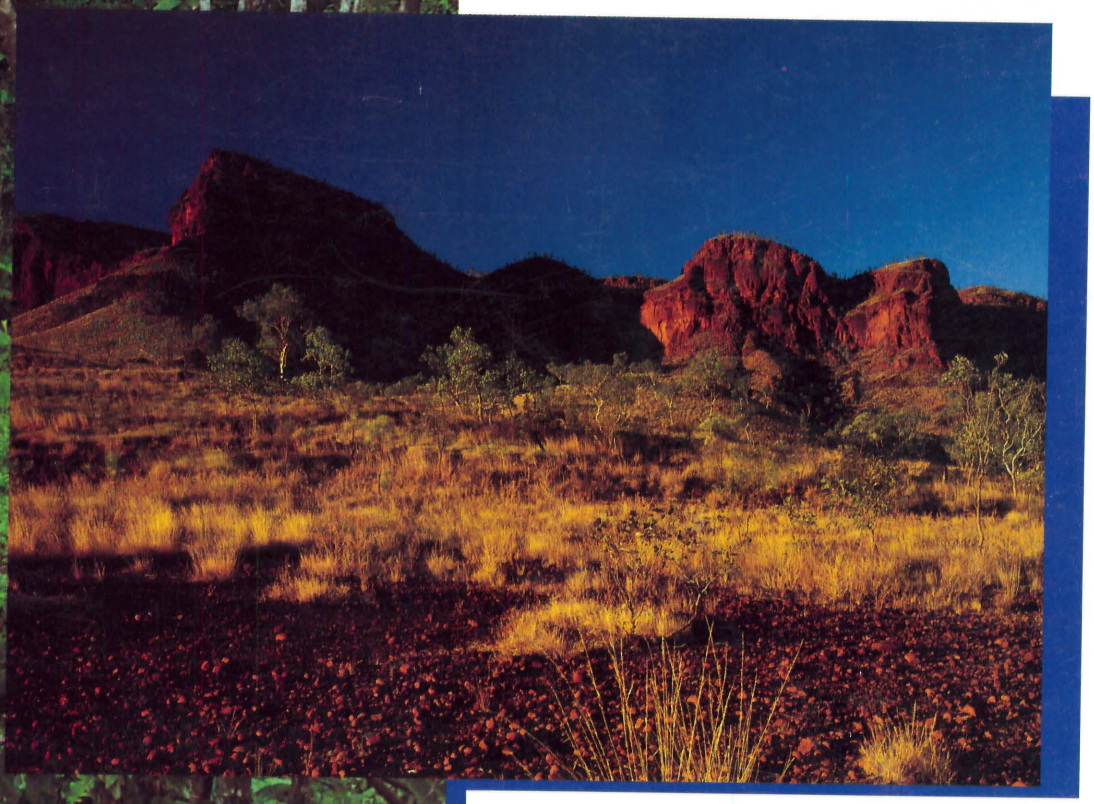
17th IGES
Exploring the Tropics
May, 1995
Townsville, Australia

Mineral Deposits of Northeast Queensland: Geology and Geochemistry

Edited by Simon D. Beams



17th International Geochemical Exploration Symposium

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Exploring the Tropics

Mineral Deposits of Northeast Queensland: Geology and Geochemistry

Compiled and Edited
by
Simon D. Beams

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Foreword and acknowledgements

Simon D. Beams

Terra Search Pty Ltd, P.O. Box 981, Hyde Park, Townsville, Qld 4812

The 17th International Geochemical Exploration Symposium, in Townsville in May 1995, provides a timely opportunity to produce this volume on the Geology and Geochemistry of Ore Deposits of Northeast Queensland.

The theme of the conference, *Exploring the Tropics*, is something the prospecting and mining community has been doing in this part of the world since last century.

The operating mines and undeveloped mineral resources of Northeast Queensland, visited by excursions association with the Symposium, have resulted from the successful application of modern exploration techniques over the last 30 years. Exploration geochemistry has played a key role in the grass roots discovery of several deposits and has significantly assisted the evaluation of many others. In terms of regional geochemical sampling, parts of Northeast Queensland are some of the most intensely explored areas in Australia. An indication of the extent to which private exploration companies have utilised geochemical data to screen large tracts of land is given by the 200,000 plus regional stream sediment, soil, and rock chip samples collected from the Charters Towers Province and the Drummond Basin alone.

Mineral projects generally follow a well defined pattern of an early regional exploration phase, (occasionally) leading to a discovery, then evaluation and development phases to prove up an ore body. At each phase of a project there are incremental leaps in the volume of data produced which tend to swamp the original, often sparse, regional surveys. Thus, for most deposits, a plethora of infill and follow-up sampling often makes it difficult to view geochemical data sets as they would have appeared to the original explorers.

When I first concieved this project, I envisaged that the end result would be a bench mark volume on the geology and geochemistry of the ore deposits of Northeast Queensland. The individual deposit papers would report, often for the first time, data on the discovery history and exploration geochemistry which are mostly locked away in company files.

In this volume, a range of deposits are examined which are at various development stages: from advanced exploration properties, undeveloped but defined resources to operating and finally decommissioned mines. In each case exploration geochemistry is discussed utilizing original data. If relevant, the role of geochemistry in the evaluation, exploitation and waste management aspects of the deposit is also examined in relation to the geology.

Many people considered that such a collection of papers would be unlikely to be assembled in the time available. Indeed this would have been so without a team of extremely dedicated and competent people. My special thanks go to: Kaylene Camuti from Lantana Exploration who collated and helped with editing of many of the papers and organized the printing; Deirdre Rodwell from Terra Search Pty Ltd who typed and collated much of the text from first to final drafts; David Jenkins from Terra Search Pty Ltd who organised many of the geochemical computer plots; finally my family who, although having to bear the brunt of my long hours in the office, still welcomed me back home.

This work would not have been possible without the tremendous support of all the mining and exploration companies and individuals involved in the deposits discussed here. They willingly provided hitherto confidential data sets and as well as allowing individual authors time to write the papers.

Sincere thanks go to:

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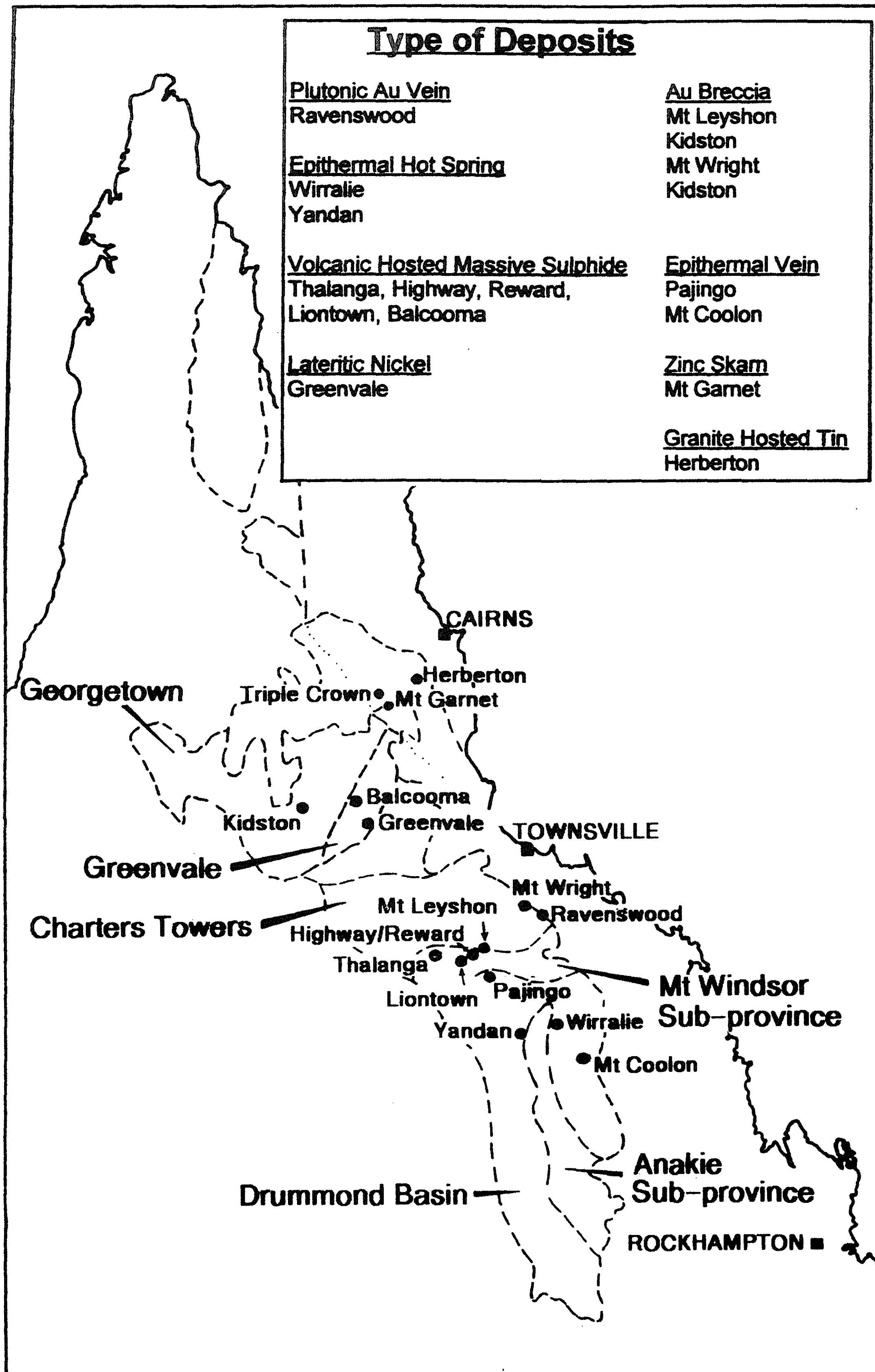
Thanks to the Economic Geology Research Unit (EGRU) at James Cook University, Townsville and its Director Associate Professor Roger Taylor for providing the ideal forum to unite such an industry group.

I am proud to say that this volume exceeds my expectations as a showcase for North Queensland geological expertise and exploration techniques. The goodwill exemplified by the cooperation necessary to bring it to fruition is an illustration of one of the strengths of the mining and exploration industry in Australia: the sharing of data for the common good. Explorers will derive great benefit from the bringing together of the practical knowledge gained on the geology, geochemistry and mining of the ore deposits of Northeast Queensland. In this era of information technology, dissemination of knowledge such as this can only lead to further discoveries and beneficial economic growth.

I would also like to thank *Economic Geology,* and the Australasian Institute of Mining and Metallurgy, for permission to reproduce the following figures:

Fig. 4, p10, from *Economic Geology*, 1992, Vol. 87, p532;
Fig. 5, p10, from *Economic Geology*, 1992, Vol. 87, p532;
Fig. 6, p11, from *Economic Geology*, 1992, Vol. 87, p479;
Fig. 7, p12, from *Economic Geology*, 1992, Vol. 87, p476;
Fig. 8, p16, from *Economic Geology*, 1992, Vol. 87, p480, 758;
Fig. 9, p17, from *Economic Geology*, 1992, Vol. 87, p757;
Fig. 10, p17, from *Economic Geology*, 1992, Vol. 87, p790;
Fig. 2, p215, from *AusIMM Monograph 14*, 1990, p1462;
Fig. 7, p227, from *AusIMM Monograph 14*, 1990, p1464.

The major gold and base metal mineral deposits of Northeast Queensland



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Geological setting and mineralisation style of ore deposits of northeast Queensland

Gregg W. Morrison[1] and Simon D. Beams[2]

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Introduction

Northeast Queensland hosts some of the major gold and metal mines in eastern Australia. The region, with its geological diversity in terms of geological age, tectonic associations, lithologies, magmatic affinitites, regolith and landscape evolution, and mineralisation styles, presents a challenge to the mineral exploration industry. The long and continuing history of mineral development in northeast Queensland is a measure of the success of explorationists in meeting this challenge.

This paper is a summary and update on the reviews of Murray (1990), Morrison (1988) and Berry et al. (1992). It includes new data on the age and geochemical character of many of the significant deposits.

Regional Settling

Northeast Queensland has a Mesozoic-Recent continental sedimentary cover on a Paleozoic continental margin assemblage and inliers of Proterozoic metamorphic basement (Figure 1). The Proterozoic terranes may be continuous beneath cover to the Mt Isa Inlier, whereas the Lower-mid Paleozoic terranes are comparable to the Lachlan Fold Belt of southeastern Australia. The Late Paleozoic terranes, particularly the Coast Range Igneous Province, are best developed in north Queensland and represent a distinctive tectonic regime that is the major influence on metallic mineralisation of this age.

The *Georgetown Province* consists of mid-Proterozoic dominantly continental sediments, progressively deformed and metamorphosed eastward from sub-greenschist up to granulite facies. In the Croydon area the metasediments are unconformably overlain by younger Proterozoic felsic volcanics with cogenetic granitoids. Possible Proterozoic metasediments comparable to these at Georgetown are basement in the *Coen and Yambo Provinces*. Those in the *Anakie Sub-Province* are compared with small inliers elsewhere in the Tasman Fold Belt. Their relationship to the Georgetown Province is uncertain (Withnall et al., 1994).

A major mylonite zone separates the Georgetown Province from the Cambro-Ordovician marine sediments and calc-alkaline volcanic rocks of the *Greenvale Sub-Province* and *Charters Towers Province*. Late Ordovician to Devonian deformation, and metamorphism up to amphibolite grade, was followed by granitoid emplacement, both in these provinces, and in the adjacent Georgetown Province. Similar granitoids are extensive under Paleozoic and younger cover to the south of Charters Towers, and may also underlie sections of the three younger Paleozoic Provinces.

The *Broken River* and *Hodgkinson Provinces* consist of Siluro-Devonian flysch sediments, deformed and metamorphosed in the Devonian, and unconformably overlain by Devonian to Carboniferous shallow marine clastic and carbonate sediments. Comparable Devonian to Carboniferous sediments also overlie the Charters Towers Province, and are extensive south of Charters Towers in the *Drummond Sub-Province*, where they are accompanied by Carboniferous intermediate volcanics. Carboniferous to Permian felsic granitoids constitute the *Coastal Range Igneous Province*, and erosional remnants of the coeval volcanic and subvolcanic complexes are preserved in all the adjacent provinces.

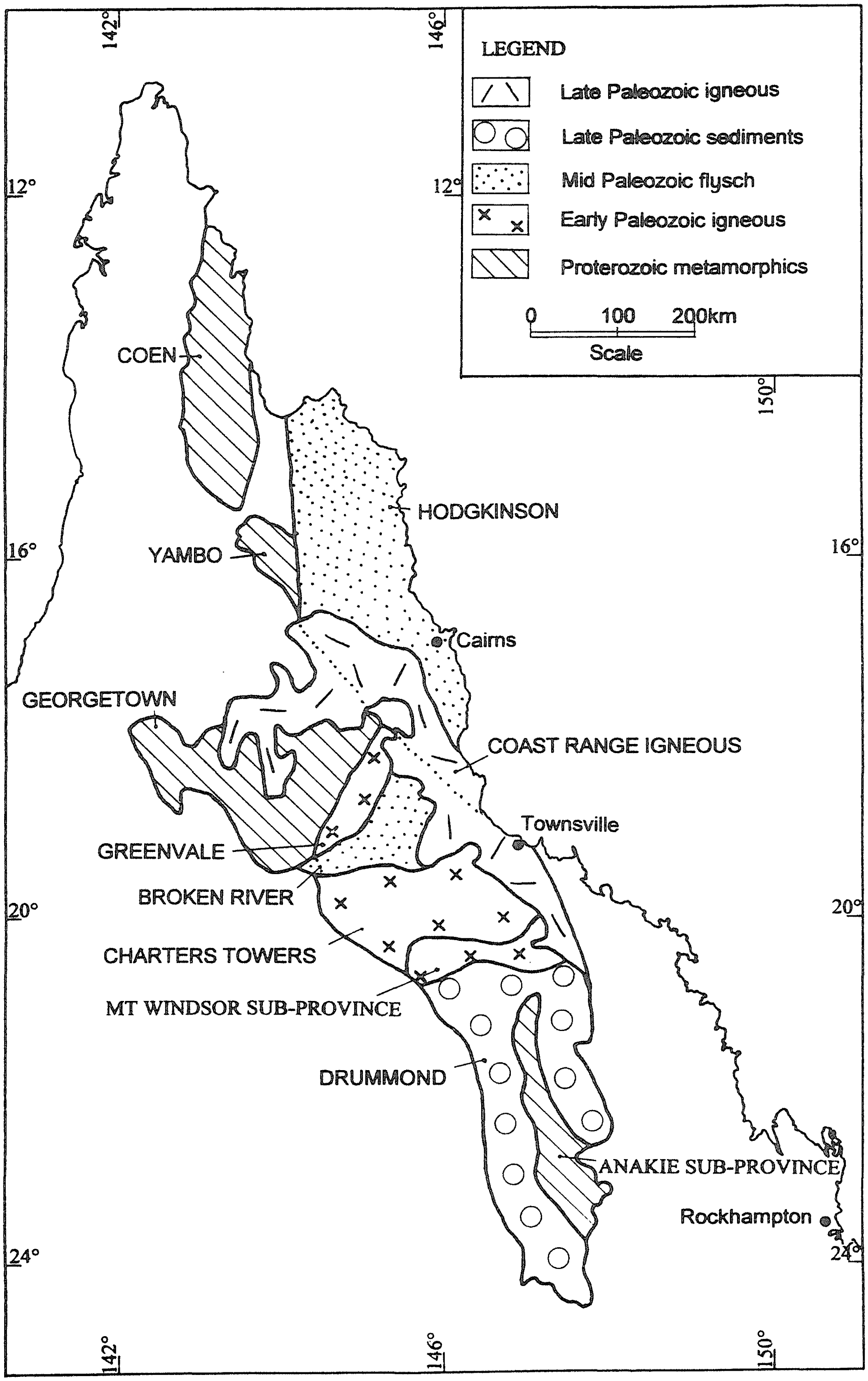


Figure 1 Geologic provinces and subprovinces of northeast Queensland (named), grouped according to age and tectonostratigraphic affiliation (patterns).

Styles of Gold Deposits

Morrison (1988) recognised five distinct environments of gold-mineralising hydrothermal systems in northeast Queensland. The mineralisation styles and their geochemical associations are summarised in Table 1 and Figures 2 and 3.

- The *slate belt* environment is characterised by deformed and metamorphosed flysch, with synsedimentary volcanic rocks and syn- to post-metamorphic granitoids (cf. the Victorian slate belt; Whiting and Bowen, 1976).

- The *plutonic* environment is characterised by batholith scale, pluton level granitoids. The mineralisation host may be older basement rocks, or coeval volcanic and sedimentary rocks. The distinctive features are the brittle-ductile deformation style and the paucity of subvolcanic intrusions (cf. the northern Mother Lode, California; Bohlke and Kistler, 1986).

- The *porphyry* environment is characterised by a complex of subvolcanic intrusions, locally with cogenetic plutons or volcanic and magmatic-hydrothermal products (cf. Laramide and Tertiary systems in the western USA; Proffett, 1978).

- The *volcanogenic* environment is characterised by dominantly submarine volcanic and volcano-sedimentary rocks locally with cogenetic intrusive bodies.

- The *epithermal* environment is characterised by dominantly subaerial volcanic and volcano-sedimentary rocks and cogenetic shallow intrusive bodies.

Quartz veins of various types are the most common style of mineralisation in northeast Queensland. Disseminated style deposits are significant in the epithermal environment, and skarn, stockwork, and breccia styles are major producers in the porphyry environment. The volcanogenic deposits are pipe or massive sulphide style. Replacement and shear-hosted lode styles also occur in the slate belt, plutonic and porphyry environments, but none of the deposits have been significant producers.

Models for the major gold mineralisation styles in the porphyry and epithermal environments are shown in Figure 2. The majority of historic gold production was from plutonic veins, whereas current production and reserves are in the porphyry related breccia systems, and epithermal vein and disseminated deposits (Table 1).

Slate Belt Deposits

Deposits in the slate belt environment are typically veins, fracture fillings and irregular replacement bodies localised by secondary brittle shears cutting larger, often regionally significant, shear zones. Small deposits of this type are widespread in the greenschist or lower metamorphic grade Siluro-Devonian flysch sequences of the Hodgkinson and Broken River Provinces.

Typical lodes have inclusion-rich lenticular quartz bodies in sheared and altered wallrocks. The quartz is massive, milky and deformed with abundant ribbons, stylolites and clear quartz veinlets. Total sulphide content is low (less than 5 percent) with pyrite, arsenopyrite and even pyrrhotite or stibnite dominant over basemetal sulphides. The gold is free, typically of high fineness (+900) and occurs as small irregular masses in the quartz not directly associated with the sulphides. Alteration is only locally observed as narrow phyllic or propylitic envelopes on mineralised veins or lodes.

