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MOUNT VISTA PORPHYRY-TYPE COPPER PROSPECT, COLLINSVILLE, QUEENSLAND

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GEOLOGICAL ENVIRONMENT OF COPPER-MOLYBDENUM MINERALISATION AT MOUNT TURNER, NORTH QUEENSLAND

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MOUNT VISTA PORPHYRY-TYPE COPPER PROSPECT, COLLINSVILLE, QUEENSLAND

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SUMMARY

The Mount Vista prospect, southeast of Collinsville, was discovered in late 1975 as a result of a drainage sampling program. During 1976 and 1977, work on the prospect included geological mapping, geochemistry, geophysics (IP, resistivity, and magnetics), and diamond drilling totalling 783 m.

The deposit lies within the Almoola Hinge Zone in a fault block of north-northwest trending porphyritic dacites and andesites of the Early Permian Lizzie Creek Volcanics. The fault block is bounded to the southwest by agglomerate and to the north and east by Late Carboniferous granodiorite. A rhyolite dyke swarm of probable Early Cretaceous age intrudes the dacite sequence and is host to alteration and mineralisation. The rhyolite is related to, and probably derived from, adamellite stocks to the north of the anomalous area. Fracturing is moderate to strong in the central prospect area and decreases with distance from it. Two small breccia pipes of the collapse type were mapped.

Alteration is locally complex and depends on proximity to dykes and fissures. Overall, a pattern emerges in which three ill-defined alteration assemblages form a distinct concentric zonation. From the centre outwards, these assemblages are potassic, phyllic, and propylitic. Veined late stage sulphate (gypsum) alteration occurs mainly in the centre of the prospect.

A double IP/copper anomaly, elongate north-northwest occurs in the central portion of the prospect. It also coincides with a magnetic low. Around this is a lead/zinc halo which is best developed to the west.

Limonite after sulphides, and rare malachite are the only evidence of mineralisation at the surface. Drilling has shown the main sulphide minerals to be pyrite, chalcopyrite, sphalerite, and galena. Silver is also present. Although sulphide content of drill core averages 1.5 to 2.0 per cent, the best copper intersections average less than 0.1 per cent over any appreciable length. Supergene enrichment is absent.

The widespread nature and zonation of alteration and mineralisation, as well as the association with calc-alkaline intrusives, indicates that the prospect is of the porphyry copper type of mineralisation.

INTRODUCTION

Departmental Area 63D of 95 sub-blocks (1 sub-block = 3 km^2 approximately) was proclaimed in May 1975, over an area southeast of Collinsville (Fig. 1) as part of a project researching porphyry-type copper-molybdenum mineralisation in Queensland.

The purpose of this reserve was, through field investigations, to (a) test the validity of a postulated Early Cretaceous porphyry-type copper belt in the Collinsville region (Horton, 1978a, in press), and (b) to locate, by geochemical means, examples of porphyry-type copper mineralisation. Detailed study of this type of deposit was planned to assist future exploration and evaluation of porphyry-type copper mineralisation in eastern Queensland.

The southern part of the original reserve was relinquished in 1977 (Horton, 1977) and an additional area was added to facilitate further investigations (Fig. 1). The amended reserve of 79 sub-blocks was relinquished in 1979 (Horton & Huber, 1979a, b).

The Mount Vista prospect was discovered in late 1975 as a result of a regional stream sediment sampling program. During 1976 and 1977, field activities on the prospect included:

(a) surveying of a 100 m grid over the anomalous area
(b) geophysical studies (IP, resistivity, magnetics)
(c) geochemical soil sampling
(d) detailed geological mapping
(e) diamond drilling

Geophysical studies were carried out by R.D. Huber, Geophysicist, while all other investigations were undertaken or supervised by D.J. Horton, Geologist. An unpublished appendix to this publication, listing assays, petrographic descriptions, and drill logs, is available from the Geological Survey of Queensland (Horton, 1978b).

REGIONAL GEOLOGY

Two major tectonic units are recognised in the Collinsville region (Fig. 2):

1. the northernmost part of the Bowen Basin, a synclinal structure comprised of Early to Late Permian terrestrial and marine sediments with underlying Early Permian Lizzie Creek Volcanics
2. the north-northwest trending Eungella-Cracow Mobile Belt to the east of the Bowen Basin. The Connors Arch, a broad rigid structure forming the western part of the mobile belt, exhibits three

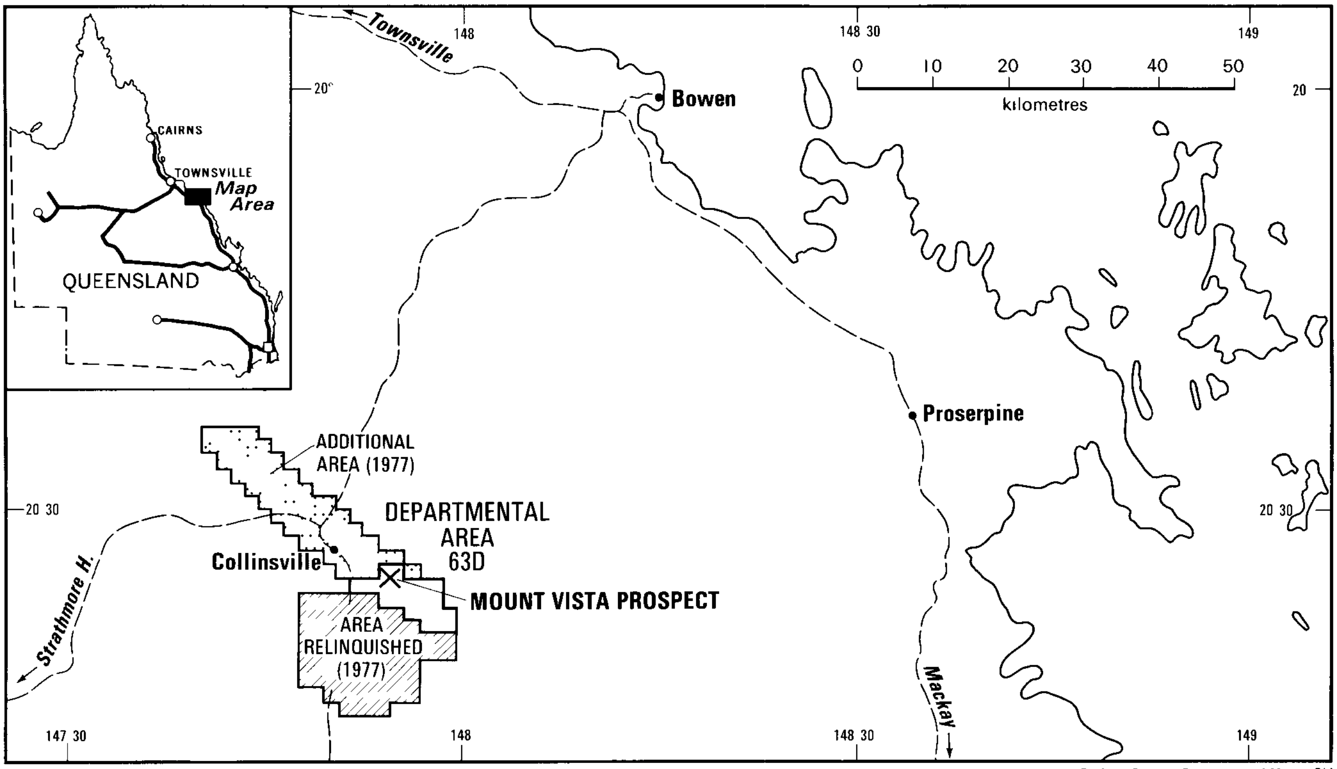

Figure 1: Locality map, Mount Vista prospect

periods of intrusive activity, Late Carboniferous, Early Permian (Thunderbolt Granite), and Early Cretaceous. The latter intrusives are not restricted to the Connors Arch but also occur within the Bowen Basin sediments.

These two tectonic units are separated by the Almoola Hinge Zone (Paine & others, 1974) which contains several major north-northwest faults and fault zones. This zone has been the main focus of uplift at the northern end of the Connors Arch with the units of the eastern flank of the Bowen Basin dipping steeply west-southwest. The Mount Vista prospect lies within the Almoola Hinge Zone in a fault block of Lizzie Creek Volcanics in contact with Late Carboniferous intrusives (Fig. 2).

MOUNT VISTA PROSPECT

The prospect is situated 8 km southeast of the township of Collinsville between Oaky and Coral Creeks (Fig. 1). Collinsville is 82 km by sealed road south-southwest of Bowen. Access to the prospect area is by way of the Collinsville-Mount Coolon road for 9 km south from Collinsville, then east along property tracks for approximately 10 km.

Physiographically, the prospect is expressed as a basin-like area between high ridges to the north and southwest (Fig. 3). It can be recognised on aerial photographs by greater concentrations of first and second order streams which give a different airphoto texture to that of the surrounding country. Parallel north-northwest trending ridges comprise the northern part of the prospect.

Annual rainfall is approximately 600 mm with most of the rain falling in a wet season which lasts from November to April. Access to the prospect is hindered during this period. The normal maximum temperature in the area is 32–34°C in January and the minimum 10–13°C in July.

Eucalypt woodland covers the area and spear grass is the dominant ground cover.

GEOLOGY

Lizzie Creek Volcanics

The Early Permian Lizzie Creek Volcanics constitute a sequence of intermediate to basic volcanics, with subordinate sediments and acid volcanics, non-comformably overlying late Palaeozoic granite (Paine & others, 1974). Attempts at subdividing the volcanics (Reid, 1929; Horton, 1977) have been hindered by their complexity and the high degree of faulting, particularly in the eastern areas.

Two lithological units of the volcanics are present in the prospect area, andesitic agglomerate and porphyritic dacite. The agglomerate is generally considered to be the basal unit of the Lizzie Creek

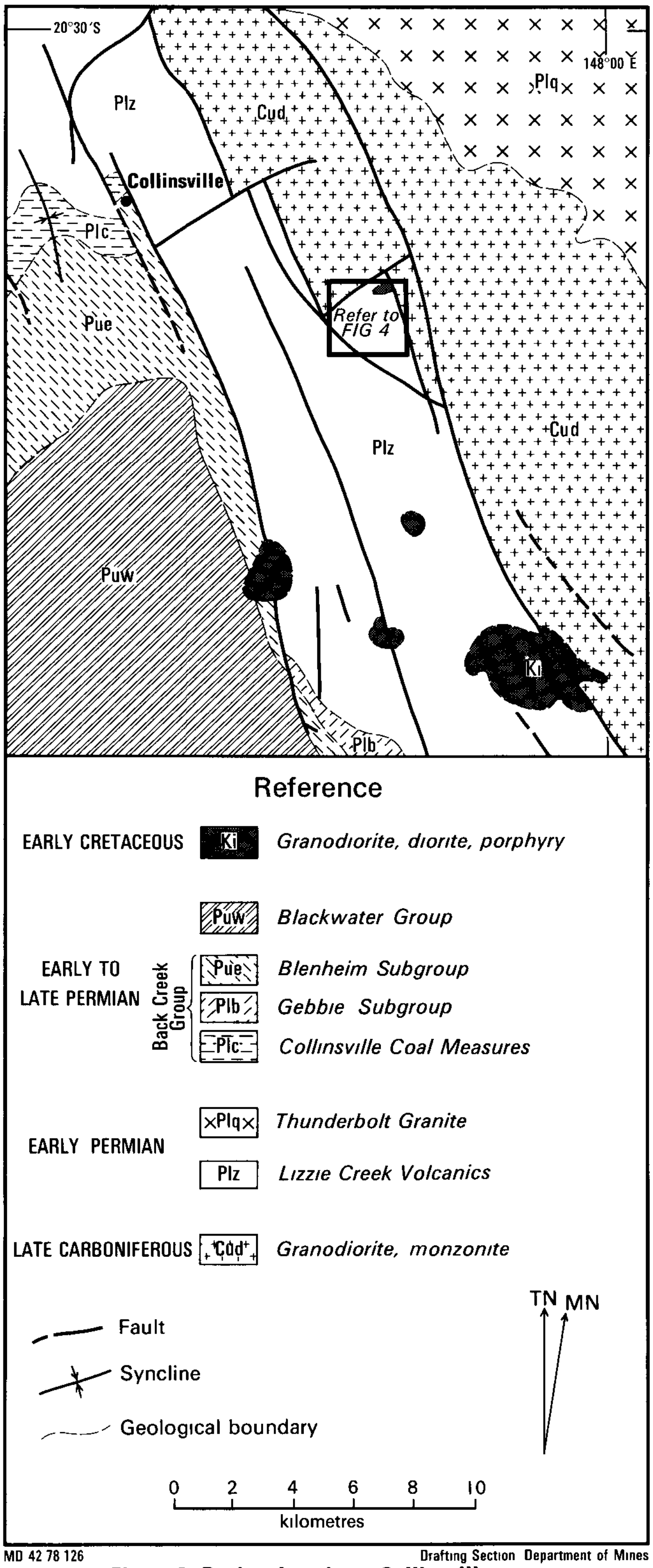

Figure 2: Regional geology, Collinsville area (after Paine & others, 1974)

Volcanics (Dickins & Malone, 1973; Horton, 1977) as it is usually faulted against the basement intrusives.

The agglomerate sequence contains andesitic volcanics and rare igneous boulders to 80 mm diameter set in a fine-grained volcanic matrix. A few bands of equigranular, medium-grained dacite and rare thin bands of porphyritic dacite are present within the agglomerate. The unit strikes 330° magnetic and dips 60° east. It is separated from the porphyritic dacite unit to the east by a major northwest fault (Fig. 4) and has not been affected by alteration and mineralisation.

The porphyritic dacite unit consists of a complex sequence of porphyrite, equigranular volcanics, fine-grained andesite, and rare agglomerate. Porphyritic rocks comprise the bulk of the unit and vary considerably in their phenocryst content and grain size. Plagioclase (An_{30-50}), quartz, biotite, and hornblende exist in various combinations as phenocrysts although plagioclase phenocrysts are generally always present. Gradation from one lithology to another is common and flow banding and welding have been found in several areas. The dacite unit strikes north-northwest (approximately 340° magnetic) in conformity with the regional strike of the Lizzie Creek Volcanics. In the southern part of the prospect, the unit has been folded slightly to strike west-northwest. The dip of these volcanics has been established only through drilling and rare observations in outcrop. To the east and north they are vertical, but towards the west and south the dip is shallower, at approximately 40° and 60° to the southwest, respectively. The eastern portion of the porphyritic dacite unit is, in part, faulted against Late Carboniferous intrusives to the east (Fig. 4). Within fault blocks in the eastern part of the prospect, flat-lying volcanics overlie these intrusives, and 'windows' of intrusives can be found in creeks draining the volcanics in this area. Xenoliths in a range of sizes (to 20 m or more) have been incorporated throughout the dacite sequence.

Late Caboniferous intrusives

Late Carboniferous coarse-grained granodiorite, diorite, and monzonite occupy the eastern and northernmost parts of the prospect. Within these intrusives, networks of andesite or microdiorite dykes to 2 m in width are common and generally strike north-northwest. Some of these dykes are very similar in appearance to those found in the porphyritic dacite unit of the Lizzie Creek Volcanics and the two may be related. Alteration of the intrusives has made it impossible to delineate individual intrusive phases (if any) in this area. Gradational changes in the composition of the intrusives over tens or hundreds of metres are suspected.

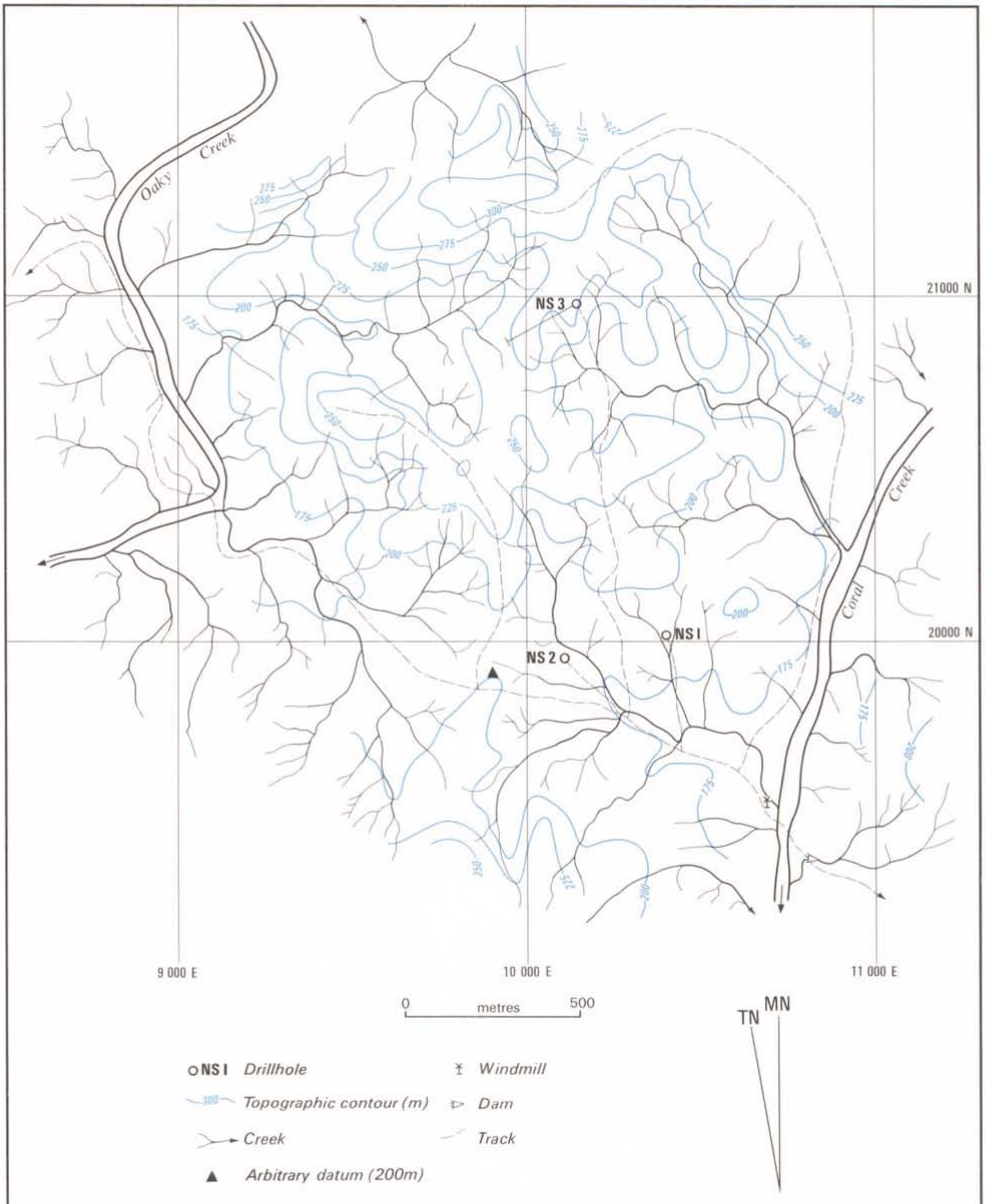

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Figure 3: Physiography, Mount Vista prospect

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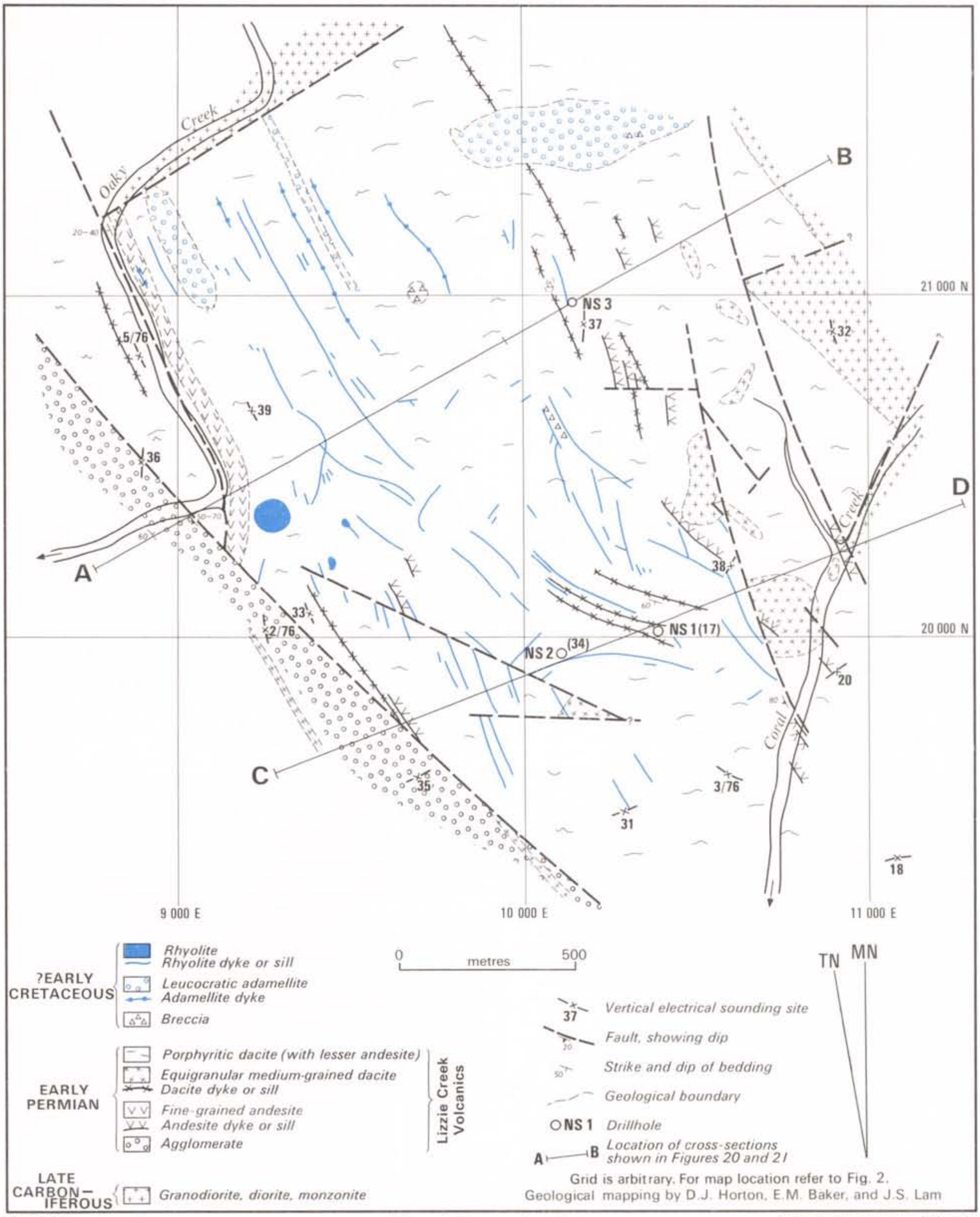

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Figure 4: Prospect geology

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Younger intrusives

Two intrusive phases of probable Early Cretaceous age are shown in Figure 4. These are fine-grained and medium to coarse-grained variants which can grade from one form to the other over a distance of several metres. Both intrusive phases are confined to the porphyritic dacite unit of the Lizzie Creek Volcanics.

The coarser grained phase is a pink, leucocratic, medium to coarse-grained adamellite containing up to 5 per cent biotite. It occurs as large stocks and dykes and has been found only in the northernmost part of the prospect area. Very weak alteration in the form of sericite-muscovite microveinlets is usually present.

Adamellite dykes tend to become progressively porphyritic and more rhyolitic towards the south. A typical transition phase consists of coarse-grained phenocrysts of quartz and plagioclase set in a fine-grained K-feldspar matrix.

The finer grained phase is rhyolite, porphyritic in places (with rounded quartz and rare feldspar phenocrysts), and easily distinguished from the volcanic sequence by its weathering characteristics and the pink, buff, or white colouration. Its colour is dependant on alteration intensity; it is pink when fresh. Rhyolite occurs predominantly as steep-dipping dykes or sills to 5 m in width. Three small bodies to the southwest may represent the upper chilled margins of adamellite. The rhyolite dykes appear to have been the igneous hosts to alteration and mineralisation.

Breccias

Two small breccia pipes were located on the prospect, the largest being 20 m in diameter. The breccia fragments are intensely sericitised and are cemented by a brown matrix containing appreciable quantities of sericite, limonite, and quartz. The fragments are angular to subangular and have a platy appearance and maximum size of 100 mm. The breccias are probably of the collapse type. Brecciation associated with dyke emplacement has also been observed.

Faults

All faults shown in Figure 4 were observed in outcrop. Many other minor faults probably exist in the area judging from the number of small faults observed in drill core.

The three major faults are a northwest-trending fault separating the two units of the Lizzie Creek Volcanics, a northeast-trending fault to the north separating the older intrusives from the volcanics, and a north-northwest-trending fault along Oaky Creek. Movement along these faults post-dates alteration and mineralisation.

Two north-northwest trending faults in the east probably represent step-faulting (west block down) with vertical, rather than horizontal displacement, antedating mineralisation and alteration. This would conform with the regional structure of the Almoola Hinge Zone (Paine & others, 1974).

Fractures

Three distinct sets of fractures were recognised in the porphyritic dacite unit at Mount Vista: northwest (300°-340°), northeast (035°), and east-northeast (080°) (Fig. 5). The northwest-trending fractures are dominant and reflect the strike of both the volcanics and the majority of rhyolite dykes. Northeast and east-northeast trending fractures parallel minor faulting and rare rhyolite dykes. A focus (or focii) for the three fracture directions is not apparent.

Although paucity of suitable outcrop prevents detailed analysis of fracture patterns, fracture intensity is seen to increase towards the centre of the prospect.

ALTERATION

A wide variety of alteration products was recognised at Mount Vista through geological mapping and drill core studies. Specific alteration assemblages proved difficult to establish owing to several factors which have produced a high degree of overprinting of the assemblages.

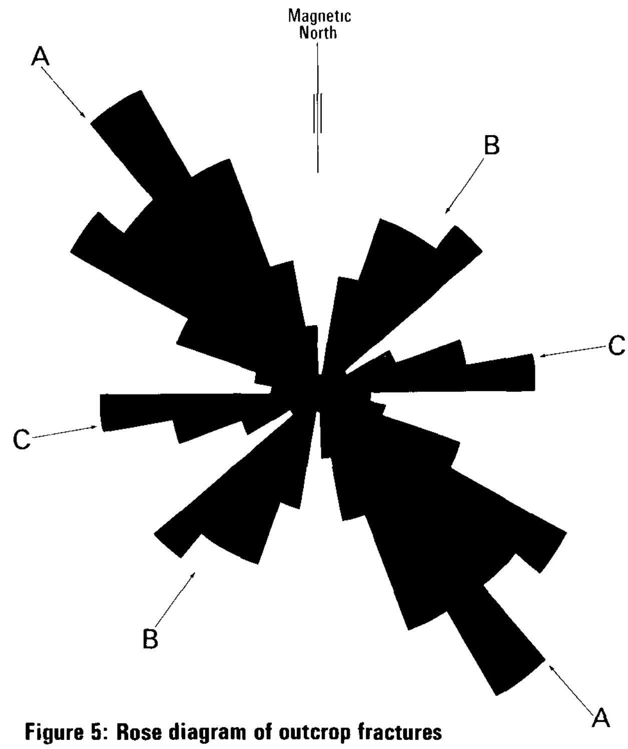

Figure 5: Rose diagram of outcrop fractures
Three fracture directions are apparent: northwest (A), northeast (B), and east-northeast (C)

Surface alteration

Through detailed mapping, a rough zonation of alteration assemblages was observed. Figure 6 shows this zonation, with a central sericite-quartz zone and an outer chlorite-epidote(zoisite)-calcite zone. These correspond to phyllic and propylitic alteration zones as defined by Lowell & Guilbert (1970). This figure, however, does not fully illustrate the complexity of alteration. The central core, which is the apex of the V-shaped sericite-quartz zone, has almost exclusively quartz-sericite-limonite(after pyrite) alteration. Surface outcrop is poor and the alteration appears pervasive over a large area. The rocks are extremely weathered, fractured, and leached. On both arms of the 'V', but particularly on the northern arm, sericitic and strong propylitic alteration occur in north-northwest trending fissure zones separating parallel ridges of weakly altered (propylitic) or fresh volcanics. These fissures parallel the strike of the volcanics and the rocks within them are strongly weathered, exhibiting a weak to moderate schistosity. Alteration also envelopes most of the rhyolite dykes, particularly those in the southern sector. Within these dykes, strong sericitic alteration predominates but becomes weaker with distance from them. Some dykes occupy the central part of the fissure zones. Weak kaolinisation of feldspars exists over all of the altered area and most is probably a function of weathering. Several highly silicified floaters have been found but such material has not been found in outcrop.

Subsurface alteration

Detailed examination of alteration products in drill core has established the existence of four alteration assemblages (Table 1) including the two main types, phyllic and propylitic, found on the surface. Overprinting of all four assemblages is very common and specific alteration zones are ill defined. Alteration type and intensity appears to be largely dependent on lithology and can change abruptly at lithological boundaries. For example, chlorite and zoisite are common in fine-grained andesites. As a general rule, the more basic rock types were susceptible to propylitic alteration whereas phyllic alteration was strongest in those that are apparently more acidic. Some quartz in the groundmass of acidic volcanics may have been introduced. Drilling did not intersect rhyolite or adamellite intrusives and little is known of their relationship to alteration or mineralisation apart from surface studies.

Potassic alteration (K-feldspar-secondary biotite-calcite ± quartz ± chlorite ± clay)

Potassic alteration, although weakly developed, is strongest in the central part of the prospect (DDH NS 1). K-feldspar occurs in short pink stubby stringers, in places with calcite or chlorite. Fine-grained pervasive K-feldspar has been observed in some volcanics through staining techniques but it is uncertain as to whether this is an alteration product. Fresh biotite in the volcanics differs from the secondary form by having a larger grain size. Both brown and green varieties of secondary biotite (thin section colours) have been found associated with quartz microveinlets in close proximity to K-feldspar stringers. Distinction between primary and secondary biotite usually can be made only in thin section as both have grain sizes generally less than 0.5 mm.

Calcite veining is commonly associated with K-feldspar stringers and is of two colour varieties, white and pink. Alteration envelopes, up to 50 mm across, usually surround the pink calcite veins. Petrographic studies have shown that plagioclase phenocrysts in these envelopes have been moderately altered to clay (?kaolin) giving them a pink colouration in hand specimen.

Phyllic alteration (sericite (clay)-quartz-pyrite)

This is strongly developed assemblage which in many places is represented simply as pervasive sericitisation. Silicification may accompany the sericitisation although this is difficult to determine. The strongest pervasive sericitisation is in volcanics that

TABLE 1: MOUNT VISTA ALTERATION ASSEMBLAGES — SUMMARY OF CHARACTERISTICS

Alteration assemblage	Pervasive mineral assemblage	Typical vein mineral assemblage
Potassic	?K-feldspar	K-feldspar-calcite-chlorite ± pyrite ± quartz ± clay Secondary biotite-quartz
Phyllic	Sericite (clay), quartz (silicification)	Quartz-sericite (clay)-pyrite
Propylitic	Chlorite, zoisite, calcite, clay*	Chlorite-zoisite ± pyrite Chlorite-calcite-pyrite ± zoisite ± kaolin Chlorite-quartz-pyrite
Late stage sulphate		Gypsum

*Some may be a product of weathering
Disseminated pyrite not shown

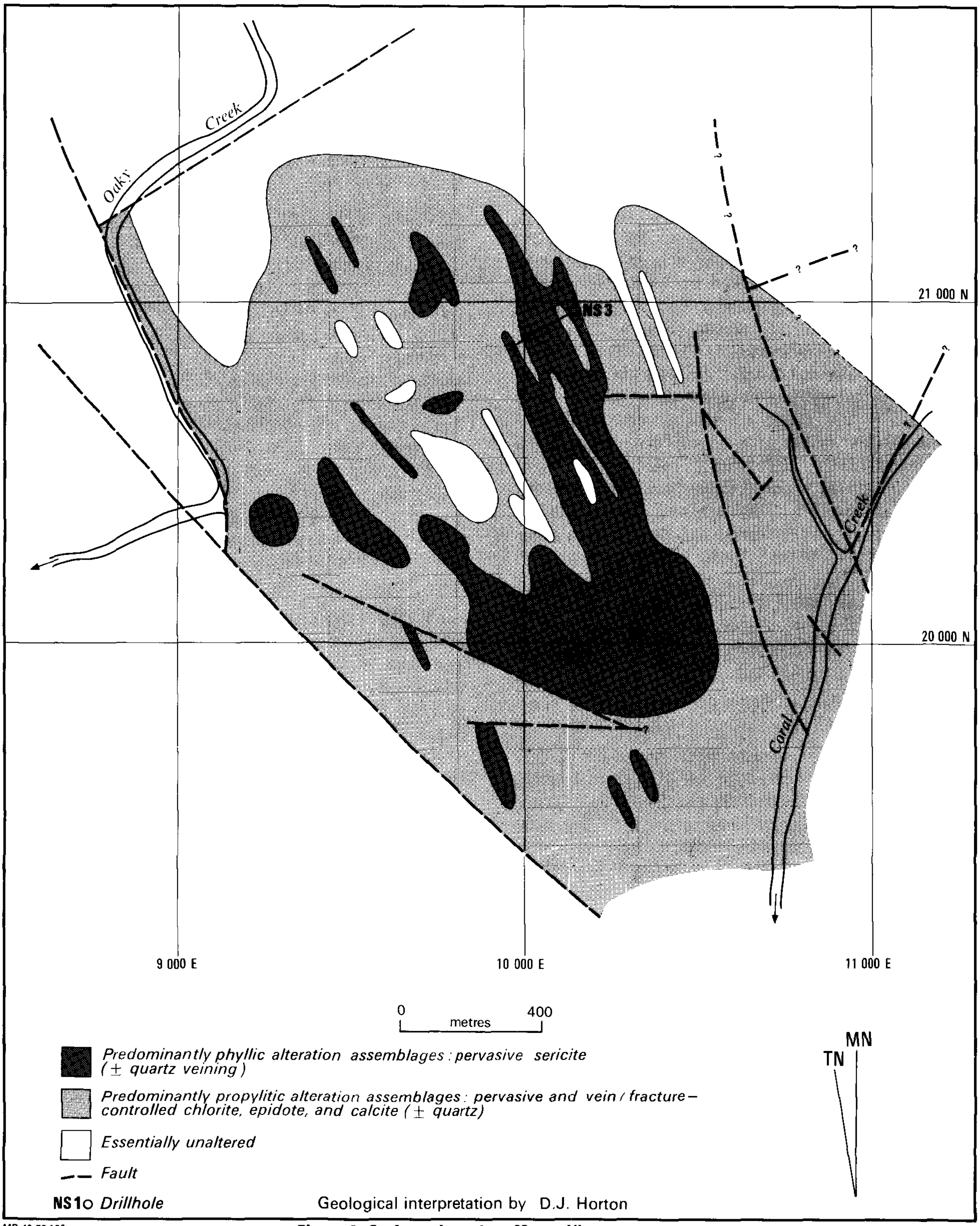

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Figure 6: Surface alteration, Mount Vista prospect

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have a large percentage of quartz in the groundmass, some of which may have been introduced.

Pyrite occurs with quartz in veins and veinlets which are in places enveloped by a strongly developed sericite-quartz zone to 50 mm across. XRD determinations of the sericite have shown it to have a high kaolinitic component.

Propylitic alteration (chlorite-zoisite-calcite-quartz ± pyrite ± clay)

This assemblage is the most widespread at Mount Vista and is predominantly pervasive. Zoisite (epidote) and chlorite occur on fracture surfaces or as microveinlets, particularly where intense propylitic alteration occurs. Calcite is usually present as veins or veinlets, or in places with kaolin on fractures. In some rock units (for example equigrandular dacite) it may be pervasive. Quartz-chlorite-pyrite veinlets are not uncommon.

Late stage sulphate alteration (gypsum)

Possibly the last alteration phase to affect the Mount Vista prospect was a sulphate phase. Subsurface studies indicate that this phase cannot be related to any of the above three alteration assemblages.

Gypsum replaces the centre section of calcite veins or in places, whole veins. Pyrite in these veins is largely unaffected. In places, irregular networks of gypsum veinlets give the volcanics a brecciated appearance. Calcite was not observed in these veinlets, indicating that gypsum may have been mobilised into a brecciated environment. Pyrite veinlets rarely offset gypsum veinlets; the reverse is usually the case.

