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Record 1970/115

GEOLOGY AND COPPER DEPOSITS OF THE PINNACLES BORES AREA, STRANGWAYS RANGE, NORTHERN TERRITORY

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CONTENTS

SUMMARY

The purpose of this survey was firstly to provide geological background for a ground geophysical survey (Haigh, 1971) designed to investigate aeromagnetic anomalies outlined by Tipper (1966) and secondly, to study the copper mineralization in the area. The work was carried out in 1969 while the author was at the Resident Geologists' Office, Alice Springs. The area was geologically mapped at the scale of the aeromagnetic survey (about 1:22 500). Data were recorded on an enlarged overlay to aerial photograph Alice Springs 3E-C/5024, which has a slightly variable scale. Copper prospects and geophysical features were examined in more detail. The geophysical survey included induced polarization (IP), self-potential (S-P), electromagnetic (Turam) traverses, and magnetic methods. The geophysical results were economically disappointing. The prospects were subsequently tested in detail by Kenneth McMahon and Partners Pty Ltd, consultants to Magellan Petroleum (N.T.) Pty Ltd. Their geochemical and drilling results, together with details of recent gouging activity by others, have been incorporated in this report.

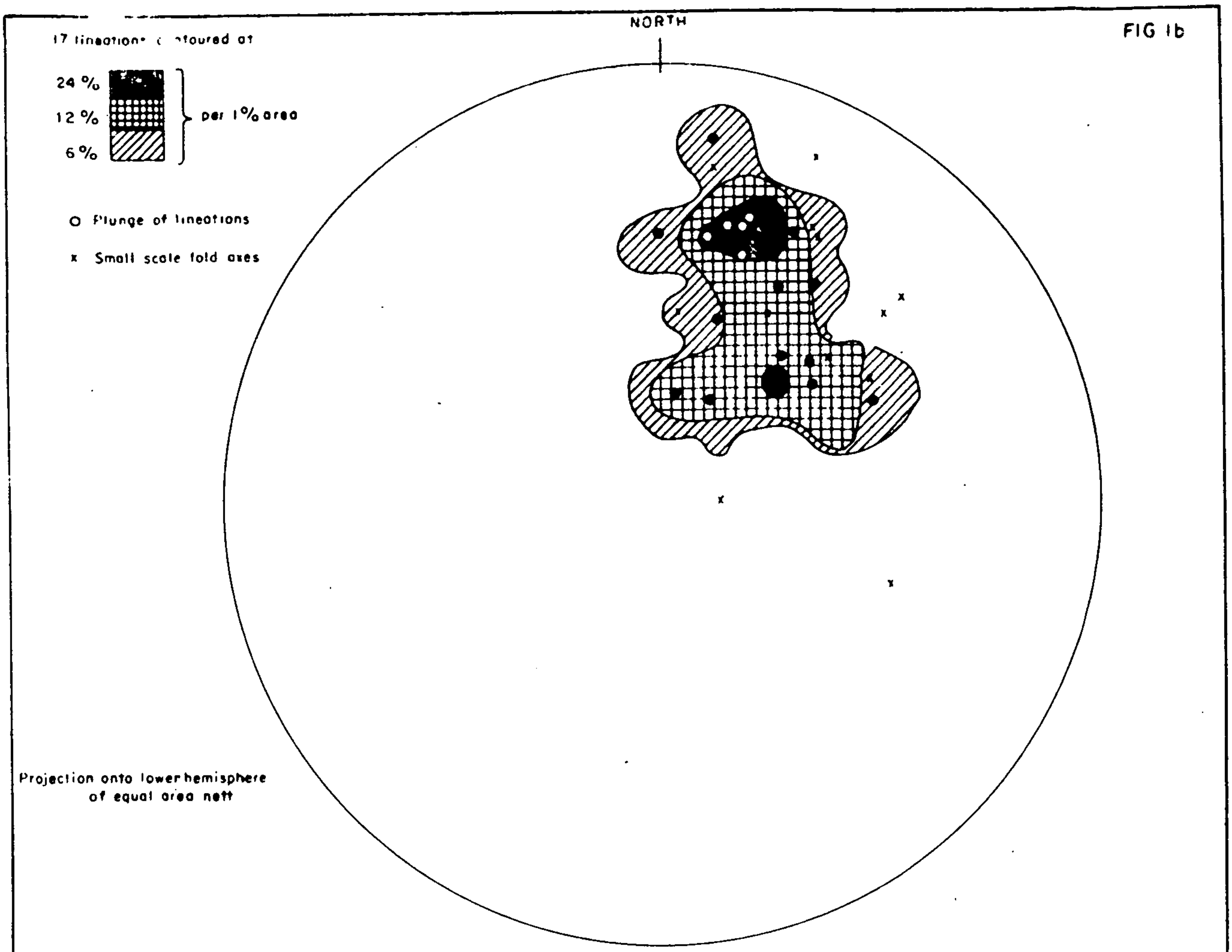
Within the area, the Precambrian Arunta Complex consists largely of calcareous rocks, with subordinate arenaceous and argillaceous rocks that have been regionally metamorphosed to upper amphibolite facies. Quartz and pegmatite veins occupy shears and small gneissic granites are thought to have intruded the rocks. Numerous sills and a few short dykes of mafic igneous rock (meta-norite) have intruded gneisses north of Southern Cross Bore.

The ore is richest near the present ground surface and is therefore considered to be mainly secondary. The copper mineralization, with the exception of chalcopyrite, is concentrated in fractures in quartz veins. Copper-bearing quartz veins, seldom more than 1 m wide, fill a series of north-trending shears that lie in north-trending zones concentrated in calcareous rock sequences. In areas occupied by marble, the veins are commonly localized in narrow intercalations of schist and calc-silicate rock that were more susceptible to shearing. Copper minerals include malachite, chalcocite, bornite, a small amount of chalcopyrite, traces of azurite and chrysocolla, and rare cuprite and native copper. The veins carry traces of gold, silver, and bismuth. They contain small amounts of black tourmaline as well as siderite gangue.

A small hypogene replacement deposit, the Johnnie's Reward Prospect, differs from the vein deposits in that it contains lead and zinc minerals. The lode consists essentially of actinolite and magnetite, with quartzite lenses and calcareous margins. Copper is present as disseminated chalcopyrite. The lode is an ellipsoidal body 180 m long and up to 55 m wide, and probably has a vertical extent of less than 75 m. Surface assays averaged 0.34% copper, 0.17% lead and 0.13% zinc. A drill hole at the northern end intersected 0.18% copper and 0.19 dwt per ton gold over an estimated true width of 30 m at a depth of 30 to 60 m.

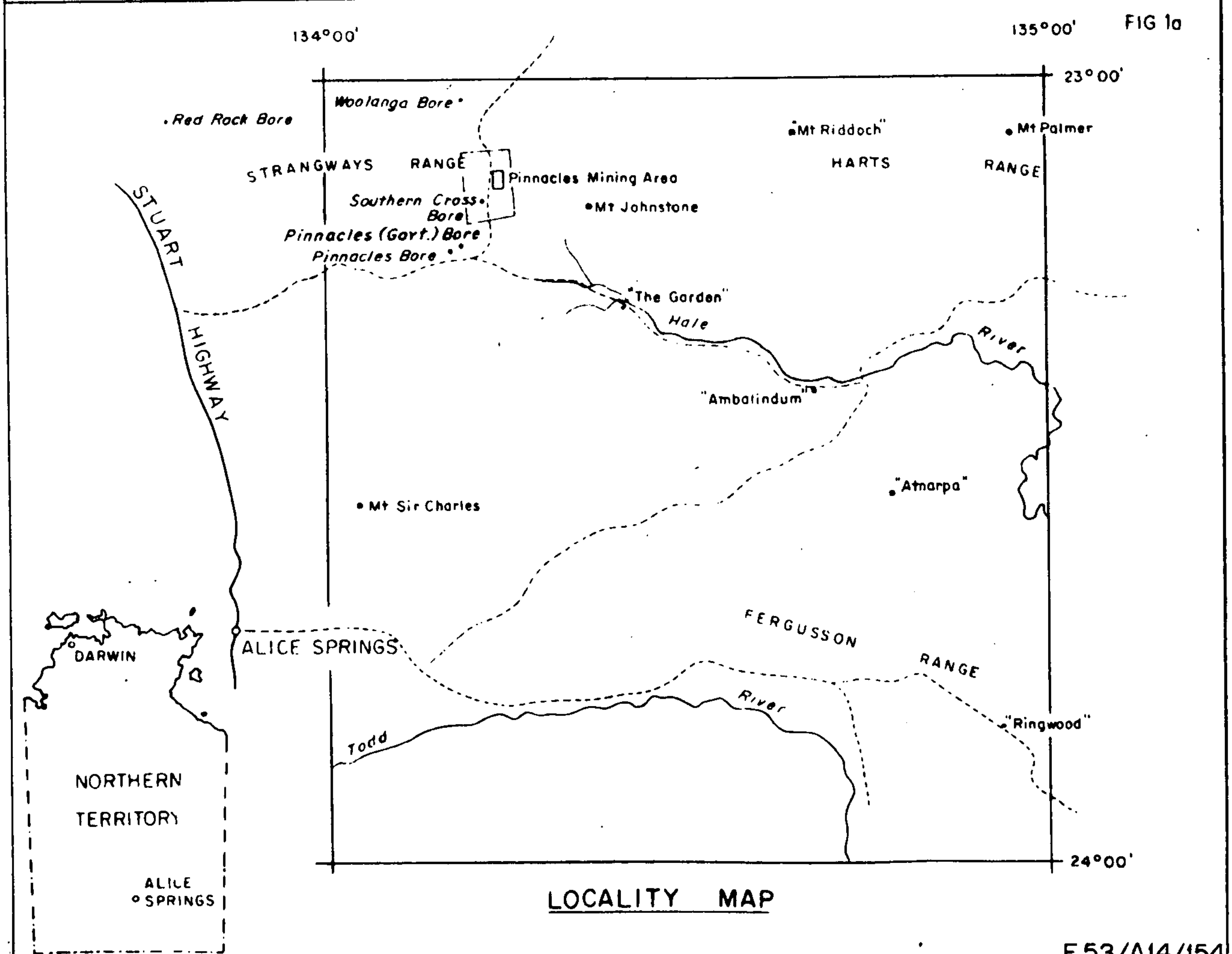
In the 1940's P. Ciccone mined the richer veins and in 1952 K. Johannsen again attempted mining the richer veins. J. Vitosky began gouging in 1964-66. Small-scale mining continued until October 1968, when it ceased because there were insufficient reserves of a high-grade ore (i.e. greater than 8% copper). Estimated production is 163 tons of ore averaging 12.4% copper.

