ECONOMIC GEOLOGY RESEARCH UNIT

University of the Witwatersrand
Johannesburg

THE AGGENEYS BASE METAL SULPHIDE DEPOSITS, NAMAQUALAND, SOUTH AFRICA

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ABSTRACT

During 1971, Phelps Dodge's exploration geologists discovered three large base metal deposits at Aggeneys in the Namaqualand District of the North-western Cape Province. These deposits are known as Black Mountain, Broken Hill and Big Syncline. In January 1980, the Broken Hill deposit was brought into production at an initial milling rate of 1 125 000 tonnes per annum.

The Aggeneys copper-lead-zinc-silver deposits are located in the Precambrian metavolcano-sedimentary Bushmanland Sequence which forms part of the Namaqualand Metamorphic Complex and has an age of about 2 000 million years. The generalized stratigraphic succession encountered at Aggeneys consist of a basal gneiss unit, overlain by pink gneiss, aluminous schist, white quartzite and the Aggeneys Ore Formation, the latter comprising a 200m-thick succession of schist in which occur the three stratiform ore bodies. Overlying the Aggeneys Ore Formation, and constituting what is thought to be the top of the stratigraphic succession in the area, is a variable sequence of conglomerate, amphibolite, and grey gneiss.

Four phases of folding are recognized in the Aggeneys area and have resulted in the development of highly complex structures. The various formations, including the stratabound ore deposits, have been severely altered thermally and tectonically, thereby destroying the original character of the rocks.

The economic base metal sulphides are intimately associated with banded iron-formations and consist of varying proportions of chalcopyrite, galena and sphalerite. These, together with pyrite and pyrrhotite, often occur as massive sulphide concentrations. The ore bodies display systematic vertical and lateral variations in base metal content and mineralogy.

The Aggeneys deposits are considered to be stratabound exhalative sedimentary deposits with close genetic affiliations with the Broken Hill and Pegmont deposits of Australia and the New Brunswick deposits of Canada.

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THE AGGENEYS BASE METAL SULPHIDE DEPOSITS, NAMAQUALAND, SOUTH AFRICA

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THE AGGENEYS BASE METAL SULPHIDE DEPOSITS, NAMAQUALAND, SOUTH AFRICA

I. INTRODUCTION

The Aggeneys base metal deposits are located on the farms Aggeneys and Zuurwater in the Namaqualand District of the North-western Cape Province. Three separate ore bodies have been discovered, known as Black Mountain, Broken Hill and Big Syncline. Aggeneys is located some 110 km north-east of Springbok and 80 km west of Pofadder (Fig. 1).

The Black Mountain Company has commissioned an underground mine, concentrator and ancillary facilities required to place the Broken Hill ore body into production at an initial milling rate of 1 125 000 tonnes of ore per year. The average grade of the extractable reserves, after allowance for dilution, is 0,43 per cent copper, 6,17 per cent lead, 2,64 per cent zinc and 80 grams of silver per tonne — sufficient for a life of about 30 years.

This paper presents a synthesis of available information relating to the geology of the Aggeneys base metal deposits. The work carried out by the geological staff over a period of approximately nine years, includes regional as well as detailed surface and underground geological mapping. Furthermore the results of some 100 000 m of surface and underground diamond drilling have been considered and petrological, mineralogical and geochemical investigations are summarized.

II. HISTORY AND EXPLORATION

In 1910, the brothers Barend and Willem Burger were granted title to the farm Aggeneys. Barend Burger had eight sons and when he died in 1941, his youngest son, Wikkie, inherited Aggeneys West and later purchased portions of the farms Zuurwater and Koeris. It was on these three farms that Phelps Dodge was later to discover the large mixed base metal sulphide deposits. In 1929 Mr. Hornemann, a German prospector, obtained permission from Barent Burger to sink a prospect shaft on Swartberg. Samples of copper ore extracted from the shaft, were sent to the Cape Copper Company for testing.

Between 1929 and 1970 the occurrences of mineralization were examined by a number of geologists from different mining companies. However, for one reason or another, nothing was done until Phelps Dodge acquired prospecting options over the farms on 27th May, 1971.

On the 21st June, 1971, the first diamond drill hole on Black Mountain was collared and shortly thereafter intersected payable mineralization. This was the start of a major diamond drilling programme, during which the three large ore bodies were delineated.

Following on the initial discovery, detailed geological mapping of the immediate outcrop area on Black Mountain was initiated and an interpretation of the basic structure was undertaken. This led to a variety of exploration techniques being implemented and tested.

The occurrence of ore in an isoclinal fold, directly associated with banded iron-formations, led to a detailed ground magnetic survey of the ore body and its expected down-plunge extensions. The early success of the detailed ground magnetic survey prompted the instigation of a low level helicopter-borne survey covering an area of some 1190 km^2 around the discovery site. This was complemented by a more regional fixed-wing conventional aeromagnetic survey. From these surveys several very significant anomalies with amplitudes in excess of 7 000 gammas above background were revealed (Fig. 2).

Geochemical exploration techniques were not used in the location or definition of the deposits. However, orientation surveys were later undertaken which indicated that substantial anomalies with little spread were present at surface directly overlying the ore bodies and that very significant dispersion patterns in alluvial fans and flash-flood drainage channels were developed for distances of up to seven kilometres from known mineralization (Beeson *et al.*, 1974). The minus 10 plus 80 mesh gave better contrast in proximity to mineralized areas.

Exposure in areas not covered by dune sand is excellent and geological mapping was found to be the most useful exploration technique. Photogeological interpretation produced the overall framework upon which more detailed structural observations were later added.

Drilling commenced following recognition of the potential of the surface gossans and continued contemporaneously with many of the techniques outlined above. Drill holes were largely vertical and spaced initially at 160 m centres closing to 80 m and finally to 40 m in selected areas. Specific gravity determinations were carried out on drill cores and all mineralized zones were split and routinely analysed for total Cu, Pb, Zn and Ag. Magnetite and metal oxides were also analysed whenever they were encountered.

In January, 1974, the decision was made to obtain bulk samples from the Broken Hill ore body. A 2,44 by 2,13 m adit was collared in competent magnetite quartzite on the side of the hill and driven more or less along the strike of the ore body. The geology and grade of all section lines, as predicted from surface drilling, was checked by horizontal underground drilling. Cross cuts were driven along two section lines and bulk samples were taken. These bulk samples were then transported to the National Institute for Metallurgy (recently renamed the Council for Mineral Technology — MINTEK) and Lakefield Laboratories for metallurgical testing and pilot plant operation.

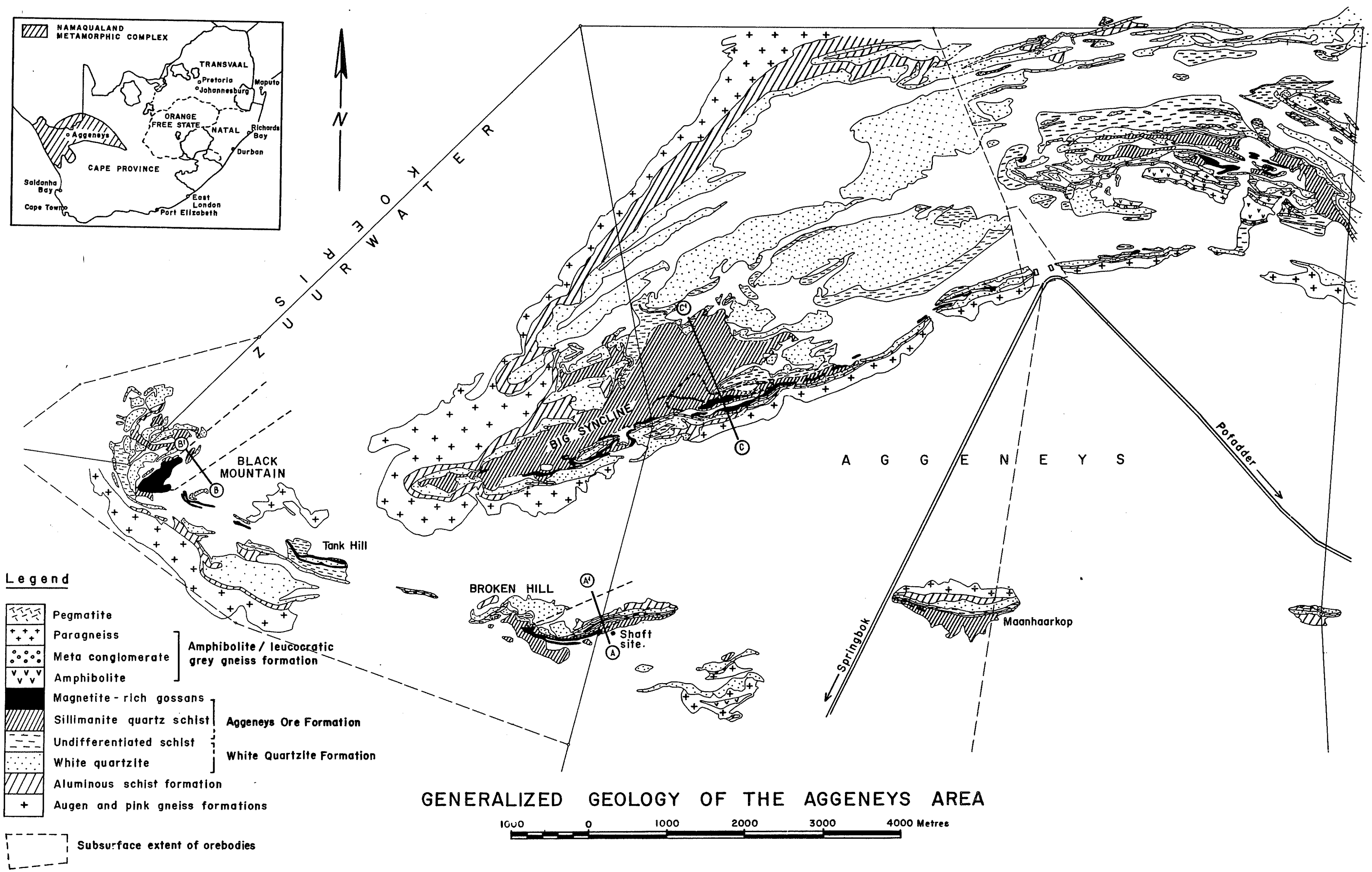

Figure 1 : *Locality map and generalized geology in the Aggeneys area, Namaqualand.*

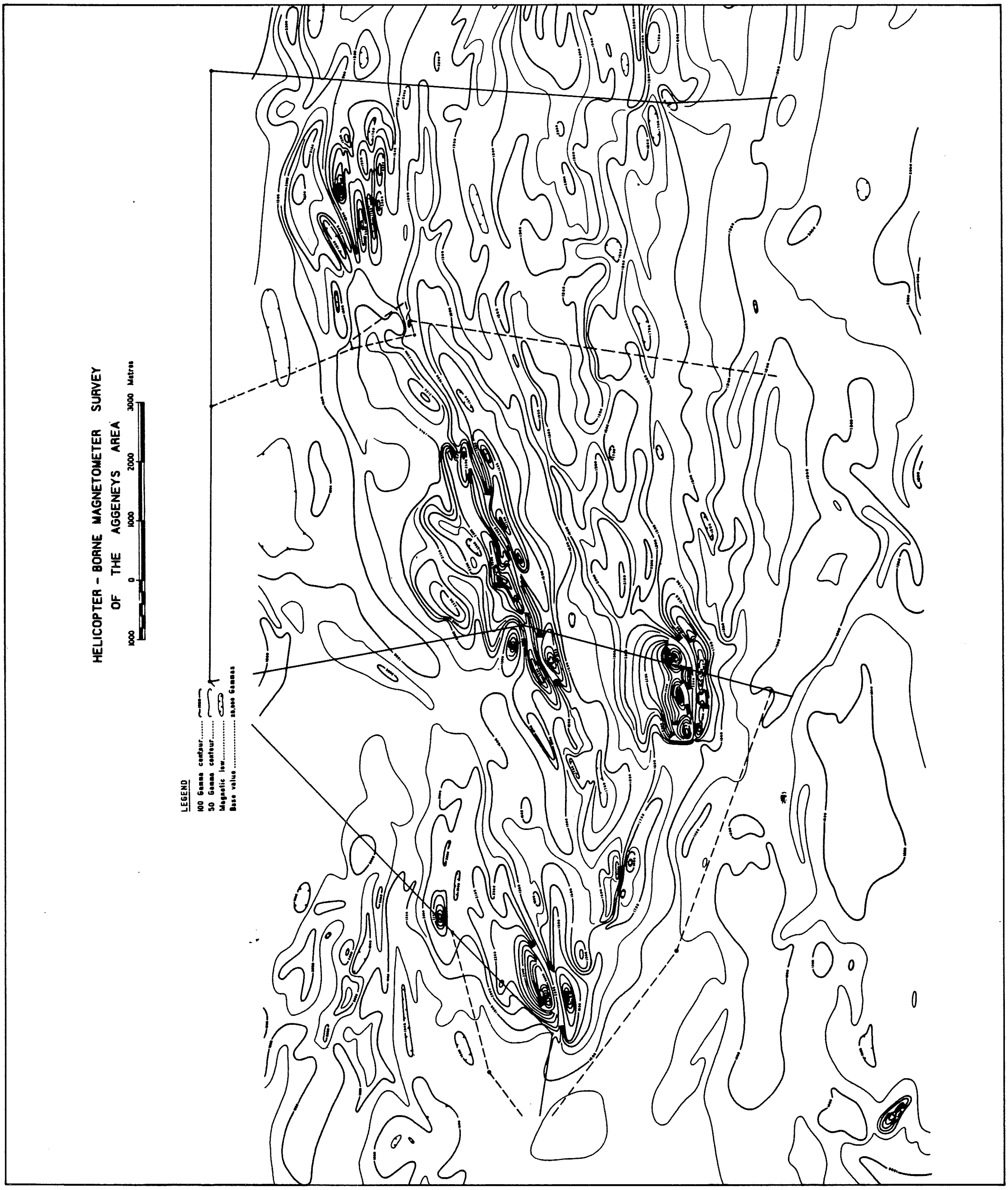

Figure 2 : Helicopter-borne magnetometer survey of the Aggeneys area.

III. REGIONAL GEOLOGICAL SETTING

Geologically the area consists of a sequence of metamorphosed Precambrian sediments, volcanics and intrusives referred to as the Namaqualand Metamorphic Complex (Joubert, 1974a).

The sequence of metasediments and metavolcanics of Bushmanland and Namaqualand have been correlated with the Kheis "System" (Mathias, 1940; Coetzee, 1940, 1941a, b, 1942, 1958; Joubert, 1971; Von Backström and De Villiers, 1972; Rozendaal, 1975; Moore,1976). Such correlations have, however, been rendered suspect by recent investigations which reveal that this "System" actually consists of formations of widely differing ages. Cornell and Barton (1979) have, for example, obtained an Archaean age (2990 ± 120 Ma) for an iron-formation in the Marydale Formation, while Malherbe (1972) has provided convincing support for a Middle Proterozoic age for the overlying Groblershoop Formation.

The Bushmanland Sequence is probably best correlated with the Haib volcanics and their metamorphosed equivalents (Bertrand, 1976, and Beukes, pers. comm., 1979) which grade into the metasediments of the Bushmanland Sequence in a southerly direction from southern South West Africa/Namibia. These volcanics have been dated at 1980 ± 40 Ma (Reid, 1977). Further support for such an age is obtained from a possible correlative equivalent in the Upington area, known as the Dagbreek Formation, which has yielded a maximum age of 2100 Ma (Malherbe, 1979).

The stratigraphic sequence generally encountered throughout Bushmanland and Namaqualand consists of a basal augen gneiss, overlain by pink gneiss, followed by amphibolite and quartz-biotite-muscovite-sillimanite schists. Overlying these rocks with a sharp contact is a prominent quartzite which is followed by a sequence of quartz-feldspar-muscovite-biotite-sillimanite schists in which occurs the banded iron-formations and the stratiform barite and base metal sulphide deposits of Black Mountain, Broken Hill, Big Syncline and Gamsberg. The regional succession is capped by amphibolite and leucocratic grey gneiss which is considered to have originally been extensively distributed throughout the region. Although most of this material has subsequently been removed by erosion it is, nevertheless, represented both at Gamsberg and Aggeneys.