Whole rock chemistry

Tables 2 and 3 list the major and minor element chemistry of selected intrusive and volcanic samples.

Fresh specimens of adamellite and rhyolite (Table 2, samples 1 and 3, respectively) show little variation apart from higher Na_2O and CaO contents for the adamellite. This confirms field evidence that the two rock types are related, with any differences accounted for by fractional crystallisation. Plagioclase is present in the adamellite but is rare (as phenocrysts) or absent in the rhyolite.

No unweathered samples of altered rhyolite were available for analysis and consequently sample 2 (Table 2), a weathered example, was included. Most notable is the deficiency in silica (SiO_2) content; presumably, silica leaching must have taken place. The higher Fe_2O_3, H_2O+, and SO_3 contents merely reflect the weathered, altered, and formerly mineralised nature of the rock.

The numerous variations of volcanic lithologies preclude detailed study of alteration facies within the country rock. Overprinting of alteration assemblages magnifies the problems involved. Thus, variation in chemistry between the various alteration assemblages can be discussed only in general terms.

TABLE 2: CHEMICAL ANALYSES OF ADAMELLITE/RHYODACITE INTRUSIVES AND DYKES

Sample	1	2	3
SiO_2 (%)	76.2	63.7	78.6
TiO_2	0.20	0.66	0.26
Al_2O_3	12.1	12.9	12.3
Fe_2O_3	0.65	9.8	1.5
FeO	0.95	0.39	0.69
MnO	<0.01	<0.01	<0.01
MgO	0.1	0.7	0.7
CaO	0.36	0.03	0.01
Na_2O	4.4	0.2	0.1
K_2O	4.1	4.7	3.9
H_2O-	0.2	0.2	0.2
H_2O+	0.6	3.2	0.8
P_2O_5	0.05	0.12	0.06
CO_2	0.2	1.0	0.2
SO_3	0.02	3.1	0.12
Total	100.14	100.71	99.45
Sr (ppm)	131	54	34
Rb	92	96	127
Cu	20	51	13
Ni	<10	12	<10
Co	<10	11	<10
Cr	13	19	13
Pb	55	63	23
Zn	58	49	37
Mo	15	12	27

1. Leucocratic adamellite, sample 1650/77. Grid Ref.: 21010 N, 9780 E.
2. Leached, fractured, and sericitised limonite rhyolite, sample 1651/77. Grid Ref.: 20160 N, 9900 E.
3. Fine-grained rhyolite (unaltered), sample 1652/77. Grid Ref.: 20820 N, 9440 E.

Analyses by Government Chemical Laboratory, Brisbane.

Samples 1, 2, and 3 (Table 3) represent one basic and two intermediate examples of fresh (surface) volcanics, respectively. Sample 3 may be slightly silicified. These three samples give the approximate chemical range that can be expected in the dacite sequence.

Volcanics exhibiting potassic, phyllic, and propylitic alteration are represented by samples 4, 5, and 6 (Table 3), respectively. Sample 7 is a mineralised volcanic containing both phyllic and propylitic alteration. The first three samples were carefully selected from drill core as samples that were not contaminated by more than one alteration type. It was impossible to avoid sampling material containing sulphides.

At best, only a visual estimate can be made of elements gained or lost for each of the various

TABLE 3: CHEMICAL ANALYSES OF VOLCANICS

Sample	1	2	3	4	5	6	7
SiO_2 (%)	54.4	60.0	60.0	59.1	63.9	54.5	62.8
TiO_2	1.0	0.74	0.73	1.10	0.62	0.95	0.63
Al_2O_3	17.4	16.0	17.2	17.3	16.4	16.2	15.6
Fe_2O_3	3.2	2.2	2.5	2.5	1.3	1.6	1.9
FeO	5.4	3.4	3.9	3.8	1.6	5.0	0.9
MnO	0.10	0.09	0.12	0.16	0.20	0.14	0.10
MgO	4.4	3.2	2.7	2.8	1.3	6.2	2.2
CaO	7.5	4.9	6.3	5.6	3.1	6.5	4.1
Na_2O	3.2	3.2	3.1	4.0	0.9	0.9	3.4
K_2O	0.9	2.1	1.5	1.5	2.9	1.2	2.6
H_2O-	0.2	0.1	0.2	0.1	1.0	0.1	0.2
H_2O+	1.7	2.6	1.2	1.3	3.6	2.7	1.2
P_2O_5	0.24	0.24	0.23	0.45	0.19	0.27	0.19
CO_2	0.2	1.3	0.1	0.1	1.7	0.7	0.4
SO_3	0.04	0.03	0.03	0.03	0.05	1.0	0.1
S^-	—	—	—	—	0.5	0.8	1.7
Fe as FeS_2	—	—	—	—	0.45	0.7	1.5
Total	99.88	100.10	99.81	99.84	99.71	99.46	99.52
Sr (ppm)	1 115	507	681	687	87	379	583
Rb	28	56	38	46	118	39	56
Cu	45	14	65	52	13	198	247
Ni	28	24	18	13	<10	38	13
Co	32	23	18	24	16	31	14
Cr	32	33	24	103	87	158	161
Pb	11	16	13	15	17	<10	<10
Zn	118	90	316	118	48	115	623
Mo	11	6	10	<5	<5	8	<5

1. Biotite-feldspar porphyry (andesite), sample 1653/77. Grid Ref.: 20610 N, 10420 E.
2. Grey feldspar-hornblende porphyry (dacite), sample 1654/77. Grid Ref.: 21100 N, 10040 E.
3. Grey feldspar porphyry (dacite), sample 1655/77. Grid Ref.: 20490 N, 10300 E.
4. Hornblende-feldspar porphyry (dacite), moderate potassic (K-feldspar–secondary biotite–calcite) alteration, sample 1656/77. DDH NS 1, 47.50 m.
5. Biotite-hornblende-quartz-feldspar porphyry (dacite), moderate phyllic (quartz-sericite) and calcite alteration, sample 1657/77. DDH NS 1, 209.80 m.
6. Hornblende-feldspar porphyry (andesite), moderate propylitic (chlorite-quartz-pyrite) alteration, sample 1658/77. DDH NS 3, 274.40 m.
7. Hornblende-feldspar porphyry (dacite), moderate phyllic (sericite/clay) and propylitic (zoisite) alteration, sample 1659/77. DDH NS 2, 37.10 m.

Analyses by Government Chemical Laboratory, Brisbane.

alteration assemblages. This can be done only by taking the acidity of each sample into consideration. The possibility of silicification prevents the use of SiO_2 content only, and so other features such as FeO and MgO contents as well as K_2O/Na_2O and Sr/Rb ratios are taken into consideration. Sample 4 (potassic alteration), for example, can be considered similar in acidity to sample 3 (fresh). The two specimens have a very similar geochemistry with no elements gained or lost.

For the remaining samples, only rough comparisons can be made (for example, sample 6 is probably slightly more acidic than sample 1). The distinguishing feature of these samples is the high H_2O+, SO_3, and S^- contents compared with the fresh samples. Most other elements show little variation once rock acidity is taken into account. High H_2O+ contents reflect the sericitic and chloritic components of the alteration assemblages. CO_2 contents are variable, as they are in the fresh examples. Variable SO_3 contents may indicate the presence of gypsum in minor quantities. S^- and Fe as FeS_2 reflect the mineralised nature of the samples.

SULPHIDE MINERALISATION

Surface mineralisation

Disseminated fine-grained pyrite is widespread within the porphyritic dacite unit and the eastern exposure of the Late Carboniferous intrusives. It generally comprises 1 to 2 per cent of the total rock with local concentrations (from gossan and limonite studies) to 10 per cent or more within the central phyllic alteration zone. The central area of the prospect is highly leached and fresh mineralisation is rare.

Sulphide mineralisation appears to be centred on the rhyolite dykes. Some of these dykes, especially those in the central part of the prospect, are gossanous and contain abundant quantities of limonite. Limonite ranges in colour from yellow to brown and from dark red to black. Minor amounts of neotocite and jarosite have been recognised. Rare galena and sphalerite were observed along the northwesterly fault zone in the southern part of the area and traces of malachite were recorded on freshly broken equigranular dacite. Gossan studies and assay of samples from rhyolite dykes indicate that pyrite, chalcopyrite, galena, and sphalerite are the predominant sulphide minerals at Mount Vista. Some silver is also present.

Subsurface mineralisation

A substantial percentage of both chalcopyrite and sphalerite (and possibly galena as well) is extremely fine grained and finely disseminated. Consequently, many estimations made of base metal content in drill core were later shown to be incorrect. Even in some specimens containing up to 0.5 per cent copper and zinc, chalcopyrite and sphalerite were not discernable to the naked eye.

Sulphide content for the three holes drilled (mainly pyrite) averages between 1.5 and 2.0 per cent. Pyrite occurs in veins and veinlets, as stringers, and in disseminated form, generally associated with, and after, mafics. Chalcopyrite exists as microfracture fillings in pyrite and as very fine stringers, but mainly as fine-grained disseminations. Primary magnetite, occasionally showing well-developed exsolution of ilmenite needles, is relatively rare. Ilmenite grains (to 0.5 mm) are generally present. Sphalerite was found in quantity only in drillhole NS 2; it occurs as fine-grained disseminations usually with an emulsion texture of chalcopyrite. Galena was not observed in polished sections.

Base of weathering is approximately 20 m in the central area, and no evidence of secondary enrichment was seen.

DEPOSIT AGE

Alteration and mineralisation at Mount Vista is related to the adamellite/rhyolite intrusives. Their leucocratic nature has eliminated the possibility of K-Ar age determinations on their mafic constituents. Attempts were made to separate sericite from three drill-core samples for isotopic age determination to establish the age of alteration. The fine-grained nature and high kaolinitic component of the sericite prevented this. Similarly, the coexistence of fine-grained secondary and primary biotite in the volcanics precluded isotopic age determinations.

The Lizzie Creek Volcanics have been assigned an Early Permian or possibly Late Carboniferous age (Paine & others, 1974). K-Ar age determinations by Webb & McDougall (1968) indicate an approximate age of 270 m.y. As the Mount Vista host rocks intrude the volcanics, the oldest possible age of the prospect is Early Permian.

Only two intrusive units in the immediate Collinsville region are of this age or younger: the Early Permian Thunderbolt Granite (265 m.y.) to the north of Collinsville and Early Cretaceous (125 m.y.) intrusives to the south (Fig. 3). Both are in close proximity to the Mount Vista prospect.

An Early Cretaceous age is favoured, however, as other mineralisation associated with large scale alteration in the Collinsville region is of Early Cretaceous age. Examples occur at Mount Leslie (Auselex Exploration (Pty) Ltd, 1972) and Mount Poole (Horton, 1976), and further afield numerous deposits occur within the Early Cretaceous Hecate Granite and Mount Abbot Igneous Complex (Horton, 1978a, in press). The Rocky Creek molybdenum deposit (Wood, 1973) and an altered area in the headwaters of Thunderbolt Creek (Paine & others, 1974) are two examples of this type of alteration/mineralisation in the Thunderbolt Granite. Both are derived from host rocks intruding the granite and their respective ages are unknown.

Leucocratic adamellite, similar to that found at Mount Vista, was observed in the eastern part of the Devlin Pocket intrusive, 10 km to the south. This intrusion has yielded an Early Cretaceous isotopic age (Paine & others, 1974).

GEOCHEMISTRY

Stream sediment sampling

Regional stream sediment sampling of minus 80 mesh material at a sample density of approximately five per square kilometre succeeded in locating the Mount Vista prospect. The immediate area was then stream sediment sampled in detail (Fig. 7) and an area of 1.5 by 1.5 km of significantly anomalous values was outlined. 'Threshold' geochemical values for streams draining Lizzie Creek Volcanics were determined at 80, 35, and 155 ppm for copper, lead, and zinc, respectively (Horton, 1977). Values within the anomaly were up to five times background.

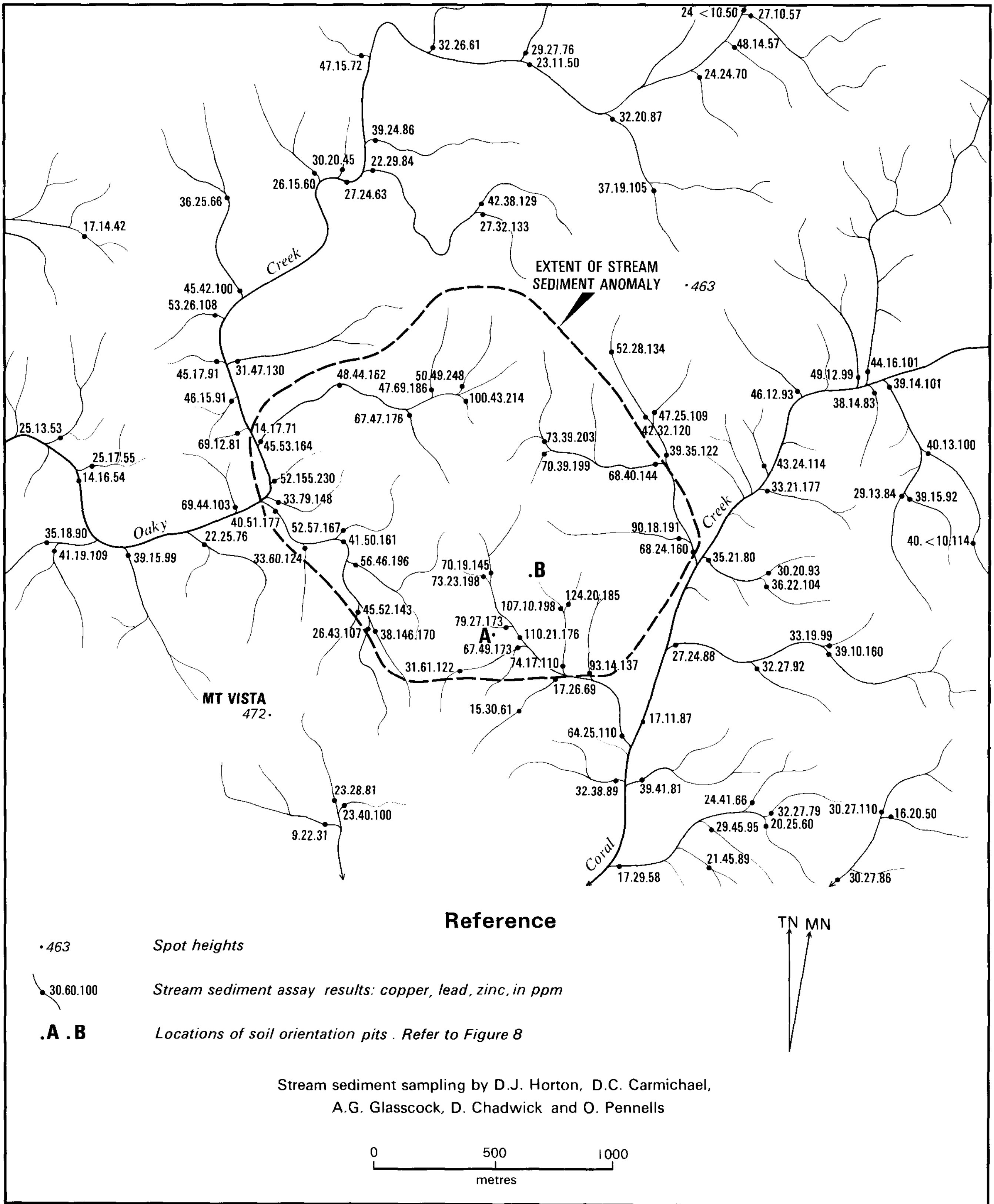

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Figure 7: Stream sediment sample results

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An acidic environment was indicated by the notable absence of calcrete in the streams draining the prospect, the leaching of almost all surface mineralisation, and a badly corroded bore and windmill in the southeastern part of the anomaly.

Soil sampling

Orientation sampling of two sample pits (Figs 7 and 8) indicated that minus 80 mesh material from a depth of 150 to 200 mm would give the best reliability for a soil sampling program. Thick clay layers were recorded in both pits and it was expected that these would dampen soil assay results.

A circular area some 2.5 km in diameter was then soil sampled at 50 m intervals along the 100 m spaced north-south grid lines. A total of 805 soil samples was taken.

Soil samples were analysed by the Government Chemical Laboratory for copper, lead, zinc, and molybdenum by emission spectrometry (Geoghegan, 1977) and results plotted as geochemical contour maps. Copper, lead, and zinc anomalies were found to occur within an oval area 2.1 km by 1.4 km elongate northwest-southeast. The anomalous area is almost entirely within the dacite porphyry unit of the Lizzie Creek Volcanics.

Copper (Fig. 9)

Anomalous copper values occur within a central, irregularly shaped area, 1.7 by 0.9 km, elongate northwest. This area corresponds with the area of surface phyllic alteration (Fig. 6). The copper values are relatively low, the highest being 500 ppm (background of 40 ppm). Two areas of high copper values correspond to the northern and southern IP anomalies (Figs 13 and 14).

Lead (Fig. 10)

Anomalous lead forms a well-developed halo around the central anomalous copper zone and is strongest in the west near the faulted contact with the agglomerate sequence. High lead (and zinc) values to the east of Oaky Creek and low values to the west confirm the presence of faulting along the creek.

Inside the halo, geochemical values for lead are exceptionally low, particularly in areas of high copper values. Large areas with lead values less than 10 ppm were outlined, compared with values up to 1 200 ppm in the halo itself.

Zinc (Fig. 11)

The zinc halo around the central copper zone is not as well developed as the halo for lead. Some zinc appears associated with copper in the central area. The western part of the zinc halo, as for lead, is strongly developed.

Molybdenum

No molybdenum values greater than 5 ppm were detected in the soil samples although values to 12 ppm were recorded in stream sediments.

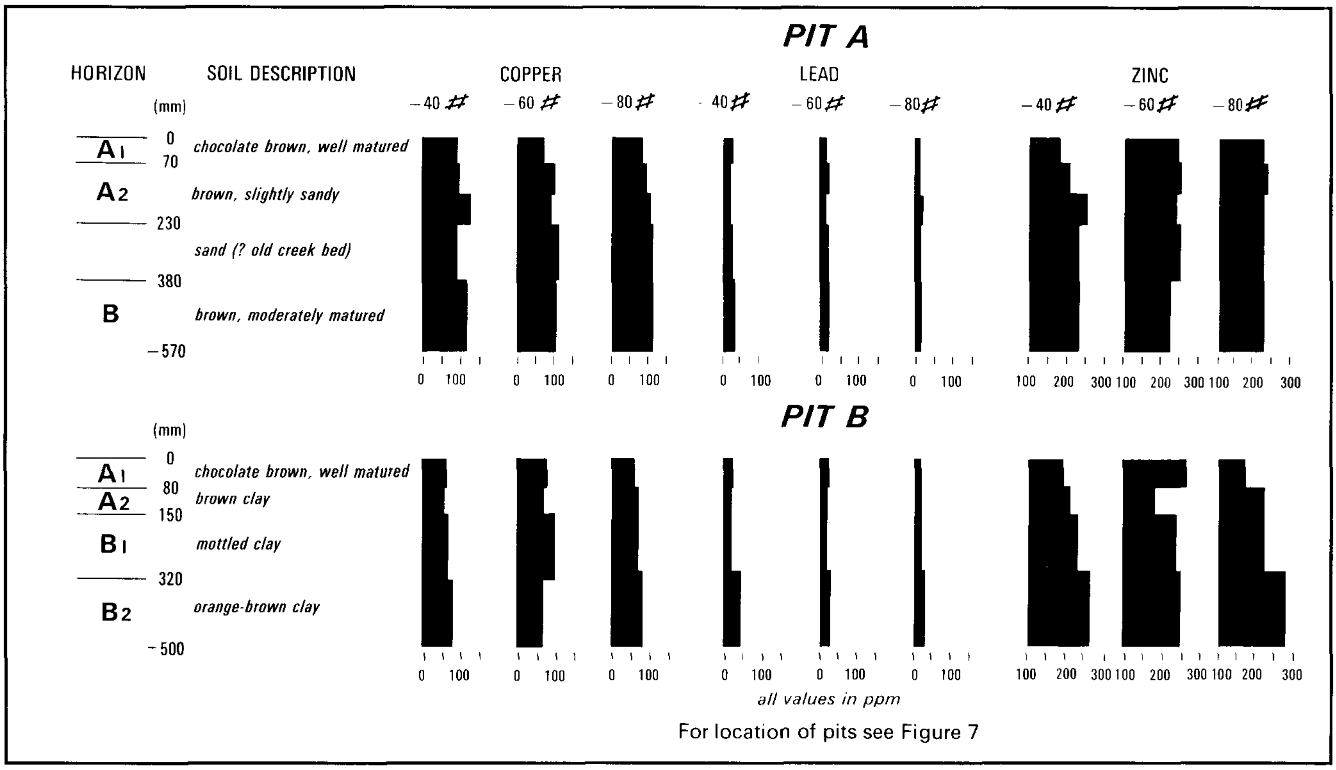

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Figure 8: Soil orientation studies

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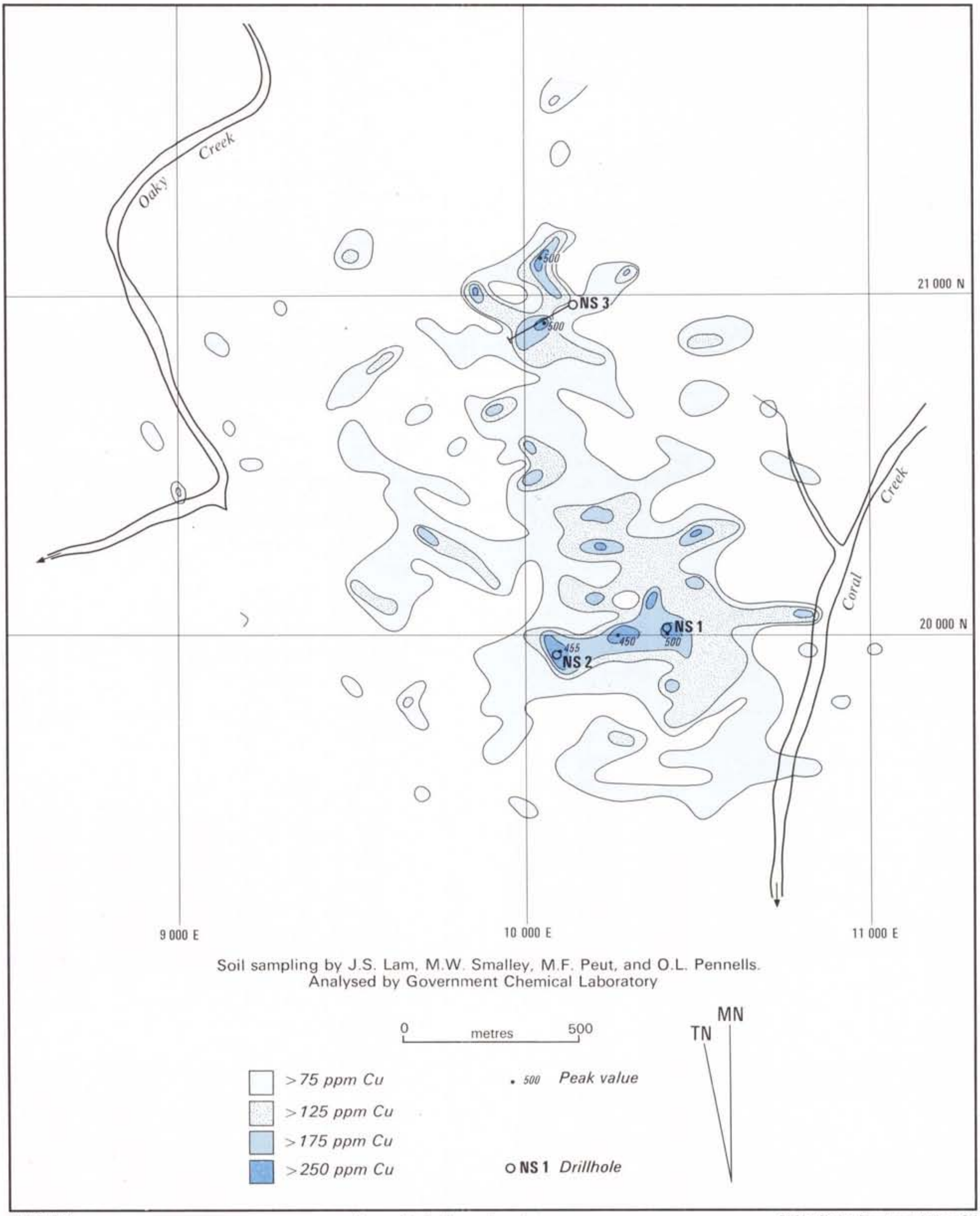

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Figure 9: Soil geochemistry — copper

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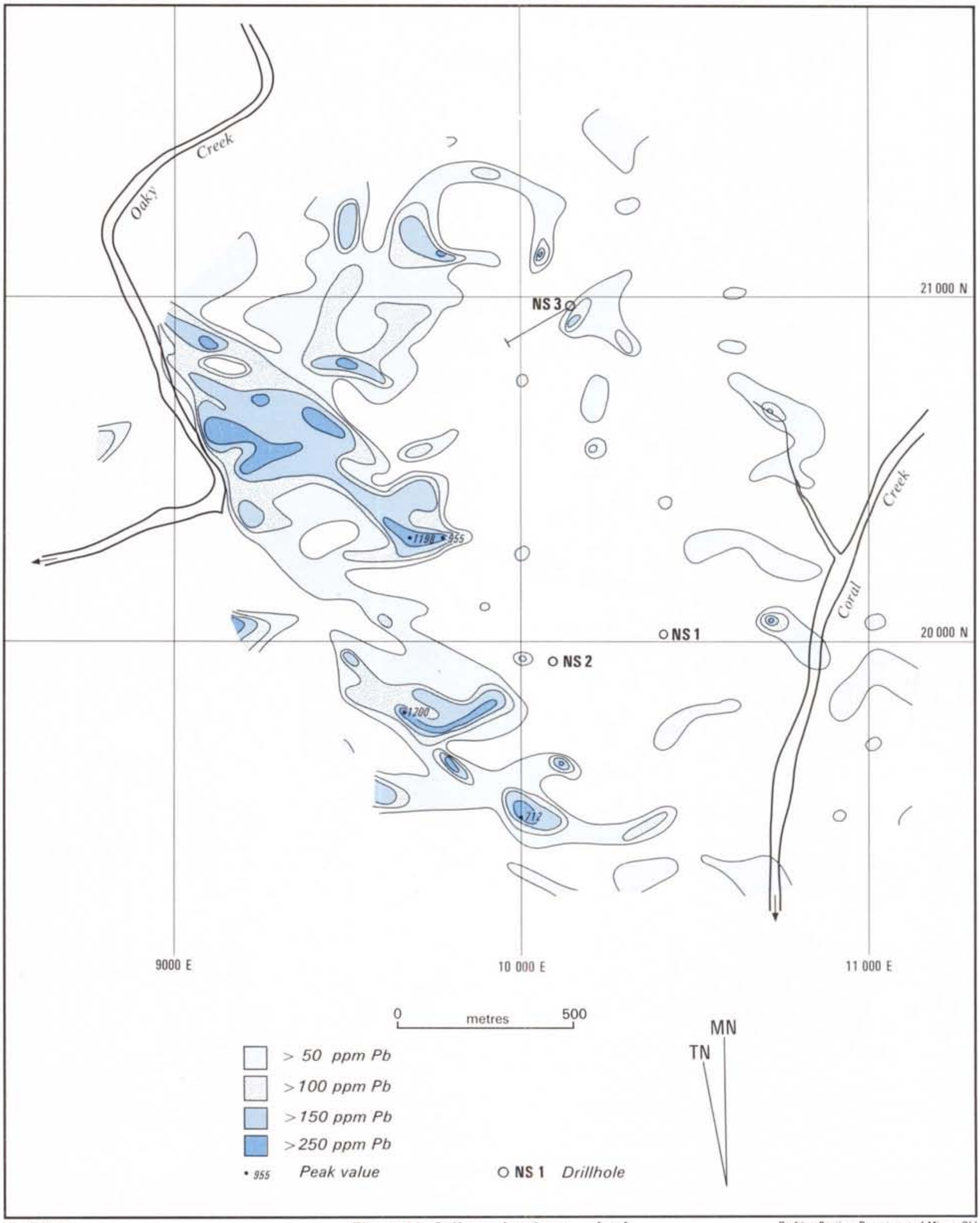

MD 42.78.126 **Figure 10: Soil geochemistry — lead** Drafting Section, Department of Mines, Qld

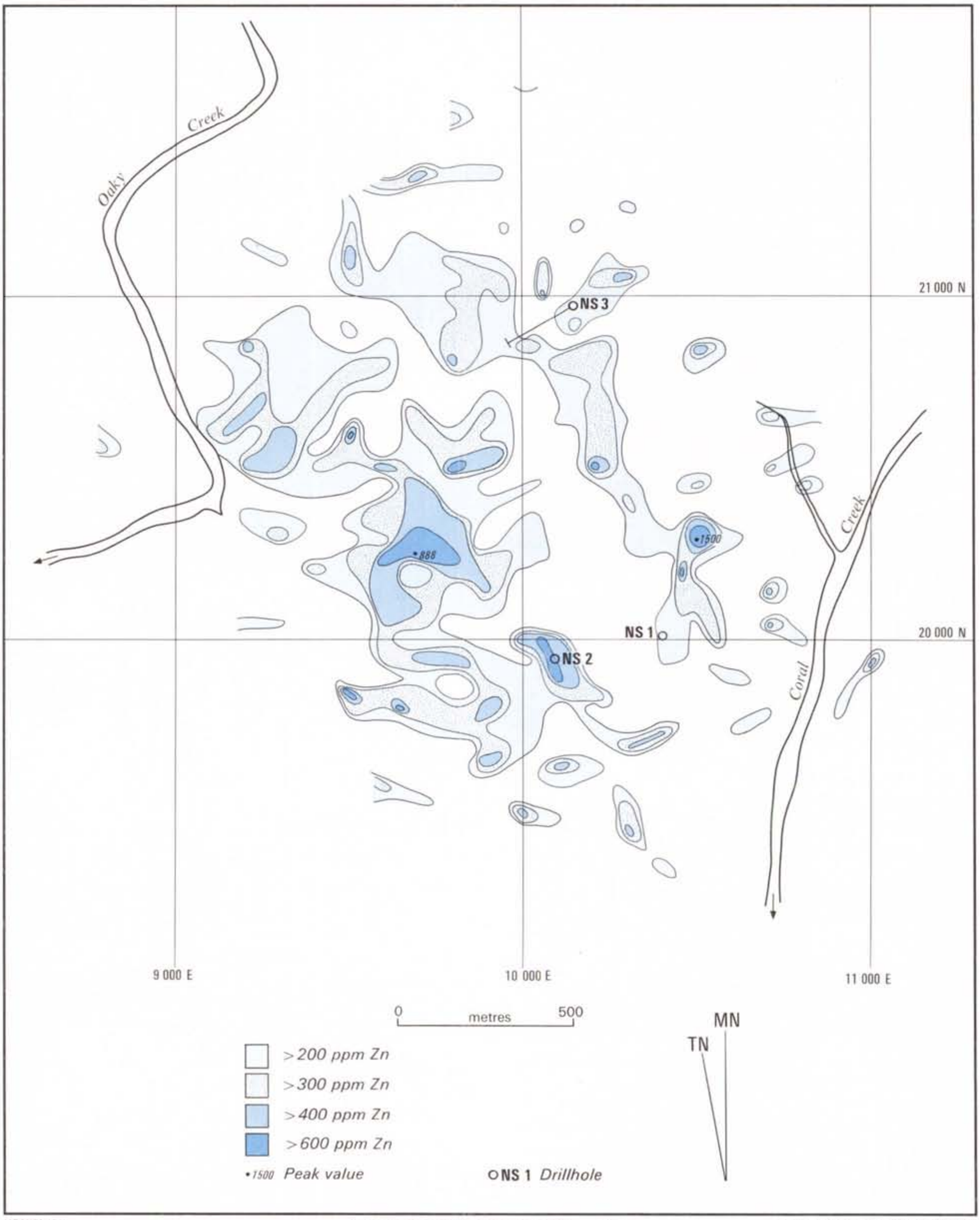

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Figure 11: Soil geochemistry — zinc

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GEOPHYSICS

Induced polarisation-resistivity

The induced polarisation-resistivity (IP/R) survey employed dipole-dipole profiling techniques on the 100 m grid and vertical electrical soundings (VES) at selected sites on the prospect. The dipole-dipole electrode configuration utilised a 100 m spacing between electrodes (a) and a 100 m and 200 m dipole spacing (n = 1, 2). The VES technique employed the Schlumberger electrode configuration with a maximum L spacing of 315 m. A description of these arrays may be found in Parasnis (1973).

Dipole-dipole profiles

Similar IP/R anomalies are apparent from the dipole-dipole profiling surveys (n = 1, 2) and any discussion of one should apply equally well to the other. Figure 12 presents the results for the 100 m (n = 1) dipole spacing and Figure 13 the results for the 200 m (n = 2) dipole spacing. The following discussion pertains to the latter.

An IP anomaly is located with the porphyritic dacite unit of the Lizzie Creek Volcanics and parallels the strike of this unit. A double-peak anomalous zone is situated along the western boundary of the volcanics where it is faulted against Late Carboniferous intrusives. It correlates exceptionally well with the copper geochemical anomaly. Between the peaks, one along 21 000 N and the other on 20 000 N, a high east-northeasterly resistivity trend is apparent. This trend correlates with a low copper-lead-zinc area determined by the geochemical survey.

Most of the profile survey grid lies on the volcanic porphyry which is the host rock for the mineralisation. High ambient IP values are observed over most of the grid and are related to the distribution of pyrite through the volcanic unit. This high ambient field may mask secondary anomalous IP zones. A perusal of the resistivity field indicates that with the exception of the high noted earlier, low to intermediate values are noted over the central portion of the grid, with high values around the perimeter. This trend may be related to mineral distributions or to geologic boundaries between the volcanics and granites or the dacite and agglomerate. The 'metal factor' (Bertin & Loeb, 1976) is a resistivity correction to the IP effect which occasionally enchances IP responses that are masked by a high ambient field. Figure 14 is a plot of the metal factor for the 200 m dipole-dipole spacing. The discontinuous nature of the mineralisation is confirmed, and in addition the plot shows a westward extension on both anomalous IP zones. These extensions correspond with geochemical zones where copper (above 125 ppm) is associated with coincident zinc and lead anomalies.

The metal factor plot indicates that the southern zone is much larger and intense and represents the more significant mineralised zone. It is also noted that the centre of this southern zone has shifted slightly north of the IP anomaly.

Vertical electrical soundings

The vertical electrical soundings (VES) give some indication of the depth to the top of the IP/R anomalies. The VES sites are located in Figure 4 and the interpreted sections are shown in Figure 15. VES 37, 17, and 3/76 are located within the profiling anomaly and indicate the top of the mineralised zone to be between 8 and 14 m from the surface. This zone has very high chargeabilities (45 to 150 ms) and high to intermediate resistivities (190 to 3 000 ohm-m). On the flanks of the profile anomaly, similar, but slightly deeper, mineralised depths are observed on the sections for VES 31, 34, and 38. Depths to the top of this zone range from 10 to 21 m and chargeabilities and resistivities range between 14 to 48 ms and 400 to 600 ohm-m. Around the perimeter of the IP/R profile anomaly the VES indicate more variable conditions. VES 5/76, 35, and 36 gave little or no indications of mineralisation. VES 2/76, 18, 20, 32, 33, and 39 indicated mineralised depths ranging between 7 and 34 m, and intermediate chargeability and resistivity values ($10 < M_a < 30$, $100 < \rho < 1000$).

There is no obvious correlation between the resistivities and mineralised zones. This is borne out by the fact that the highest basement resistivities were measured within the high IP zone. It appears then that mineralisation only has a marginal effect, if any, on the resistivity.

A correlation of the VES with the profile resistivities suggests that the dipole-dipole 200 m configuration had a sensing depth between 20 and 40 m and that the final depth depends on the near surface resistivities.

The lack of any observed resistivity response to mineralisation is probably due to the wide distribution of pyrite in the volcanic sequence, which tends to standardise the electrical response. The electrical variations observed on the sections are probably related to variations in weathering, clay products, and porosities.