Future prospecting, especially for small, high-grade copper deposits, should be concentrated along north or northwest-trending faults particularly those in calcareous rocks or adjacent to tourmaline-bearing orthogneisses. Disseminated ore of lower grade but larger tonnage, such as the Johnnie's Reward Deposit, might be found by search of magnetic bodies, particularly those near north or northwest-trending faults.



STEREOGRAPHIC PROJECTION

Showing plunge of lineations and small scale fold axes



LOCALITY MAP

To accompany Record 1970/115

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INTRODUCTION

Location

The Pinnacles copper mines are situated near Southern Cross Bore, 116 km northeast of Alice Springs by road. The mines derive their name from Pinnacles Well, now replaced by the Pinnacles Bores, 10.5 km south-southwest of the mines (Fig. 1a).

Mining and Prospecting History

A trace of gold was found in quartz veins in 1889 and since then the area has been prospected intermittently. Copper was first mined by P. Ciccone in the 1940's (Sullivan, 1942; Jensen, 1943, 1944a). He held leases MLS, 140H, 141H, 142H (known as the Pinnacles Copper Workings) until 1948, when because of uneconomic operation mining ceased.

K. Johannsen attempted mining of the 'calcite' and 'calcite copper' leases, MLS, 216H, 231H, and 255H in 1952. He relinquished his leases in 1957.

Since 1964, secondary ore has been mined by J. Vitosky and others from the old workings and from new workings within a 5-km radius of the older workings. These mines were later named the Centralian Mines. The high-grade ore (10% and higher) necessary for economic small-scale mining had a very patchy and often unpredictable distribution. Owing to a lack of ore reserves, mining ceased in October 1968.

In 1964, the Johnnie's Reward Prospect, a tremolite-actinolite lode containing disseminated chalcopyrite and magnetite, was found 1 km north-northwest of Southern Cross Bore. The prospect appears to be uneconomic.

Water Supply

Slightly salty, yet palatable drinking water is obtainable from Southern Cross Bore. The depth to water here is not known, but is about 9 m at the Pinnacles Bores.

Units of Measurement

In this report distances including footages from drill holes, are given in the metric form. Production figures are given in avoirdupois weights (i.e. long tons).

Previous Investigations

Sullivan (1942) described the mineralization in Ciccone's Shaft. He recommended that the shaft, then 8.5 m, be deepened to 15 m and the lode be cross-cut at this depth.

Jensen (1943) described the Pinnacles ore, which he thought was primary, as stockworks of red copper oxide and copper sulphides in quartz. He suggested a plant to crush and concentrate lower-grade ores. He also made brief hand-specimen descriptions of the rock types in the area.

In 1948 Thomson made a geological reconnaissance of the prospects for Enterprise Exploration Co.

In 1952 Bell and Firman mapped Johannsen's and Ciccone's workings using a chain and compass, and inferred ore reserves for a vertical depth of 6 m to be 100 tons of 20% copper and 9 000 tons of 5% copper. (Bell & Firman, 1952; Bell, 1953). Two drill holes recommended by Bell (1952) were put down within Johannsen's workings in October, 1952, but they did not penetrate the main ore zone.

Youles (1964a) examined the area around Centralian No. 2 Mine and Johnnie's Reward Prospect in 1964 and proposed a low-level aeromagnetic survey. Later he carried out a geological reconnaissance to provide a background for the survey (Youles in Tipper, 1966). He recommended four diamond drill holes (Youles, 1966); two to test for sulphides below an ironstone body located 500 m northwest of the Centralian No. 2 Mine, and two to determine the depth of secondary enrichment in the vein deposits. The drilling was not carried out.

An aeromagnetic survey over the area by Geophysical Branch, BMR in 1965 did not detect any anomalies associated with the vein deposits, but a small anomaly was produced by the magnetite-rich chalcopyrite lode at the Johnnie's Reward Prospect (Tipper, 1966).

In 1965 Geopeko Ltd drilled the Johnnie's Reward Prospect to test self-potential and ground magnetic anomalies. Only small, uneconomic quantities of chalcopyrite were intersected (Williams, Geopeko, 1965).

In 1967 Grainger (1967) briefly examined the Polly Boy Mine. He also collected samples from the general area. These samples were described by Fander (1967) of Australian Mineral Development Laboratories. Specimens collected during the present survey were described by Williams (1967) and Haslett (1968a, b) both of A.M.D.L. Locations of specimens petrographically described by A.M.D.L. are marked on the enclosed geological map (Plate). A set of descriptions and cross-reference to locality numbers is held in the BMR technical files.

TABLE 1. - Summary of Ground Geophysical Traverses

Traverse	S - P	I.P.	Magnetic	Turam	Comment
Johnnie's Reward Grid	Two small anomalies at Johnnie's Reward Prospect and 180 W, 4700 - 4900 N	Several weak anomalies correspond with weak Turam anomalies at Johnnie's Reward Prospect and 150 W on Trav. 4800 N and 4880 N.	Magnetically disturbed area with very irregular profiles. Anomaly at Johnnie's Reward Prospect	See I.P. result. A large Turam anomaly (21 800 E on Traverse 4600 N, 4800 N and 5000 N) is not associated with any S-P - I.P. anomaly	Causative body at prospect shallow and of small depth extent
Pinnacles Grid	No anomalies	Broad, weak I.P. anomaly on Traverse 00 between 400 E and 2400 E and on Traverse 1200 N between 1200 E and 2400 E and on 2400 N from 1800 E to 2400 E	No anomalies	-	Wide grid spacing aimed to test for possibility of large mineralized zones beneath alluvial plains. I.P. anomaly possibly due to magnetite contained in amphibolite or mafic calc-silicate rocks, though a broad zone of weak mineralization is remotely possible
New Folly Grid	No anomalies	No anomaly recorded with 100 ft dipole lengths; a weak anomaly recorded with 25 ft dipole lengths	-	Turam anomaly shows good correlation with exposed mine and quartz vein	Weak mineralization observed at shallow depths does not persist in depth
Traverses B and C	No significant anomalies	-	-	-	Traverse along fault zones
Traverse D	-	None	-	-	Traverse along fault zones
Traverse E	-	Weak MP anomaly associated with a very weak FE anomaly	-	-	Anomaly not considered significant
Traverse G	No anomaly	-	-	-	Traverse over rocks containing visible magnetite to test theory that no anomaly would be produced in this environment from magnetite in the absence of sulphide mineralization
Traverse H	No anomaly	No anomaly	No anomaly	-	-

The results of the Bureau's detailed ground geophysical survey, carried out at the same time as the present geological study, are available in record form (Haigh, 1971). Several weak IP anomalies were located and most are thought to be due to mafic igneous rocks. In two areas there was good agreement between IP, Turam, and S-P results. One, the Johnnie's Reward Prospect, was later drilled by Magellan Petroleum (N.T.) Pty Ltd; the other, to the north of the Johnnie's Reward Prospect, is considered too small to warrant further investigation. In general the magnetic results were too erratic to be of any value. The layout of the geophysical traverses is shown in Figure 4 and a summary of results for each traverse given in Table 1. The geophysical results for each prospect are detailed in the chapter 'Description of Individual Prospects'.

In the summer of 1967-68, the prospects were investigated by McMahon and Partners (1968) on behalf of Magellan Petroleum (N.T.) Pty Ltd. The survey consisted of detailed mapping, together with sampling by percussion drilling to depths up to 3.7 m. Dust samples were usually collected 0.6 or 0.9 m (2-3 ft) intervals and analysed by atomic absorption. An 8 square mile map at a scale of 1:12 000 was prepared. Four inclined diamond drill holes, ranging in down-hole depth from 95 to 166 m, were put down; two at the Ophir Prospect, one at Ciccone's Shaft, and one at Johnnie's Reward Prospect. Only minor mineralization was found.

The only published reports that contain descriptions of rock types from the Arunta Complex similar to those in the Pinnacles area are the regional studies of Jensen (1944b) and Joklik (1955) on the Harts Range and Plenty River areas, and Hossfeld's (1954) general study of the Northern Territory.

GENERAL GEOLOGY

Summary of rock types

Within the area, the Precambrian Arunta Complex consists largely of calcareous rocks, together with arenaceous and argillaceous rocks. The rocks have been regionally metamorphosed to the upper amphibolite facies. Two small bodies of granite are thought to have intruded the rocks before metamorphism. In other parts of the area, veins of quartz and pegmatite have filled shear zones. Numerous lenticular sills and a few short dykes of mafic igneous rock have intruded the gneisses north of Southern Cross Bore.

Classification of Rock Types

The calcareous rocks include marble, calc-silicate rocks, calcareous quartzite, and semi-calcareous rocks. Where possible marble and calcareous quartzites have been mapped as separate units. Other calcareous rocks have been subdivided where possible into leucocratic and mafic varieties. The leucocratic varieties invariably contain only small amounts of amphibole or pyroxene and have a colour index of less than 20. The mafic varieties, with a colour index greater than 20, are less easily distinguished from igneous rocks.

The distribution of metamorphic index minerals is shown on the geological map.

Many of the rocks, particularly those of calcareous composition, are granoblastic textured, but have not been metamorphosed to a sufficiently high grade to be termed granulites: they are therefore described as calc-silicate rocks and gneisses.

Details of Geology

Calcareous rocks (a) Leucocratic Varieties

The leucocratic rocks comprise calcareous metaquartzite, marble, and mafic calcareous rock. They typically contain quartz, calcite, epidote-clinozoisite, calcic plagioclase (andesine to labradorite), clinopyroxene (diopside), amphibole (tremolite-actinolite, hornblende), scapolite. Calcite, quartz, and feldspar are plentiful. The rocks may also contain microcline, phlogophite, dolomite, and garnet. Accessory minerals include magnetite, sphene, tourmaline and apatite. Feldspar is partly replaced by scapolite in most calcareous rocks of the area.

