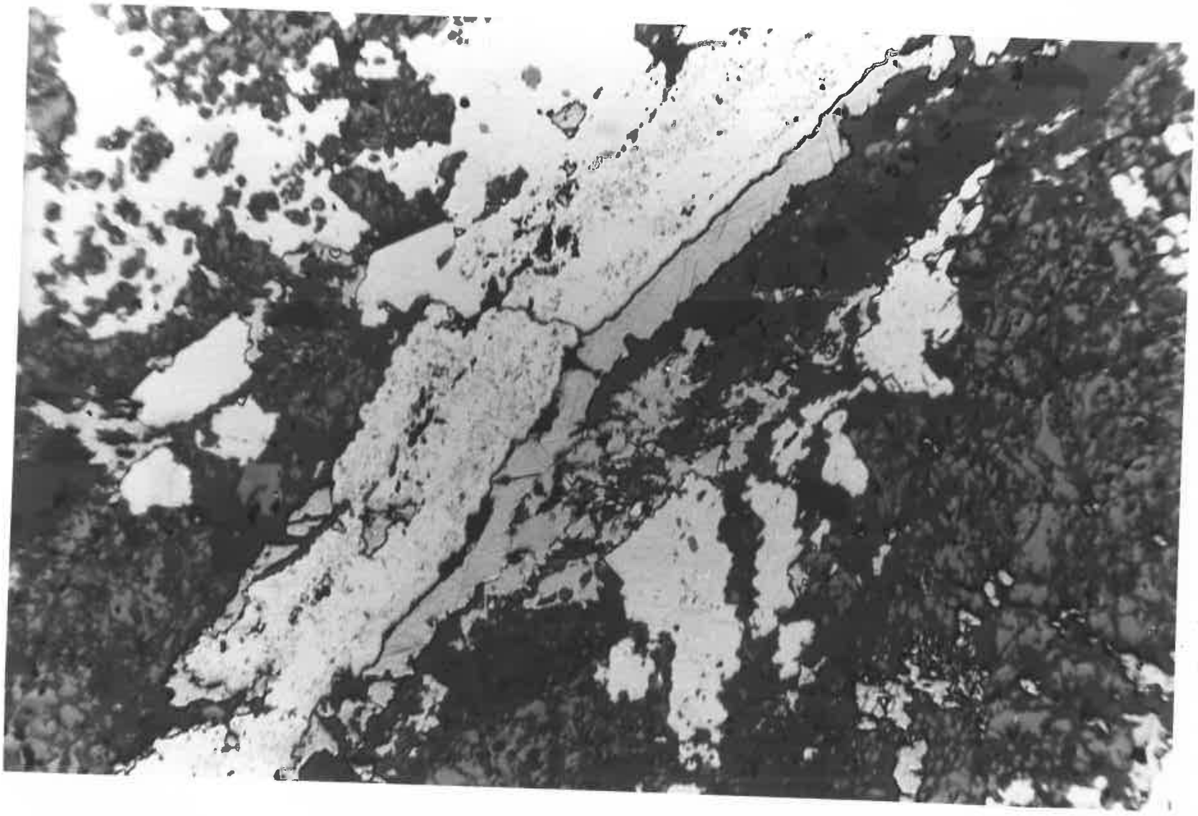


Fig. 96.

Peko ore.

polished section x 70.

The lattice texture of massive magnetite which resulted from the grouping of magnetite granules into intersecting columnar aggregates. Black areas in lattice structure are residuals of unreplaced country rock silicates, mainly chlorite. The light grey areas are chalcopyrite which replaced some of the silicate amongst the magnetite.

830 foot level, Peko Mine.

Fig. 97.

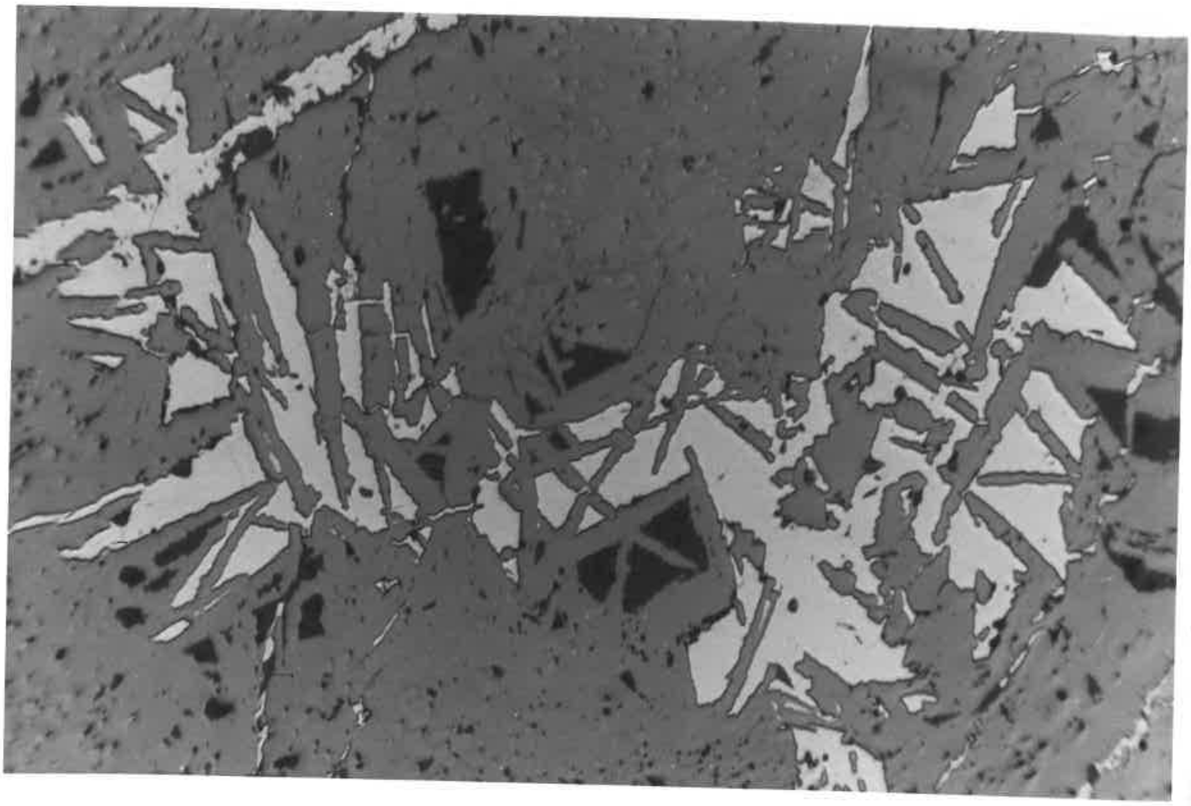
Peko ore.

polished section x 220.

Pneumatolytic wall rock alteration associated with sulphide mineralisation.

Tourmaline (medium grey tapering prisms) and chalcopyrite (white), emplaced among quartz (darker grey) and chlorite (black).

830 foot level, Peko Mine.



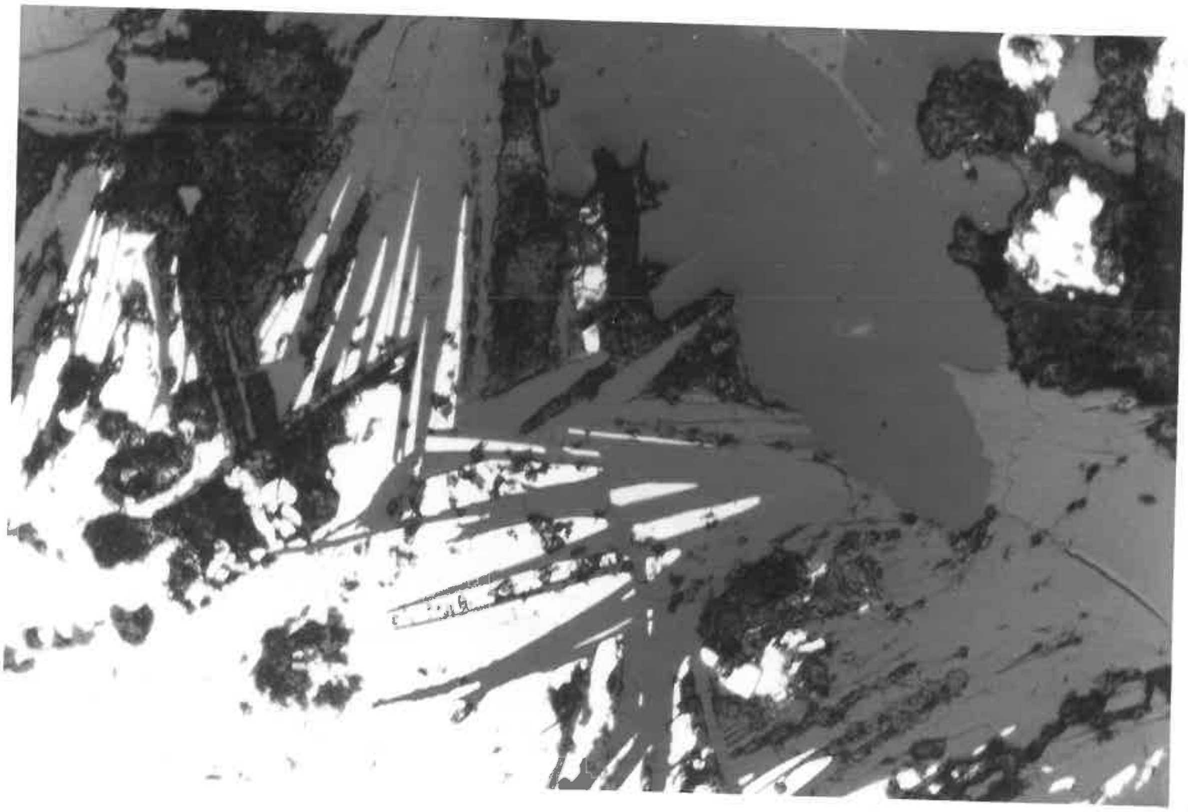


Fig. 98.

Peko ore.

thin section x 200.

The graphic intergrowth of quartz (light grey) and magnetite (black) which is common in areas of brecciation. The particles of magnetite tend to form into aggregates with a general idiomorphic outline. The quartz, when examined under crossed nicols, consists of euhedral individuals continuous over wide areas and including much magnetite.

980 foot level, Peko Mine.

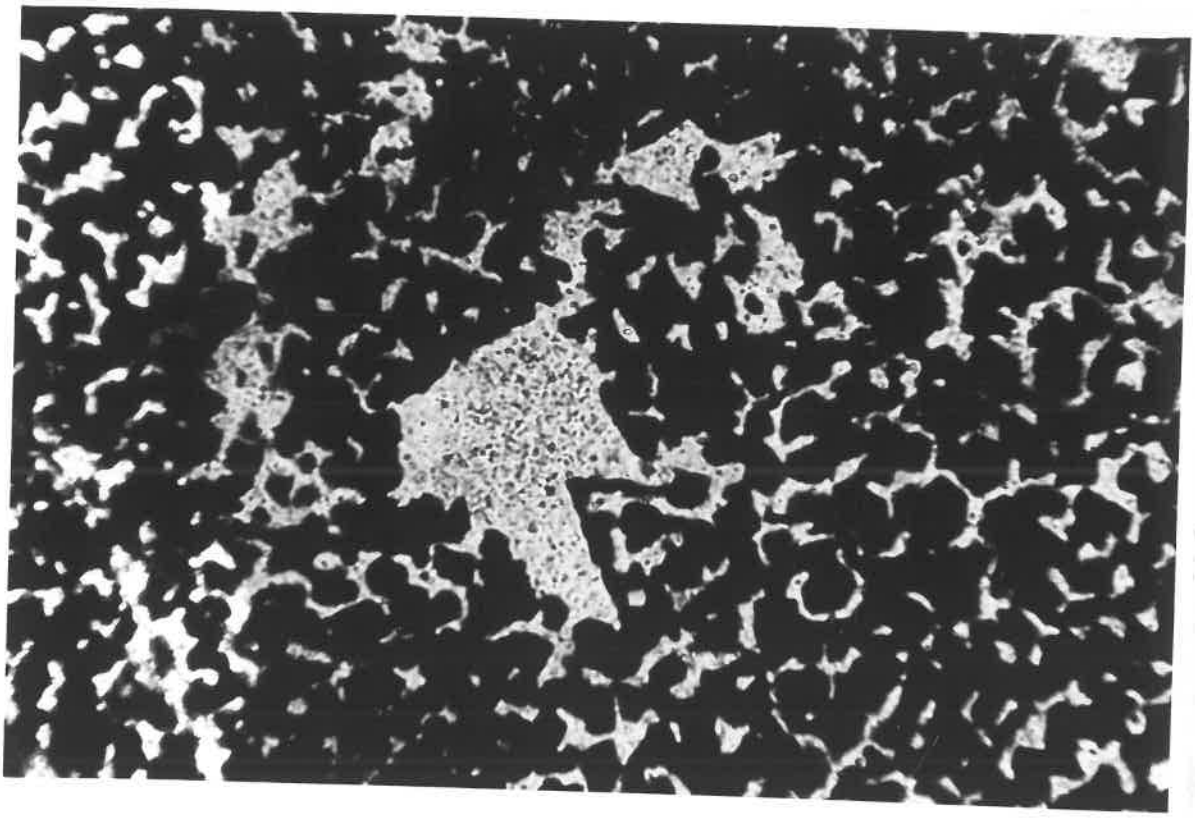
Fig. 99.

Peko ore.

polished section x 110.

A satellitic ore shoot in the wall rock zone which exhibits a contrast with the main lode ore in respect to texture and mineralogy. Galena and chalcopyrite (indistinguishable in light greys), have replaced in pseudomorph the structure of anthophyllite schist some of which remains (oriented dark grey material). Slightly embayed pyrite euhedra (white) and magnetite (medium grey), both originally components of the anthophyllite rock, persist in lead-copper sulphides.

980 foot level, Peko Mine.



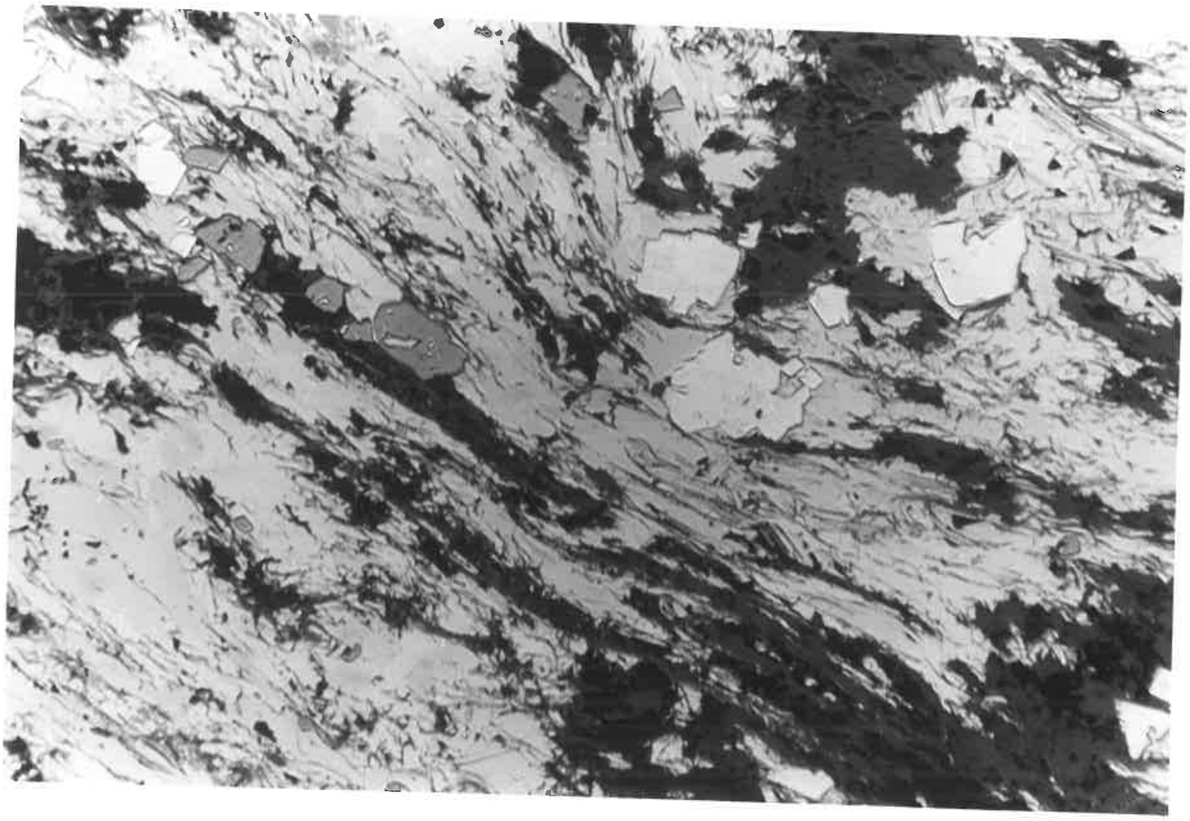


Fig. 100.

Peko ore.

polished section x 250 - oil immersion.

A section from the zone of lead mineralisation in which marcasite (white), replaced magnetite (dark grey) and chlorite (black). The forms of the chlorite-filled fractures in the magnetite were preserved in the marcasite. Galena (light grey) of later generation entered these fractures.

980 foot level, Peko Mine.

Fig. 101.