Magnetic total field

The results of a total field magnetic survey conducted on the Mount Vista grid are presented in Figure 16. A magnetic low coincides with the mineralised zone indicated by the IP anomaly. To the west the field becomes more intense and complicated, corresponding with the faulted zone between Lizzie Creek Volcanics and Late Carboniferous intrusives. The granodiorites are more magnetic and are responsible for the increased magnetic field. The faulted zone is characterised by a series of complex, overlapping

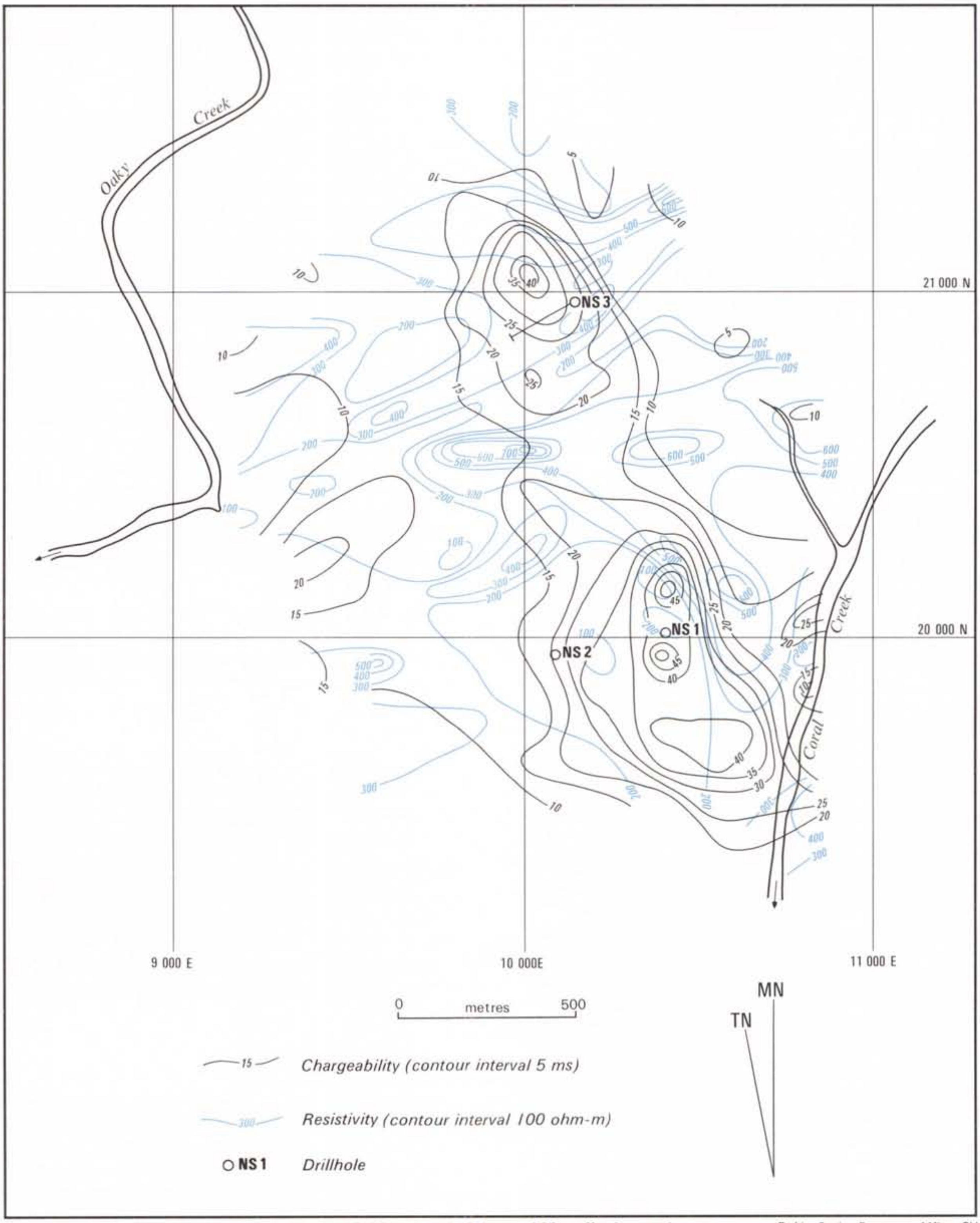

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Figure 12: IP and resistivity — 100 m dipole spacing

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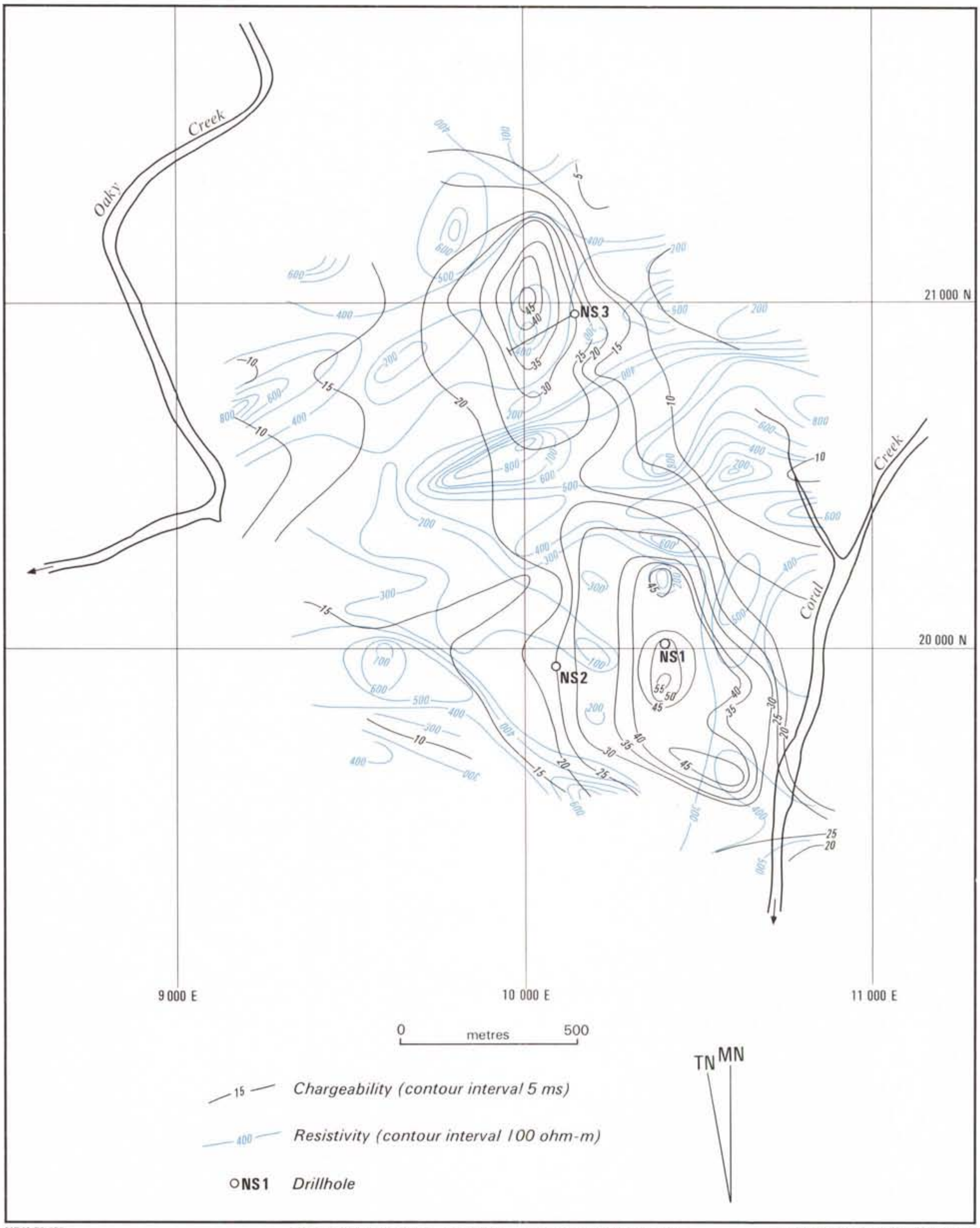

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Figure 13: IP and resistivity — 200 m dipole spacing

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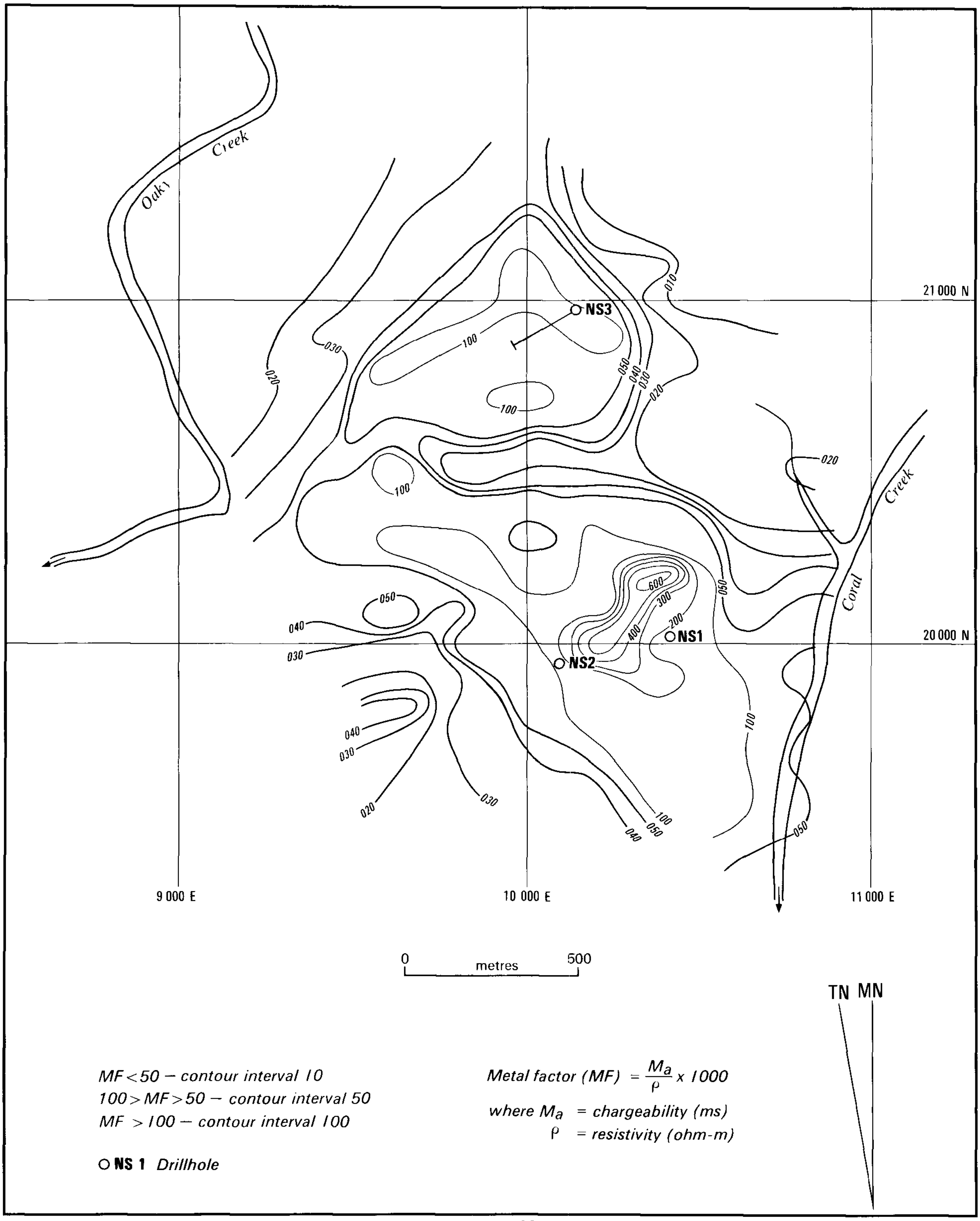

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Figure 14: Metal factor — 200 m dipole spacing

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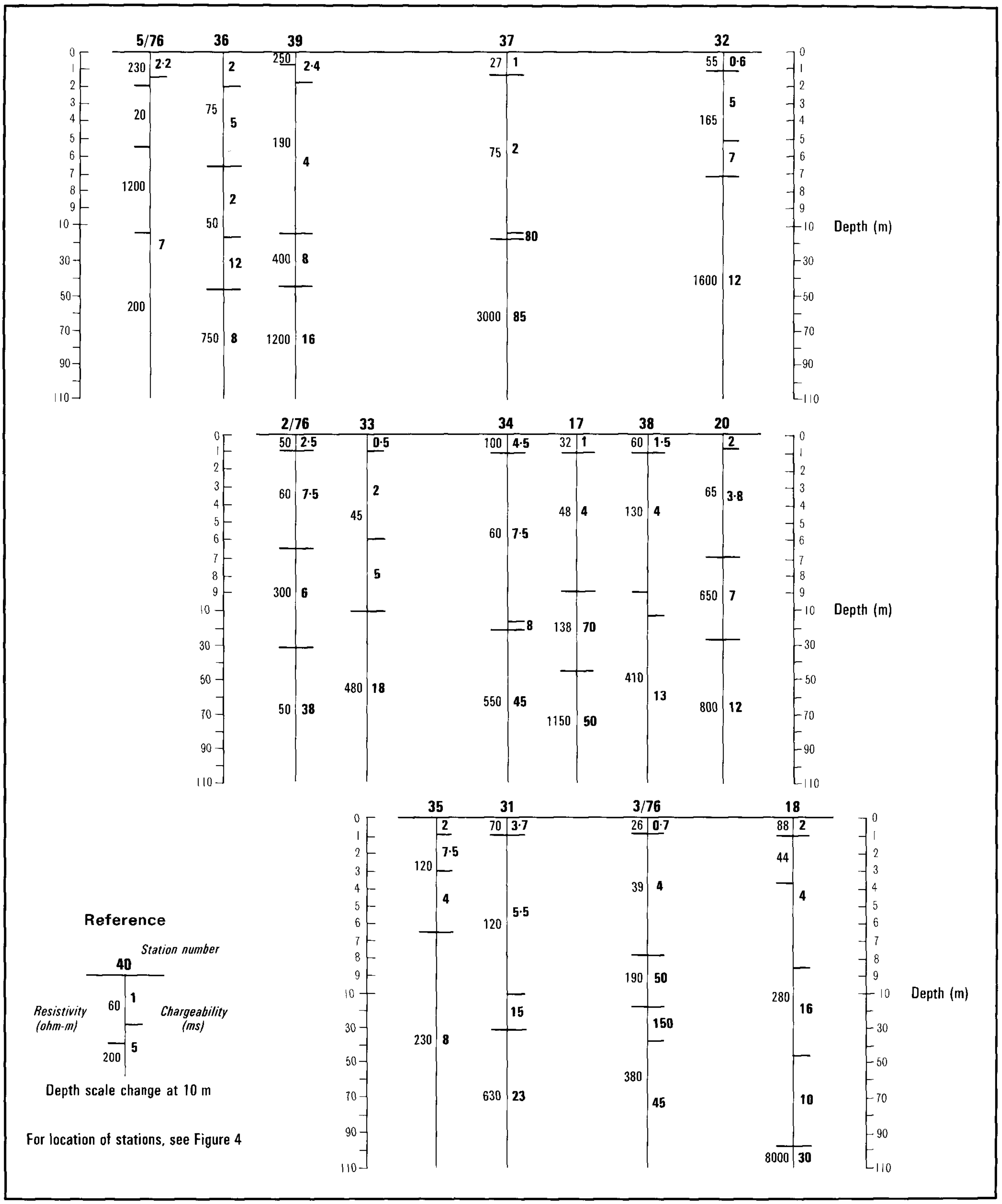

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Figure 15: Vertical electrical soundings

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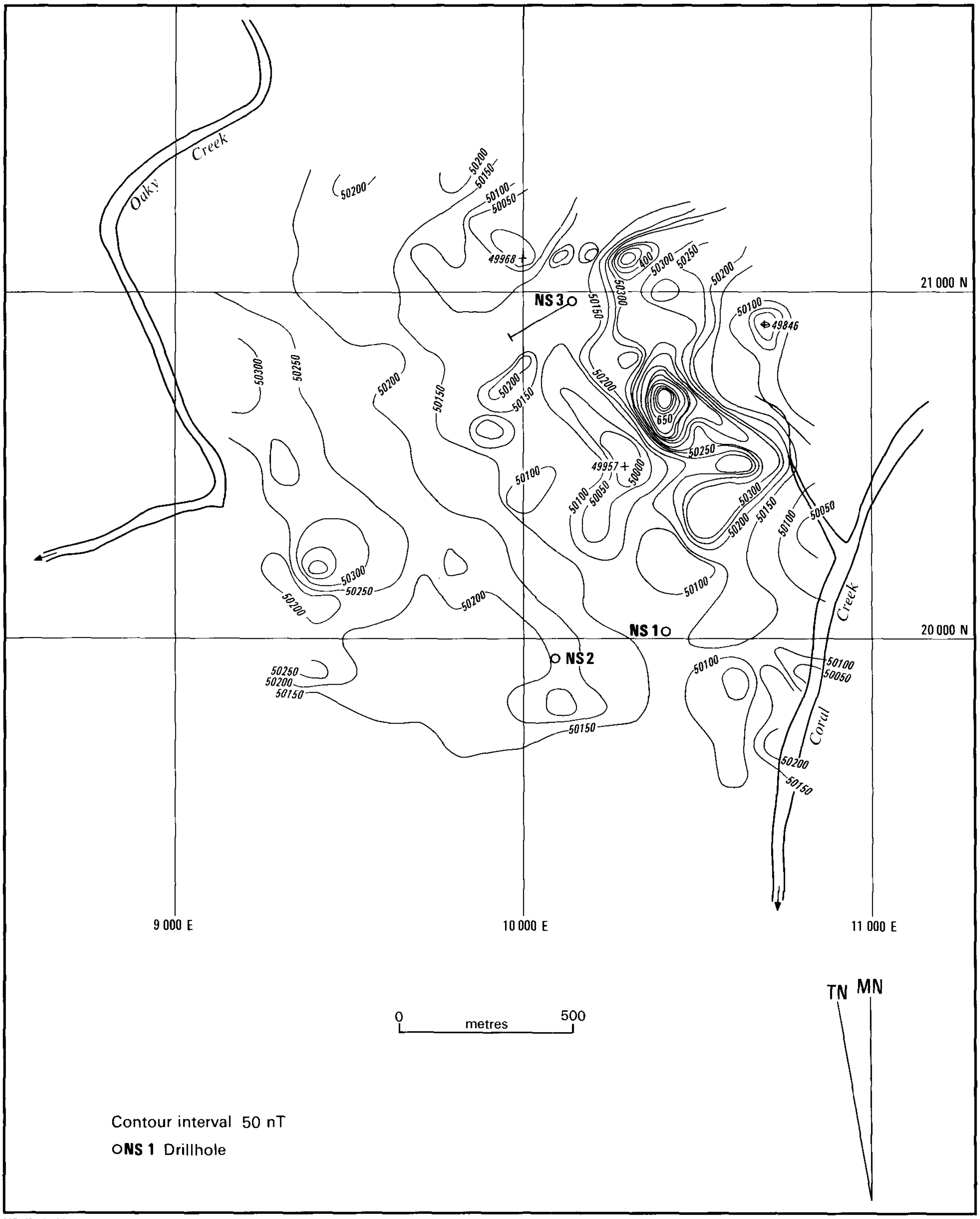

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Figure 16: Total field magnetics

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magnetic dipole anomalies and the dominant anomalies lie on the extension of the high resistivity zone between the IP anomalies. The relationship between resistivity and magnetics appears to be coincidental as the high magnetic activity in this zone does not extend between the double-peak anomaly.

DRILLING

During the period March to June 1977, three diamond drillholes totalling 783 m were drilled on the prospect by the Department of Mines Drilling Branch using a Longyear 34 rig. The holes were sited on the basis of the geochemical and geophysical data.

DDH NS 1

Grid Reference: 20016 N, 10396 E
Vertical hole to 224.70 m (Fig. 17)

Diamond drillhole NS 1 was sited to test the centre of the southern copper/IP anomaly (Figs 10, 13, and 14) in the area of strongest alteration, fracturing, and leaching.

The hole intersected various rock types of the porphyritic dacite unit (Fig. 17), each generally less than 7 m thick and dipping at 30° to the core axis (60° S). Calcite breccia, consisting of subangular calcite clasts to 200 mm set in a carbonate matrix with minor chlorite was recorded between 210.50 and 212.40 m. A pervasive silica-sericite-calcite envelope 2 m wide surrounds the calcite breccia.

Potassic alteration assemblages are weakly developed between 44 and 146 m, being typified by K-feldspar veining, lesser secondary biotite (identifiable only in thin section), and associated calcite and chlorite. Pervasive and lesser vein and fracture-controlled phyllic and propylitic assemblages are generally present throughout, as is late stage gypsum vein alteration which accompanies calcite veining.

Pyrite veining is strongest in the upper portion of the hole with some 5 m sections containing over 5 per cent. Sulphides average 2 per cent over the entire hole. Disseminated pyrite is typically associated with and was possibly derived from the mafic constituents of the volcanics. Weak copper mineralisation is present in the upper 100 m (Table 4; Horton, 1978b). Chalcopyrite is present as fine stringers, microfracture infillings in pyrite grains, and as very fine-grained disseminations with associated sphalerite in places. Copper values range up to 0.19 per cent over a 2 m interval but average considerably less. No relationship can be established between the pyrite and chalcopyrite contents of the drill core.

The geophysical logs comprise *in situ* measurements of induced polarisation and resistivity (IP/R), and self potential (SP), and measures of drill core magnetic susceptibility (Fig. 17). The IP/R response is consistent with the geophysical section determined by VES 17, coincident with the drillhole. Between 55 and 80 m, a resistivity increase and IP decrease parallels an increase in gypsum veining (stockwork in parts). Gypsum, in effect, acts as an insulator in this instance. Between 80 and 100 m, the IP/R response is reversed (R decreases and IP increases) owing to a reduction in gypsum and an increase in pyrite veining. Over the remaining portion of the log, constant resistivity and IP values reflect a uniform mineral environment.

TABLE 4: DRILL INTERSECTIONS — GRADE

Hole	From	To	Interval (m)	Assays (ppm) Cu	Pb	Zn	Ag
NS 1	1.75	98	96.25	413	<20	75	3.3*
	50	60	10	796	<20	96	—
NS 2	22	48	26	857	<20	1 814	1.5 (5.0*)
	122	132	10	574	56	3 322	—
	126	132	6	760	<20	5 200	—
NS 3				680*	140*	600*	1.3*

*Maximum for 2 m sample interval

The magnetic susceptibility log indicates magnetic minerals in the upper portion of the drillhole, coincident with the zone of pyrite veining. The irregular susceptibility response supports the premise that pyrite has replaced primary magnetite in the near vicinity of the veins. Small quantities of magnetite are still present between veins.

DDH NS 2

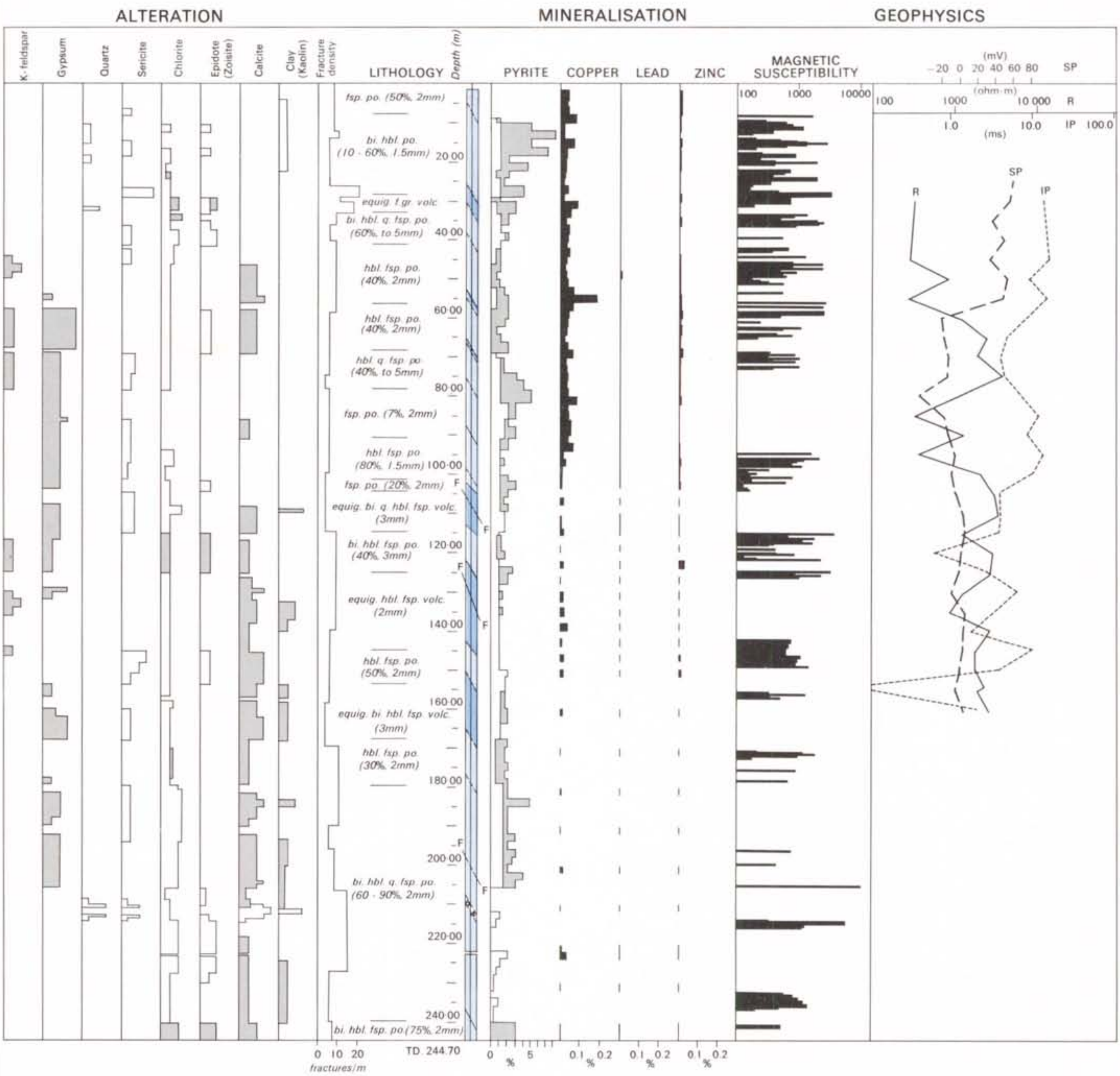
Grid Reference: 19950 N, 10100 E
Vertical hole to 258.25 m (Fig. 18)

Drillhole NS 2 was positioned on the western edge of the southern IP anomaly in an area of high copper geochemistry.

As in NS 1, porphyritic dacite rock types were recorded over the entire length of the drill core, again with most contacts at 30° to the core axis.

Only traces of potassic (K-feldspar) alteration are found, at a depth of 132 m. Calcite and to a lesser extent quartz veining are present throughout the core, as are phyllic and propylitic alteration assemblages.

Pyrite veining is less abundant in this hole and bears no relationship to base metal content. Sulphides average 1.5 per cent. Both chalcopyrite and sphalerite are extremely fine grained and were rarely observed in hand specimen. Two zones of copper and zinc mineralisation were recorded, the first between 22 and 48 m, and the second between 122 and 132 m (Fig. 18; Table 4; Horton, 1978b). Both zones are associated with pervasive zoisite alteration, although sericite alteration was recorded in the upper zone and K-feldspar alteration in the lower. The deeper zone is restricted to a feldspar porphyry unit of the volcanics. Volcanics in both zones are acidic and may be partially silicified.



REFERENCE FOR FIGS 17, 18 AND 19

ALTERATION

- *Pervasive or disseminated*
- *Vein or fracture controlled*
- *Weak*, *Moderate*, *Strong*, *Intense* } *intensity*

All information is based on hand specimen description with limited thin and polished section work.

All drillholes logged by D.J. Horton
Geophysical logging by R.D. Huber
Assays by Government Chemical Laboratory

- *Porphyry*
- *Volcanics*
- *Intrusive (diorite)*
- *Breccia*
- *Gradational or inferred lithological contacts. These are at 30° to core axis for NS 1 and NS 2, and at 45° to core axis for NS 3.*
- *Observed geological contacts*
- *Fault, observed*
- *Fault, inferred*

ABBREVIATIONS

bi.	*biotite*
hbl.	*hornblende*
q.	*quartz*
fsp.	*feldspar*
po.	*porphyry*
(20%, 2mm)	*phenocryst %, grain size of phenocryst*
equig.	*equigranular*
f.gr.	*fine grained*
volc.	*volcanic*

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Figure 17: Drill section NS 1

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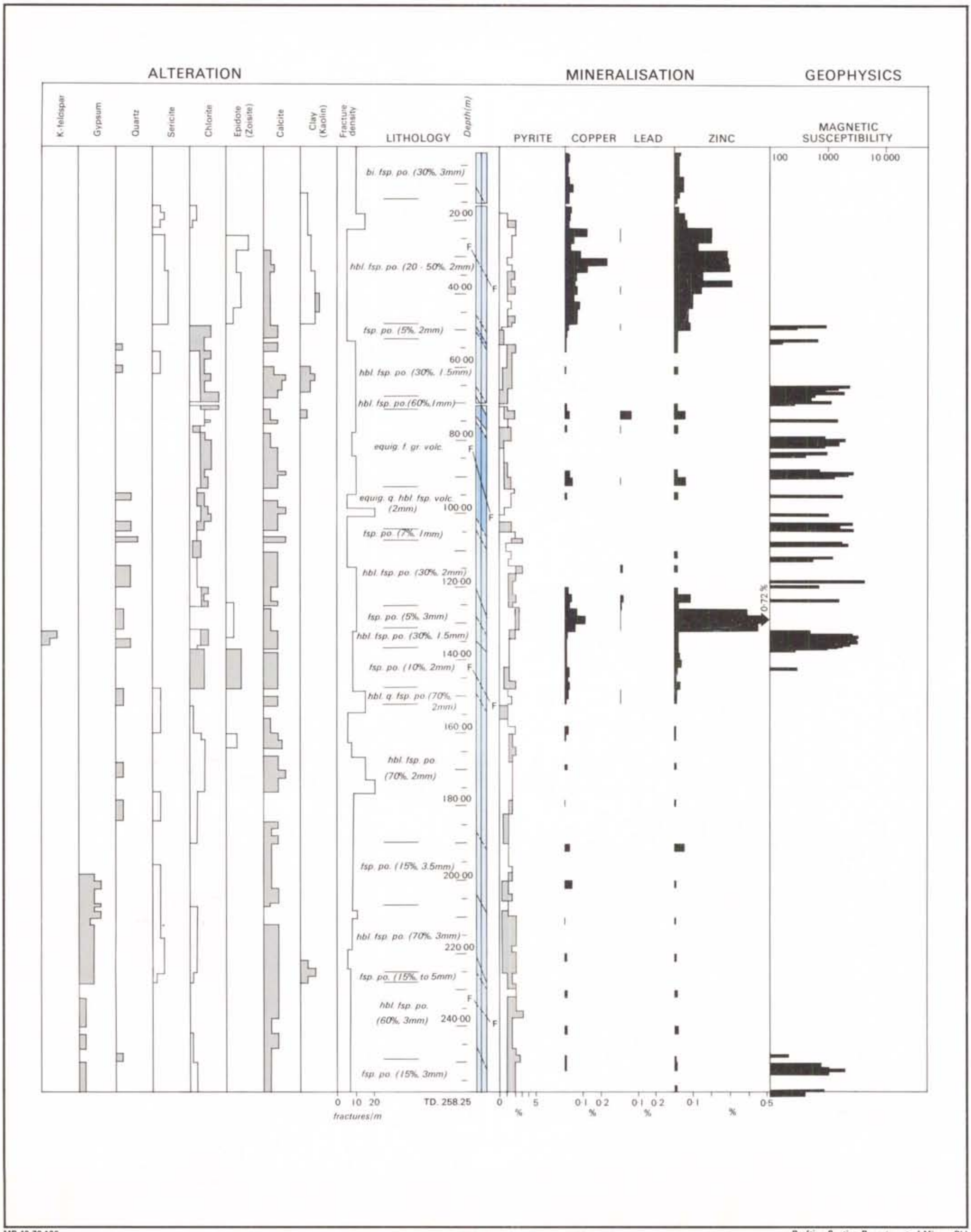

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Figure 18: Drill section NS 2

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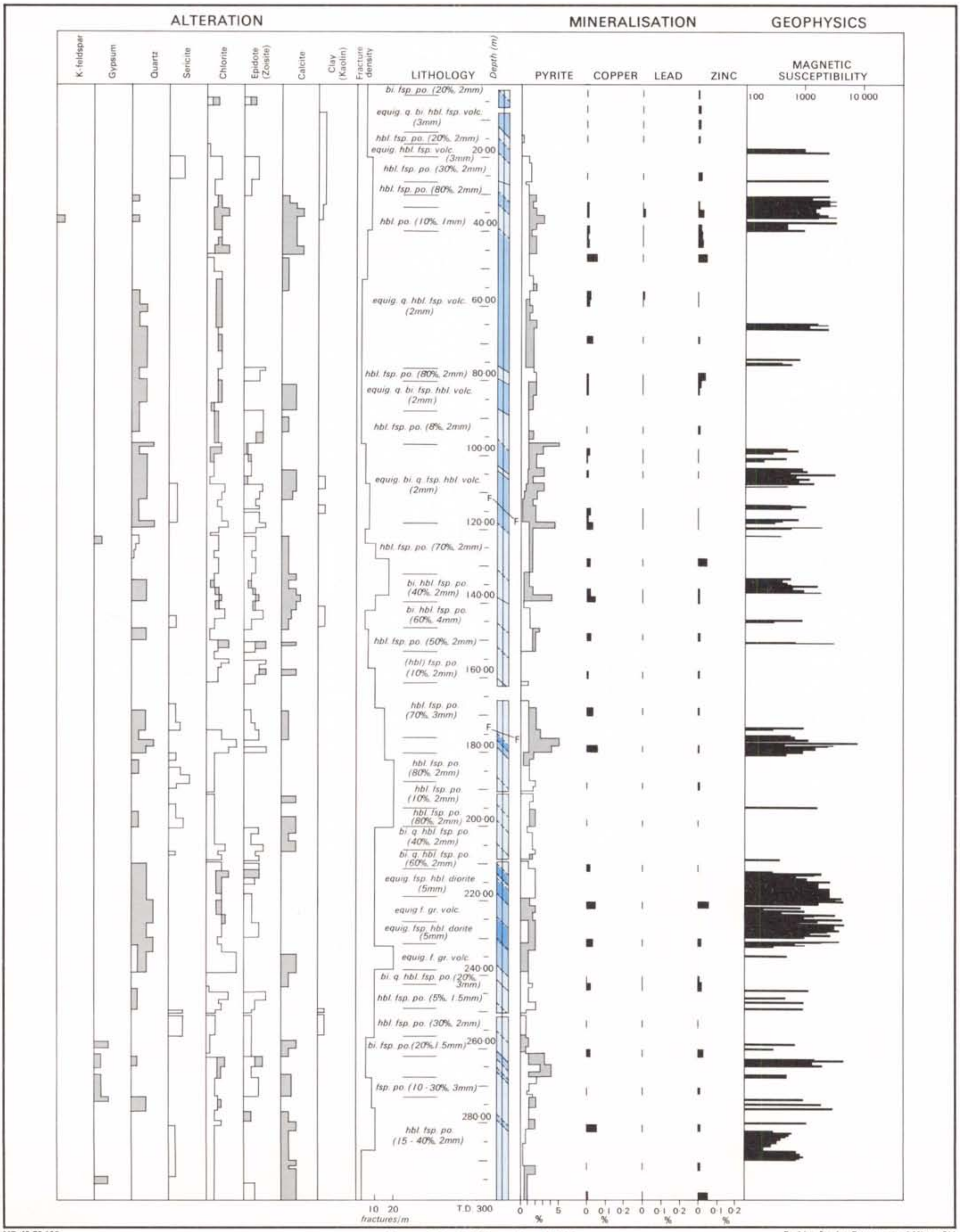

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Figure 19: Drill section NS 3

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No down-the-hole geophysics was carried out on NS 2 or 3 but magnetic susceptibility testing was carried out on the core.