The calc-silicate rocks are usually composed of pale and dark grey layers, the dark layers containing slight concentrations of mafic minerals. A few greenish rocks contain a high proportion of epidote.

The marble consists largely of calcite but in places may also contain small inclusions of dolomite, green diopside(?), and epidote as well as small amounts of garnet. It is white to pink and very coarsely crystalline. Less common varieties include impure brown marble and finely crystalline grey marble. Small lenses of metamorphosed impure marble, dusted with fine specks of magnetite, crop out 700 m and 135 m north of the Johnnie's Reward Prospect. Most of the marble occurs as thick lenses forming low rounded hills.

Calcareous metaquartzite is blue-grey or grey when fresh, and brown or dark brown on weathered surfaces. It typically forms strike ridges.

Leucocratic calcareous rocks form rugged hills and strike ridges near the Centralian No. 2 Mine. They are also interlayered with biotite gneiss in the southwest quadrant of the area. In the southeast the calcareous rocks grade into more mafic rock. In the northeast and west they grade into and are interlayered with biotite gneiss and other leucocratic gneisses.

Calcareous rocks (b) Mafic varieties

Mafic calcareous rocks (colour index greater than 20) are considered to be metamorphosed impure calcareous sediments, since they are commonly interbedded with the leucocratic calcareous rocks (including marble) of more obvious sedimentary derivation. Many of the rocks contain calcareous minerals such as tremolite, diopside, calcite or epidote. The mafic mineral is either amphibole or clinopyroxene. Accessory magnetite is common and consequently, large bodies of the mafic calcareous rocks commonly produce the aeromagnetic anomalies noted by Tipper (1966).

Typical constituents of the mafic calcareous rocks are: amphibole (tremolite-actinolite, hornblende), clinopyroxene (hedenbergite, diopside), plagioclase (andesine-labradorite), quartz, feldspar (partly replaced by scapolite in places), and biotite. Less abundant minerals include: scapolite, calcite, epidote, garnet, microcline, cordierite?, and magnetite. Opaque minerals and sphene are accessory.

The rocks are hard, dark grey, blue-grey, or pale grey, and weather to pale brown. Most have an irregular compositional layering of felsic and mafic minerals, which is believed to be remnant bedding. The texture is commonly granoblastic. Amphibole prisms generally define a lineation.

The mafic rocks crop out in the southeast corner of the area. From the results of an aeromagnetic survey, Tipper (1966) suggested that the proportion of mafic rocks (amphibolite) increases to the southeast. The mafic rocks are interlayered with narrow layers of biotite gneiss and calc-silicate rock (i.e. rock with a colour index less than 20). Lenses of amphibole-bearing mafic rock also crop out 2.5 km southwest of Southern Cross Bore and may account for the aeromagnetic anomalies in Tipper's zone 'F' (1966). Similar rock crops out in the limbs of an overturned anticline 2.5 km east of Southern Cross Bore, and probably caused the anomaly in Tipper's aeromagnetic zone 'D'.

A coarse-grained (1-5 mm) amphibolite? containing abundant quartz crops out as prominent rounded hills 6 km north-northwest of Southern Cross Bore. The amphibolite is different from other mafic rocks mapped in the area. It is considered to be of sedimentary origin since it contains abundant quartz.

Metaquartzite (non-calcareous)

Prominent ridges of metaquartzite extend from 1.6 km south of Southern Cross Bore to the south-central part of the area. The quartzite is a silicified medium- to coarse-grained sandstone, feldspathic in parts. Narrow bands of muscovite-quartz schist and biotite-quartz schist are interlayered with the quartzite.

Quartzo-feldspathic and pelitic gneisses

Biotite gneiss together with narrow layers of quartzite and calc-silicate rock crop out as rugged hills northeast of Southern Cross Bore. A belt of similar rock about 400 m wide extends northwest from about 2 km southwest of Southern Cross Bore. They are massive, grey or greenish-grey rocks and weather to pale orange-brown. They contain sparsely disseminated garnet porphyroblasts up to 10 mm in diameter. Sillimanite in quartzo-feldspathic gneiss has been recorded at the Johnnie's Reward Prospect (McMahon and Partners, 1968) and 0.5 km farther east (Fander, 1967, spec. 9).

Quartzo-feldspathic and pelitic gneisses form strike ridges, and in some cases small hills in the extreme northeast corner of the area. The gneisses are interbedded with calc-silicate lenses 120-300 m wide. Banding in the gneisses is probably remnant bedding. Biotite gneiss and schist forming low ridges and valleys are also interlayered with calc-silicate rock in the southwestern quadrant. Biotite-rich types are generally schistose and almost black, whereas feldspar-rich types are gneissic and mottled off-white and grey. Garnet porphyroblasts are scarce, but widespread and are more plentiful in the biotite-rich types.

Orthogneisses

Two small bodies of gneiss are thought to be deformed, metamorphosed granites.

Biotite gneiss with accessory tourmaline and garnet crops out 1.2 km east of the Jill's Penny Prospect. The foliation of the gneiss is discordant to that in the calc-silicate country rock. A patch of copper staining occurs near the edge of the gneiss.

Garnet-biotite gneiss containing porphyroblasts of alkali-feldspar form a high range about 3 km northwest of the Johnnie's Reward Prospect. It is considered to be an orthogneiss because of its massive structure and homogeneous composition.

Pegmatites

Two types of pegmatite are widespread. The more abundant type occurs as segregations in the metasediments and typically consists of quartz and feldspar, together with small amounts of biotite, muscovite and garnet. These pegmatites are unrelated to the mineralization.

The second type is transgressive and contains accessory tourmaline as well as quartz and feldspar, and small amounts of biotite and garnet. This type of pegmatite occupies the fault zone east of the Centralian No. 2 Mine. Malachite stains rock adjacent to one of these pegmatites.

Quartz veins

Several tourmaline-bearing quartz veins infilling north-south faults and shears are mineralized. A line of barren quartz veins fills a major fault that parallels the north-south track to the Centralian No. 2 Mine and hut. A number of both mineralized and barren quartz veins are limonite stained. The few that are measurable dip steeply east.

Meta-Norite

Numerous small sills and a few short dykes of meta-norite were mapped north and northwest of the Johnnie's Reward Prospect near the biotite gneiss calc-silicate rocks contact. The meta-norite is massive, very hard, and dark green. Williams (1967, spec. 17) estimated the following constituents -

hypersthene	46%	
plagioclase	33%	
opaques	10%	(including magnetite)
clinopyroxene	7%	
hornblende	2%	
quartz	2%	

Accessory minerals include apatite, biotite, sericite, and calcite. Parallel alignment of hypersthene suggests that the rock has been metamorphosed. It is the most abundant magnetite-rich rock north of the Johnnie's Reward Prospect.

METAMORPHISM

In most of the area the rocks have been regionally metamorphosed to the higher grade part of the amphibolite facies. In the northwestern part of the area, however, rocks have been metamorphosed to the granulite facies. Retrogressive metamorphism is evident along shears.

Mineral assemblages indicating a sillimanite metamorphic grade zone in pelitic assemblages include -

(1) quartz-biotite-sillimanite-garnet (specimen 9, Fander, 1967);

(2) quartz-sillimanite-phlogopite-bytownite (An ca80) - orthoclase-andalusite-opaques (specimen 19, Williams 1967).

The coexistence of sillimanite and orthoclase in the absence of muscovite indicates the assemblage could have been formed in the upper sillimanite zone. The presence of andalusite (5% of rock) is unusual and suggests a relatively low pressure or later retrograde metamorphism.

Mineral assemblages in calcareous rocks include -

(1) quartz-diopside-calcite-andesite (specimen 6, Fander, 1967);

(2) hornblende (green)-dipside-andesine-quartz-microcline-sphene-scapolite (specimen 14, Fander, 1967)

(3) plagioclase?-hedenbergite-scapolite-calcite-sphene-epidote-garnet (specimen 18, Williams, 1967)

(4) quartz-calcic plagiocase-clinozoisite (epidote) - actinolite-sphene-diopside-calcite-scapolite (specimen 12, Fander, 1967) (scapolite is partly replaced by calcite).

Hornblende, diopside, and andesine are characteristic of calcareous rocks metamorphosed to a higher grade part of the amphibole facies (cf. Trommsdorff, 1966), in Turner, 1968; Engel & Engel, 1962 p. 43, 1960 p. 53; Misch (1964), and in Turner 1968). Mineral assemblages (3) and (4) contain an unusually large number of minerals, possibly owing to wide compositional variations between layers in one rock (or possibly representing a meta-stable

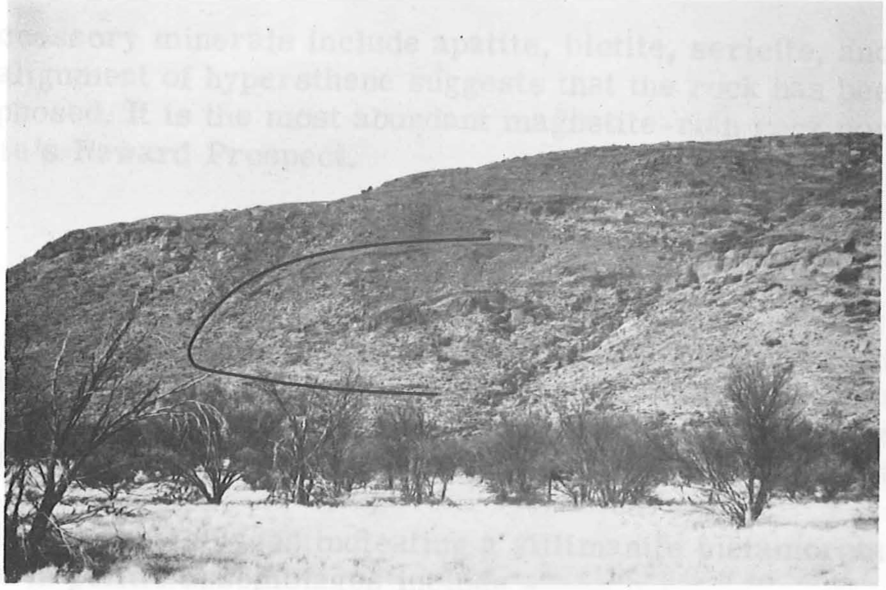


Figure 2. Recumbent fold with amplitude of about 40 m, two kilometres southeast of Jill's Penny Prospect.