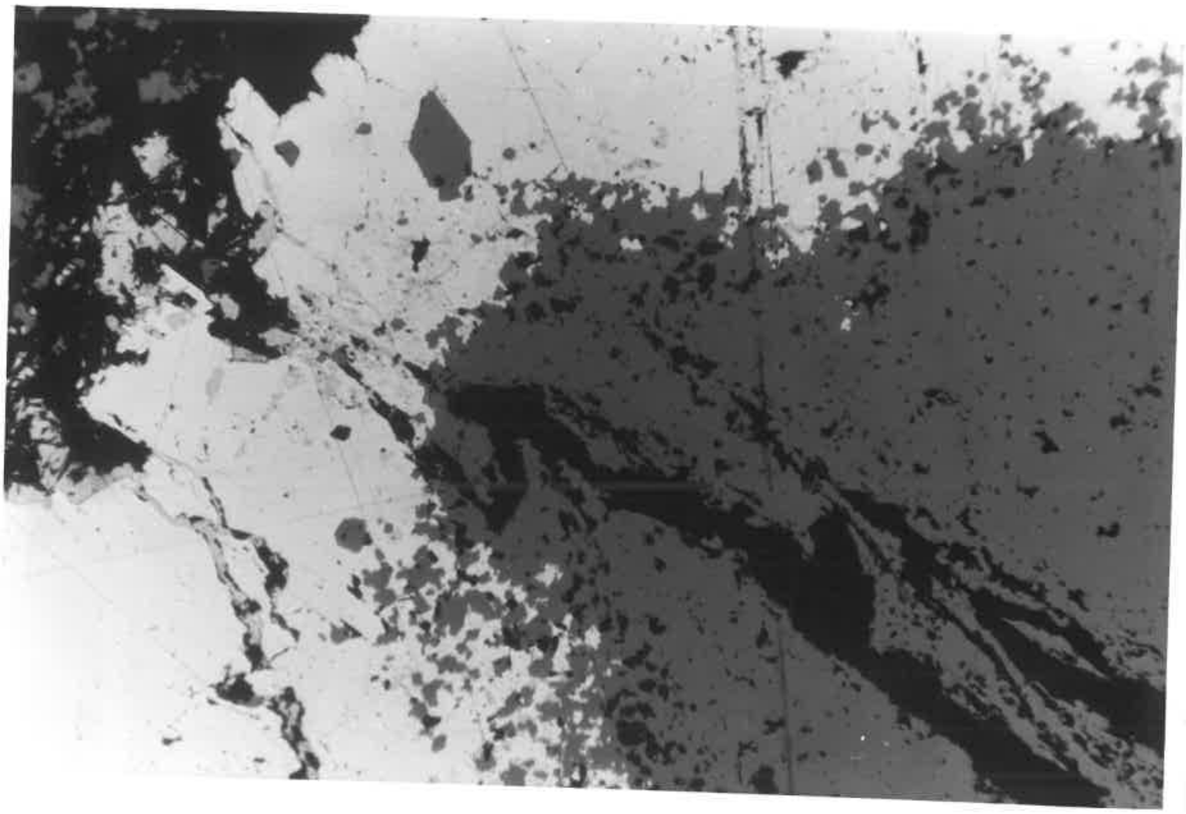
Peko ore.

polished section x 330.

A section from the zone of lead mineralisation in which coarse grained euhedral arsenopyrite (white), replaced pre-existent magnetite (medium grey), and quartz-chlorite rock (darker grey and black material).

Later galena (light grey) replaced the remaining quartz-chlorite rock and slightly embayed the edges of arsenopyrite.

980 foot level, Peko Mine.



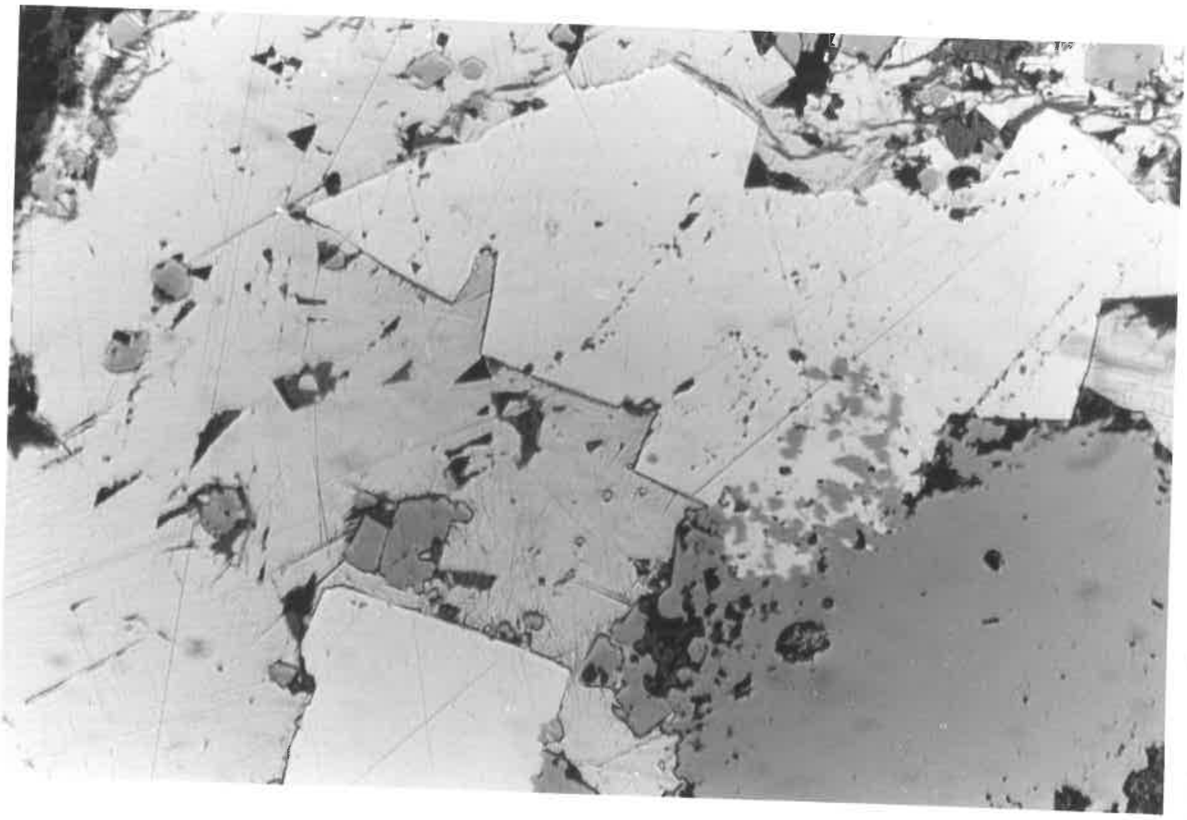


Fig. 102.

Peko ore.

polished section x 330.

Small gold particles (white), contained mainly in bismuthinite (medium grey, low relief) and partly in chalcopyrite (lighter grey, higher relief). The black areas are silicates.

980 foot level, Peko Mine.

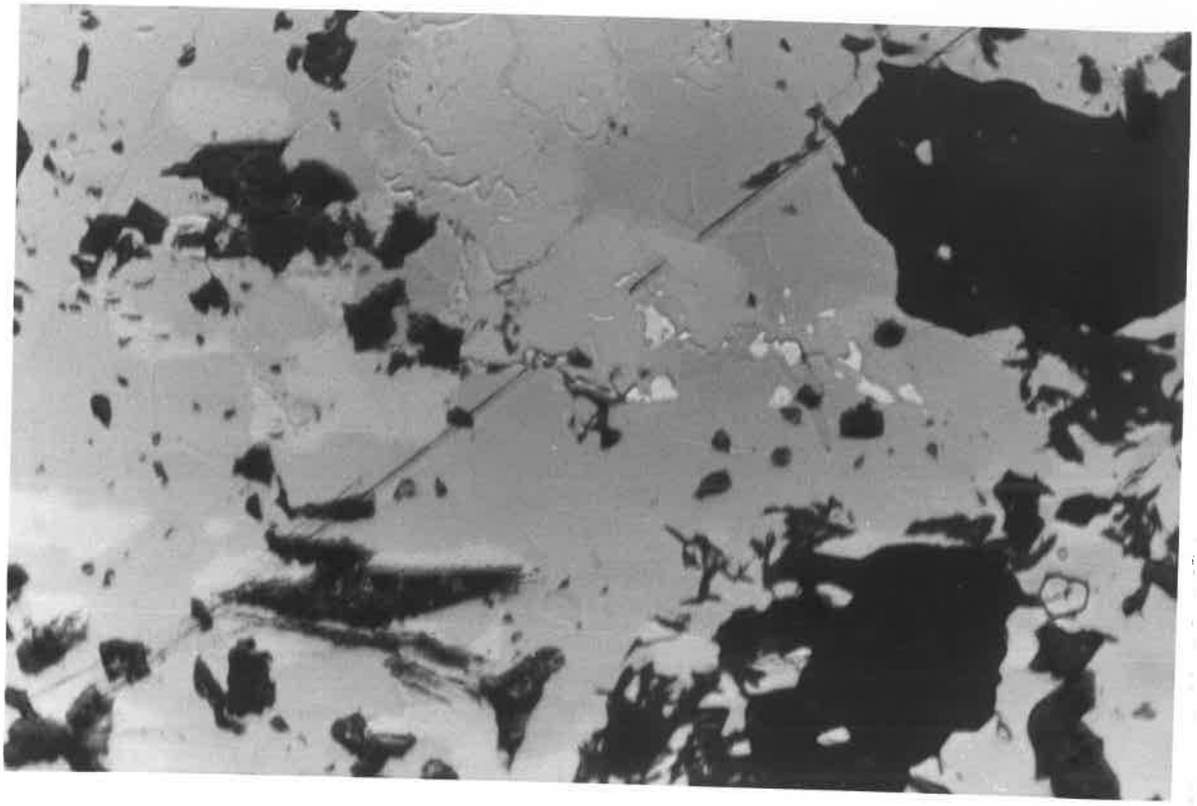
Fig. 103.

Peko ore.

polished section x 330.

Ring-like cobaltite relicts contained in chalcopyrite (light grey) which replaced quartz (black), and magnetite (dark grey). The concentric zoned texture in some magnetites, and the presence of shells of cobaltite among quartz and magnetite, suggest that cobaltite may have been intergrown with, or replaced by magnetite and quartz, prior to the entry of chalcopyrite.

980 foot level, Peko Mine.



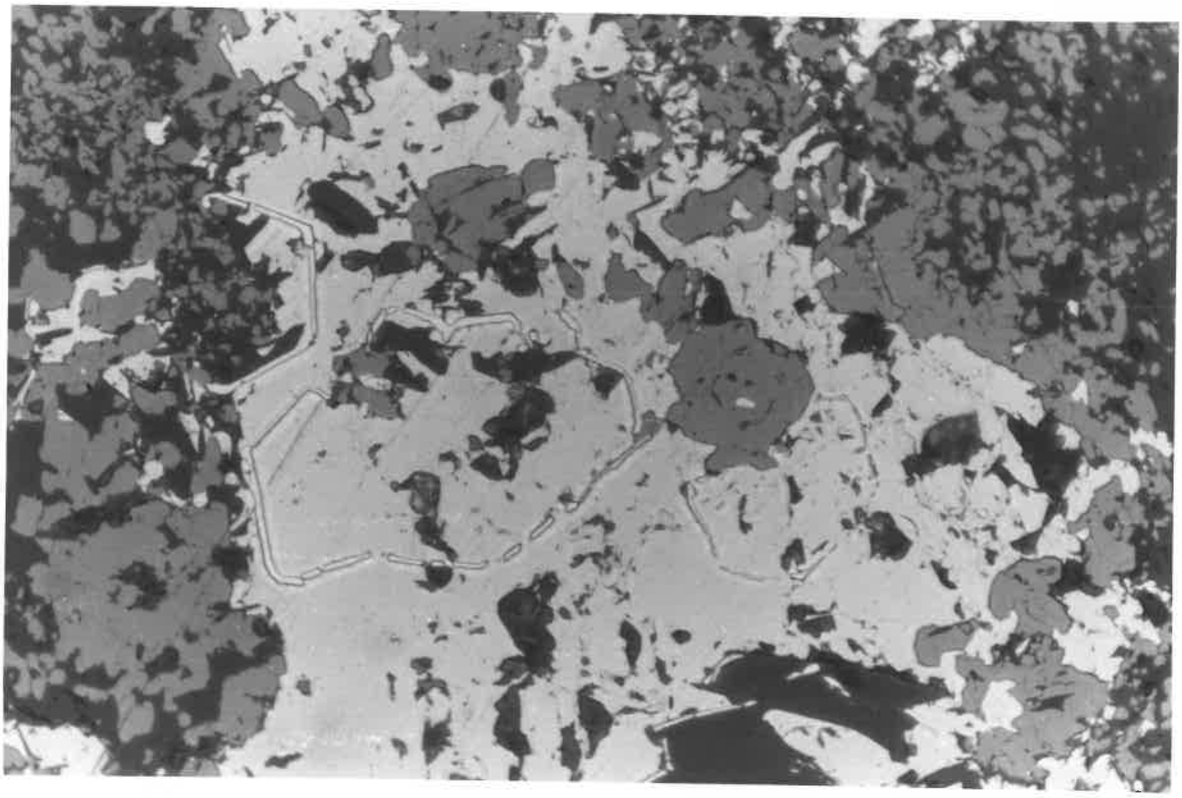


Fig. 104.

Peko ore.

polished section x 35.

Incipient replacement of massive quartz-free magnetite (grey) along two directions of fracture, by chalcopyrite (white).

Black and dark grey areas in magnetite and in chalcopyrite are residual ferromagnesian silicates.

1130 foot level, Peko Mine.

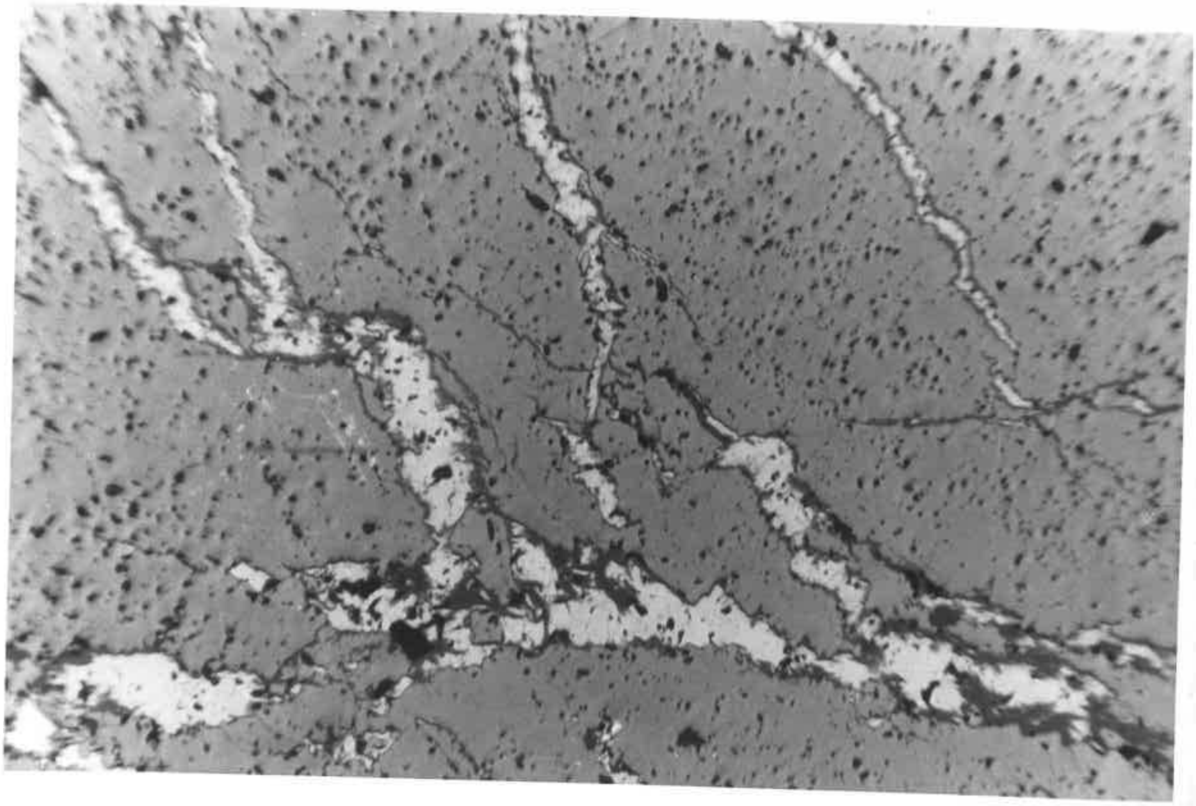
Fig. 105.

Peko ore.

polished section x 35.

The common variety of ore which contains more than 60% massive magnetite. Coarse grained pyrite euhedra (white), pre-existent in magnetite (dark grey), are corroded by chalcopyrite (pale grey). Black areas are silicate relicts in magnetite.

1130 foot level, Peko Mine.