The metavolcano-sedimentary units of the Bushmanland Sequence (Joubert, 1974a, b) usually occur as major, often overturned, synformal infolds in the basal gneisses. These infolds, or "schist belts" as they are known locally, generally form ranges of hills, whereas the basal gneisses usually weather negatively and underlie the sand-filled valleys (Fig. 1).

IV. GEOLOGY OF THE AGGENEYS AREA

In order to describe the geology of the Aggeneys area as a whole, a generalized account of the stratigraphy, structure and metamorphism is first outlined. Later, detailed descriptions of the geology in the vicinity of each ore body is provided.

A. Stratigraphy

A generalized stratigraphic column for the Bushmanland/Namaqualand region is shown in Table I.

TABLE I

STRATIGRAPHY OF THE NAMAQUALAND METAMORPHIC COMPLEX

Amphibolite/Leucocratic Grey Gneiss Formation	Bushmanland Sequence	Namaqualand Metamorphic Complex
Aggeneys Iron-Formation		
White Quartzite Formation		
Aluminous Schist Formation		
Pink Gneiss Formation		
Augen Gneiss Formation		

1. *Augen Gneiss Formation*

Limited outcrops of the augen gneisses occur below the pink gneiss as, for example, along the south-western flanks of the Aggeneys Mountains. Diamond drilling has, however, shown that augen gneiss sub-outcrops extensively below the cover of superficial sand and calcrete in the flats surrounding the various ranges of hills in the area (Fig. 1). When fresh the rock is light grey and rounded boulders characterize the outcrops.

The augen gneiss typically consists of leucocratic poikiloblastic microperthite augen, the latter elongated parallel to the foliation. The matrix consists of quartz, microcline (with minor perthite), plagioclase and biotite. Isolated lens-shaped xenoliths of calc-silicate rock occur within these gneisses and the contact with the overlying pink gneiss is usually sharp. Moore (1976) found, however, that the augen gneiss intrudes a prominent band of amphibolite at the base of the supracrustal sequence in the Namies Mountains some 20 km to the east.

2. *Pink Gneiss Formation*

The pink gneiss outcrops extensively along the western flanks of the Swartberg range and as a continuous outcrop around the Aggeneys Mountains. This formation is estimated to have a maximum thickness of 20 m. In outcrop it weathers to a pink-brown colour, often displaying granitic exfoliation. The contact with the overlying Aluminous Schist Formation is usually sharp.

Thin discontinuous layers and lenses of schist, quartzite and amphibolite occur within the pink gneiss. In thin section the rock has a heteroblastic texture and consists of quartz, microcline, perthite, plagioclase and small amounts of biotite and opaque minerals.

3. *Aluminous Schist Formation*

The aluminous schist outcrops extensively along the western slopes of the Swartberg range and almost continuously around the margins of the Aggeneys Mountains. It is also known to exist below the scree slopes on the northern side of Broken Hill. It forms a sharp conformable contact with the overlying White Quartzite Formation and has an average thickness of about 80 m (Fig. 1).

The schists weather negatively and are usually mantled by a thin layer of hillslope scree. The schists are composed mainly of quartz, muscovite, K-feldspar and ore minerals. In some areas sillimanite and biotite each constitute in excess of 25 per cent of the rock. De Jager and Von Backström (1961) noted that virtually all the deposits of sillimanite in the Bushmanland/Namaqualand region occur in the Aluminous Schist Formation. Common accessory minerals in the aluminous schists include tourmaline, spessartine-almandine garnet, rutile, anatase, hematite and ilmenite.

4. *White Quartzite Formation*

Due to the resistant nature of the quartzite, it usually occurs as a protective cap to the ranges of hills in the area (e.g. in the Aggeneys Mountains and along the crest and northern flanks of Broken Hill). According to Lipson (1978), the quartzite varies in thickness from 5-900 m and averages about 50 m in the Aggeneys Mountains. Thicknesses in excess of 100 m are usually the result of duplication due to folding (Fig. 1).

The quartzite is milky white to grey and displays a glassy texture. It consists of about 95 per cent recrystallized quartz, with lesser amounts of muscovite, sillimanite, biotite, magnetite and rutile.

The white quartzite often contains an irregular, discontinuous, zone of pelitic schist (5-10 m thick) near the top of the formation, displaying gradational contacts with the quartzite. The pelitic schist consists of quartz, muscovite, biotite, sillimanite, magnetite and garnet. The schist weathers negatively and has the effect of dividing the White Quartzite Formation into two more or less parallel ridges, a good example of which is seen at Broken Hill. At Tank Hill and Broken Hill (Fig. 1) thin lenses of magnetite amphibolite and magnetite quartzite occur within the schist. The magnetite-rich rocks on Broken Hill contain small quantities of copper mineralization.

The upper contact of the White Quartzite Formation, with the overlying Aggeneys Ore Formation, can be either gradational or sharp.

5. *Aggeneys Ore Formation*

The Aggeneys Ore Formation derives its name from the fact that the Black Mountain, Broken Hill and Big Syncline stratiform ore bodies all occur within this part of the sequence. Although not proved, it seems likely that this unit is the stratigraphic equivalent of the total succession extending from the base of the "Gams Iron-Formation to the base of the Psammitic Schist Member" (as defined by Rozendaal, 1975), and in which the Gamsberg zinc deposit, located some 15 km to the east, occurs.

Essentially the Aggeneys Ore Formation consists of a 200 m-thick succession of quartz-muscovite-biotite-sillimanite schist interbanded in places with thin units of micaceous quartzite and calc-silicate rock. In places the Aggeneys Ore Formation schists contain abundant K-feldspar and lesser amounts of plagioclase. Almost all the known banded iron-formations as well as the bedded sulphide and barite deposits occur in this succession which will be described in detail when discussing the individual ore bodies.

The schist which occurs stratigraphically above the magnetite-rich ore body at Broken Hill, is characterized by the presence of 3-6 per cent pyrite which, on weathering, gives these rocks a reddish-brown gossanous appearance. Lipson (1978) is of the opinion that the schist comprising the upper portion of the Aggeneys Ore Formation at Black Mountain and Broken Hill, is the stratigraphic equivalent of the Spring Schist and Quartzite Formation in the Aggeneys Mountains and in which the Big Syncline ore body occurs.

The top of the Aggeneys Ore Formation is not well-exposed in the Aggeneys area, but drilling to the south of Broken Hill has indicated that a leucocratic grey gneiss probably constitutes the top of the stratigraphic succession in this area. However, in the southeastern portion of the Aggeneys Mountains, Lipson (1978) found that the Aggeneys Ore Formation is probably terminated by a sequence of amphibolites and grey gneiss.

Geological mapping by Joubert (1972, 1974a), Stedman (1974, Unpubl. Company Rep.), Rozendaal (1975, 1978), Moore (1976), and Lipson (1978) has shown that this economically important mineralized unit must originally have been extensively distributed throughout the Namaqualand-Bushmanland region, but that subsequent erosion has resulted in vast areas being completely removed. Only in a limited number of areas where the formation occurs in synformal fold structures has it been preserved.

6. Amphibolite/Leucocratic Grey Gneiss Formation

Due to a lack of data, the grey gneiss is poorly defined at present. However, in the eastern portion of the Aggeneys Mountains mapping has shown that at a stratigraphic level deduced to be above the White Quartzite Formation, quartzites grade into conglomeratic bands which in turn are interbanded with a highly variable succession of gneisses and amphibolites. Whereas the conglomerate pebbles are mainly quartzite fragments in a quartz-mica matrix, the leucocratic gneisses consist of quartz, feldspar and muscovite, and the more mafic gneisses consist of biotite, amphibole and magnetite in a matrix of quartz and feldspar. The amphibolites, in which hornblende is the predominant mineral, contain quartz-filled "amygdale-like" structures.

In the axial portion of the synclinal structure at Broken Hill, drilling has revealed the existence of a tight synclinal keel of leucocratic grey gneiss consisting of quartz, K-feldspar, plagioclase and subordinate biotite within an envelope of amphibolite, and these rocks are thought to terminate the stratigraphic succession in this area. Although by no means proved, it is tentatively suggested that these rocks can be correlated with the variable amphibolite and gneiss succession in the eastern portion of the Aggeneys Mountains.

V. STRUCTURE

A comprehensive analysis of the structural geology of the Aggeneys area is beyond the scope of this paper, but a limited amount of detail is provided for the individual ore bodies in the following sections. Joubert (1971) recognized the existence of polyphase deformation in the Aggeneys area which he termed, from oldest to youngest, F_1, F_2, F_3 and F_4.

A. First Phase of Deformation (F_1)

Reservations concerning the positive identification of F_1 folds at Broken Hill and elsewhere in the district have been expressed by some company geologists. Others have postulated large scale F_1 folds to explain the complex structure of the Black Mountain and Broken Hill ore bodies and the southern area of the Aggeneys Mountains. According to Joubert (1971), F_1 deformation is characterized by isoclinal folds with sharp tapering hinge zones and axial planes parallel to the prevalent banding. No associated lineation has been recognized with this phase of deformation.

B. Second Phase of Deformation (F_2)

This is the most important period of deformation as most of the ore bodies appear to be localized in the vicinity of F_2-fold closures where thickening of individual zones of mineralization has occurred. The folds are isoclinal and display rounded hinged zones. They are generally symmetrical, but asymmetric minor folds also occur. Limbs of folds are characteristically long, and the axial planes are usually inclined due to overturning. In certain lithotypes axial-planar schistosity, penetrating through the hinge zones, was found to be one of the most useful characteristics in recognizing F_2 folds. The plunge of F_2 fold axes is generally to the north-east and east, as for example at Black Mountain and Broken Hill. Lipson (1978) found ℓ_2 lineations, rods, and minor fold hinges to be the best developed linear features associated with any period of deformation in the Aggeneys Mountains and this observation can be said to hold true throughout the entire area.

C. Third Phase of Deformation (F_3)

The third phase of deformation was responsible for the large-scale, open, asymmetric, synformal and antiformal structures in the Aggeneys area (Fig. 1). It is also usually responsible for the preservation of the Bushmanland Sequence (as defined by Joubert, 1974a) in the major synforms and the exposures of underlying gneisses in the cores of F_3 antiforms.

Weak re-foliation in s_3 and a poorly defined ℓ_3 lineation has been observed at Broken Hill, Black Mountain and in the Aggeneys Mountains. The axial planes of F_3 folds are usually vertical or steeply dipping to the north and strike to the east-north-east. The plunge of the fold axes is east-north-east at 20-30°, except where locally bent by F_4 folds.

D. Fourth Phase of Deformation (F_4)

The fourth deformational event is represented by north and north-north-west trending monoclinal folds with steep limbs which dip to the east, and by northerly trending faults, fractures, and shear zones.

These structures have been encountered in the underground workings at Broken Hill, at Black Mountain and in the Aggeneys Mountains. They deform all pre-existing structures and their influence is mostly evident in the closure areas of F_2 and F_3 folds.

VI. METAMORPHISM

The metamorphic nomenclature employed in this paper follows that of Winkler (1976). "Low grade" coincides with greenschist facies, "medium grade" with most of the amphibolite facies, while "high grade" corresponds with granulite facies and the upper amphibolite facies. High grade is characterized by "the coexistence of K-feldspar with Al_2SiO_5 and/or almandine and cordierite" (Winkler, 1976, p. 65).

Joubert (1974a) concluded that in the Pofadder area, to the east of Aggeneys, the main period of deformation (F_2) was accompanied and outlasted by the highest degree of metamorphism (M_2) which ranged from medium to high grade. Moore (1976) recognized at least three metamorphic events for the Namiesberg to the east of Gamsberg, and Rozendaal (1978) found that, in the Gamsberg, prograde metamorphism falls within medium grade, bordering on high grade, with prevailing temperatures of 630°-670°C and pressures of 2,8-4,5 kb. Lipson (1978) recognized four episodes of metamorphism in the Aggeneys Mountains the first two (M_1 and M_2) being retrograde.

Little can be concluded from the (M_1) metamorphism as recrystallization during the (M_2) event has, to a large extent, obliterated much of the evidence. However, based on thin section investigations, it is suggested that (M_1) metamorphism was the same or slightly lower in grade than (M_2).

Based on the mineral paragenesis observed in thin sections derived from Black Mountain, Broken Hill and Big Syncline, it has been concluded that the main metamorphic event (M_2) was one of medium grade, bordering on high grade. Some schist units possessing specific albite/anorthite ratios show partial anatexis.

The presence of orthoclase, sillimanite and cordierite in the Aluminous Schist Formation, diopside in the amphibolites, and grossular garnet in the calc-silicate rocks, confirms the high temperature of this metamorphic event. Temperatures of 670°-695°C and pressure of 3,4-6,0 kb are thought to have existed.

Retrograde metamorphism (M_3) followed the M_2 event resulting in garnets altering to chlorite, sillimanite to sericite and plagioclase to sericite and epidote. Talc is also present. Assuming that the pressure remained the same as, or lower than during M_2, then temperatures of approximately 440°C are indicated.

The distinctive mineralogy of the banded iron-formations at Broken Hill aided in the identification of the pre-metamorphic mineral assemblages. The occurrence of fayalite is highly distinctive and has previously been described in the Pegmont lead-zinc deposit in Queensland Australia (Stanton and Vaughan, 1979).

The sulphide-rich sections of the iron-formations show many of the features now regarded as typical of the metamorphism of sulphides. The predominance of pyrrhotite over pyrite, the large amounts of Fe in the sphalerite, the frequent euhedral nature of the pyrite, sulphide breccias, and the coarseness of the individual sulphide grains, as well as remobilized coarse-grained cross-cutting veins, are all characteristics indicative of relatively high grade metamorphic deformation of a pre-existing sulphide deposit.

Within the banded iron-formations thin bands of sulphides, some of which contain rounded fragments of the enclosing rock type (usually arranged parallel to foliation), and frequent hair-like veins (mainly consisting of galena or sphalerite), spread out from the breccia into the adjoining rock. Brecciation here is most probably due to translation along the sulphide bands. Elsewhere, particularly in the schistose and baritic sulphide zones, flow-type folding and "raindrop" folds (i.e. closures detached from their limbs) were observed.

The presence of the zinc spinel gahnite, which occurs in small quantities throughout the mineralized zones, but is commonest at the contact of cross-cutting pegmatites, is regarded as having been derived from the metamorphism of sphalerite (Suffel *et al.*, 1971).

VII. THE BROKEN HILL ORE BODY

The location of the Broken Hill deposit and its position relative to the other two ore bodies in the Aggeneys region is shown in Fig. 1. The deposit outcrops on the southern slopes of Broken Hill as a well-defined, 600 m-long, east-west striking massive and magnetite-rich gossan. The outcrop is terminated to the east and west by north-east plunging isoclinal fold closures (Fig. 3). Surface diamond drilling has proved a down plunge extent of 1 200 m and, to date, the in-depth limits of the ore body have not been fully defined. The *in situ* geological ore reserve for the Upper and Lower ore bodies was found to be :

Tonnes 000's	SG	Cu %	Pb %	Zn %	Ag gm/ton	Magnetite %
85 000	3,80	0,34	3,57	1,77	48,10	48,90

The average grade and tonnage of the Upper and Lower ore bodies at an economic underground mining cut-off, was found to be :

Tonnes 000's	SG	Cu %	Pb %	Zn %	Ag gm/ton	Magnetite %
37 900	3,94	0,45	6,35	2,87	82,25	43,19

Exploration and evaluation of the deposit was achieved by detailed surface mapping, the systematic logging and sampling of 167 surface diamond drill holes and of some 200 underground holes. Based on this information, it has been possible to establish a geological succession in spite of the fact that shearing, accompanied by thickening or attenuation and frequent dismembering of the lithological units, has locally obscured some of the details.