Figure 3. Small-scale fold in calc-silicate rock, 1 km southwest of Southern Cross Bore. Note: folding is disharmonious; fold hinges are sharp and no foliation is visible parallel to the axial plane. (Neg. No. GA/4646)

assemblage indicating poly-metamorphism over a wide range of pressure-temperature conditions within the Amphibolite Facies). Mineral assemblage (4) includes actinolite, suggesting metamorphism to lower grades of the amphibolite facies.

The meta-norite 1 km north of the Johnnie's Reward Prospect (spec. 17, Williams, 1967) has the granulite mineral assemblage hypersthene-bytownite-magnetite-clinopyroxene-quartz-(hornblende). The parallel alignment of hypersthene suggests a metamorphic texture.

Greenschist facies mineral assemblages in pelitic rock from the shear zones are:

(1) quartz-albite-muscovite-biotite (specimen 7, Fander, 1967) (biotite is reverting to chlorite).

(2) biotite-muscovite-quartz-chlorite (specimen 8, Fander, 1967).

(3) chlorite-muscovite-quartz-garnet (garnet relic) (specimen 13, Fander, 1967).

(4) quartz-chlorite-muscovite (specimen 21, Haslett, 1968b).

STRUCTURE

Folding

Most of the small-scale fold axes and lineations plunge steeply to the northeast (Fig. 1b). Measured axes of larger scale (amplitude greater than 30 metres), folds also plunge to the northeast (Fig. 2). Axial planes dip northeast, east and southeast, at moderate to steep angles.

The style of folding is consistent in the area mapped. The folds are cylindrical and generally disharmonic. Their hinges are angular and they lack an axial-plane schistosity (Fig. 3). Rodding of quartz veins and elongation of amphiboles form lineations parallel to the fold axes (Fig. 1b).

Sets of superposed folds whose axes have the same orientation crop out 7 km northwest of Southern Cross Bore and suggest synchronous refolding.

Large-scale folding is also evident, a structure 2 km east of Southern Cross Bore is interpreted as a fold, plunging steeply to the northeast with an axial plane dipping to the southeast. Beds have been flexed into broad arcs north of Southern Cross Bore, and in the southeast corner of the area.

Faulting

Faults divide the area into three blocks:

1. A large western block where the rocks strike northwest to west-northwest and dip to the northeast.

2. A central-eastern block where the rocks strike north to northeast to east and in most cases dip to the east or southeast.

3. A northeastern block where the rocks generally strike north and dip to the west.

A meridional fault apparently dipping eastwards separates the western and central blocks. A shorter parallel fault lies about 1½ km to the east, near the Polly Boy Mine. A zone of quartz filled shears and fractures extends from the Centralian No. 9 prospect to Ciccone's Shafts. A quartz filled north-northwest aligned fault, in sericite schist, passes through the Baldy Rise Prospect. Two faults south of Southern Cross Bore intersect the meridional fault at an angle of about 45°. A cross-fault displaces(?) the more northerly of the two faults. Small cross-faults were noted by Bell & Firman (1952) in the area of early workings near the Centralian No. 2 Mine. Two parallel faults, part of a regional fault zone extending for 50 km from west of 'The Garden' homestead to Woolanga Bore (Fig. 1a), divide the central block from the northeastern block. The more westerly fault roughly coincides with a positive aeromagnetic trend-line; Tipper (1966) considers that it may be filled with veins containing magnetic minerals.

ECONOMIC GEOLOGY

Production

The estimated production for the period 1952 to 1968 was 163 tons of ore which averaged 12.4% copper. Two lots of the same ore, totalling 21.6 tons, contained an average of 2.9 oz per ton of silver. An additional 35 tons visually estimated to contain from 2% to 5% copper are believed

TABLE 2. – Production

Date	Prospect	Production claimed by Vitosky	Ore Sold (Tons)	Grade Copper (%)	Grade Silver (oz ton)	Production Recorded by Mines Branch	Year	Location of Buyer	Reference
1942 & 43	Probably from Ciccone's Shafts		50	? 20 est					Ludbrook, 1949
1952	Johannsen's Shaft		20	20				Unknown	est. by Bell & Firman, 1952
? before 1966	Polly Boy (ML358H)	22 tons of 17.8% copper	10	15		20 tons of 15% copper from Centralian No. 2, 1964 to 7/1/69, est. by D. Woolley	1964	Adelaide	Est. by R. Harris Alice Springs
1964-65	S. Cross Miners (ML327H) probably Centralian No. 2 (ML335H)	1000 tons broken 30-40 tons containing 15-20% copper hand-picked	12	11.66			1965	Port Kembla via Eric Marchant Pty Ltd	Table 2, Vierk (1966)
Sent Aug 66	Probably Centralian No. 2 (ML335H)		9.4835	21.18	2.93	500 tons broken. Trial of 9 tons 18 cwts hand picked and sent to Port Kembla	1965 - 66	Port Kembla	Buyers Records
Sent Nov 66	Centralian No. 2 (ML335H)		12.0943 N.D.W.	14.43	2.88	23 tons yielding copper worth $3220 sent to Pt Kembla & Mt Isa	1966 - 1967	Port Kembla	Value $1601, Adams (1968); Buyers
Sent Dec 67	Ophir North (ML372H)		70 crushed at Alice Springs			50.95 tons containing 4.72 tons copper valued at $3525	1967	Adelaide	Est. Reg. Harris
			43.7 of above					Adelaide	Buyers Records
June Aug 68	Urals No. 1 (ML380H)	8 tons	7.25 N.D.W.	8.24				Mt Isa	Buyers Records
Sent 31/7/68	Ophir South (ML372H)		17.93 N.D.W.	5.27		Unavailable	1968	Mt Isa	Buyers Records
Sent 20/8/68			19	5.27		Unavailable		Mt Isa	Est. by R. Harris Alice Springs
Oct 1968	Midland		7	2-5%		Unavailable			Inferred by R.D. Shaw

to have been mined from the Ophir and Midland Prospects, but were of too low grade for sale. A small amount of ore, not included in the estimate, was mined by K. Johannsen in 1952, and at least 50 tons was mined by Ciccone in the 1940's. Production from individual prospects is given in Table 2 .

The Ore Deposits

Copper ore was deposited in quartz veins, seldom more than 1 m wide, filling small north-trending shears. The shears commonly dip steeply to the east and are confined to north-trending zones that generally cut dominantly calcareous rocks. The veins are aligned roughly parallel to the foliation, but in places are slightly oblique to the country rock.

The copper content of veins varies from a trace in quartz stringers to 30% in rich ore-pockets within thick quartz veins. The veins also carry traces of gold, silver, and bismuth. The grade of ore is extremely variable. Ore is richest near the present ground level possibly due to capillary enrichment, and is considered to be mainly secondary. Most copper minerals are concentrated in fractures in the quartz veins; chalcopyrite occurs in the unfractured quartz.

Copper minerals present are malachite, chalcocite, bornite, a small amount of chalcopyrite, traces of azurite and chrysocolla, and rare cuprite. The veins contain small amounts of black tourmaline as well as siderite gangue and hence are thought to be related to a few pegmatites in the same area.

At the Ophir Prospect copper minerals are deposited in marble near small-scale shears localized near contacts between marble and schist. At the surface, malachite is contained in quartz stringers which also include a few patches of tourmaline. Below ground-level bornite and chalcocite are disseminated throughout narrow bands of marble that commonly contain tourmaline. These mineralized zones do not appear to be adjacent to any shears. The bornite and chalcocite are believed to be replacement of chalcopyrite.

The vein deposits occupy secondary faults and shears within four major north-trending deformed zones or, in some cases, single faults.

(1) The largest zone is up to 240 m wide and 2.5 km long and passes through the Centralian No. 9 and Ophir Prospects, Ciccone's Shafts and possibly the Urals No. 1 Prospect. It contains quartz veins localized in thin bands of schist and calc-silicate rock in what is otherwise marble.

(2) Baldy Rise and Flat Depth Prospects are situated on a second deformed zone in which a new schistosity has developed.

(3) A third fault extends from the Polly Boy Mine to 1 km east of Centralian No. 2 Mine.

(4) A fourth fault zone extends from Paul's Run and Midland Prospect to about 4 km south of Southern Cross Bore.

The only replacement lode, the Johnnie's Reward Prospect, contains chalcopyrite and a small amount of disseminated pyrite in an amphibole-quartz-magnetite lode. Copper values in the lode average 0.34% (from 23 shallow scattered percussion holes) at the surface, and 0.18% in the interval of 30 to 60 m of a drill hole put down at the northern end of the lode. At the surface average lead content in the lode is 0.17% and zinc 0.13%. At the surface the lode is barren of gold but core from the drill hole lode intersection yielded 0.19 dwt/ton. A small amount of pyrite and accessory cuprite, bornite, and molybdenite were deposited near the margins of the lode and in the wall rock. Gangue minerals include abundant magnetite, small amounts of calcite and quartz, and accessory garnet. The lode is thought to be a ellipsoidal-shaped body 180 m long, 6 to 55 m wide and probably less than 75 m in vertical extent.

Secondary Enrichment and Oxidation

Malachite, chalcocite, and, probably, bornite are thought to have been concentrated near the present ground surface by secondary enrichment. A secondary origin is considered likely, since the richest ore is concentrated in fractured quartz veins, and in the upper 5 m of workings.

At Ciccone's and Polly Boy Prospects, surface enrichment is deeper. The enrichment differs from classic supergene processes since replacement of primary minerals has been negligible. Enrichment above the present water table may be due to the neutralizing effect of carbonate minerals or to capillary processes. A falling water table and erosion since the Tertiary may also account for the enrichment.

High-grade ore includes chalcocite, malachite and bornite. Chalcocite is generally concentrated in or close to sub-surface quartz veins. Malacite stains fractures in the country rock as well as in quartz. Secondary(?) bornite is associated with malacite in fractured quartz in the Centralian No. 2

Mine and in the fissure vein at the Ophir Prospect. Small grains of bornite and chalcocite believed to be replacements of chalcopyrite are scattered in marble at the Ophir Prospect. Azurite, chrysocolla, native copper, and cuprite are less common minerals in the oxidized zone.