K-Ar dating of alteration muscovite in the Hodgkinson Goldfield suggests mineralisation is mid-Carboniferous (Morrison, 1988). This post dates the major phases of folding, metamorphism and melange development in the Province, overlaps a phase of brittle reactivation and predates emplacement of nearby igneous complexes. Fluid inclusion and isotope data suggest a crustal fluid with a metamorphic or distal magmatic source and interaction with organic matter closer to the site of deposition (Peters et al., 1990).

TABLE 1: Major gold deposits of northeast Queensland

Classification		Size tonnes Au	Production 1994 oz	Mineralisation Age	Host Rock	Ore Element Association	Gold Fineness Average (Range)
EPITHERMAL							
Vein	Pajingo	13	30398	342	Carbonif. volcanics	Ag Cu Pb Zn ± As Sb Te	700 (632-798)
	Mt Coolon	9	---	316	" "	Ag	
	Woolgar	2	---	Carbonif	Prot. metamorphics	Ag Zn Cu As Sb	603 (550-660)
Hotspring	Wirralie	19	0	344	Carbonif. sediments	Ag As ± F Hg	
	Yandan	13	78825	346	" "	Ag Sb ± Se Hg Te As	~ 500 (460-530)
	Twin Hills	12		345	" "	Ag As Cu Zn F Ba ± U Mo Sn	550 (535-598)
	Hill 273	2		Carbonif	" "	Ag As Sb F ± Cu Zn Te	
VOLCANOGENIC							
Pipe	Highway	2.5	0	Ordovician?	Cambro-Ord volcanics	Ag Cu Zn Pb Ba As	
Massive	Thalanga	5	4650	"	" "	Ag Zn Pb Cu As Sb Bi Mo	830 (320-890)
sulphide	Liontown	2	---	"	" "	Ag Zn Pb Cu	
	Balcooma	2		500	" "	Ag Cu Bi Zn Pb As Sb Mo	740 (670-790)
PORPHYRY							
Breccia	Kidston	140	208962	335	Carbonif. breccia	Ag Bi Zn Pb Cu Mo ± Te F	880 (530-890)
	Mt Leyshon	106	233491	280	Carb-Perm breccia	Ag Bi Zn Cu Pb Mo ± Te Co As Sb	850 (770-898)
	Mt Success	1	---	Permian?	" " "	Ag Zn Cu Pb	
	Mt Wright	1	---	Carbonif?	Carbonif? breccia		
	Triple Crown	1		Carbonif?	" "	Ag Zn Pb Cu As	
Stockwork	Far Fanning	4	0	Permian?	Devonian sediments	Ag Zn Cu Pb Bi	870 (860-885)
	Horn Is	6	0	Carbonif?	Carbonif. granite	Ag Pb Zn As Cu	? 700 (625- 750)
Vein	Coen	4	---	"	Devonian granite	As Pb Zn	600 (460-615)
	Ravenswood	55	41975	310	" "	Ag Zn Cu As Pb	900 (460-940)
Skarn	Red Dome	39	43310	320	Silurian sediments	Ag Cu Zn Bi Te	? 900 (800-995)
PLUTONIC							
Vein	Charters Towers	224	0	400	Devonian granite	Ag Zn Pb Cu ± Te	810 (720-860)
	Croydon	35	0	Carbonif?	Proterozoic granite	Ag As Pb Zn Cu	720 (550-740)
	Etheridge	28	4432	420	" "		675 (660-690)
Lode	Mt Hogan	6	41993	420	" "	Ag Pb Cu Zn ± Sb	740 (705-770)
	Merrilands	1		Devonian?	Cambrian metasediments	Pb Cu As Zn	
	Belyando	5	5887	Devonian?	" "	Ag As Pb Cu Zn	780 (771-794)
	Rishton	8	38374	Devonian	Silurian granite	Ag Pb Cu Zn ± Sb As	>670?
	Christian Kruck	2		Devonian?	Ordovician granite	Ag Pb Cu Zn	

TABLE 1: Major gold deposits of northeast Queensland

Classification		Size tonnes Au	Production 1994 oz	Mineralisation Age	Host Rock	Ore Element Association	Gold Fineness Average (Range)
SLATE BELT							
Lode	Hodgkinson	10	0	328	Silurian flysch	As Pb Zn Cu ± Sb W Mo	810 (710-875)
	Maytown	3	---	Carbonif.	" "	As ± Sb Cu	
	Camel Creek	2	0	"	" "	Sb As ± Zn	
	Minnie Moxham	6	0	" ?	" "	Sb As	~ 900
	Tregoora	2		"	" "	Sb As ± Zn	
Stockwork	Belfast Hill	2		"	" "	Sb As Pb	

Classification: Updated from Morrison (1988)
Size: Based on Morrison (1988) updated by Woodall (1990) and data supplied by current operators
1994 Production: Gold Mining Journal March 1995. 0 = production in last 10 years. --- = historic production only. blank = never produced.
Mineralisation Age: Perkins et al. (1995), Morrison (1988)
Host Rock: Morrison (1988)
Element Association: NQ Gold database - Klondike Exploration
Gold Fineness: Morrison et al. (1991), Rose (1987), Bobis (1992), Sennitt (1991), Digweed (1991)

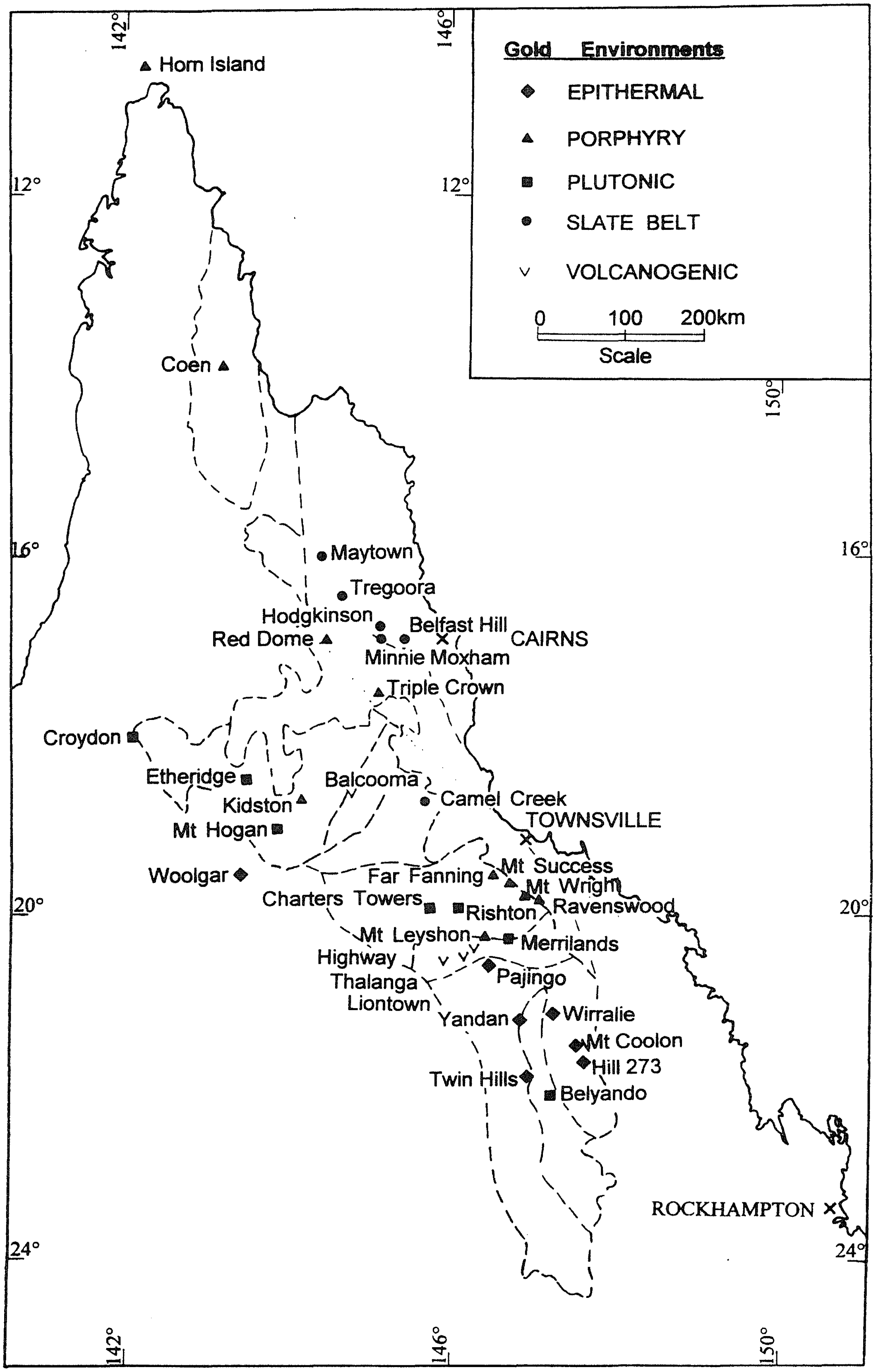


Figure 2 Northeast Queensland gold deposits with more than 1 tonne contained gold (Table 1). Classification by mineralising environment. Base is geologic provinces (Figure 1).

The association of basemetals in the ore and the relatively low gold fineness (average 810: Table 1) suggests the Hodgkinson field has some similarities to the deposits in the plutonic environment and in fact there are plutonic deposits of similar age in the province.

Plutonic deposits

Lodes in the plutonic environment are typically extensive tabular quartz reefs in fissures, particularly in granitoid hosts, or lenticular anastomosing quartz bodies in faults or shear zones. The most productive plutonic veins in the region occur in the Charters Towers area.

Quartz in the lodes is massive and consists of tightly interlocked euhedra; it is sheared, brecciated, cut by veinlets, and infilled with a further generation of vugh-forming quartz in the ore shoots. Mineralisation is restricted to the cross-cutting generations of quartz and is rarely in the primary quartz or the wallrock. A simple pyrite-basemetal sulphide assemblage constitutes up to 20 percent of the shoot, and gold occurs as free grains adjacent to the sulphides, particularly galena. Silver is generally only in gold grains with moderate fineness (approx. 770).

Alteration is a narrow selvage up to two or three times the width of the vein or lode. Close to the vein the assemblage is bright green sericite, with minor carbonate, pyrite and chlorite, and unaltered primary K-feldspar. Further from the vein, dark green montmorillonite-carbonate gives way to pink carbonate, then weak propylitic alteration. No distinct vertical zoning of alteration is evident, even in veins exposed at great depth. However, individual ore shoots may be enveloped by zoned alteration (Peters & Golding, 1989).

The distinctive features are the close spatial and timing relationships to granitoid emplacement in general, but a lack in detail of a specific causative intrusion and the classic magmatic fluid evolutionary path. If the fluid is of magmatic derivation, then it must have originated at deep crustal levels and not within the exposed intrusive bodies (Peters and Golding, 1989).

Porphyry-related deposits

Porphyry-related skarn, vein stockwork and breccia deposits are known from all the provinces but are best developed in the Georgetown and Charters Towers Provinces. All the significant occurrences are associated with Permo-Carboniferous subvolcanic complex with dykes, plugs, stocks and breccias of rhyolitic to trachytic composition. There are distinct clusters of camps adjacent to the major outcrop areas of Permo-Carboniferous granitoids and volcanics but very few occurrences actually hosted within these units. Rather the occurrences are in discrete corridors characterised by concentrations of subvolcanic intrusions and gravity and magnetic anomalies suggesting underlying plutons and in some cases crustal scale faults.

These deposits occur in a variety of forms, including hydrothermal breccias (e.g. Kidston, Mt Leyshon), skarns (e.g. Red Dome), veins (e.g. Ravenswood) and stockwork style mineralisation (e.g. Far Fanning) (see Figure 3).

Common characteristics of porphyry-related deposits are:

- localisation in, or adjacent to, a regional scale lineament;
- association with a multiphase subvolcanic intrusive complex, and demonstrably close timing between intrusive and mineralisation phases;
- brittle mineralised structures with a predominance of fissure fill and open space ore textures;
- early potassic alteration with Cu-Mo stockwork mineralisation formed from overpressured magmatic fluids at approximately 500°C and 30-50% salinity;
- main mineralisation stage with phyllic alteration and base metal-rich mineralisation formed from a magmatic gas condensate at approximately 300-400°C with less than 10% salinity and minor CO_2;

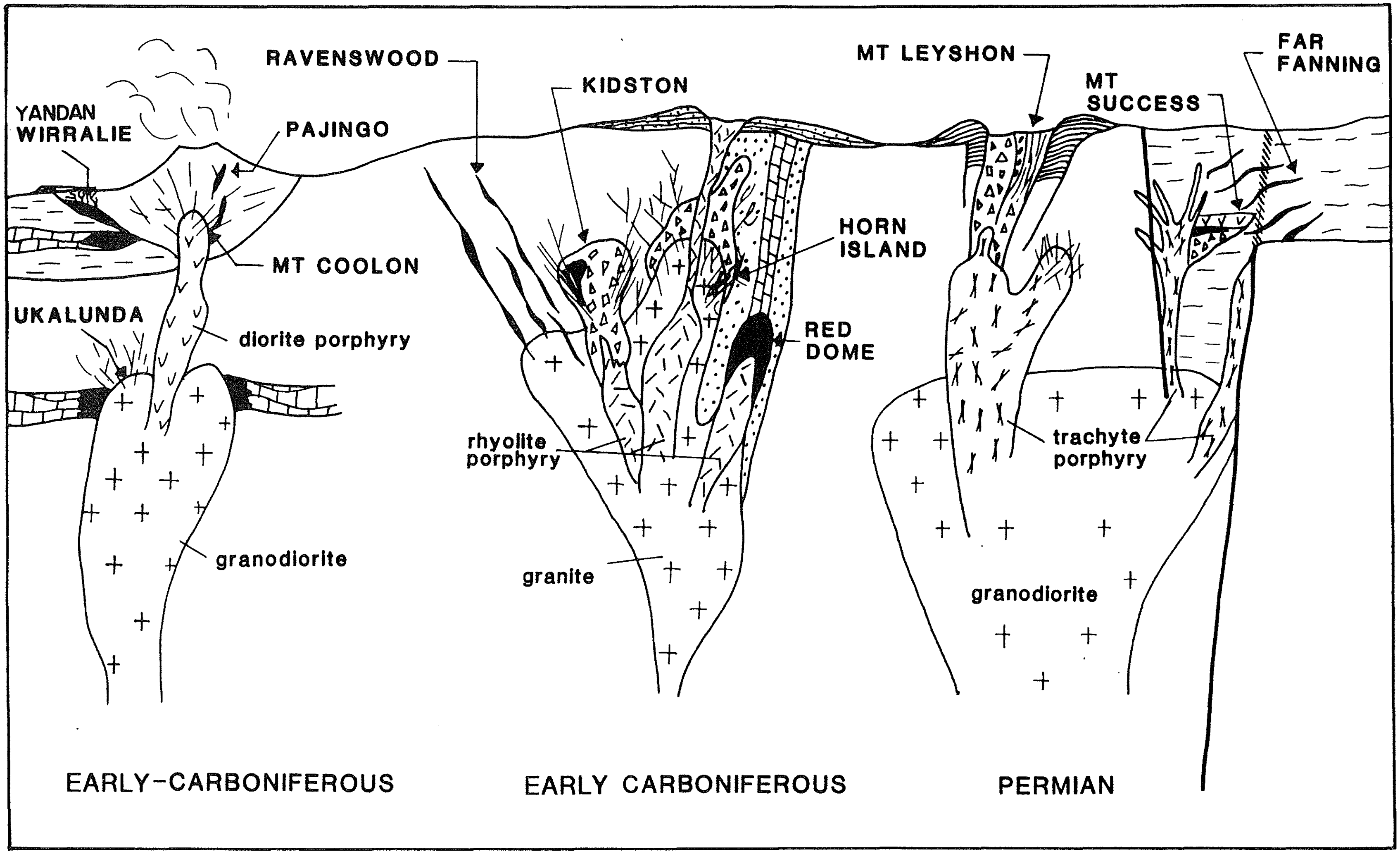


Figure 3 Porphyry and epithermal styles of gold mineralisation in different igneous associations in north Queensland.

- main stage sulphide paragenesis and zoning Fe±As→ Cu+Zn+Pb→Bi+Ag+Au±As,Sb,Te;

- gold locally throughout main stage, but best developed in the bismuth assemblage as free grains, inclusions in sulphides, or as alloys with Te, Ag;

- prominent zoning on a 100-500m scale, from deep barren quartz-pyrite, to intermediate quartz-base metal sulphides-bismuth phases-gold-carbonate to shallow carbonate;

- little or no development of advanced argillic alteration, and minor late stage meteoric water input.

These features are more typical of gold-bearing polymetallic continental felsic porphyry Cu-Mo systems such as Bingham or Battle Mountain than of island arc intermediate Cu-Au porphyry systems (cf. Sillitoe, 1983). The distinctive feature of the northeast Queensland deposits is the development of major low grade polymetallic gold deposits superimposed on sub-economic, poorly developed Cu-Mo mineralisation. In addition, all of the studied deposits have been shown to relate to magmatic hydrothermal systems with little or no evidence of meteoric water input or development of peripheral epithermal mineralisation. However, at Red Dome/Mungana there is a suggestion of peripheral epithermal mineralisation (Nethery et al., 1994) and at Ravenswood difficulties in distinguishing plutonic and porphyry characteristics.

Epithermal deposits

The majority of known epithermal deposits are in Permo-Carboniferous subaerial volcanic terranes with the best examples in the eastern part of the Drummond Sub-Province (Figure 2). Early Carboniferous andesitic volcanic rocks and intercalated sediments host simple vein deposits whereas rhyolitic volcanics and intercalated sediments intruded by flow dome complexes host a variety of vein, stockwork, breccia and disseminated styles collectively referred to as hotspring deposits (Tate et al., 1992).

The simple vein deposits, typified by Pajingo, are sulphide-poor, adularia-sericite types with the classical alteration, ore mineral and vein texture zonation modelled by Buchanan (1981), Heald et al., (1987) and Morrison et al., (1990). Ore shoots, which locally reach bonanza grades, are characterised by a strong silicic-sericitic-argillic alteration envelope, multiphase internal brecciation and a distinctive quartz texture assemblage dominated by crustiform, colloform and moss textures. They are localised by syn-mineralisation deactivation of the lode and its host structure which is commonly a regional scale extensional fault.

The hotspring class of epithermal mineralisation includes the Yandan, Wirralie and Twin Hills gold deposits. Each of these occurrences is characterised by a broad area of both stockwork and truly disseminated mineralisation below a siliceous cap rock. The siliceous cap rock takes the form of a sinter at Twin Hills, a siliceous alteration zone at Wirralie, and possibly both at Yandan. Other characteristic features include an association with major structures, which are often shallowly dipping, and the presence in the district, if not in the deposit itself, of rhyolitic flow dome complexes which may be contemporaneous with the mineralisation.

The characteristics of the north Queensland Late Paleozoic epithermal deposits are quite consistent with current models for Tertiary-Recent vein and hotspring deposits (of Buchanhan, 1981; Nelson, 1988). Fluid data from a range of deposits suggests the systems are dominated by meteoric water and that boiling of deep circulating heated fluids and mixing with cooler near surface fluid are the principal mechanisms of mineralisation. A magmatic source of metal cannot be proven or discounted from the fluid data, but distinct metal assocations for epithermal districts containing intrusive rocks and porphyry style deposits of different chemical character suggest there may be a link (Tate et al., 1992; Figure 3).

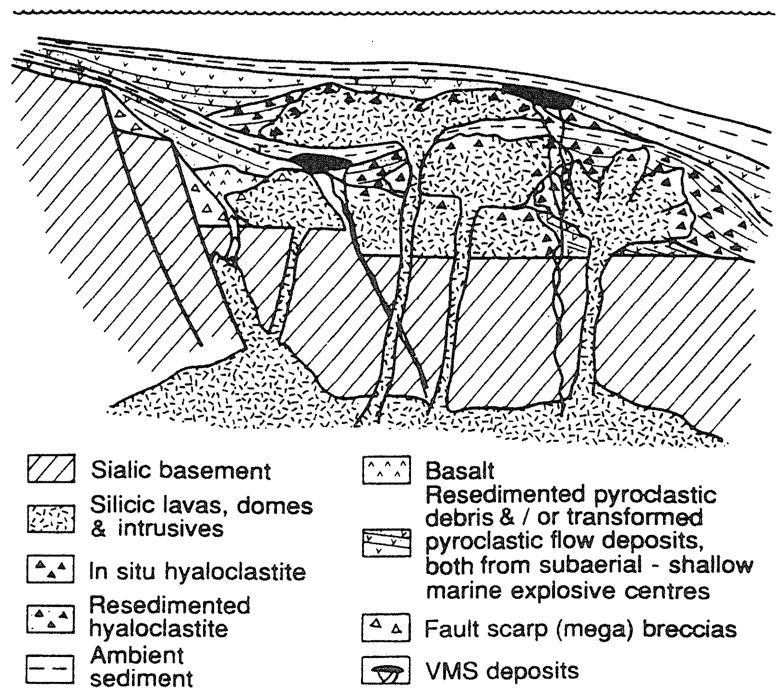


Figure 4 Schematic representation of relation of VHMS mineralisation to submarine silicic lava dome volcanism. From Cas, 1992.