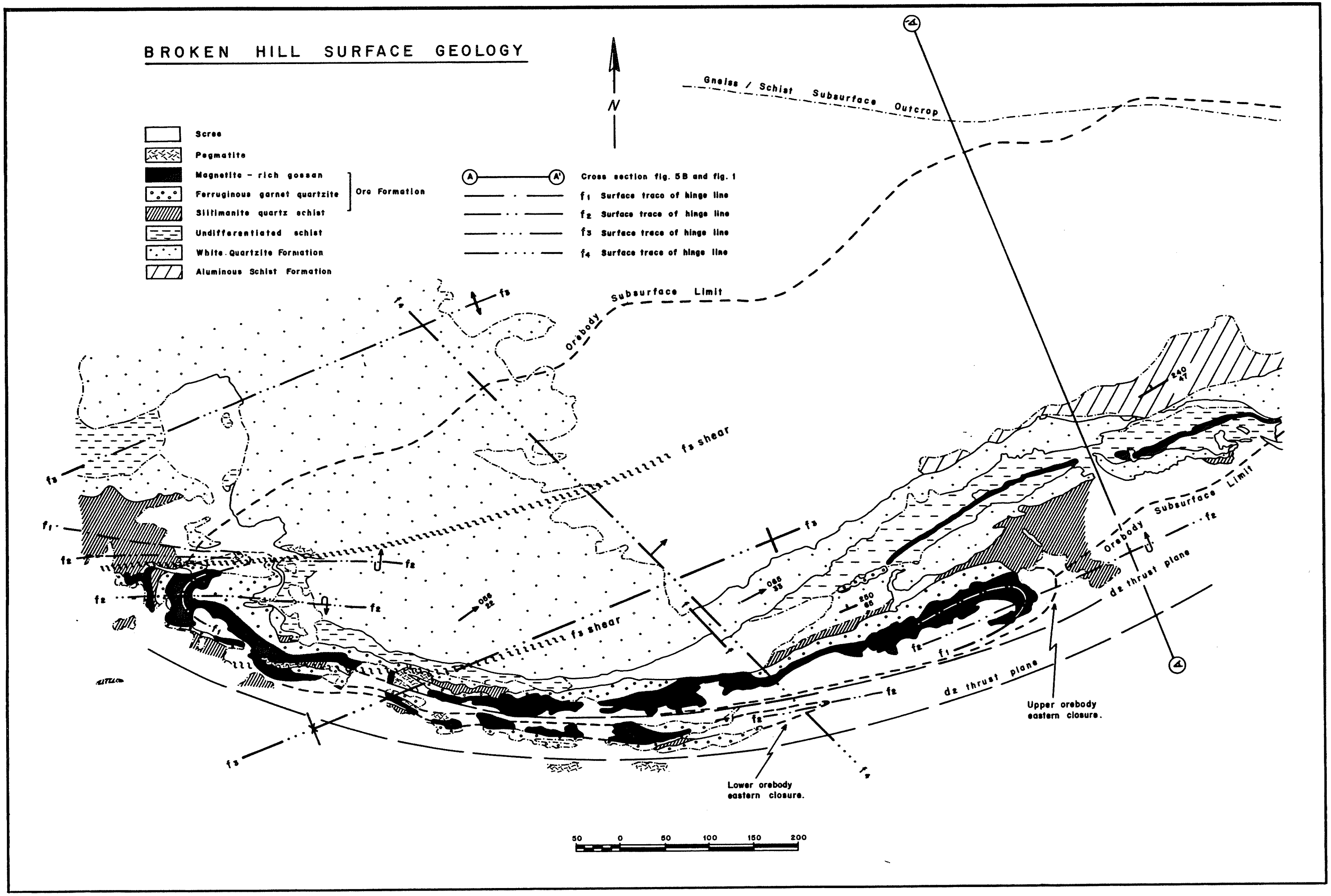

Figure 3 : *Surface geological map of the Broken Hill ore body, Aggeneys area.*

A. Stratigraphy

At Broken Hill an Upper and a Lower ore body, separated in part by unmineralized sillimanite-quartz schist, have been recognized. The precise relationship between these two ore bodies is not yet fully understood. The original depositional sequence (Fig. 4A) is thought to have been overfolded (Fig. 4B) and then refolded (Fig. 5A and 5B). The succession in the Broken Hill deposit is depicted in Fig. 5 and is derived from section A-A1 (Fig. 5B). In the sections that follow a more detailed account of the stratigraphic succession in the vicinity of the ore bodies is provided.

1. *Upper Ore Body Succession*

The stratigraphic succession in the Broken Hill deposit has been overturned by folding resulting in the lower formations occurring both in the hangingwall of the Upper ore body and in the footwall at depth (Figs. 4, 5). Therefore, in section A-A1 (Fig. 5), the *sillimanite-quartz schist* (4.1) lies stratigraphically "above" the White Quartzite Formation and consists of sillimanite (10-20%), quartz (30-40%), biotite (5-25%), garnet (5-15%), muscovite and feldspar.

The *ferruginous garnet quartzite* (4.2 and 4.13) consists of thin bands of magnetite (5-20%), and garnet (5-10%), set in a quartz matrix. The magnetite content increases stratigraphically upwards and its topmost layers are gradually replaced by magnetite quartzite.

The well-banded *magnetite quartzite* (4.3, 4.5, 4.10 and 4.12) is the predominant unit in the Upper ore body succession. It consists of thin, alternating, bands of magnetite and quartz with the magnetite content ranging from 40-60 per cent. Other minerals present include garnet (up to 15%), and minor biotite. Base metal sulphides, including galena, sphalerite and chalcopyrite are disseminated throughout this unit.

The banded magnetite quartzite in turn grades into a banded *magnetite amphibolite* (4.4 and 4.11) consisting of thin, alternating, bands rich in quartz, spessartine garnet, magnetite, orthopyroxene, grunerite, cummingtonite and fayalite. The combined base metal content is slightly higher than the magnetite quartzite. The magnetite amphibolite is considered to be the highest stratigraphic unit of the Upper ore body succession as shown in Fig. 4A).

The *baritic and banded massive sulphide units* are of limited distribution and lie stratigraphically below the magnetite quartzite (Fig. 4A).

The *baritic massive sulphide* (4.6) is localized in extent and grades laterally into banded massive sulphide. It occurs directly below, and in sharp contact with, the magnetite quartzite. Barite constitutes 3-50 per cent of the rock and averages about 15 per cent.

The *well-banded pyrrhotite-pyrite massive sulphide* (4.9) is the host rock to the bulk of the chalcopyrite, galena, sphalerite and silver mineralization in the ore body. The combined pyrrhotite and pyrite content ranges from 15-50 per cent. The dominant gangue silicate mineral is quartz. This unit is often coarsely recrystallized and brecciation of the base metal sulphides occurs along the sharp upper contact with the overlying magnetite quartzite. The recrystallized equivalent of this unit has been called the *massive sulphide* unit (4.7).

The *sulphide quartzite* (4.8) lies stratigraphically below the massive sulphide units (Fig. 4A) and is preserved in the core of the F_2 fold (Fig. 5A) about which the entire succession has been refolded. Quartz is the predominant mineral with very finely disseminated pyrite, pyrrhotite, chalcopyrite, galena and sphalerite as accessory minerals. The contact with the banded massive sulphides is gradational.

2. *Lower Ore Body Succession*

The two ore bodies are separated by the *sillimanite-quartz schist* (5.1 - Fig. 5). The *ferruginous garnet quartzite* (5.2 and 5.6) which lies structurally below the schist (Fig. 5B) is essentially the same as that described in the Upper ore body. The Lower ore body differs in that the ferruginous quartzite generally grades stratigraphically upwards into magnetite amphibolite (5.3 and 5.5) instead of magnetite quartzite as is the case in the Upper ore body. The base metal mineralization, particularly the galena, is very finely disseminated and of a higher grade than in the equivalent unit in the Upper ore body.

The *massive sulphide* (5.4) is very much thinner than in the Upper ore body and is largely a recrystallized massive sulphide.

The Lower ore body succession is characterized by an overall thickening down plunge to the north-east, where the width of the Upper ore body correspondingly decreases.

The *pyritic graphitic biotite schist* is a distinct zone about 17 m wide within the footwall succession (Fig. 5). The stratigraphic position of this unit, relative to the ore bodies, is uncertain as thrust faulting on a significant scale has possibly occurred between the Upper and Lower ore bodies and in the pyritic graphitic biotite schist.

The unit consists of biotite (40-60%), quartz (20-40%), variable amounts of clay, and lesser amounts of muscovite, feldspar, graphite and pyrite. Numerous pegmatites occur in this zone and appear to have been emplaced along shears and planes of weakness, thereby adding weight to the argument that the unit represents a major zone of thrusting. The pyritic graphitic biotite schist grades into a *pyritic sillimanite-quartz-biotite schist*, the latter thought to be the stratigraphic equivalent of the Spring Schist and Quartzite Member in the Aggeneys Mountains (Lipson, 1978).

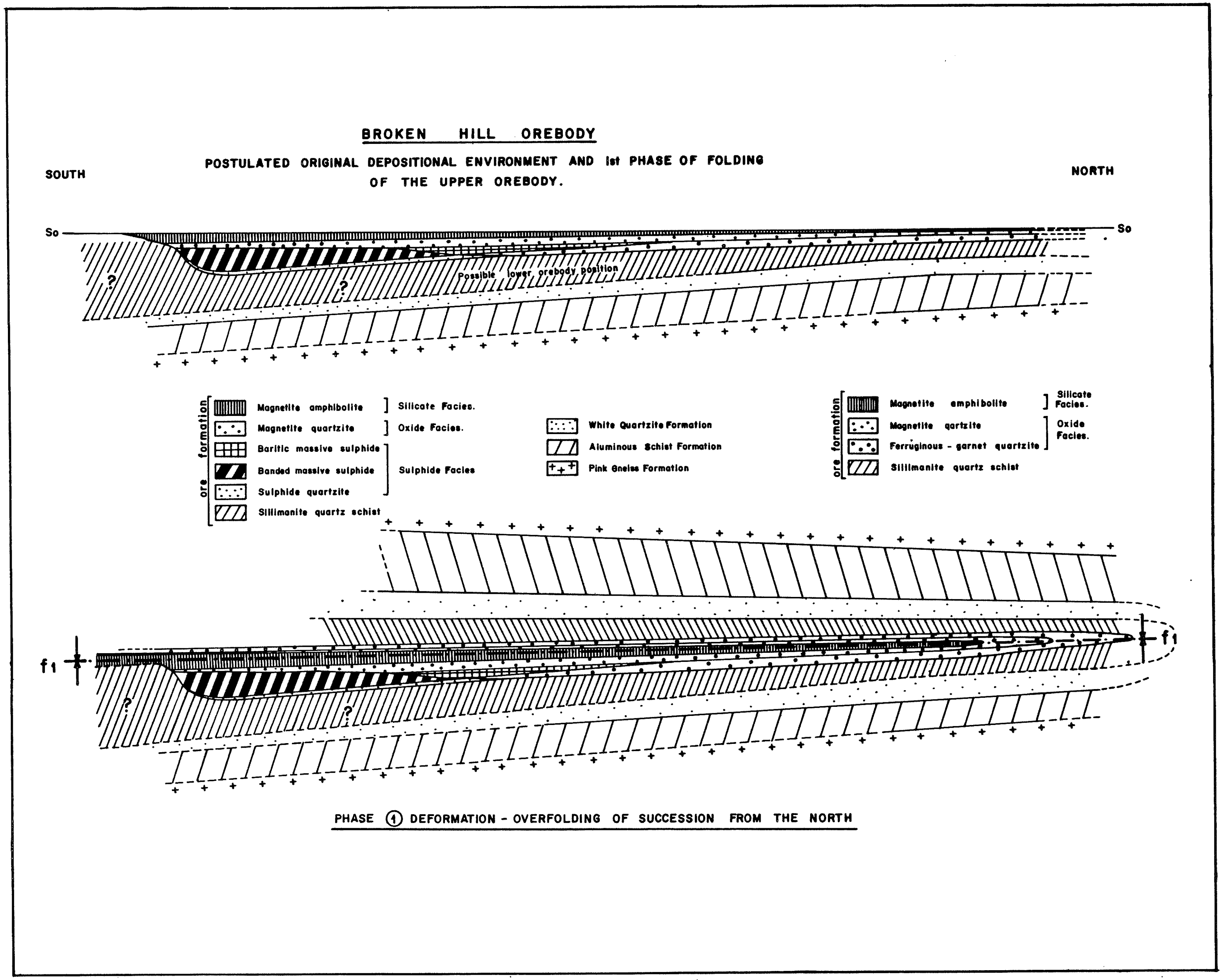

Figure 4 : *Idealized sketches of the depositional environment and phase 1 folding of the Broken Hill ore body.*

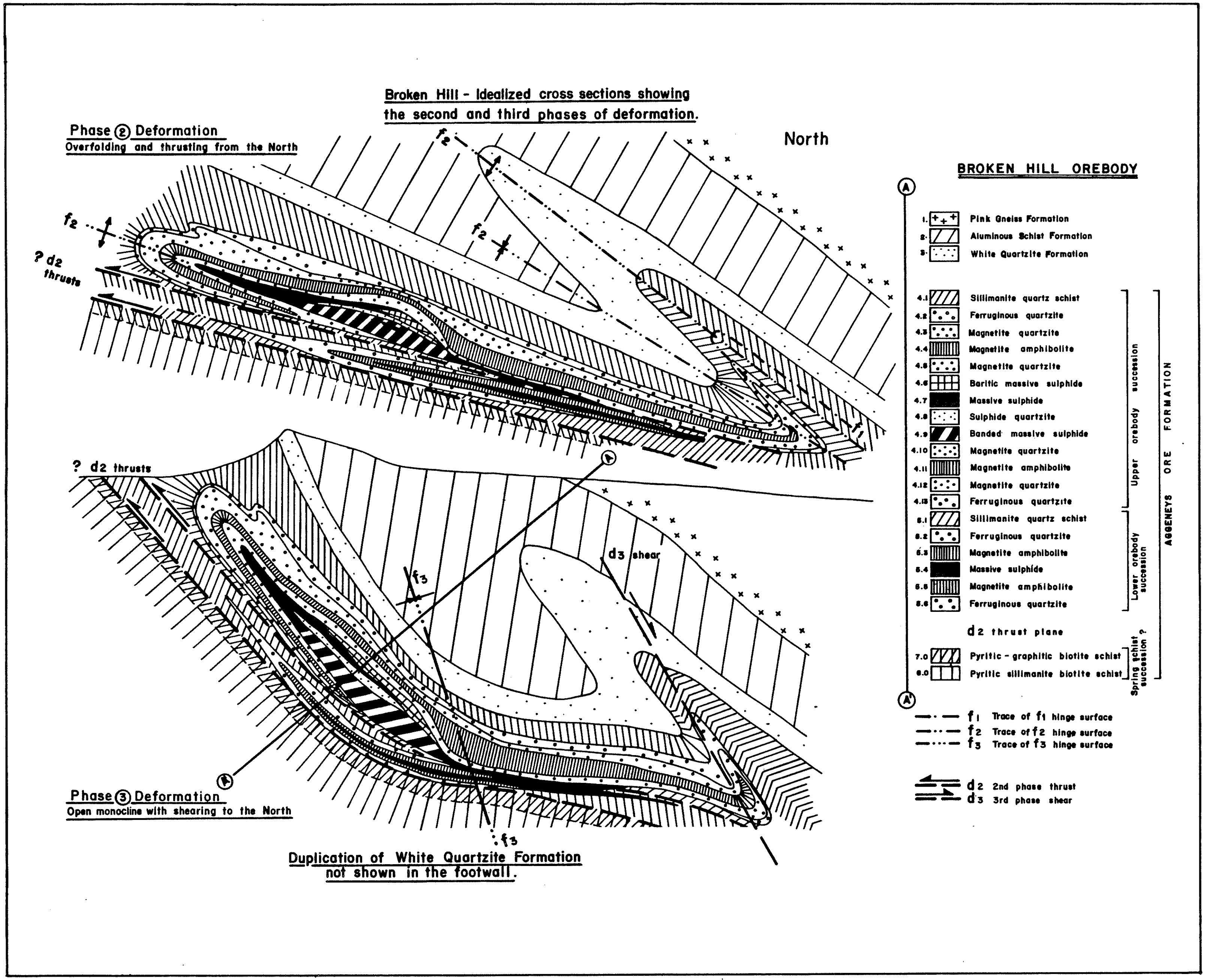

Figure 5 : Idealized sketches of phases 2 and 3 folding of the Broken Hill ore body.