The replacement lode at the Johnnie's Reward Prospect has undergone negligible secondary enrichment.

Origin of Mineralization

The ore is thought to have been deposited from hydrothermal solutions that filled shears and, at Johnnie's Reward Prospect, replaced a favourable calc-silicate rock. The presence of tourmaline in many of the vein deposits and of tremolite-actinolite, magnetite, and garnet in the Johnnie's Reward replacement lode suggests that both types of deposit are hypothermal (Park & MacDiamid, 1964).

Solutions that produced the mineralization at the Johnnie's Reward Prospect contained lead and zinc mineralization, unlike those producing the vein deposits, and could belong to a different mineralizing fraction.

In the Arltunga and Winnecke mineral fields rare gold and copper are contained in quartz veins cutting orthogneiss, pelitic gneiss, mafic gneiss and quartzite in a wide zone of refoliation and retrograde metamorphism in the east-trending 'root' of the Arltunga Nappe Complex (Forman et al., 1967). Two minor lead, silver and bismuth prospects also occur in the deformed zone.

Much of the Pinnacles mineralization is localized in a series of faults that form a zone not unlike the Arltunga deformed zone.

Age of Mineralization

Isotopic dating in the Arltunga Nappe Complex 50 km to the southeast suggests that the deformation and related retrograde metamorphism in that area occurred during the Alice Springs Orogeny in the period Middle Silurian to Early Carboniferous (431-345 m.y.) (Forman et al., 1967; K/Ar mineral ages, Stewart, 1970). Muscovite from two pegmatites in the Harts Range have isotopic ages of 400 + 20 and 410 m.y., i.e. Lower Devonian-Silurian (G.H. Riley in Forman et al., 1967; Wilson, Compston, Jeffery, & Riley, 1960). The mineralized tourmaline-bearing quartz veins in the Pinnacles area may have been intruded or reheated at the same time as the pegmatites in the Harts Range.

DESCRIPTION OF INDIVIDUAL PROSPECTS

Centralian No. 9 Prospect (ML338H) (also referred to as The Centralian Centre No. 5 Prospect).

Location

The prospect is situated 2 km east-northeast of Southern Cross Bore and about 360 m south-southeast of Johannsen's Shaft.

Geology

Four or five veins, each up to 1.8 m wide, are about 9 m long and dip shallowly to the east. The easternmost veins contain malachite and small amounts of azurite staining. The veins occur in the upper part of a calc-silicate band near the contact with the overlying marble.

Development

A shallow costean and a pit about 3 m deep were excavated on the easternmost vein before 1952. In 1968 a few costeans were dug 18 m north of the shaft, both across and parallel to the easternmost vein. A pit, 2 m deep, was dug in a patch of malachite staining, 23 m northeast of the old shaft. The shaft intersected powdery fault breccia containing concretionary nodules with an inner core of azurite, calcite or malachite enveloped by chrysocolla. No mineable ore was recovered.

Geophysics

An induced polarization traverse (Line 1200 N) using 200-ft dipole lengths was made across the veins 60 m north of the second shaft (1200 N); no anomaly was detected (J. Haigh, 1971).

Ophir Prospect (ML373H)

The Ophir Prospect consists of a mineralized quartz fissure vein, and a zone of patchy mineralization at the margins of a schist. The zones containing minerals are about 30 to 40 m apart, and extend along the eastern side of a hill 150-425 m south of the Centralian No. 2 Mine. They pass southwards into the mineralized area at Johannsen's Shaft.

The Mineral Quartz Fissure Vein

Geology

Bornite, small amounts of chalcocite, malachite, and siderite, and a trace of gold occupy fractures in a quartz vein. The vein is about 120 m long with an average width of 0.6 m. In places it is severely fractured. It is discontinuous at its northern end. The country rock is mainly marble with narrow bands of schist.

Development

Initially the northern end of the vein was excavated by K. Johannsen (1952), later by J. Vitosky in 1967 to a depth of 3.7 m over a length of about 16.8 m. At the south-central end of the vein a costean, about 0.3 to 4.6 m deep and 14 m long, was dug by K. Johannsen. Vitosky dug small prospecting pits across the southern and northern ends of the vein.

Assay Results from Shallow Drilling

Seven percussion holes 3-4 m deep were drilled into the central and northern parts of the vein under the supervision of McMahon and Partners (1968). The vein is richest over a length of 30 m in the central part, where the vein and wall rock yielded average assays of between 3.3% and 1.6% copper over 0.9 to 1.2 m intersections in three holes. The highest assay for a 0.6 m interval was 8%.

Wall rock up to 1.2 m away averaged 1 000 ppm of copper in seven samples. In two holes, 8 m and 15 m to the north, the grade was only 0.8% copper and 0.1% copper over 0.6 m intervals of rock. No anomalous values were obtained for lead, zinc, silver, bismuth or gold, although visible gold was found by Vitosky in the central part of the quartz fissure vein.

Diamond Drilling Results

Drill hole Pinnacle No. 1 (McMahon and Partners, 1968) was sited 100 m east of the lode at an inclination of 40° on a bearing 280°MN. The hole was drilled to 106 m and intersected the northern, very thin and poorly mineralized end of the lode (i.e. quartz fissure vein).

The intervals 44 - 65.5 m and 75.5 - 84 m contain slight copper enrichment (770 ppm), the section 200 - 205 m, 5 700 ppm. The copper enrichment tends to be confined to schist.

Malachite has impregnated marble near the surface, and together with siderite, fills fractures at depth. Native copper stains several chlorite seams and calcite veins and is also disseminated in a thin band of schist. Traces of bornite and chalcocite are disseminated in tourmaline-bearing marble.

Mineralization at the margins of the schist unit

Geology

Patchy malachite mineralization has been deposited in marble at the margins of a lenticular layer of schist on the east bank of the main creek. Numerous quartz veins and stringers, and a few small patches of tourmaline rock, are scattered through the mineralized zone.

Development

K. Johannsen dug five benches up to 9 m into the hillside at the southern end of the mineralized zone. In 1968 J. Vitosky mined fine veinlets of bornite and malachite in highly brecciated marble and a small number of veins and stringers of quartz, on a bench about 6 m wide and 14 m long in the same area, but nearer the end of the fissure vein. A short adit just north of Vitosky's bench follows a mineralized quartz vein 10 to 45 cm wide for about 2.4 m.

Geochemical and Shallow Drilling Results

Grab samples taken from three of Johannsen's benches by Bell & Firman (1955) assayed from 1% to 6.9% copper. Thirty nine shallow percussion holes, (average 2 m), were drilled into the ore zone. Ten surface specimens were also collected (McMahon & Partners, 1968). Only four samples assayed over 1 000 ppm copper, the highest being 7 600 ppm; the remainder contained little more than a trace of copper.

Johannsen's Shaft (Southern Ophir Prospect) ML372H

Location

The shaft is on the southern side of a small spur, 500 m south of the Centralian No. 2 Mine (at the southern end of the 'Calcite-Copper' Lease).

Geology

Chalcocite, malachite, a small amount of calcite, and a trace of azurite fill fractures in a siderite-quartz vein. The vein is exposed only in the shaft and does not extend to the surface on the north side of the spur. Malachite and chalcocite-filled fractures in marble (containing quartz stringers and quartz-filled joints) extends southwest, west, and northwest from the shaft.

Development

In 1952 Johannsen sunk an inclined shaft and a short drift to follow a 0.3 to 0.6 m wide vein horizontally for about 12 m and down-dip at 30° for 6 m. Vitosky extended the shaft northwards to form an adit 14 m long. In 1968 Vitosky dug two crossed costeans, 3 and 9 m long, to expose quartz stringers in the marble overlying the schist units 18 m northwest of the adit.

Assay results

Channel samples taken by Bell & Firman (1952) from the shaft assayed 15% copper across 45 cm of vein and 21% copper across about 75 cm of vein. Assays of six rock samples taken by McMahon and Partners (1968) from various places within the shaft and drift varied from 1.1% to 30% copper and averaged 12.2%. Sampling of ore in Vitosky's adit later proved that these high values persisted for a short distance only.

Eleven samples taken by McMahon and Partners (1968) from percussion holes drilled into the mineralized zone in marble within 23 m southwest and west of the shaft ranged from a trace to 2.3% copper, and averaged 0.4% copper.

Diamond Drilling Results

Pinnacle No. 2 drilled at the southern end of the Ophir Prospect, 90 m north-northeast of Johannsen's shaft, was inclined at 70° on a bearing of 226° MN and reached a total depth of 101 m (McMahon and Partners, 1968). Only traces of copper mineralization were intersected. The interval 23 to 46 m contained veins, blebs, and coarse disseminations of chalcocite, malachite, bornite, and cuprite in a layer of fractured schist and in the adjacent marble. However, the highest value was 0.15% copper for the core interval 26 to 27.5 m the interval 39.5 to 41 m assayed 0.05% copper.

Geophysics

An induced polarization traverse using 200-foot (61 m) dipole lengths (Line 2400N, Pinnacles area), about 20 m south of the shaft, did not register any anomaly (J. Haigh, 1971).

The Centralian No. 2 Mine (ML335H) (also known as the 'Open Cut' and unofficially as the Southern Cross Mine).

Location

The mine is situated 2 km northeast of Southern Cross Bore.

Geology

Bornite, malachite, and a small amount of chalcocite, together with abundant siderite gangue, occupy shallow dipping fractures in massive quartz and marble and are also concentrated in quartz veins and stringers, from 2 to 45 cm wide. Irregular stockworks of quartz are common in the marble. The veins and stringers are confined to a zone 12 m wide and 90 m long, and commonly dip east. Steeply dipping cross-faults cut the veins.

Assay and Geochemical Results

The mine is in Bell & Firman's Zone 'D' (1952). Two channel samples, 1.83 m long, taken across the reef by J. Firman in 1952 gave copper values of 6.3% and 9.0%.

A sample of the lode, analysed by emission spectroscopy, contained 150 ppm silver and 700 ppm bismuth (see appendix 1).

Development

Since 1964 an open cut has been excavated into the hillside about 30 m long, 9 m deep, and 3 to 6 m wide.

Geophysics

An induced polarization traverse (Line 4000N, Pinnacles area), just north of the open cut, did not detect any anomaly (J. Haigh, 1971).