The magnetic susceptibility response is reduced and much deeper than in NS 1. Correlation between reduced magnetic response and pyrite veining was also observed in NS 2, adding substance to the suggestion of pyrite replacement of magnetite. The magnetic response is only associated with pyrite as there is no correlation with copper and zinc concentrations.

DDH NS 3

Grid Reference: 20970 N, 10140 E
Inclined hole (45°) to 300 m bearing 240° magnetic (Fig. 19)

Drillhole NS 3 was designed to test the northern IP/copper anomaly in an area of vertically dipping volcanics.

A wide variety of volcanics from the porphyritic dacite unit were found in this drillhole. Contacts between them are generally at 45° to the core axis (vertical dip) with most lithological units being less than 3 m thick. Several intersections of coarse-grained diorite (xenoliths of Late Carboniferous intrusives) were recorded in the lower portion of the hole.

Only traces of potassic and late stage gypsum alteration are present. Moderate to strong propylitic and weak phyllic alteration products occur throughout. Increased fracture density between 170 and 205 m accompanied by sericitic alteration underlies the main IP/copper surface anomaly.

Pyrite content is relatively uniform throughout and averages 1.5 per cent. Very weak copper and zinc assays were recorded (Table 4); only traces of chalcopyrite were observed.

As indicated in previous discussions, the uniform pyrite content is paralleled on the magnetic susceptibility log by a uniform response. No other magnetic correlations are obvious.

DISCUSSION

Correlation of data

The Mount Vista prospect consists of a central north-northwest trending IP/copper/magnetic anomaly sited on a zone of moderately developed phyllic alteration assemblages. It is surrounded by a lead/zinc halo which is best developed in the western part of the prospect. The entire anomaly occurs within a fault block of north-northwesterly trending and steeply dipping intermediate porphyritic volcanics. A rhyolite dyke swarm of probable Early Cretaceous age parallels the strike of the volcanics and is presumed to be the intrusive host to the alteration and mineralisation.

Within the central anomaly, two peaks of corresponding anomalous IP and copper values form what are termed the northern and southern anomalies (Figs 9, 12, and 13). The spacing between the two IP peaks is closer for the 200 m (n = 2) dipole spacing than it is for the 100 m (n = 1) spacing and may indicate that the two anomalies join at depth. The northern and southern anomalies are separated by an east-northeast trending zone of high resistivity which correlates with an area of weak copper values. This indicates that mineralisation is not continuous along strike.

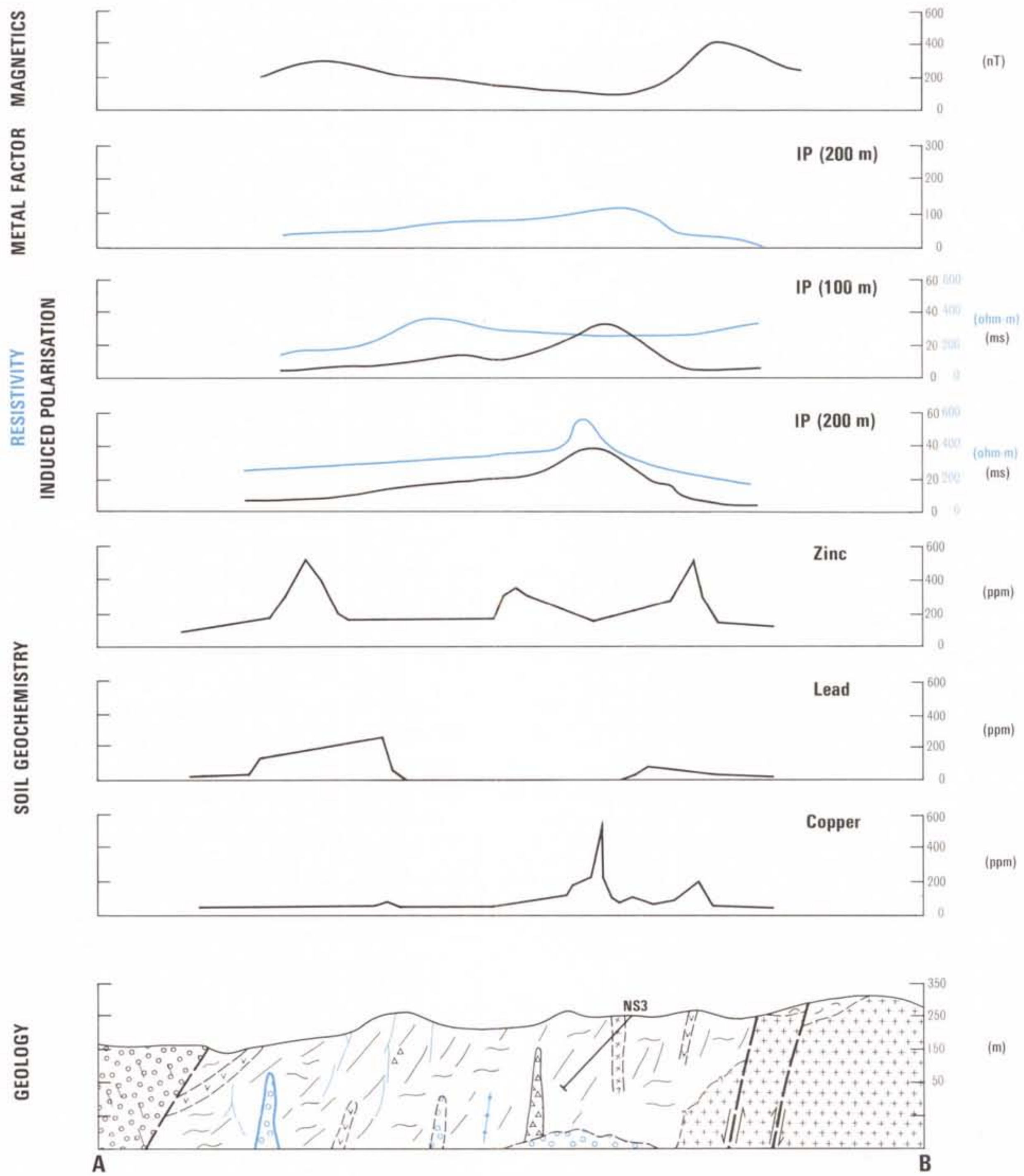
The northern anomaly is coincident with the northern limb of the V-shaped phyllic alteration zone (Fig. 6) in an area of north-northwest trending vertical fissures. Figure 20 represents an east-northeasterly cross-section through the anomaly. The main features to note on this figure are the central copper/IP anomaly with high lead and zinc values on either side. Total magnetic intensity is low over the central area but rises sharply to the east where it is underlain by Late Carboniferous intrusives. Magnetic highs within these intrusives (Figs 4 and 16) are very irregular and probably reflect the numerous basic dykes in the area.

The southern, more significant anomaly occurs at the apex of the V-shaped phyllic alteration zone where the volcanics are intensely sericitised, weathered, and leached. Figure 21 is a cross-section through this anomaly. Like the northern anomaly, the central copper/IP anomaly is well defined, as is the lead halo surrounding it. The zinc halo is ill defined. Unlike the northern anomaly, resistivity is low in the central area and this accounts for the greater metal factor anomaly.

One of the more significant correlations to arise from the geochemical and geophysical surveys is the close correspondence between the IP and copper anomalies (Figs 9, 12, and 13). As the high ambient IP values have been shown to relate mainly to pyrite distribution, it follows that copper sulphides and pyrite mineralisation should be closely associated. An exception to this occurs on the western limb of the phyllic alteration 'V' mentioned earlier (Fig. 6), where low IP values are recorded over a weak to moderate copper anomaly. From drill core studies, a direct relationship between chalcopyrite and pyrite is not apparent and it is suggested that only on a large scale is such a relationship recognisable. This would be due to the restriction placed on the distribution of chalcopyrite by fissures and dykes. The widely spaced sampling interval (50 and 100 m) prevents features such as fissures and dykes being distinguished by copper geochemistry (Fig. 9).

Low IP and high lead and zinc soil geochemical values suggest lower sulphide (mainly pyrite) concentrations outside the central anomalous zone.

An interesting facet of the geology of Mount Vista is a north-south progression of east-northeasterly



For reference to geology and location of cross-section refer to Figure 4. Subsurface geology is idealised

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Figure 20: Cross-section AB — northern anomaly

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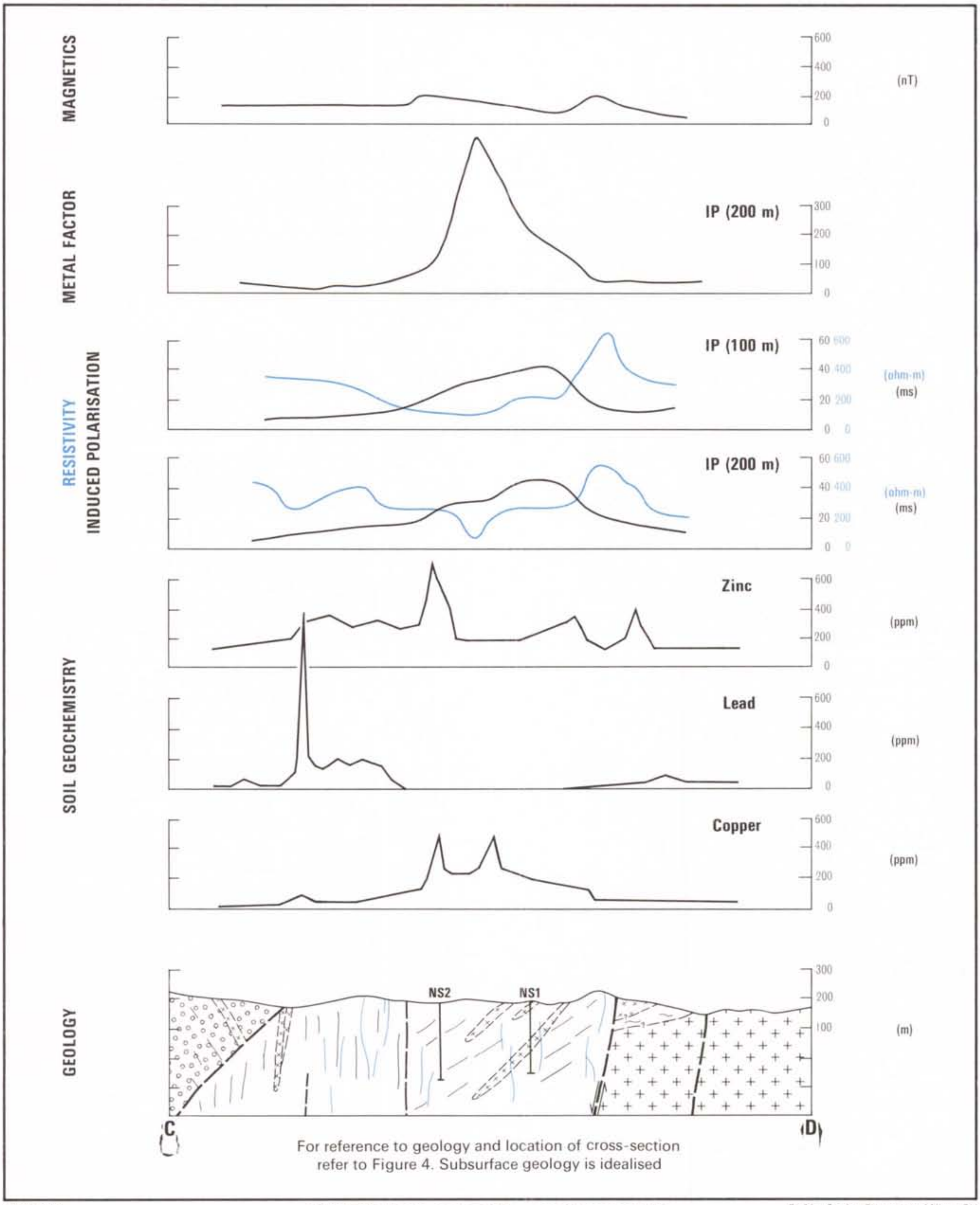

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Figure 21: Cross-section CD — southern anomaly

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trending features. From north to south, adamellite, breccia, rhyolite dykes, and rhyolite stocks comprise a distinct zonation.

Genesis

All available information suggests that the Mount Vista prospect is of the porphyry copper class of mineralisation. Specifically, the presence of potassic alteration, the nature and zonation of sulphides and alteration assemblages, the association with calc-alkaline intrusions, and the overall size of the prospect are excellent indications of genesis. Usage of the term 'porphyry-type copper deposit' instead of the popular term 'porphyry copper' is followed as a consequence of the low copper grade. This term has been defined by Horton (1978a, in press) to describe the Queensland occurrences.

The north-northwest strike of the Lizzie Creek Volcanics has influenced the shape of the Mount Vista anomaly, as well as the orientation of the rhyolite dyke swarm, fractures, and fissures. It has also locally controlled the distribution of alteration products, and to a lesser degree, sulphide mineralisation.

Alteration and sulphide mineralisation centres on the rhyolite dykes. Surface mapping and sampling has shown most dykes, especially those in the centre of the prospect, to be rich in sulphides and to have undergone moderate to intense phyllic alteration. Volcanics surrounding these dykes become less altered with distance from them. Thus, evidence points towards the dykes having been carriers of volatiles for mineralisation and alteration at Mount Vista. The dykes form a unit distinct from, and younger than, the Lizzie Creek Volcanics. This is evident in their relationship to the adamellite intrusives and thus a volcanogenic genesis for alteration and mineralisation (where the rhyolite forms part of the volcanic sequence) is highly improbable.

The moderate to high degree of fracturing, particularly in the central part of the prospect, indicates that the country rocks were effectively shattered, allowing easy access for volatiles. Phillips (1973) envisaged that this happens when the vapour pressure of an ascending water-saturated magma exceeds the confining lithostatic pressure. Retrograde boiling results and the consequent rapid expansion causes intense fracturing. The rapid cooling associated with this leads to porphyritic textures forming in the host intrusives with the associated volatiles percolating into the newly made fractures. Brecciation, particularly in the form of breccia pipes, usually accompanies this process.

Alteration zonation conforms with the classic porphyry copper model (Lowell & Guilbert, 1970) in that potassic alteration occurs in the central part of the prospect with surrounding phyllic and propylitic alteration. The three alteration assemblages are, however, ill defined and strongly overprinted. On a large scale, alteration facies are zoned concentrically but on a smaller scale, alteration type is dependant on lithology and proximity to rhyolite dykes and fissures.

The complexity of volcanic lithologies has prevented detailed study of alteration geochemistry although the limited data available suggest that the alteration system as a whole was essentially isochemical apart from the introduction of water, sulphur, and possible carbon dioxide, as well as base metals. Lead geochemistry (Fig. 10), however, does show evidence of remobilisation of this metal from the inner part of the prospect to the outer part, although it was probably originally introduced.

Introduced water, combined with other non-introduced elements, has facilitated production of phyllic and propylitic alteration minerals. Specifically, water has led to the production of sericite, chlorite, zoisite, and kaolin. Free quartz can be produced as a by-product of the breakdown of feldspar (both plagioclase and K-feldspar) to sericite (Meyer & Hemley, 1967) and then mobilised along fractures to form veins.

The source of calcite is obviously the dacites and andesites as these have high calcium contents (Table 3) contained as plagioclase feldspar. Free calcium is produced by sericitisation (Meyer & Hemley, 1967) and combines with introduced carbon dioxide to form calcite.

Potassic alteration is presumably an isochemical process with K-feldspar and secondary biotite produced from existing K-feldspar (in the volcanic groundmass) and primary biotite. Minor water and carbon dioxide would have to be introduced to form other minerals in this alteration assemblage (Table 1).

Meyer & Hemley (1967) noted that anhydrite, which is commonly produced in the potassic alteration zone, can undergo hydration, mobilisation, and deposition as gypsum. This may have happened at Mount Vista, as gypsum is restricted to veins mostly within the potassic alteration zone. However, anhydrite has not been recognised in drill core or thin section. Alternatively, the gypsum could have been derived from calcite by the action upon it of acidic sulphated waters. The occurrence of gypsum in the middle of calcite veins is evidence for this. The gypsum 'breccia' observed in drill core is more likely to have formed from introduced gypsum rather than to have been replaced from calcite *in situ*. Thus, both mobilisation and replacement processes appear to have been involved in the formation of gypsum veining.

Base metal zonation is similar to that of many porphyry deposits; it is zoned with copper in the centre and lead/zinc towards the periphery of the prospect. The presence of silver with such a base metal combination is not uncommon (Lacy, 1974). A pyrite halo is not evident as the greatest concentrations of pyrite are in the central area (1.5 to 2.0 per cent). Pyrite concentrations become weaker with distance from the centre of the prospect.

Economic potential

The Mount Vista prospect is a sulphide-rich, base metal poor, porphyry-type copper system with an absence of secondary enrichment. Although the prospect could not be said to be conclusively tested by three drillholes, the results were not sufficiently encouraging to warrant further drilling.

Should the price of silver rise sufficiently there may be a possibility of finding economic silver mineralisation in the outer lead/zinc halo, particularly near the fault zone to the southwest. However, silver grades for the central portion of the prospect (Table 4) are not encouraging.

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GEOLOGICAL ENVIRONMENT OF COPPER-MOLYBDENUM MINERALISATION AT MOUNT TURNER, NORTH QUEENSLAND

E.M. BAKER and D.J. HORTON

CONTENTS

SUMMARY

The Mount Turner copper-molybdenum-lead-zinc prospect, 14 km west-northwest of Georgetown, was discovered late in 1975 during the course of joint investigations by the Bureau of Mineral Resources and the Geological Survey of Queensland. It has been the subject of detailed geological, geochemical, and geophysical investigations including a total of 1 300 m of drilling.

Alteration and mineralisation at Mount Turner is associated with probable Late Carboniferous intrusives and associated breccias which intrude a basement of Proterozoic granite and metamorphics.

Rhyolite intrusion, the first phase of igneous activity, occurs as stocks centred in a northerly trending rhyolite dyke swarm. Three types of collapse and intrusive breccias are associated with the stocks. The main phase of alteration and mineralisation accompanied the rhyolite and resulted in a concentric zonation of alteration and mineralisation assemblages. From the centre of the deposit the assemblages are as follows:

1. secondary biotite alteration with disseminated pyrite-chalcopyrite-bornite mineralisation;
2. first phase fissure-controlled sericite-chlorite-kaolinite alteration with associated sulphide veining and disseminated pyrite mineralisation; peripheral alteration lacks silicification, but a zone of silicification of fissures occurs in the inner part of the prospect.

Following the intrusion of rhyolite, two phases of intrusion of microgranodiorite and six types of brecciation (including a quartz-molybdenite breccia) were emplaced to the west and northwest of the rhyolite stocks. The second phase of microgranodiorite was accompanied by intrusive breccia pipes associated with second phase sericite-chlorite-kaolinite alteration and pyrite-chalcopyrite-sphalerite-galena-arsenopyrite mineralisation. Peripheral galena-sphalerite veining, commonly along fissures was the last hydrothermal event at Mount Turner.

The deposit is considered to be of the porphyry copper class. It is compared to the Phyllis May prospect, 16 km to the west, and to porphyry copper deposits of the southwestern United States, which occur in a similar tectonic environment.

INTRODUCTION

The Mount Turner copper-molybdenum-lead-zinc prospect is situated 14 km west-northwest of the township of Georgetown, 280 km southwest of Cairns. Access to the prospect is by way of the Gulf Development Road to the Aspasia mine turnoff, 11 km by sealed road west of Georgetown, and by bulldozed vehicle tracks through the prospect (Fig. 1). During the wet season which lasts from November to April, access to the prospect may be hindered.

Mount Turner is the highest of a group of hills rising to about 60 m above an otherwise flat to gently undulating plain.

HISTORY OF INVESTIGATION

Investigation of the Mount Turner deposit was prompted by the discovery of an extensive area of hydrothermal alteration by geologists of a joint Bureau of Mineral Resources (BMR)-Geological Survey of Queensland (GSQ) regional geological mapping party in September 1975. Encouraging results from preliminary rock chip and drainage geochemical investigations influenced the Queensland Department of Mines to proclaim a reserve (Departmental Area 71D) over the prospect on 13th November 1975. A joint GSQ-BMR program of investigations was than carried out during the 1976 and 1977 field seasons.

Stream sediment and ridge and spur geochemical sampling programs were completed during 1976. These programs effectively delineated the extent of copper, lead, zinc, and molybdenum mineralisation at Mount Turner (Appendix 1). Geophysical investigations were also undertaken at this time; the principal technique being an induced polarisation–resistivity survey using vertical electrical soundings. Gamma-ray spectrometry, total count radiometrics, and total magnetic induction surveys were also conducted. The results of these surveys are summarised in Appendix 2. Geological mapping of the prospect at a scale of 1:10 000 was undertaken by E.M. Baker in conjunction with a program of 11 holes totalling 500 m drilled by the BMR.

In 1977, an additional geophysical survey, together with 800 m of deeper drilling (Appendix 3) was carried out by the GSQ. The deeper drilling was designed to assist the interpretation of geophysical data and to obtain further information on mineralisation.

The Departmental Area was relinquished in February 1978. A brief summary of the entire investigation was published by Baker (1978a) who also prepared a first draft of this report. D.J. Horton supervised the soil geochemical survey and was responsible for finalising this report. Drill logs, petrographic descriptions, and other pertinent data relating to the Mount Turner prospect are recorded in Baker (1978b).

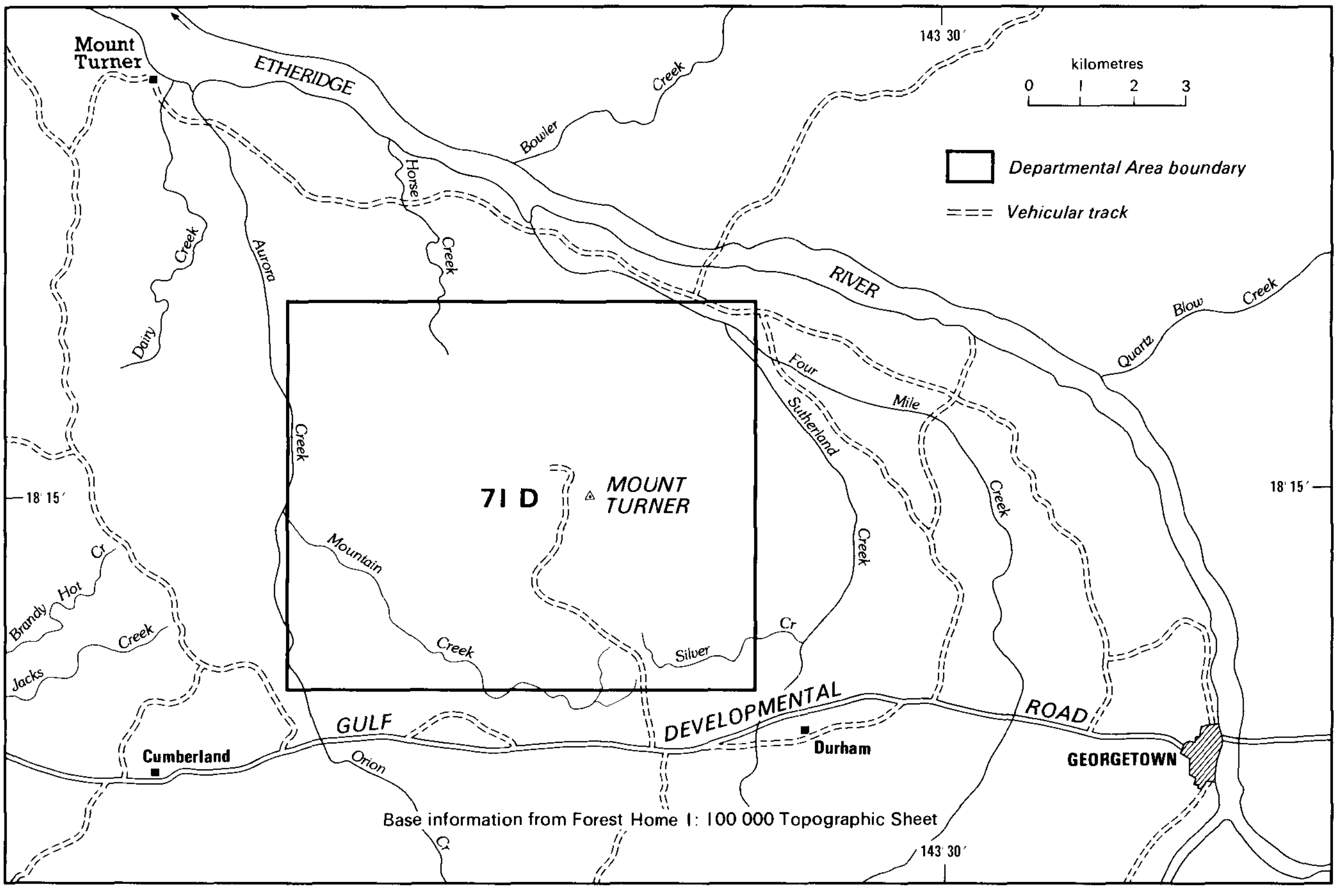

Figure 1: Location map showing Departmental Area 71D

MINING HISTORY

Mining activity in the area has been restricted to small silver-lead mines located on three of a series of northerly trending sulphide veins peripheral to the central hydrothermal alteration zone at Mount Turner. The mines — Aspasia, Cobar line of reef, and Three Musketeers — were worked between 1911 and 1952 (Fig. 2; Table 1). Blackwells uranium prospect described by Walpole & Langron (1955) was probably part of the Three Musketeers line.

The two mines shown in Figure 2 to the north of Mount Turner are the Morning Light and Drummer Hill (Leggo's Lode). Morning Light was mined for gold between 1904 and 1910 (Table 1). Drummer Hill, a low grade gold-lead-zinc prospect in an east-trending fissure system was investigated by Consolidated Mining Industries Ltd in 1972.

No mining companies had investigated the Mount Turner area prior to the discovery of the alteration zone in 1975. The area had been included in Authority to Prospect 649M held by Forsayth Mineral Explorations NL. However, a geochemical survey done for the company by Sampey Exploration Services extended only as far as the southern periphery of the area where there were known silver-lead deposits (Zimmerman, 1970). An arcuate area of lead-zinc anomalies was outlined in this area and Zimmerman suggested it may have represented the outer zone of a porphyry copper system. Although one anomalous copper value, detected just to the north of the lead-zinc zone, appeared to substantiate Zimmerman's interpretation, no follow-up work was undertaken.

GEOLOGY

REGIONAL GEOLOGICAL SETTING

The Mount Turner prospect occurs in middle Proterozoic basement rocks in the northwestern part of the Georgetown Inlier. Lying immediately west of the Palaeozoic to early Mesozoic Tasman Orogenic Zone, the Georgetown Inlier forms part of the Precambrian craton and consists of Proterozoic metamorphics and granites and Palaeozoic volcanics and intrusives.

The middle Proterozoic basement, previously mapped as Etheridge Formation and Forsayth Granite (White, 1962, 1965) has been remapped and subdivided into Robertson River Formation, Delaney Granite, and Aurora Granite (Withnall & others, 1980). The Delaney Granite consists of medium-grained, porphyritic

TABLE 1: RECORDED PRODUCTION FROM MINES IN THE VICINITY OF MOUNT TURNER

	Ore (tonnes)	Gold (kg)	Silver (kg)	Lead (tonnes)	Copper (tonnes)
Aspasia					
1916–29; 1936–37; 1947–52	716.0	1.168	457.064	285.4	0.8
Cobar line of reef (includes Cobar, Cobar South, Cobar Extended, Hamilton, Argent Queen, Silver King, Silver King Amalgamated, Silver Ridge)					
1911–29; 1937; 1947–50	879.5	0.862	447.795	332.2	0.2
Three Musketeers					
1925	65.0	0.003	29.540	25.1	—
Morning Light					
1904–10	498.4	21.219	—	—	—
Drummer Hill (Leggo's lode)	No recorded production				

from Annual Reports of the Department of Mines

muscovite-biotite granite and is the predominant basement rock in the Mount Turner area. The Aurora Granite is a coarse to medium-grained equigranular muscovite-biotite leucogranite. The Robertson River Formation consists of muscovite-biotite-quartz schist and micaceous quartzite (Fig. 2).

Alteration and mineralisation is intimately associated with post-Proterozoic igneous activity, represented at Mount Turner by rhyolite and microgranodiorite which intrude the Precambrian basement. These intrusives are of late Palaeozoic age — probably Carboniferous — as they are petrologically similar to Late Carboniferous intrusives and volcanics near Mount Darcy, 16 km to the west.

LATE PALAEOZOIC IGNEOUS INTRUSIVES

Two late Palaeozoic phases of intrusion have been recognised at Mount Turner. The first phase is rhyolitic and occurs as rhyolite stocks and dykes with associated marginal intrusive and collapse breccias. The rhyolite and associated breccias are centred on two large stocks (the larger with dimensions 2 km x 2 km) in the centre of the prospect, but east of Mount Turner itself (Fig. 2). A predominantly north-south trending rhyolite dyke swarm radiates from these bodies.

The second intrusive phase is microgranodioritic and is represented by numerous small bodies of microgranodiorite, associated collapse breccia, and several breccia pipes. Two phases or 'pulses' of microgranodiorite are recognisable. Both are assigned to the Mount Darcy Microgranodiorite, defined by Mackenzie (1980). The microgranodiorite and associated breccias form a linear, northeast-trending zone across the northern part of the prospect, with the main intrusive activity centred on Mount Turner. The main microgranodiorite stock, with dimensions 1 km by 1 km, is located immediately west of Mount Turner. One small body of microgranodiorite occurs to the south of the prospect within Robertson River Formation (Fig. 2).

Rhyolite

Rhyolite characteristically forms areas of higher relief covered by angular rubble (Pl. 1a). It is a fine-grained light pink to green rock with up to 7 per cent quartz and feldspar phenocrysts. Quartz phenocrysts (1-4 mm; 0-5 per cent) range from euhedral bipyramidal to anhedral. Feldspar inclusions are common. Quartz phenocrysts typically show embayed edges, quartz overgrowths, and inclusion trails especially where no undulose extinction is visible. Feldspar phenocrysts (3-5 mm; 0-2 per cent) are invariably sericitised and in weathered outcrop are usually replaced by exotic limonite. Small biotite grains, where present, are altered to sericite and chlorite; they are not visible in hand specimen. The groundmass consists of quartz and sericite — the high percentage of quartz in many specimens (up to 80 per cent) suggests that the rock has been silicified in places.

Although no fresh feldspar phenocrysts were observed, B.S. Oversby (personal communication) has observed similar rocks elsewhere in the Georgetown district which are of rhyolitic composition. On this basis, it is assumed that the rocks at Mount Turner are rhyolitic.

The rhyolite dykes, which are up to 2 m wide, were emplaced before, or at the same time as, the rhyolite stocks as they do not intrude these bodies (Fig. 2). Many of the dykes have intruded along north-trending fissure zones and cut across the central quartz veins within these fissures. Although the fissures are probably older than the rhyolite stocks, they do show some degree of convergence towards the stocks.

Three types of breccia associated with the rhyolite have been recognised: rhyolite autobreccia, rhyolite pebble breccia, and rhyolite collapse breccia.

Rhyolite autobreccia consists of angular clasts or xenoliths of flow-banded rhyolite generally less than 200 mm in diameter within a rhyolitic matrix of similar

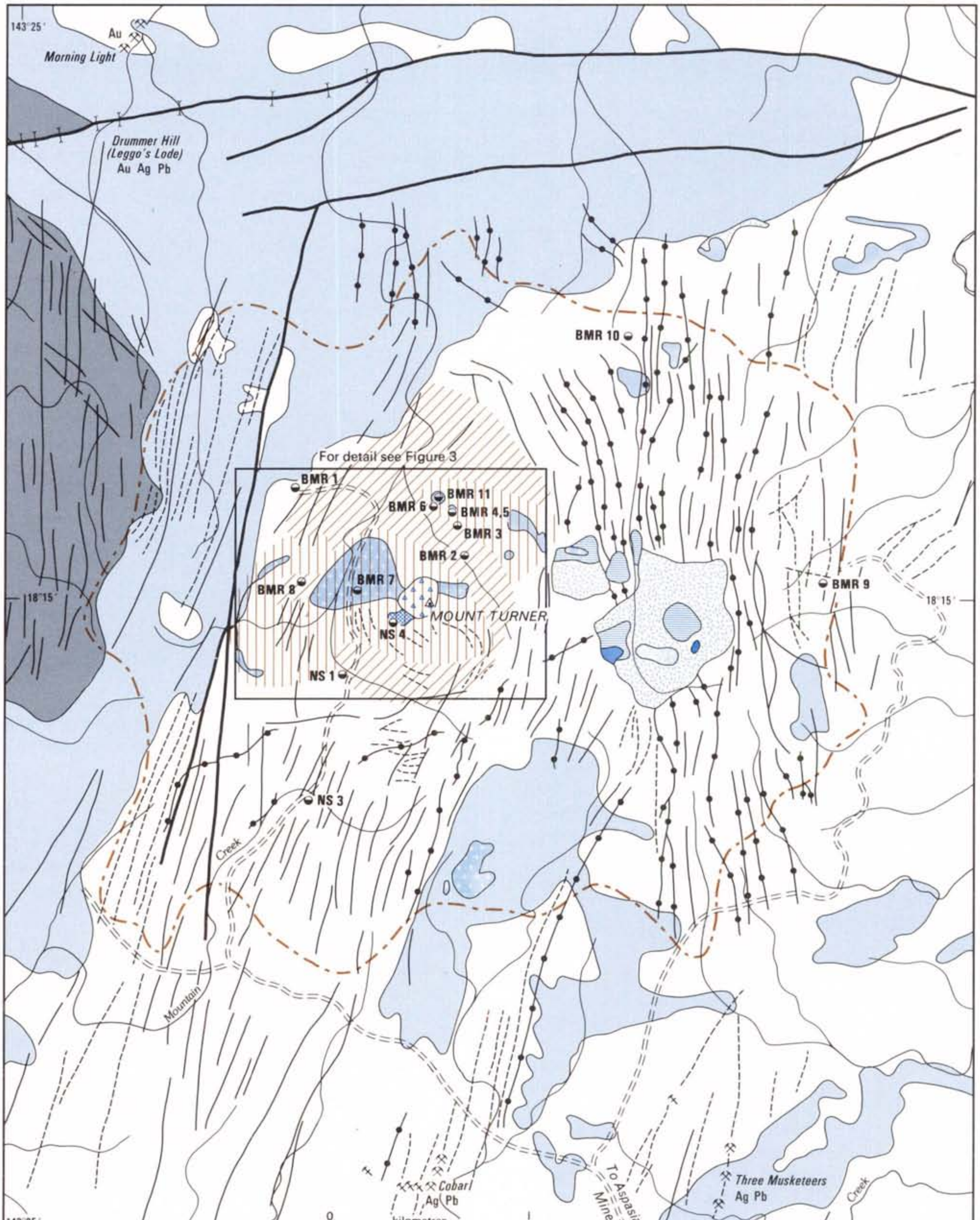

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Figure 2: Geology of the Mount Turner prospect

Drafting Section, Department of Mines, Qld

appearance. Small cavities lined with limonite and less than 20 mm in diameter are present with the matrix. The autobreccia intrudes the eastern rhyolite stock and crops out as a small hill (Fig. 2).

Rhyolite pebble breccia crops out as a small rounded body, which may be a breccia pipe, on a small hill immediately east of the rhyolite autobreccia. It consists of subangular to rounded clasts of non-porphyritic rhyolite less than 400 mm in diameter in a fine-grained matrix of quartz and sericite, presumably derived from rhyolite. Small cavities lined with drusy quartz and less than 20 mm in diameter are present in the matrix.