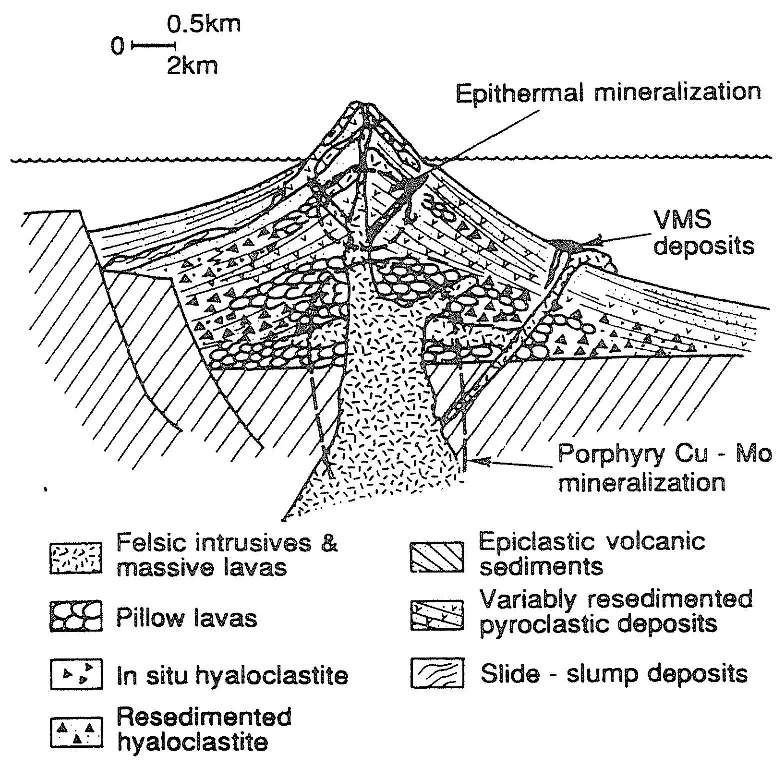


Figure 5 Facies architecture marine strato volcano showing relation to VHMS deposit and epithermal and porphyry mineralisation (Cas, 1992). In this context the VHMS deposit is likely to be derived from a mixture of magmatic and circulation of seawater fluids.

Styles of Polymetallic Base Metal Deposits

Volcanic-Hosted Massive Sulphide Mineralisation

The Cambro-Ordovician Mt Windsor Subprovince, south of Charters Towers, is the most prospective geological province for volcanic-hosted massive sulphide mineralisation in North Queensland.

A steadily increasing knowledge of the geology of the Mt Windsor Volcanic Belt, built up from prospect and regional scale mapping, has allowed interpretation with reference to genetic models of volcanic-hosted massive sulphide deposits. Explorationists have combined this geological understanding with systematically collected bedrock geochemical and (mostly electrical) geophysical data to discover all the known massive sulphide deposits, apart from Liontown, in a little over fifteen years.

The geological and geochemical models for the formation of volcanic hosted massive sulphide (VHMS) deposits have been considerably refined over recent years. Nowadays there is a much greater understanding of the volcanic facies architecture which allows interpretation of the host rock sequence. Figures 4 to 6 from Cas (1992) and Large (1992) show some of the styles of subaqueous volcanic systems and the relationships to massive sulphide mineralisation. Similar facies and relations are interpreted to occur in the North Queensland volcanic belts eg. subaqueous pumiceous breccia, quench fragmental lavas (hyaloclasites) and pepperites have all been recognized (Berry at al., 1992; Beams & Dronseika, 1995).

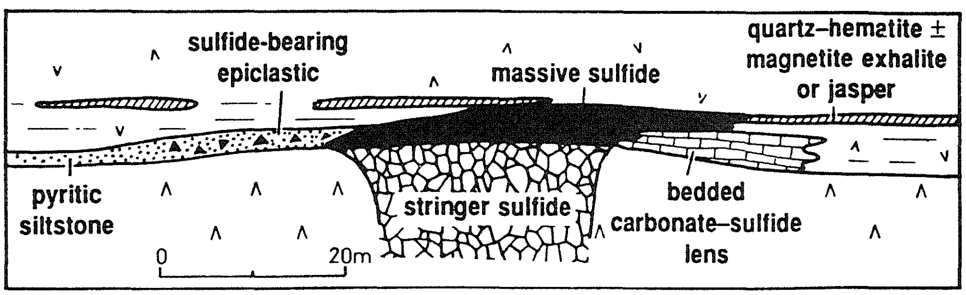
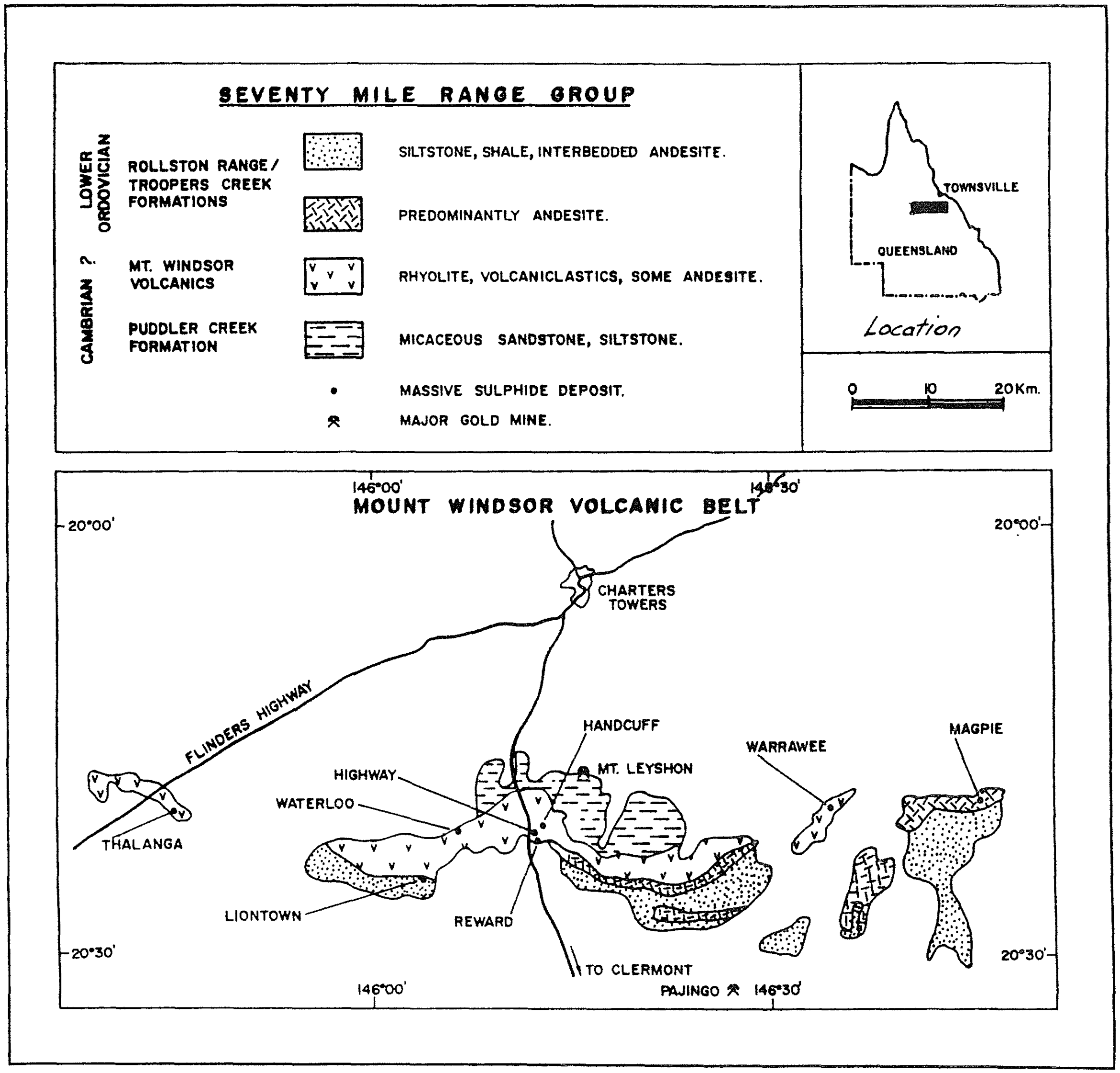


Figure 6 Relationship of mineralisation styles to a favourable horizon within typical Australian VHMS Depsits. Large, 1992.

Massive sulphide mineralisation in the Mt Windsor Subprovince is hosted in the volcanic and sedimentary sequence of the Seventy Mile Range Group (Henderson, 1986). At the base, the sequence consists of a thick series of interbedded micaceous sandstones and siltstones (Figure 7) of the Puddler Creek Formation, which contains no volcanic lithologies, and is derived from granitic/metamorphic basement. Overlying the Puddler Creek sediments are the Mt Windsor Volcanics, a complex suite of rhyolitic, rhyodacitic, and andesitic to basaltic lavas, fragmentals and volcaniclastics. The Mt Windsor Volcanics are overlain by the transitional Trooper Creek Formation, comprising interbedded basalt, andesitic to dacitic lavas and fragmentals, volcaniclastics, and non-volcanic arenites and black shales. The predominantly fine-grained, non-volcanic, sedimentary units of the Rollston Range Formation occur at the top of the sequence.

Subaqueous deposition for most of the Seventy Mile Range Group is indicated by features such a mafic pillow lavas, graded volcaniclastic units, and extensive epiclastic sediments. A graptolite fauna places the Trooper Creek Formation in the Lower Ordovician; the lower units are possibly Cambrian (Henderson, 1983). The sequence is intruded and metamorphosed by Upper Ordovician to Devonian granitoids of the Ravenswood Batholith. Much of the southern and western sections of the Mt Windsor Belt are covered by Tertiary to Recent fluviatile sediments and laterite.



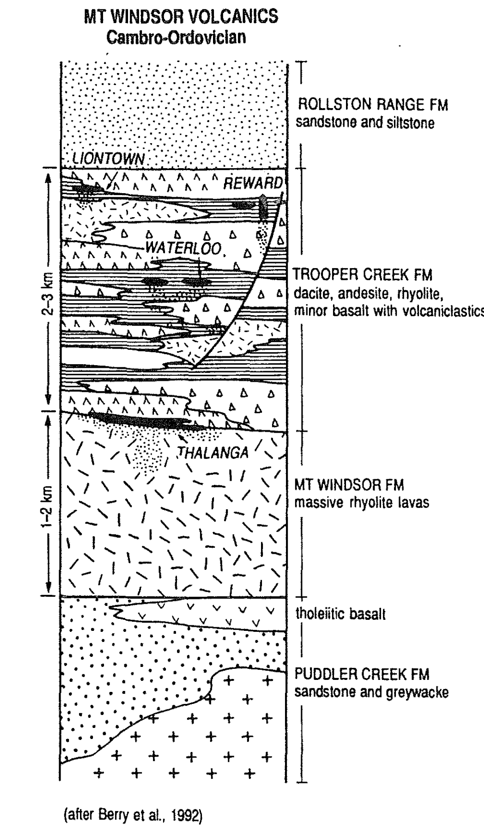


Figure 7
Location & regional stratigraphic relations
Mt Windsor Subprovince.

The succession generally strikes east-west and youngs to the south. It is characterised by low grade slate belt-type deformation of lower greenschist facies, with simple open folding about a subvertical slaty cleavage that trends east-west. Structural complications occur locally, notably in the Highway Synclinorial Zone in the central part of the Belt.

Volcanic hosted polymetallic massive sulphide mineralisation occurs along the length of the Belt (Figure 7). In addition, massive sulphide mineralisation at Balcooma, 250km to the north west in the Greenvale Province (see Figures 1 and 11) is hosted by metamorphosed volcanics which are correlated with the Mt Windsor Sub-Province (Huston et al., 1992, Withnall et al., 1991). Geological setting and mineralisation styles of some of the key deposits in the Mt Windsor Volcanic Belt are illustrated in Figures 8 and 9. Table 2 lists key characteristics of the mineralisation styles. The deposits are described in Berry et al., 1992.

The most prominent deposit is Thalanga; other significant deposits are Liontown, Highway, Waterloo, Reward and Magpie. The mineralisation at Thalanga and Liontown occurs mainly in bedding-parallel lenses of banded sulphides, with barite and fine grained silica + carbonate, interlayered with siliceous volcanic sediments and rare Fe-Mg rich alteration zones (chlorite-carbonate rocks) now interpreted as altered mafic volcanics (Herrmann, 1995). The massive sulphide lenses and associated sediments occur at breaks within the predominantly rhyolitic volcanic pile.

The chemical sediments and banded, predominantly Zn-rich, sulphides are interpreted as volcanic exhalative in origin, formed contemporaneously with the host volcanic sequence (see Berry et al., 1992). Handcuff, Waterloo and Liontown are low total sulphide systems containing only minor massive pyrite and characterised by fine grained, iron poor sphalerite.

At Reward and Highway, large pipe-like massive pyrite-chalcopyrite bodies are transgressive to the stratigraphy. Beams et al., 1989, interpreted the Reward pyrite pipe as being emplaced syn- or post-cleavage development, at the time of peak metamorphism. However, the close association with stratabound/stratiform sulphides (hosted by volcaniclastic units) still suggests a volcanogenic affiliation. More recent work by Aberfoyle Resources Ltd. and their consultants (Beams & Dronseika, 1995; this volume) interpret the pyrite-chalcopyrite pipes as representing high temperature sub-surface replacement feeder zones, at the centre of a large hydrothermal system. These pipes are surrounded by a halo of altered pyritic rocks containing sporadic lower temperature zinc-lead-barite mineralisation as disseminations, veinlets and small exhalitive lenses.

Nearby at Highway, gossanous barite-silica pipe-like breccia bodies are oxidised equivalents of a Reward-type pipe.

Magpie is a small massive sulphide deposit hosted in andesitic to basaltic lavas. Intrusion of granodiorite and gabbro has subsequently metamorphosed the altered volcanic sequence to cordierite-andalusite schists and recrystallised the massive sulphides (Mulholland, 1991).

Feldspar-destructive hydrothermal alteration is associated with all the deposits. Sericite, silica and pyrite dominate the alteration envelopes. Many of the original textures in the stratigraphic footwall are obliterated, whereas fresh feldspar-bearing volcanics occur in the hanging wall sequences overlying the deposits.

In the Greenvale Subprovince the Balcooma deposit occurs as a series of stacked massive zinc-rich sulphide lenses and copper rich stronger zones in a deformed pelitic lens within a sedimentary sequence dominated by metagreywackes (Figure 10, Huston et al., 1992). Nearby the Dry River South massive sulphide consists of a single Zn-Cu-Pb lens which occurs at the contact between intensely altered footwall volcanics and hanging wall metagreywacke.

TABLE 2: VHMS Deposits of Northeast Queensland (After Berry et al., 1992; Huston et al., 1992; Beams, 1993)

DEPOSIT	Thalanga	Liontown	Waterloo	Highway	Reward	Handcuff	Magpie	Balcooma	Dry River South
RESOURCES Grade & Tonnage								Balcooma District	
Primary	7.5mt @ 1.6% Cu, 9.3% Zn, 3.0% Pb, 77 g/t Ag, 0.4 g/t Au	2mt @ 0.5% Cu, 6.6% Zn, 2.3% Pb, 50 g/t Ag, 0.9 g/t Au	0.372mt @ 3.8% Cu, 19.7% Zn, 2.8% Pb, 94 g/t Ag , 2.0 g/t Au	1.2mt @ 5.5% Cu, 6.5 g/t Ag, 1.2 g/t Au	0.2mt @ 3.5% Cu, 13 g/t Au, 1.0 g/t Au	1mt @ 0.4% Cu, 0.2% Pb, 7.4% Zn, 8.8 g/t Au, 0.2 g/t Au	0.25mt @ 1.2% Cu, 1.7% Pb, 8.3% Zn, 37 g/t Ag, 0.2 g/t Au	Polymetallic Primary 3.4mt @ 0.97% Cu, 3.6% Pb, 10.14% Zn, 77 g/t Ag, 0.7 g/t Au Copper Primary 2.1mt @ 3.27% Cu, 19 g/t Ag, 0.5 g/t Au	
Supergene	0.667 mt @ 5.8% Cu, 8.3% Zn, 2.1% Pb, 83 g/t Ag , 0.8 g/t Au				0.3mt @ 11.6% Cu, 21 g/t Ag, 1.8 g/t Au				
Oxide	0.184 mt @ 96 g/t Ag, 1.7 g/t Au			0.07 mt @ 6.04 g/t Au	0.1mt @ 33 g/t Ag, 6.49 g/t Au			Oxide Polymetallic 0.37mt @ 1.4% Cu, 6.0% Pb, 2.5% Zn, 96 g/t Ag, 1.0 g/t Au Oxide Copper 0.36mt @ 4.4% Cu, 15 g/t Ag, 0.4 g/t Au	
Reference	Herrmann, 1995 (this volume) Berry et al., 1992	Berry et al., 1992	Berry et al., 1992	Russell. 1986 Aberfoyle, 1995	Aberfoyle, 1995	Aberfoyle, 1995	Aberfoyle, 1995	Moore, 1995 (this volume)	Moore, 1995
STRATIGAPHIC POSITION	Contact between the Mt Windsor and Trooper Creek Formations	Contact between Trooper Creek and Rollston Range formations	Central Trooper Creek Formation	Central Trooper Creek Formation	Central Trooper Creek Formation	Central Trooper Creek Formation	Central Trooper Creek Formation	Clayhole Creek Beds	Contact Dry River Volcanics & Clayhole Creek Beds
Geometry	Tabular blanket	Tabular	Lens	Pipe	Pipe	Tabular	Lens	Stacked Lenses	Lens

TABLE 2: VHMS Deposits of Northeast Queensland (After Berry et al., 1992; Huston et al., 1992; Beams, 1993)

DEPOSIT	Thalanga	Liontown	Waterloo	Highway	Reward	Handcuff	Magpie	Balcooma	Dry River South
FOOTWALL LITHOLOGY	Rhyolitic volcanics	Rhyolitic volcanics	Dominantly andesitic and lesser felsic volcaniclastic rocks	Rhyolitic to rhyodacitic lavas and volcaniclastic rocks	Rhyolitic lavas and volcaniclastic rocks	Rhyolitic and dacitic to andesitic lavas	Sediments and intermediate to mafic volcanics	Metagreywacke & volcaniclastics	Rhyodacitic metavolcanics
HANGING WALL LITHOLOGY	Dominantly dacite with lesser andesite	Siltstone, shale, arenite and crystal-rich dacite	Felsic volcaniclastic rocks, argillite and greywacke	Rhyolitic to rhyodacitic lavas and volcaniclastic rocks	Rhyolitic lavas and volcaniclastic rocks	Very coarse rhyodacitic to dacitic fragmental rocks	Dacitic lavas and fragmental rocks	Metagreywacke	Metagreywacke
STYLE OF ALTERATION	Dominantly quartz-sericite-pyrite±chlorite	quartz-sericite-pyrite±carbonate ± sphalerite	sericite-pyrite±quartz	chlorite-anhydrite and quartz-sericite-pyrite	quartz-sericite-pyrite(?)	quartz-sericite-pyrite	chlorite-sericite and quartz-sericite metamorphosed	pyrite-magnetite chlorite schist, quartz-muscovite	pyrite-quartz-muscovite
Year Discovered	1975	1905	1985	1953/1990	1987	1981	1981	1978	1986
Total Sulphide Content	High	Low	Low	High	High	Low	High	High	High
Metal Association									
Primary	Zn-Pb-Cu-Ag-Au	Zn-Pb-Cu-Ag-Au	Zn-Cu-Pb-Ag-Au	Cu-Au-Ag	Cu-Au-Zn-Ag	Zn-Cu-Pb-Ag-Au	Zn-Pb-Cu-Ag	Zn-Pb-Cu-Ag-Au	Zn-Pb-Cu-Ag-Au
Minor & Trace	Magnetite, Bi, Mo, quartz		Arsenopyrite				Pyrrhotite, magnetite	Gahnite, magnetite pyrrhotite, Bi	Magnetite, Bi, Sn, Pyrrhotite
Gangue	Barite, chlorite, carbonate	Barite, carbonate, uartz	Barite, sericite, carbonate, quartz	Barite, quartz	Gypsum, anhydrite, barite	Quartz, barite, carbonate	Quartz, anthophyllite, cordierite	Quartz, cordierite	Quartz, cordierite