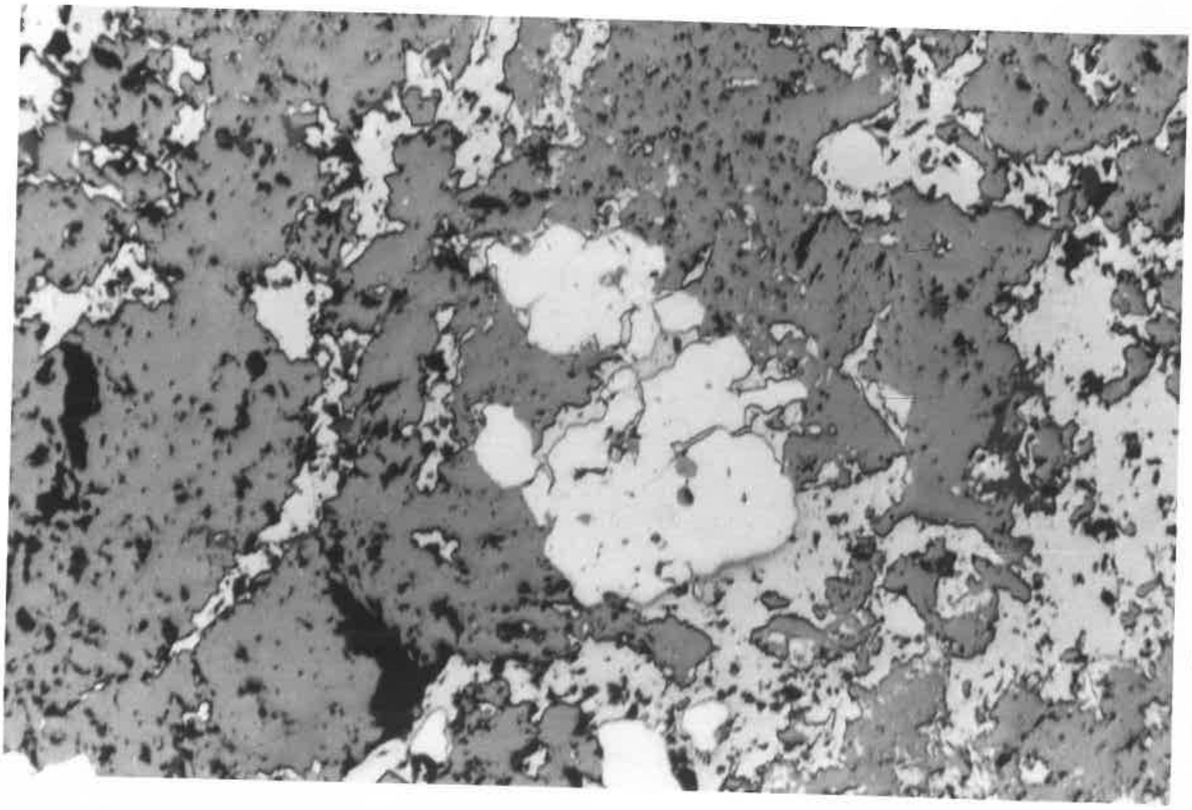


Fig. 106.

Peko ore.

polished section x 110.

The contact of a vein composed of magnetite (ragged medium grey), felspar and chlorite (the black areas), against pyrite (white) and associated quartz (smooth dark grey). Pyrite and quartz formed a distinctly banded rock and much of the pyrite has zoned texture. The zoning was preserved in pseudomorph in the magnetite which replaced the pyrite.

1130 foot level, Peko Mine.

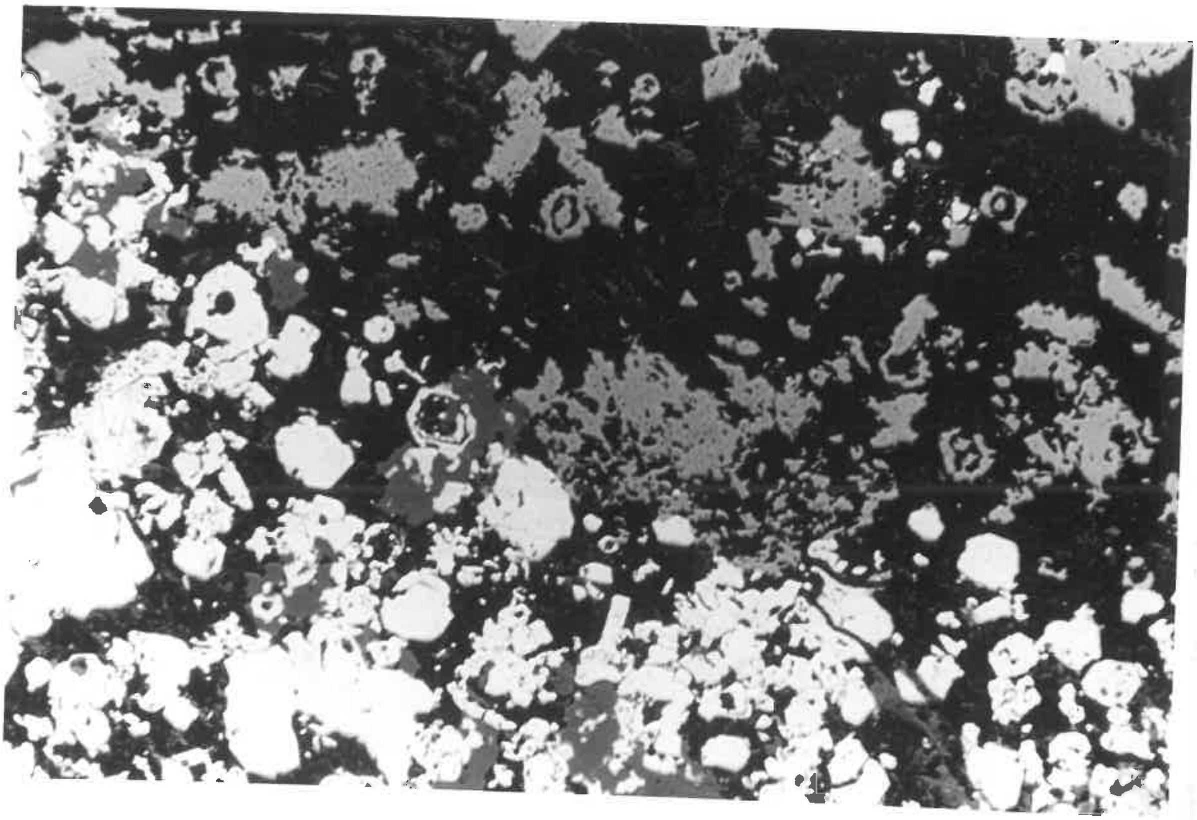
Fig. 107.

Peko ore.

polished section x 330.

The detail of a portion of the contact above showing the progressive replacement of zoned pyrite (white) by magnetite (grey), felspar and chlorite (dark grey).

1130 foot level, Peko Mine.



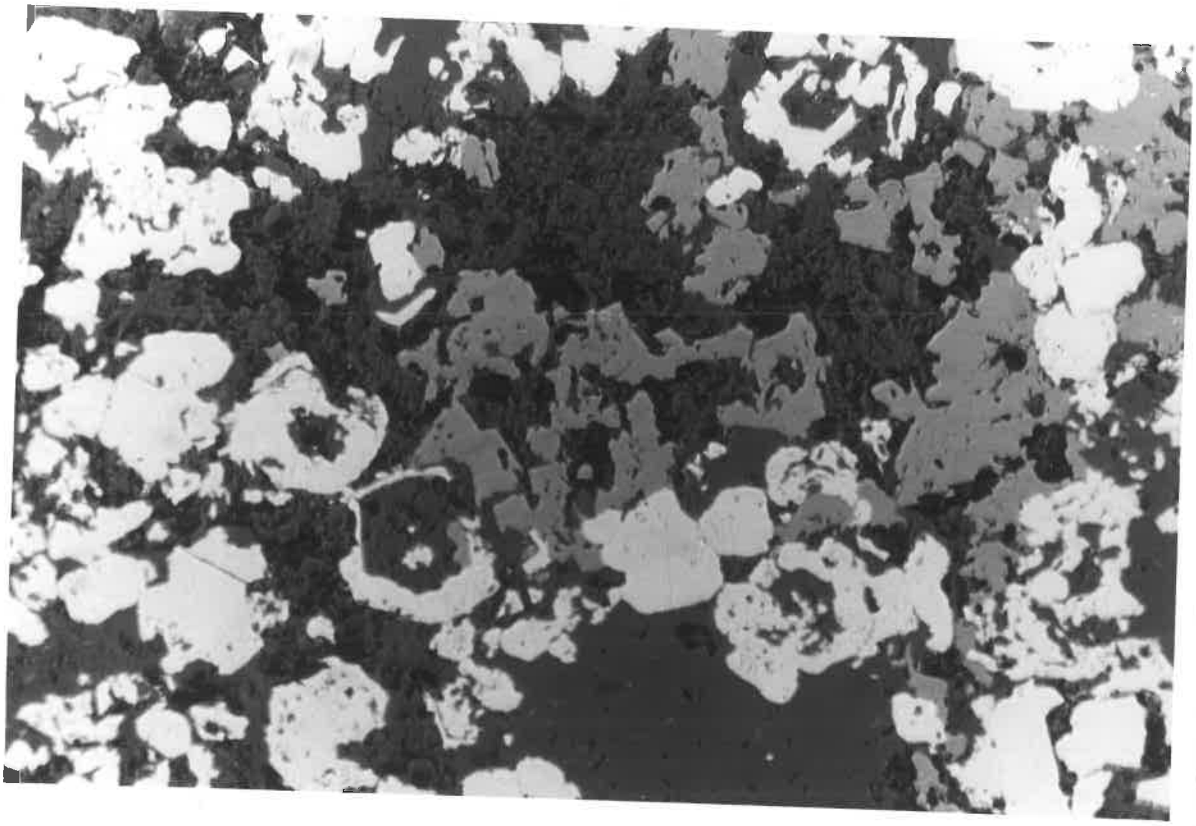


Fig. 108.

Pinnacles lode.

thin section x 56.

Translucent granules of allophane (black), of less than 0.01 mm. diameter, were formed throughout sericitic slate in the hanging wall.

Hanging wall bleached zone, Pinnacles Mine.

Fig. 109.

Pinnacles lode.

thin section x 56.

Oriented flakes of muscovite (pale grey) are visible throughout the fabric of the highly chloritic slate (darker grey). The muscovite, probably the oriented recrystallised equivalent of sericite in an original shale, persists in the chloritised rock. Chloritisation probably followed upon shear since there is random orientation amongst chlorite flakes.

Hanging wall contact with lode shear, Pinnacles Mine.

Fig. 110.

Pinnacles lode.

polished section x 35.

Well-formed euhedra of magnetite (black), and embryo specularite crystals (black), occur in abundance in coarse grained chlorite gangue (light grey). The specularite is in process of formation in the cleavage planes of the chlorite flakes.

Lode zone, Pinnacles Mine.

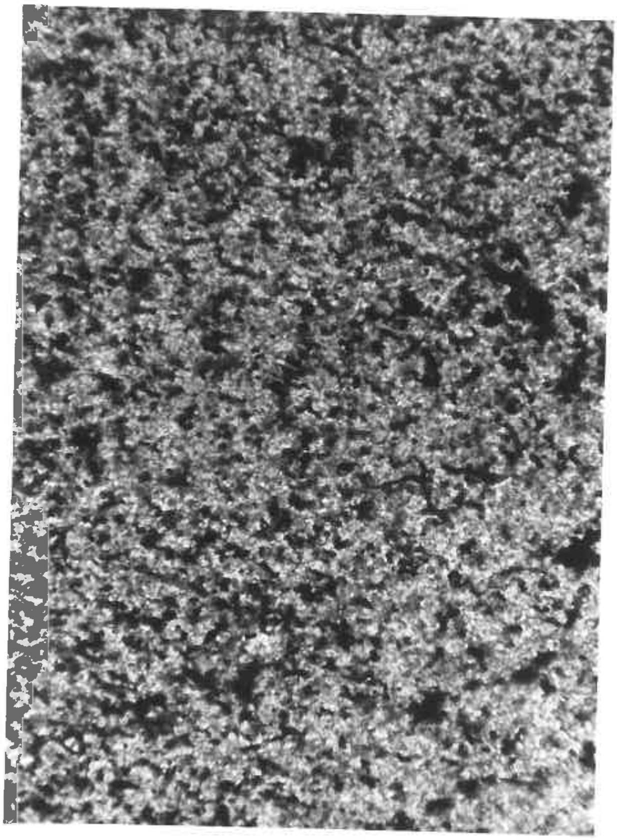
Fig. 111.

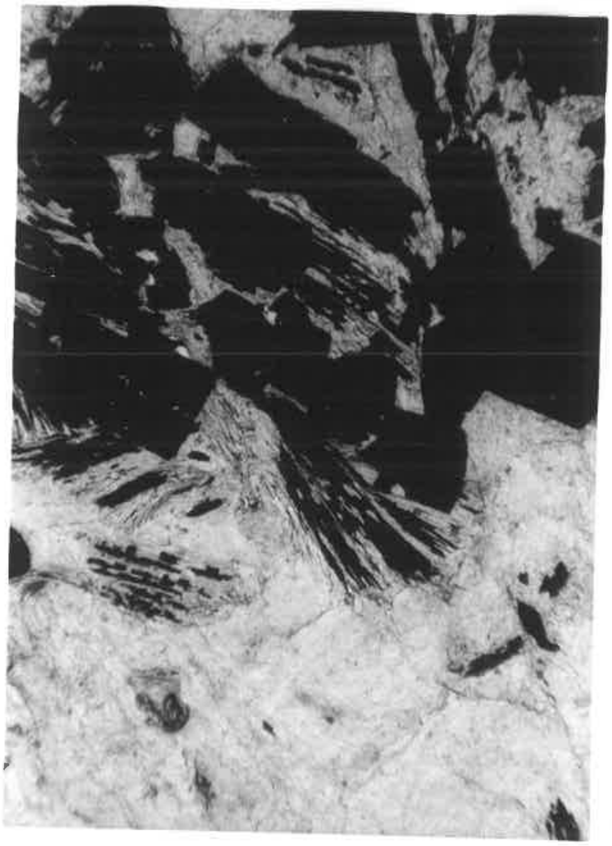
Pinnacles lode.

thin section x 100.

This highly fissile talc-anthophyllite schist acquired a crudely banded structure through the partial segregation of the two magnesian silicate minerals. Magnetite (black) formed thin selvedges at the junctions of the bands of the different silicates. Coarser grained magnetites, also conforming to the banding, formed at wider intervals.

Footwall contact with lode shear, Pinnacles Mine.





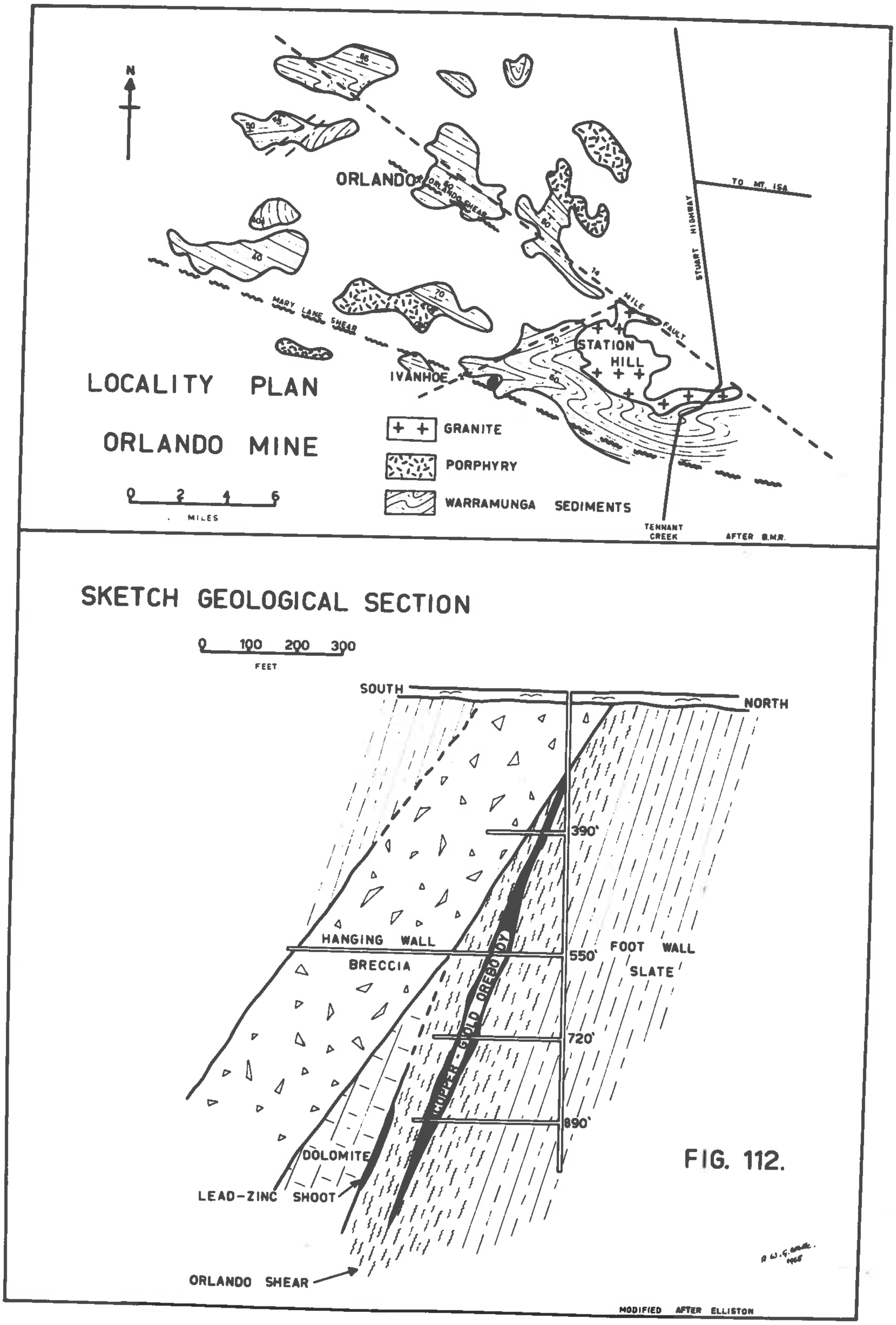

N
ORLANDO
ORLANDO SHEAR
MARY LANE SHEAR
MILE FAULT
STATION HILL
IVANHOE
STUART HIGHWAY
TO MT. ISA
LOCALITY PLAN
ORLANDO MINE
0 2 4 6
MILES
GRANITE
PORPHYRY
WARRAMUNGA SEDIMENTS
TENNANT CREEK
AFTER B.M.R.
SKETCH GEOLOGICAL SECTION
0 100 200 300
FEET
SOUTH
NORTH
390'
550'
720'
890'
HANGING WALL
BRECCIA
FOOT WALL
SLATE
COPPER - GOLD OREBODY
DOLOMITE
LEAD-ZINC SHOOT
ORLANDO SHEAR
MODIFIED AFTER ELLISTON

FIG. 112.