B. Structure

The Broken Hill deposit is exceedingly complex structurally and many questions remain unanswered. The following model employs four phases of deformation to explain the complex structural relationships. It must, however, be stressed that a number of alternate models have been proposed by company geologists in the past.

1. *First Phase of Deformation (F_1)*

A large-scale F_1 fold is postulated at Broken Hill. This feature is suggested by an isoclinal closure outcropping on the western extremity of the ore body (Fig. 3), and is apparently responsible for duplication of the ferruginous garnet quartzite in the west and the magnetite quartzite and magnetite amphibolite units throughout the ore body (Figs. 4B and 5A).

Characteristic copper: lead + zinc ratios in the ore-bearing units of the Upper ore body, and the expected reversal of these ratios about the F_1 axial plane, lend support to this theory. The inversion of the entire stratigraphic succession at Broken Hill (Fig. 4B) is thought to have occurred during F_1. The long tapered north-eastern limit of the Upper ore body succession (Fig. 6) is thought to represent the east-west trending F_1 closure.

2. *Second Phase of Deformation (F_2)*

Two prominent F_2 isoclinal fold closures terminate the Upper ore body on the eastern and western extremities (Figs. 3, 6). These two large-scale folds plunge N 60°E at 25°, which is the same as the overall plunge of the Broken Hill deposit. The folds are symmetrical with rounded hinge zones. Smaller folds of the same generation are formed along the limbs of these major folds and are characterized by tightfolds on the lower limbs and more open folds on the upper limbs of the eastern F_2 fold.

The Lower ore body is also thought to be terminated on its eastern extremity by a tight, plunging F_2 fold, the limbs of which have been attenuated and dismembered in the west (Fig. 3). As the limbs are parallel to the banding, S_2 foliation is essentially parallel to S_1. Refoliation in the hinge zones is not a prominent feature at Broken Hill and has only been observed, to a limited extent, in the hinge zone of the eastern closure.

The effect of F_2 deformation on the two ore bodies resulted in the refolding of the postulated F_1 fold (Figs. 4B, 5A), while the banded massive sulphide unit of the Upper ore body was folded for the first time (Fig. 5A). During this deformation phase most of the remobilization, recrystallization and brecciation of the banded massive sulphide is thought to have occurred. Coarse, transgressive, galena-rich veinlets also occur commonly in the massive sulphide units situated in the core of the F_2 closure (Fig. 5A). Intrusions of massive sulphide into the footwall sillimanite-quartz schist have been observed. The thrust faulting described earlier is thought to have taken place during F_2 deformation (Fig. 5A).

3. *Third Phase of Deformation (F_3)*

The F_3 deformation phase at Broken Hill is characterized by a left-lateral drag fold. The axial plane of the synclinal part of this fold is nearly vertical and strikes in a direction N 70° E. The F_3 deformation is also responsible for the change in dip of the ore body from 60° to 20° (Figs. 5B, 7). No significant refoliation occurred during this phase. The fold is situated immediately south of a shear zone, thought to be F_3 in age (Fig. 5B), which is evidenced by lateral movement of the White Quartzite Formation in the hanging wall of the ore body and extensive pegmatization of the schists and quartzites along the shear (Figs. 3, 5).

4. *Fourth Phase of Deformation (F_4)*

The F_4 phase at Broken Hill is characterized by relatively small monoclinal folds with the steeper limb to the east (Fig. 7). These folds trend in the direction N 46°W and, as described by Joubert (1971), they are not continuous and die out fairly rapidly along strike. Movement along associated fracture zones is always right lateral and the failure planes are vertical or dip steeply to the east. The effects of F_4 folding on the ℓ_2 lineation is pronounced and is seen in the periodic increase and decrease of the angle of plunge across the trend of F_4 folds. The steepening is well-illustrated by an analysis done on the footwall surface contours of the Upper ore body unit (Fig. 7).

C. Mineralogy

The mineralogy of the Broken Hill ore is complex and approximately 40 minerals have been identified in core samples. According to S.A. de Waal (1974, confidential N.I.M. report) the Broken Hill ore is, in essence, a fine-to medium-grained, banded granulite with zones of brecciation in which coarsely crystalline sulphide material has concentrated. The relative abundance and dispersion of the minerals in the Broken Hill ore body is illustrated in Fig. 8 (after de Waal, ibid). It was possible to make a provisional classification of the minerals into three genetic groups, namely, primary metamorphic, retrograde metamorphic and supergene alteration products (Table 2). The following features of interest were noted by de Waal:-

1. The primary metamorphic minerals appear in varying proportions and constitute the mosaic framework of the granulite. Most of the minerals form stout crystals and are xenoblastic to subxenoblastic, with the exception of magnetite, apatite and zircon, which are distinctly idioblastic in places. Signs of mineral strain and fracturing are visible in most rocks, particularly the breccias,

2. The primary metamorphic carbonate is sideritic, which corresponds with the iron-rich character of the other minerals,

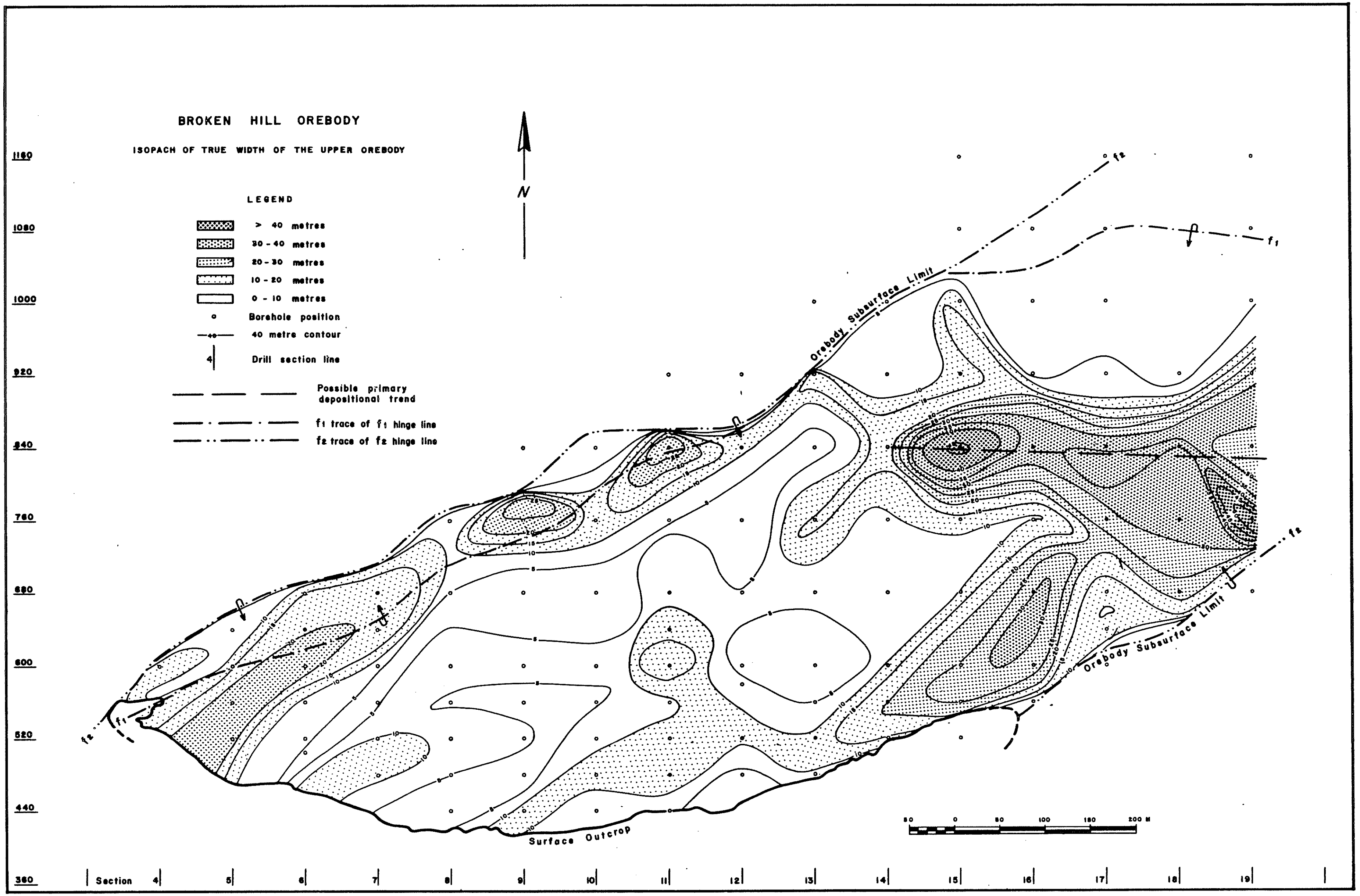

Figure 6 : *Isopach map of the Upper ore body at Broken Hill. Phases 1 and 2 folding depicted.*

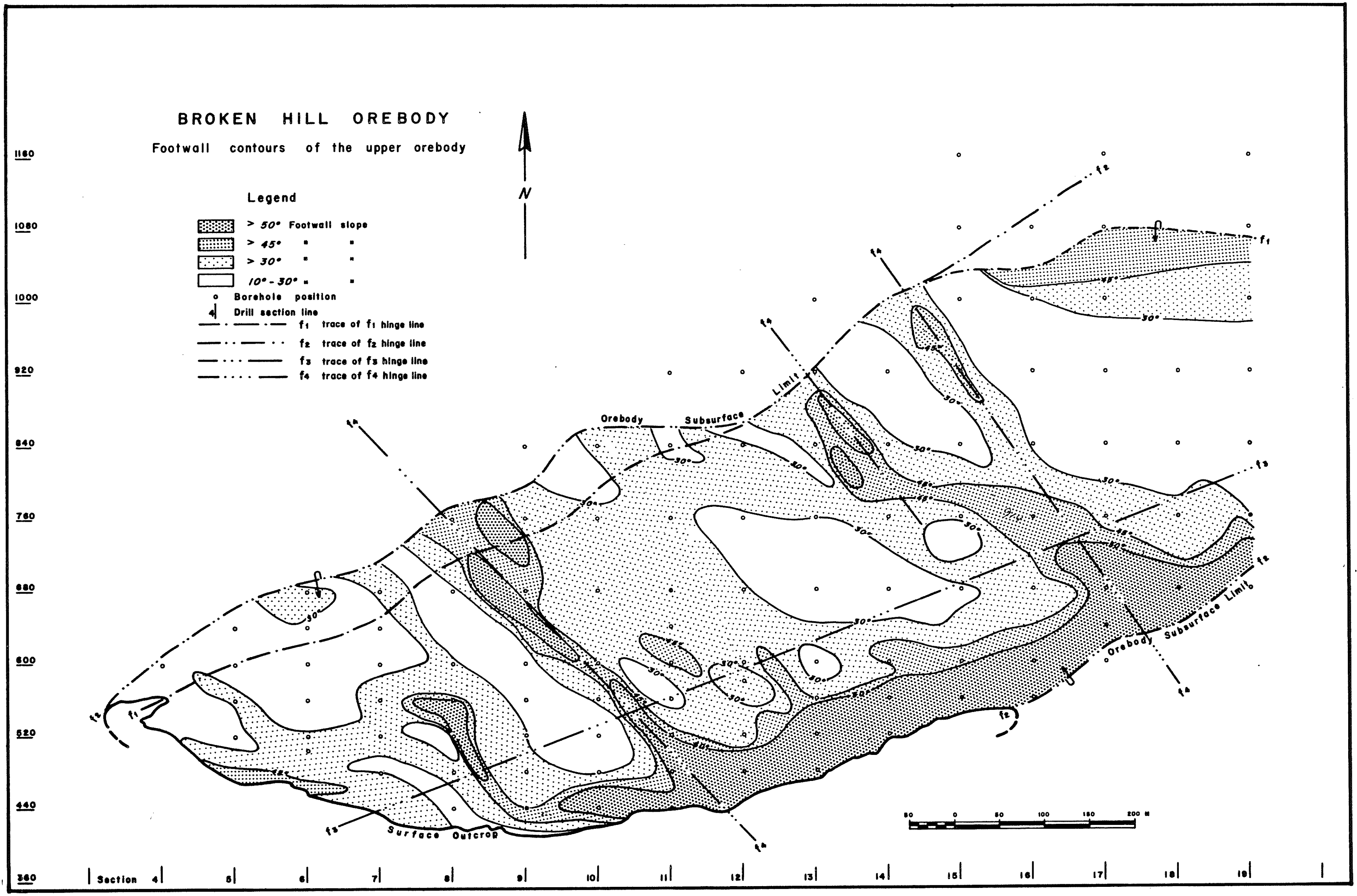

Figure 7 : *Footwall contours of the Upper ore body at Broken Hill. Phases 3 and 4 folding depicted.*

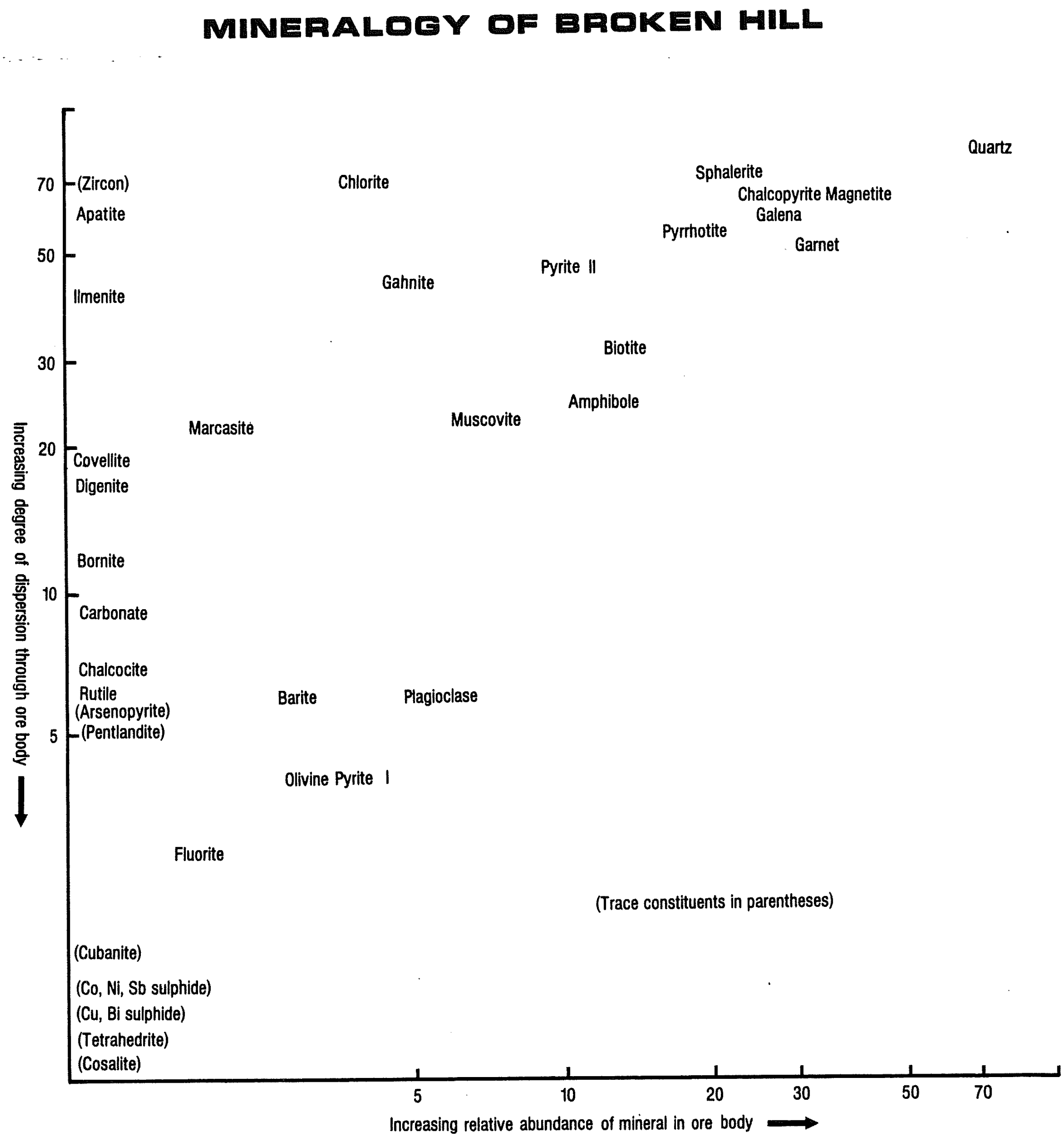

Figure 8 : *Broken Hill mineralogy: Relative abundance and dispersion of minerals.*

3. Ilmenite occurs as exsolution lamellae in magnetite and as discrete dispersed grains,

4. In addition to its primary metamorphic mode of formation, sphalerite also formed through the retrograde metamorphic breakdown of gahnite.