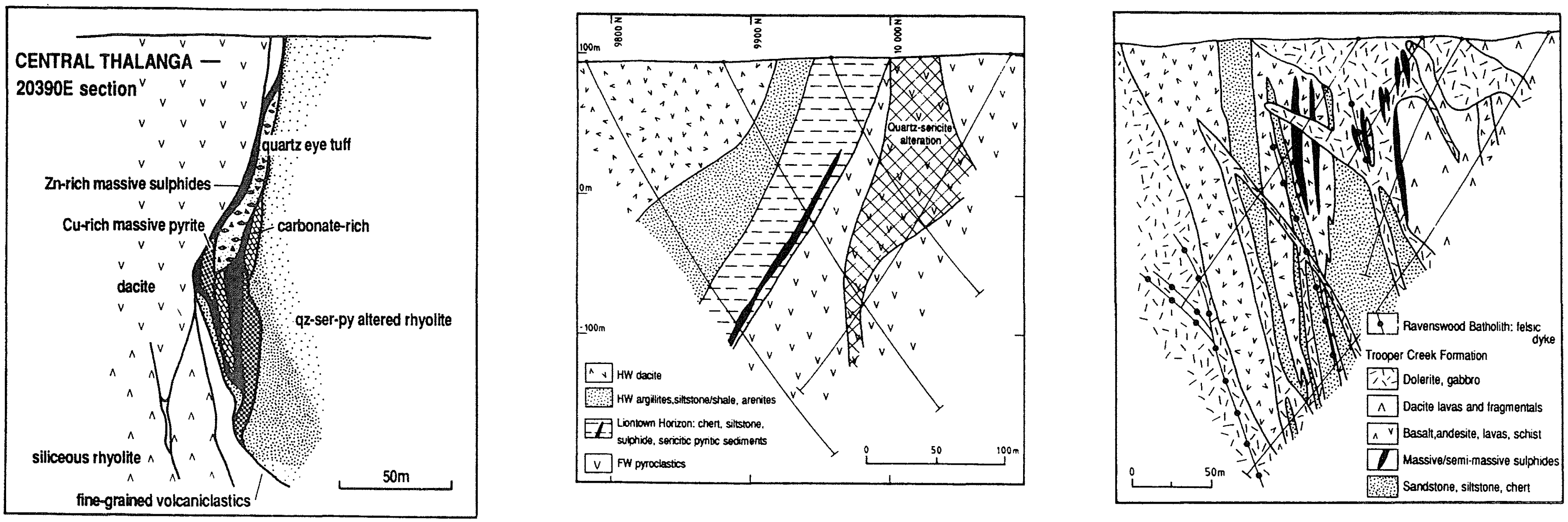


Figure 8 Mt Windsor volcanic hosted massive sulphide deposit styles (From Berry et al. 1992).

A. Thalanga: blanklet like deposit at major volcanic and alteration break. Associated with volcaniclastic units.

B. Liontown: Thin lense hosted in volcaniclastic sediments at major break in volcanism. Massive sulphide also associated with quartz-sericite alteration zone.

C. Magpie: Thin lenses hosted within contract metamorphosed basaltic to dacitic lavas.

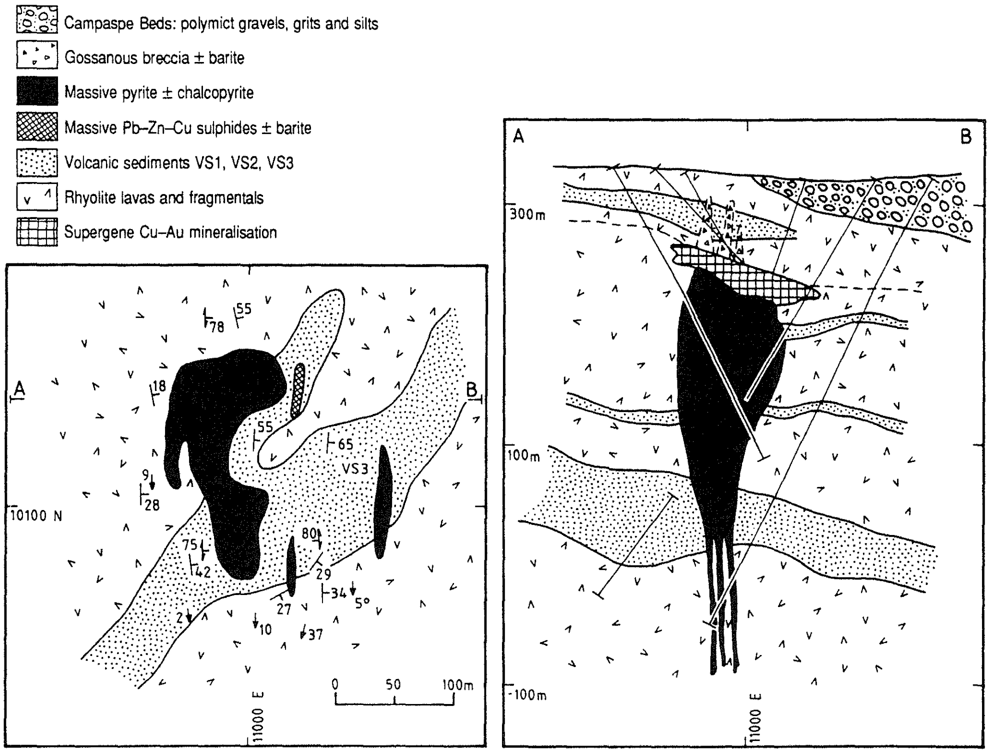


Figure 9 Mt Windsor Subprovince pipe like massive sulphide. Reward deposit plans & section. After Beams et al., 1989; Berry et al., 1992.

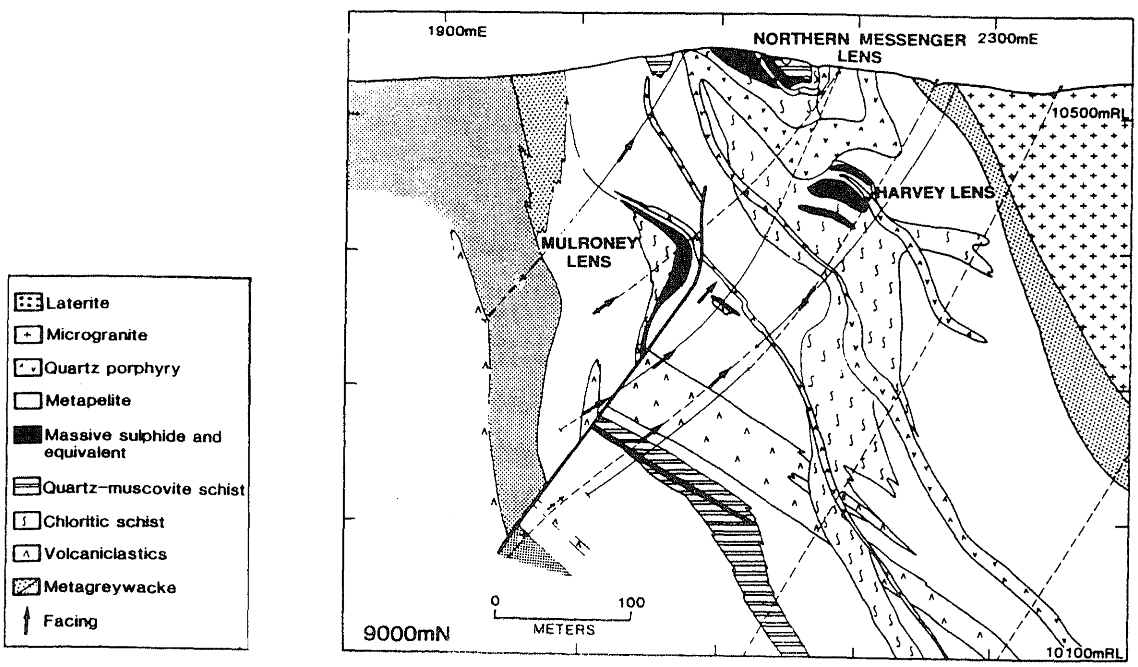


Figure 10 Balcooma, Greenvale Subprovince. Stacked massive sulphide lenses hosted by deformed metasediments. Huston et al., (1992).

Other Base Metal Deposits

Other northeast Queensland base metal deposits of various styles are listed in Table 3.

The Einasleigh Metamorphics within the Georgetown Province host more than twenty small base metal deposits in the Einasleigh and Gilberton areas. (Bain et al., 1990). These are generaly massive stratabound concentrations of iron and copper sulphides ± silver (e.g. *Einasleigh*), iron and zinc sulphides (e.g. *Eveleigh*), iron-lead-zinc-copper sulphides ± silver (e.g. *Mount Misery*), and cupriferous, ferruginous, siliceous and baritic gossans (e.g. *Werrington* area).

The deposits are concentrated at a common stratigraphic level within the Einasleigh Metamorphics: at the transition between a lower, dominantly calcareous psammitic sequence and an upper psammopelitic sequence. The deposits are commonly associated with epidositic and diopsidic quartzite, and quartzo-feldspathic granofels and gneiss that may be of volcanic origin. Detailed studies of the Einasleigh deposit (Patrick, 1978) argued for a stratiform and probably exhalative nature of these deposits. It seems likely that most of the other base metal sulphide deposits in the Einasleigh Metamorphics have a similar form and origin. However, recent interpretation by graduate students at James Cook University indicate a skarn replacement origin for the Einasleigh deposits (Mike Rubenach, pers. comm. 1995).

Gregory et al. 1980 described the *Dianne* deposit as a stratiform copper- and zinc-rich pyritic body which forms a small steeply pitching lens within an overturned sequence of interbedded shale and greywacke of the Siluro-Devonian Hodgkinson Formation. No stockwork mineralisation is evident. The strike extension of the stratiform massive sulphide mineralisation is represented by a thin pyritic chert and locally by stratabound pyrite, chalcopyrite and minor sphalerite in a sericitic shale host.

The Mt Molloy deposit comprises two lenses of mineralisation, one cupreous pyrite and the other layered copper- and zinc-rich horizon enclosed in interbedded shale, greywacke, basaltic siltstone breccia and minor basalt. Pyritic chert forms the hanging wall to one lens. A pyritic siliceous siltstone defines a distinct zone in association with the mineralisation and its strike extension.

The deposits have a surface expression as massive to banded gossans. The lower limit of supergene enrichment extends vertically to about 90m with oxidation down to 27m.

Texturally, the deposits show features typical of volcanogenic mineralisation at low greenschist facies grade. These include a prominent primary layering of sulphides, slump features, slaty cleavage folding and transposition, deformation-recrystallisation fabrics and framboidal and colloform textures (Gregory et al., 1980).

The Mt Garnet zinc skarn deposit occurs in a near vertically dipping sphalerite bearing calc silicate garnet skarn. The mineralised host occurs at the contact of Paleozoic sediments and mylonitic schists. (Hartley & Williamson, 1995.)

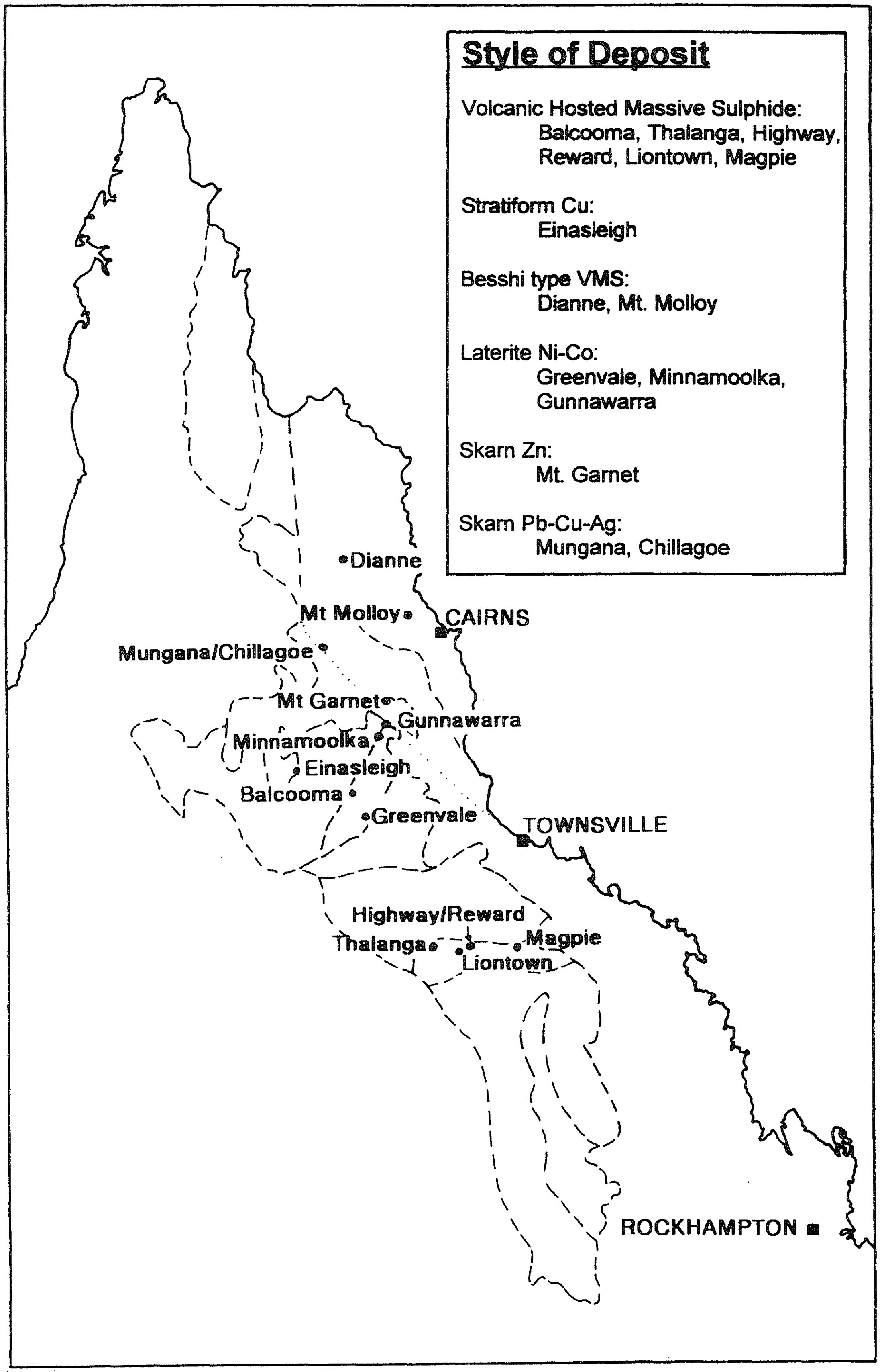


Figure 11 Base metal deposits of northeast Queensland.

TABLE 3: **Other Styles of Base Metal Deposits, Northeast Queensland.**

DEPOSIT	TYPE & AGE	RECORDED PRODUCTION & YEAR	RESOURCE	REFERENCES
Greenvale	Tertiary to Recent Ni-Co laterite	39 mt @ 1.5% Ni, 0.1% Co, 1974-1992	40 mt @ 1.57% Ni 0.12% Co	Bain & Withnall, 1980. Burger, 1979 Queensland Nickel, 1992
Gunnawarra	Tertiary to Recent Ni-Co laterite		9.8 mt @ 1.55% Ni	Bain & Withnall, 1980
Minnamoolka	Tertiary to Recent Ni-Co laterite		3.15 mt @ 1.27% Ni	Bain & Withnall, 1980
Einasleigh	Proterozoic stratiform	0.14 mt @ 6% Cu 31 g/t Ag, 0.5 g/t Au 1900-1924		Patrick, 1978
Dianne	Besshi-Kieslager type volcanogenic massive sulphides of Siluro-Devonian age	1500t Cu 1000kg Ag 1980-1983		Murray, 1990 Gregory et al., 1980
Mt Molloy	Besshi-Kieslager type volcanogenic massive sulphides of Siluro-Devonian age	3870t Cu 1903-1910		Murray, 1990 Gregory et al., 1980
Mungana/Chillagoe Almaden	Skarns in calcareous rocks at contacts with Carboniferous granite	12225t Cu, 42340t lead, 129600kg Ag 1894-1927		Murray, 1990 Gregory et al., 1980
Mt Garnet Copper	Lenses & pipes in calc silicate skarn at contact with Carboniferous granitoid	0.1 mt @ 4.5% Cu, 30 g/t Ag, 4.7% Zn 1901-1903		Hartley & Williamson, 1995
Mt Garnet Zinc	Skarn within Palaeozoic sediments adjacent to mylonite		2 mt @ 9% Zn 0.5% Cu 25 g/t Ag	Hartley & Williamson, 1995

Regolith Related Deposits: Ni-Co Laterite
Nickel-cobalt deposits have been concentrated to economic grade during Cenozoic weathering of ultramafic complexes on the edge of the Greenvale Subprovince.

The only mined deposit (1974-1994), Greenvale has been described by Fletcher & Couper (1975); Burger (1979), and Burger (1995, this volume). Figure 12 is a schematic representation of the styles of mineralisation at Greenvale (after Burger, 1979).

The Greenvale Orebody comprises a series of contiguous laterite profiles developed terrace-like during the Cainozoic over a serpentinized harzburgite intrusive emplaced within Proterozoic schists. Each terrace displays individual characteristics of metal distribution. Topographically higher (older) profiles have been partially eroded and metal concentrations reworked.

Within the laterite profile, metals have been concentrated or depleted according to their relative solubilities. At tropical temperatures, acidic meteoric waters have progressively depleted the ultrabasic parent rock of Si and Mg, leaving Al and Fe to form a surface duricrust. Ni, Co, Mn and Cr have accumulated in the lower and middle levels of the weathering mantle. Only Ni and Co have accumulated to exploitable grades. Fractures control the depth of weathering and grade, more siliceous "pinnacle areas" were generally uneconomic.

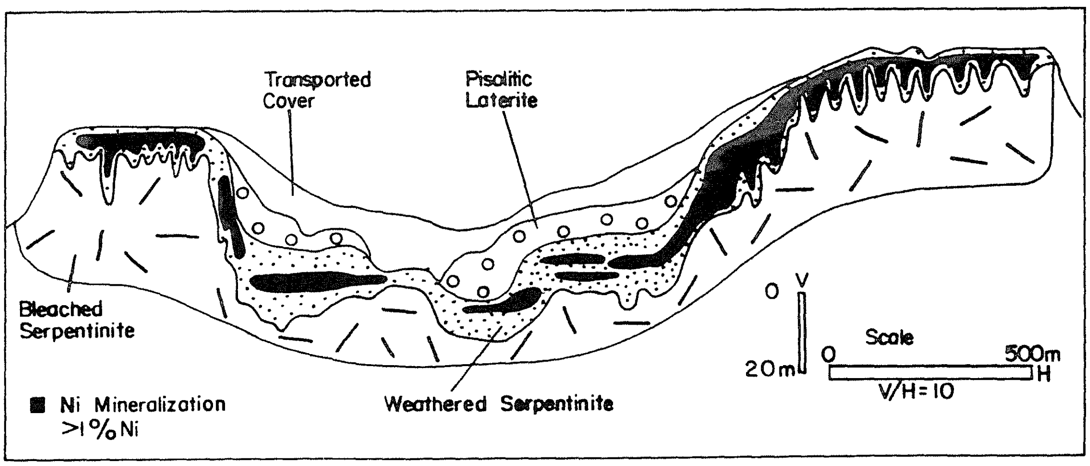


Figure 12 Schematic section showing Greenvale laterite profile and location of main zones of nickel mineralisation. After Burger, 1979.

Tin and Tungsten Deposits

Approximately 200,000 tonnes of tin concentrate have been won from numerous small alluvial and hard rock showings principally in the Herberton-Tate River, Cooktown and Kangaroo Hills Tinfields. Reserves remain in all the fields and in six large low grade deposits (Table 4). Tungsten production is approx. 31,000 tonnes WO_3 of which more than half come from the Mt Carbine mine. Much of the remainder was from two other W-Mo-Bi deposits (Wolfram Camp and Bamford Hill) and approx. 5000 tonnes as by-product from tin mining (Hall, 1980).