Fig. 113.

Orlando ore.

thin section x 70.

The calcite (coarse grey crystals with cleavage), and the sulphide (black) formed a crustified open space filling in sheared chlorite-talc-quartz schist of the hanging wall.

550 foot level, Orlando Mine.

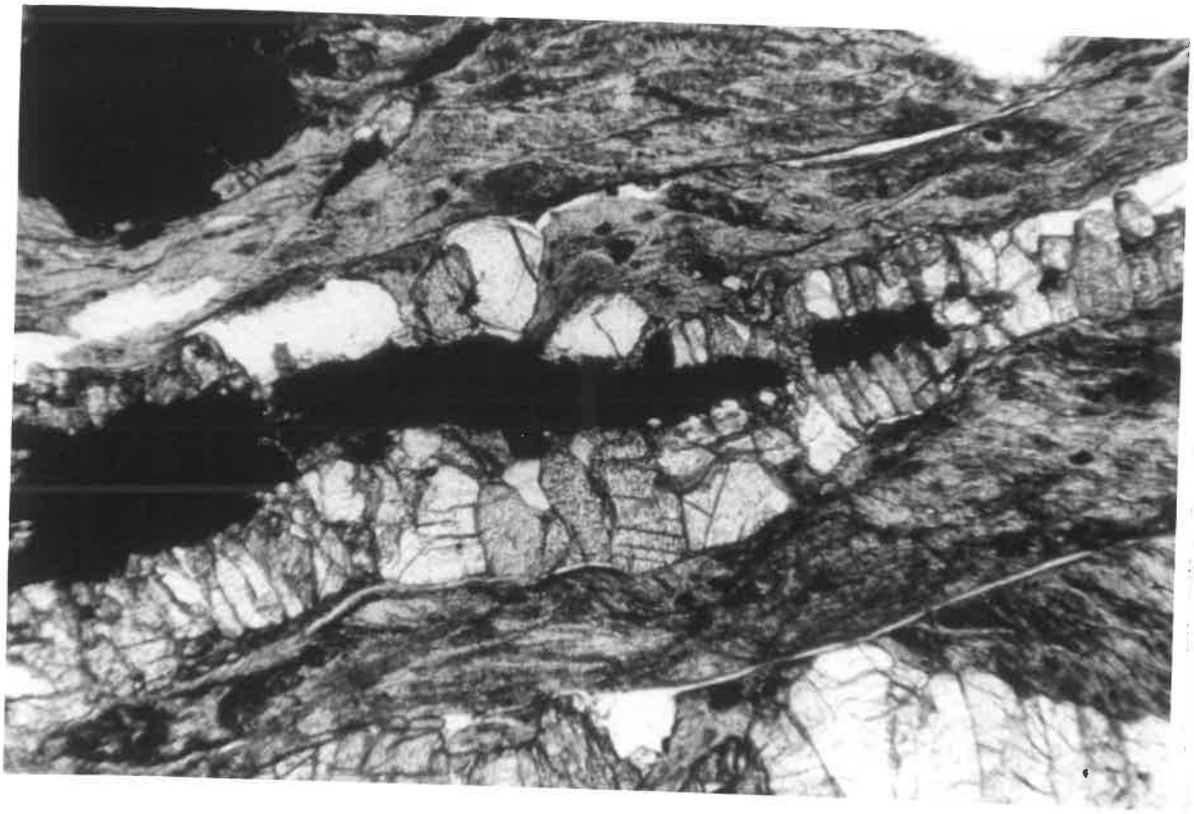
Fig. 114.

Orlando ore.

thin section x 20.

This section of sheared slate (grey) from the lode which encloses augen-like fragments of siltstone (light grey), was mineralised by irregularly shaped and elongate aggregates of sulphides and magnetite (black).

720 foot level, Orlando Mine.



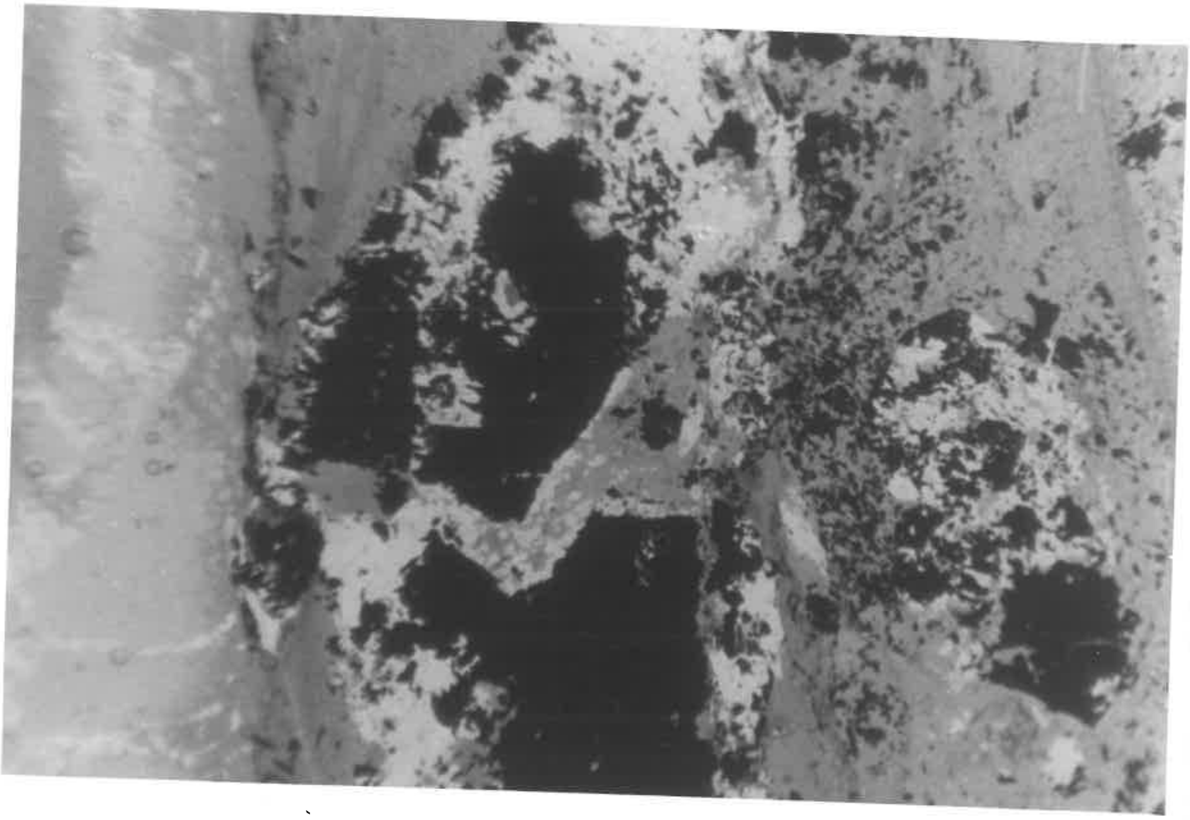


Fig. 115.

Orlando ore.

polished section x 110.

High grade copper ore which contains in chalcopyrite (pale grey) embayed partially replaced magnetite euhedra (medium grey), zoned pyrite euhedra (white), relicts of quartz (dark grey) and relicts of chlorite (black).

The chalcopyrite replaced most of the quartz and chlorite of the host rock, but little of the magnetite and none of the pyrite.

720 foot level, Orlando Mine.

Fig. 116.

Pseudomorphed slump structure.

polished section x 70.

The structure preserved by magnetite (medium grey) and by pyrite (white), may be a pseudomorph of slumped lamellae present in the original sediment. The sediment was completely replaced since only magnetite, pyrite and quartz (dark grey), are contained in the rock.

1130 foot level, Peko Mine.

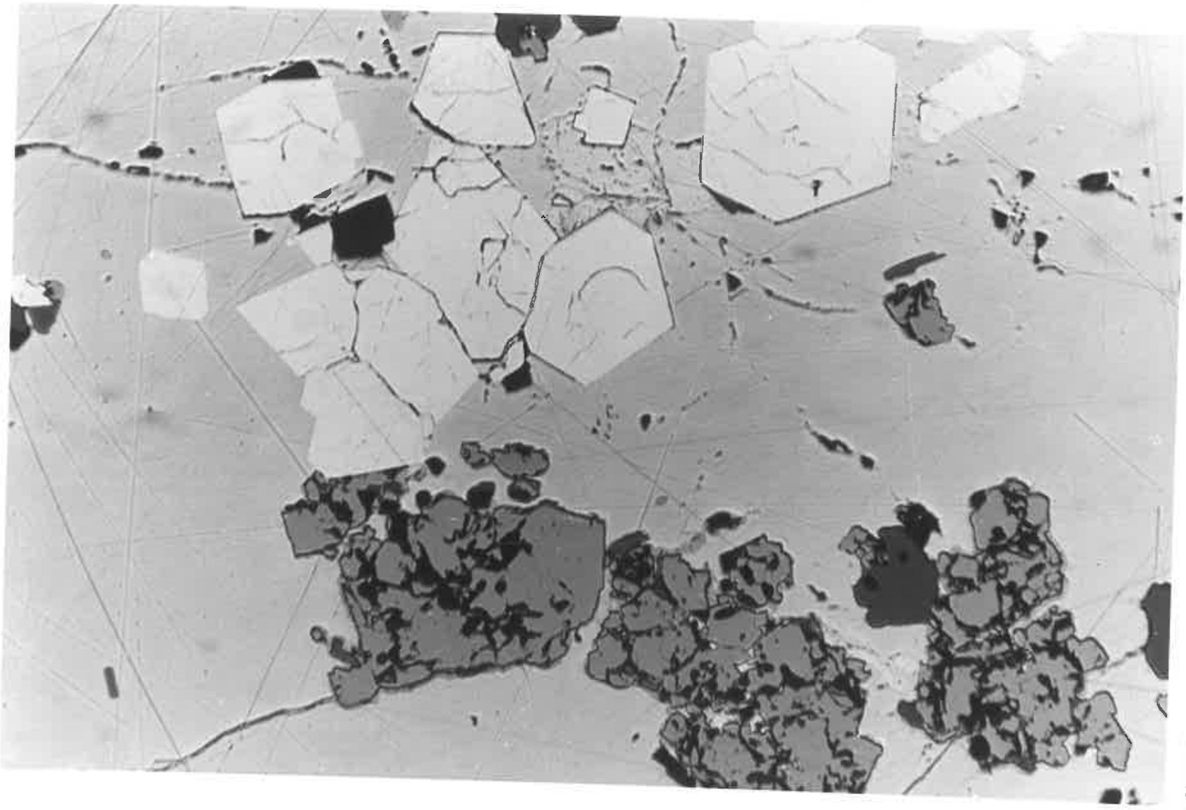


Fig. 117.

Orlando ore.

polished section x 110.

The chloritic slate (dark grey) contains parallel bands of coarser or finer grained magnetite (light grey): the coarser magnetite is associated with coarse grained, random oriented chlorite (dark grey flakes) while the finer magnetite exists directly in the slate. The subsequent entry of chalcopyrite (white) was directed mainly along the coarse chlorite-magnetite bands.

720 foot level, Orlando Mine.

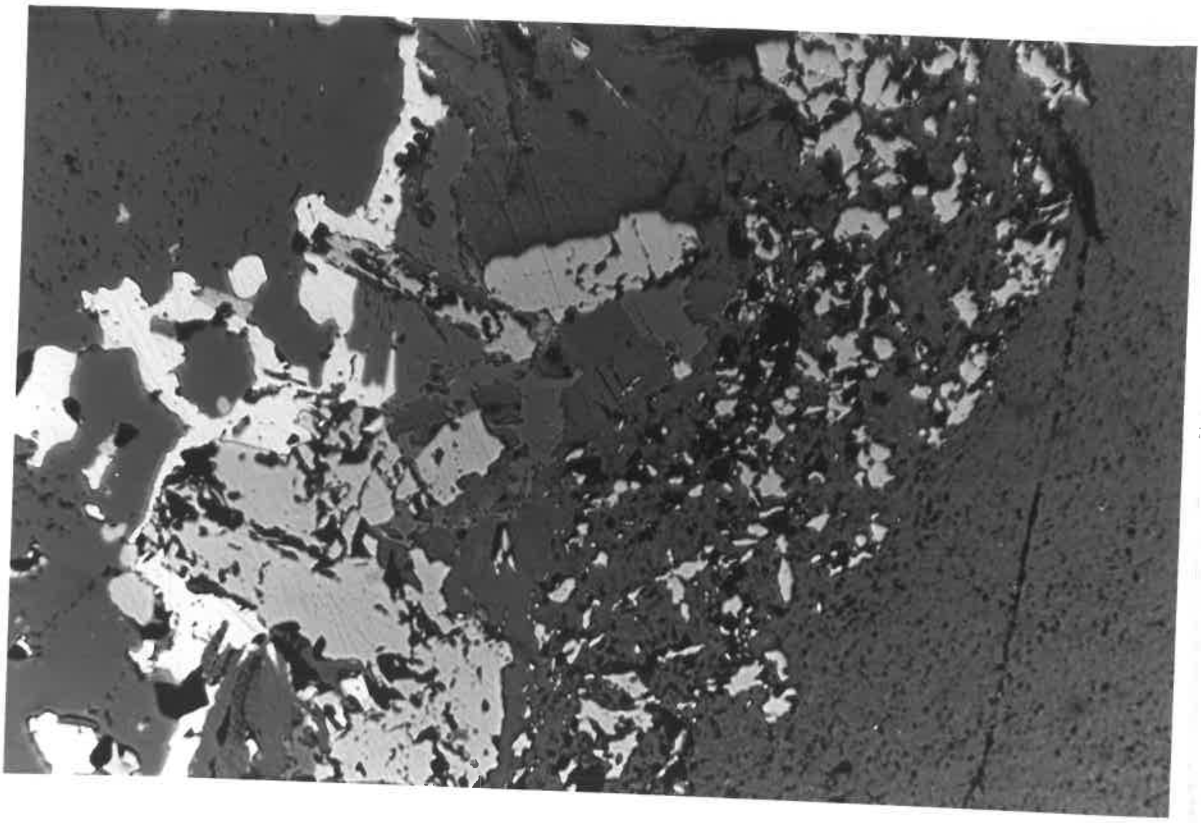
Fig. 118.

Orlando ore.

polished section x 330.

This section illustrates the replacement of chlorite along its cleavages by chalcopyrite (white). Magnetite euhedra (light grey), existing with coarse chlorite in certain bands in the slates, was not corroded by the chalcopyrite.

720 foot level, Orlando Mine.



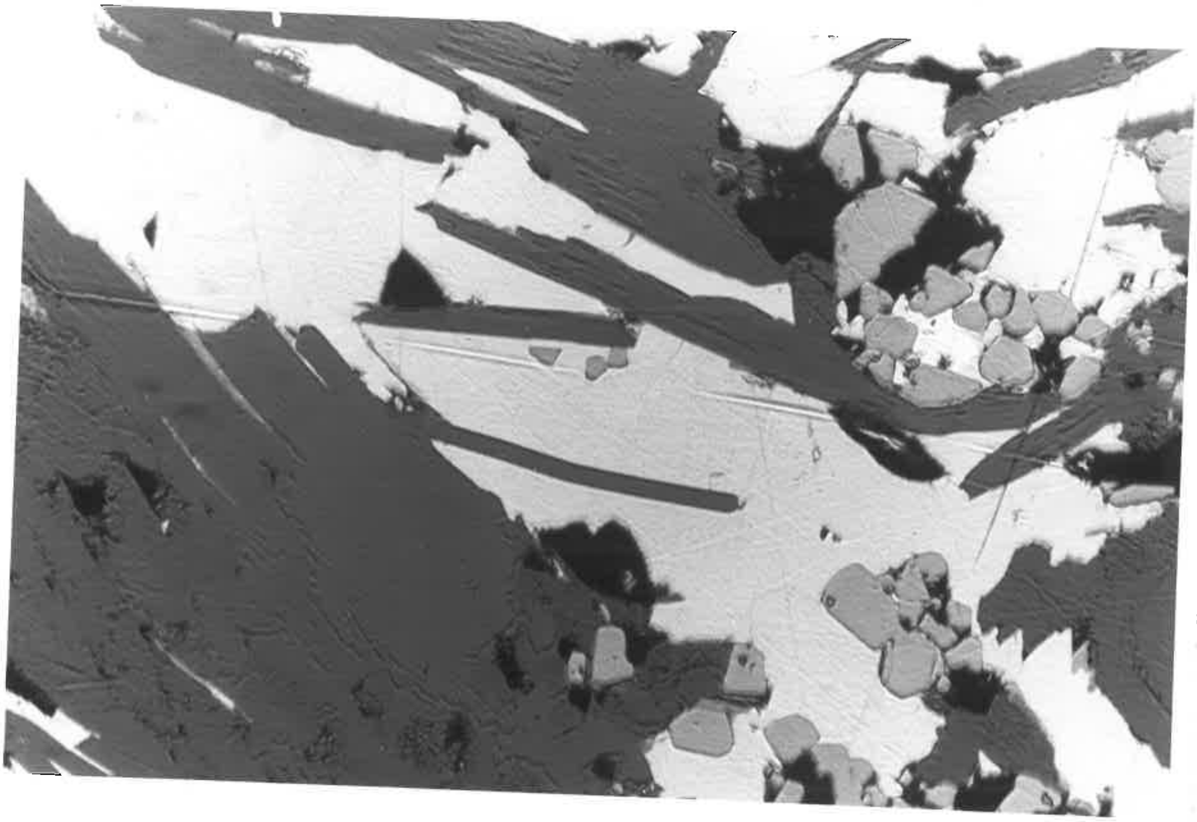


Fig. 119.