   Gahnite $\rightarrow$ sphalerite + chlorite + sericite

   Semiquantitative microprobe work indicates that this secondary sphalerite contains less iron than does the primary metamorphic sphalerite, which has an average iron content of 7 - 9 per cent. A third generation of sphalerite originated in the supergene alteration zone (i.e. partly as a replacement of chalcopyrite and partly as an overgrowth on chalcopyrite). This variety is closely associated with the supergene covellite, digenite, bornite and chalcocite, and is also iron-poor relative to the primary metamorphic sphalerite,

5. Rutile replaces ilmenite, but is also present as discrete grains between the primary metamorphic minerals,

6. Apatite is well-dispersed throughout the ore body, but is present in small quantities. This mineral has an average concentration of 0,7 per cent with a maximum concentration of 2 per cent,

7. The chalcopyrite and sphalerite have an inverse relationship,

8. The galena and silver have a sympathetic relationship,

TABLE 2

MODE OF FORMATION OF THE BROKEN HILL MINERAL ASSEMBLAGE

Mineral	Mode of Formation			
	Primary metamorphic (exsolution from primary mineral in parentheses)	Retrograde metamorphic (minerals replaced are listed)	Metasomatic (minerals replaced are listed)	Supergene alteration (minerals replaced are listed)
Quartz	x			
Garnet	x			
Orthopyroxene	x			
Amphibole	x			
Olivine	x			
Plagioclase	x			
Muscovite	x	Gahnite		
Biotite	x			
Chlorite	x(?)	Gahnite Biotite Pyroxene Olivine (?)		Ferromagnesian minerals
K-feldspar	x(?)		x(?)	
Sillimanite	x			
Tourmaline	x			
Apatite	x			
Zircon	x			
Rutile	x	Ilmenite (?)		Ilmenite (?)
Gahnite	x			
Carbonate	x			x
Magnetite	x (Gahnite)			
Ilmenite	x (Magnetite)			
Pyrrhotite	x			
Pyrite I	x			
Pyrite II				Pyrrhotite Chalcopyrite Galena Sphalerite
Marcasite				Pyrrhotite Chalcopyrite
Galena	x			
Cosalite			Galena	
Sphalerite	x (Chalcopyrite)	Gahnite		Chalcopyrite
Covellite				Chalcopyrite
Bornite	(Chalcopyrite)			Chalcopyrite
Chalcopyrite	x (Sphalerite)			
Digenite				Chalcopyrite
Chalcocite				Chalcopyrite
Arsenopyrite	x			
Tetrahedrite	x			
Co,Ni,Sb sulphide	x			
Cu,Bi,Fe sulphide	x(?)			
Fluorite	x			
Barite	x			

9. The galena in the ore is present as:

   (i) grains interstitial to the other primary metamorphic minerals,

   (ii) a type rich in intergrowths of chlorite,

   (iii) fine inclusions of magnetite, sphalerite and garnet, or

   (iv) narrow veins in silicate material.

10. In the pyrrhotite-rich massive sulphide areas there is a tendency for the galena to enclose pyrrhotite.

D. Value Distribution Patterns

The distribution of base metal grades is determined firstly, by the original depositional environment and, secondly, by subsequent phases of isoclinal folding.

It appears that the depositional environment influenced the distribution of the significantly higher grade banded massive sulphides in the region below the overlying lower grade banded magnetite quartzite and magnetite amphibolite (Fig. 4).

The postulated first phase of isoclinal folding duplicated the banded magnetite-rich iron-formations. The second phase of isoclinal folding then reduplicated the banded magnetite-rich iron-formations and, more significantly, the banded massive sulphide formations. The high grade massive sulphide ores were finally contained in the core of the north-east plunging isoclinal F_2 fold on the eastern extremity of the ore body (Figs. 4 and 9).

The grade distribution in the Upper ore body is best illustrated with generalized frequency distribution curves for copper, lead, zinc and silver in the magnetite and massive sulphide units respectively (Fig. 10). It is obvious from these distribution curves that there are two distinct populations for the magnetite and massive sulphide units. The preferential grade trend direction was estimated from field observations to follow the plunge and trend of the F_2 folds. This was subsequently shown to be correct by variogram studies of the grade trends (Lemmer and Wilson, 1978, Unpubl. Comp. Rep.).

VIII. THE BLACK MOUNTAIN ORE BODY

The Black Mountain ore body is the most westerly of the four major base metal sulphide deposits in the Aggeneys-Gams area (Figs. 1 and 11). It was the discovery of the potential of this deposit that gave impetus to the subsequent major exploration in the Namaqualand/Bushmanland area. To date, 144 diamond drill holes have outlined geological reserves of 81,6 million tons at 0,75 per cent copper, 2,67 per cent lead, 0,59 per cent zinc and 29,83 gm/tonne silver. This reserve was based on a 0,5 per cent copper equivalent cut-off, and can be substantially upgraded with a concomitant decrease in tonnage. The deposit is open in depth and the above reserves are contained in a 1,3 km section of the plunging ore body.

A. Stratigraphy

The overall stratigraphy in this area follows the regional pattern and is contained in a major recumbent isoclinal synformal infold into the basal gneisses. As a result, the succession in the upper limb of this fold (Figs. 11 and 12) is overturned and hence the stratigraphy is reversed. Quartzo-feldspathic pink gneisses therefore overlie the sequence and are followed structurally downwards by aluminous schist, white quartzite and, finally, the Aggeneys Ore Formation in the core of this major structure. Below this, the sequence is reversed, displaying the correct stratigraphic order. The detailed succession within the Aggeneys Ore Formation, as can be followed structurally downwards but stratigraphically upwards, from the upper white quartzite on Fig. 12 is as follows:

TABLE 3

STRATIGRAPHY OF THE BLACK MOUNTAIN ORE BODY

7.	Lower ore body			
6.	Baritic quartz schist		AGGENEYS ORE FORMATION	(5-25m)
5.	Magnetite-barite rock		AGGENEYS ORE FORMATION	(10-25m)
4.	Magnetite amphibolite	Economic Ore Body	AGGENEYS ORE FORMATION	(0-45m)
3.	Magnetite quartzite	Economic Ore Body	AGGENEYS ORE FORMATION	(0-20m)
2.	Mixed zone consisting of gradations between garnet quartzite and various quartz schists	Economic Ore Body	AGGENEYS ORE FORMATION	(30-65m)
1.	Banded quartz schist		AGGENEYS ORE FORMATION	(10-25m)
	WHITE QUARTZITE FORMATION			
	ALUMINOUS SCHIST FORMATION			
	PINK GNEISS FORMATION			

The above detailed Aggeneys Ore Formation succession only becomes evident when the sequence has been unfolded and restored to its original attitude (an aspect which will be discussed later under the section on structural geology). It is possible that formations stratigraphically above the baritic quartz schist are present,

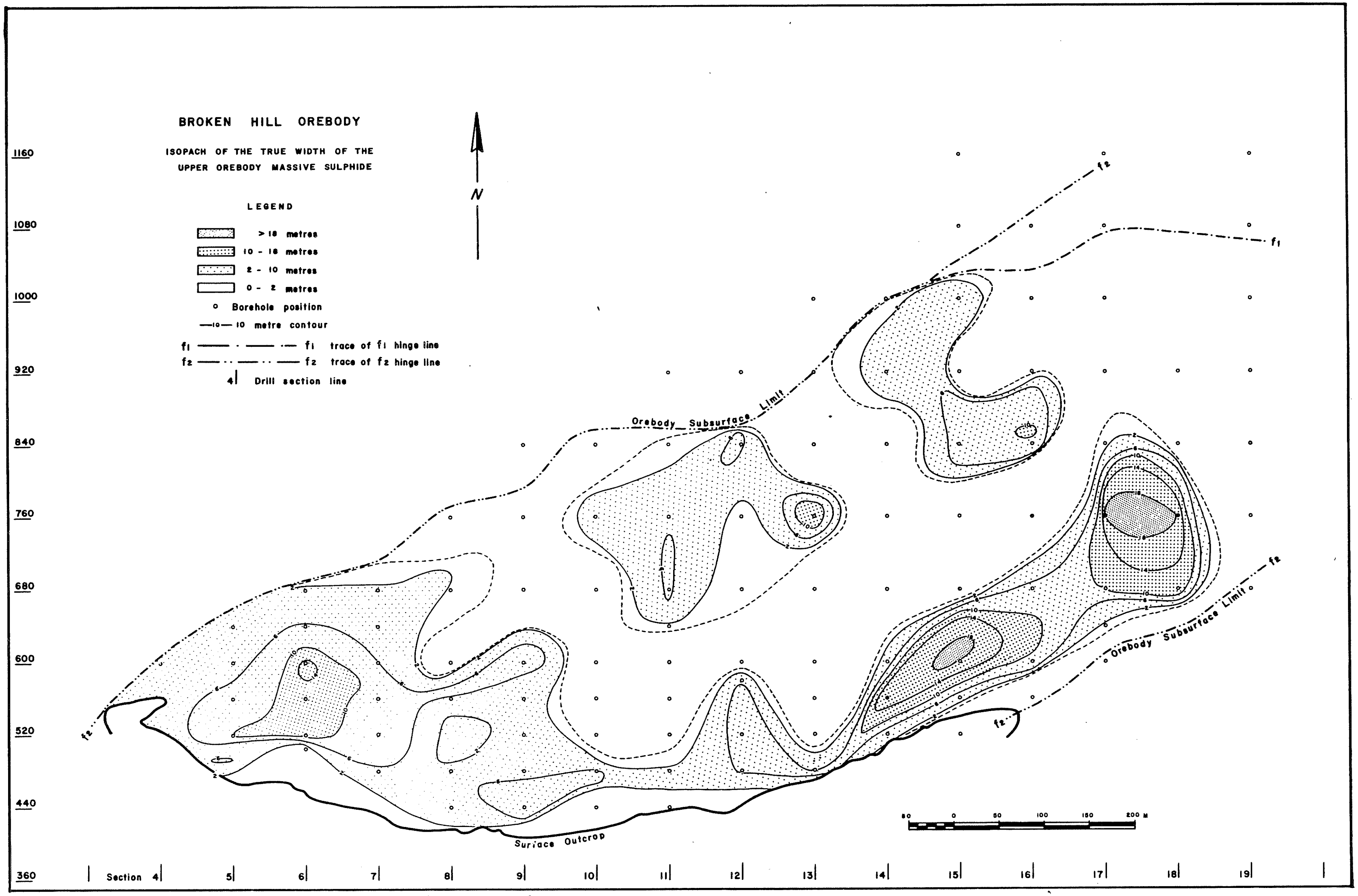

Figure 9 : *Isopach map of the Upper ore body massive sulphides, Broken Hill.*

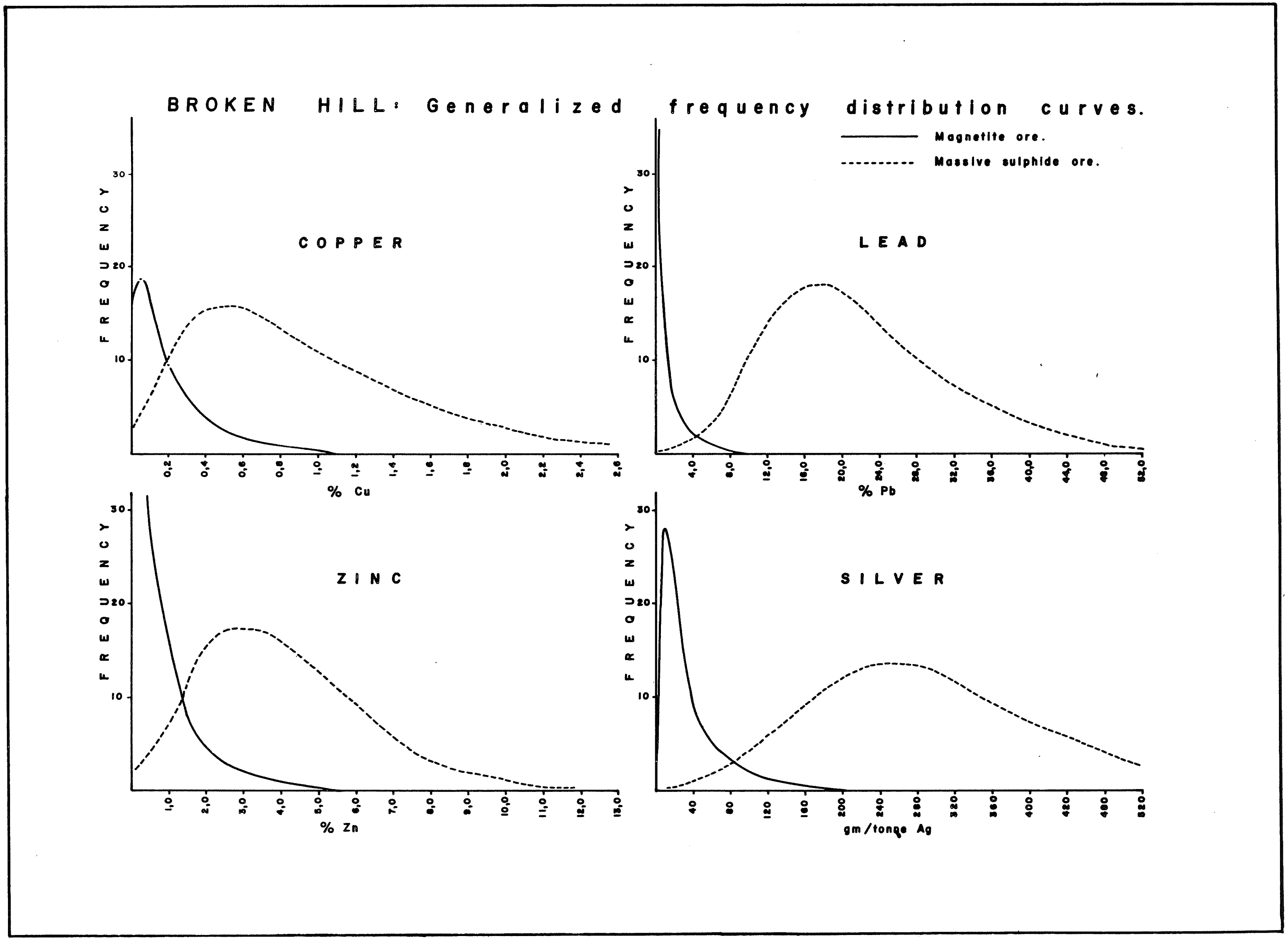

Figure 10 : *Generalized frequency distribution curves of Cu, Pb, Zn and Ag in the magnetite and massive ore units, Broken Hill.*