Tin and tungsten mineralisation is present in all the provinces N and W of Townsville, but is well developed in the Coast Range Igneous (C.R.I.P.), Hodgkinson and eastern Broken River Provinces (Figure 13). All the major deposits of both tin and tungsten have a Paleozoic sedimentary basement. The most common host in Siluro-Devonian flysch but Permo-Carboniferous granitoids and Proterozoic metamorphics are also locally important.

TABLE 4: Major Sn, W, U deposits of north Queensland

Classification	Name	Size	Production	Reserves		Mineralisation Age	Element Association	Host
Sn-W SUBVOLCANIC		x10³t Sn	t Sn con.	m.t.	%Sn			
vein/pipe	Herberton	77	140,000			315	Sn As Cu Pb Zn Bi W ± Ag Sb Mo, U, In, F	I-type granite + flysch
	Koorboora	8.1	14,600			~ 300	Sn Pb Cu As B	S-D flysch
	Kangaroo Hills	5	9,000			~ 300	Sn Cu Ag Pb As ± Zn, W, Mo, Bi, B, F	I-type granites & S-D flysch
pipe	Vulcan	8	13,712				Sn Bi Pb Cu	S-D flysch
dissem/greisen	Sailor	13		13.5	0.1	315?	Sn, W, F	I-type granite & S-D flysch
dissem/stockwork	Baalgammon	28		11	0.25	313	Sn Cu Pb Zn Ag W As Bi	porphyry + S-D flysch
PLUTONIC								
vein	Jeannie River	54		6.7	0.8	? 275	Sn Pb Zn Cu As W	S-D flysch I-type granite
	Cooktown	8	14,000			?275	Sn W As Cu ± Pb Zn Mo Bi	S-D flysch S-type granite
dissem/sheet vein	Collingwood	28		4	0. 7	257	Sn Cu As Zn B F	S-type granite
skarn	Gillian	13		2	0.67	~ 315?	Sn F Cu Zn	I-type granite & S-D carbonate
	Pinnacles	8		3.2	0.26	314	Sn F Cu Zn As ± Pb, W, Bi, Be	" "
W-Mo-Bi SUBVOLCANIC		x10³t W	t W0$_3$	m.t.	WO$_3$			
vein	Mt Carbine	20	16,400	28	0.1	280	W, Sn, F, B, Zn Cu Mo Bi Cu As	S-type granite & S-D flysch
pipe/greisen	Wolfram Camp	3	7,100			291	W Bi Mo As Cu Zn Pb Sn Ag B, F, Be Te Sb	I-type granite
	Bamford Hill	1	2,250			297	Bi W Mo As F, B, Pb, Zn Cu Ag Au	I-type granite
PLUTONIC								
skarn	Watershed	39				Early Carb?	W As Cu Sn ± Zn, F	S-type granite + brokenite

TABLE 4: Major Sn, W, U deposits of north Queensland

Classification	Name	Size	Production	Reserves		Mineralisation Age	Element Association	Host
U-Mo-F		x10^3t U		m.t	%U			
vein/dissem	Ben Lomond	4.0		1.9	0.21	282?	U, Mo, P ± Cu, Pb, Zn, As, Sb, Ba, B	Early Carb felsic volcanics
replacement	Maureen	2.5		1.65	0.15	Carboniferous?	U, F, Mo P ± Pb Zn Cu As Ba	Early Carb continental seds.

Notes: Production, Reserves, element associations & some geologic data from Murray (1990) and papers referred to therein.
Size calculated from production + reserves assuming tin concentrate at 70% SnO_2
Mineralisation age, interpreted from closest associated granite. Age & composition from Bultitude & Champion (1992) and Champion & Chappell (1992)
Data on Watershed courtesy R. Skryzienski, BHP Minerals pers. comm., 1995.

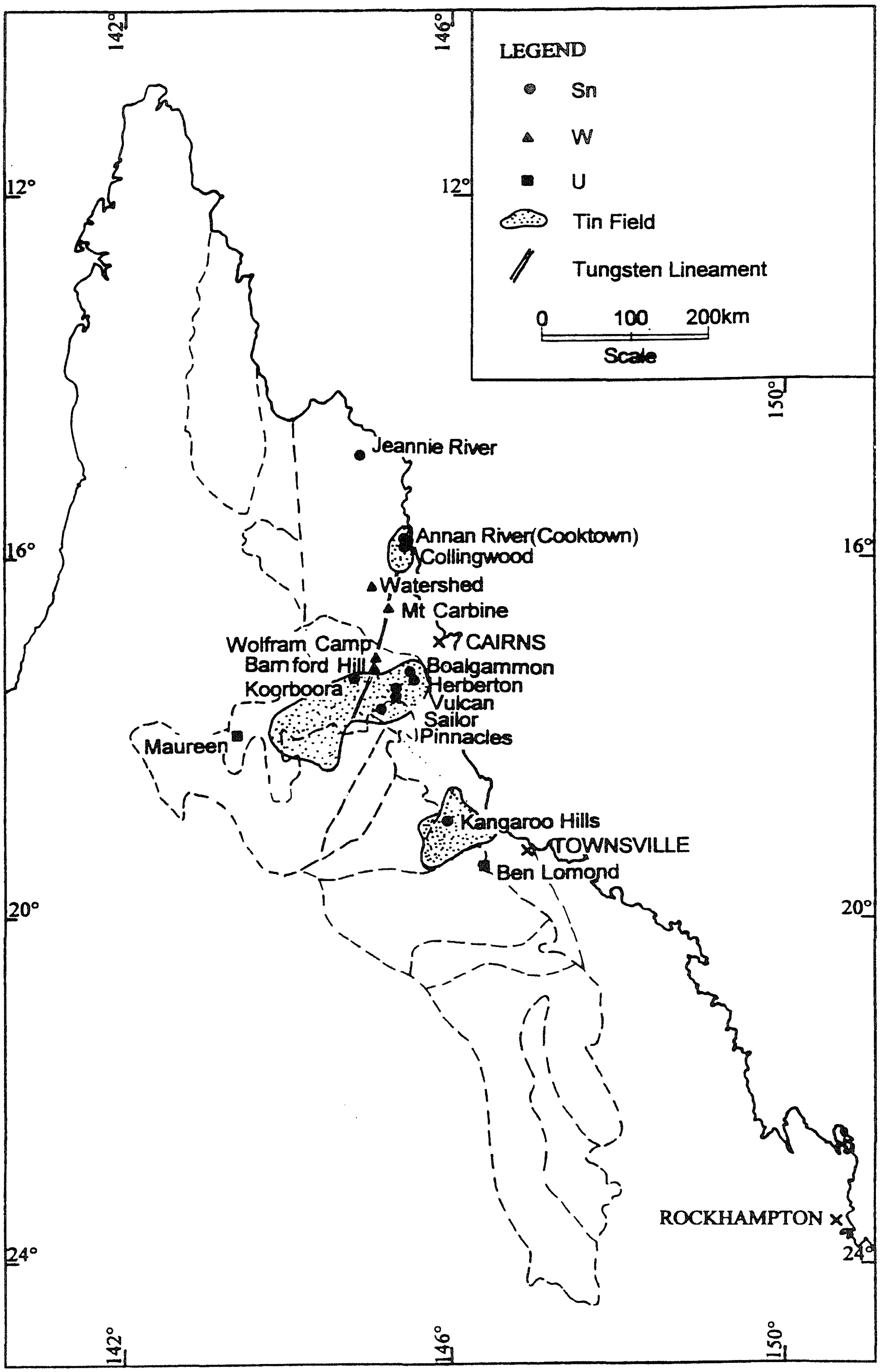


Figure 13 Major Sn, W, U deposits in northeast Queensland and extent of major tinfields.

A distinct group of W-Mo-Bi deposits with little or no Sn are distributed along a NNE trending "tungsten lineament" that crosses both tectonic and igneous provinces (Figure 13). There may be a deep crustal influence on the development of these deposits as there is on the magmas with which they are associated (Champion and Chappell, 1992).

With the exception of the Proterozoic deposits near Croydon, all the studied deposits are genetically related to Permo-Carboniferous igneous rocks. In the C.R.I.P., which includes the Herberton and Kangaroo Hills tinfields, they are felsic I-type granites of Late Carboniferous (320-290 Ma) age (Champion and Chappell, 1992). In the Cairns-Cooktown area, they are S-type granites of Early Permian (~ 280 Ma) age (Bultitude and Champion, 1992). Tin-dominant and tungsten-dominant deposits are associated with both the S- and I-type granites., In the Herberton region tin deposits are associated with the most strongly fractionated supersuite, W deposits with a less strongly fractionated supersuite and basemetal-gold deposits with the most mafic supersuite of the I-type granites. The degree of fractionation may also influence metal ratios within the S-type supersuites.

The tin and tungsten deposits can be classified according to their level of formation in the magmatic hydrothermal system and the style of mineralisation (Table 3, Figure 14). The dominant style of mineralisation is veins and pipes formed by fracture filling and replacement near the contact of intrusives and sediments. Discrete high grade lodes of this style are typical of the shallow to deep subvolcanic environment in the Herbedrton Field (Figure 14). Elsewhere, particularly at Cooktown, there are sheet veins, networks or greisen style complexes that form larger but lower grade deposits more typical of the deep subvolcanic to plutonic environment (Figure 14). Skarns and replacement bodies also occur in this environment where there are carbonate or mafic volcanic hosts, particularly along the western margin of the Hodgkinson Province. Hydrothermal breccia pipes are present in the subvolcanic environment, but no significant deposit has yet been found in them. Rare veins occur in volcanic rocks and some as at Orient Camp and Dover Castle, have an epithermal character but little or no Sn-W mineralisation at this level.

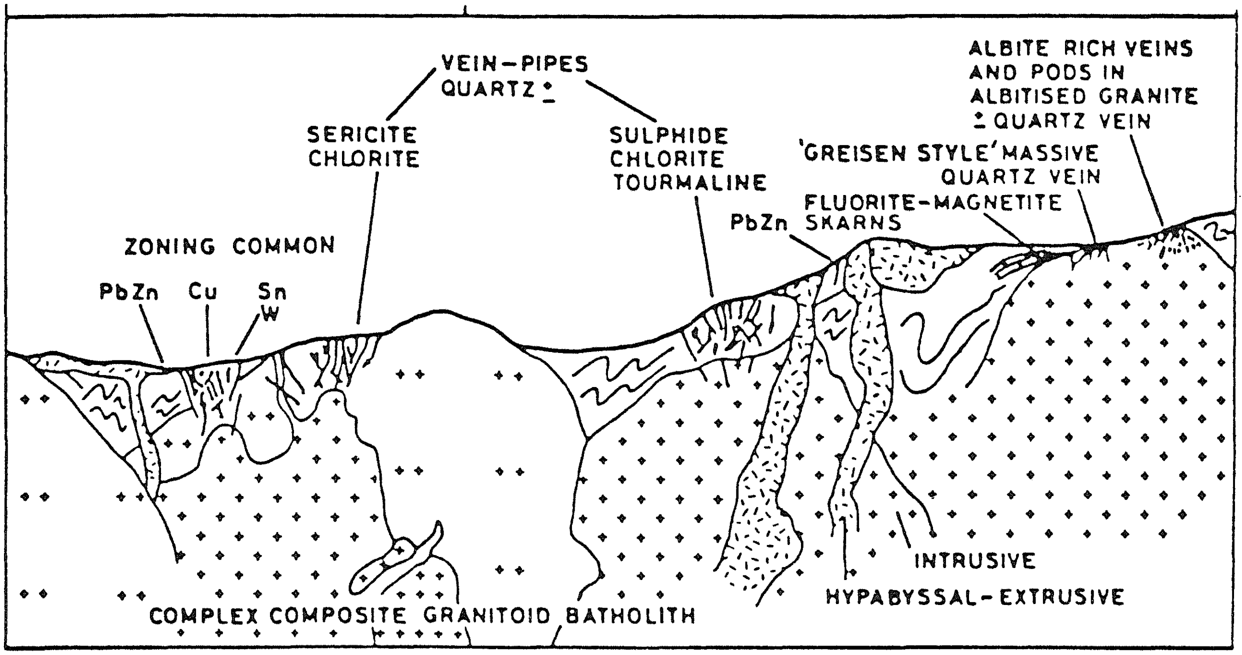
There are distinct zoning patterns for alteration and ore minerals related to the level of emplacement of the magmatic hydrothermal system and position relative to fluid source and channelways. The general sequence represents declining temperature through feldspar/skarn/tourmaline to biotite-chlorite to greisen and argillic alteration. Metal zoning is typically Sn + W + Fe (oxide) ± Mo, Bi, F, As → Cu ± Sn → Pb Zn Ag ± Sb, Au. All or part of these sequences may be present in any particular camp but at some scale the zoning pattern is usually the best vector to mineralisation of various element associations.

U-Mo-F Deposits

Two deposits and numerous small uranium occurrences are associated with the volcanic and subvolcanic parts of the C.R.I.P. (Table 4). Typical deposits are fault localised veins or shear infill hosted in massive volcanics or basement rocks. Fracture networks with replacement zones are in porous hosts such as clastic sediments or volcaniclastics where they are capped by impermeable volcanics. The sedimentary sequences in or below Carboniferous-Permian ignimbrites are favoured, but basement units cut by fault zones that are boundaries to the volcanic fields may also be utilised.

Ore minerals are U-bearing complex phosphates, sulphates or molybdates (e.g. autunite, uranopilite or iriginite) associated with flourite, Ba phases, minor basemetal and As, Sb sulphides and apatite. Clays, sericite, chlorite, silica and hematite are typical alteration phases.

As noted by Bain (1977) the character and setting of the deposits is most comparable to volcanic hosted hydrothermal deposits. The element association and alteration types, particularly the presence of basemetals and As suggests the deposits are of telethermal/epithermal type and possibly part of a larger zoned hydrothermal system. The distribution of the deposits within the C.R.I.P. and the presence of U minerals in some of the lode Sn-W deposits at Herberton suggest they may be the distal part of zoned polymetallic Sn-W hydrothermal systems.



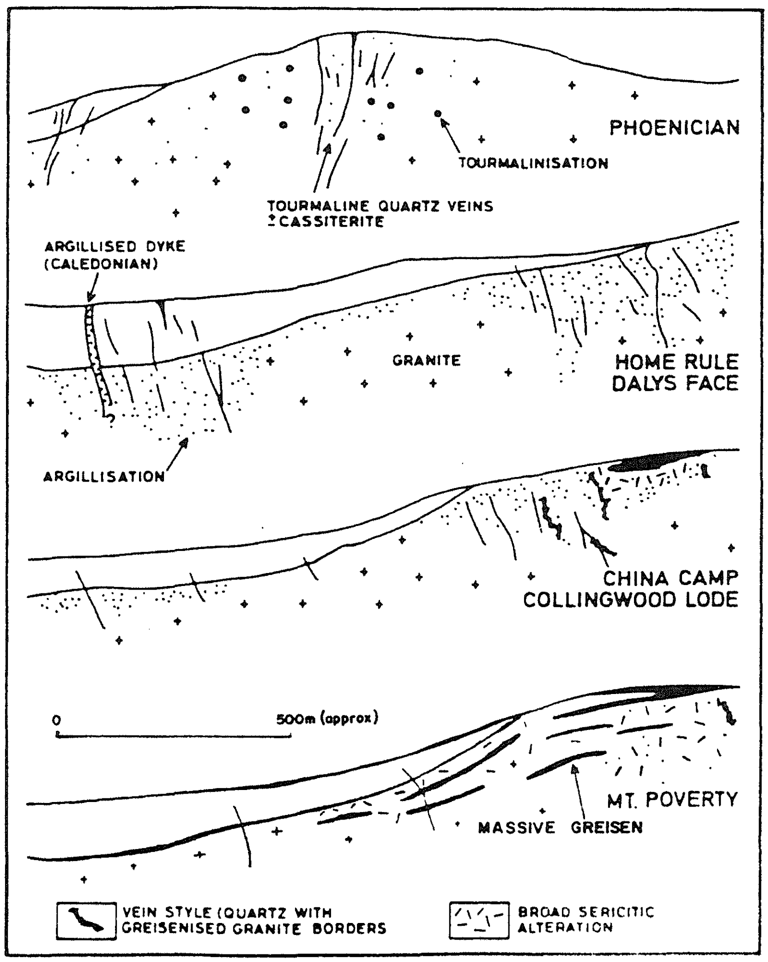


Figure 14 Styles of mineralisation typical of northeast Queensland tinfields.
A. Subvolcanic environment represented by Herberton.
B. Plutonic - deep subvolcanic environment represented by Cooktown.
From Gregory et al. (1980).

Element Associations and Zoning

A compilation of metallic element associations and typical zoning patterns for representative examples of hydrothermal deposits in northeast Queensland (Table 5) demonstrates overlap between deposit classes and consistency within the zoning patterns. The most consistent overall feature is the classic hydrothermal zoning pattern: Sn, W, Mo → basemetals → Au Ag As Sb which is suggestive of deposition on a declining geothermal gradient in all the deposit classes.

The fundamentally polymetallic nature of the deposit classes and partial overlap in element association between classes suggests a common source for the mineralisation. Isotopic studies undertaken on ore fluids (e.g. Baker and Andrew, 1991; Peters and Golding, 1988) and on granitoids associated with mineralisation (Champion and Chappell, 1992; Champion and Bultitude, 1994) suggest a dominant lower crustal source for both magmas and ore fluids. Within the group of magmatic hydrothermal deposits, the difference between Cu-Mo, W-Mo-Bi and Sn-W deposits is partly explained by differences in the nature of the lower crustal, granite source regions and partly by processes that take place in the magma during its ascent (cf Blevin and Chappell, 1992). The confinement of Cu-Mo porphyry deposits to the Charters Towers and Georgetown Provinces is consistent with the interpretation of a dominant I-type source for Permo-Carboniferous magma in these provinces. The extension of Sn-W and W-Mo-Bi deposits from the dominantly S-type source terrane in the eastern Hodgkinson Province into the dominantly I-type C.R.I.P. suggest a composite I-S source for the C.R.I.P. In the northern C.R.I.P. the Sn-W deposits are associated with more fractionated supersuites than the W-Mo-Bi deposits.

In the case of VHMS deposits, it is likely that the metals are derived from a mixture of magmatic fluid and seawater convection and leaching of the volcanic pile (Large, 1992). Seawater convection is likely to contribute more soluble metals: Zn, Pb, Ba, Ag, and Au as a bisulphide complex. Magmatic fluid contributes Cu-Au and possibly less soluble metals such as Bi, Mo (Large 1995). Applying this model to the northeast Queensland context, the Reward Cu-Au pyrite pipe maybe closer to a magmatic centre, likewise the Balcooma deposits with high background Cu, Bi. Deposits dominated by Zn, Ba, Au (eg. Handcuff, Liontown, Reward volcanclastic hosted Pb-Zn-Ag-Au) are likely to be derived largely from hydrothermal seawater circulation.

Metallogenic Epochs and Tectonic Models

Four epochs of hydrothermal mineralisation are recognised in northeast Queensland.

1) Middle Proterozoic (~ 1550 Ma) represented by the Sn deposits at Croydon.

2) Cambro-Ordovician (~ 510 Ma) represented by the massive sulphide deposits of the Mt Windsor and Greenvale Sub-provinces.

3) Siluro-Devonian (420-400 Ma) represented by the mesothermal (plutonic) gold-quartz veins in the Charters Towers, Georgetown, Anakie and Coen Provinces.

4) Permo-Carboniferous (330-280 Ma) represented by mesothermal (Slate Belt and Plutonic) gold-quartz veins and by a wide range of magmatic-hydrothermal (Porphyry-Epithermal) deposits with Sn, W, Mo, basemetals, U and Au. These deposits are spread through the provinces but are genetically linked to emplacement and evolution of the Coast Range Igneous Province.

The Middle Proterozoic epoch is well represented in the Mount Isa Inlier and the Cambro-Ordovician epoch is best compared with western Tasmania. The Siluro-Devonian epoch overlaps with the major phase of magmatism and gold mineralisation in the Lachlan Fold Belt of Victoria and central N.S.W. The tectonic setting during these mineralising epochs is poorly constrained for north Queensland.