Rhyolite collapse breccia occurs as subcircular bodies around the margins of the rhyolite stocks. Field mapping suggests it overlies rather than intrudes the rhyolite, which in turn suggests the rhyolite intrusion is domal in form. The nature of the breccia is dependant on the country rock and a distinct change over several metres can be observed where the breccia crosses the contact between rhyolite and Delaney Granite. Within the Delaney Granite, the breccia consists of angular and equigranular clasts of granite averaging 200 mm in diameter within a matrix of quartz and sericite flour. The matrix does not contain cavities and is unmineralised. Within the rhyolite, the breccia is of a more open form and consists entirely of rhyolite (Pl. 1b). Rhyolite clasts are usually tabular in shape and less than 100 mm in diameter. The matrix consists of small angular fragments of rhyolite up to several millimetres in diameter cemented by limonite (after pyrite) and quartz. Cavities between clasts are commonly lined with drusy quartz and limonite after pyrite. In one locality, the contact between the rhyolite and the breccia is sharp and strongly flow banded parallel to the contact. The breccia clasts are tabular and indicate that this breccia is probably of the collapse type (Lacy, 1976).

Mount Darcy Microgranodiorite

Two separate phases of microgranodiorite intrusion have been recognised at Mount Turner. Mapping at Mount Darcy, 20 km west of Mount Turner, revealed at least three phases of intrusion within Mount Darcy Microgranodiorite.

The main body of first phase microgranodiorite is an irregular, elongate, steep-walled intrusion, the margins of which are locally brecciated (Fig. 3). The contacts of the main body truncate rhyolite dykes and areas of tensional breccia. Five hundred metres to the west, the microgranodiorite forms a ring dyke which occupies nearly 160° of arc. The ends of this dyke grade through intrusive breccia into a zone of sericitisation and intense silicification. Numerous small bodies of predominantly second phase microgranodiorite are associated with and intrude second phase intrusive breccia.

When fresh, the microgranodiorite is characterised by phenocrysts of bipyramidal to elliptical quartz, euhedral to anhedral plagioclase, and biotite set in a light to dark grey matrix containing up to 1 per cent disseminated pyrite and chalcopyrite (Pl. 1c). Quartz phenocrysts (1–5 mm; 1–10 per cent) commonly show embayed edges. They are usually strained and fractured and many contain plagioclase and biotite inclusions. Plagioclase phenocrysts (1–10 mm; 3–15 per cent) show distinct normal and oscillatory zoning and contain biotite inclusions. Anorthite content ranges from 30 to 40 per cent. Biotite grains (0.5–2 mm; 1–5 per cent; X = light brown, Y = Z = dark red-brown) are partly chloritised and contain inclusions of zircon. The groundmass is predominantly fine-grained, partly sericitised plagioclase, orthoclase, and quartz. Accessories include epidote, zoned allanite, pyrite, and chalocopyrite. The microgranodiorite alters to form a light grey porphyritic rock consisting of quartz grains in a groundmass of sericite.

At one locality at the margin of the main microgranodiorite intrusion (Fig. 3) a peculiar rock containing contorted quartz-ilmenite veining was observed (Pl. 1d). The veins cut a rock consisting of fine-grained quartz and sericite, and a few quartz phenocrysts. The rock may represent the chilled margin of the microgranodiorite intrusion and the structures may be the result of replacement of flow banding. Alternatively, the peculiar pattern of quartz-ilmenite veining may have resulted from quartz filling shrinkage cracks formed during chemical alteration which involved a volume decrease.

Six different types of brecciation have been recognised in association with the microgranodiorite: tensional breccia, pebble dykes, two phases of intrusive breccia, microgranodiorite collapse breccia, and sulphide breccia.

Tensional breccia occurs in several small localities in the centre of the prospect. It was described by Baker (1978a) as a quartz-molybdenite-pyrite stockwork. The breccia consists of angular fragments of granite cemented *in situ* by quartz-molybdenite veins (Pl. 2a) and grades laterally into generally shallow-dipping, quartz-molybdenite fissure veins. The granite fragments are tabular in shape and up to 0.5 m in diameter. They show little sign of displacement or rotation. The breccia probably formed by shattering of rock in a tensional environment without the introduction of any material other than quartz fill. The breccia and associated quartz-molybdenite fissure veins are cut by the microgranodiorite and in drillhole NS 4 quartz-molybdenite veins are seen to cut a rhyolite dyke. Although field relationships show that the breccia is older than the microgranodiorite, a spatial relationship probably exists between the two (Fig. 3). Quartz-molybdenite veining is usually associated with secondary biotite alteration although in places it is also associated with intense sericitic alteration. Minor pyrite and, less commonly, chalcopyrite occur within the veins. Molybdenite is present as a thin film along fractures and as disseminated grains.

Pebble dykes, consisting predominantly of well-rounded clasts of Delaney Granite from 10 to 200 mm in diameter set in a matrix of fine-grained sericite and quartz (Pl. 2b), are associated with, and distributed immediately southeast of, the main microgranodiorite stock (Fig. 3). The well-rounded nature of the clasts, the dyke-like structure of the breccia, and the fact that it grades into igneous rock, indicate that it is intrusive in nature. Some angular clasts are present, presumably included in the breccia by late stage collapse prior to consolidation. As the pebble dykes grade laterally into unbrecciated micrograonodiorite (Fig. 3), they were probably synchronous with the emplacement of the microgranodiorite.

A first phase of **intrusive breccia** occurs at the contact between microgranodiorite and wall rock. It consists of angular fragments of sericitised Delaney Granite, quartz, and microgranodiorite in a light grey matrix of fine-grained quartz and sericite.

A capping of **microgranodiorite collapse breccia** less than 20 m thick over the main microgranodiorite intrusion forms Mount Turner itself (Pl. 2c). Horizontal slab-like fragments in a matrix of rock flour were observed at the breccia contact (Pl. 2d). The matrix shows a horizontal layering of foliation which is thought to have formed by compaction. The tabular fragments, by virtue of their configuration within the breccia, are considered to have formed by the flaking off of slabs from the walls of a void under the effect of gravity. Elsewhere within the breccia, clasts are angular and equidimensional but do not show alignment. Clasts range in size from several millimetres up to 0.5 m. They are predominantly of altered granite although rhyolite, microgranodiorite, and fragments of tensional breccia are also present. Well-rounded clasts of granite within the collapse breccia were only observed adjacent to the truncated pebble dyke and are presumably clasts recycled from the dyke. Although the fragments have undergone a certain amount of rotation and displacement, no evidence of extensive vertical movement has been recognised. Very few cavities are present as the matrix is essentially compacted rock flour derived from Delaney Granite. At the surface, the breccia is sericitised and unmineralised although fragments of previously mineralised rock are present within it.

A second phase of **intrusive breccia** forms numerous subcircular pipes less than 30 m in diameter in the northern part of the prospect. Drillhole BMR 11 intersected 55 m of one of these pipes without visible change in lithology. The breccia consists of angular clasts of sericitised granite, rhyolite, and microgranodiorite up to 1 m in diameter in a dark grey, sericite-rich matrix containing numerous quartz phenocrysts derived from microgranodiorite. In most of the breccia pipes the clasts and matrix are largely derived from the microgranodiorite, although microgranodiorite is not present at the surface. Cavities are commonly lined with drusy quartz and partly filled with chalcopyrite. Minor disseminated pyrite, chalcopyrite, sphalerite, and molybdenite occur in the matrix. Fine-grained pyrite is present along some fractures. Where sulphides are present in substantial amounts, the rock is termed **sulphide breccia** (Fig. 3).

Dykes of intrusive breccia ranging in thickness from 10 mm to several metres intrude the wall rock adjacent to several of the breccia pipes. Alteration within the breccias ranges from sericite in the centre to sericite-chlorite-epidote at the periphery. The breccia pipes form a narrow belt extending northeast from the centre of the system for 4 km. The composition of the breccias suggests that a large elongate body of microgranodiorite is present in depth. At least two pipes are surrounded by zones of older, steeply inward-dipping, comb-structured quartz veins (Pl. 2c), some of which contain sphalerite gossans. Clasts of microgranodiorite cut by these quartz veins are present within the breccia. Breccia is also intruded by a second phase microgranodiorite, indicating that it was emplaced between the two phases of microgranodiorite. The pipe-like shape of these breccias, the presence of dyke-like extensions, and association with the actual emplacement of microgranodiorite strongly indicate the intrusive nature of these pipes.

LATE PALAEOZOIC INTRUSIVE HISTORY

Rhyolite (Fig. 4)

Late Palaeozoic magmatic and related hydrothermal activity at Mount Turner appears to have been initiated by the presence of a rhyolitic magma chamber at depth. Magmatic pressure exerted by this body produced a set of radial fissures which were then silicified. According to Koide & Bhattacharji (1975), formation of radial structures occurs during the initial phase of intrusion when magma and hydrothermal fluid pressures are relatively low but higher than lithostatic stress. The large area over which these fissures occur suggests that one large, or several small, rhyolite magma chambers were initially present below the system. The magma chamber provided the heat source and hydrothermal fluids which resulted in a first phase of alteration and mineralisation. Rhyolite dykes were then emplaced along many of these fissures while two rhyolite stocks were emplaced to their present level. Following the emplacement of the rhyolite stocks and associated intrusive breccias, collapse breccias formed around the upper margins of the body, probably as a direct result of shrinkage of the magma during consolidation.

Mount Darcy Microgranodiorite (Fig. 5)

A second igneous event commenced with the emplacement of an elongate microgranodioritic magma chamber to the northwest of the centre of rhyolitic activity. Magmatic pressure exerted by this body resulted in the formation of a tensional breccia with associated molybdenum mineralisation. The breccia is thought to have developed as the pressure of the ascending magma formed a series of concentric fracture patterns and zones of brecciation in the rocks above the magma. The voids produced within the fissures and breccia were filled with quartz and molybdenite. Numerous small bodies of microgranodiorite then ascended to their present level of emplacement, pushing rubble ahead of them to form the pebble dykes and first phase of intrusive breccia. A collapse breccia capping then formed over the main body during crystallisation. Norton & Cathles (1973) described a process by which collapse breccia exhibiting similar characteristics to that at Mount Turner could form: a void formed by magmatic waters exsolved at low pressure and shallow depths is trapped for a time beneath the cooled rind in the apical region of the pluton. Eventual piercement of the rind by the hydrous bubble would lead to (1) a drop in pH_2O in the bubble, (2) pinching of the lower portion of the void by the viscous magma, (3) crystallisation of the magma as pH_2O drops, (4) buckling of the void walls and onset of stope caving, (5) continued stope cave filling of the void, and (6) invasion of the breccia by groundwater, not in equilibrium with the fragments.

Following the formation of the collapse breccia, the second phase breccia pipes and microgranodiorite were emplaced. The mechanism envisaged for the formation of these pipes differs from that described by Sillitoe & Sawkins (1971) and Norton & Cathles (1973) as there is a clear association between microgranodiorite emplacement and brecciation at Mount Turner. Prior to the breccia formation, several small microgranodiorite bodies were emplaced. This was followed by a fluctuation in the pressure of the magma chamber resulting in the formation of steeply inward-dipping concentric fractures subsequently filled by the combed quartz veins. Only then was the intrusive breccia emplaced, along with a second pulse of microgranodiorite magma.

ALTERATION AND MINERALISATION

At least two separate phases of hydrothermal alteration and mineralisation have been recognised within the Mount Turner system. The first and most extensive phase consists of three concentric alteration zones centred on, but older than, the main microgranodiorite stock (Fig. 6). An area of central secondary biotite alteration grades outwards into a zone of fissure-controlled sericitisation and silicification associated with disseminated and vein-controlled pyrite. The peripheral zone is defined by fissure-controlled chlorite-sericite-kaolinite-calcite alteration.

The second phase of alteration and mineralisation is characterised by sericite-chlorite-kaolinite alteration associated with disseminated microveinlet pyrite, chalcopyrite, chalcocite, galena, sphalerite, and arsenopyrite. It is confined to small areas recognised only within, and overprinting, the first phase secondary biotite zone. Late stage peripheral galena-sphalerite veining follows this phase of alteration.

Overall, alteration is fissure and fracture controlled rather than pervasive, with an average sulphide content of less than 0.5 per cent. Secondary enrichment is absent.

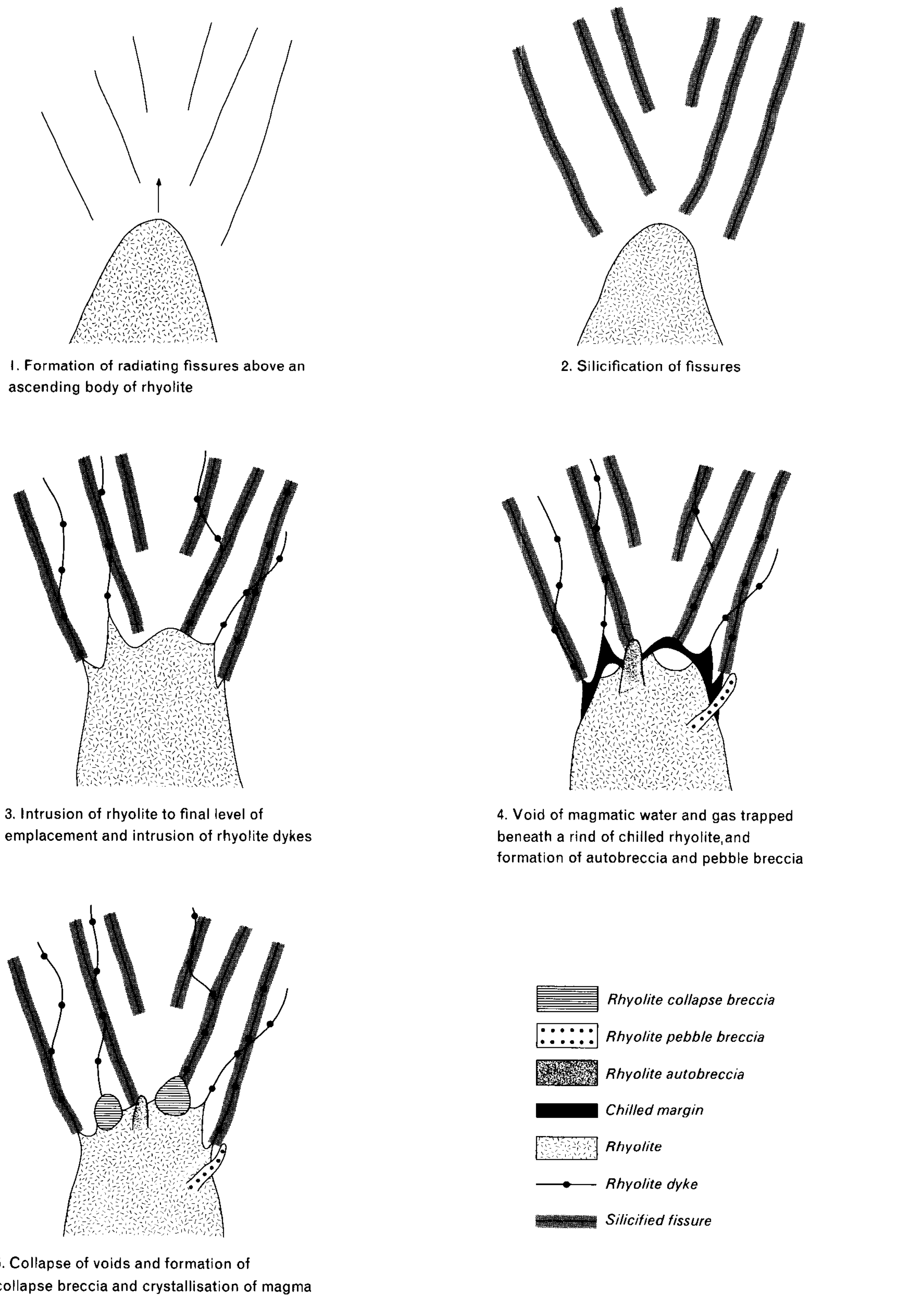
FIRST PHASE

Secondary biotite alteration zone

The central secondary biotite alteration zone forms an area of generally low relief, apart from several small steepsided hills of breccia. In this zone (Fig. 6), weakly altered Delaney Granite differs only slightly in appearance from hand specimens of fresh granite. Plagioclase usually has a light green tint owing to slight sericitisation, biotite is partly recrystallised and dull grey rather than black, and very minor disseminated pyrite, chalcopyrite, and molybdenite are present. More intense alteration is restricted to narrow envelopes generally less than 0.5 m wide surrounding fractures. It is commonly associated with microveinlet and disseminated pyrite, chalcopyrite, molybdenite, and bornite, as well as quartz-molybdenite-pyrite veining. The intensely altered granite is dark grey and all original minerals except quartz are replaced by biotite, sericite, and locally andalusite.

In the less altered rock, orthoclase and microcline are unaltered but turbid due to numerous minute inclusions of quartz, biotite, and plagioclase. With increasing intensity of alteration, they are replaced by secondary biotite and sericite. Replacement commences along cleavage planes and in extreme cases completely pseudomorphs grains. Plagioclase is usually partly replaced by sericite and secondary biotite. However, with more intense alteration, it is pseudomorphed by aggregates of fine-grained sericite, secondary biotite, quartz, and in some places andalusite. Primary biotite (X = light yellow; $Y = Z$ = red-brown) is metastable but commonly recrystallised to fine-grained, sugary-textured secondary biotite (X = light yellow, $Y = Z$ = dark brown). Green chlorite appears to be a transitional phase between the primary and secondary biotite. Microveinlet and disseminated pyrite is associated with the alteration. Coarse-grained ?primary muscovite is stable within this zone.

Secondary biotite alteration associated with



I. Formation of radiating fissures above an ascending body of rhyolite

2. Silicification of fissures

3. Intrusion of rhyolite to final level of emplacement and intrusion of rhyolite dykes

4. Void of magmatic water and gas trapped beneath a rind of chilled rhyolite, and formation of autobreccia and pebble breccia

5. Collapse of voids and formation of collapse breccia and crystallisation of magma

MD 42.80.146

Figure 4: Schematic representation of rhyolite intrusive history

Drafting Section, Department of Mines, Qld

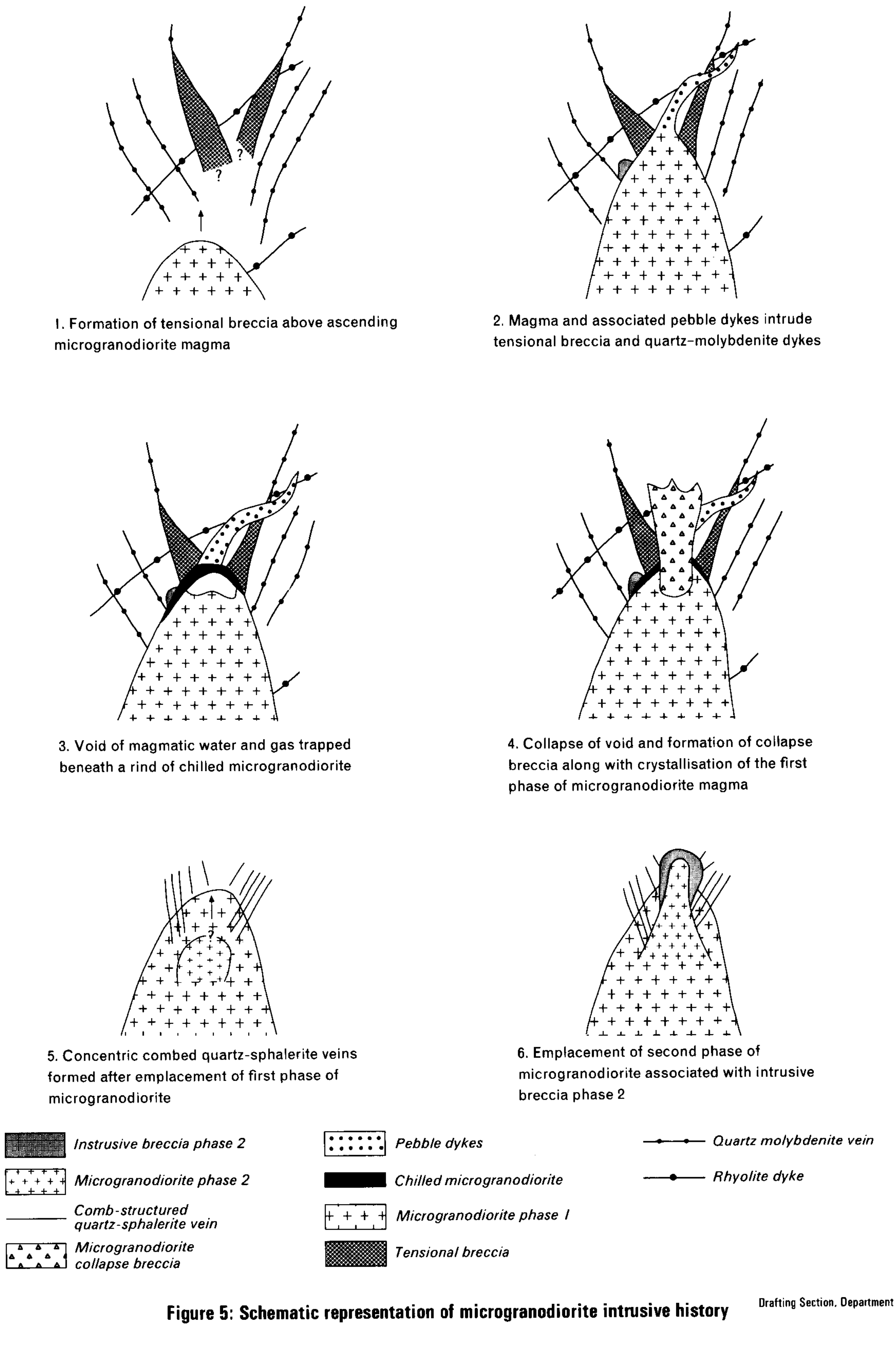


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Figure 5: Schematic representation of microgranodiorite intrusive history

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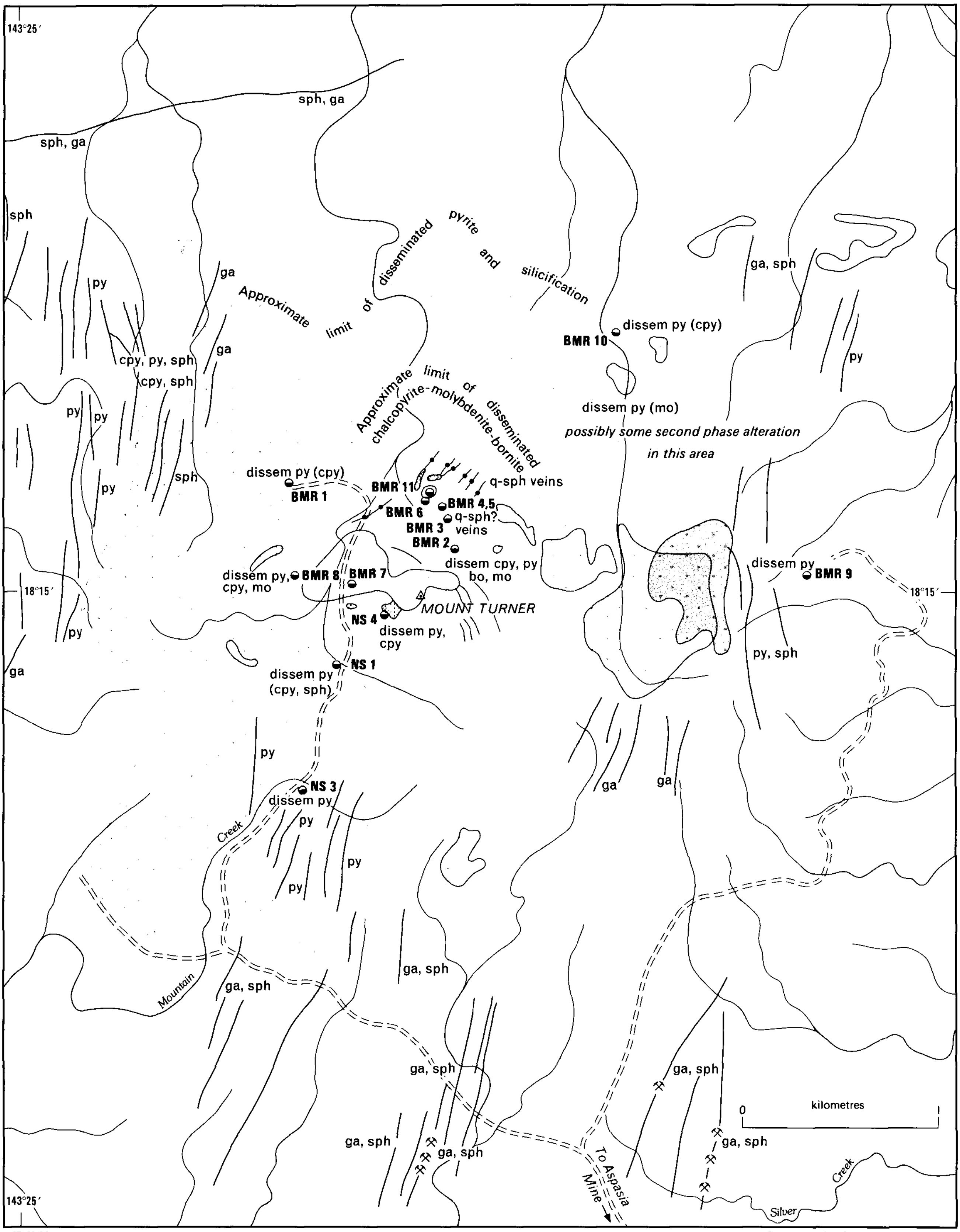
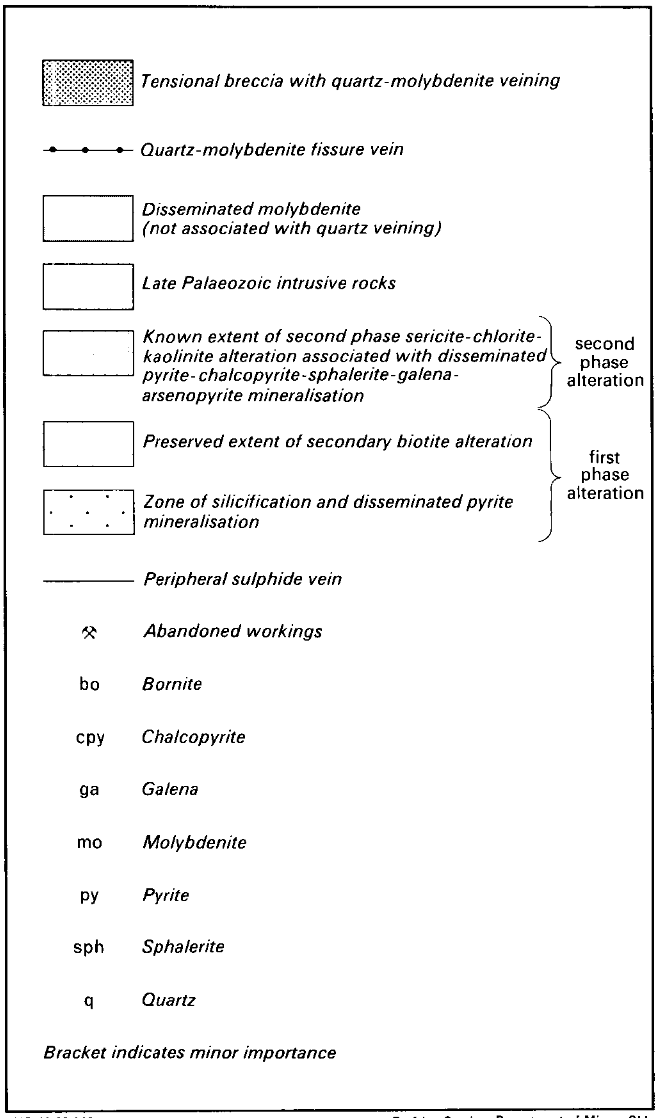


Figure 6: Distribution of alteration and mineralisation at Mount Turner

disseminated-microveinlet pyrite was noted in drillholes BMR 9 and 10 on the eastern and northern extremities of the prospect. Although it is overprinted by sericite-chlorite-kaolinite alteration, it may indicate that the zone of secondary biotite alteration was originally more extensive (Fig. 6). Second phase alteration overprinting and surface weathering presumably obliterates any indications of secondary biotite alteration at the surface in these areas.

Quartz-molybdenite veining, associated with the tensional breccia is almost entirely restricted to the zone of seconary biotite alteration (Fig. 6). Secondary biotite alteration is also associated with the micro-graonodiorite collapse breccia. However, the upper 100 m of this breccia has been affected by later un-mineralised sericite-kaolinite alteration that is probably a product of weathering.



MD 42.80.146 Drafting Section, Department of Mines, Qld

Reference for Figure 6

Zone of silicification

The zone of silicification forms a distinct rim of dissected hills around the central core of secondary biotite alteration. Silicification of the altered rock is responsible for its resistance to weathering and gives this zone its characteristic rugged topography. Alteration and mineralisation is generally fissure controlled and is restricted to an envelope several metres in width both sides of predominantly north-south trending fissures. Probably less than 50 per cent of the total rock within the zone of silicification is actually altered and mineralised. It is cut by minor fracture zones of intense alteration containing micro-veinlet pyrite. Progressively closer to the main fissures, plagioclase becomes increasingly altered to sericite, kaolinite, and minor calcite. Biotite is progressively replaced by chlorite and coarse-grained muscovite. Orthoclase and microcline are at first metastable and turbid owing to very fine-grained inclusions along fractures, then altered to chlorite and sericite along cleavages, and finally completely replaced by sericite and chlorite. Quartz or quartz-sulphide veins up to 400 mm wide are occasionally present at the centre of the fissures (Pl. 3a). The veins are closed and unmineralised in the inner part of the zone of silicification but change to comb-structured quartz-sulphide veins in the outer regions.

The overall sulphide content within the zone of silicification is less than 0.5 per cent.

Peripheral alteration zone

The peripheral alteration zone has no mappable outer limit and lacks a characteristic surface expression. Airphoto lineaments within this zone reflect extensions of silicified fissures. Alteration is generally restricted to an evelope several metres each side of the vertical fissures. Within these envelopes, plagioclase ranges from being partly altered to completely altered to sericite, kaolinite, and calcite. Biotite alters to chlorite and coarse-grained muscovite. Orthoclase (and microcline) is generally metastable although chlorite-sericite does occur along cleavage planes. Associated vein minerals include quartz, calcite, sphalerite, galena, chalcopyrite, and pyrite.

SECOND PHASE

Sericite-chlorite-kaolinite alteration

The second phase of alteration consists of sericite-chlorite-kaolinite alteration similar to the alteration in the zone of silicification. It is only recognisable where it overprints secondary biotite alteration or unaltered granite (Pl. 3b). This type of alteration characteristically forms hills of sericitised granite which are spatially associated with the microgranodiorite and related breccia. The second phase of intrusive breccia and the surrounding wall rock for a distance of up to 50 m are altered under these conditions. Within the wall rock, alteration is associated with steeply inward-dipping comb-structured quartz-sphalerite veins (Fig. 3). Similar alteration is also spatially associated with the main microgranodiorite intrusion, the ring dyke, and the microgranodiorite collapse breccia.

The alteration is predominantly fracture controlled and consists of partial to complete retrogression of feldspar and biotite. Plagioclase is replaced by kaolinite, chlorite, epidote, calcite, and sericite. Orthoclase and microcline are partly or completely replaced by chlorite and sericite, the alteration having commenced along fracture and cleavage planes. Primary and secondary biotite are partly to completely replaced by chlorite, sericite, and epidote.

Within the wall rock and microgranodiorite, vein minerals associated with alteration include quartz, chlorite, calcite, galena, sphalerite, pyrite, arsenopyrite, and chalcopyrite. Microveinlet and disseminated mineralisation adjacent to these veins has a similar mineralogy and is associated with chlorite, kaolinite, and sericite alteration. There appear to be several phases of pyrite, chalcopyrite, and molybdenite mineralisation present, some of which may be related to the earlier secondary biotite alteration. In places chalcopyrite is partly replaced by chalcocite, bornite, and neodigenite. Elsewhere chalcopyrite forms rims around galena. Within the second phase of intrusive breccia, minor disseminated pyrite, chalcopyrite, sphalerite, and molybdenite are present.

The main body of microgranodiorite just west of Mount Turner is pervasively altered under second phase alteration conditions. Minor disseminated-microveinlet pyrite and chalcopyrite are associated with the alteration, which is most intense adjacent to fractures (Pl. 1c). A small body of microgranodiorite immediately south of drillhole BMR 6 is altered in the vicinity of a pipe of second phase intrusive breccia. The altered microgranodiorite and wall rock are cut by vertically dipping comb-structured quartz veins. In surface outcrop, the microgranodiorite collapse breccia and the adjacent tensional breccia in the vicinity of drillhole NS 4 are altered under second phase alteration conditions. In drillhole NS 4, this alteration only extends vertically for 80 m, below which the quartz-molybdenite veining and collapse breccia are associated with secondary biotite alteration. As the tensional breccia and the emplacement and collapse of the main body of microgranodiorite were associated with secondary biotite alteration, the second phase of alteration must have commenced during, or following, the emplacement of the second phase of microgranodiorite and intrusive breccia.

The grade of alteration within the second phase intrusive breccia pipes decreases from the centre of the system outwards. In the centre of the system (drillhole BMR 11), the matrix and clasts of the breccia are completely sericitised. However, within the breccia pipes to the northeast of the system (Fig. 2), alteration is not as intense, and alteration products include kaolinite, epidote, and chlorite.

Late-stage sulphide mineralisation

The quartz and quartz-sulphide veins (mentioned previously) in the zone of silicification, as well as the later rhyolite dykes, are cut by sulphide veins. These late-stage veins can be shown to cut the microgranodiorite within the secondary biotite zone as well as the second phase of intrusive breccia. The microveinlet and disseminated sulphides associated with alteration in the zone of silicification are probably older than this late stage of mineralisation.

The late-stage sulphide veins are up to 1 m wide and are generally present at the centre of fissures on the periphery of the prospect (Fig. 6). The veins within the zone of silicification consist predominantly of pyrite and chlorite with traces of sphalerite and chalcopyrite, and contain fragments of vein quartz, altered granite, and rhyolite. Up to 2 per cent disseminated and microveinlet pyrite and minor chalcopyrite are present within the envelope surrounding the fissures. Towards the south in the peripheral alteration zone, the veins contain predominantly galena and sphalerite. Several of these have been mined for silver and lead (see Mining History). Elsewhere on the periphery of the prospect, the veins contain predominantly pyrite and sphalerite.