Orlando ore.

polished section x 35.

Preservation of the sheaf-like structure of chlorite aggregates after their replacement by magnetite (grey). Portions of the original chlorite (black) remain in the magnetite. Subsequent veins of chalcopyrite (white) transect the aggregate.

720 foot level, Orlando Mine.

Fig. 120.

Orlando ore.

polished section x 220.

The partial replacement of chlorite aggregates (black) of the host rock, by the entry of chalcopyrite (white) along cleavages and grain boundaries. Chalcocite (grey) formed later by the process of secondary sulphide enrichment.

720 foot level, Orlando Mine.

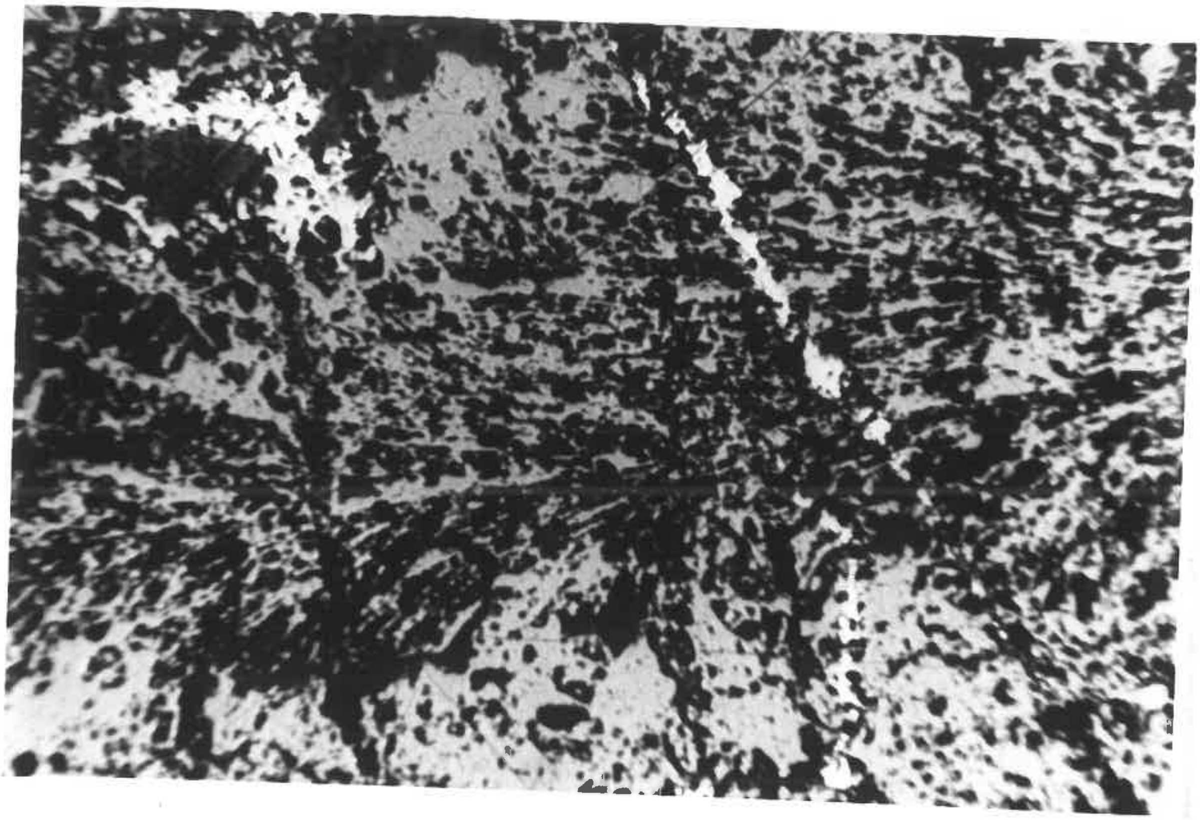
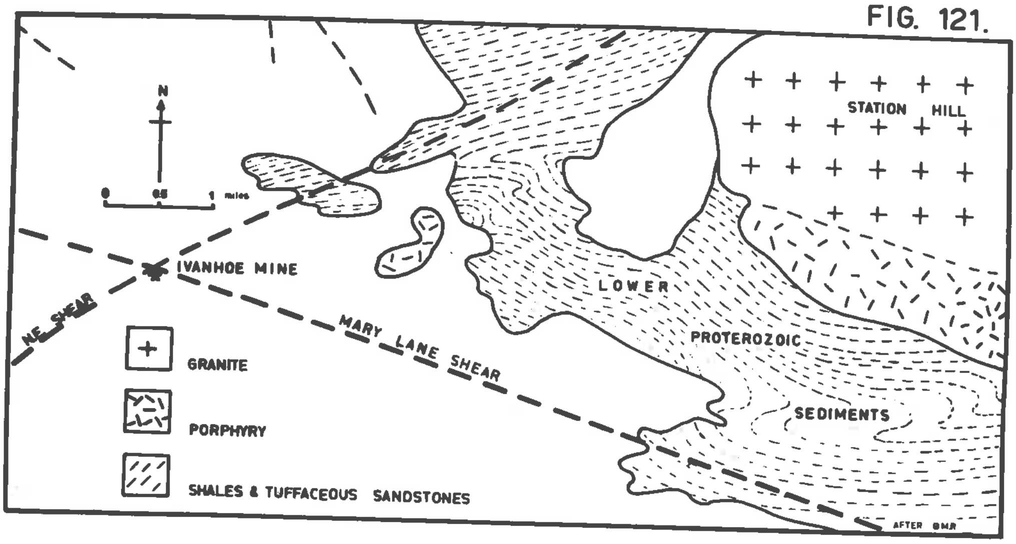


FIG. 121.



IVANHOE Mine

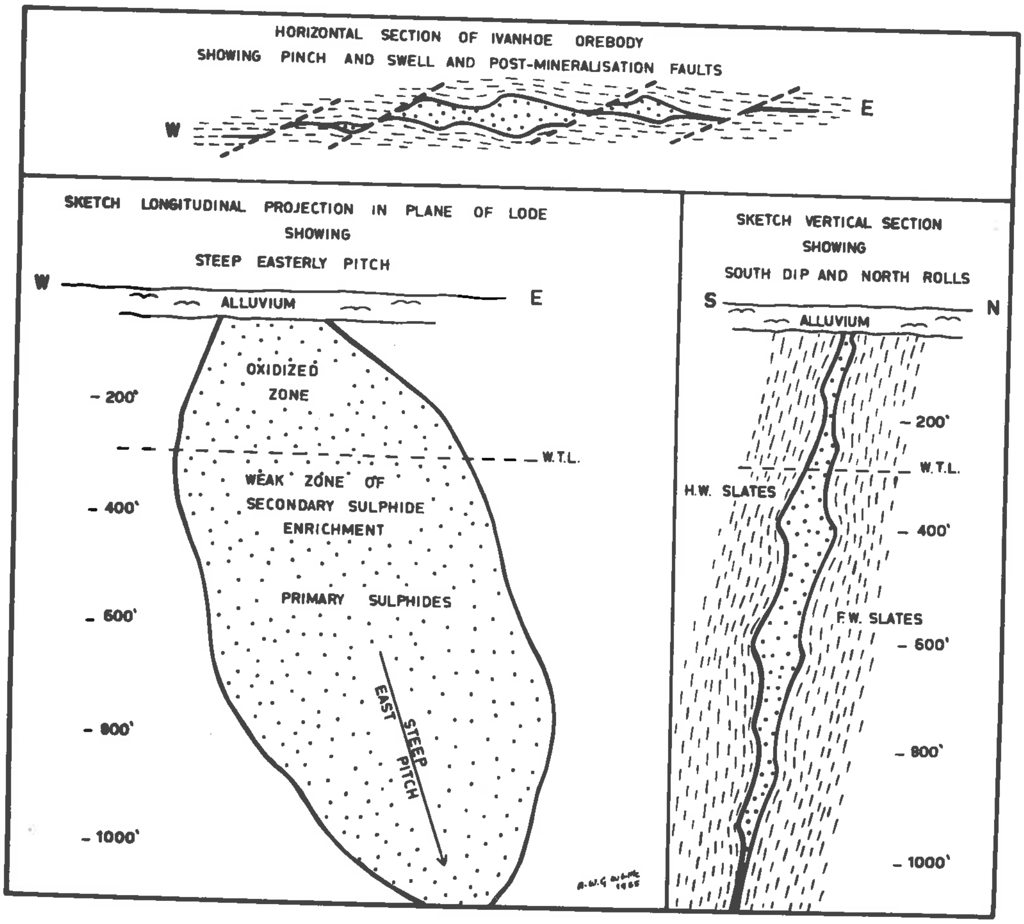


Fig. 122.

Ivanhoe ore.

polished section x 110.

Banded ore composed of layers of euhedral pyrite (white), and of magnetite (medium grey) with irregularly dispersed chlorite (black), quartz (dark grey) and unreplaced rock (dark grey, left hand side). Small amounts of anhedral chalcopyrite (also white) occur in the magnetite-rich foliae and follow the banding.

390 foot level, Ivanhoe Mine.

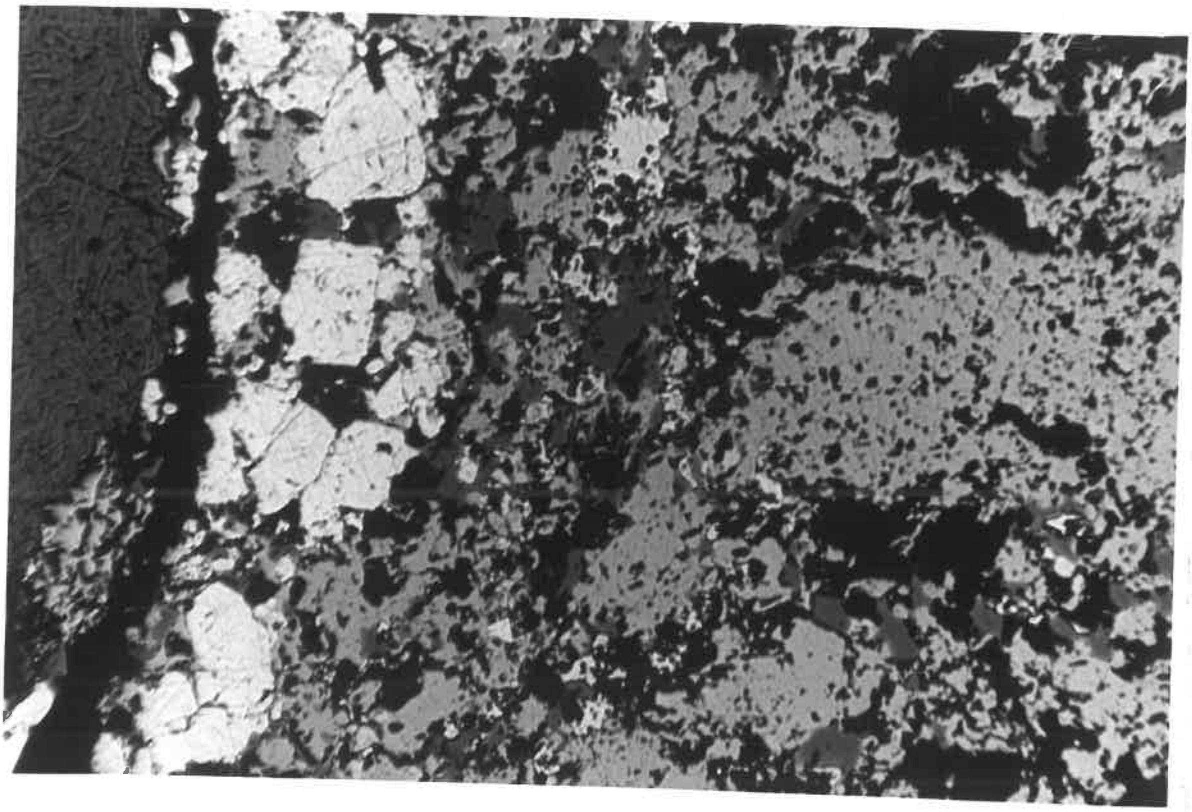
Fig. 123.

Ivanhoe ore.

polished section x 500 - oil immersion.

The detail of Fig. 122 (above) which illustrates the mode of emplacement of chalcopyrite (white) amongst magnetite euhedra (dark grey) by replacement of interstitial chlorite (black). Hypogene hematite (medium grey), is moulded upon some of the magnetite.

390 foot level, Ivanhoe Mine.



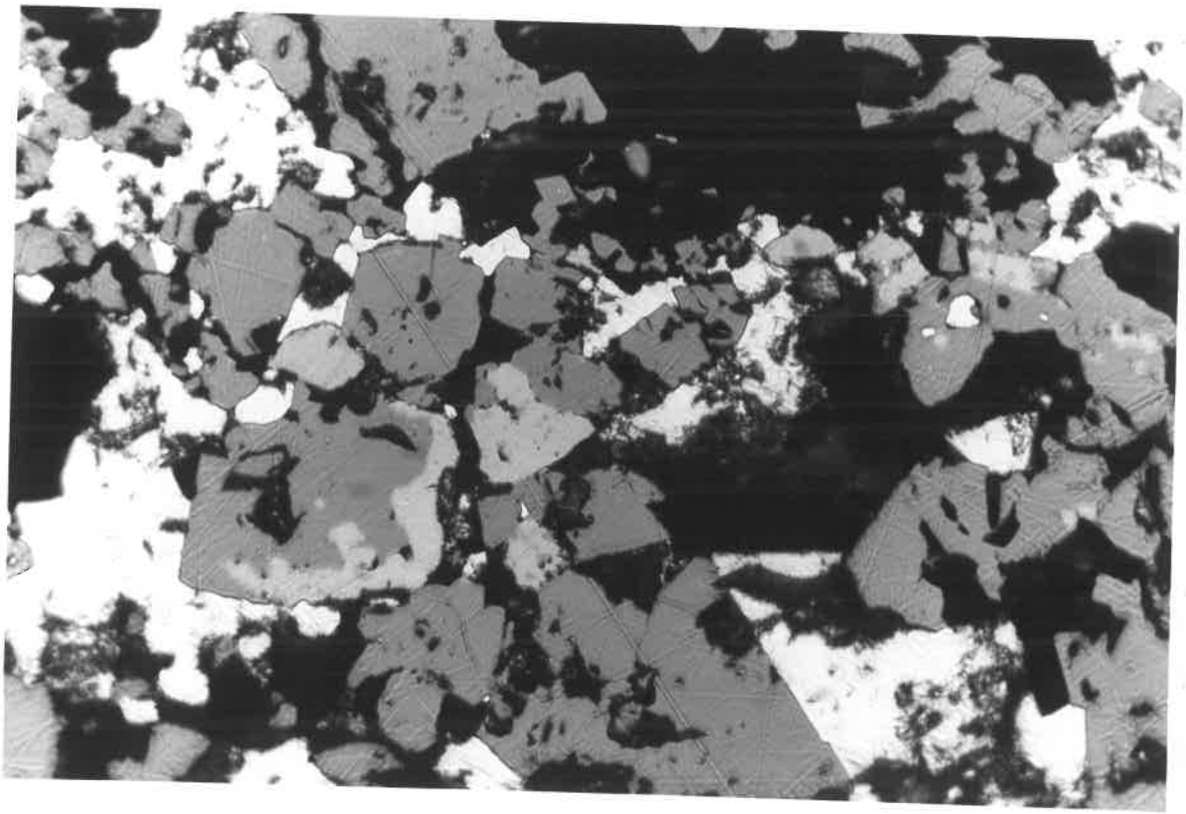


Fig. 124.

Ivanhoe ore.

polished section x 110.

High grade copper ore in which some relicts of the original oriented flakey silicates (chlorite and actinolite - black), remain in chalcopyrite (light grey) which replaced the slate of the lode zone.

Euhedral pyrite (white) shows little evidence of replacement by chalcopyrite, whereas magnetite (dark grey) was corroded and partly replaced. Both pyrite and magnetite were components of the lode structure prior to the influx of chalcopyrite.

390 foot level, Ivanhoe Mine.

Fig. 125.