Table 5: Zonation of Element Association for Hydrothermal Ore Deposits in North Queensland
Brackets indicate anomalous but minor zones

ORE	U	Sn	Sn	Au	W	Au	Au	Au	Au	Au Cu Pb Zn
ENVIR	Telethermal	Porphyry	Plutonic	Epithermal	Porphyry	Epithermal	Porphyry	Plutonic	Slate Belt	VHMS
E.G	Maureen	Herberton	Collingwood	Yandan	Wolfram Camp	Pajingo	Mt Leyshon	Charters Towers	Hodgkinson	Reward
Shallow/Late	U, Mo, F			(Sb. F)						
		(Sb. Au)	(As. F)	Au Ag As	(Sb. Au)	Au. Ag. As	Au, Ag (As)	Au, Ag	Au, As, Sb	Au Zn Ba
	(Pb Zn Cu As)	Pb Ag Cu (Zn)	(Zn Pb Ag) Cu Bi	(Cu. Pb. Zn)	Pb. Ag. Cu. Zn	(Pb. Zn. Cu)	Zn Cu Pb Bi	(Pb, Zn, Cu)	(Pb, Zn, Cu)	Pb Zn Ag Cu (Au)
Deep/Early		(W. Mo. Bi. F)	(W. Mo)	(W. Mo)	W. Mo. Bi. F				(W, Mo?)	
	(Sn, W)	Sn, W	Sn. B				(Cu, Mo)			

For the Permo-Carboniferous epoch, mineralisation can be related to emplacement of the Coast Range Igneous Province during transtensional disruption of the established Late Devonian-Early Carboniferous Sumatran-type continental arc (e.g. Morrison et al., 1992). Initial crustal scale dewatering gave rise to the mesothermal deposits and was followed by large scale, deep crustal melting centred on one of the major transtensional faults. Hydrothermal fluid evolution in these magmas at subvolcanic levels and interaction with near surface fluids localised the magmatic-hydrothermal deposits.

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Regional exploration geochemistry and the regolith of Northeast Queensland

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Introduction

Over the last 30 years, exploration geochemistry has played a key role in the grass roots discovery of several mineral deposits in Northeast Queensland, and has significantly assisted the evaluation of many others. Mineral exploration companies have utilized geochemical techniques such as stream sediment, soil and rock chip sampling on a regional scale to screen outcropping bedrock. Complimentary to data gathered in these areas of outcrop, bedrock drilling has provided a geochemical data set in regions of transported cover.

This paper presents an overview of the exploration procedures utilised in Northeast Queensland, supported by data from regional exploration programs. It discusses the impact that regolith and landform development has on the design of geochemical exploration programs.

Regolith in Northeast Queensland: General Features

Northeast Queensland, along with most of Eastern Australia, is characterised by complex landscape development and weathering history. Review papers on the topic are: Grimes, 1979; Grimes, 1980; Grimes, 1993; Henderson and Nind, 1994, and Pain, 1994. Beams, 1993, discussed the impact of the regolith on geochemical exploration procedures.

Recent uplift has affected the region. In areas of high relief, east of the Pacific coastal ranges, weathering products can be quickly stripped off. Active erosion, which is currently occurring in this region, probably extends back into the Tertiary, with accompanying sediment deposition and inundation occurring along the coastal strip.

West of the coastal ranges a more complex weathering history is preserved (Figure 1). Several peneplained land surfaces indicate periods of long-lived weathering, interspersed with erosion and deposition of fluviatile, colluvial and lacustrine sediments.

The variability of the effects of weathering is a reflection of the amount of relief. Resistant topographic highs emerge from the peneplains and are characterised by shallow weathering and skeletal soils. Fresh sulphide can be common in surface exposures. In contrast, deep weathering can be present below the peneplained land surface, although even here, total depth of weathering is variable. Inverted drainage often imparts a complexity to the weathering profile. The land surfaces themselves are characterised by duricrust and ferricrete, which caps Tertiary sediments or weathered Paleozoic bedrock.

There are two prominent land forms:

- older surfaces forming dissected plateaux and isolated mesas; and
- younger surfaces which are preserved over topographic lows on a landscape similar to the present day.

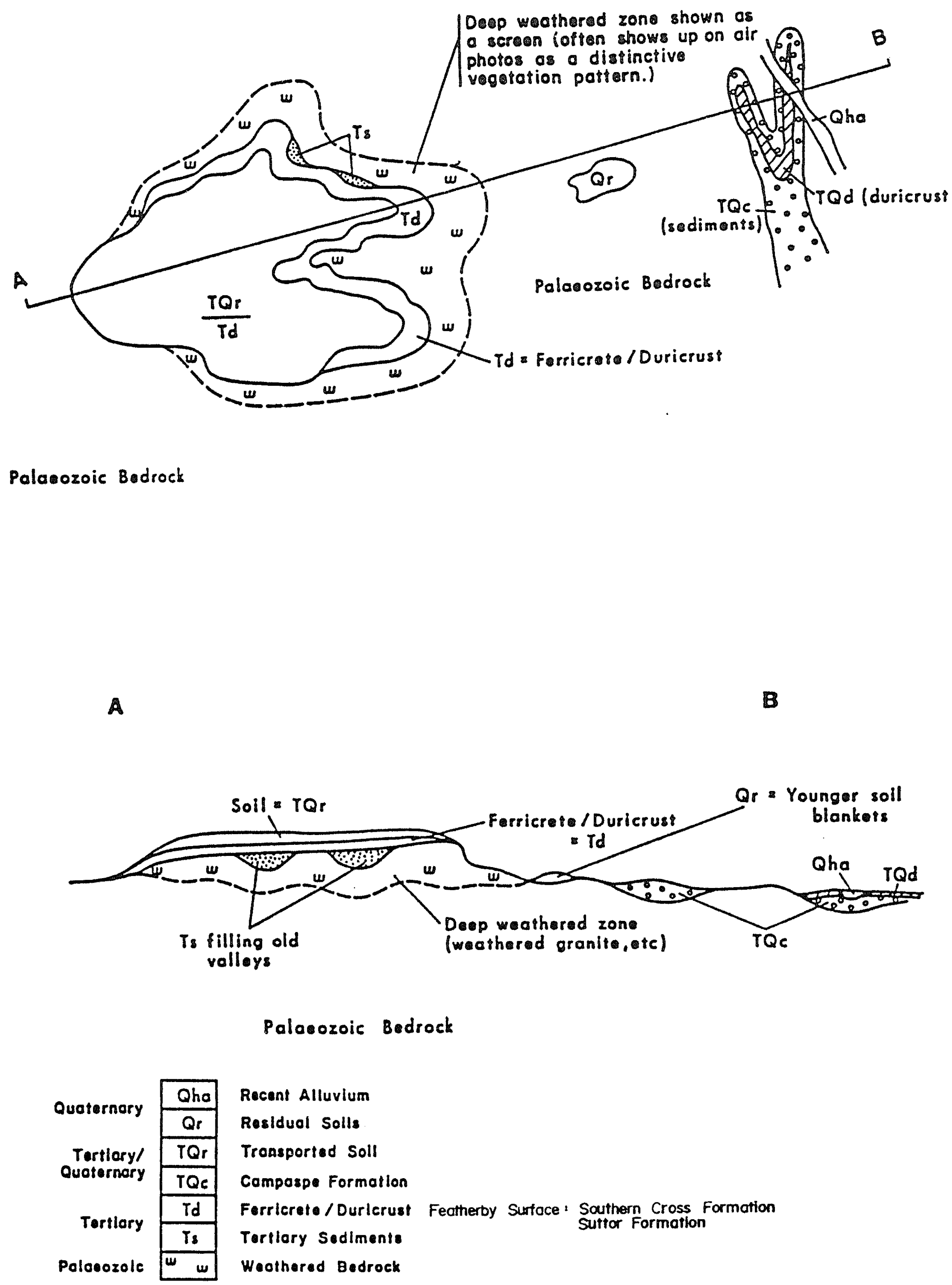


Figure 1 Schematic relations of the North Queensland regolith - plan and cross section. (After Grimes, 1980, pers. comm. 1992; Henderson & Nind, 1994; Beams, 1993)

In the latter instances, cover sediments are primarily channel fill deposits which have smoothed out many of the irregularities in the Tertiary and Quaternary palaeo-surfaces. Grimes (1980, & pers. comm. 1992) broadly identified the older land surface and underlying sediments, represented by the Featherby Land Surface and the Southern Cross and Suttor Formations, as Early to Mid Tertiary.

Henderson and Nind (1994) have summarized the Southern Cross Formation regolith features (see Figure 2). "Sedimentary characteristics indicate a fluviatile and perhaps lacustrine origin for much of the formation but textural immaturity of some exposures suggests that colluvium also contributed to the Southern Cross depositional system. Deep weathering is ubiquitous and ferricrete duricrust is commonly developed in its upper horizons. The upland association of the formation is the product of topographic inversion resulting from the duricrust development. The full weathering profile has ferricrete, mottled and pallid zones and may extend into the bedrock beneath. It is a typical lateritic regolith thought to be developed under a regime of fluctuating water table and warm climate. Tracts of deeply weathered bedrock not directly associated with Southern Cross Formation, and the sporadic development of ephemeral silcrete (grey billy) crusts, are likely to represent parts of this regolith assemblage."

In the Mt Dalrymple area, 125 km southeast of Charters Towers, dating of a basalt flow overlying ferruginous Suttor Formation with which the Southern Cross Formation is correlated, indicates that the latter could be as old as early Eocene (53 Ma) (Sutherland et al., 1977).

The younger surface is represented by the Late Tertiary to Early Quaternary Campaspe Formation sediments and possible correlatives, e.g. the Sellheim Formation.

Geochemical exploration data provided by extensive bedrock drilling has helped to understand the physiography of the basement contact with the Campaspe Formation, adjacent to tracts of bedrock upland (Henderson and Nind, 1994). This palaeosurface shows clear evidence of substantial erosional incision with valleys up to 50m in depth. The direction of palaeodrainage determined by contouring the bedrock substrate is invariably similar to that of the contemporary streams. This relationship, together with the nature of the Campaspe Surface, indicates that deposition of the formation is related to a physiography similar to, but generally with more relief than, that of the present day.

The age of the Campaspe Formation is constrained by its stratigraphic relationships with dated basalt flows. In the environs of Hann Creek it overlies the 3.8 Ma Murrlumbing Flow and underlies the 1.35 Ma Hann Creek Flow (Nind, 1988). Its likely age is therefore Pliocene.

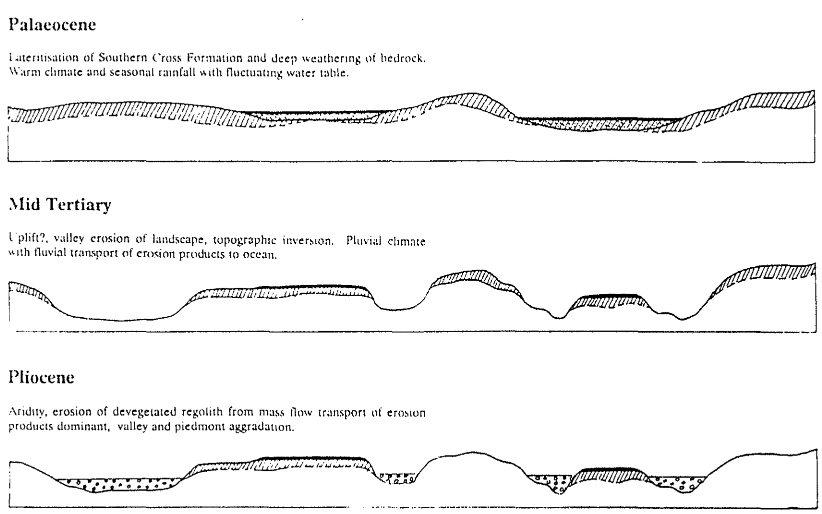


Figure 2 Abridged Cenozoic History of Southern Cross & Campaspe Formation deposition. From Henderson & Nind, 1994.

FERRUGINOUS GRAVEL LAG. TERTIARY?	REWORKED NODULAR FERRICRETE TERTIARY/QUATERNARY?
Mineralogy (weight %) (XRD results) go hm ka qz pdm 25% <5% 22% 31% 22% (±5%) Al-substitution in goethite 9 mole% (±2.6 mole%)	Mineralogy (weight %) (XRD results) go hm ka qz pdm 14% <5% 19% 49-60% 18% (±5%) Al-substitution in goethite 4-7 mole% (excluding re-worked gravel lag sample)
Geochemistry ppm unless otherwise stated (detection limits in brackets) (XRF results) Al_2O_3 (wt%) Fe_2O_3 (wt%) 11-16% (>1 wt%) 17-34% (>1 wt%) As(1) Sb(0.3) Pb(>2) Cu(>4) †Au(ppb)(>3) 132 1.9 34-40 24-36 <3 †Ce(>5) Ba(10) Zr(50) †Hf(0.05) Ti(wt%>0.05) 85-270 230-245 110-224 3.7 0.34-0.51 Σbases(wt%)*ΣR_2O_3(wt%)*R=(FE_2O_3 + Al_2O_3) 0.3-0.8 34-46 Bases = (K_2O + Na_2O + CaO + MgO) †(NAA results)	Geochemistry ppm unless otherwise stated (detection limits in brackets) Al_2O_3 (wt%) Fe_2O_3 (wt%) 6-9% (>1 wt%) 9-27% (>1 wt%) As(1) Sb(0.3) Pb(>2) Cu(>4) †Au(ppb)(>3) 39 1.3 24-34 20-36 <3 †Ce(>5) Ba(10) Zr(50) †Hf(0.05) Ti(wt%) 15-100 15-150 148-296 4.9 0.32-0.35 Σbases (wt%) ΣR_2O_3(wt%) 0.3-0.5 15-36
Micromorphology Ferruginous gravel lag formed by aggradation and hardening of ferruginous mottles developed further down profile. Similar quartz grains textures to underlying weathered granodiorite and mottled zone. Gravel lags possibly formed in situ from granodiorite.	Micromorphology Multi-stage reworking of transported gravel lag with several stages of goethite rinds developed. Quartz grains in the ferricretes are of ranging textures, angular to sub-rounded they bear little resemblance to underlying sediments. Goethite possibly precipitated from iron rich solution carried into detrital gravels laterally by groundwaters.
Landscape positioning Ferruginous gravel lag overlies weathered granodiorite and to a lesser extent Tertiary sediments in the field. Gravel lag was observed in the middle of some mesas and at change in slope on the edges of mesas. Recent effects associated with dissection of mesas may have led to cementing of some of this lag into ferricretes.	Landscape positioning Slabs of nodular ferricretes unconformably overlie Tertiary/Quaternary fluviatile sediments. Such nodular ferricretes also accumulate on valley sides and are generally lower in the landscape than Tertiary sediments and Tertiary duricrusts.

Table 1. Selected characteristics of the two main types of ferruginous accumulations observed at Puzzler Walls. Full results, field and analytical procedures presented in Rivers (1993).

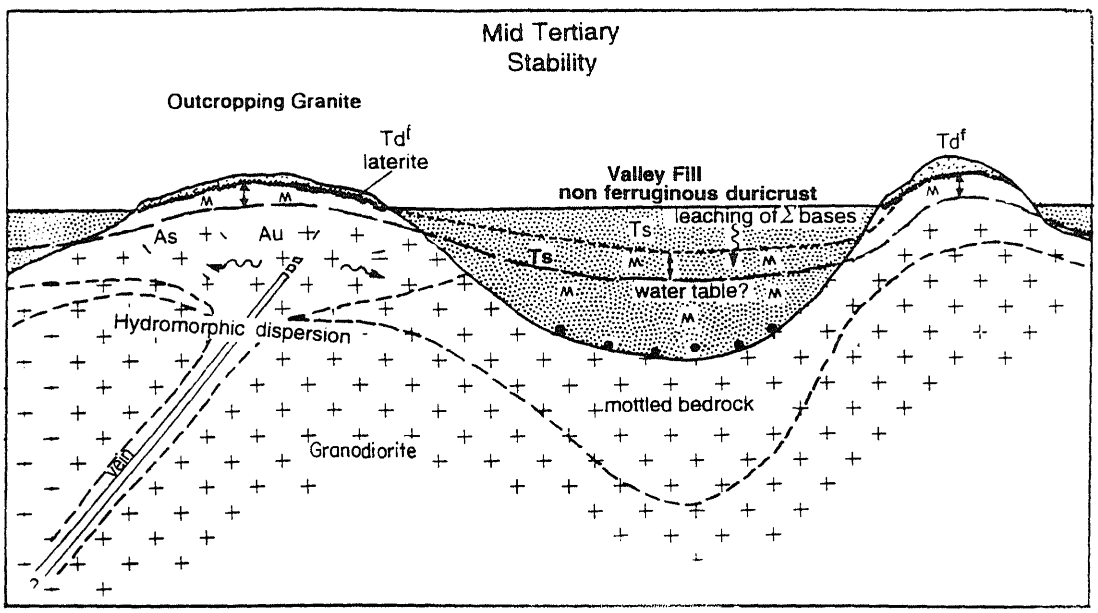


Figure 4a Formation of deep weathering profiles, characterised by lateritic material, during a period of tectonic stability in the mid Tertiary.

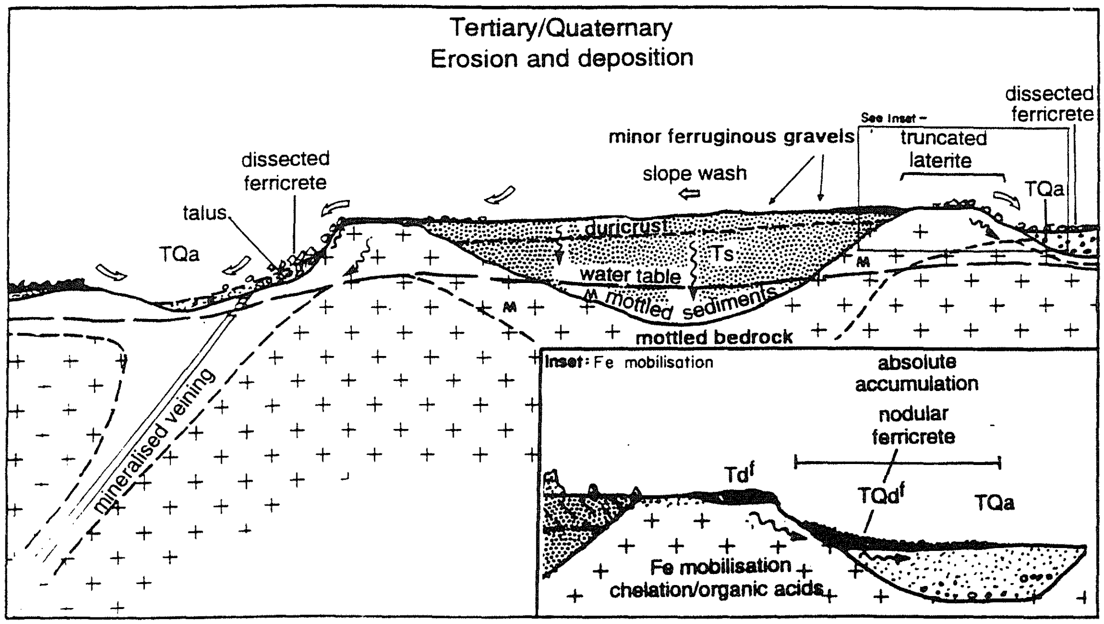


Figure 4b Erosive phase of the late Tertiary early Quaternary, formation of duricrust and partial stripping of lateritic profiles.
Inset: Weathering effects during the Tertiary/ Quaternary and the formation of nodular ferricretes in the Puzzler field area by absolute accumulation of iron.