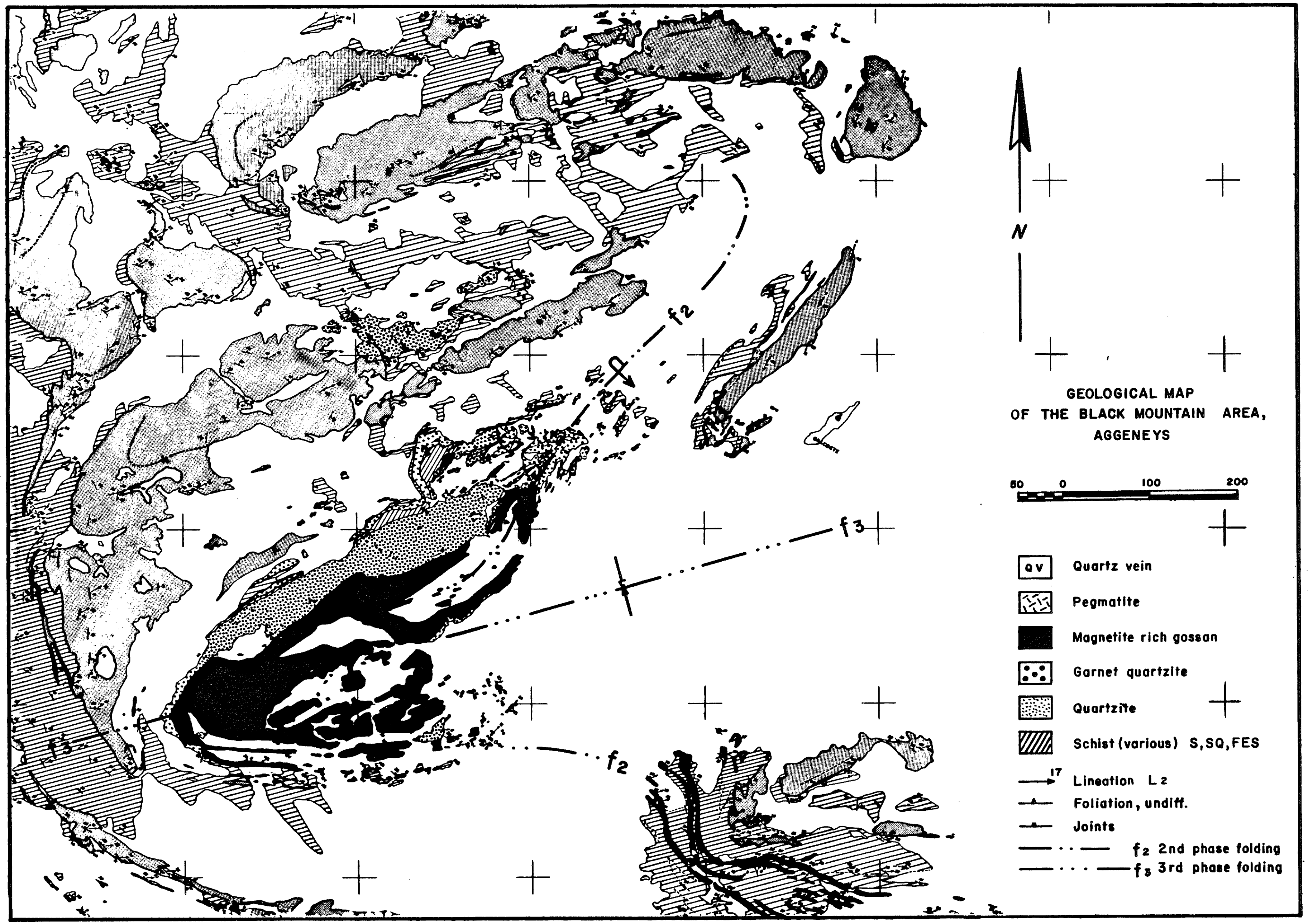

Figure 11 : *Surface geological map of the Black Mountain area, Aggeneys.*

but definitive information in this regard is not currently available. The exact stratigraphic position of the narrow Lower ore body also remains uncertain and will be discussed more fully later.

The lithotypes constituting the Aggeneys Ore Formation in the vicinity of the Upper ore body (Fig. 12) are described in the following sections.

1. *Banded Quartz Schist*

The banded quartz schist is characterized by the alternation of the quartzose and schistose material, the former displaying a similar composition to the white quartzite, while the latter are similar to the aluminous schists. In certain micro-units, a gradation from quartzose to schistose material is bounded by two sharp contacts. This is interpreted as representing the metamorphosed equivalent of graded bedding in a unit displaying cyclic sedimentation and implies a sedimentary origin for the more massively bedded quartzites and schists. Sulphides are rare and are generally represented by small amounts of disseminated pyrite.

2. *Mixed Zone*

The gradations in the mixed zone, which form the stratigraphic footwall of the stratiform portion of the ore body, are demonstrated in Fig. 12 where a progression from garnet quartzite to garnet-quartz schist to banded schist is evident with increasing distance from the high grade ore. The latter is contained near the core of the major F_2 antiform (dashed line on Fig. 12).

(a) Garnet-Quartz Schist

The garnet-quartz schist displays a composition intermediate between the garnet quartzite and the banded quartz schist. The K-feldspar, sillimanite and muscovite contents are higher than in the former and the quartz (40 - 70%) and garnet contents are higher than in the latter. Traces of pyrite are disseminated throughout the rock, especially near the gradation zone to garnet quartzite. Sporadic minor chalcopyrite concentrations are also present in this position.

(b) Garnet Quartzite

Besides the gradation into garnet-quartz schist, the garnet quartzite is distinctive in its form, since it thickens considerably in the vicinity of the high grade ore and displays a gradual decrease of ferromagnesian minerals towards the north-west, grading into a variety of glassy quartzites (Fig. 12). The adjacent magnetite quartzite, a lithotype of comparable competence, displays a far less pronounced thickening in the same structural position. This implies a pre-deformation thickening of the garnet quartzite, as illustrated in Fig. 13.

Quartz is the dominant mineral (generally 80 per cent), while garnet (almandine component dominant) and biotite are subordinate. Cordierite and sillimanite are accessory minerals, and there is a sudden increase in magnetite close to the contact with the magnetite quartzite. The rock is generally massive with banding being very poorly developed in the core of this unit, i.e. away from the gradational contacts with the schists.

Although the sulphide content is variable, there is a general increase towards a position near the hinge of the F_2 fold closure where concentrations approaching massive sulphide have been found. Pyrite is the dominant sulphide with subordinate chalcopyrite. These minerals decrease in all directions (i.e. away from the high grade ore) with pyrite persisting beyond the chalcopyrite. Minor sphalerite, galena and pyrrhotite are encountered near the contact with the magnetite quartzite.

3. *Magnetite Quartzite*

Quartz and magnetite are dominant in the magnetite quartzite (70 - 100% combined), and are in places accompanied by accessory amounts of garnet (almandine-spessartine), biotite, chlorite, and, rarely, by apatite. In the lower flank of the F_2 antiform (in the vicinity of point C, Fig. 12), magnetite decreases relative to quartz in both bands. Between point A and line DF, a mm-scale compositional banding (s_0) is displayed, while in the hinge zone of the F_2 antiform, this is obliterated by rotation about the b-geometric axis.

Pyrite is the dominant sulphide and is accompanied by subordinate pyrrhotite. Galena is the dominant economic sulphide, followed by chalcopyrite and accessory sphalerite. The greatest concentrations occur within the high grade contour, i.e. stratigraphically overlying the high grade metallization in the garnet quartzite (Figs. 12, 13B).

4. *Magnetite Amphibolite*

Magnetite and grunerite are dominant components of the magnetite amphibolite and are accompanied, in decreasing order, by pyroxmangite, quartz, hedenbergite, garnet (spessartine-rich), fayalite and apatite.

Pyrrhotite predominates over pyrite, while galena and sphalerite are the most abundant economic sulphides. Chalcopyrite is an accessory mineral together with minor amounts of arsenopyrite.

5. *Magnetite-Barite Rock*

Close to position C in Fig. 12, where the barite content is highest (25 - 70%), this mineral is accompanied by quartz and magnetite (10%) and accessory fine-grained orange garnet and micas. In this area, the rock is coarse grained and displays moderate compositional banding. The sulphide content is negligible, although this member is flanked by two very thin pyritic massive sulphide bands near position C.

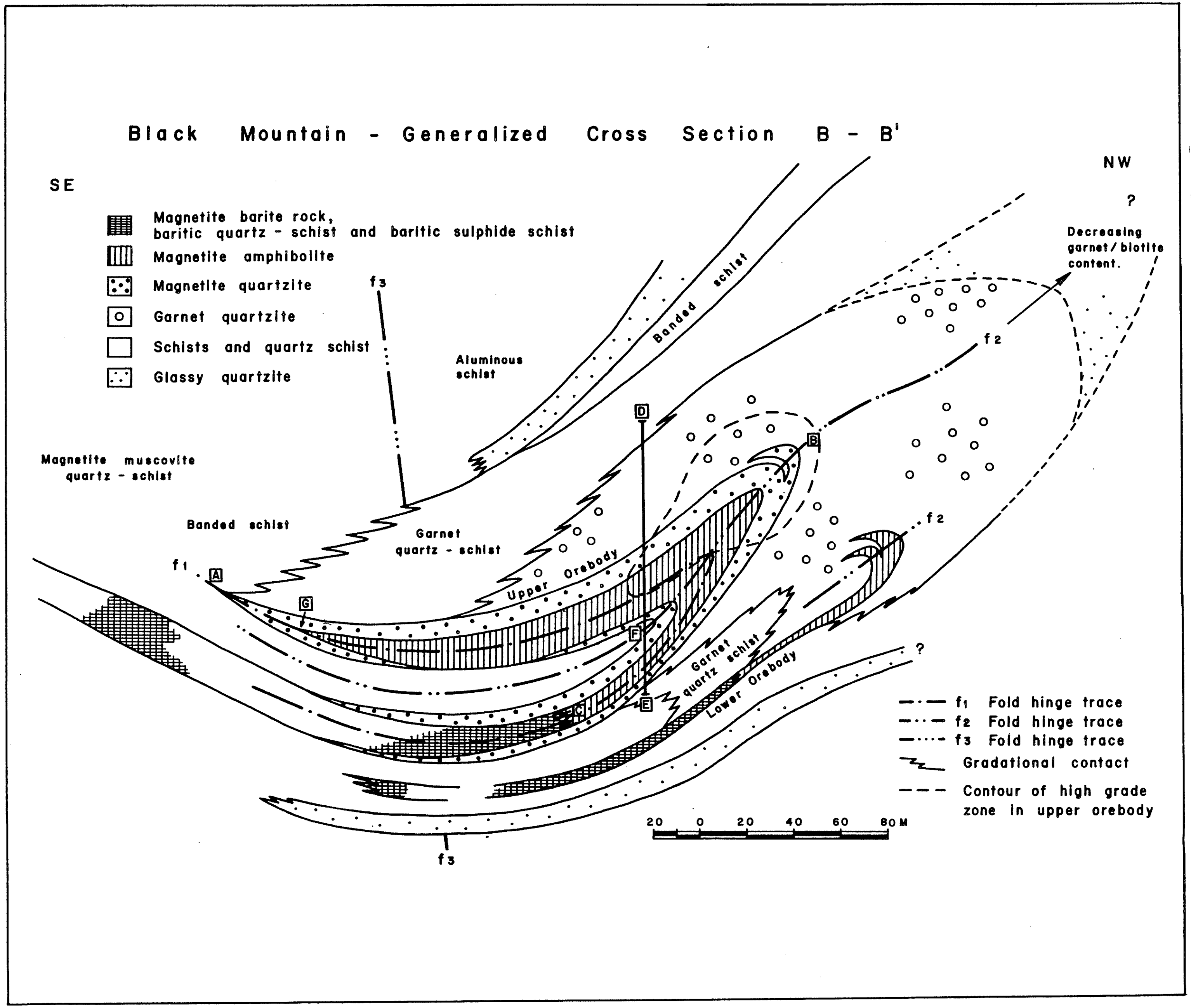

Figure 12 : *Generalized cross section of the Black Mountain ore body showing fold phases 1 - 3.*

6. *Baritic Quartz Schist*

The magnetite-barite rock displays a gradational change towards the south-east. Since this position is considered to occupy the core of a large F_1 syncline, the gradation occurs stratigraphically upwards, as can be deduced from Figs. 12 and 13. This unit therefore represents the top-most observable member of the local Swartberg stratigraphy.

Barite and magnetite decrease relative to quartz in the baritic quartz schist while muscovite, biotite and chlorite increase until the rock displays a decidedly schistose character.

7. *Lower Ore Body*

This thin magnetite-and sulphide-rich body which is situated structurally below the Upper ore body (Fig. 12) is problematic with regard to its stratigraphic position. Two alternatives are possible. Firstly, it might represent a separate unit situated stratigraphically above or below the Upper ore body. A second alternative is that these iron-rich lithotypes are the stratigraphic equivalents of the Upper ore body, having been brought into their current position by a series of isoclinal folds. Should the latter interpretation be correct, it implies that the magnetite- and sulphide-bearing units of the two ore bodies were deposited in separate sub-basins since there is no apparent continuity of this material between the two deposits.

Convincing evidence for either interpretation is lacking at present. The structure at Black Mountain has revealed evidence for an exceedingly tight isoclinal F_1 fold in the Upper ore body. It is unlikely that this is the only example of the earliest recognizable folding and, therefore, the presence of two stratigraphic positions containing iron-formations cannot be considered to be axiomatic.

The previous descriptions of the magnetite-rich units apply to the Upper ore body. The Lower ore body consists of three dominant lithotypes, namely garnet quartzite, magnetite amphibolite and sulphide schist.

The garnet quartzite is identical to that described in the Upper ore body and, once again envelopes the magnetite-rich rocks where the latter are present in the hinge zone of an F_2 fold. Pyrite is the dominant sulphide, followed by chalcopyrite, and galena, pyrrhotite and sphalerite occur in accessory amounts.

The magnetite amphibolite differs from the corresponding lithotype in the Upper ore body in that it consists of dominant grunerite and subordinate spessartine, the magnetite content having decreased markedly. The ore mineralogy also differs, with sphalerite and chalcopyrite constituting the main ore minerals, as opposed to the preponderance of galena in the Upper ore body.

Down-dip, to the south-east, the magnetite amphibolite grades rapidly over one or two metres into a baritic sulphidic schist (Fig. 12). This latter lithotype often attains massive sulphide character. Pyrite is dominant with subordinate galena and sphalerite, and traces of chalcopyrite. Barite is irregularly distributed reaching 40 per cent in places, while gahnite is a common gangue silicate, together with quartz, white mica and hematite.

8. *Leptites and Amphibolites*

At Black Mountain the Bushmanland Sequence contains lithotypes other than those which occupy specific stratigraphic positions. Since these are also present in the Aggeneys Ore Formation, they will be described below.

Leptites and amphibolites are the two most common rock types which are irregularly distributed in the succession as lenticular bodies, varying from 1 to 30 m in width and generally being oriented parallel to the layering. The leptites are medium-grained quartzo-feldspathic rocks characterized by a low ferromagnesian mineral content. They vary in colour from pink through white to greenish and both foliated and non-foliated varieties are present. The dominant minerals are quartz and microcline with subordinate plagioclase and muscovite, together with accessory biotite. Poorly defined sillimanite nodules are preserved in places. This lithotype is similar in appearance to the pink gneiss, but differs in its stratigraphic position.

The amphibolites, which almost invariably accompany the leptites, are dominantly composed of hornblende together with very fine-grained retrogressive products such as clinozoisite and albite after oligoclase. Variations include biotite and/or chlorite in addition to hornblende. This rock also displays foliated and non-foliated varieties.

A leptite transgresses magnetite-rich rocks in the lower limb of the F_2 antiform in the Upper ore body. Detailed petrographic studies have suggested that the leptites were formed by anatexis of the matrix of nodular schists in certain positions such as at the contact between the pink gneiss and aluminous schist formations and in the case of the F_2 fold (Fig. 12). The amphibolites associated with the leptites are considered to represent the ferromagnesian components of the precursor schists.

B. Structure

Four dominant phases of folding are present in the Black Mountain tectonites and all contributed to the deformation of the Upper ore body. The unravelling of this deformation, illustrated in Fig. 13, led to the establishment of the detailed stratigraphy of the banded iron-formations as outlined in the previous section.

1. *First Phase of Deformation (F_1)*

These early structures are notoriously difficult to demonstrate on surface. Nonetheless, a major F_1 fold is considered to be present in the Black Mountain ore body (Figs. 12, 13), for the following reasons :

(a) The termination of the duplicated succession in the vicinity of point A (Fig. 12), which is considered to be the F_1 hinge,

(b) The overall duplication of the magnetite-rich sequence on line DE (Fig. 12) is obviously due to deformation by the F_2 antiform. Each limb (sections DF and FE) display internal duplication which is folded about the F_2 hinge trace and is therefore due to pre-F_2 deformation,

(c) Between G and DF (Fig. 12) the magnetite amphibolite displays fine compositional banding and strongly oriented grunerite needles. Within the F_2 antiformal hinge zone this fabric was strongly deformed during the formation of ℓ_2 mullions. The grunerite was subsequently annealed to give rise to a randomly oriented network of needles. The fabric which was deformed is therefore pre-F_2 in age, i.e. $s_{0/1}$ and ℓ_1, and

(d) The present relationship between the magnetite-barite rock and the magnetite amphibolite, as diagrammatically illustrated in Fig. 13 where F_1 folding is invoked, is more feasible than any other mechanism considered.