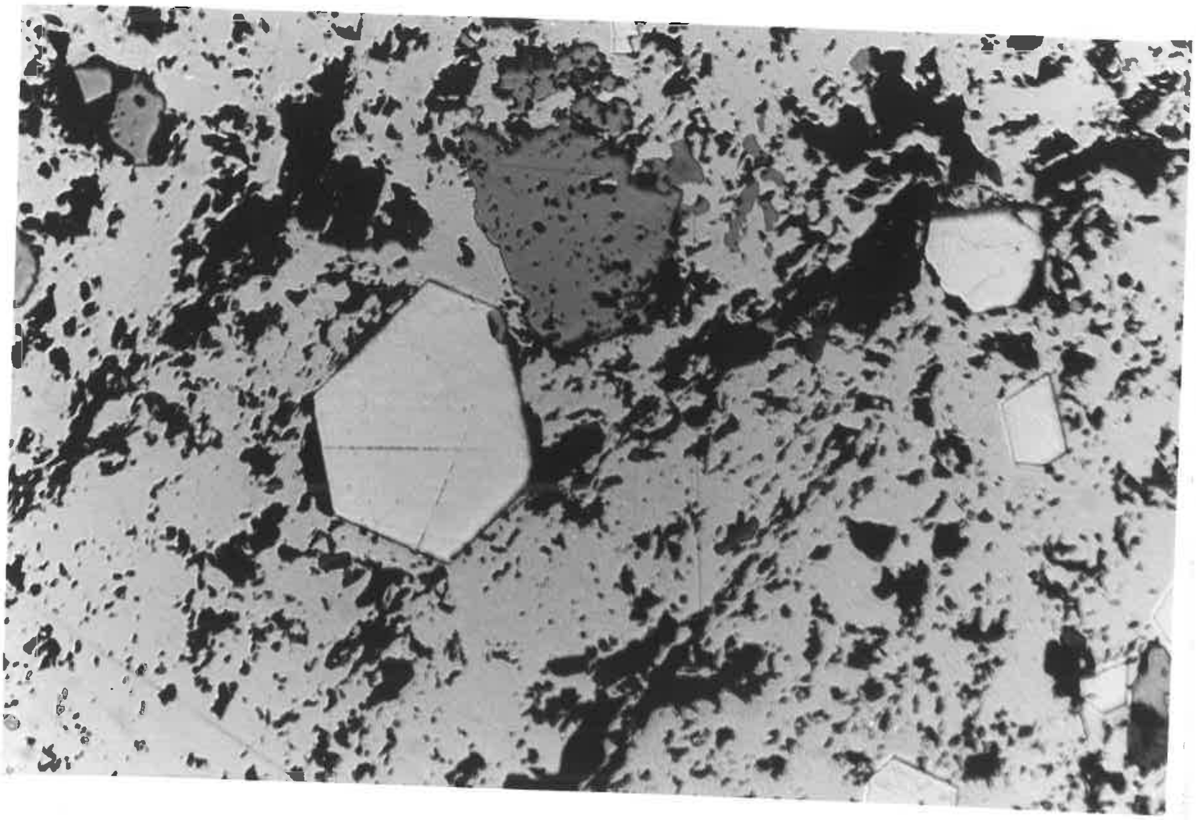
Ivanhoe ore.

polished section x 250 - oil immersion.

Banded pyrite-magnetite-chlorite lode replaced by chalcopyrite. Chalcopyrite (very light grey) replaced pyrite (white with numerous inclusions) and chlorite (black), but not euhedral magnetite (dark grey).

The arrangement of dusty inclusions in pyrite reflects the structure of the silicate rock which the pyrite replaced.

590 foot level, Ivanhoe Mine.



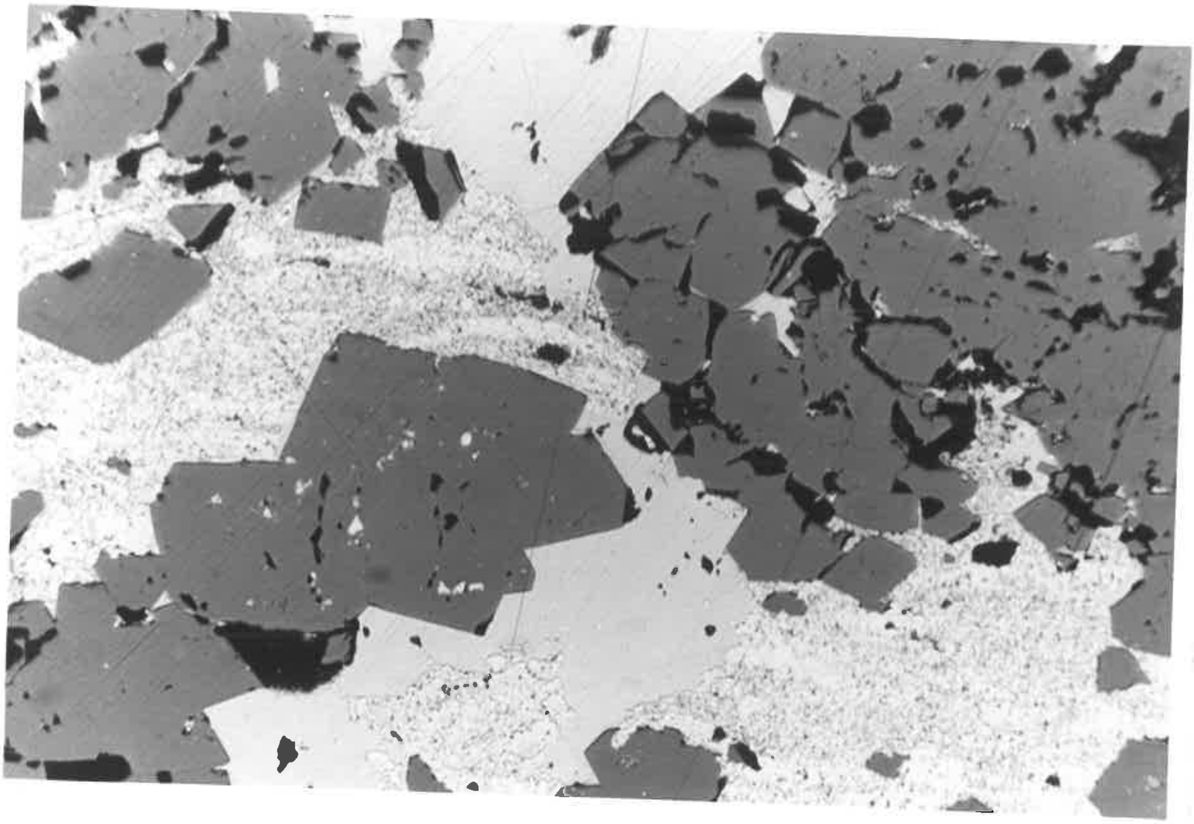


Fig. 126.

Ivanhoe ore.

polished section x 110.

Veins of chalcopyrite (white) and of chalcopyrite and specularite (white and light grey) follow two intersecting systems of fractures in massive magnetite (medium grey). The black inclusions in magnetite are relicts of replaced chlorite.

590 foot level, Ivanhoe Mine.

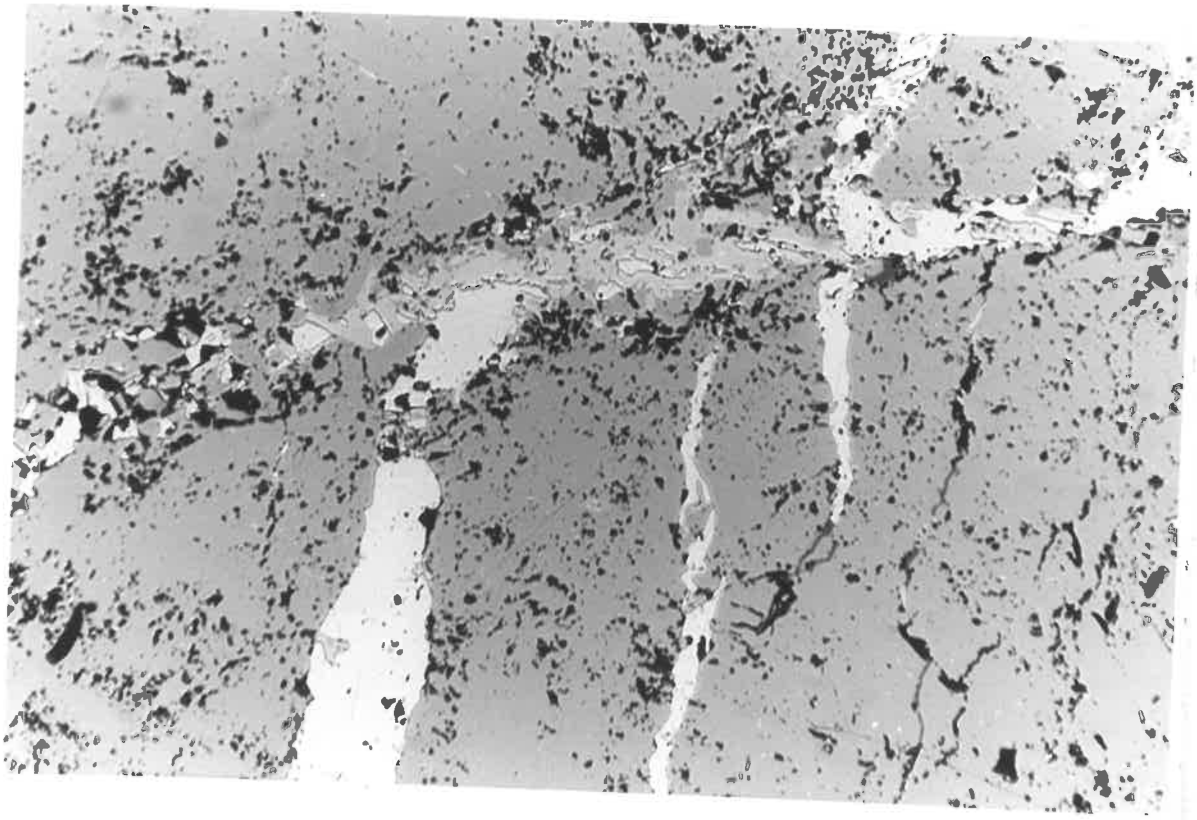
Fig. 127.

Ivanhoe ore.

polished section x 250 - oil immersion.

The equidimensional sphalerite grains (dark grey) are enclosed in an intergranular aggregate of galena (light grey) and chalcopyrite (light grey), and although scarcely distinguishable in the photomicrograph, the galena is conspicuous by its triangular cleavage pits. On the assumption that sphalerite and chalcopyrite formed simultaneously through unmixing and segregation from solid solution, the galena may be regarded as having entered the intergrowth later, by replacement, mainly of the chalcopyrite.

590 foot level, Ivanhoe Mine.



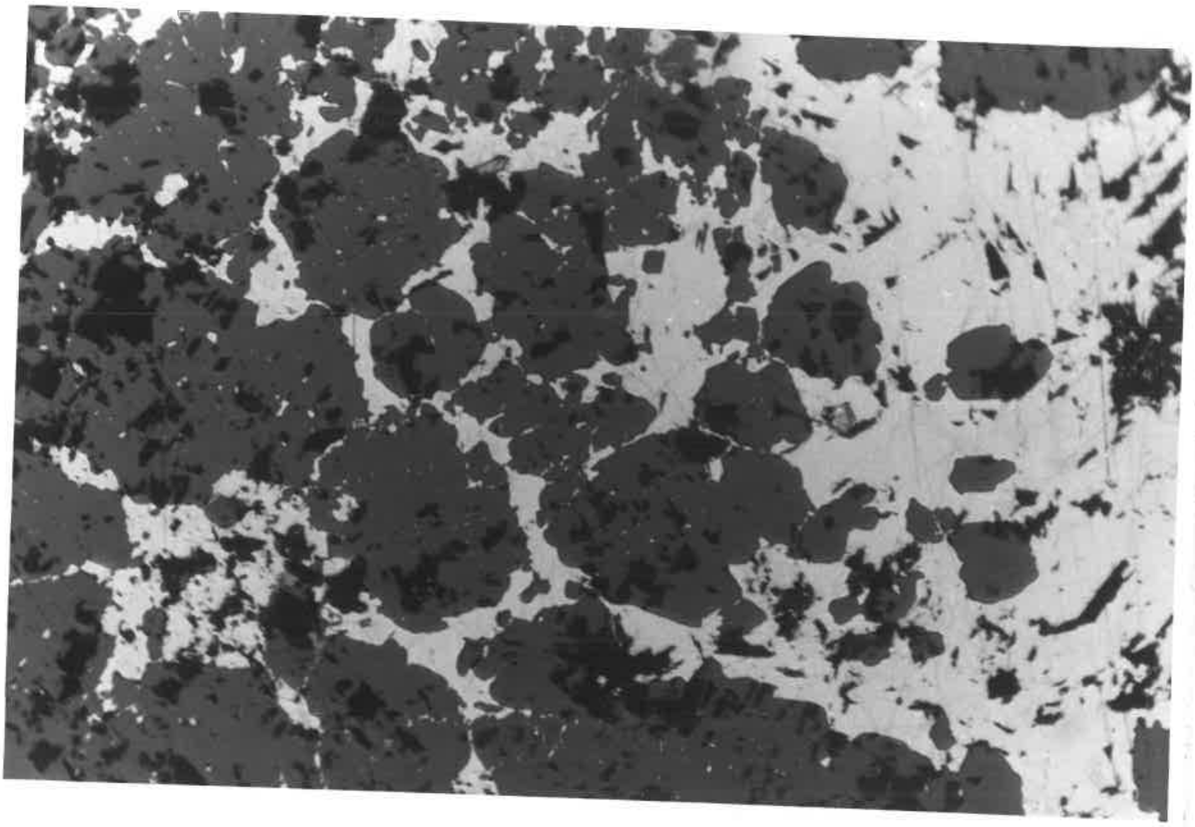


FIG. 128. SEQUENCE OF GEOLOGICAL EVENTS.