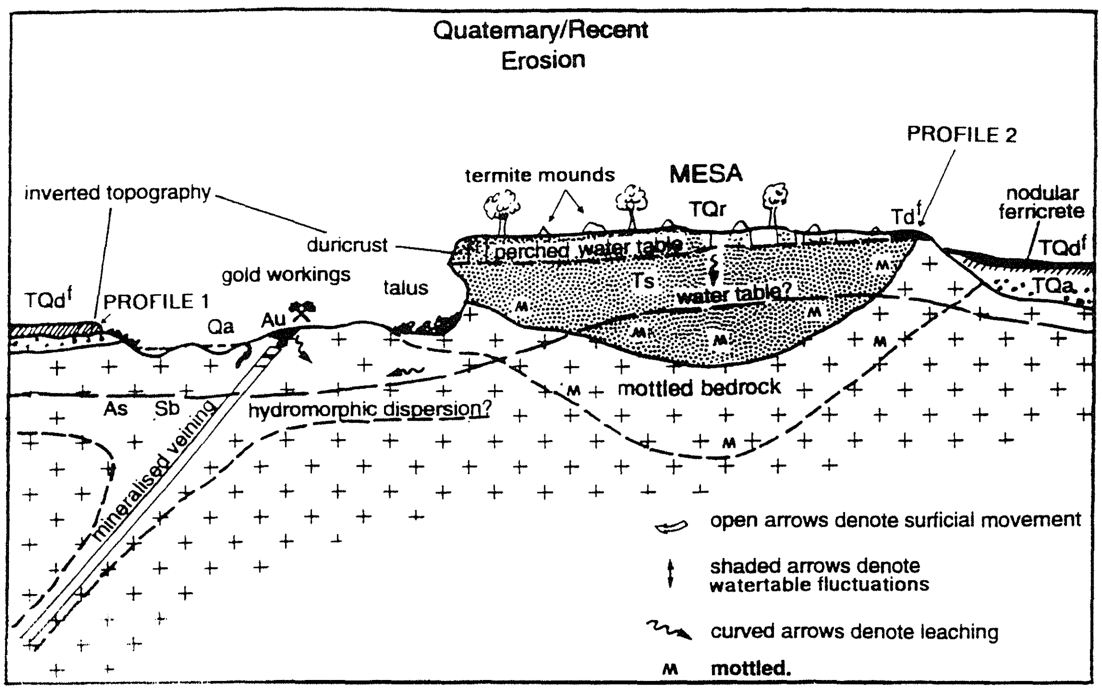
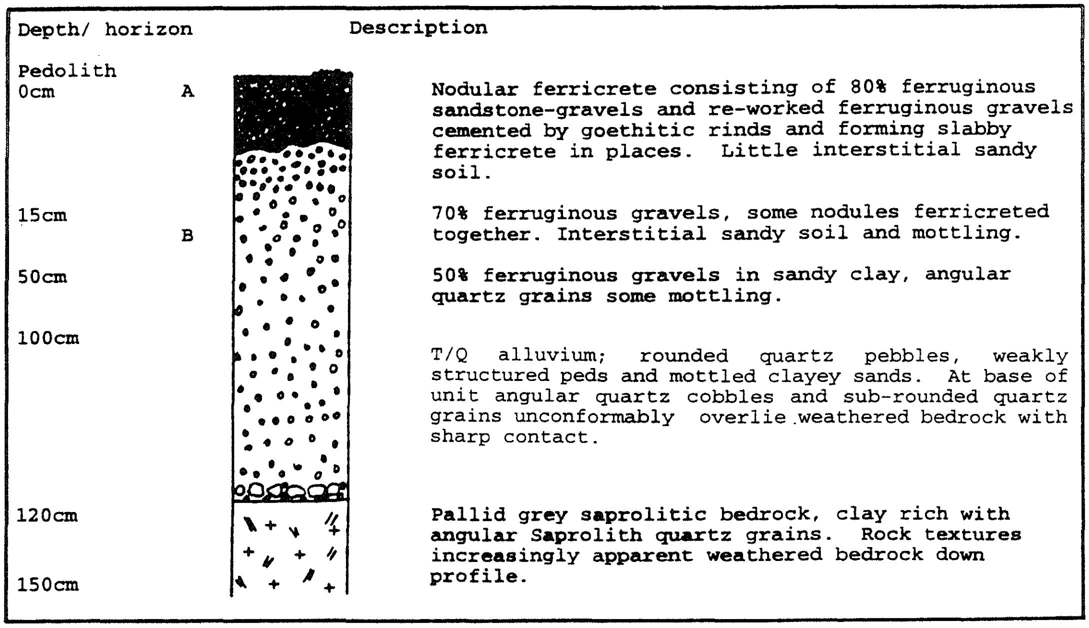
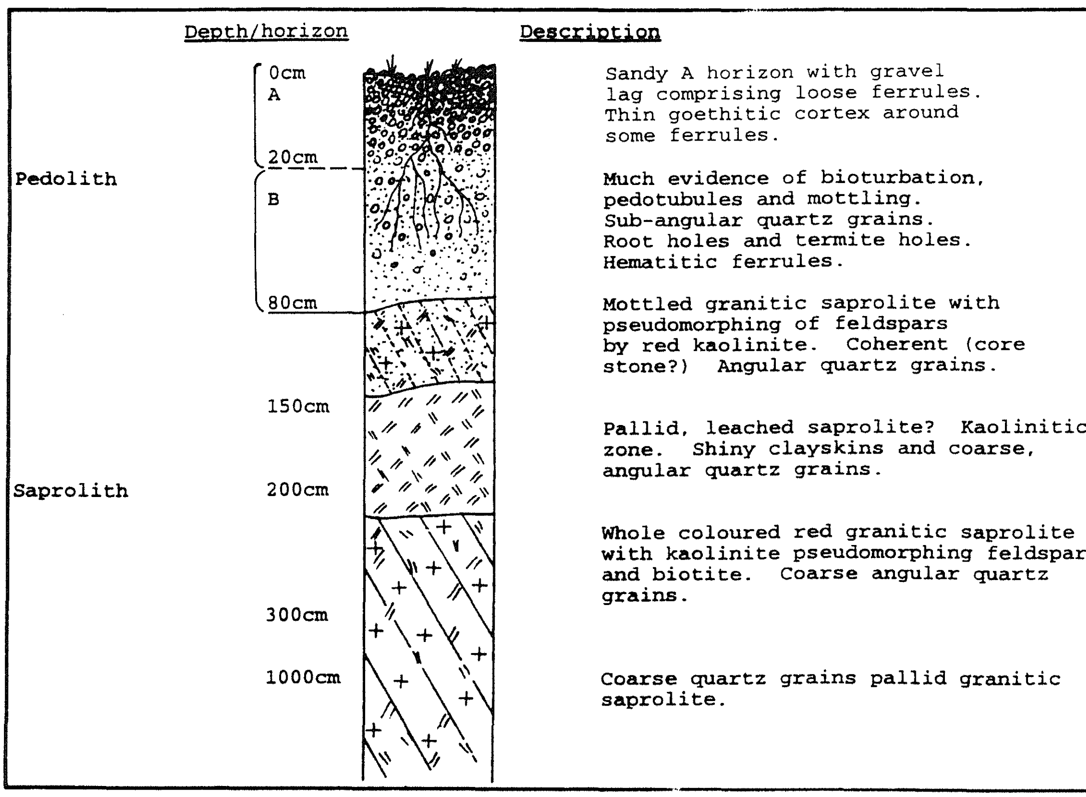


Figure 4c Effects of recent weathering on the Puzzler Walls, showing relative position of selected sample sites.



Tertiary/Quaternary Nodular Ferricrete — PROFILE 1

Reworked nodular ferricrete developed on Tertiary/Quaternary sediments unconformably overlying weathered bedrock.



Tertiary gravel lag — PROFILE 2

Lateritic deep weathering profile developed on granodiorite.

Figure 5 — General profiles Tertiary and Tertiary/Quaternary ferricretes and duricrust developed on Puzzler area. From Rivers et al. (1995).

Ni-Co laterites at Greenvale - Regolith Related Mineralization

The lateritic Ni-Co deposits at Greenvale are a particular example of outcropping/subcropping mineralisation upgraded into ore bodies by weathering processes. (Burger 1979, 1995 this volume). In this instance surface leaching and supergene enrichment has occurred in the weathering profile. Figure 6 (after Perriam, 1979) shows the expected sites of metal enrichment in a lateritised land surface. The rates of water infiltration and phreatic zone drainage vary with topography. Oxidation is greatest on slopes where additional water has become available by run-off from crests. Soluble products, e.g. silica and bases, are readily flushed because of the sloping water table. Consequently, lateral as well as vertical controls act upon pedogenesis: vertical processes dominating on the interfluves, lateral processes having a significant influence, and possibly being dominant, upon the slopes.

The result is a connected series of profile characteristics. "Normal" profiles develop within interfluve areas where leaching and vertical processes predominate. On the slopes, components that are sparingly soluble may be added to the deeper horizons by solution from upslope. The valley floors, with their high degree of saturation and low gradients are sites of precipitation of sparingly soluble components and also clastic sediment deposition. Plant communities are sensitive to the surface expressions of these profile differences and the vegetation of each environment is quite distinct. Faunal differences correspond.

Figure 7 (after Burger, 1979) is a schematic section through the Greenvale mine area illustrating the terracing of the lateritic profile and location of nickel mineralization. Figure 8 from Fletcher & Couper, 1975, shows the chemical characteristics of the lateritic profile in relation to the physical and mineralogical characteristics.

Geochemical Procedures and Regional Geochemical Exploration in Northeast Queensland

Outcropping deposits

In Northeast Queensland, as elsewhere, the regolith influences what type of geochemical exploration procedures are adopted (Table 2). Surface geochemical techniques developed for locating outcropping mineralisation prevail in areas where bedrock is exposed, depth of weathering is shallow and outcrop is good.

Widely used techniques in this category include rock chip sampling, prospecting for gossan and vein outcrop/subcrop, -80 mesh grid soil sampling, stream sediment sampling (-80 mesh, pan concentrate and Bulk Cyanide Leach extractable gold and other metals (BCL)), ridge and spur sampling and BCL soil sampling. Examples of outcropping mineralisation discovered in this fashion are: Au vein/deposits at Pajingo, Wirralie, Belyando, Yandan, and massive base metal sulphide deposits at Thalanga, Balcooma and Magpie. Some previously worked deposits also fall into this category, in the sense that, if they had been unknown, surface techniques would undoubtedly have led to their discovery. Large scale Au breccia ore bodies at Kidston and Mt Leyshon, Au vein deposits at Ravenswood, Charters Towers, Disraeli and Mt Coolon, the tin deposits of Herberton, and massive sulphide deposits at Liontown, are all examples.

The variability of the depth of weathering in the regolith has meant that surface geochemical models cannot be applied uniformly. For example, Porter (1991) argues that there is no surface enrichment at Pajingo, where very high surface gold values in fine grained quartz vein material were very similar to those returned from drilling above and below the base of oxidation. There are many other examples in Northeast Queensland where surface enrichment does not appear to operate.

Elsewhere, in areas of high sulphide development, leaching and supergene enrichment is evident e.g. Reward, Thalanga, Mt Leyshon. Supergene processes are also present in the laterite profiles at Greenvale.

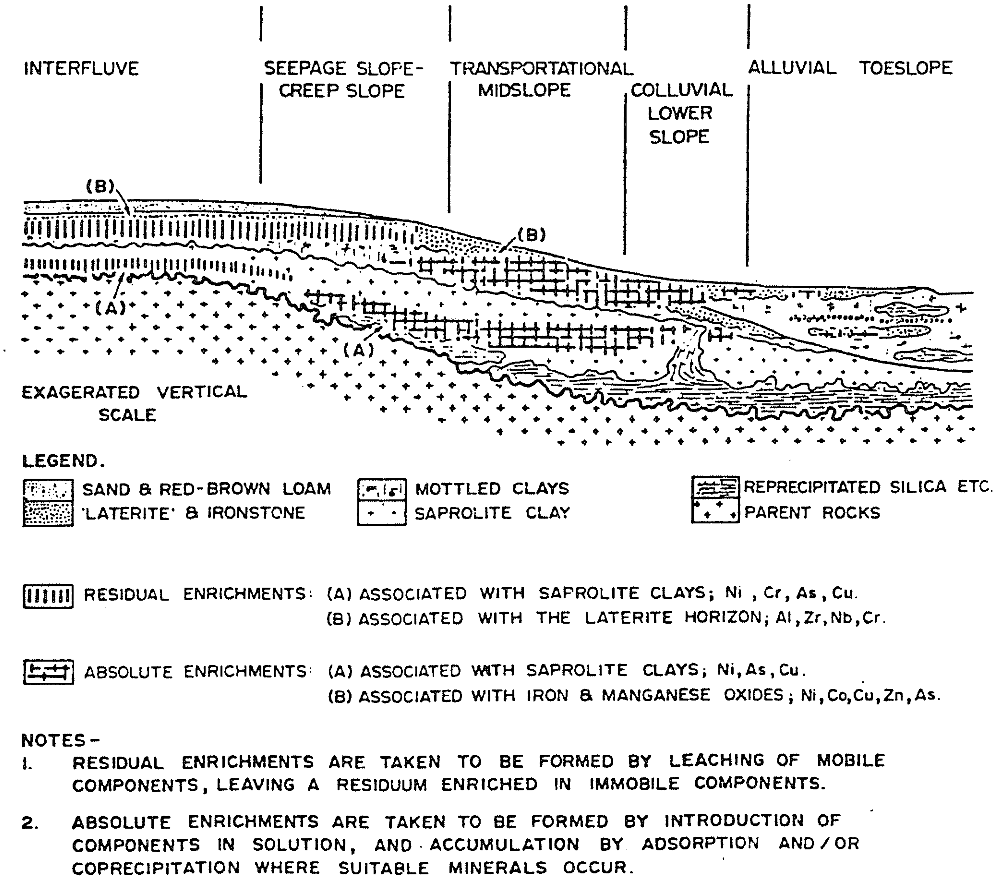


Figure 6 Expected sites of metal enrichment in the lateritised landsurface.
After Perriam 1979.

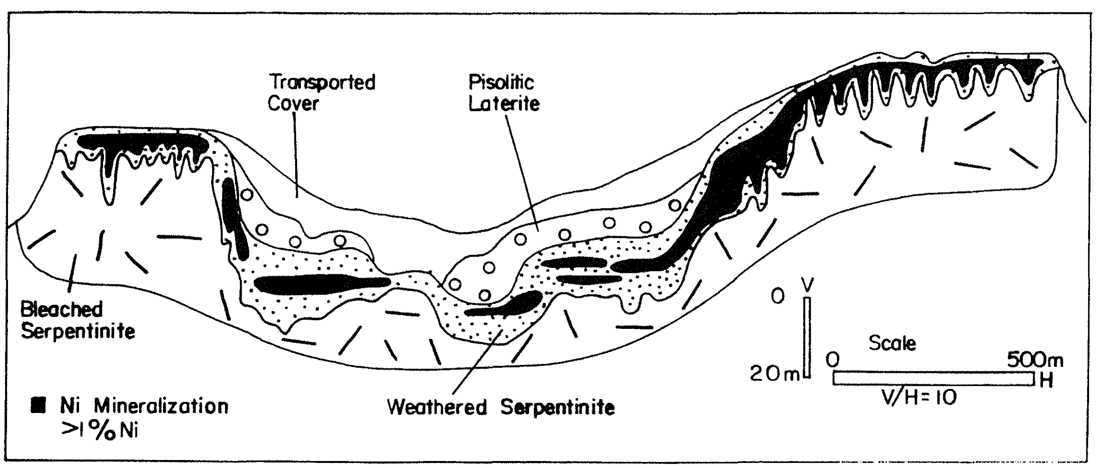


Figure 7 Schematic section showing Greenvale laterite profile and location of main zones of nickel mineralisation.
After Burger 1979.

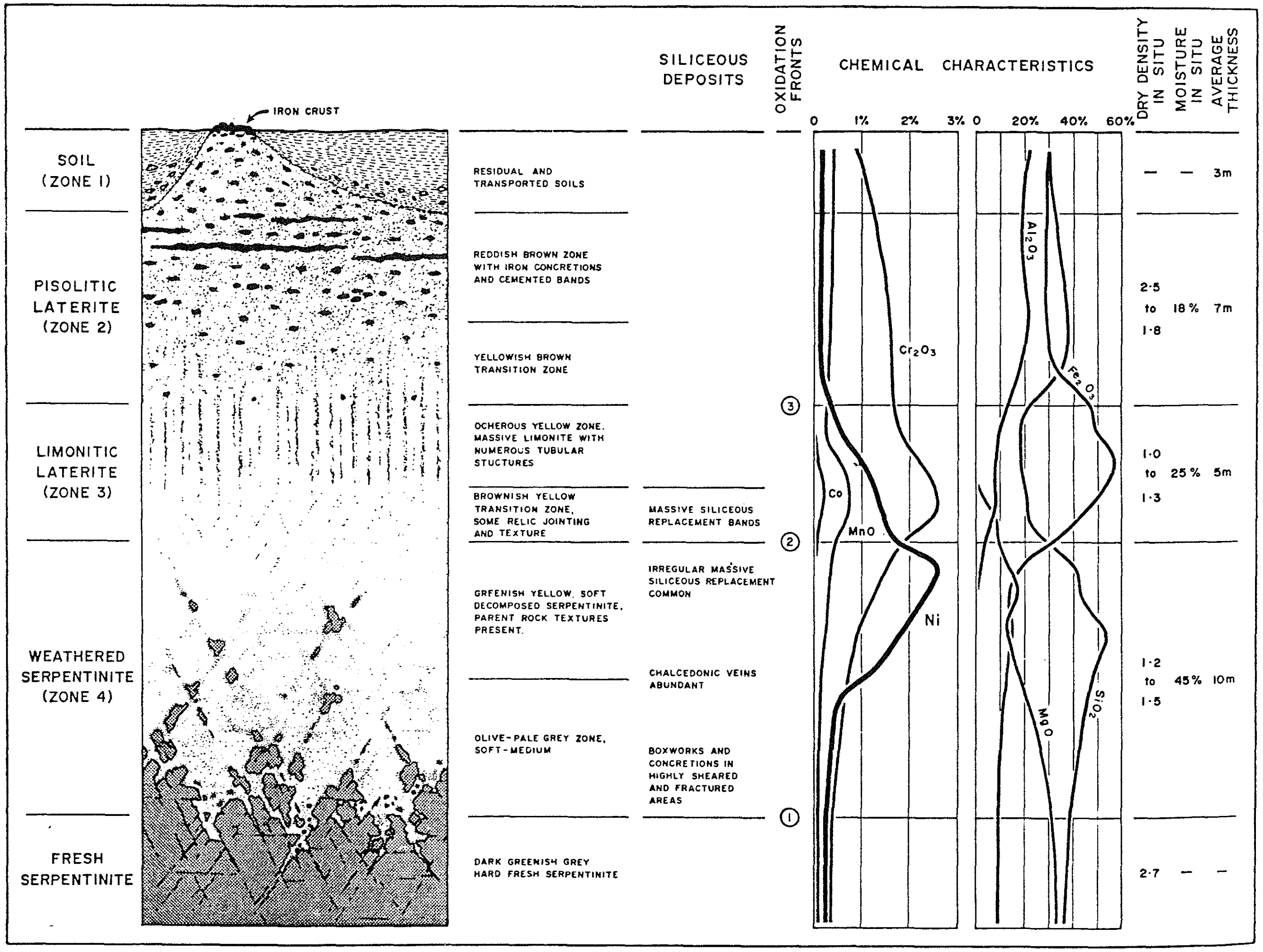


Figure 8 Principal physical and chemical characteristics of the laterite profile at Greenvale.
From: Fletcher & Couper, 1975.

Sub outcropping/blind deposits
With these deposits, the top of significant mineralisation is sub-surface, although there may be surface signs of hydrothermal activity such as outcropping alteration and favourable host stratigraphy, or weak mineralisation. The Twin Hills/Lone Sister Au deposits, Mt Wright Au breccia, Handcuff, Highway and Reward massive sulphide deposits are blind deposits discovered by utilisation of geochemical exploration techniques including stream sediment sampling, soil sampling, prospecting and rock chip sampling, RAB and shallow percussion drilling and trench evaluation.

Concealed/covered deposits
Transported cover overlies a large portion of Northeast Queensland. Exploration to date has involved obtaining subsurface information through RAB and shallow percussion drilling. Although there has been limited use of the secondary dispersion haloes in transported cover overlying mineralisation, interpretation of anomalies in the Campaspe Beds led to discoveries of massive sulphide base metal mineralisation at Thalanga East, Waterloo and Reward (Hartley & Alston, 1995 this volume; Beams et al., 1989).

Some Examples of Regional Exploration Programs

Example 1: Mt Windsor Volcanic Belt: outcropping, blind and covered massive sulphide mineralization
Sieved stream sediment sampling (mainly -80 mesh) has covered the outcropping areas of the Mt Windsor Volcanic Belt, which hosts several massive sulphide deposits. Figure 9 illustrates the effectiveness of these programs in locating outcropping and subcropping mineralisation such as Liontown, Handcuff and Highway. Several large scale (uneconomic to date) alteration systems have also been located e.g. Gidgee, Trooper Creek, Merri Creek. Almost all the samples in this population have been sieved in the field to -80 mesh, then submitted to commercial laboratories, where a solution has been prepared utilizing a perchloric acid digest at 220°C and analysis for Cu Pb Zn by Atomic Absorption Spectrophotometry. Detection limits are generally Cu (2 ppm) Pb (5 ppm) Zn (2 ppm). This data set has built up since the late 1960's and represents more than 5 different companies exploration programs: Mt Isa Mines (Russi, 1967), Jododex (1974), Esso Australia (Fraser, 1976), Pennaroya (Becerra, 1982), Pan Australia Mining (Beams, 1990).

Regional soil programs have also been effective in delineating zones of outcropping/subcropping mineralisation e.g. Handcuff/Reward, Liontown. Bedrock drilling (Rotary Air Blast (RAB) and Auger) has been the primary geochemical tool under cover, and has led to discoveries at Waterloo (Hartley & Alston, 1995 this volume) and Reward (Beams et al., 1989).