GEOCHEMISTRY OF ALTERATION

Short sections of core representing different types of alteration within the system were analysed to determine the chemical changes which occurred during alteration and to indicate the nature of the hydrothermal fluids. A list of whole rock chemical analyses is given in Table 2. There were problems in obtaining representative samples of altered rock which could be compared to their unaltered equivalents. It was decided to try, where possible, to avoid sampling vein mineralisation. However, the inclusion of thin calcite veins could not be avoided, making comparison of Ca, CO_2, SO_3, Fe, Pb, Zn, Mo, and Si between samples difficult to interpret. Only samples of medium-grained porphyritic Delaney Granite with approximately 5 per cent biotite or its altered equivalent were analysed. A comparison between altered and unaltered specimens of microgranodiorite was not attempted as significant inherent chemical differences were likely to be present within the microgranodiorite, which is not lithologically uniform. The limited number of analyses and the presence of scattered vein mineralisation impose severe limitations on any quantitative interpretations based on comparison of different

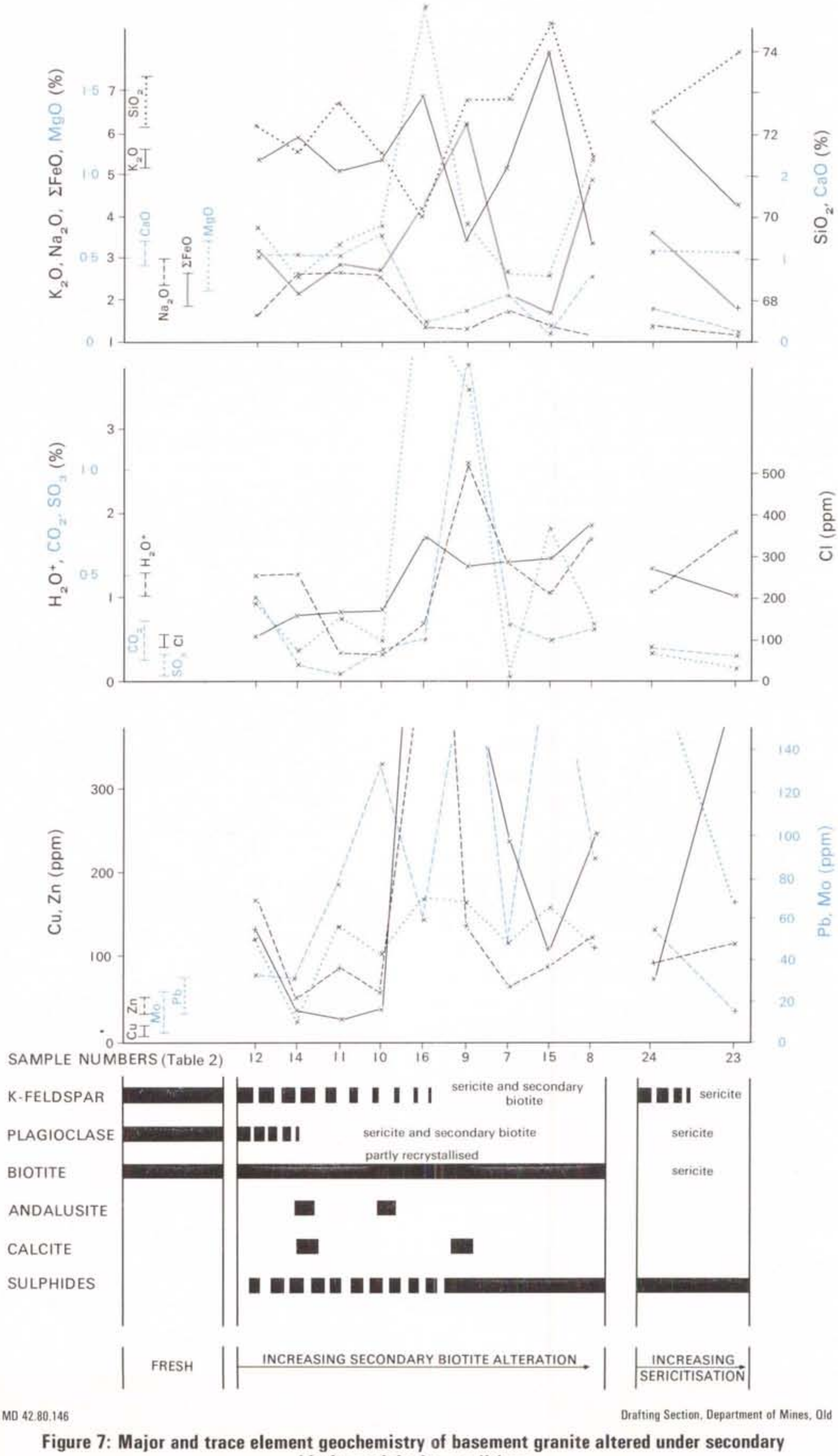


Figure 7: Major and trace element geochemistry of basement granite altered under secondary biotite-andalusite conditions

TABLE 2: WHOLE ROCK ANALYSES

Sample	1*	2*	3	4	5	6	7	8	9	10	11	12	13	14	15
SiO_2 (%)	71.99	56.18	72.2	73.0	73.1	72.8	72.9	71.5	72.9	71.6	72.8	72.2	70.4	71.6	75.1
TiO_2	.29	.84	.24	.22	.22	.25	.26	.22	.20	.24	.23	.29	.32	.31	.21
Al_2O_3	13.95	16.62	14.0	13.7	14.1	14.1	14.1	13.7	11.4	13.8	13.3	13.4	13.1	14.1	12.0
Fe_2O_3	1.84	1.84	.3	.6	.2	.5	.6	.7	1.8	.1	.4	.74	1.00	.30	.5
FeO	2.15	7.75	1.78	1.47	1.80	1.80	1.6	4.3	4.6	2.6	2.5	2.49	2.23	1.80	1.21
MnO	.08	.14	.02	.02	.02	.03	.01	.06	.10	.02	.02	.03	.04	.03	.02
MgO	.56	4.06	.4	.6	.3	.4	.4	1.1	.7	.7	.6	.7	.8	.4	.4
CaO	.11	1.70	1.1	.9	1.2	1.1	.6	.8	.4	1.3	1.1	1.1	1.3	1.0	.1
Na_2O	.29	.28	2.5	2.5	2.4	2.4	1.8	1.1	.4	2.6	2.7	1.5	1.1	2.6	.4
K_2O	6.45	5.86	5.3	5.3	5.3	5.3	5.2	3.4	3.5	5.4	5.1	5.4	5.5	5.9	8.1
SO_3	—	—	.09	.12	.12	.07	.03	.28	1.4	.19	.31	.39	.58	.15	—
H_2O^-	.19	.34	.03	.04	.09	.06	.55	.51	.20	.36	.37	.3	.5	.3	.09
H_2O^+	1.57	2.60	1.0	1.0	1.2	.9	1.48	1.82	2.66	.38	.33	1.3	2.7	1.3	1.0
P_2O_5	.08	.74	.13	.12	.10	.11	.09	.13	.10	.28	.17	.08	.08	.11	.10
CO_2	.05	.05	.2	.2	.2	.3	.28	.26	1.58	.16	.03	.4	.4	.08	.2
Total	99.60	99.00	99.29	99.79	100.35	100.12	99.90	99.88	101.94	99.73	99.96	100.31	100.05	99.98	99.43
Cu (ppm)	95	70	30	16	26	14	238	242	450	38	22	130	69	37	104
Pb	28	5	38	41	42	40	45	47	65	40	56	260	49	36	62
Zn	50	290	37	39	40	37	65	128	137	54	71	140	231	48	88
Mo	4	4	5	5	5	5	45	87	1 100	134	75	31	51	31	15
Au	$<$.005	$<$.005	—	—	—	—	—	—	1	—	—	—	—	—	—
Ag	1	1	—	—	—	—	—	—	1	—	—	—	—	—	—
Cl	—	—	92	97	103	89	283	379	273	172	166	104	90	170	288

Analyses by Government Chemical Laboratory, Brisbane except * by AMDEL
Petrographic descriptions have been included in Baker (1978b)

Mount Turner

1. Delaney Granite, Drillhole BMR 10 84.90 m (Assay No. 217/77)
2. Delaney Granite, Drillhole BMR 10 51.00 m (Assay No. 218/77)
3. Delaney Granite (slight sericite-chlorite-kaolinite alteration), Drillhole NS 3 162.26-162.62 m (Assay No. 1905/77)
4. Delaney Granite, Drillhole NS 3 164.59-164.92 m (Assay No. 1906/77)
5. Delaney Granite, Drillhole NS 3 165.51-166.00 m (Assay No. 1908/77)
6. Delaney Granite, Drillhole NS 3 182.30-183.00 m (Assay No. 1909/77)
7. Delaney Granite (secondary biotite alteration), Drillhole BMR 8 20.00 m (Assay No. 113/77)
8. Delaney Granite (secondary biotite alteration), Drillhole BMR 8 52.25 m (Assay No. 114/77)
9. Delaney Granite (secondary biotite alteration), Drillhole BMR 8 72.20 m (Assay No. 116/77)
10. Delaney Granite (secondary biotite alteration), Drillhole BMR 2 70.20 m (Assay No. 121/77)
11. Delaney Granite (secondary biotite alteration), Drillhole BMR 2 70.41 m (Assay No. 122/77)
12. Delaney Granite (secondary biotite alteration), Drillhole NS 1 64.40-64.57 m (Assay No. 1625/77)
13. Delaney Granite (secondary biotite alteration), Drillhole NS 2 64.94-65.58 m (Assay No. 1626/77)
14. Delaney Granite (secondary biotite alteration), Drillhole NS 1 89.86-89.90 m (Assay No. 1629/77)
15. Delaney Granite (secondary biotite alteration), Drillhole NS 4 147.00-147.36 m (Assay No. 1911/77)

samples. Fresh or only weakly altered Delaney Granite is represented by samples 3, 4, 5, and 6 in Figures 7, 8, and 9.

Cl, CO_2, SO_3, and H_2O

Comparison of the above figures indicates that more Cl, CO_2, and possibly SO_3 were added to the zone of secondary biotite alteration than to the zone of silicification during the first phase of alteration, and that these elements were actually removed from the wall rocks during the second phase of alteration. The amount of water (H_2O^+) added to the wall rock increases with increasing intensity of alteration everywhere in the system.

Na_2O, CaO, and K_2O

CaO and Na_2O become increasingly depleted with increasing intensity of alteration under all types of alteration conditions. This decrease in CaO and Na_2O is accompanied by a corresponding increase in H_2O^+. The depletion of sodium and calcium results from the breakdown of plagioclase to sericite and kaolinite (Equations 1 and 2). Calcite is probably produced as a result of such alteration (Equation 3) and removed from the alteration area.

Equation 1

$$\underbrace{.75Na_2CaAl_4Si_8O_{24}}_{\text{andesine}} + 2H^+ + K^+ = \underbrace{KAl_3Si_3O_{10}(OH)_2}_{\text{sericite}} + 1.5\,Na^+ + .75Ca^{++} + \underbrace{3SiO_2}_{\text{quartz}}$$

Equation 2

$$\underbrace{Na_2CaAl_4Si_8O_{24}}_{\text{andesine}} + 4H^+ + 2H_2O = \underbrace{2Al_2Si_2O_5(OH)_4}_{\text{kaolinite}} + 4SiO_2 + 2Na^+ + Ca^{++}$$

Equation 3

$$\underbrace{.75Na_2CaAl_4Si_8O_{24}}_{\text{andesine}} + 1.25H^+ + K^+ + .75HCO_3^- = \underbrace{KAl_3Si_3O_{10}(OH)_2}_{\text{sericite}} + 1.5Na^+ + \underbrace{.75CaCO_3}_{\text{calcite}} + \underbrace{3SiO_2}_{\text{quartz}}$$

after Hemley & Jones (1964)

16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
70.0	72.9	71.6	68.2	70.6	72.4	71.4	76.1	72.6	67.1	67.3	67.4	68.0	66.4	68.5	70.1
.34	.30	.27	.29	.34	.27	.26	.21	.19	.42	.41	.39	.41	.5	.5	.46
12.0	13.5	12.9	16.3	14.9	14.1	14.5	12.5	13.5	14.2	14.0	13.6	14.0	16.1	15.2	15.3
1.3	.79	1.00	1.56	.54	.31	1.3	1.2	.5	.3	.7	1.0	.8	1.6	.7	.17
3.09	2.53	6.10	4.18	2.50	2.06	1.47	.64	3.2	4.1	4.2	4.1	4.2	2.7	2.6	2.7
.07	.03	.04	.16	.05	.02	.01	.01	.05	.11	.09	.07	.05	.04	.01	.02
2.2	.8	.7	.6	.5	.4	.5	.6	.6	1.5	1.3	1.7	1.3	1.6	1.0	.9
.2	.1	.1	.1	.4	1.0	.3	.1	.4	1.2	1.5	1.7	1.6	2.9	2.9	2.9
.4	.5	.2	.1	2.7	3.0	.8	.3	.6	1.9	2.8	1.4	1.8	3.0	2.9	3.1
7.0	5.9	3.4	4.5	5.6	5.2	5.0	4.4	6.5	4.4	3.7	4.6	5.0	2.8	3.6	3.1
—	.36	.14	.33	.08	.04	—	.05	.13	.13	.04	.04	.14	.10	.08	.03
.12	.2	.5	.2	.3	.2	.04	.02	.30	1.34	.83	1.37	.79	1.2	1.1	.6
.7	1.8	3.1	2.7	1.5	1.3	2.2	1.8	1.12	2.55	2.15	1.84	1.02	.16	.10	.05
.16	.09	.07	.15	.11	.10	.11	.10	.11	.11	.11	.11	.12	.09	.14	.11
.2	.1	.02	.16	.12	.10	.4	.1	.15	.73	.75	.38	.07	.4	.2	.2
97.78	99.90	100.14	99.53	100.24	100.50	98.29	98.13	99.95	100.09	99.88	99.70	99.30	99.59	99.53	99.74
770	118	500	70	59	14	174	1 360	76	890	17	18	129	10	182	18
66	38	20	270	40	49	12	10	177	10	25	22	39	16	19	22
1 550	76	60	450	101	48	37	123	93	108	79	71	68	46	53	41
58	47	19	11	24	26	5	12	55	57	63	53	68	5	5	5
—	—	—	—	—	—	—	—	1	1	—	—	—	—	—	—
—	—	—	—	—	—	—	—	<1	<1	—	—	—	—	—	—
365	99	82	51	105	118	79	195	256	51	69	56	65	—	—	—

16. Delaney Granite (secondary biotite alteration), Drillhole NS 4 154.60-155.32 m (Assay No. 1912/77)
17. Delaney Granite (secondary biotite alteration overprinted by sericite-chlorite alteration), Drillhole NS 1 64.44-65.06 m (Assay No. 1627/77)
18. Delaney Granite (sericite-chlorite alteration), Drillhole NS 1 77.36-77.52 m (Assay No. 1628/77)
19. *Delaney Granite (sericite-chlorite-kaolinite alteration)*, Drillhole NS 2 50.50-50.77 m (Assay No. 1630/77)
20. Delaney Granite (sericite-chlorite-kaolinite alteration), Drillhole NS 2 51.20-51.44 m (Assay No. 1631/77)
21. Delaney Granite (sericite-chlorite-kaolinite alteration), Drillhole NS 2 77.30-77.69 m (Assay No. 1632/77)
22. Delaney Granite (sericite alteration), Drillhole NS 3 164.98-165.22 m (Assay No. 1907/77)
23. Delaney Granite (sericite alteration), Drillhole NS 4 145.95-146.42 m (Assay No. 1910/77)
24. Delaney Granite (sericite alteration), Drillhole BMR 8 71.30 m (Assay No. 115/77)
25. Mount Darcy Microgranodiorite, Drillhole BMR 7 14.93-15.17 m (Assay No. 117/77)
26. Mount Darcy Microgranodiorite, Drillhole BMR 7 35.00 m (Assay No. 118/77)
27. Mount Darcy Microgranodiorite, Drillhole BMR 7 18.30 m (Assay No. 119/77)
28. Mount Darcy Microgranodiorite, Drillhole BMR 7 41.90 m (Assay No. 120/77)
29. Mount Darcy Microgranodiorite, location unknown (Assay No. 1964/77)

Mount Darcy

30. Mount Darcy Microgranodiorite, location unknown (Assay No. 1962/77)
31. Mount Darcy Microgranodiorite, location unknown (Assay No. 1963/77)

The potassium required for sericitisation may possibly have been produced by the chloritisation of biotite (Equation 4) and for more intense alteration from the sericitisation of orthoclase and microcline (Equation 5).

Equation 4

$$2K(Mg,Fe)_3(AlSi_3)_{10}(OH)_2 + 4H^+$$
biotite
$$= Al(Mg,Fe)_5AlSi_3O_{10}(OH)_8 + (Mg,Fe)^{++} + 2K^+ +$$
chlorite
$$3SiO_2$$

after Meyer & Hemley (1967)

Equation 5

$$1.5KAlSi_3O_8 + H^+ = .5KAl_3Si_3O_{10}(OH)_2 + SiO_2 + K^+$$
K-feldspar sericite quartz

after Hemley & Jones (1964)

An overall slight loss of potassium is apparent in all alteration types except secondary biotite alteration. K_2O values in this zone are too erratic for meaningful interpretation.

SiO_2

Silica is removed from the wall rocks within the zone of silicification (Fig. 8). The silicification of the central zone of the fissures probably results from the migration of silica released during sericitisation from the sericite-chlorite-kaolinite alteration envelope into the centre of the fissure.

Total Fe, Cu, Pb, Zn, and Mo

Total iron values are generally erratic, although in the zone of silicification (Fig. 8) an increase in total iron is associated with increasing alteration intensity. Presumably this iron is present as sulphide and would account for high values in altered specimens. Copper, lead, zinc, and molybdenum values are generally erratic except for the second phase alteration (Fig. 9) where a decrease is observed with increasing alteration

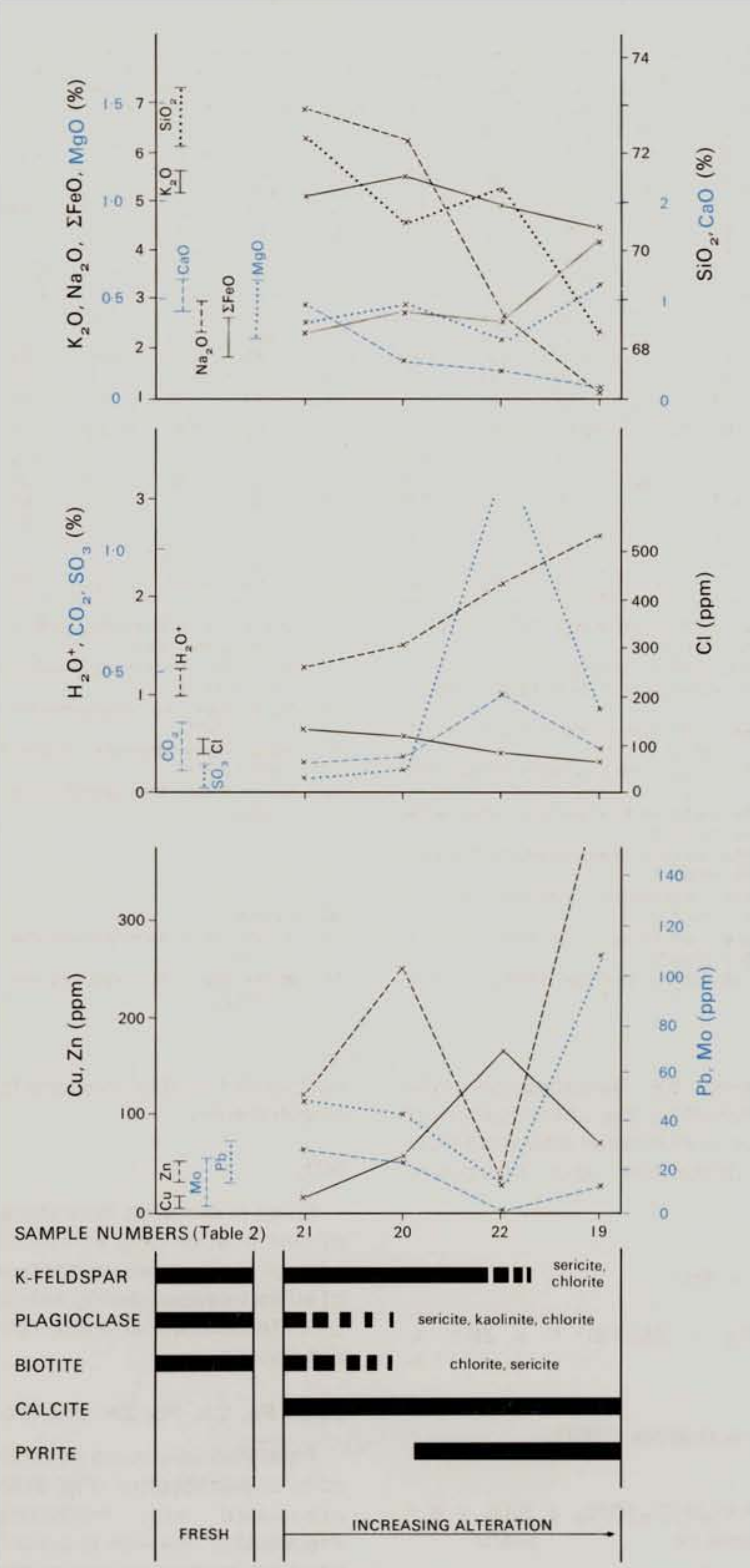


Figure 8: Major and trace element geochemistry of basement granite altered under first phase sericite-chlorite-kaolinite conditions

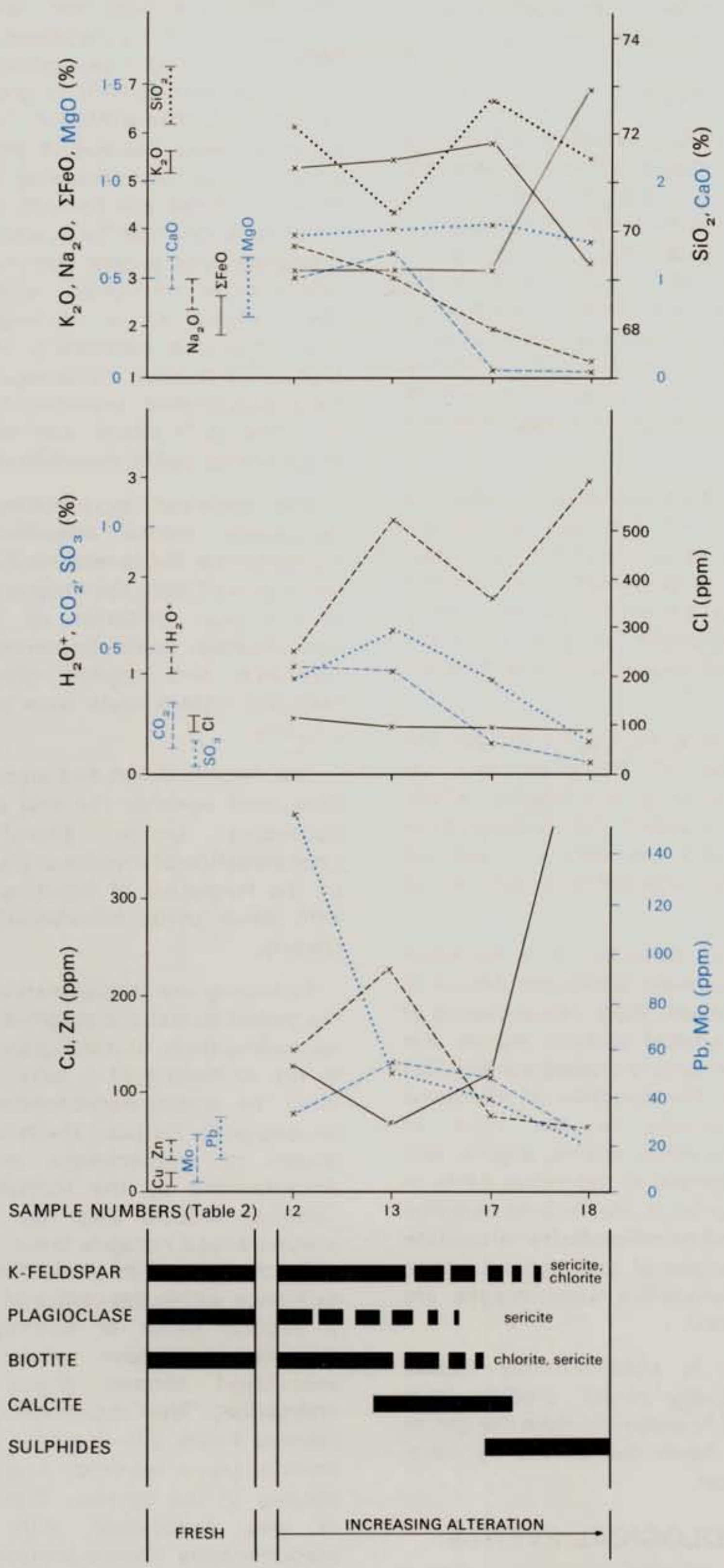


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Figure 9: Major and trace element geochemistry of basement granite altered under second phase retrogressive sericite-chlorite-kaolinite conditions

intensity for each element except copper, which increases. Molybdenum may have been leached out of the zone of silicification during alteration (Fig. 8).

DISCUSSION

According to Burnham (1967), experimental results indicate that the first hydrothermal fluids to separate from a felsic magma will be greately enriched in CO_2 and Cl relative to later separated fluids. The cooling of these chloride-bearing hydrothermal solutions in contact with the wall rock will initially result in the replacement of plagioclase by K-feldspar and biotite. Occasionally, quartz and molybdenite will be deposited as well. Upon further cooling, the fluid will enter the stability field of muscovite, and plagioclase will be replaced by sericite and other base metal sulphides will be deposited.

The chemical and field data available confirm this interpretation in so far as Cl and CO_2 values are enriched in the core of the system and the secondary biotite alteration is accompanied by quartz-molybdenite veining. Disseminated bornite, chalcopyrite, pyrite, and molybdenite are present in the zone of silicification and associated with sericitisation of feldspars and biotite.

The leaching of Cl, CO_2, total Fe, Cu, Pb, Zn, and Mo during the second phase of alteration may be associated with the deposition of late-stage sulphide veins on the periphery of the system. This is conjectural as the relationship between the second phase of alteration and the late-stage sulphide mineralisation is not accurately known.

Secondary biotite-sericite-?chlorite is a common mineral assemblage of potassic alteration (Meyer & Hemley, 1967; Lowell & Guilbert, 1970). The presence of andalusite in intensely altered granite within the secondary biotite alteration zone is probably a function of contact metamorphism. The zonation of alteration assemblages around fissures in the zone of silicification means that the terms phyllic, argillic, and propylitic can be applied locally to individual parts of the zonation. The terms argillic or phyllic best describe the quartz-sericite-kaolinite-chlorite-calcite alteration in this zone. Both the peripheral and second phase sericite-kaolinite-chlorite alteration assemblages are similar to propylitic alteration.

In summary, alteration is predominantly fissure controlled and concentrically zoned, grading from potassic to argillic (phyllic) to propylitic from the centre of the deposit. This has been overprinted by retrogressive propylitic alteration.

SUMMARY OF GEOLOGICAL EVENTS

The Mount Turner hydrothermal system was initiated by the presence of an ascending 'wet' rhyolitic magma (Fig. 10). At a critical depth in the crust, where confining lithostatic pressure was less than the combined magmatic and fluid pressures, fracturing and fissuring of the enclosing rocks occurred. This was probably contemporaneous with, or occurred slightly later than secondary biotite alteration. The predominant northerly trend of these fissures is probably the result of the anisotropy of the enclosing rocks. The formation of these fractures and fissures enhanced the movement of the hydrothermal fluids within the system. Peripheral propylitic and argillic (phyllic) alteration, including silicification, occurred within and adjacent to the fissures as a consequence. At this stage, the influences controlling the potassic (secondary biotite) alteration withdrew and overprinting by fissure-controlled sericite-chlorite-kaolinite alteration occurred, with which was associated disseminated-microveinlet pyrite mineralisation.

The increase in chlorine associated with the secondary biotite alteration suggests that the hydrothermal fluids responsible for this alteration zone were derived from the magma. Outside this zone there is no clear evidence as to the source of the hydrothermal fluids responsible for the formation of propylitic and argillic (phyllic) alteration types. Meteoric waters could have been involved, but this is doubtful.

The rhyolite dykes and stocks were intruded to their final level towards the end of the inward retreat of secondary biotite alteration conditions. The crystallisation of rhyolite at this level was accompanied by the formation of intrusive and collapse breccias, with minor pyrite mineralisation within the collapse breccia.

Following the crystallisation of the rhyolite magma, the hydrothermal and magmatic pressure exerted by an ascending body of microgranodiorite magma resulted in the formation of a tensional breccia which was filled by quartz-molybdenite veining. The magma subsequently intruded the tensional breccia. The final stages of emplacement and crystallisation were accompanied by the formation of two phases of intrusive breccia and the formation of relatively unmineralised collapse breccia.

Secondary biotite alteration conditions were still in existence within the centre of the system at this stage. A second pulse of microgranodiorite magmatism produced numerous intrusive breccia pipes and associated second phase alteration and mineralisation. The introduction of late-stage hydrothermal fluids into the core of the system by these breccia pipes resulted in or accompanied the final cooling of the system. This event was followed by or was associated with the emplacement of predominantly fissure-controlled sulphide veins. The metals for these veins could have been derived from the country rocks by the retrogressive second phase

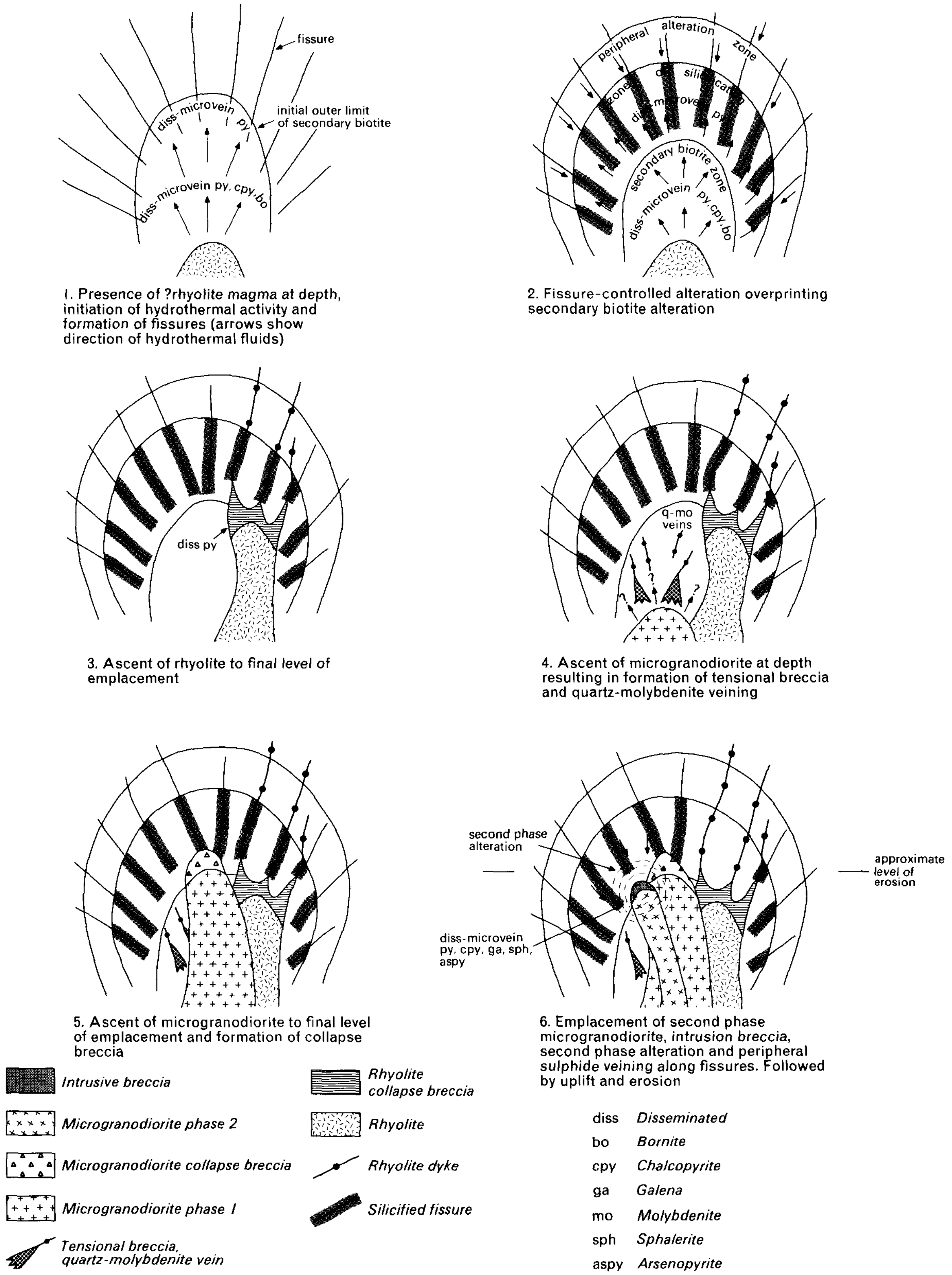

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Figure 10: Diagrammatic representation of geological events at Mount Turner

alteration as the country rocks appear leached. The sulphide in the veins ranges from predominantly pyrite in the centre of the system to galena and sphalerite towards the periphery. The emplacement of sulphide veins was the last hydrothermal event within the Mount Turner system.

CONCLUSIONS

The following criteria point to the conclusion that the Mount Turner hydrothermal system belongs to the porphyry copper class of deposit as defined by Lowell & Guilbert (1970):

(a) the overall large size of the deposit;
(b) the association of alteration and mineralisation with porphyritic calc-alkaline felsic intrusives;
(c) the concentric alteration zonation of potassic, argillic (phyllic), and propylitic alteration outward from the central core;
(d) the nature and zonation of central copper-molybdenum mineralisation and lead-zinc mineralisation on the periphery.

More than 80 porphyry-type deposits have been discovered in eastern Queensland (Horton, 1978, in press). Most of these occur in the Tasman Orogenic Zone, Mount Turner being one of only three deposits within the Georgetown Inlier. All three are considered to be of Late Carboniferous age. The Split Rock (Mountain Maid) deposit is located to the northeast, 70 km west of Chillagoe. The third deposit, Phyllis May (Mount Darcy), occurs some 16 km west of Mount Turner.

The Mount Turner and Phyllis May porphyry-type deposits are both associated with rhyolite and microgranodiorite intrusives. The two deposits are quite similar in that secondary biotite alteration, quartz-molybdenite mineralisation, fissure-controlled sericitisation and silicification, and galena-sphalerite veining are present in both areas. The main difference is the absence of a distinct zone of silicification and fissure-controlled alteration at Phyllis May.

The depth of emplacement of the Mount Turner and Phyllis May systems is difficult to determine. The Phyllis May prospect is 3 km south of the Dismal Creek Volcanics (Mackenzie, 1980), a sequence of mainly acid pyroclastics, minor basic lavas and intercalated sediments of Carboniferous age. Similar rocks, the Cumberland Range Volcanics, which crop out 12 km to

TABLE 3: COMPARISON OF THE GEOLOGICAL CHARACTERISTICS OF MOUNT TURNER AND PORPHYRY ORE DEPOSITS OF SOUTHWESTERN USA

Feature	USA	Mount Turner
1. Igneous host rock:		
Shape	Elongate, irregular	Elongate multiple plugs, circular with radiating dykes
Controlling structures	Faults	None
Sequence of intrusion	Diorite–adamellite	Rhyolite–granodiorite
Rock types mineralised	Preore and host rock	Preore and host rock
2. Orebody:		
Shape	Oval, pipelike	Oval, pipelike
Dimensions	1 200 x 2 000 m	2 400 x 4 000 m*
Hypogene grade	0.45% Cu, 0.015% Mo	0.01% Cu and Mo
3. Peripheral zone:		
Alteration	Chlorite, epidote, kaolin	Chlorite, epidote, kaolin, sericite
Mineralisation	Galena, sphalerite, Ag, Au (vein and veinlets)	Galena, sphalerite, Ag (vein)
4. Intermediate zone:		
Alteration	Quartz, kaolin, sericite, montmorillonite	Quartz, kaolin, sericite, chlorite
Mineralisation	Pyrite, galena, sphalerite, chalcopyrite (veinlet disseminated)	Pyrite, chalcopyrite, sphalerite (veinlet disseminated)
5. Innermost zone:		
Alteration	Quartz, K-feldspar, biotite, sericite	Quartz, K-feldspar, biotite, sericite, andalusite
Mineralisation	Pyrite, chalcopyrite, molybdenite, bornite (veinlet disseminated)	Pyrite, chalcopyrite, molybdenite, bornite (veinlet disseminated)
6. Breccia pipes:	Present and mineralised	Present and mineralised
7. Supergene sulphide:	Chalcocite, covellite	None

After Lowell & Guilbert (1970)
* to the edge of zone of silicification

the south, probably once coalesced with the Dismal Creek Volcanics forming a continuous blanket over the Phyllis May area and probably the Mount Turner area. Both the Mount Turner and Phyllis May hydrothermal systems occur within the basement at an unknown depth beneath the presumed volcanic cover. Porphyritic microgranodiorite similar to that at Phyllis May and Mount Turner intrudes the Dismal Creek Volcanics, but hydrothermal alteration systems have not been identified within the volcanics although they are common within the surrounding basement. The present thickness of the volcanics is less than 1 000 m. However, the amount removed by erosion and the extent to which the areas preserved represent downwarped or downfaulted blocks are not known. Therefore consideration of the regional geological setting of the systems provides no conclusive evidence on their depth of emplacement. A depth of greater than 4 km would be unlikely, however. The presence of andalusite in the secondary biotite zone in particular suggests shallow emplacement.

The Mount Turner deposit is located in an ensialic (cratonic) environment. Table 3 compares it with the porphyry copper deposits of the southwestern United States, which were emplaced in a similar environment. These deposits are, however, much younger, being predominantly of Tertiary age. The main difference, apart from the grade of mineralisation is the absence of any truly pervasive alteration and mineralisation at Mount Turner. This is probably the result of the development of only an immature convection plume of volatiles, which is normally considered responsible for pervasive alteration and mineralisation in porphyry systems. The relatively 'dry' environment of the granitic host rocks at Mount Turner, a relative deficiency in magmatic volatiles, or emplacement at considerable depth, or all three may have been responsible for the immature convection plume.