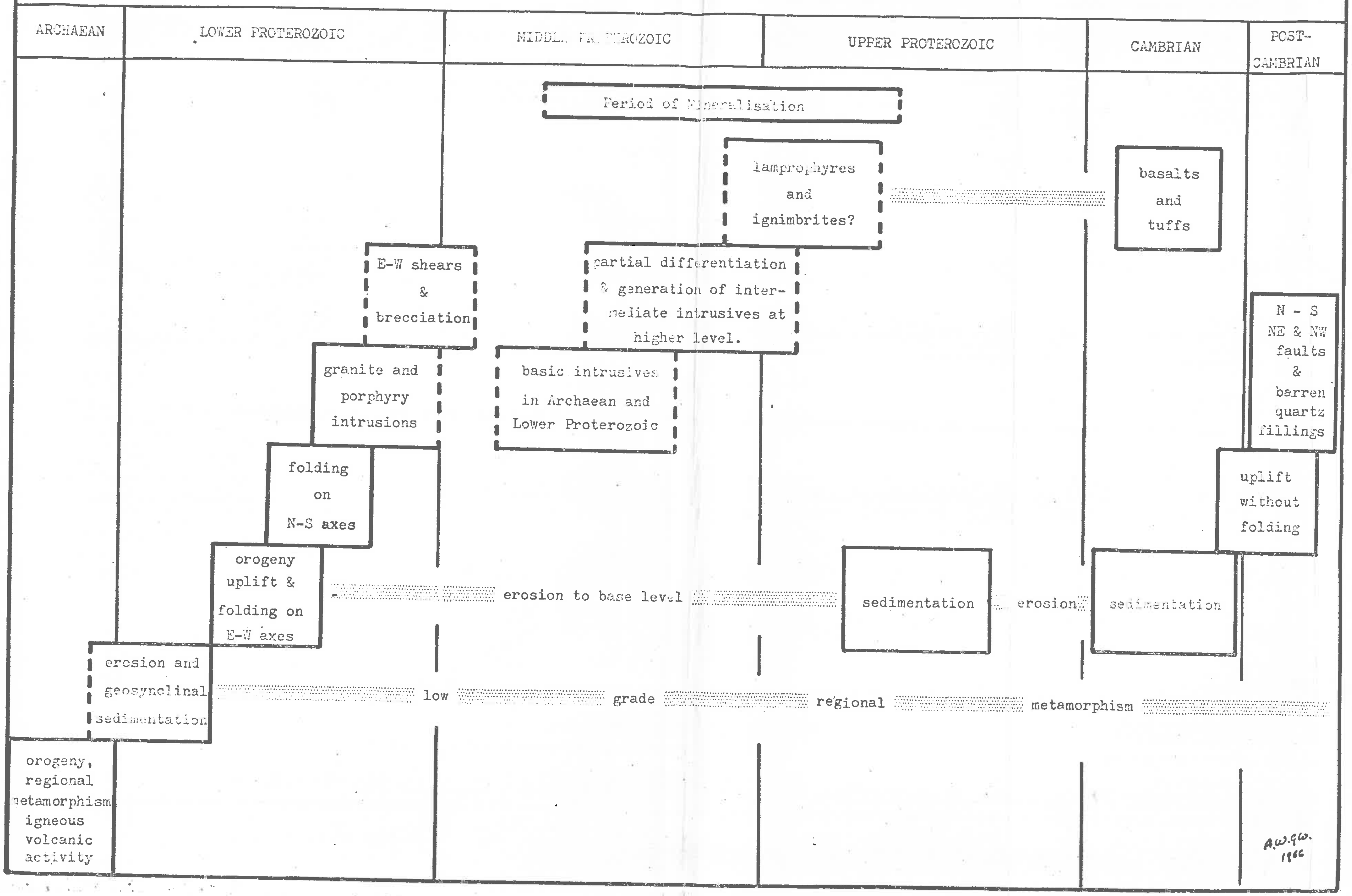
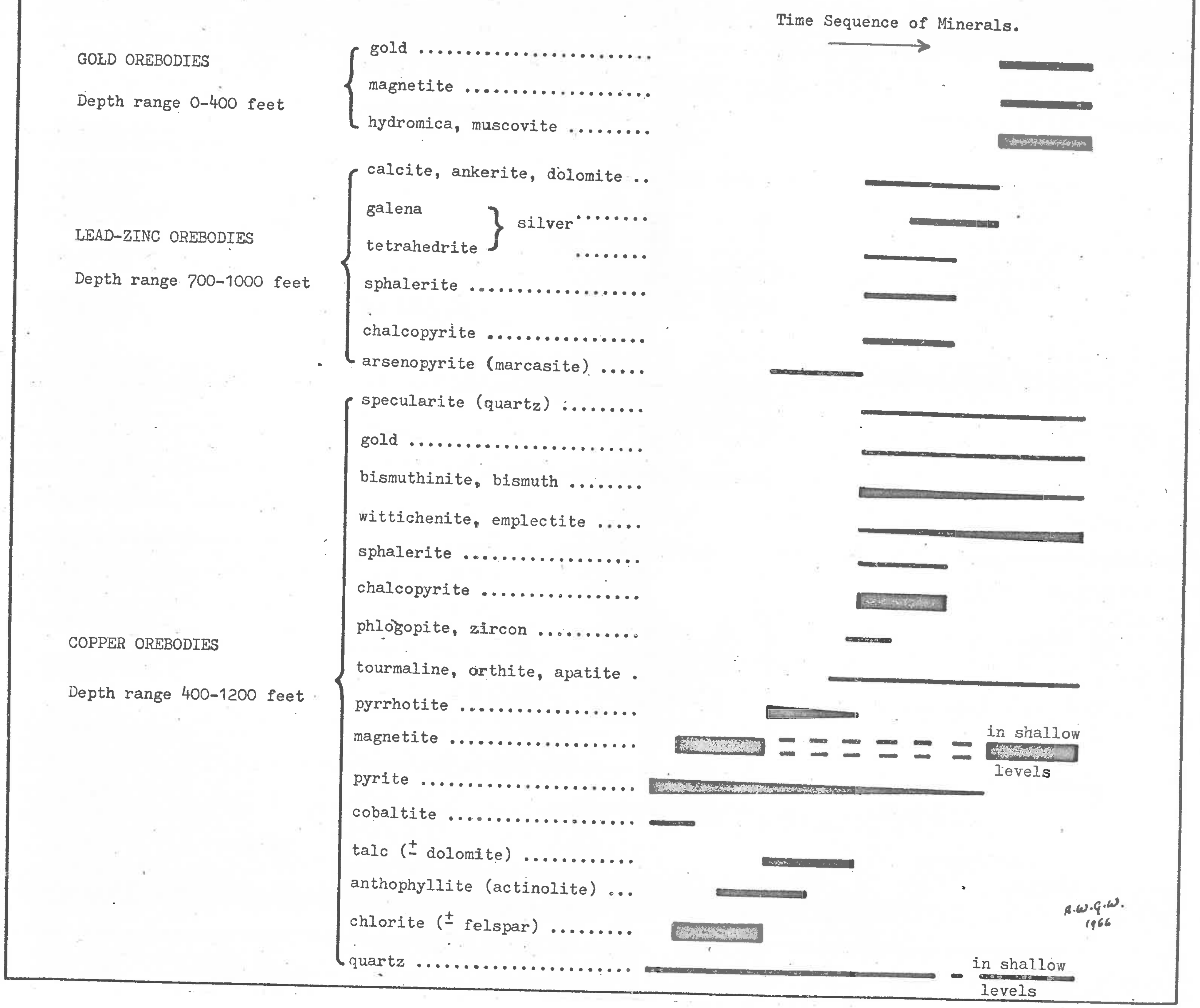
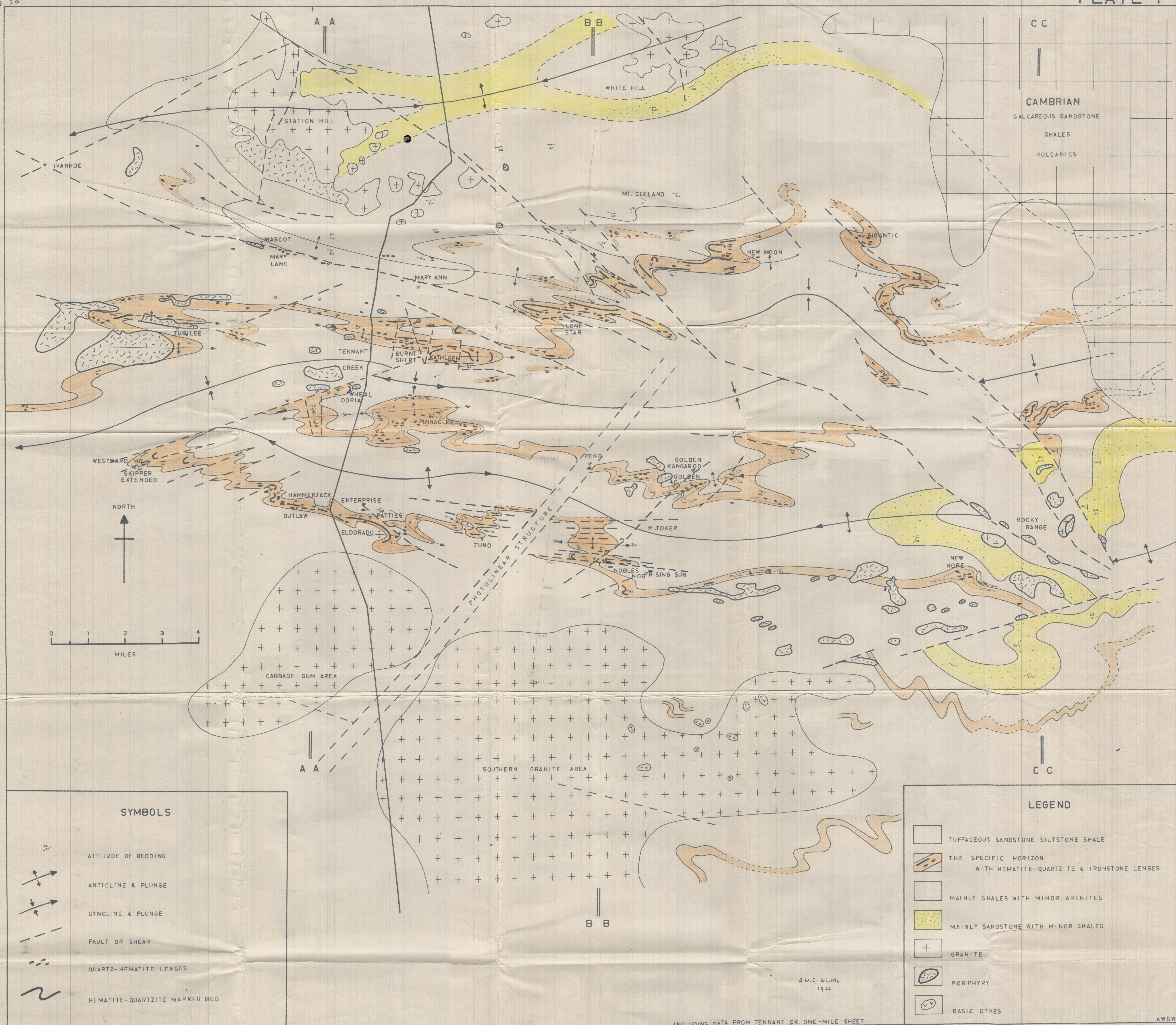


FIG. 129. PARAGENETIC DIAGRAM.



TENNANT CREEK
STRUCTURAL INTERPRETATION PLAN

PLATE 1



TENNANT CREEK

STRUCTURAL INTERPRETATION SECTIONS

PLATE 2

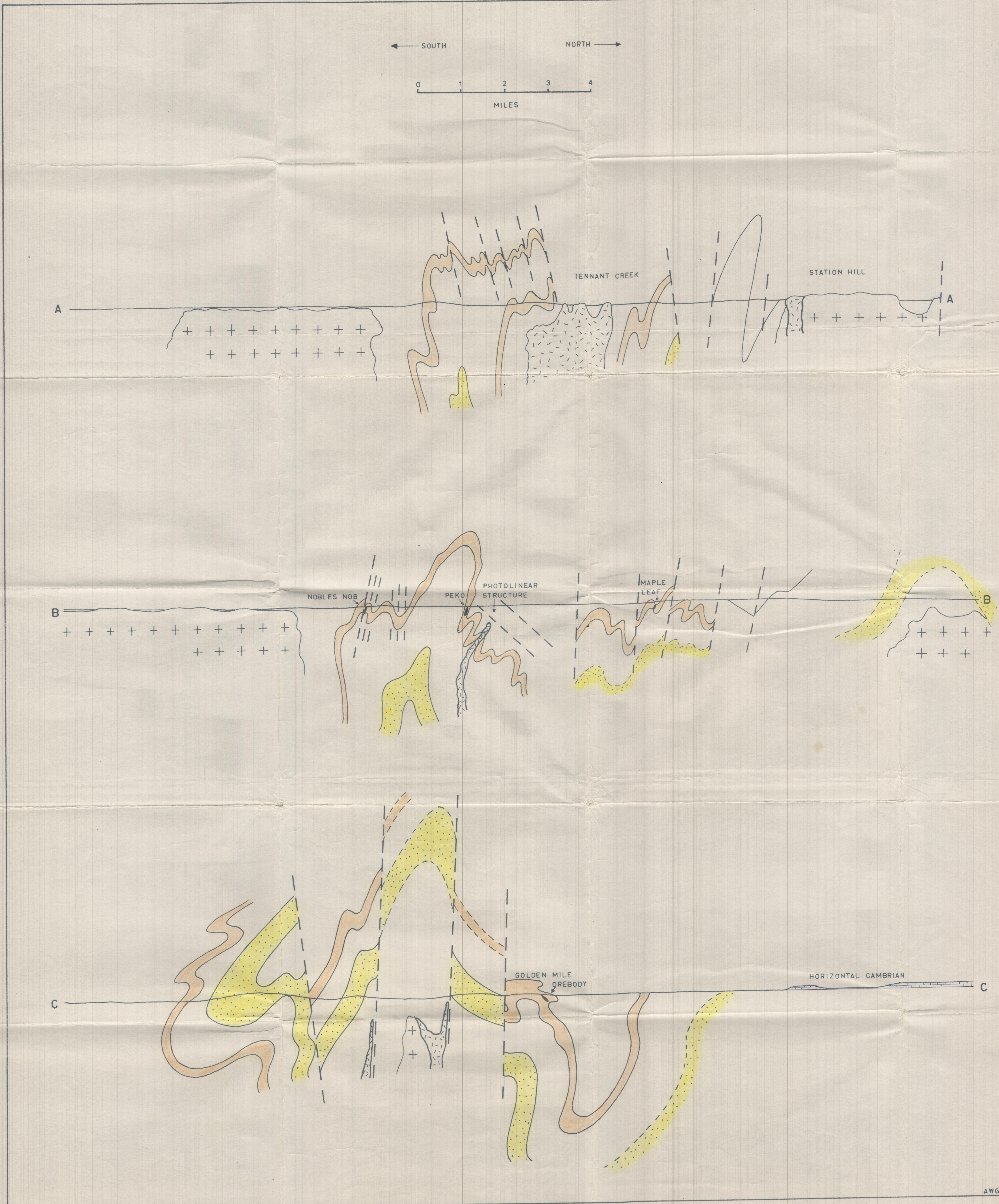


PLATE 3

NOBLE'S NOB GOLD MINE

CONTOURED ASSAY SECTION OF MAIN LODE

PROJECTED ON 5050N

LODE DIP VERTICAL

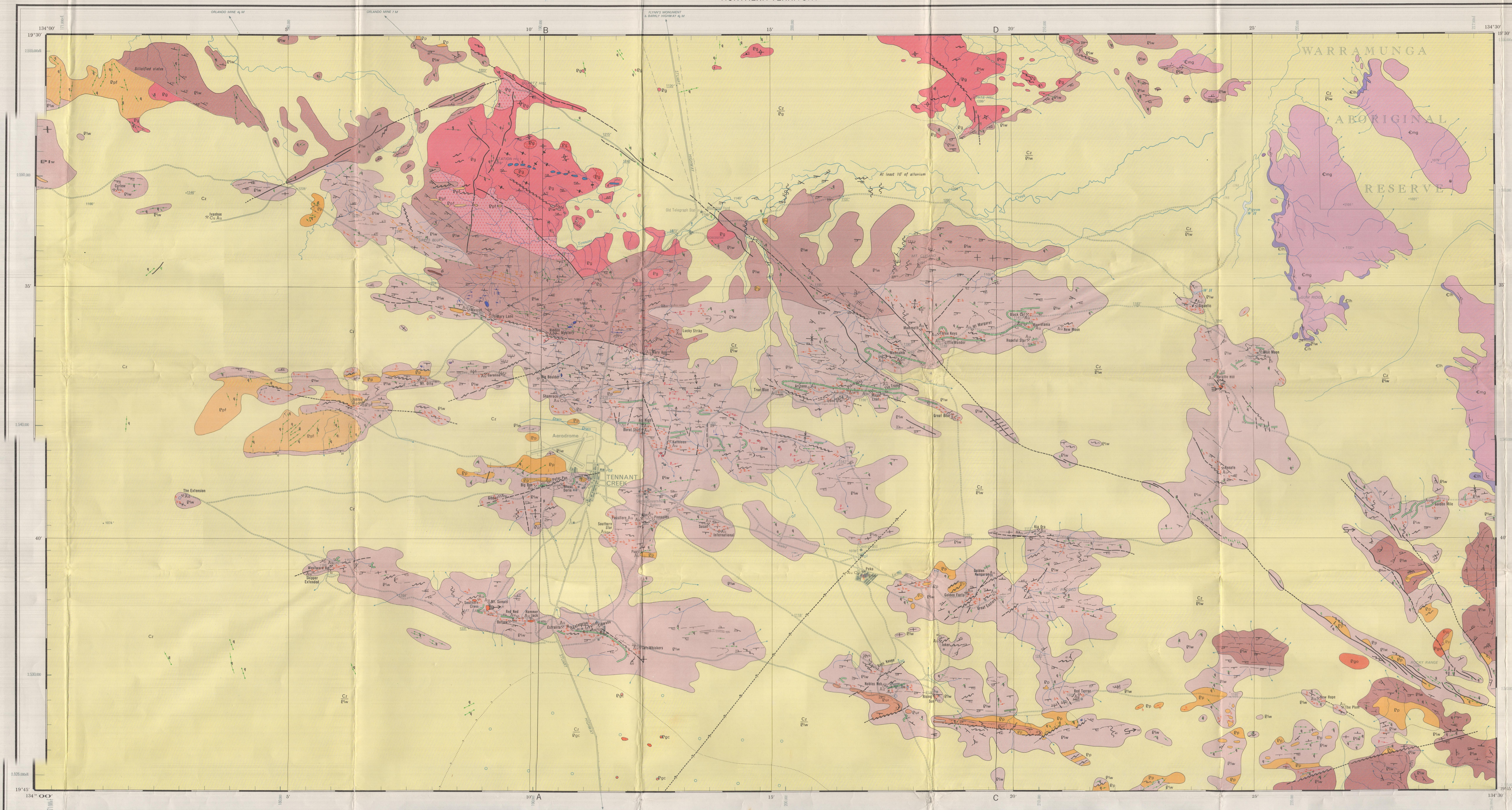
AUSTRALIA 1:63,360

TENNANT CREEK

NORTHERN TERRITORY

1 MILE GEOLOGICAL SERIES SHEET 238 ZONE 5

FIRST EDITION 1966



Compiled and published by the Bureau of Mineral Resources, Geology and Geophysics, Department of National Development. Base map compiled by the Division of National Mapping, Department of National Development. Aerial photography by the Royal Australian Air Force at 1: 50,000 scale and by the Bureau of Mineral Resources at 1: 25,000 scale; complete vertical coverage at 1: 50,000 scale. Transverse Mercator Projection

Geology, 1958-59, by: P. W. Crohn, W. Oldershaw, G. R. Ryan, K. Rochow
Compiled, 1963, by: P. W. Crohn, W. Oldershaw
Drawn, 1965, by: Mapping Systems, Brisbane

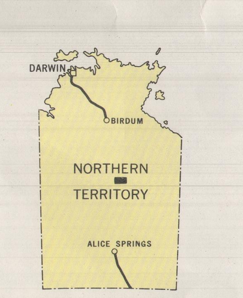
Reference

CAINOZOIC				Cz	Gravel, sand, silt, clay
PALAEOZOIC	CAMBRIAN	UPPER	Gum Ridge Formation	€mg	Calcareous sandstone, shale, chert
		LOWER	Helen Springs Volcanics	€lh	Basaltic flows and pyroclasts
PRECAMBRIAN	PROTEROZOIC	UPPER	Rising Sun Conglomerate	Pur	Conglomerate, quartzite, sandstone, shale
		UPPER & LOWER		q	Quartz (dykes and veins)
				l	Lamprophyre (dykes and veins)
		LOWER		h	Quartz-hematite-magnetite (dykes and veins)
				j	Hematite-jasper (dykes and veins)
				p	Quartz-feldspar porphyry (dykes and veins)
				fp	Quartz-baveno feldspar porphyry (dykes and veins)
				d	Dolerite (dykes and veins)
				di	Diorite
				s	Serpentine
				Pp	Quartz-feldspar porphyry
				Ppf	Quartz-baveno-feldspar porphyry
			Tennant Creek Granite Complex	Pg	Fine-grained granite
				Pg	Foliated coarse-grained porphyritic granite
				Pg	Coarse-grained granite
				Pg	Porphyritic granite (foliated in places)
			Cabbage Gum Granite Complex	Pgc	Porphyritic adamellite, gneissic granite, augen gneiss
				Pgo	Granite
			Warramunga Group	Plw	Greywacke, shale; Hematite shale; Sandstone, shale, siltstone; Pebble beds; Pebble beds; Shale, some greywacke

- Geological boundary
- Anticline, showing plunge
- Syncline
- Fault (q indicates quartz filled)