Ciccone's Shafts (ML385H)

Location

Two shafts about 6 m and 18 m deep are 2½ km northeast of Southern Cross Bore.

Mining History

The shafts were sunk in 1942 to intersect a small quartz vein rich in chalcocite, close to a contact between calc-silicate(?) rock and marble (Sullivan, 1942). The vein lensed out at the bottom of the shaft, then 8.5 m deep, but lode with chalcopyrite, cuprite, and malachite persisted over a 1 m width. The mineralization cuts out near the bottom of the 18 m shaft.

Shallow Drilling Results

Two sets of percussion holes, each of 26 holes, were drilled on westerly lines 30 m south and 140 m north of Ciccone's Shafts (McMahon and Partners, 1968). The holes were up to 3 m deep. Samples were analysed for copper, lead, and zinc, but no anomalous values were obtained. Some of the holes may have been drilled in alluvium.

Diamond Drilling Results

Pinnacles No. 4 was sited by McMahon and Partners (1968) to intersect a mineralized zone of quartz veins and fractures just south of Ciccone's Shafts. The hole, sited 55 m southeast of the northern shaft, was inclined at -40° on a bearing of 262° MN and reached a total depth of 95 m. No more than a trace of copper was detected in the intervals 37 - 43 m and 49 - 55 m.

Geophysics

An induced polarization traverse using 30 m dipole lengths extended from about 245 m south of Ciccone's Shafts to the Urals No. 1 prospect (Traverse E, Pinnacles area) (J. Haigh, BMR. pers. comm.). A very weak frequency effect anomaly was observed in the vicinity of the shafts (1 to 1.4%, background 0.8%) accompanied by a mild metal factor anomaly (100-140, background 50). The known weak mineralization in the area is considered sufficient to explain the anomalies (J. Haigh, BMR pers. comm.).

Urals No. 1 Prospect (ML380H)

Location

The prospect is situated on the north bank of a small valley 1½ km north of the Centralian No. 2 Mine.

Geology

Widely spaced fractures in places filled with quartz and containing malachite, small amounts of azurite and chalcocite, traces of bornite, and rare galena, are localized in a siderite-rich marble. In the hanging wall, a bed of micaceous calc-silicate rock dips at 50° east. Malachite is also exposed south of the stream in a slightly brecciated marble near the hanging wall.

Development

In 1968, a 3 by 2 m pit was sunk to a depth of 3.7 m.

The Jill's Penny, Midland and Paul's Run Prospects

Mineralized quartz veins occur as fillings in minor north-trending faults at the Jill's Penny and Midland Prospects south of Southern Cross Bore. An isolated vein, the Paul's Run Prospect, is situated just west of a major fault 180 m southwest of the Midland Prospect.

Jill's Penny Prospect (ML329H)

Geology

The country rock consists largely of garnet-biotite-quartz schist, with intercalations of calc-silicate rock, quartzite, and marble, and cut by several pegmatites.

Chalcocite, malachite, and a trace of bornite seen in a 3 m pit occur in quartz stringers that dip east at 50° - 60° parallel to the foliation in a schist. A tourmaline-bearing quartz reef possibly contemporaneous with the mineralization, lies 10 m to the southeast, on strike with a small quartz reef containing traces of malachite and chalcocite exposed 50 m farther south.

Shallow Drilling and Geochemistry

Two holes drilled into the eastern side of the tourmaline-quartz reef failed to intersect ore. Four holes drilled into the country rock east of the prospect did not give anomalous copper values.

The Midland Prospect

Geology

Three mineralized and two unmineralized quartz veins fill faults in dark-grey sericite schist and gneiss over a length of about 305 m. Malachite and traces of chalcopyrite and chalcocite are exposed in the mineralized veins at the surface. Several veins contain limonite and tourmaline.

The ore consists of chalcopyrite, chalcocite, and accessory bornite and azurite. Malachite is common in fractures both in and around the vein. The mineralized quartz vein is 0.8 m wide at its northern end; at the southern end it grades into a number of narrow quartz lenses (up to 10 cm across) in a malachite-stained shear-zone.

Development

In 1968, two shafts, 4.5 m apart, were sunk on the richest vein to about 4.5 m. Mineralization in the northern shaft was very patchy, locally the copper content being as high as 23%. In the southern shaft malachite is contained in shears.

Paul's Run Prospect

Malachite and chalcocite with rare chalcopyrite and chrysocolla are contained at the northern and southern limits of a massive quartz vein about 8 m wide and 75 m long. Tourmaline is an accessory gangue mineral. The vein is up to 8 m wide, 75 m long, and strikes at 20°. It occurs as in-filling in a shear between a layer of marble and a layer of calc-silicate rock.

Polly Boy Mine (also known as the New Polly Mine, ML3581H)

Location

The mine is situated 2 km east of Southern Cross Bore.

Geology

A quartz vein 25 m long containing small amounts of primary and secondary copper minerals fills a shear parallel to the strike of calc-silicate country rock. The vein strikes north and dips at 60° to 80° east. It is 0.6 m wide at the surface and 0.9 m wide on the mine-floor. Slickenside faces in the vein are considered to be evidence of reverted faulting. At the bottom of the mine the vein contains bornite and chalcopyrite.

Chalcocite and malachite are contained in two small quartz veins 90 m east and 145 m northeast of the mine. According to J. Vitosky, a sample from the northern vein assayed 24.8% copper, 4 dwt per ton gold and 4 oz per ton silver.

Assays

Two sets of chip samples taken at 6-inch intervals across the north-face on the floor of the mine yielded 0.46% and 0.69% copper and a trace of gold. Similar samples from the south face contained 0.47% and 0.43% copper and a trace of gold.

Prospecting

The vein has been explored down-dip for about 10 m by means of a trench about 18 m long, then by two inclined shafts joined by a short drift. Shallow trenches have been dug at both minor prospects.

Geophysics

The results of a detailed geophysical survey (J. Haigh, 1971) suggest that ore is unlikely to extend below about 30 m. A small induced polarization anomaly of shallow origin was detected about 90-120 m north of the shaft. A 'Turam' anomaly indicated a better conductor here than under the shaft.

Other prospects of vein-type

The Baldy Rise (ML339H) and Flat Depth Prospects (ML340H) are localized in a belt of sericite schist believed to be a product of retrograde metamorphism. The Urals No. 3 Prospect (ML382H) and a malachite-stained tourmaline pegmatite, exposed just to the east, are situated on a major north-trending fault just east of the Polly Boy Mine. According to J. Vitosky and other prospectors, several tons of ore containing up to 18% copper ore have been mined from the Urals No. 3 prospect.

Ironstone Bodies

About 1 km northeast of the Centralian No. 2 Mine, two hills are capped with ironstone, which together are about 150 m long and 3 to 6 m wide (ML327H). Youles (1966) considered these to be laterites, or alternatively, gossans. Spectrographic analysis of the ironstone did not reveal a significant copper content (Johnston, 1955, see appendix 2).

McMahon and Partners (1968) collected 12 samples from three percussion holes drilled into quartz veins stained with malachite immediately east of the ironstone. The samples averaged 111 ppm copper (per 0.6 m i.e. 2 ft interval). Assays for lead, zinc, and silver are negligible.

An induced polarization traverse (Line 5000N, Pinnacles area) crossed the southern end of the ironstone body, but no anomaly was detected (J. Haigh, 1971).

Two similar bodies are situated 550 m west-northwest of the mine.

Johnnie's Reward Prospect (ML328H)

Location

The Prospect is 1 km northeast of Southern Cross Bore.

Summary

The lode consists of chalcopyrite disseminated through amphibolite-gneiss. Copper values in the lode average 0.34% at the surface. At 60 m below ground level, core from a 7.5 m interval in a drill hole at the northern end assayed similar values. Anomalous gold values were not detected at the surface, but averaged 0.49 dwt per ton in the core. Surface samples of the lode averaged 0.17% lead and 0.13% zinc. The Bureau's geophysical survey predicted the lode to be a shallow ovoid body roughly 180 m long, 6-60 m wide, and less than 75 m deep. A hole drilled by Kenneth McMahon Pty Ltd at the southern end of the lode did not intersect ore.

Surface Geology

The lode is discontinuously exposed for 180 m as four prominent exposures of amphibole-gneiss enclosing quartzite and magnetite-rich lenses. The lode strikes at 355°, dips to the east at about 65°, and appears to be conformable with the country rock. The dip steepens to vertical on the eastern side of the most prominent exposure of the lode near a short north-trending fault. The most prominent exposure is the outcropping portion of a fold nose which plunges steeply to the northeast.

At several places chalcopyrite, pyrite, and rare galena are sparsely dispersed in the rock. Malachite and less commonly white smithsonite coat a few fractures near the margins of the main exposure of the lode.

A very small body of pyroxenite is exposed in the centre of the lode. Haslett suggests that the pyroxenite contains rare pseudomorphs of limonite after pyrite and chalcopyrite. The pyroxene is very slightly altered to amphibole (Haslett, 1968a).

The amphibole in the outcropping lode is in the form of pale-brown aggregates of parallel fibres (possibly tremolite). Unweathered crystals are pale green to colourless and acicular. Asbestos veinlets cut the amphibole rock near the most prominent exposure of the lode. The amphibole gneiss lode rock contains thin lenses of garnet-biotite gneiss and has calcareous margins in places. Magnesite float occurs near the exposed margins of the amphibole rock.

Quartz-rich garnet gneiss forms the footwall at the southern end of the lode. Elsewhere the country rock is biotite-garnet-quartz-gneiss. A few pegmatite lenses intrude the country rocks and a narrow lenticular sill of mafic rock (meta-norite?) crops out 75 m east of the most prominent exposure of the lode, but both rocks are thought to be unrelated to the mineralization.

Geochemical and Shallow Drilling Results

Assay results from surface samples collected by I.P. Youles (1964b) from the Johnnie's Reward Prospect are as follows:

Sample No.	Specimen	Gold	Silver	Copper
F53/14-2A	Chalcopyrite in limestone	1.6 dwt	trace	3.35%
F53/14-2B	Gossanous limestone	trace	Nil	0.4%
F53/14-2C	Gossanous magnetite	trace	Nil	0.35%
F53/14-2D	Magnetite-chalcopyrite	Nil	Nil	1.25%
F53/14-2E	Magnetite in limestone	Nil	Nil	0.45%

The assay results for the 23 percussion holes (53 samples) drilled into the lode under the supervision of McMahon and Partners are shown in Table 2.