The overall sulphide content of the Mount Turner deposit is less than 0.5 per cent. Most of this is pyrite. As most of the sulphides are fissure controlled, especially in the outer regions of the prospect, consistently high grade intersections of base metal sulphides cannot be expected.

The absence of a secondary enrichment zone is also a detracting factor. Lacy (1974) noted that in the western United States only in rare instances is additional enrichment not required to effect economic grades. Unless the style and grade of mineralisation can be shown to change with depth, the likelihood of finding economic bulk low grade base metal concentrations at Mount Turner is low. However, the possibility of discovering more silver-lead-zinc veins on the periphery of the system, particularly at depth, is good.

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APPENDIXES

1: SUMMARY OF GEOCHEMICAL INVESTIGATIONS

Stream sediment geochemistry

One hundred and sixty stream sediment samples were collected over an area of 42 km^2 by a joint BMR-GSQ geochemical party in June 1976 (Rossiter, 1979). The samples were sieved for the minus 80 mesh fractions which were analysed for copper, lead, zinc, and molybdenum by atomic absorption spectrometry. The graphical method described by Lepeltier (1969) was used to determine anomalous values. A 2 km^2 area with copper values exceeding 400 ppm and two areas of anomalous molybdenum with values from 15 to 20 ppm were outlined (Figs 11 and 12). Lead and zinc anomalies present around the margin of the system reflect peripheral vein mineralisation (Figs 13 and 14).

Soil geochemistry

A ridge and spur soil sampling program covering an area of 16 km^2 over the copper and molybdenum stream sediment anomalies was undertaken by the GSQ in July 1976 (Lam, 1977). Three hundred and sixty samples were collected and the minus 80 mesh fractions were analysed at the Government Chemical Laboratory for copper, lead, zinc, and molybdenum using emission spectrometry (Geoghegan, 1977). Soil samples were taken every 100 m along prominent ridges and spurs and collected from the top 100 mm of soil as indicated by orientation soil sampling (Lam, 1977).

The **copper** anomalies outlined by soil sampling were small and erratically distributed within the area defined by the stream sediment anomaly (Fig. 11). Two of the major soil anomalies occur downstream from the associated stream sediment anomalies. This situation indicates that copper is highly mobile in this environment and has been leached from soil and rock in areas of high relief and concentrated in flatter areas.

Two separate **molybdenum** anomalies, each less than 1 km^2 in area, were outlined by soil sampling (Fig. 12). The western anomaly is coincident with the tensional breccia and associated quartz-molybdenite vein mineralisation (Fig. 2). Examination of surface outcrop on the eastern anomaly indicated that molybdenum mineralisation there is disseminated and not associated with quartz veining.

Lead and zinc soil anomalies are coincident with the areas defined by stream sediment anomalies. The outer limits of lead and zinc mineralisation have not been defined (Figs 13 and 14).

2: SUMMARY OF GEOPHYSICAL INVESTIGATIONS

Geophysical investigations of the Mount Turner prospect by the joint BMR-GSQ field party during 1976 included induced polarisation (vertical electrical soundings), down hole induced polarisation-resistivity logging of drillholes, gamma-ray spectrometry, total count radiometrics, and total magnetic induction. The following is a brief summary of Major (1979).

Induced polarisation-resistivity

The objective of the IP/R survey was to obtain a three-dimensional picture of chargeability and resistivity which could be interpreted in terms of sulphide concentration and alteration zoning within the system. Soundings were made at intersections of the 1 km square metric grid. A Schlumberger array was used, and results were interpreted using a forward modelling technique for calculating apparent chargeability of layered media (Dixon & Doherty, 1977).

The vertical electrical soundings (VES) provided useful results for interpreting mineralisation in the top 200 m of the prospect (Fig. 15). Resistivity is an extremely variable parameter, tending to reflect properties of the rock (such as amount of fracturing and extent of weathering) rather than sulphide content. Outside the alteration zone, the basement is resistive (1 500 ohm-m) and is typical of unweathered granite. Within the alteration zone, there are areas of less

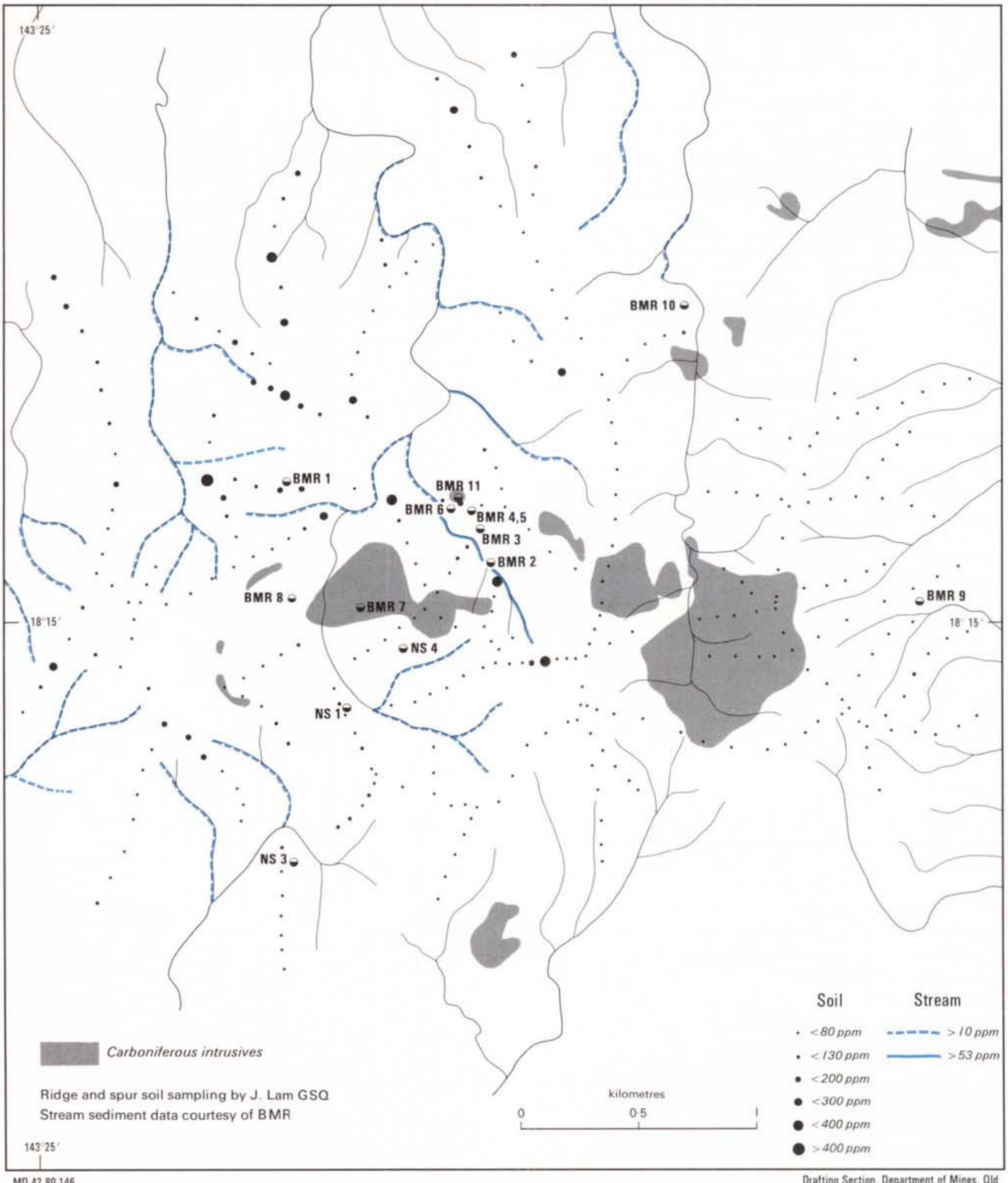

Figure 11: Soil and stream sediment geochemistry — copper

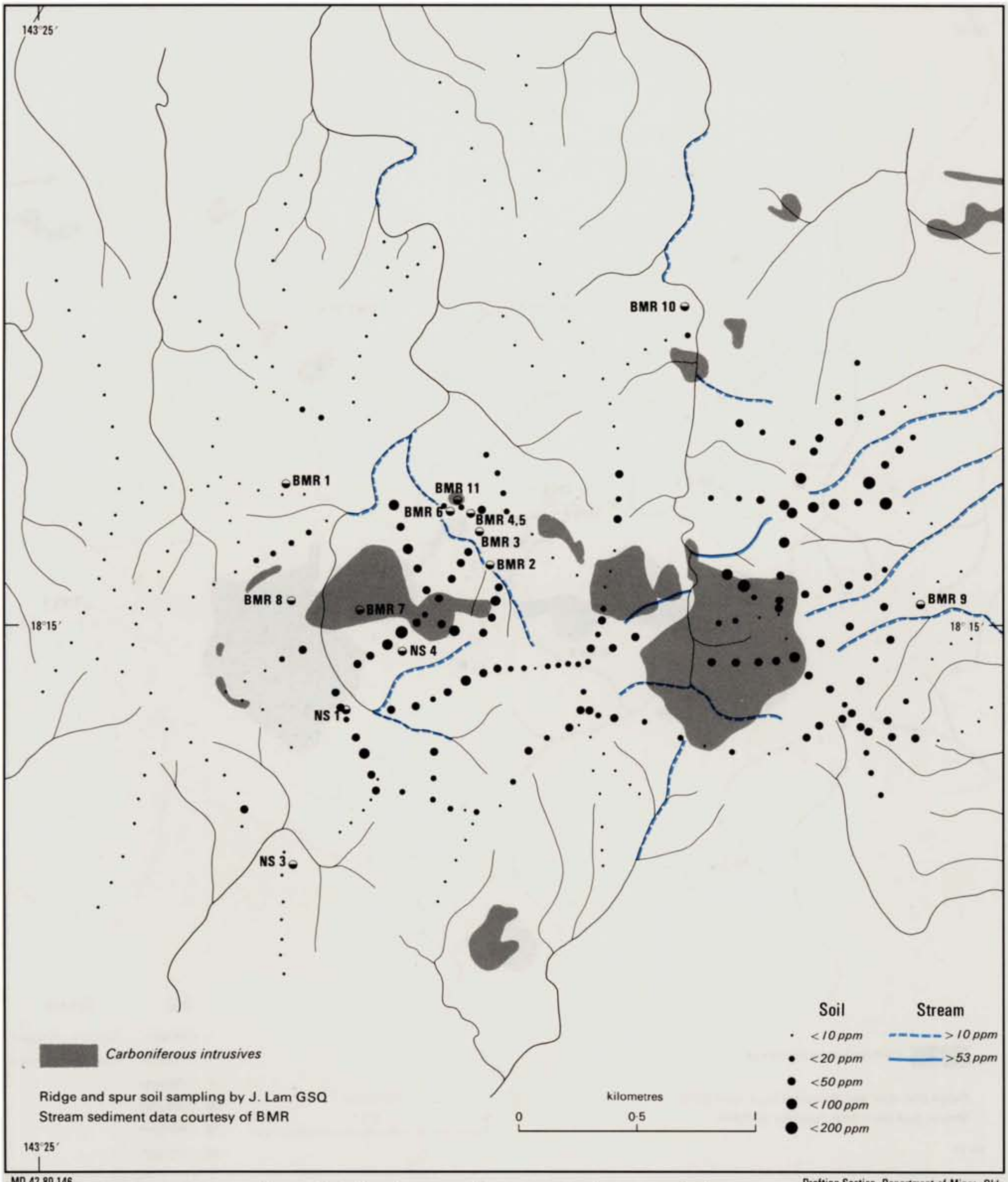

Figure 12: Soil and stream sediment geochemistry — molybdenum

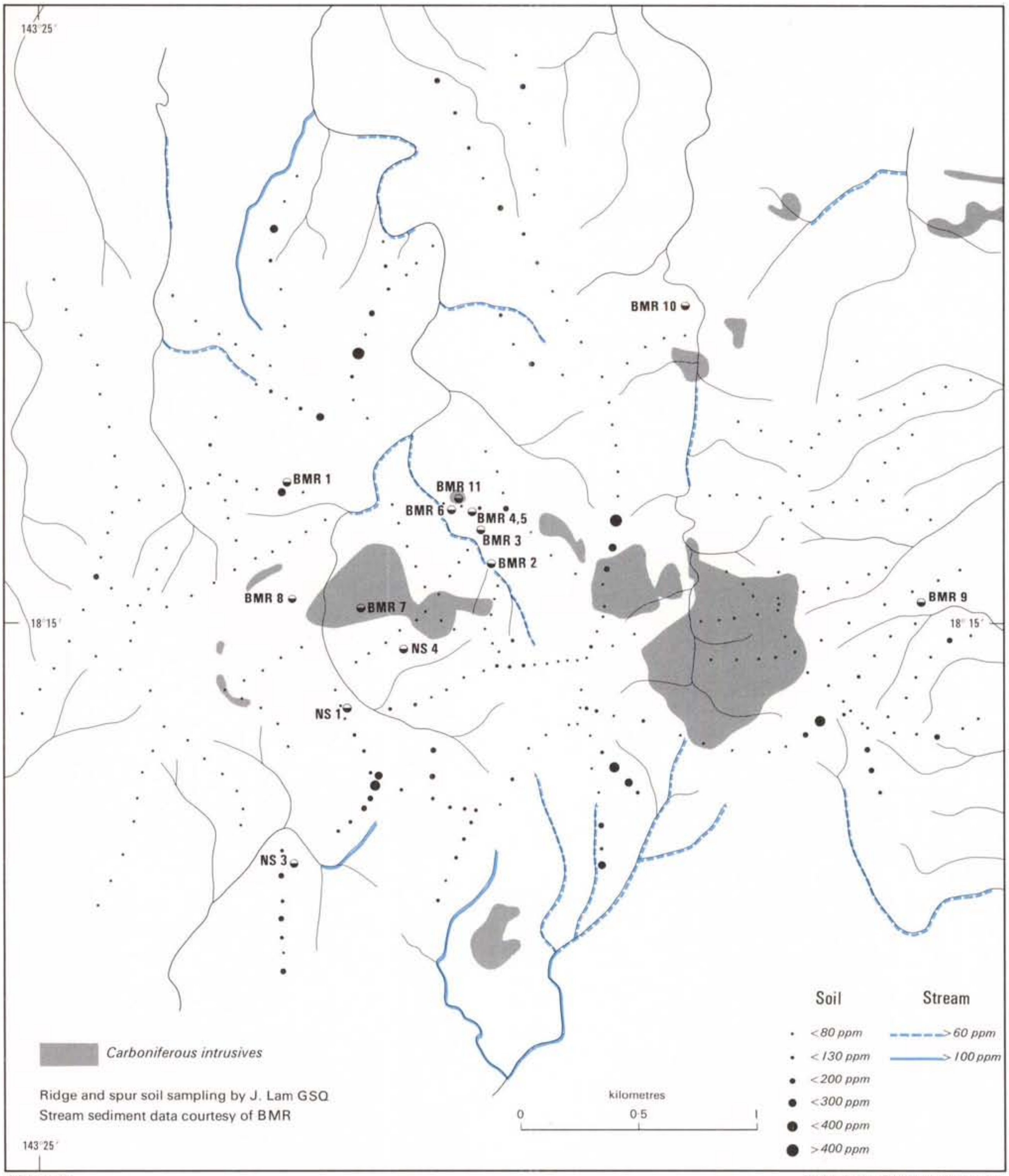

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Figure 13: Soil and stream sediment geochemistry — lead

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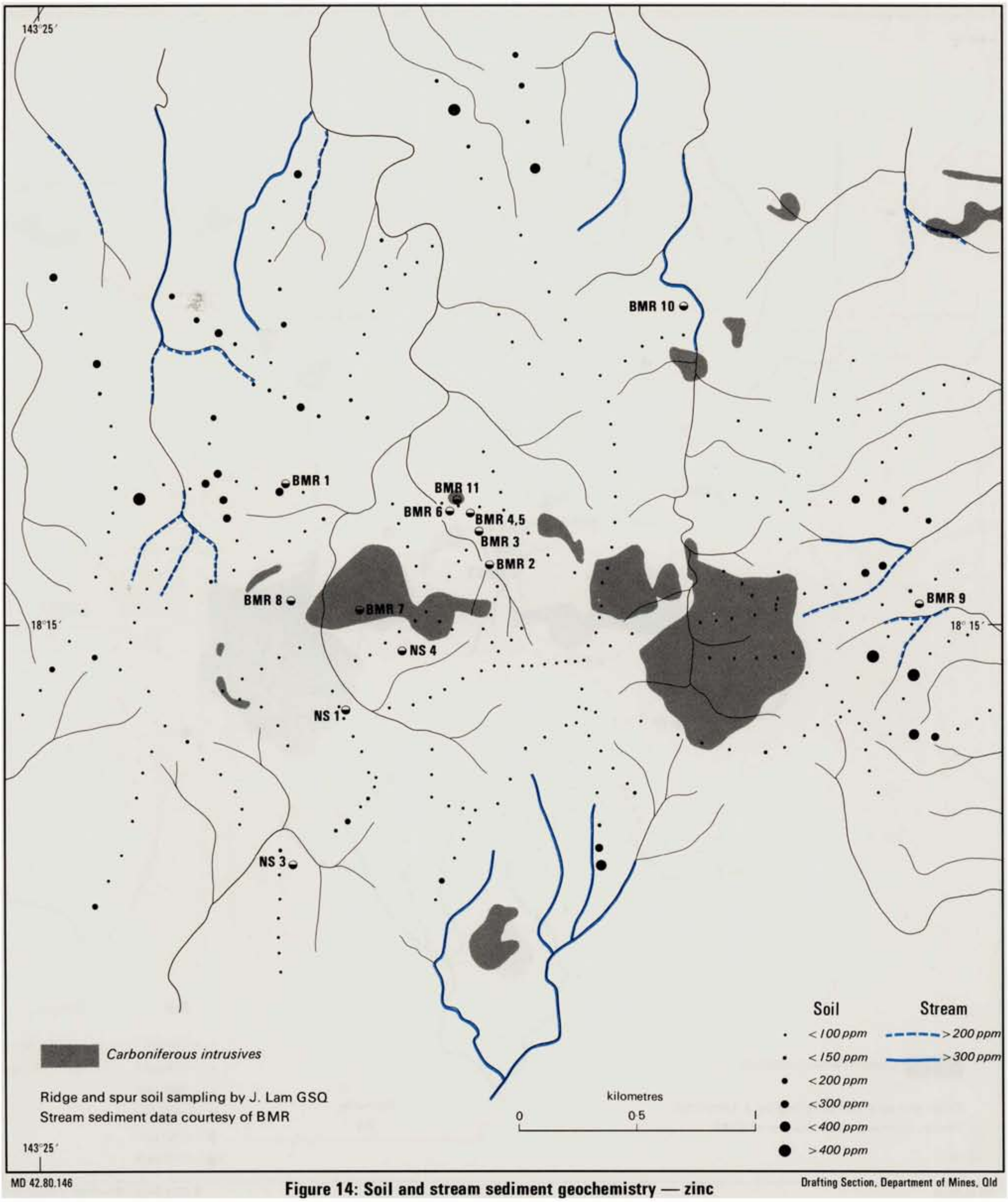

Figure 14: Soil and stream sediment geochemistry — zinc

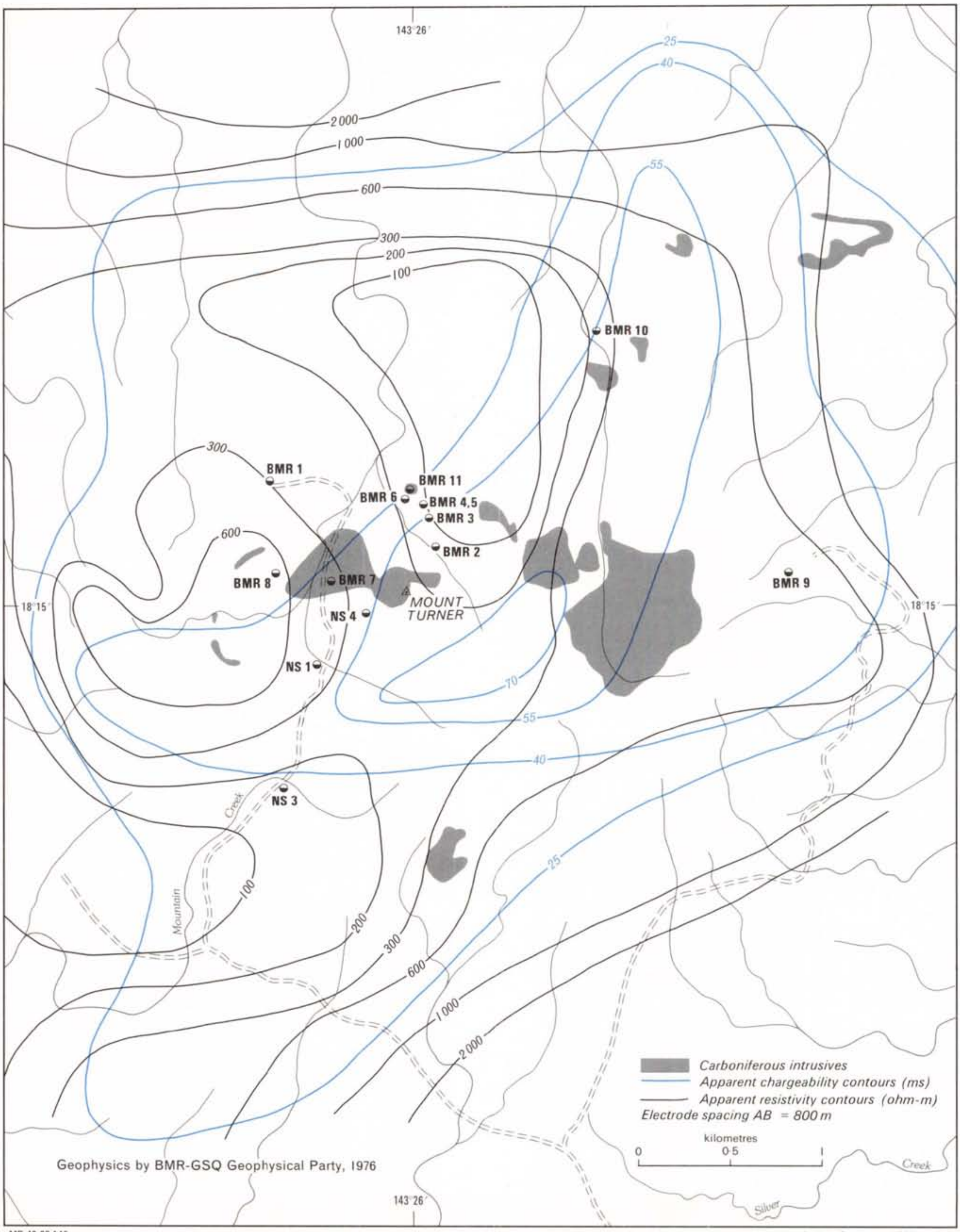

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Figure 15: IP and resistivity contours from vertical electrical soundings

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resistive basement (40–600 ohm-m) which probably represent more altered and fractured rock. A central zone of high resistivity shows reasonable correlation with the zone of biotite-andalusite alteration.

Chargeability (IP) is believed to be more diagnostic of sulphide distribution. However, mode of mineralisation (vein or disseminated), grain size of sulphide minerals, porosity, pore fluids, and clay minerals may also be contributing factors to IP response. A high chargeability zone correlates approximately with the area of fissure-controlled alteration (Fig. 15).

Drillholes were logged with either of two dipole-dipole array probes with distance between adjacent electrodes of 3 m and 1 m, respectively. Logs generally showed poor agreement between the resistivity measured down hole and that predicted by VES.

Gamma-ray spectrometry

The objective of the gamma-ray spectrometry work was to establish the K, U, and Th distribution within the prospect. Readings were taken at the intersections of the 1 km square metric grid using a DISA-400A gamma-ray differential spectrometer. No discernible zoning of any of these elements was observed.

Total count radiometrics

Total count radiometrics were read to see whether the changes in radioactivity could be correlated with any of the rock types in the area and to outline areas for further investigation by gamma-ray spectrometry. The instrument used was an Austral SG-26 broadband scintillometer covering an energy band from 300 KeV to over 3 MeV. Variations in dose ratios were observed for Delaney Granite, Aurora Granite, Mount Darcy Microgranodiorite, and rhyolite.

Total magnetic induction

The object was of the ground magnetic work were to better define small aeromagnetic anomalies near Mount Turner and to see whether any correlation could be made between the surface geology and ground magnetics. The instrument used was a portable Geometrics proton magnetometer. Apart from delineating major geological units, this method did not detect any variations.

3: SUMMARY OF DRILLING

During 1976, a BMR Gemco 210B rig was used to drill ten shallow vertical holes for a total depth of 500 m, the deepest hole being 85 m, to assist the geological mapping of the prospect. In 1977, a Queensland Department of Mines Longyear 34 rig drilled two vertical and two inclined holes for a total depth of approximately 800 m. This program was designed to test the deposit at depth. The core size of both rigs was BQ. Detailed drill logs for each of these holes have been presented in Baker (1978b).

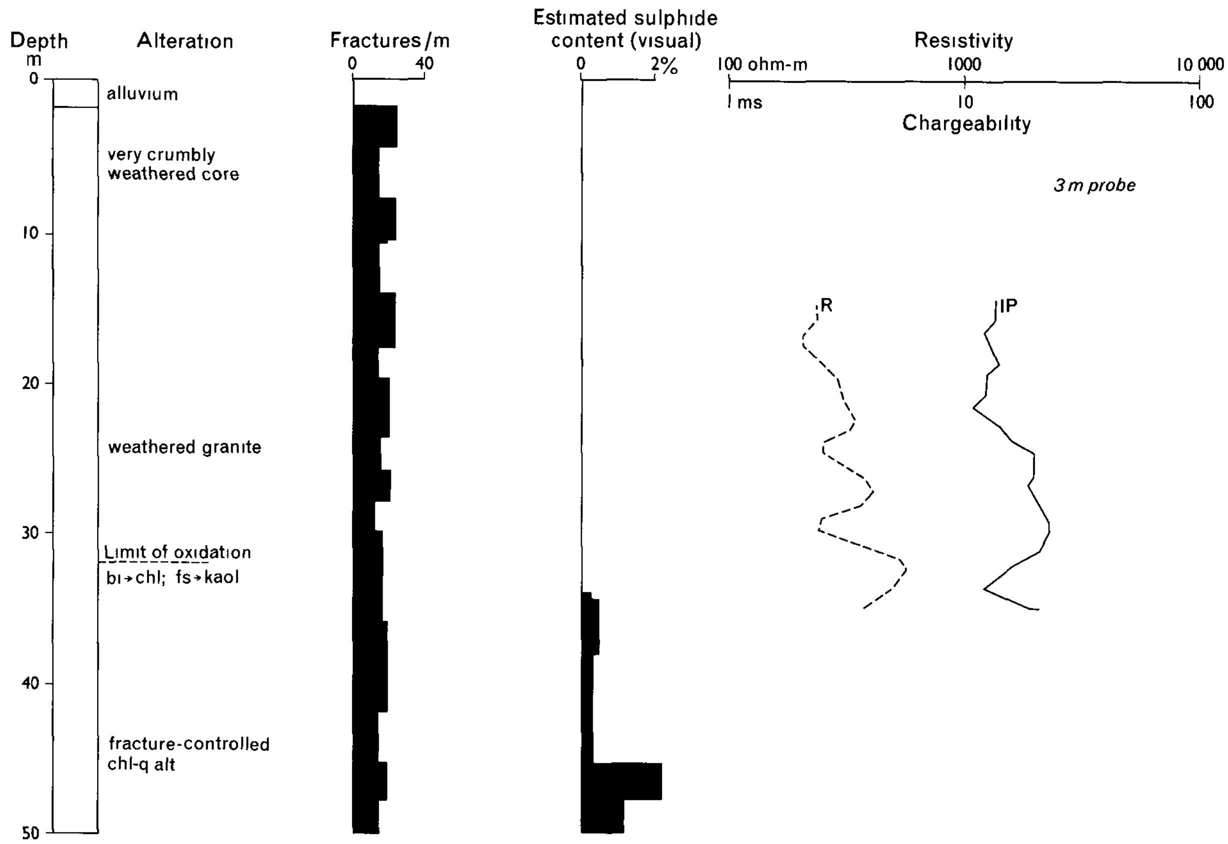
Only representative sections of unmineralised and mineralised core were split and analysed. The overall low sulphide content and the virtual absence of copper sulphides precluded the splitting and analysis of the total core. The assay results (Table 4) clearly demonstrate the low base metal grades.

TABLE 4: COPPER, LEAD, ZINC, AND MOLYBDENUM ANALYSES FROM DRILL CORE

Drillhole	Assay No.	Depth (m)	Interval (m)	Assays in ppm Cu	Pb	Zn	Mo
BMR 2	840/76	28.95	0.20	18	40	61	7
	837/76	38.00	0.20	71	45	54	57
	836/76	45.55	0.20	70	40	56	70
	838/76	55.50	0.20	200	86	180	18
	111/77	62.40	0.20	1 600	400	280	46
	839/76	67.30	0.20	51	31	69	14
	110/77	69.80	0.20	354	31	55	1 300
	121/77	70.20	0.12	38	40	54	134
	122/77	70.41	0.16	22	56	71	75
BMR 4	112/77	18.00	0.16	21	51	54	46
BMR 7	107/77	14.66	0.21	470	18	99	49
	117/77	14.93	0.24	890	10	108	57
	119/77	18.30	0.09	18	22	71	53
	118/77	35.00	0.15	17	25	79	63
	108/77	40.20	0.13	73	21	68	53
	109/77	41.20	0.22	36	28	77	53
	120/77	41.90	0.14	129	39	68	68

		Depth	Interval	Assays in ppm			
Drillhole	Assay No.	(m)	(m)	Cu	Pb	Zn	Mo
BMR 8	98/77	17.30	0.12	625	183	102	77
	113/77	20.00	0.16	238	45	65	45
	99/77	31.00	0.23	26	81	72	63
	100/77	32.00	0.15	111	109	66	72
	101/77	35.70	0.24	91	83	60	77
	102/77	36.00	0.20	64	166	77	64
	103/77	49.00	0.74	74	66	66	68
	114/77	52.25	0.27	242	47	128	87
	104/77	60.50	0.50	115	42	67	225
	115/77	71.30	0.16	76	177	93	55
	116/77	72.20	0.25	450	65	137	1 100
	105/77	75.70	0.21	3 500	1 600	1 830	55
BMR 9	209/77	19.60	0.10	90	8	20	22
	210/77	37.80	0.26	32	10	120	8
	106/77	38.50	0.27	920	141	291	4
	211/77	38.80	0.42	120	12	120	
BMR 10	212/77	34.00	0.17	540	5	80	6
	213/77	38.30	0.16	120	5	380	4
	214/77	41.60	0.17	850	8	28	4
	216/77	42.20	0.22	170	10	70	4
	218/77	51.00	0.23	70	5	290	4
	219/77	53.00	0.24	48	5	240	4
	215/77	60.00	0.10	48	8	90	4
	217/77	84.90	0.20	95	28	50	4
BMR 11	106/77	38.50	0.27	920	141	291	41
NS1	1625/77	64.40-64.57	0.17	130	260	140	31
	1626/77	64.94-65.58	0.64	69	49	231	51
	1627/77	64.44-65.06	0.12	118	38	76	47
	1616/77	65.65-67.00	1.35	880	10	70	28
	1617/77	67.00-69.00	2.00	480	10	140	28
	1618/77	69.00-71.00	2.00	490	10	50	29
	1619/77	71.00-73.00	2.00	370	10	40	87
	1628/77	77.36-77.52	0.16	500	20	60	19
	1629/77	89.86-89.90	0.14	37	36	48	31
NS 2	1630/77	50.50-50.77	0.27	70	270	450	11
	1631/77	51.20-51.44	0.24	59	40	101	24
	1620/77	56.46-58.00	1.54	1 100	140	870	20
	1632/77	77.30-77.69	0.39	14	49	48	26
	1621/77	89.26-89.50	0.24	730	30	150	20
	1622/77	110.65-117.40	6.75	1 120	60	1 470	20
	1623/77	148.64-150.00	1.36	2 260	10	30	20
	1624/77	188.30-190.02	1.72	810	10	30	20
NS 3	1905/77	162.26-162.62	0.36	30	38	37	5
	1906/77	164.59-164.92	0.33	16	41	39	5
	1907/77	164.98-165.22	0.24	174	12	37	5
	1908/77	165.51-166.00	0.49	26	42	40	5
	1909/77	182.30-183.00	0.70	14	40	37	5
NS 4	1913/77	48.00-50.00	2.00	174	47	180	27
	1914/77	58.00-60.00	2.00	138	48	140	55
	1915/77	68.00-70.00	2.00	470	46	100	20
	1916/77	119.00-120.00	1.00	800	108	303	12
	1910/77	145.95-146.42	0.47	1 360	10	123	12
	1911/77	147.00-147.36	0.36	104	62	88	15
	1912/77	154.60-155.32	0.72	770	66	1 550	58
	1917/77	180.00-187.00	2.00	92	39	79	7
	1918/77	293.00-295.00	2.00	323	58	246	24

Analyses by Government Chemical Laboratory, Brisbane by emission spectrometry



Reference to Figures 16-25

→	*Altered to*	fs	*Feldspar*	sec	*Secondary*
alt	*Alteration*	kaol	*Kaolinite*	ser	*Sericite*
bi	*Biotite*	k-spar	*Orthoclase*	sl	*Slightly*
calc	*Calcite*	m vein	*Microveinlet*	sph	*Sphalerite*
cc	*Chalcocite*	min	*Mineralisation*	t	*Trace*
chl	*Chlorite*	mo	*Molydenum*	unalt	*Unaltered*
cpy	*Chalcopyrite*	mu	*Muscovite*		*Intense alteration*
cup	*Cuprite*	plag	*Plagioclase*		*Less intense alteration*
dissem	*Disseminated*	py	*Pyrite*		*Collapse breccia*
ep	*Epidote*	q	*Quartz*		

MD 42 80 146

Figure 16: Drill section BMR 1

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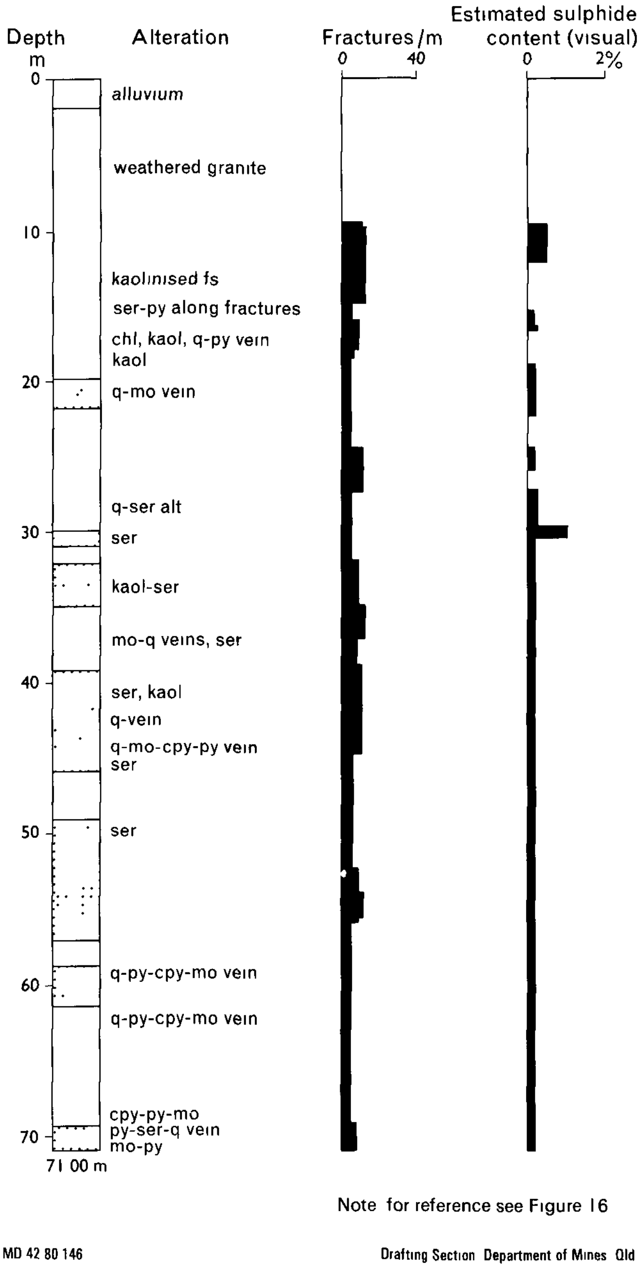

Figure 17: Drill Section BMR 2

A brief summary of each hole follows — their locations are shown in Figure 2 and in Figures 11 to 15.