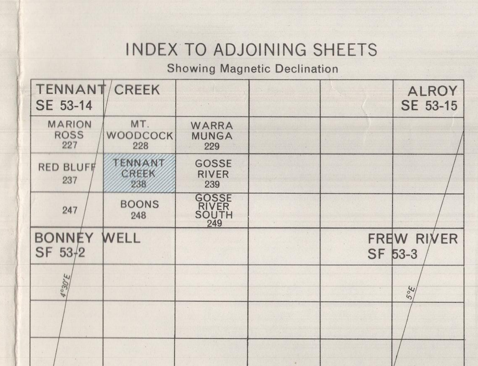
Where location of boundaries, folds and faults is approximate, line is broken; where inferred, queried; where concealed, boundaries and folds are dotted, faults are shown by short dashes

- Strike and dip of strata
- Vertical strata
- Horizontal strata
- Overturned strata
- Trend of bedding, showing direction of dip
- General strike and dip of undulating strata
- Platy flow, vertical
- Platy flow, inclined
- Strike and dip of foliation
- Plunge of drag-fold
- Plunge of minor anticline
- Shear zone
- Vertical joint
- Major mine
- Mine
- Au Gold
- Bi Bismuth
- Cu Copper
- Battery
- Macrofossil locality
- WH Waterhole
- Dam
- Water bore
- Windpump
- Tank
- HIGHWAY Highway
- Road
- Vehicle track
- Telegraph line
- Building
- Yd Yard
- Radio mast
- 1137' Height in feet, instrument levelled (datum: mean sea level)
- 1097' Height in feet, barometric (datum: mean sea level)



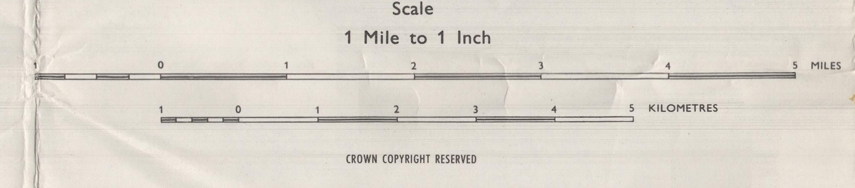
INDEX TO ADJOINING SHEETS

Showing Magnetic Declination

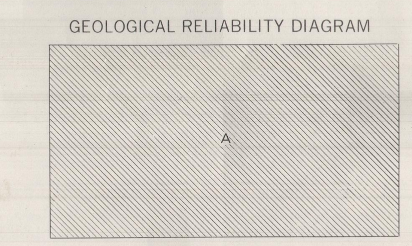


Scale

1 Mile to 1 Inch



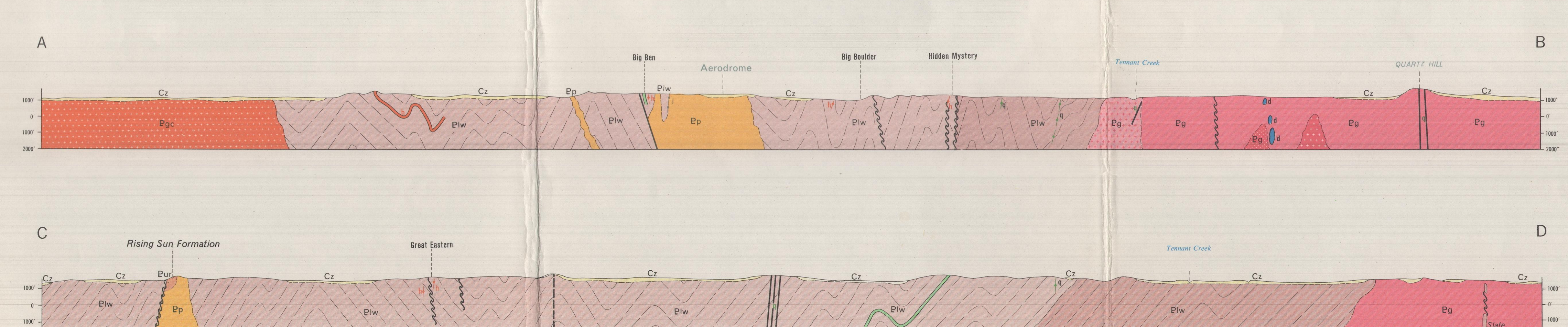
GEOLOGICAL RELIABILITY DIAGRAM



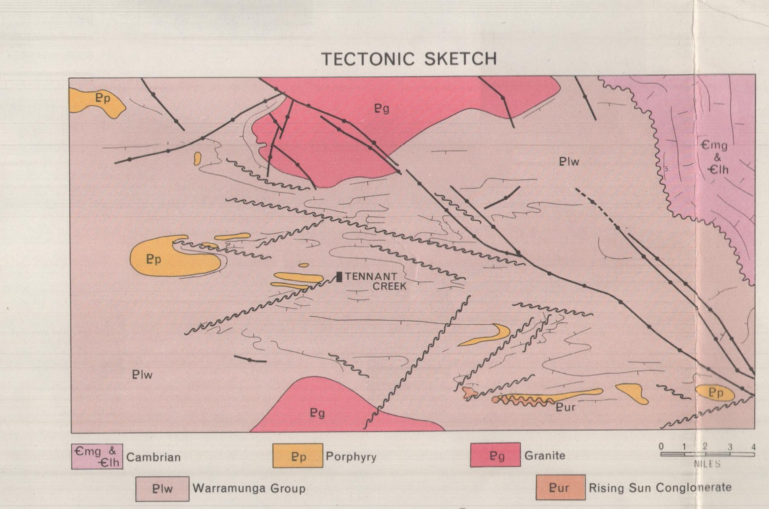
A Detailed Mapping

Sections

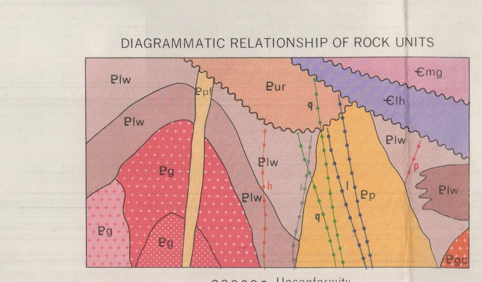
Folding Diagrammatic



TECTONIC SKETCH



DIAGRAMMATIC RELATIONSHIP OF ROCK UNITS



Printed by Mercury Press Pty. Ltd. Hobart

TENNANT CREEK

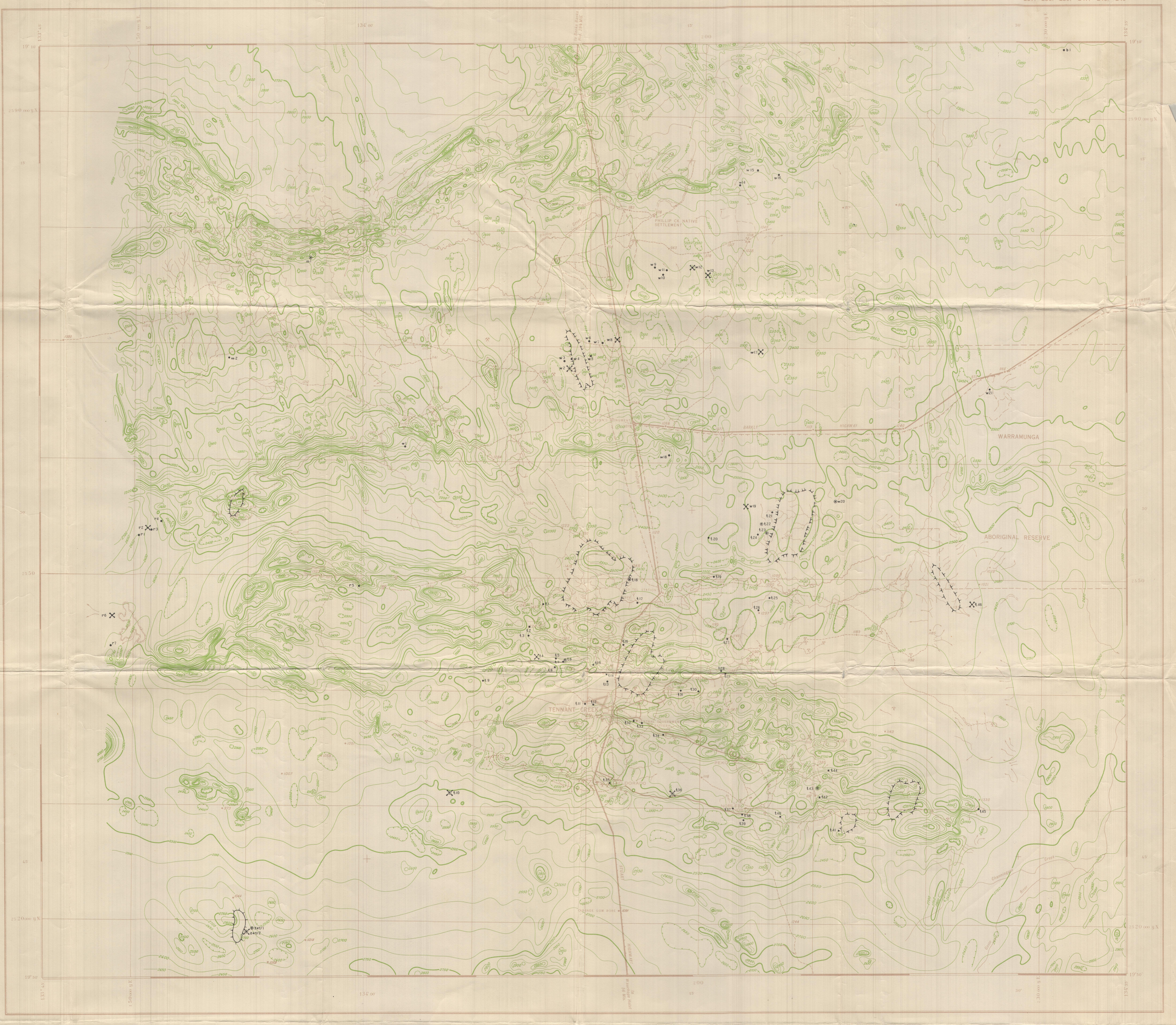
SHEET 238 ZONE 5

Copies of this map may be obtained from the Bureau of Mineral Resources, Geology and Geophysics, Canberra, A.C.T., or Darwin, N.T.

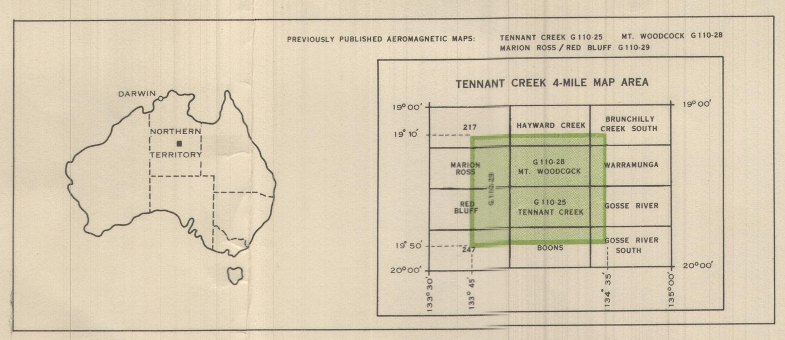
AUSTRALIA SPECIAL 1:126.720

NORTHERN TERRITORY
TENNANT CREEK (SPECIAL)

ZONE 5 SHEET E/53/14
No's. 217, 218, 219, 227, 228, 229, 237, 238, 239, 247, 248, 249

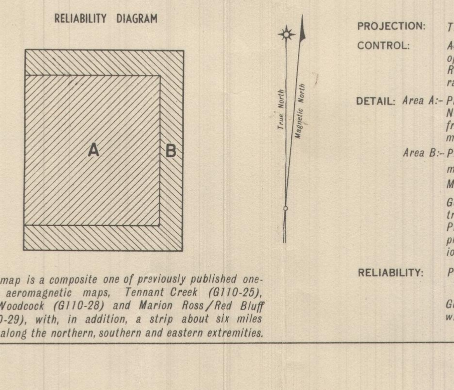


LOCATION DIAGRAM



GEOPHYSICAL SECTION, BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS AND DIVISION OF NATIONAL MAPPING, DEPARTMENT OF NATIONAL DEVELOPMENT

MAP DATA



This map is a composite one of previously published one-mile aeromagnetic maps, Tennant Creek (G110-25), Mt. Woodcock (G110-28) and Marion Ross/Red Bluff (G110-29), with, in addition, a strip about six miles wide along the northern, southern and eastern extremities.

PROJECTION: *Transverse Mercator, Australian Series.*

CONTROL: *AN-APN/3, AN-CPN/2 Shoran beacon control system operated by the Geophysical Section, Bureau of Mineral Resources, Geology and Geophysics. The beacons were ranged into existing trigonometrical survey stations.*

DETAIL: *Area A:- Planimetric detail was compiled by the Division of National Mapping, Department of National Development, from a Shoran-controlled slotted template photogrammetric assembly.*

Area B:- Planimetric detail traced from the Tennant Creek four-mile planimetric map compiled by Division of National Mapping, and adjusted to the perimeter of area A.

Geophysical data were plotted from Shoran-directed traverses at approximately one-fifth of a mile separation. Plotting and reproduction drawing of these data and completion of base map were carried out by the Geophysical Section, Bureau of Mineral Resources, Geology and Geophysics.

RELIABILITY: *Planimetric detail: Area A; reliable, within ± 75 yards. Area B; within ± 150 yards.*
Geophysical data: reliability of plotted position of aircraft, within ± 75 yards.

SCALE

MILES 2 0 2 4 6 8 MILES

YARDS 2.000 0 4 8 12.000 YARDS

MAGNETIC CONTOUR INTERVAL 50 GAMMAS

MAP SHOWING

TOTAL MAGNETIC INTENSITY

MEASURED BY AIRBORNE MAGNETOMETER

AND

RADIOACTIVE ANOMALIES

DETECTED BY AIRBORNE SCINTILLOGRAPH

LEGEND

MAGNETIC DATA

- Magnetic Contours
- Magnetic Low

TOPOGRAPHICAL DATA

- Creek or watercourse
- Highway or main road
- Road (gravelled)
- Track (vehicular)
- Buildings
- Mill
- Windpump
- Wireless mast
- Dam
- Mine
- Spot height (•1107)
- Aerodrome

SCINTILLOGRAPH ANOMALY DATA

1st Order Anomaly / 2nd Order Anomaly / 3rd Order Anomaly: *An anomaly occurs where the intensity of radioactivity is considerably above the average intensity of the area in which it occurs. An anomaly is graded as 1st, 2nd or 3rd order depending on whether the above difference of intensity is Nine, Six or Three times the random variations of intensity.*

Anomaly Sharp along Line of Flight

Intensity change A / Intensity change B / Intensity change C: *These symbols indicate a change in average intensity of radioactivity in passing from one area to another; the short hachured lines point to the area with the lower average intensity. The magnitude of the change is graded as A, B or C depending whether it is Nine, Six or Three times the random variation of intensity of the area with the lower average intensity.*

Note: *Numbering of anomalies on this map corresponds with that on previously published one-mile maps of the area. Alphabetical or numerical prefixes have been added to indicate the one-mile area in which an anomaly falls.*

EXPLANATORY NOTES

MAGNETOMETER SURVEY *The total magnetic intensity was recorded continuously along flight lines by an airborne magnetometer installed in a DC3 aircraft. The magnetometer was flown where practicable at a constant height of 500 feet above ground level along flight lines spaced one-fifth of a mile apart. The height of the aircraft was controlled through a radio altimeter and its position determined by a radar navigation aid. The magnetic data remain uncorrected for a regional gradient in total magnetic field of 11 gammas per mile in a direction S 4·5° W, but this has no adverse effect on the use of the contour map in a search for ore bodies.*

In areas where the earth's magnetic field is disturbed by the magnetisation of rocks and minerals, the magnetometer records the resultant anomalous changes in magnetic intensity. In magnetic surveys for metalliferous deposits, the anomalous changes which are most likely to be associated with ore bodies containing magnetic minerals are pronounced and localised magnetic highs.

The contour map gives a generalised picture of the anomalous changes in magnetic intensity. Owing to the limitations imposed by the flight line spacing, height of the aircraft and positioning errors, the positions of localised anomalies are not sufficiently accurate to warrant using the contour map directly as a basis for a drilling programme. It is necessary that ground magnetic surveys be conducted over the areas of anomaly in order to give greater detail and more accurate positioning so that an economical testing programme may be planned.

The contour maps of the Tennant Creek area show magnetic "ridges" or zones of high magnetic intensity of considerable linear extent. The known ore bodies are in general confined to such ridges. The effect of some of the known magnetic bodies which gave intense localised magnetic highs in previous ground surveys can be seen in high magnetic closures of small extent superimposed on the "ridges", but other bodies which gave less intense magnetic highs are not obvious in the general magnetic pattern.

The airborne results show clearly those places along the magnetic "ridges" where ground magnetic surveys should be concentrated to locate magnetic highs which might be related to magnetic ore bodies.

SCINTILLOGRAPH SURVEY *The gamma radiation from the ground surface was recorded continuously along flight lines by an airborne scintillograph. At the flying height of 500 feet, the scintillograph effectively scanned a strip of ground 250 yards wide.*

Anomalies marked on the map indicate where the radioactive intensity was substantially greater than the average intensity of the surrounding area. The sources of the anomalies may lie anywhere within a radius of 125 yards of the plotted positions of the anomalies.

Some anomalies are sharper and of more restricted length along the line of flight than others and are marked thus ⁙ on the map. They are probably due to localised sources close to the line of flight. Similar sources remote from the line of flight would give anomalies of lower relative intensity.

The average intensity may change from area to area, and where such a significant change occurs it is indicated by a symbol which shows the magnitude and direction of the change.

It should be noted that it is only the radioactivity of the ground surface that has been measured because radiation may be completely screened or substantially reduced in magnitude by a few inches of soil.

No claim is made that the anomalies correspond to uranium deposits of economic significance. Investigation on the ground is necessary to determine their importance.

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