TABLE 3.

Assay results of shallow percussion drill holes, Johnnie's Reward lode (53 random samples)

	Copper	Lead	Zinc
Range of Values	1.61% to 132 ppm	1.7% to 32 ppm	2% to 33 ppm
Average Values	0.345%	0.175%	0.135%

Several samples analysed for gold, silver, and nickel gave a negative result.

Diamond Drilling Results

Two diamond drill holes have been put down to test the lode, one in 1966 by Geopeko Ltd at the northern end and the other in 1967 by Magellan Petroleum (N.T.) Pty Ltd at the southern end.

The Geopeko drill hole was sited 55 km east of the northern-central exposure of amphibolite gneiss and magnetite-quartzite to test self-potential and ground magnetic anomalies. The hole, inclined at 60° on a bearing of 268°, intersected the lode in the interval 40 - 80 m and reached a down-hole depth of 141 m. Copper values within the lode, estimated to be about 30 m thick, varied between 0.5% and 0.45% and average 0.18% (per 1.5 m interval). Gold values varied between 0.05 and 1.09 dwt per ton and average 0.19 dwt per ton.

Williams (1965) described the lode as tremolite-actinolite-magnetite rock with calcite? - actinolite margins.

Disseminated chalcopyrite is normally associated with magnetite, but also occurs in irregular patches within the host rock, where it accounts for up to 30% of the constituents. Two thin layers of quartzite and garnet-biotite gneiss occur within the lode. The lode is locally cut by calcite stringers. Molybdenite is a rare constituent.

Contacts between the country rock quartz-biotite-garnet gneiss and the lode are gradational. Disseminated chalcopyrite, with occasional pyrite, also occurs in the country rock, (i.e. in drillhole sections 98 - 107 m, 120 - 121 m and 140 - 140.5 m).

A second hole, Pinnacles No. 3, was drilled at the southern end in late 1967 by McMahon and Partners Pty Ltd for Magellan Petroleum (N.T.) Pty Ltd in 1968. The hole, situated 67 m east of the most prominent exposure of the lode, was inclined at 53° on a bearing of 268° and reached a depth of 166 m. It undercut the lode and intersected only traces of ore down-dip from the footwall in semi-calcareous gneiss and in the underlying and overlying garnet-biotite gneiss.

The mineralized intervals intersected are shown in Table 4.

The assays indicate that the drill hole, intersected wall rock rather than the lode. The low copper values and the comparatively lower lead and zinc values suggest that the hole intersected wall rock slightly enriched in copper, since zinc would be expected to have a high mobility, copper a moderate mobility, and lead a low mobility (Hawkes & Webb, 1962).

Geophysics

An aeromagnetic anomaly was detected over the lode (Tipper, 1966). The causative body was calculated to be less than 300 m long and to dip almost vertically.

TABLE 4. Anomalous copper zones intersected in D.D.H. 3, Johnnie's Reward Prospect.

Interval (feet)	Average assay in ppm per five-ft interval			Host rock
	Copper	Lead	Zinc	
95	Bornite in hair-like veinlet			quartz-biotite-epidote-hornblende-gneissic amphibolite.
275-295	8	18	71	(sillimanite)-garnet biotite-quartz-(feldspar) gneiss.
310-330	432	11	31	garnet-biotite-quartz-feldspar gneiss
360-390	2 592	21	48	hornblende-epidote-garnet-quartz-biotite gneiss
370-378	0.82%	21	54	
395-400	610	14	49	garnet-biotite-quartz gneiss
420-415	700	9	35	
453- and 456	traces of disseminated chalcopyrite			

(After Kenneth McMahon & Partners, 1968)

Small magnetic, self-potential, induced polarization, and 'Turam' anomalies were outlined in the area during a surface survey by the Bureau of Mineral Resources in 1967 (J. Haigh, 1971). The anomalies indicate the lode is a shallow ellipsoid body that lies largely above Geopeko's drill hole.

Induced polarization frequency effects of 4% to 5% occurred in a well-defined anomalous zone over the lode and contrasted with a background of less than 2%. High apparent resistivities caused low metal factors. The centre of the I.P. anomaly was estimated to be just west of the exposed lode (grid position 45°E, 4N and 10N). The self-potential anomaly roughly corresponds with the induced polarization anomaly. The highest self-potential values (75 mv) are at the northern end of the lode. The maximum depth of mineralization is not expected to exceed 75 m. A linear magnetic anomaly was outlined about 7 to 30 m west of the exposed lode. The asymmetry of the anomaly suggests that the lode has an easterly dip.

Origin of the lode

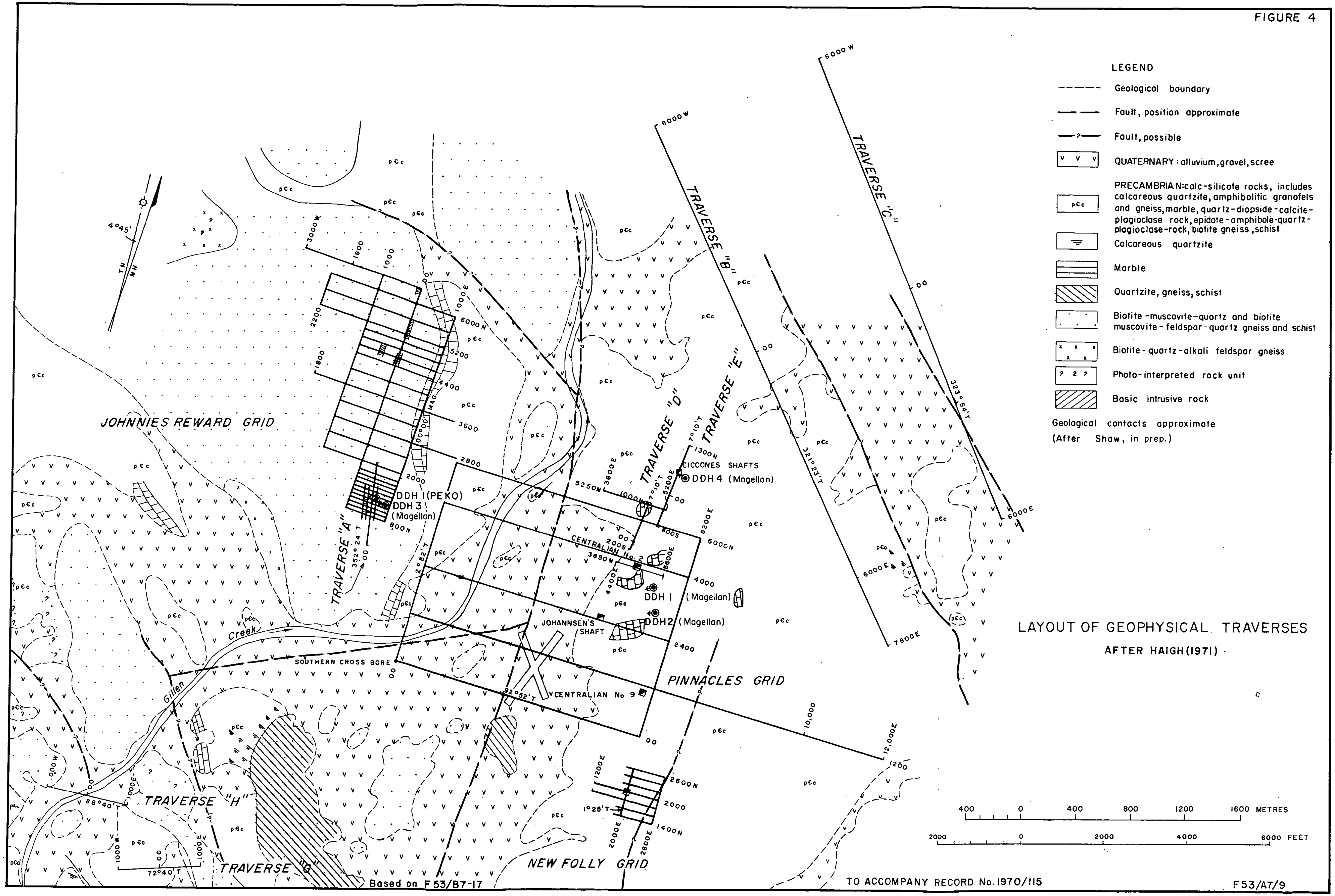
Youles (1964a) considered the lode to be 'a massive-chalcopyrite replacement of a lens of limestone'. He also described 'a small basic boss, heavily stained with secondary copper minerals, that has intruded the limestone'. His 'replaced limestone' is probably the amphibole gneiss and the basic boss is possibly the small pyroxenite.

McMahon and Partners (1968) suggested that the mineralization may be related to a skarn-type alteration of a metamorphosed, calcareous sediment.

The apparent lack of plagioclase in both the pyroxenite and tremolite-actinolite lode rocks favours an igneous origin for both host rocks. The pyroxenite could be an unmetamorphosed, though altered, igneous remnant, the rest of the lode being altered to an amphibole-rock. If the pyroxenite was igneous, as implied by Youles (1964a) and suggested by Haslett (1968), it may be the source rock. Haslett (1968a) suggests that the sulphide minerals were deposited after the pyroxenite was altered, but he gives no evidence.

A number of features are slightly anomalous if the ore was introduced at the time of intrusion of a mafic igneous rock. The nickel values for the lode (26 samples from 8 shallow drill holes average 17.6 ppm) are lower than those typical of mafic igneous rocks (Hawkes & Webb, 1962). Nickel, having low mobility, might be less likely than copper or zinc to be removed from a mafic or ultramafic igneous rock during metamorphism. The layers of quartzite and garnet-biotite gneiss incorporated in the amphibole-gneiss lode would be more simply explained if the amphibole gneiss were of sedimentary origin. The patchy distribution of chalcopyrite and magnetite and the presence of chalcopyrite in a semi-calcareous gneiss away from the main lode suggests external introduction of the ore by hydrothermal replacement.