BMR DDH 1 (Fig. 16) was sited on a copper anomaly defined by stream sediment geochemistry (Fig. 11). The hole was drilled to a vertical depth of 50 m within unaltered to sericitised and chloritised Delaney Granite. Mineralisation is predominantly fissure and fracture-controlled pyrite and lesser chalcopyrite associated with sericite-chlorite alteration. Down hole IP logging below 35 m was not possible owing to the collapse of the hole. Average sulphide content is less than 0.5 per cent.

BMR DDH 2 (Fig. 17) was drilled vertically to a depth of 71 m within the central alteration zone. The core is predominantly unaltered Delaney Granite cut by a few quartz-sulphide veins with associated alteration. The overall sulphide content is less than 0.5 per cent and the rock is poorly fractured (less than 8 fractures/m).

BMR DDH 3, 4, 5, and 6 were shallow vertical holes used to obtain samples in areas of poor and weathered outcrop. They were not drilled below the weathered zone and signs of significant mineralisation were not found. DDH 6 was drilled only to 4.8 m because of technical problems. No drill logs are provided for these holes.

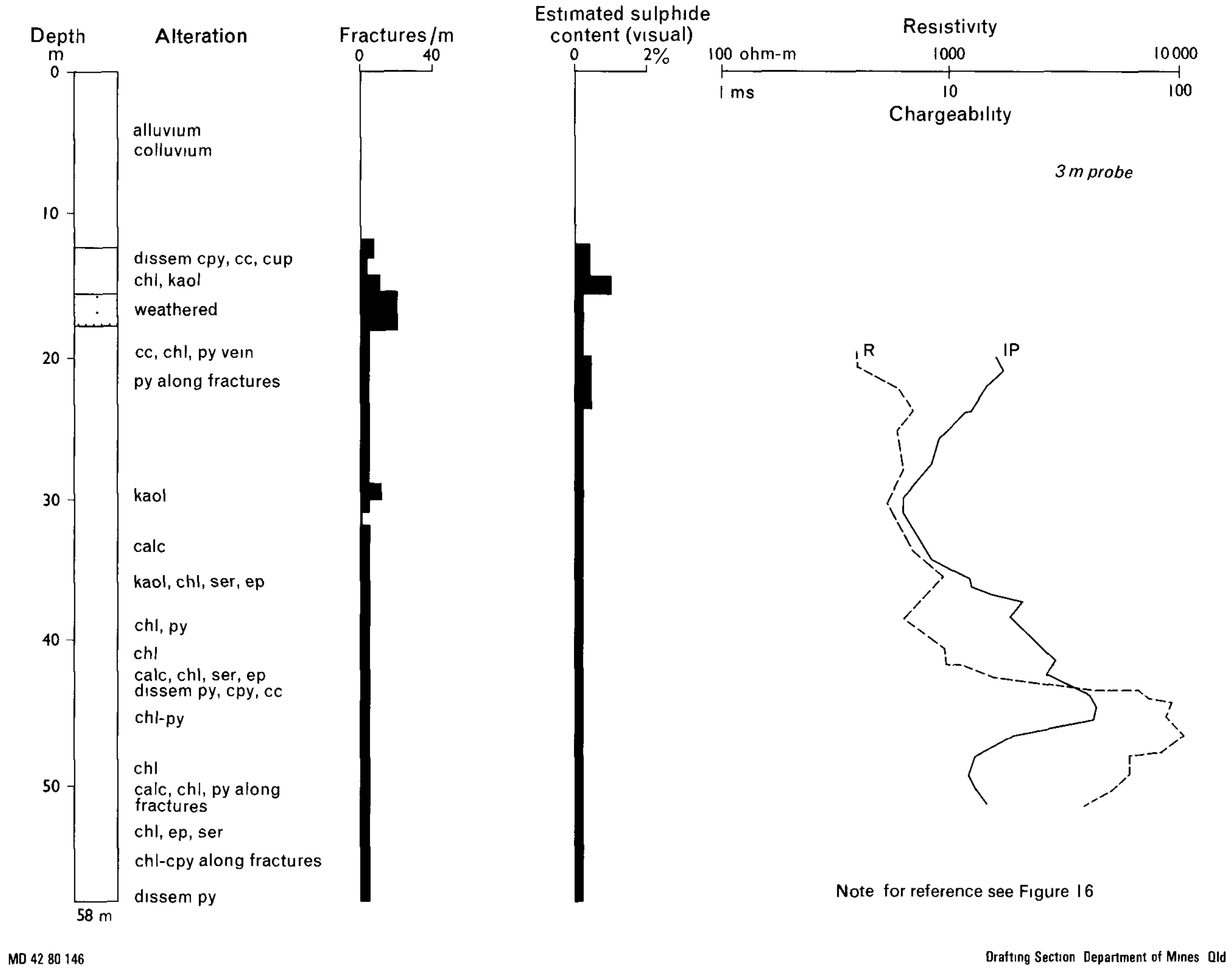

Figure 18: Drill section BMR 7

BMR DDH 7 (Fig. 18) was drilled to a vertical depth of 58 m within porphyritic microgranodiorite to obtain unweathered samples. Both disseminated and fracture-controlled pyrite and chalcopyrite mineralisation are present. Minor disseminated hematite, partly replaced by goethite was observed at 14 m.

BMR DDH 8 (Fig. 19) was drilled vertically to a depth of 80.95 m within the central alteration zone adjacent to the western margin of the main porphyritic microgranodiorite intrusion. It was hoped to obtain core showing progressive retrogressive alteration approaching the intrusion and possibly breccia capping the intrusion. However, because of the steep-walled nature of the intrusion this was not achieved.

The core is predominantly Delaney Granite with minor intersections of biotite schist or schlieren. Disseminated pyrite-chalcopyrite mineralisation and quartz-molybdenum-pyrite veins are present. The overall sulphide content is very low.

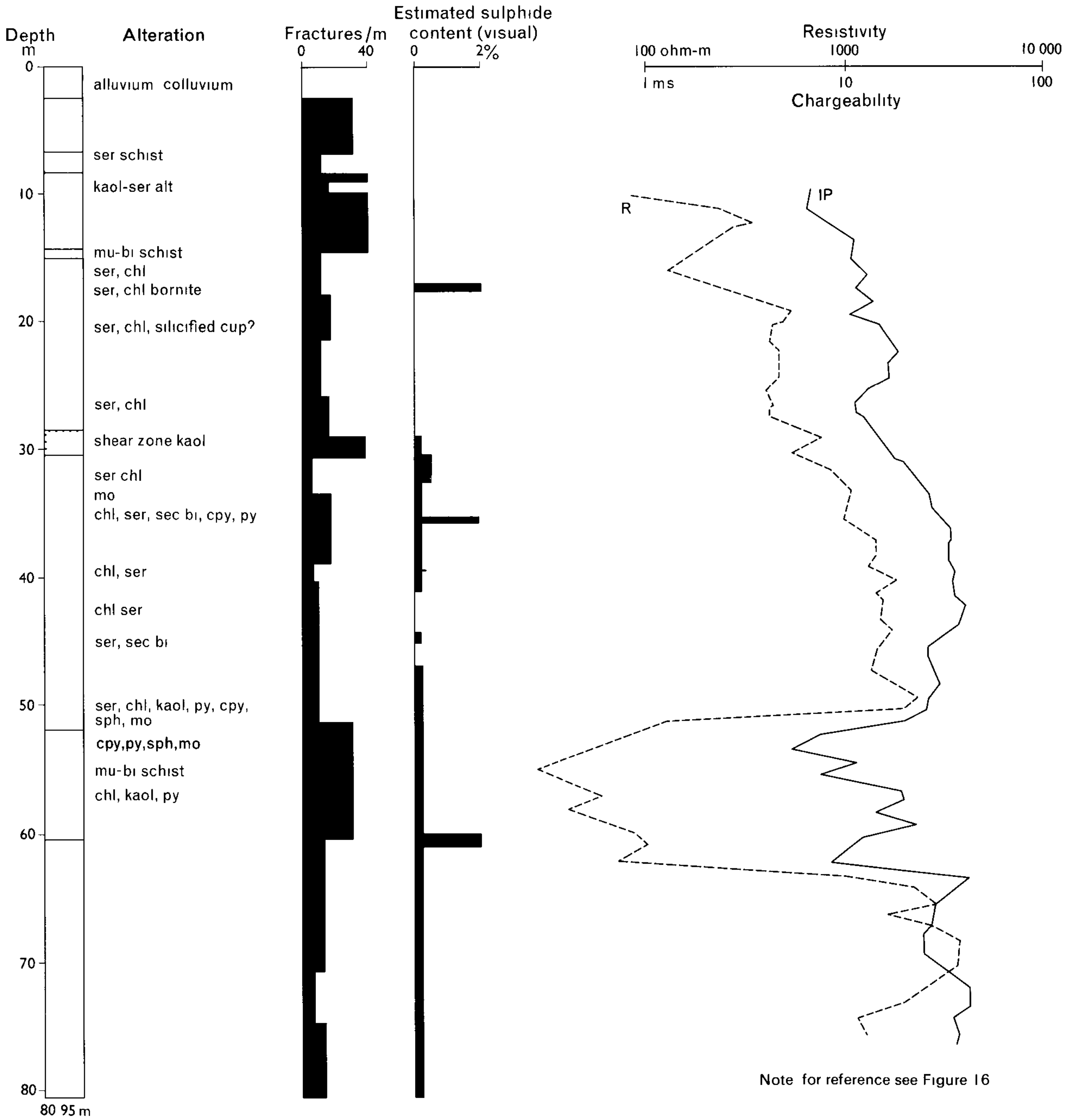

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Figure 19: Drill section BMR 8

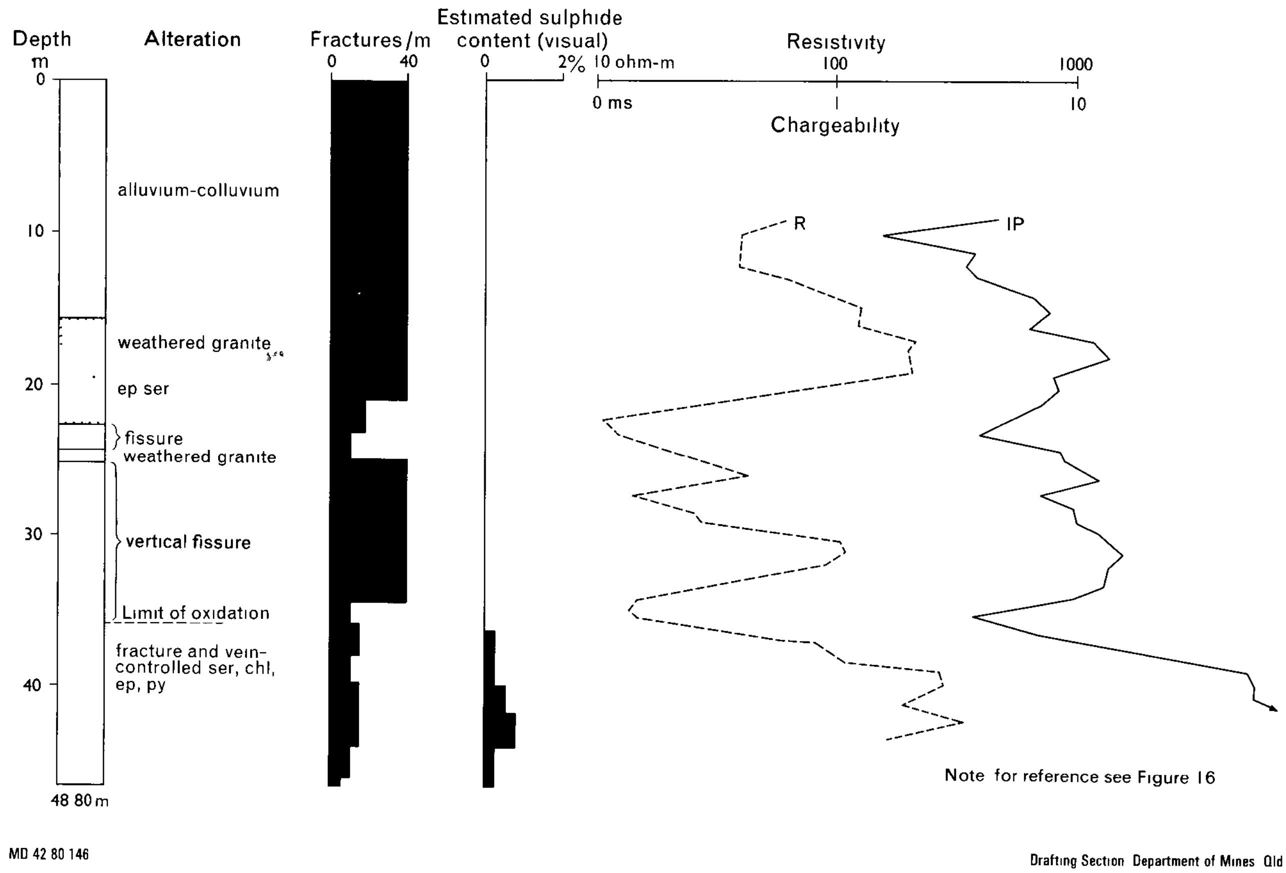


Figure 20: Drill section BMR 9

BMR DDH 9 (Fig. 20) was drilled vertically to a depth of 46.80 m; it was designed to obtain fresh core from the periphery of the system. Fracture-controlled pyrite averages less than 0.5 per cent for the hole. Chalcopyrite was not observed.

BMR DDH 10 (Fig. 21) was positioned on the periphery of the system within predominantly unaltered melanocratic Delaney Granite. The hole was drilled to a depth of 85.20 m to test a geophysical anomaly with chargeability values as high as 56 ms and resistivity less than 100 ohm-m. Overall sulphide content of the hole was less than 2 per cent.

GSQ NS 1 (Fig. 22) was drilled vertically to a depth of 126.79 m at the boundary between the zone of secondary biotite alteration and the zone of fissure-controlled sericite alteration. Sulphide content is less than 0.5 per cent and is predominantly fracture-controlled pyrite.

GSQ NS 2 (Fig. 23) was drilled vertically to a depth of 206.13 m within Delaney Granite and was designed to provide control for geophysical soundings. Core consisted of unaltered granite with steeply dipping intervals of fracture-controlled sericite-chlorite alteration associated with pyrite-chalcopyrite mineralisation. Overall sulphide content is less than 0.5 per cent.

GSQ NS 3 (Fig. 24) was drilled within the zone of fissure-controlled sericitic alteration to obtain further geological correlation for geophysical soundings. The hole was inclined at 49° bearing 062° magnetic for a total inclined depth of 219 m. A major fissure zone containing significant pyrite mineralisation (10 per cent) was intersected between 80 and 110 m. Minor mineralisation and alteration zones occur within unaltered granite below this depth.

GSQ NS 4 (Fig. 25) was drilled to intersect the zone of tensional breccia on the southern side of Mount Turner and to pass into collapse breccia. The hole was inclined at 68-70° bearing 008° magnetic for a total inclined depth of 295.15 m. No significant mineralisation was encountered.

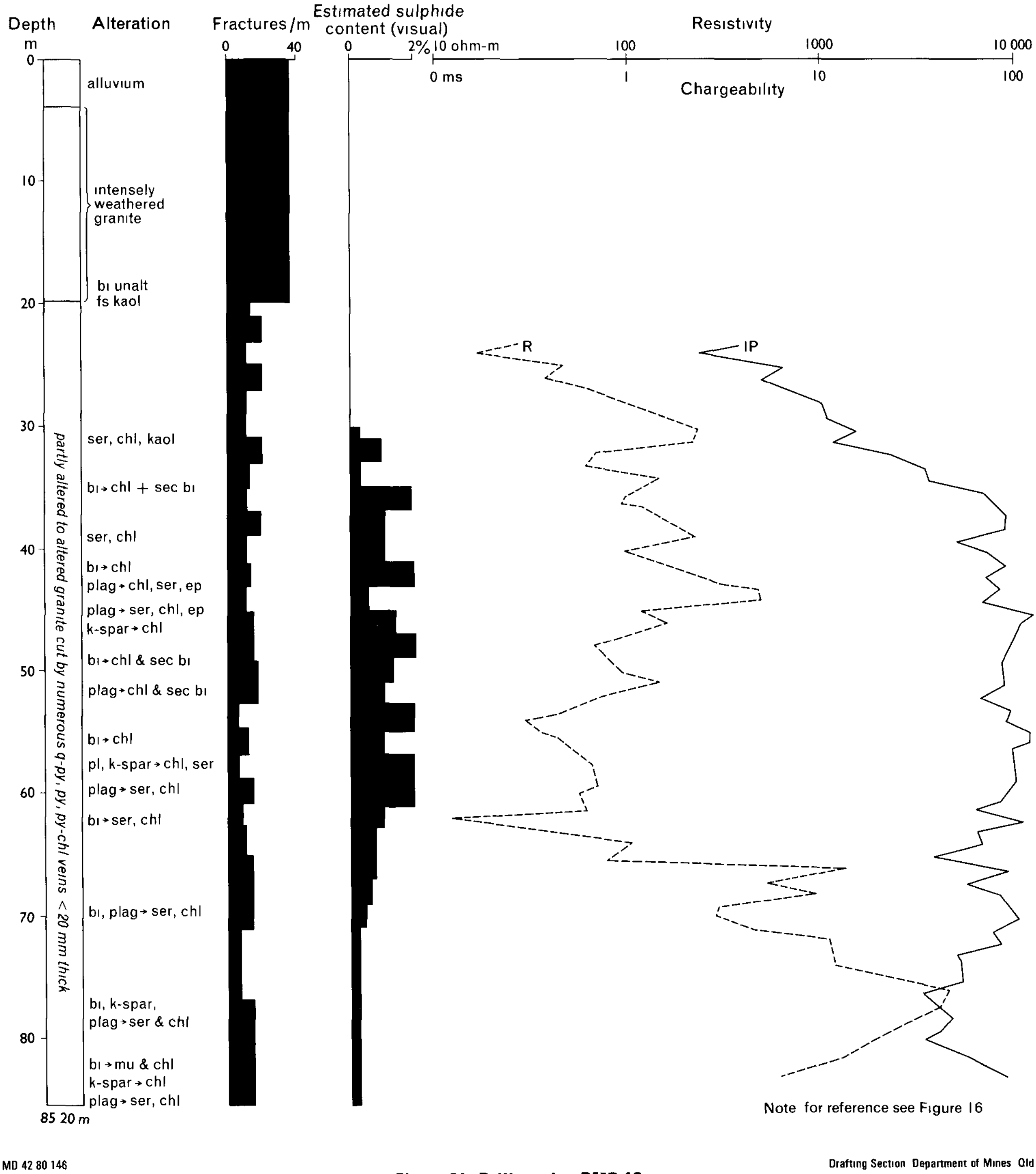


Figure 21: Drill section BMR 10

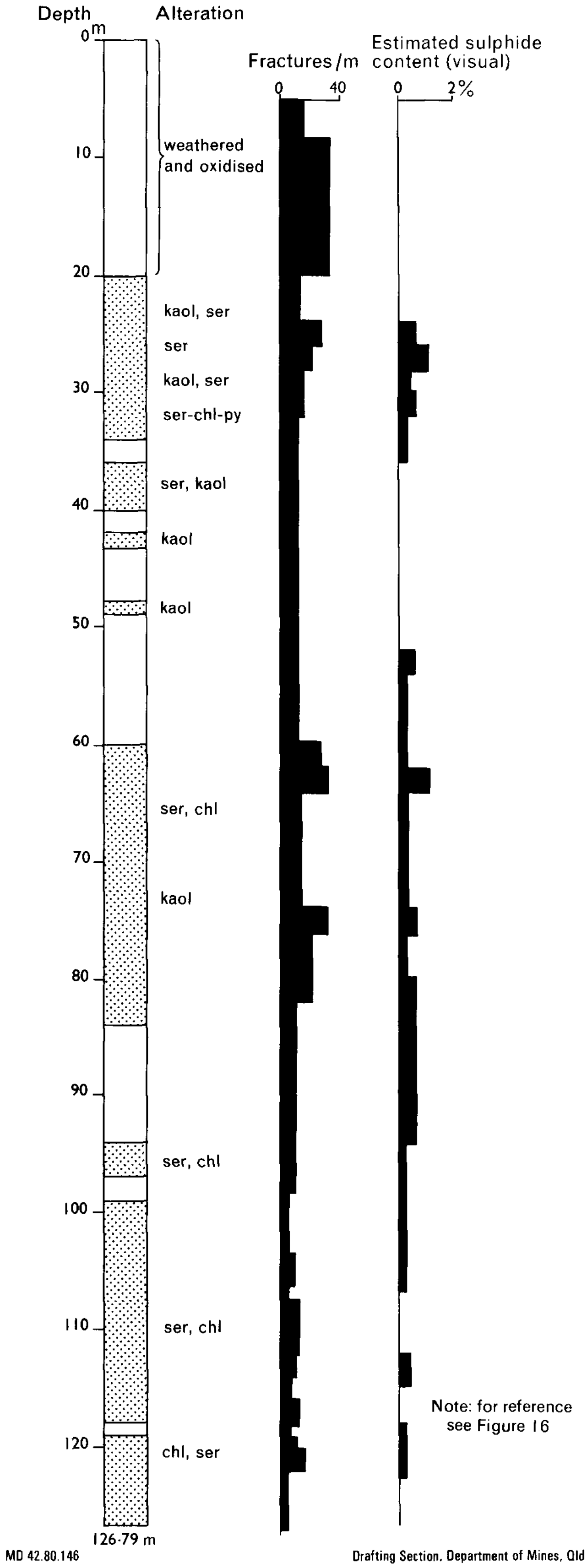


Figure 22: Drill section NS 1

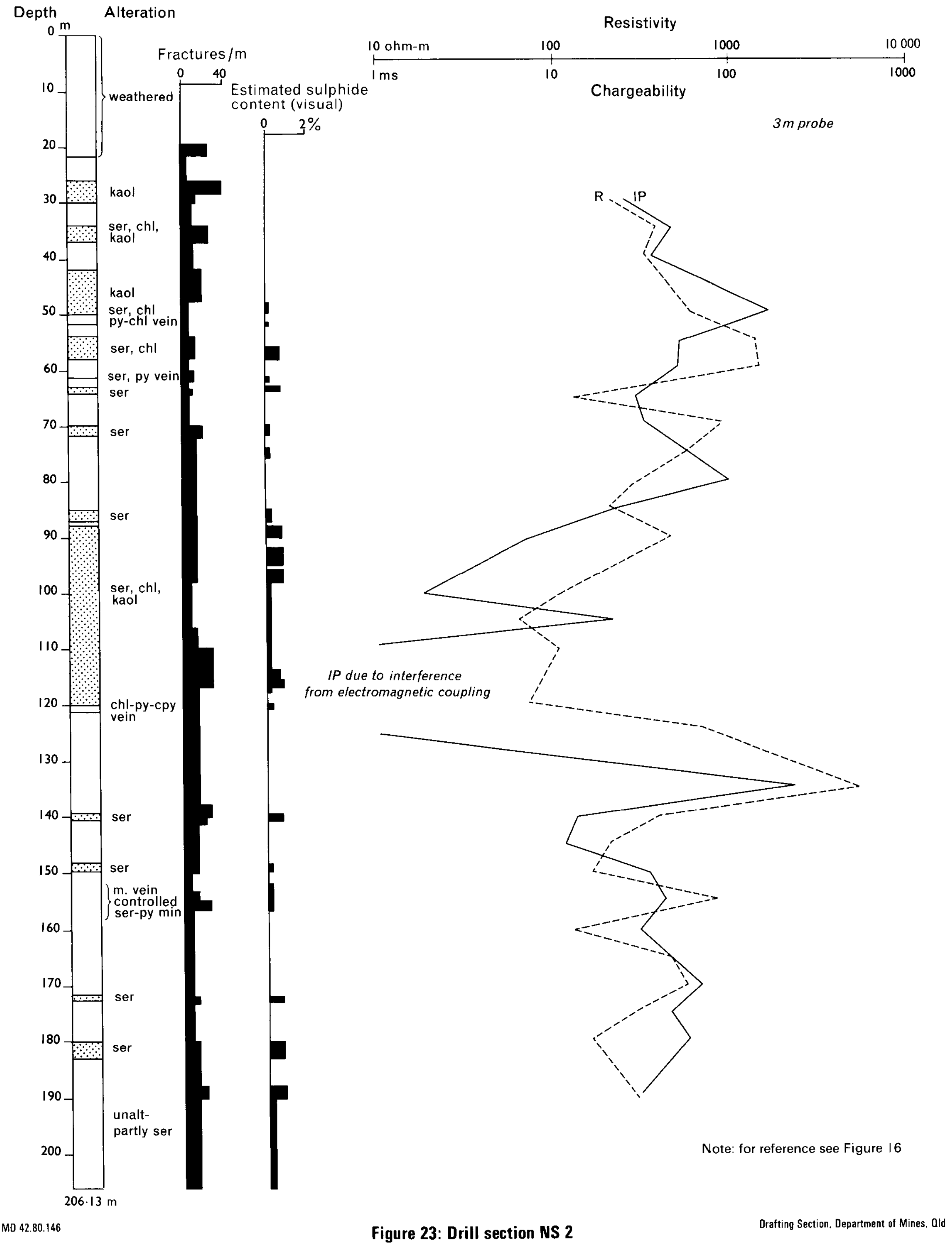


Figure 23: Drill section NS 2

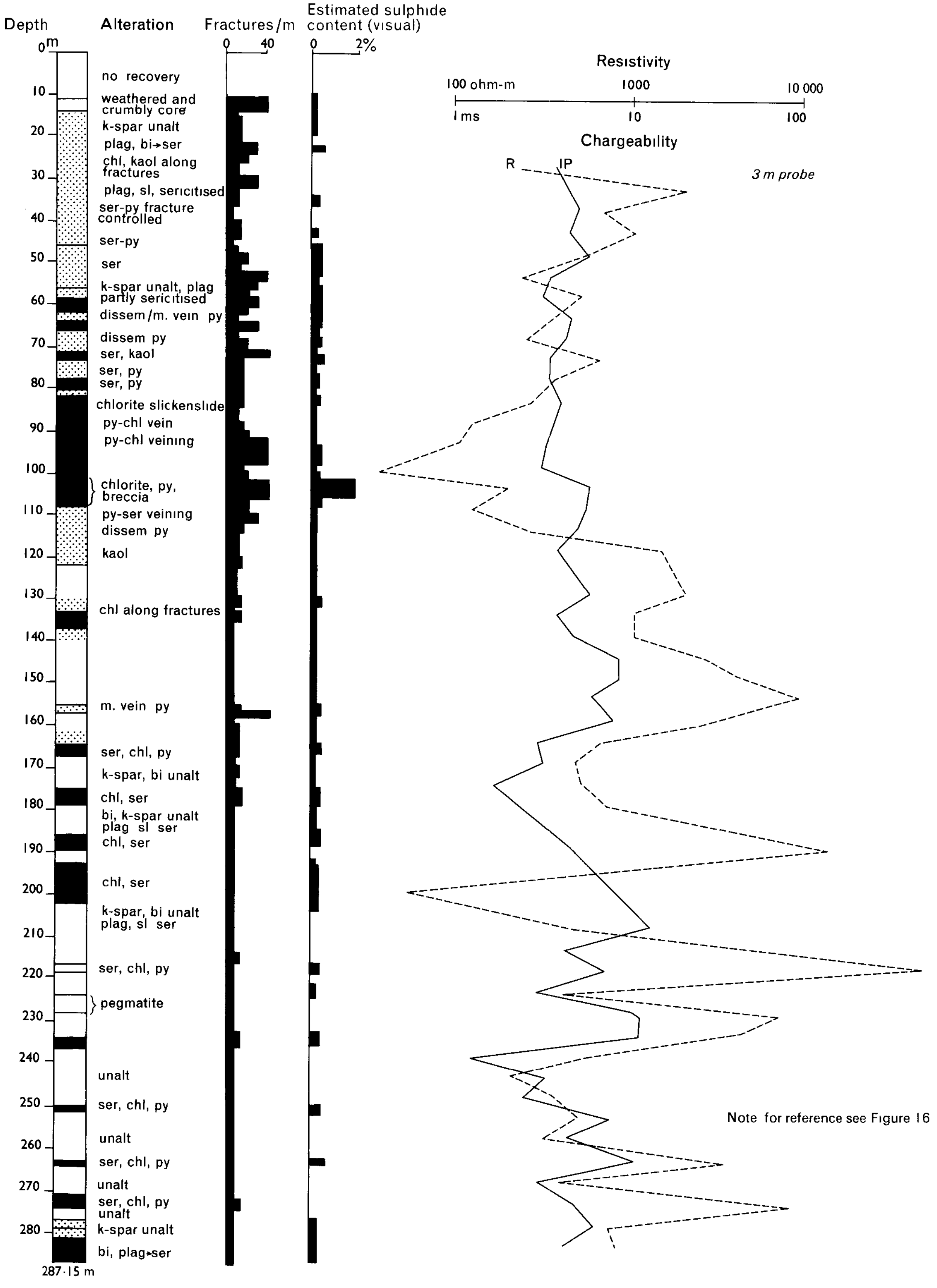


Figure 24: Drill section NS 3

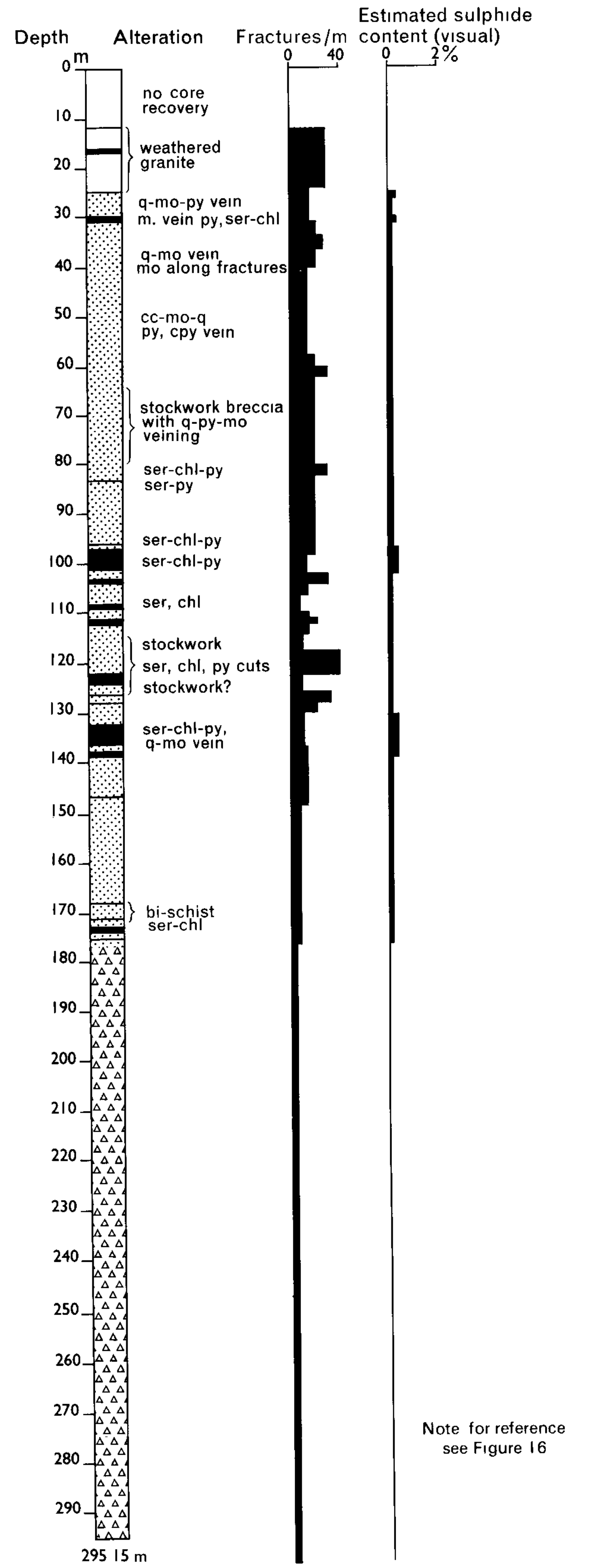


Figure 25: Drill section NS 4

PLATE 1: a Typical angular rhyolite rubble, Mount Turner.
b Rhyolite collapse breccia consisting of angular fragments of rhyolite with open cavities between fragments.
c Porphyritic microgranodiorite with subhedral quartz phenocrysts in an equigranular groundmass of plagioclase, quartz, and biotite. It is cut by a calcite-pyrite vein with an envelope of sericite-chlorite-kaolinite alteration. Scale 20 mm.
d Contorted quartz-ilmenite veins within ?chilled margin of microgranodiorite. This feature may form by quartz filling shrinkage cracks during alteration, involving a volume decrease.

a

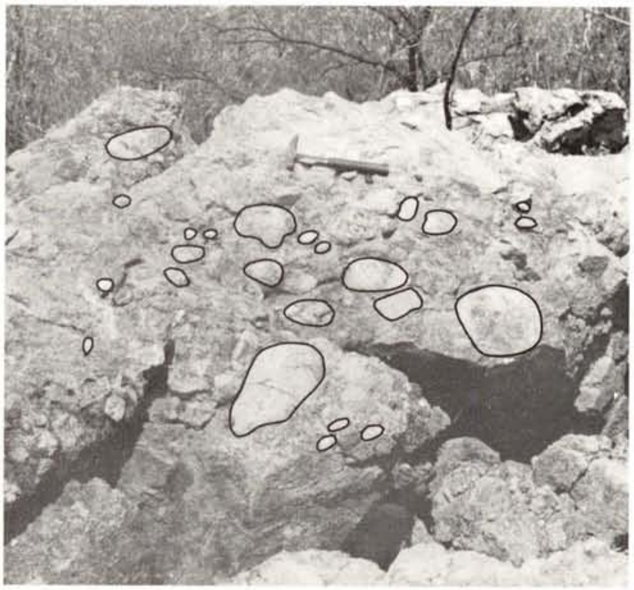
c

b

d

PLATE 2: a Tensional breccia with blocks showing relatively minor displacement.
b Pebble dyking showing rounded clasts of sericitised granite (some of which are outlined) in a fine-grained quartz-sericite matrix.
c The western face of Mount Turner showing collapse breccia cap.
d Microgranodiorite collapse breccia. Note the tabular sheets of granite set in a fine-grained matrix of quartz and sericite with horizontal foliation owing to compaction.
e Comb-structured quartz veins cutting sericitised Delaney Granite.

a



b

c

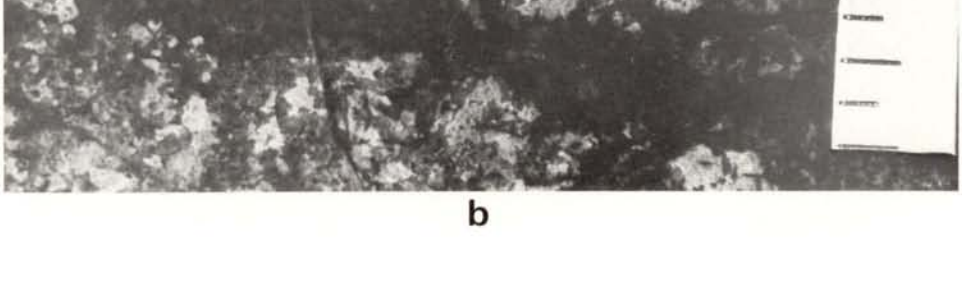
d

e

PLATE 3: a View along a northwesterly trending fissure showing central closed quartz vein.

b Delaney Granite altered under secondary biotite conditions cut by a vein of pyrite-chalcopyrite enveloped by second phase sericite-chlorite alteration. Scale 20 mm.

a



b