It is conceded that the reasons given above are not the only explanations for the pre-F_2 attitude of the ore body. A further possibility is that this attitude is simply the result of primary sedimentological features such as wedging of individual layers and facies changes. However, it is considered that the evidence weighs more heavily in favour of an F_1 influence.

2. *Second Phase of Deformation (F_2)*

A typical F_2 fold with a characteristic rounded hinge zone (at position B) is illustrated in Figs. 12 and 13. Strong ℓ_2 mullions are present in the magnetite-amphibolite within this hinge. A similar F_2 antiform deforms the magnetite amphibolite of the Lower ore body where on surface spectacular ℓ_2 mullions are developed.

3. *Third Phase of Deformation (F_3)*

Open, often asymmetric, folds are common on all scales in the Black Mountain area. A large anticline deforms the White Quartzite Formation, displaying a hinge zone 600 m north-east of the surface outcrop of the Upper ore body (Figs. 11 and 12). The corresponding syncline to the south-east is responsible for the open flexuring of the ore bodies in Fig. 12.

4. *Fourth Phase of Deformation (F_4)*

The F_4 folds, which are typically monoclinal, cause local steepening of ℓ_2 lineations, fracturing of the competent rocks, and downward displacement to the east, of the various litho-stratigraphic units.

5. *Orientations*

The first three phases of deformation are approximately co-axial, although local deviations occur. The average axial trend is 70° with a plunge angle of 25°. The F_4 phase, with its northerly to north-westerly axial trend, is a major departure from the former orientation.

6. *Pre-deformation Attitude of the Ore Strata*

Figure 13A provides a cross-section of the Upper ore body before deformation by phases F_2 and F_3. The earliest deformational effects, namely those of F_1, have been removed from Fig. 13B, and this represents the pre-deformation nature of the ore sequence. The interdigitation of magnetite amphibolite and magnetite-barite rock at position C, is believed to be an s_1 feature and not a sedimentary effect. The essential features of the F_1 deformation are diagrammatically represented in Fig. 13C.

7. *Further Structural Effects on the Upper Ore Body*

Besides the previously discussed folding of the ore-bearing units, additional structural influences are present. Within the finely banded portions of the magnetite-quartzite and magnetite-amphibolite (i.e. away from the F_2 antiformal hinge zone), sulphides are often present as small grains aligned along the micro-banding. In the vicinity of the F_2 hinge, the ore has recrystallized to form coarse aggregates.

The high grade base metal mineralization outlined in Fig. 12, follows the plunge of the F_2 antiform. In detail, however, this mineralization displays asymmetry with respect to the F_2 hinge trace (Fig. 12). The high grade metallization in all three mineralized units stratigraphically overlie each other, centred around a position which corresponds to the thickest development of garnet quartzite. This concentration is considered to be a primary effect, although limited subsequent remobilization has occurred.

C. Diagnostic Features of the Upper Ore Body

The following are the main features of the Upper ore body in the Black Mountain deposit :

(a) Galena and sphalerite occur *throughout* the magnetite-quartzite and magnetite-amphibolite, dominantly as low grade material, but also as the high grade zone previously discussed. The galena-sphalerite portion of the Upper ore body is therefore stratiform. Chalcopyrite is dominant in the garnet quartzite, but this unit is generally massive, displays transgressive gradational contacts, and is not ubiquitously mineralized,

(b) Massive sulphides are rarely developed,

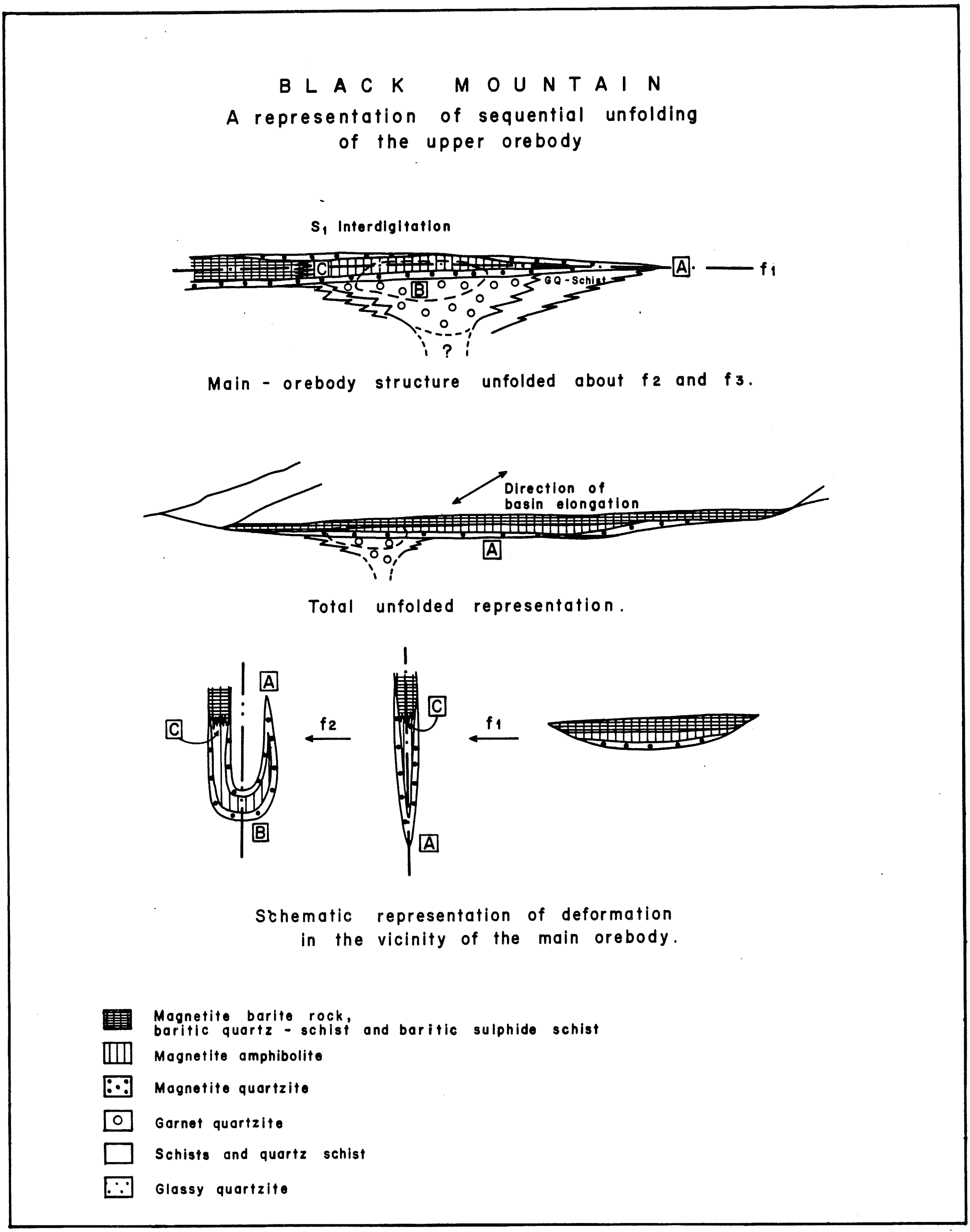

Figure 13 : *Schematic diagram illustrating the sequential unfolding of the Black Mountain upper ore body.*

(c) The high grade portion of the ore body is to some extent offset from the F_1 and F_2 hinges,

(d) The ore body displays vertical stratigraphic metal zoning, with chalcopyrite in the garnet quartzite, galena-chalcopyrite in the magnetite quartzite and galena-sphalerite in the magnetite amphibolite. This is overlain by a very poorly mineralized baritic unit. The vertical zoning is accompanied by an upward increase in pyrrhotite-pyrite ratios, and

(e) In general, the highest grade zones in the various mineralized lithotypes stratigraphically overlie each other. Grades decrease laterally away from these positions.

IX. THE BIG SYNCLINE ORE BODY

The Big Syncline ore body is situated in the south-western part of the Aggeneys Mountains (Fig. 1). To date, 30 diamond drill holes have delineated some 101 million tonnes of base metal sulphide mineralization containing 0,04 per cent copper, 1,01 per cent lead, 2,45 per cent zinc and 12,90 gm/tonne silver.

Ore reserves were based on a 0,4 per cent copper equivalent cut-off.

A. Stratigraphy

In the Aggeneys Mountains the Aggeneys Ore Formation conformably overlies the White Quartzite Formation. The stratigraphic succession in the Big Syncline region is provided in Table 4.

TABLE 4

STRATIGRAPHIC SUCCESSION IN THE BIG SYNCLINE

Stratigraphic Unit	Thickness	
6. Spring Schist and Quartzite Member	5-300 m	AGGENEYS ORE FORMATION
5. Calc-silicate Member	0- 50 m	
4. Nodular Schist Member	0- 10 m	
3. Pyribolite Member	0- 20 m	
2. Magnetite Quartzite Member	0- 60 m	
1. Fly Schist Member	0-200 m	
WHITE QUARTZITE FORMATION		

1. *The Fly Schist Member*

The Fly Schist Member lies conformably on the White Quartzite Formation and consists of a quartz-muscovite-biotite matrix hosting elongated quartz 'pebble-like' inclusions.

Where the magnetite-rich rocks are no longer present in the north of the Big Syncline (Figs. 1 and 14), the distinction between the Fly Schist and the Nodular Schist members is extremely difficult to determine.

2. *Magnetite Quartzite Member*

The magnetite-quartzite unit lies conformably on the Fly Schist Member and consists of interbanded magnetite-rich and quartz-rich layers, and locally, gives rise to garnet quartzite where the garnet content increases at the expense of magnetite (Fig. 14). Sub-economic pyrite-chalcopyrite disseminations occur throughout this rock.

3. *Pyribolite Member*

Sporadic boudinaged remnants of a baritic pyribole plus magnetite (or pyrrhotite)-bearing rock, overlies the Magnetite Quartzite Member in the extreme southern part of the Aggeneys Ore Formation. Coarse-grained clusters and disseminations of sphalerite and galena, approaching economic grades, occur in association with pyrite, pyrrhotite, marcasite and chalcopyrite.

4. *Nodular Schist Member*

The barren nodular schist hosts quartz-sillimanite-muscovite nodules and K-feldspar porphyroblasts and separates the Pyribolite Member from the overlying Calc-silicate Member (Fig. 14).

5. *Calc-silicate Member*

The calc-silicate unit comprises four beds with three of the rock types dominated by spessartine garnet and epidote group minerals, while bands of andraditic garnet and wollastonite, set in a calcite matrix, characterizes the limestone. The member contains sub-economic concentrations of sphalerite, galena, chalcopyrite,

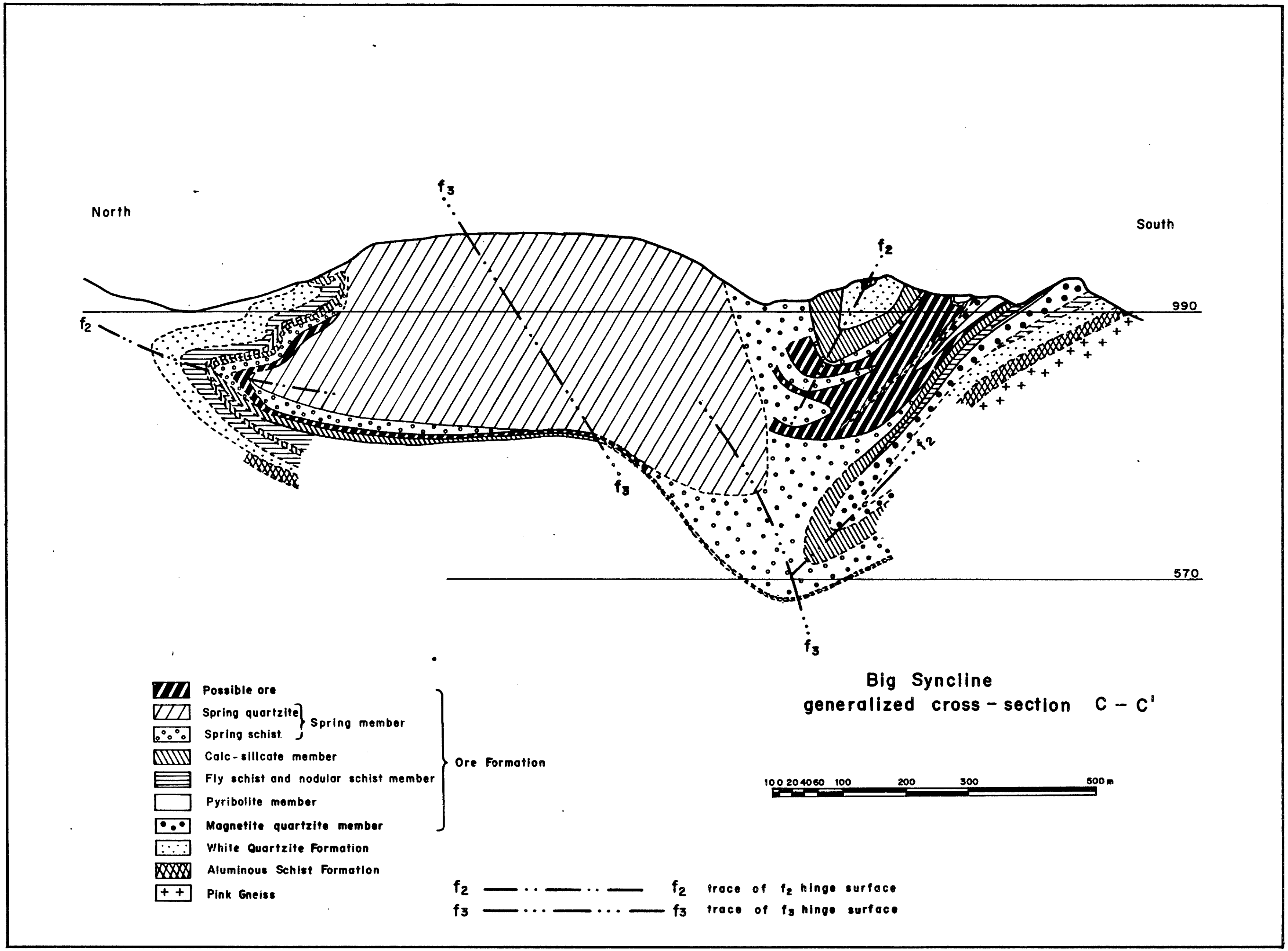

Figure 14 : *Generalized cross section of the Big Syncline ore body.*

pyrite, and pyrrhotite. The contact between the Calc-silicate Member and the overlying Spring Schist Member can be traced for many kilometers through a series of complex folds (Fig. 14).

6. *The Spring Schist and Quartzite Member*

The Spring Schist and Quartzite Member consists of a schist grading upwards into a quartzite (Fig. 14). The well-mineralized portions of the Spring Schist constitute the stratabound Big Syncline ore body. The sphalerite and galena, in association with coarse-grained pyrite, pyrrhotite and marcasite, occur within the coarse-grained, schistose, silicate, host consisting of quartz, muscovite, K-feldspar, biotite, sillimanite and garnet. S.A. de Waal (1975, Confidential N.I.M. Rep. 1965) described galena as somewhat finer than sphalerite, with those grains less than 20 mm in size occurring as closely knit clusters in association with silicate minerals. In addition to accessory covellite and arsenopyrite, De Waal further noted that 40-50 per cent of all the chalcopyrite occurs included in sphalerite as grains that are 1-10 mm in size. Copper never comprises more than 0,1 per cent of the ore zone.

Besides quartz, the Spring Quartzite consists of altered calcic plagioclase together with muscovite, sillimanite, biotite and skeletal garnet. Sulphides, in the form of pyrite, pyrrhotite, sphalerite and galena, are always present in low concentrations. As at Broken Hill and Black Mountain, accessory apatite occurs throughout the Aggeneys Ore Formation. Rutile also occurs in accessory amounts throughout the ore body.