FIGURE 4



LAYOUT OF GEOPHYSICAL TRAVERSES

AFTER HAIGH (1971)

TO ACCOMPANY RECORD No. 1970/115

F53/A7/9

The mineral assemblage chalcopyrite-magnetite-garnet-tremolite/ actinolite indicates a high-temperature deposit (Park & MacDiarmid, 1964) which would have been formed under greenschist or lower amphibolite facies conditions. The tremolite-actinolite, if correctly identified, suggests pressure-temperature conditions lower than those of the regional metamorphism. The pyroxene was probably altered to amphibole after the regional metamorphism and perhaps at the same time as the mineralization was introduced.

Geophysical Traverses North of Johnnie's Reward Prospect

At least three small IP anomalies were found north of the Johnnie's Reward Prospect (J. Haigh, 1971). Two coincided with SP and 'Turam' anomalies. These two could not be related to exposed rocks and are presumed to signify sub-surface sulphides.

An IP and SP anomaly on a traverse 146 m north of Southern Cross Bore appears to be due to the pyrite content of a fine-grained pegmatite. At the surface the pegmatite is weathered, but small cavaties are considered to be pyrite boxwork.

Cause of Magnetic Anomalies North of Johnnie's Reward Prospect

An aeromagnetic anomaly north of Johnnie's Reward Prospect is similar in shape to that over the Johnnie's Reward lode and was investigated geophysically to see if the anomaly was produced by a similar lode. The most abundant magnetic rocks exposed in the northern area are unlike the Johnnie's Reward lode and consist of lensic sills and dykes of meta-norite as well as a few lenses of magnetite-rich impure marble and amphibolite derived from calc-silicate rock. One shallow IP anomaly at 300 E on a traverse 730 m north of Southern Cross Bore was slightly offset to the west of an impure marble containing abundant magnetite.

Throughout the area north of Johnnie's Reward Prospect magnetite is only superficially altered to hematite. Consequently, this chemical couple is unlikely to have affected the induced polarization results.

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J. Vitosky was a valuable informant and guide to the prospects. Geopeko Ltd provided a log of their drill hole at the Johnnie's Reward Prospect. Central Pacific Minerals N.L. kindly made available the report by Kenneth McMahon and Partners on the prospect. Information on production was provided by R. Harris of Alice Springs, Mount Isa Mines Ltd, The Electrolytic Refining and Smelting Co. of Australia Ltd, Adelaide and Wallaroo Fertilizers Ltd, and the Statistical Section, Mines and Water Resources Branch, Northern Territory Administration. Many discussions were held with P. Braham and J. Whyte of the Mines Branch, Alice Springs.

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APPENDIX

Result of semi-quantitative analysis by emission of spectroscopy of selected samples

1. Samples taken of the Johnnie's Reward Lode.

Sample 6518/2 was collected by I.P. Youles (letter 10/2/65) and submitted to Australian Mineral Development Laboratories by E.N. Milligan on 23/2/65. Sample F53/14-2F was submitted from the Resident Geologist's Office, Alice Springs and analysed by Holden (1964).

Element	Sample 6518/2 ppm	Sample F53/14-2F ppm
Iron	-	3
Copper	5 000	-
Zinc	600	80
Lead	40	11
Cobalt	40	10
Manganese	-	50
Bismuth	20	50
Tin	6	20
Chromium	-	30
Silver	4	7
Molybdenum	3	5
Nickel	1	7
Beryllium	-	7
Gallium	-	10
Germanium	-	20
Barium	-	2
Antimony	less than 30	-
Arsenic	less than 30	-

2. Sample taken from the lode at the Centralian No. 2 Mine

Sample 6518/2 was submitted with sample 6518/1. Results are given in parts per million.

Copper	greater than	10 000
Bismuth		700
Silver		150
Lead		20
Zinc		20
Nickel		12
Cobalt		4
Tin		4
Molybdenum		3
Arsenic	less than	30
Antimony	less than	30

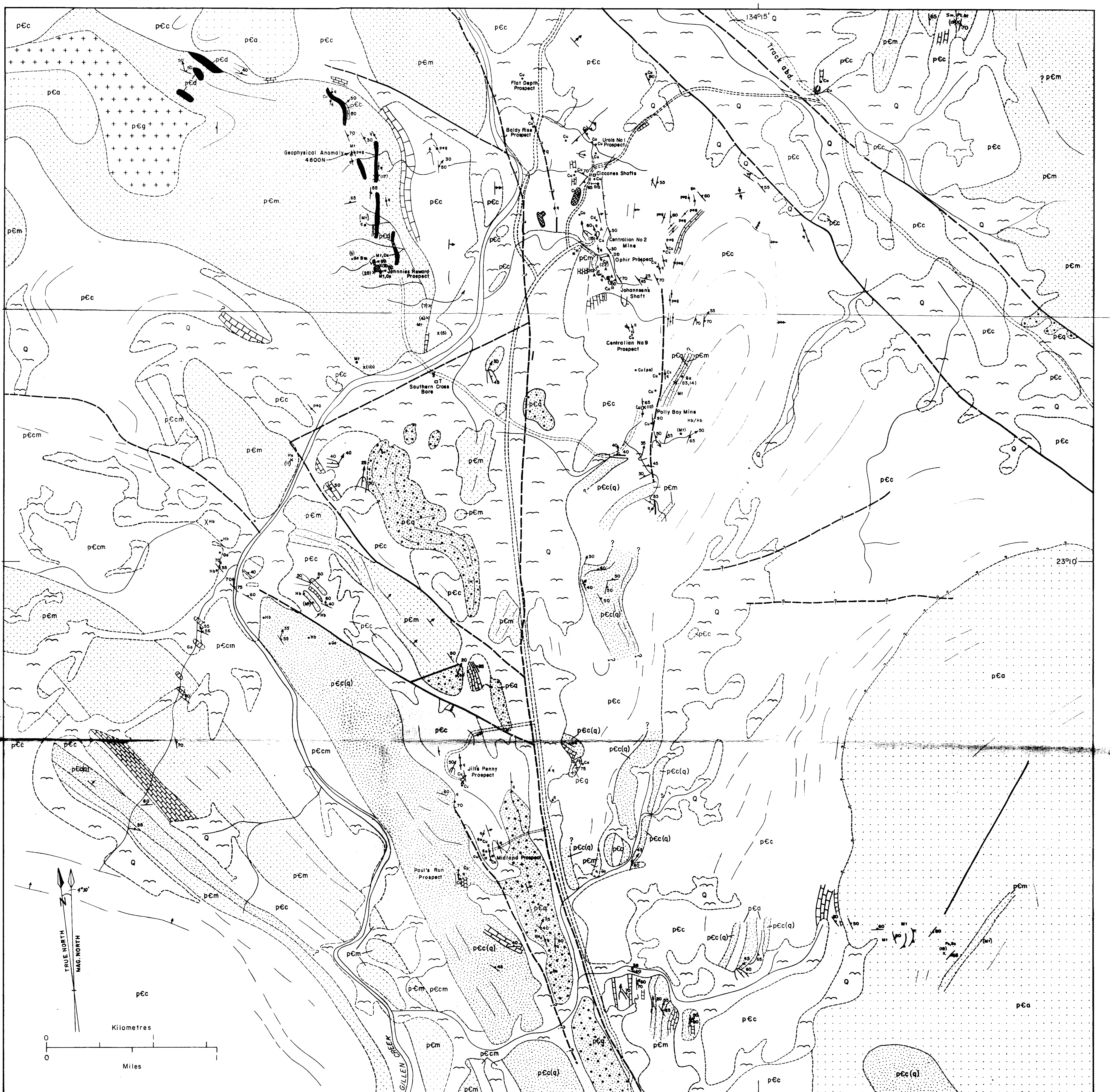
3. Samples taken from an ironstone body 1 600 feet northeast of the Centralian No. 2 Mine

Samples F53/14-2H1, 2H, 2J, and 2K were collected by I.P. Youles and analysed by N.V. Johnson (1960) of Australian Mineral Laboratories.

Report AN1306/66.

Sample	Copper ppm	Lead ppm	Gold ppm	Cobalt ppm	Manganese ppm
F53/14-2G	6	2	less than	120	4 000
2H	70	5	" " 3	15	1 000
-2J	5	3	" " 3	25	2 000
-2K	50	5	" " 3	150	800

GEOLOGY OF THE PINNACLES BORES AREA



Q	Alluvium, gravel, scree
p€c	Calc-silicate rock, calcareous metaquartzite, marble, some amphibole and pyroxene-bearing calc-silicate rocks, biotite gneiss
p€c(q)	As above, calcareous, metaquartzite dominant
p€cm	Calcareous rocks interlayered quartzo-feldspathic and pelitic gneisses
	Marble
p€a	Amphibole and pyroxene-rich calc-silicate rocks, some biotite-gneiss and amphibolite
p€q	Metaquartzite, feldspathic metaquartzite, some gneiss, schist
p€m	Quartzo-feldspathic and pelitic gneisses
p€g	Orthogneiss
p€d	Meta-norite

- Geological boundary
- Syncline
- Plunge of minor anticline
- 35 50 Plunge of minor fold axis with strike and dip of axial plane
- Plunge of drag fold
- Fault, position accurate
- Fault, position approximate
- Fault, inferred
- 50 Measured strike and dip of strata
- Dip < 15°, Dip 15°-45°, Dip > 45° } air photo interpretation
- Trend lines
- Strike and dip of foliation
- 25 30 Strike and dip of foliation with plunge of lineation
- Strike and dip of foliation, unmeasured
- X(5) Specimen locality
- Dyke or vein, gn-granite, peg-pegmatite, q-quartz

- □Cu Shaft abandoned showing minor occurrence of copper
- Costean and shallow excavation
- A Costean abandoned
- A Benches abandoned
- Gossan, ironstone body
- Cu Mine dump
- DD Drill hole
- Bore with pump
- Creek
- □"T" Tank
- □"H" Hut
- Vehicle track

Occurrences of metamorphic index minerals

Ga	Garnet	visible in handspecimen
Hb	Haematite, goethite	visible in handspecimen
Mt	Magnetite	visible in handspecimen
(Mt)	Magnetite, detected with a magnet	
Hb	Amphibole	where 15%
Pl	Phlogophite	where 15%
Px	Pyroxene	where 15%
Sc	Scapolite	where 15%
Sm	Sillimanite	where 15%
At	Andalusite (where 5% in handspecimen)	
Pa	Position approximate	
•Cu	Minor mineral occurrence, copper	

To accompany Record 1970/115

F53/A14/127