An important feature of the Big Syncline deposit is that the prominant magnetite-rich assemblages of the south (Fig. 1) do not appear to be developed in the north. These iron-rich rocks are thought to be part of a banded iron-formation sequence and that the change from oxide facies (Magnetite Quartzite Member) to sulphide facies (Spring Schist and Quartzite Member) reflects a deepening of the original depositional basin to the (present) north.

B. Structure

The Big Syncline deposit has a broadly synclinal cross-section over most of its 7 km of strike. True thicknesses of mineralization vary from 10-90 m, as illustrated in the typical profile shown in Fig. 14. The ore body displays higher and more consistent grades on the southern limb of the syncline, with a gradual drop in tenor through the hinge zone. An accurate assessment of the northern limb is made difficult by the limited amount of sub-surface information.

Synformal F_2 anticlines comprising waste Pyribolite and Calc -silicate members project downwards into the Spring Schist. To the north, a layer of low grade Spring Schist, with widths not exceeding 10 m, folds about the open F_3 anticline and extends for over 1 km along the lower limb of a macroscopic recumbent F_2 fold (Fig. 14). This closure terminates the northern development of mineralization with the overturned limb of Spring Schist being well-preserved down-plunge to the east of the area depicted in Fig. 14.

The extension of mineralization to the west is terminated by present day erosion. Surface structural data along the southern Aggeneys Mountains suggests that an antiformal F_2 syncline also prevents a southerly extension of the ore zone. Towards the east, grades increase where Spring Schist becomes constricted between two massive quartzite bands. To date this is the only feature of grade variation which might be attributable to structural control. The eastern limit of the ore body remains to be defined. Total leaching of surface outcrops of the mineralized zone extends to depths of 12-30 m below surface and constitutes a spongy gossan. No evidence of supergene enrichment has been observed below this gossan with the exception of minor enrichment of copper at the interface between the leached gossan and the fresh sulphide.

X. GENESIS

A. The Bushmanland Sequence

The Namaqualand Metamorphic Complex displays similarities with highly deformed Proterozoic terranes in other parts of the world, e.g. the Grenville Province in Canada and the Willyama Block in Australia. As is the case in these latter areas, the Bushmanland Sequence and the Pink Gneiss Formation is considered by some contributors to this paper, to have been deposited ensialically on a granitic floor, the metamorphosed product of which is represented by the Augen Gneiss Formation. However, Joubert (1974c) envisaged that the overlying volcano-sedimentary sequence was intruded by remobilized basement or a granite batholith, today preserved as augen gneiss.

The overlying schist and quartzites could be the metamorphosed derivatives of leached felsic eruptives and silicic outpourings respectively, although tentative indications of pristine graded bedding imply a sedimentary origin. In addition, the fact that the Aluminous Schist and White Quartzite Formations maintain relatively uniform lithological characteristics and thicknesses over extensive areas of Namaqualand and Bushmanland suggest that they were probably deposited in an extensive body of water.

The iron-formations, in association with base metal sulphides and barite, display textural features such as fine compositional banding, thereby implying a chemogenic origin. The calc-silicate rocks and marbles within the iron-formations, are considered to represent original marls and limestones. The beds of conglomerate in the eastern portion of the Big Syncline are also of obvious sedimentary derivation. It is, therefore, clear that in the Aggeneys area much of the Bushmanland Sequence is of sedimentary origin.

To the north of the Orange River, Beukes (pers. comm., 1979) has postulated the presence of metamorphosed volcanic rocks adjacent to, and grading into, the Haib volcanic sequences. These decrease in frequence towards the Aggeneys area. A possible reconstruction suggests subaerial volcanism in the north, passing into an intermediate region and finally the metasediments of the Aggeneys area. Since the Haib Volcanics have been dated at 1980 ± 40 Ma (Reid, 1977), a similar age might be implied for the Bushmanland Sequence and its stratiform ores. In contrast to these ages, Köppel (1978) has obtained an age of 1300 Ma by lead isotope methods for the ores themselves.

B. The Ore Bodies

The ore bodies in the Aggeneys area display the following features which need to be considered when discussing the genesis of these deposits :

(a) The ore bodies are stratabound and in most cases stratiform,

(b) Economic sulphides consist of varying proportions of chalcopyrite, galena and sphalerite, which together with pyrite and pyrrhotite, often attain massive sulphide concentrations,

(c) The ore bodies are intimately associated with banded iron-formations,

(d) Stratiform baritic units are present and appear to stratigraphically overlie the sulphide-rich layers,

(e) The mineralization occurs within the same general stratigraphic interval,

(f) There is an increase in the manganese content of the hanging and footwall rocks as the ore bodies are approached and manganese-rich garnet is ubiquitous throughout the ore bodies,

(g) The deposits display a diagnostic presence of accessory minerals such as apatite and fayalite,

(h) Thin, discontinuous, banded iron-formations in the schist within the White Quartzite Formation below the Aggeneys Ore Formation are thought to represent the precursors to the main pulse of mineralization,

(i) The individual ore bodies show systematic variations in base metal content and mineralogy both in a vertical and lateral sense,

(j) The TiO_2 content of the magnetite is negligible (0,03%), a feature also noted by Stanton (1978) in the Broken Hill deposits in Australia,

(k) The base metal sulphides have been recrystallized and, in places, remobilized during metamorphism, and

(l) The copper:lead + zinc ratio of the ore bodies increases stratigraphically upwards, with the ore sequence being capped by a baritic unit. This characteristic vertical metal zoning is a common feature of deposits of suggested exhalative origin.

Reconstructions of the Broken Hill ore environment suggests the presence of three distinct facies, viz., oxide, sulphide and silicate, all of which are well-defined in a vertical sense by their respective characteristic mineral assemblages (Table 5).

TABLE 5

SUGGESTED FACIES VARIATIONS, ROCK TYPES, MINERALOGY AND ORE TYPES IN THE VICINITY OF THE BROKEN HILL ORE BODY, AGGENEYS AREA

Facies	Rock Rypes	Minerals	Mineralization
Silicate	Magnetite Amphibolite	Quartz Magnetite Grunerite Cummingtonite Spessartine Garnet Fayalite	Moderate mineralization with galena > sphalerite > chalcopyrite
Oxide	Magnetite Quartzite	Magnetite, Quartz Garnet, Biotite	Moderate mineralization with galena > sphalerite > chalcopyrite
	Ferruginous Garnet Quartzite	Quartz, Magnetite, Garnet, Biotite	Very-weak mineralization with sphalerite > chalcopyrite > galena
Sulphide	Massive Sulphide	Pyrrhotite, Pyrite, Quartz	High-grade mineralization with galena > sphalerite > chalcopyrite
	Sulphide Quartzite	Quartz, Pyrrhotite, Pyrite	Moderate-to-high-grade mineralization with galena > sphalerite > chalcopyrite

The relative positions of the three facies for the Broken Hill deposit are indicated in Fig. 4A. It is postulated that the sulphide-quartzite and ferruginous garnet quartzite are stratigraphic equivalents, probably representing a lateral facies change from the central, deeper, parts of the depositional basin to the oxide facies at the margins of the basin. A characteristic feature of the ferruginous garnet quartzite on the edges of the basin is that galena is virtually absent, and small amounts of chalcopyrite and sphalerite become the dominant sulphides present. The base metal (Pb + Zn) sulphide development is strongest in what is thought to have represented the central parts of the depositional basin.

Vertical and lateral metal zoning is also evident in the Big Syncline ore body. The magnetite quartzites display a relatively high copper: lead + zinc ratio, while in the stratigraphically overlying Spring Schist, the ratio is much lower.

The magnetite-rich members below the mineralized portion of the Spring Schist are restricted to the extreme southern limits. The magnetite quartzite, magnetite-bearing pyribolite and magnetite-bearing calc-silicate members grade northwards into pyrite- and pyrrhotite-bearing varieties and provide an excellent illustration of the transgression from shallow water oxidizing conditions into deeper water reducing conditions.

From the southern margins of the Big Syncline deposit the Spring Schist and Quartzite Member thickens rapidly towards the north where it becomes by far the thickest unit, indicating that basin subsidence was more rapid in that direction.

The fact that the base metal sulphides in all three ore bodies have been recrystallized and re-mobilized during metamorphism, strongly suggests that these minerals were deposited prior to deformation and associated dynamothermal metamorphism.

Considering the above features, it is tempting to postulate an exhalative origin for the Aggeneys ores. However, if this is the case, some evidence of fumarolic alteration of the footwall rocks would be expected. The garnet quartzite at Black Mountain is considered by some company geologists to possibly represent the metamorphosed equivalent of such an alteration zone. This massive, apparently transgressive, siliceous chalcopyrite-pyrite-bearing unit is situated in the footwall of the stratiform lead-zinc-copper-bearing iron-formation sequence, as a body of limited lateral extent.

At Broken Hill ferruginous garnet quartzite is similar to the Black Mountain garnet quartzite with respect to its metal zoning characteristics, and also in its siliceous character and footwall stratigraphic position. However, at Broken Hill the garnet quartzite is much thinner and stratiform instead of transgressive. Concordant footwall alterations are displayed in many exhalative massive sulphide deposits and are considered to result from the alteration of sea-floor rocks from above by dense brines collecting in local depressions away from the actual feeder conduit.

On a regional basis there is a west to east decrease in the relative abundance of alteration effects. This regional trend is accompanied by an apparent metal zoning between the various ore bodies. Table 6 provides a list of the changing grades of the base metal deposits from west to east in the Aggeneys area.

TABLE 6

VARIATIONS IN METAL GRADES IN THE AGGENEYS AREA

Azimuth	Ore Body	Base Metal Content		
West		% Cu	% Pb	% Zn
↓	Black Mountain	0,75	2,67	0,59
↓	Broken Hill	0,34	3,57	1,77
↓	Big Syncline	0,04	1,01	2,45
↓	Gamsberg	-	0,50	7,00
East				

A progressive increase in copper to the west and zinc to the east is clearly demonstrated.

The Aggeneys base metal deposits display many of the characteristics of the exhalative model. However, available data suggests that they are probably hosted in a metasedimentary succession and it would therefore be more correct to assign an exhalative-sedimentary origin to them. With respect to conditions of ore genesis, the ferruginous Red Sea deposits appear to offer the closest parallel in recent ores.

Much more detailed work has yet to be done on the mineralogy and whole-rock chemistry of the individual ore bodies in order to reconstruct their depositional environments and relative palaeo-geographical settings. However, at this early stage it is clear that the Aggeneys base metal sulphide deposits have many similarities with the famous Broken Hill deposits in Australia (Stanton, 1978). Other deposits with apparently similar genetic characteristics are New Brunswick in Canada and Pegmont in Australia (Stanton and Vaughan, 1979).

XI. SUMMARY AND CONCLUSIONS

During 1971 Phelps Doge discovered three major lead-zinc-copper-silver ore bodies near Aggeneys. One of these, viz. the Broken Hill ore body, was brought into production in January, 1980 by the Black Mountain Mineral Development Company (Pty) Limited (51% owned by Gold Fields of South Africa Limited and associated companies, and 49% by Phelps Dodge Corporation) at an initial milling rate of 1 125 000 tonnes per annum. The average grade of the extractable reserves at Broken Hill is 0,43 per cent copper, 6,17 per cent lead, 2,64 per cent zinc and 80 grams of silver per tonne.

Following the initial discovery, detailed surface geological mapping, ground and airborne magnetic surveys, and surface diamond drilling techniques were used to explore for and delineate the ore bodies. At Broken Hill, underground development, followed by geological mapping and diamond drilling, was used to further define the geometry and economic mining limits of the deposit.

The Aggeneys base metal sulphide deposits occur in the regionally developed metavolcano-sedimentary Bushmanland Sequence which forms part of the Precambrian Namaqualand Metamorphic Complex.

The stratigraphic sequence encountered at Aggeneys consists of a basal augen gneiss, overlain by pink gneiss, followed by aluminous schist, which in turn is overlain by white quartzite. Conformably overlying these rocks with a gradational contact, is the Aggeneys Ore Formation which consists of a 200 m-thick succession of quartz, muscovite, biotite, feldspar, sillimanite schist, the latter interbanded in places with thin units of micaceous quartzite and calc-silicate rocks. It is in this sequence that the Black Mountain, Broken Hill and Big Syncline stratiform ore bodies occur.

Although this economically important mineralized stratigraphic unit appears to have originally been extensively distributed throughout the Namaqualand/Bushmanland region, subsequent erosion has resulted in vast areas being completely removed. Only where the Bushmanland Sequence is infolded into the basal gneisses have the mineralized formations been preserved in the cores of folds.

Lying conformably above the Aggeneys Ore Formation, and constituting what is thought to be the top of the stratigraphic succession in the area, is a variable sequence of amphibolites and leucocratic grey gneisses.

Four phases of deformation have been recognized, the latter resulting in the production of highly complex refolded and faulted structures. The various rock types in the area, including the banded sulphide ores, have been subjected to dynamothermal metamorphism bordering on granulite facies, and the highest degree of regional metamorphism is thought to have occurred during, and outlasting, the F_2 period of deformation. Retrograde metamorphism has also affected the rocks in the area.

In spite of the fact that the ore bodies have been subjected to intense structural deformation, it has been possible to recognize characteristic stratigraphic successions for each ore body. These are summarized in Table 7.

TABLE 7

STRATIGRAPHIC SUCCESSIONS OF THE AGGENEYS ORE BODIES

Black Mountain	Broken Hill	Big Syncline
	Pyritic sillimanite Biotite schist	
Garnet quartz schist	Pyritic graphitic Biotite schist	Spring Schist and Quartzite
Magnetite-barite rock		Calc-silicate rock
Magnetite amphibolite	Magnetite amphibolite Massive sulphide Ferruginous quartzite	
Sillimanite quartz schist	Sillimanite quartz schist	Nodular schist
Magnetite-barite rock		
Magnetite amphibolite	Magnetite amphibolite	Pyribolite
Magnetite quartzite	Magnetite quartzite	Magnetite quartzite
	Banded massive sulphide	
	Baritic massive sulphide	
	Sulphide quartzite	
Garnet quartzite	Ferruginous quartzite	
Schist and quartz schist	Sillimanite quartz schist	Fly Schist
WHITE QUARTZITE	WHITE QUARTZITE	WHITE QUARTZITE

The ore bodies occur in the same general stratigraphic interval and are intimately associated with banded iron-formations. The economic sulphide minerals consist of varying proportions of chalcopyrite, galena and sphalerite which, together with pyrite and pyrrhotite, often reach massive sulphide concentrations. At Black Mountain the sulphide-rich layers are overlain by barite-rich rocks.

The manganese content of the hanging and footwall rocks increases as the various orebodies are approached and manganese-rich garnet is a characteristic mineral throughout all three ore bodies. Apatite and fayalite occur as accessory minerals throughout the deposits and appear to be diagnostic in that they have also been reported in the mineral suites of the Broken Hill and Pegmont ore bodies in Australia.

The presence of more than one zone of base metal sulphide mineralization at Big Syncline and the possibility of two distinct ore bodies at Black Mountain and Broken Hill, demonstrates that the main periods of base metal sulphide deposition were interrupted by periods of more or less barren detrital sedimentation.

The ore bodies display systematic variations in base metal content and mineralogy in both a vertical and lateral sense. The diagnostic mineral assemblages of the banded iron-formations associated with the ore bodies indicate that oxide, sulphide and silicate facies of deposition were represented.

At Broken Hill and Black Mountain there is very clear evidence of an increase in base metal content in the cores of the F_2 fold closures. Whether this concentration is due to the migration of base metal sulphides into fold closures, or whether the fold closures took place about the more massive sulphide sections of the ore body, is not known.

Detailed mineralogical and geochemical investigations of the ore bodies will, no doubt, shed more light on the depositional environments, palaeogeography and genesis of the ores. However, at this stage the writers are confident that the Aggeneys ore bodies are stratabound exhalative sedimentary deposits with close genetic affiliations with the Broken Hill and Pegmont deposits of Australia and possibly some of the New Brunswick deposits of Canada.

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oOo

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