Figure 10 is a bedrock geochemical plot of Pb values produced by combining soil and RAB data in the Highway-Handcuff area. Most of these samples were collected by Esso Minerals in the period 1980-1984 (Castle 1982; Beams 1984). In this instance the soil data is derived from -80 mesh sieved surface samples, whereas the RAB values are samples taken from bedrock in the deepest parts of holes generally drilled to refusal i. e. as deep as could be drilled with a blade bit. Holes adjacent to outcrop areas often reach bedrock within 1-5m, whereas in palaeodrainage channels, transported cover can be up to 50m deep. Almost all analytical procedures involved AAS with a perchloric acid digest at 220°C.

The Highway/Reward and Handcuff anomalies occur over areas of 200m x 200m and 500m x 200m respectively, where Pb+Zn are greater than 500 ppm, Cu is greater than 200 ppm.

Deeper drilling of these zones which extend from the outcropping areas under cover has resulted in massive or semi-massive sulphide discoveries.

TABLE 2

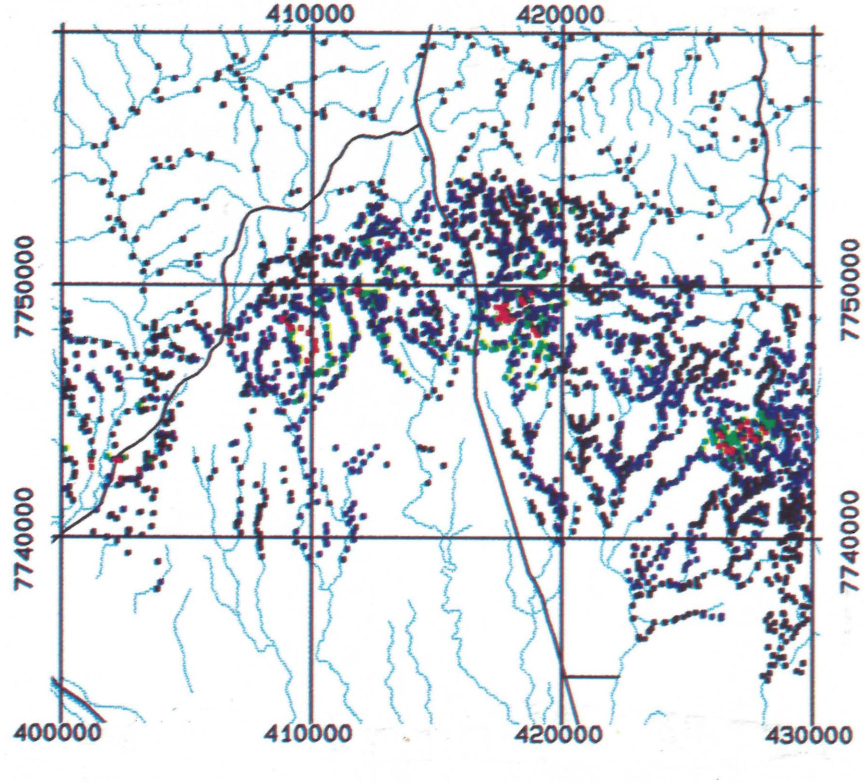
NORTH EAST QUEENSLAND BASE AND PRECIOUS METAL DEPOSITS: EFFECTIVENESS OF GEOCHEMICAL TECHNIQUES

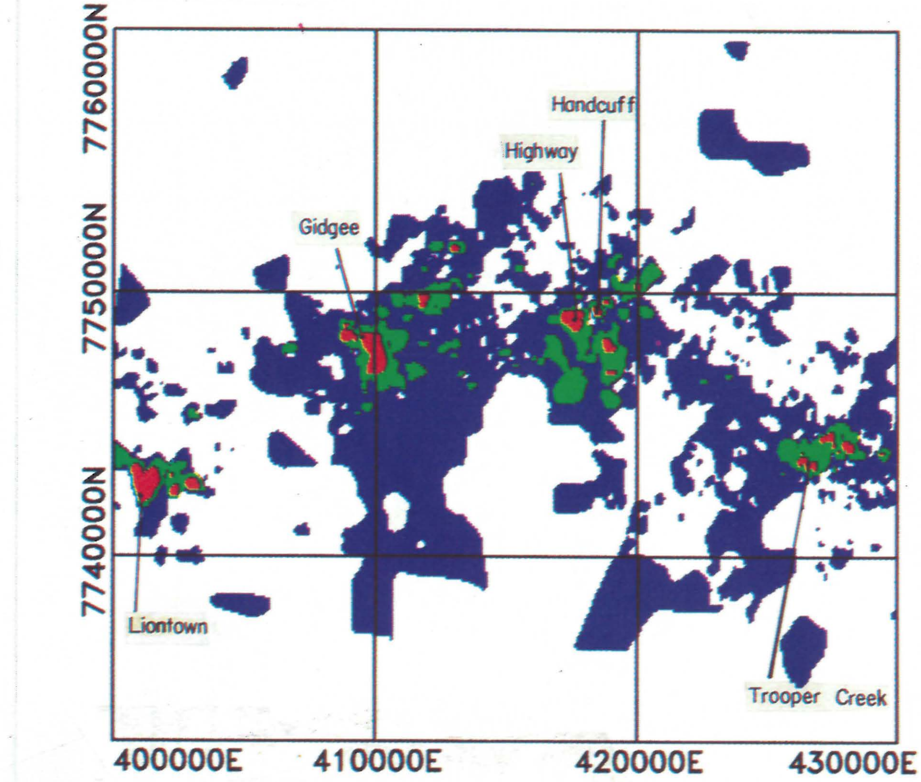
		SURFACE SAMPLING					SUB SURFACE SAMPLING		
	DEPOSIT STYLE	Rock Chip Sampling Prospecting	-80 Mesh Stream Sediment (Base Metals)	BCL Stream Sediment	Pan Concentrate	Soil Sampling	Trench Evaluation	RAB Drilling	Shallow Percussion Drilling
Outcropping Deposits									
Pajingo	Epithermal Au Vein	Key		Effective	Effective		Key		
Wirralie	Epithermal Au Vein	Key		Key					
Mt Coolon	Epithermal Au Vein	Key		Key	Key				
Belyando	Vein Breccia	Key							
Thalanga	Volcanic Hosted Massive Sulphide	Key	Key	Effective		Key	Key		
Balcooma	Volcanic Hosted Massive Sulphide	Key	Key			Key	Key		
Magpie	Volcanic Hosted Massive Sulphide	Key	Key			Key	Key		
Liontown	Volcanic Hosted Massive Sulphide	Key	Key	Effective		Key	Key		
Kidston	Au Breccia	Key	Effective	Effective	Key	Key	Key		
Mt Leyshon	Au Breccia	Key	Effective	Effective	Key	Key			
Ravenswood	Mesothermal Au Vein	Key	Effective	Effective	Key		Key		
Charters Towers	Mesothermal Au Vein	Key	Effective	Effective	Key				
Disraeli	Mesothermal Au Vein	Key		Effective	Key				
Yandan *	Epithermal Au	Key	Key			Key	Key		
Greenvale	Lateritic Ni	Key						Key	Key
Herberton	Granite Tin	Key			Key				
Subcropping/Blind Deposits									
Twin Hills	Epithermal Au Disseminated	Key				Key	Key	Key	Key
Lone Sister	Porphyry/ Epithermal Au	Key		Effective		Key		Key	Key
Highway	Volcanic Hosted Massive Sulphide	Key	Key			Key	Key	Key	Key
Handcuff	Volcanic Hosted Massive Sulphide	Key	Key			Key	Key	Key	Key
Mt Wright	Au Breccia	Effective	Effective	Key		Effective			
Concealed Deposits									
Reward	Volcanic Hosted Massive Sulphide							Key	Key
Thalanga East	Volcanic Hosted Massive Sulphide							Key	Key
Waterloo	Volcanic Hosted Massive Sulphide							Key	Key

Key Technique

Effective Technique but did not play key role in discovery

* NB -200 mesh stream data





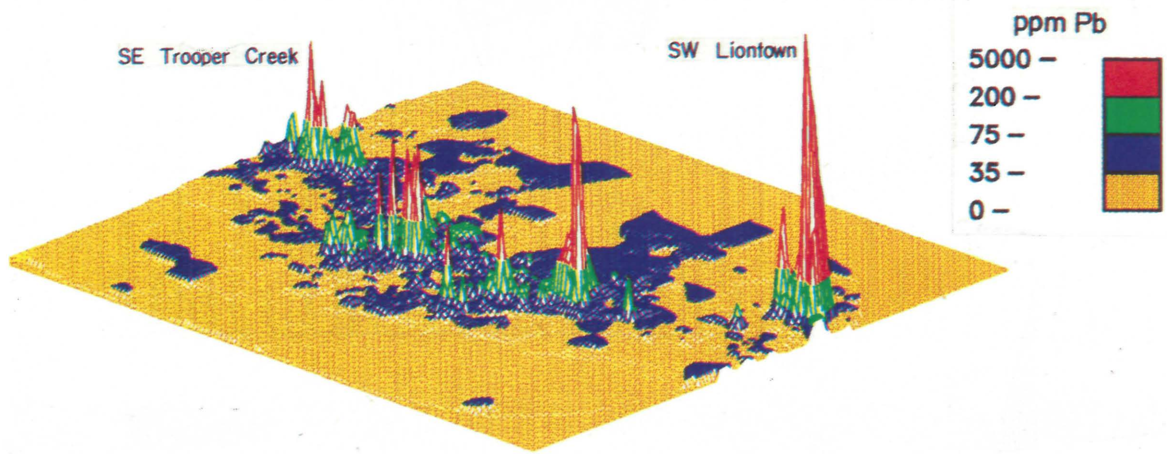


Figure 9
Sieved Stream Sediment Pb Data Mt Windsor area.
A. Sample point data
B. Gridded and shaded contours
C. 3-D perspective looking from northwest
For location see Figure 3

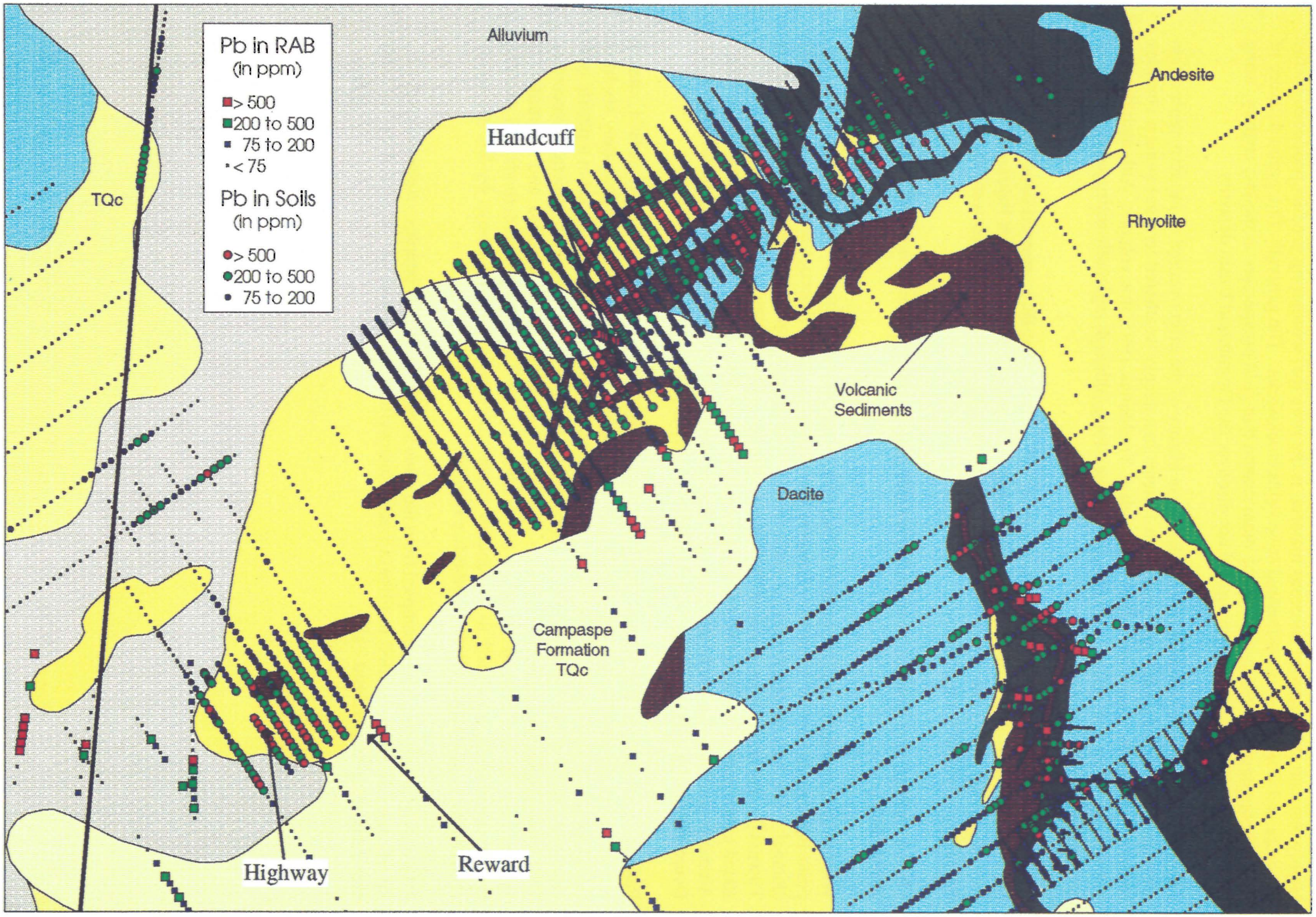


Figure 10 Pb ppm in soils and RAB bedrock drillholes, Highway-Reward-Handcuff area Mt Windsor Subprovince
See Figures 3 and 9 for location.

Example 2: Epithermal gold mineralisation. Outcropping & Subcropping vein systems of the Pajingo area.

Highly resistant, fine grained siliceous material is the principal weathering product produced by the exposure and weathering of epithermal style veins/stockworks. The generally fine grained nature of the gold contained in these systems is the main reason that gold prospectors in the last century, using traditional methods such as panning, did not discover the Drummond Basin deposits.

The Pajingo Mine area provides an excellent case history of the effectiveness of modern exploration techniques in locating small high-grade vein systems in a deeply weathered terrain having a complex landscape evolution. See Porter 1990, Cornwell & Treddinick 1995, this volume. Although Pajingo was discovered by geological prospecting, there is a strong, although regionally restricted geochemical drainage signature.

Using Battle Mountain Australia data, Cameron 1991, found that BCL, panned concentrate stream sediment, and rock chip float all successfully located the main mineralisation at Pajingo (Figure 11). BCL sampling shows the entire area to be anomalous. Panned concentrates were much better at targeting individual prospects.

Float sampling, like panned concentrate sampling, also clearly located mineralisation within the overall area.

With the BCL samples, approximately 4.5kg of sediment was collected from "semi-trap" sites, e.g. point bar deposits within streams. Samples were taken to avoid charcoal patches in the drainage channel. The bulk material was screened in the field using -2mm sieve, then submitted to ALS, Townsville for analysis by method PM216. A cyanide solution is mixed with the sample, lime is added to bring the pH within 10-14 as is an activated carbon pad. The mixture is agitated for 24 hours. After completion of the leach, the pad is dried, ashed and digested with a gold determination by AAS. Detection limit for this highly sensitive, partial extraction method is 0.05 ppb Au.

Panned concentrates were obtained from trap sites at approximately the same locality as BCL sites in the stream drainage channel. After selection and digging of the trap site, approximately six litres (≈ 13 kg @ 2.2 kg/litre) of -1.5mm sieved material from the sample site was placed in a plastic non-permeable bag and later panned down to approx 30-50 grams to produce a heavy mineral concentrate. This concentrate was then placed into a paper geochemistry bag, labelled and submitted to Pilbara Labs, Townsville for weighing and analysis by fire assay for gold (Methods 313 or 326). Results were then converted to a standard (μg/6l) by multiplying the assays by the weight of concentrate in grams in order to standardise results.

Siliceous float was selectively sampled from the same sites as the stream samples. Approximately 1-2 kg of material was submitted to Pilbara Labs, Townsville crushed and then analysed by 50 gram fire assay for gold (Method 313).

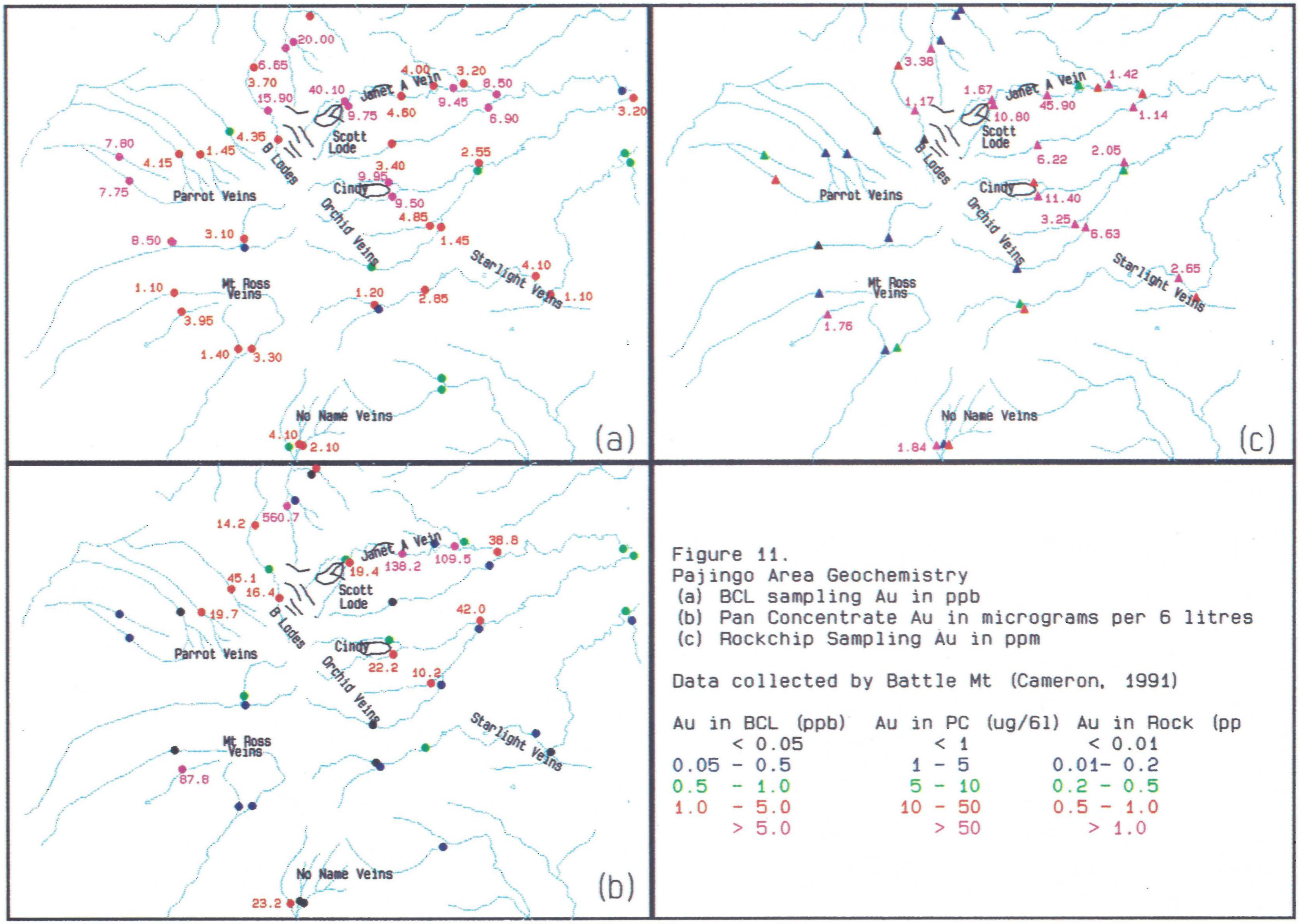


Figure 11.
Pajingo Area Geochemistry
(a) BCL sampling Au in ppb
(b) Pan Concentrate Au in micrograms per 6 litres
(c) Rockchip Sampling Au in ppm

Data collected by Battle Mt (Cameron, 1991)

Au in BCL (ppb)	Au in PC (ug/6l)	Au in Rock (pp
< 0.05	< 1	< 0.01
0.05 - 0.5	1 - 5	0.01- 0.2
0.5 - 1.0	5 - 10	0.2 - 0.5
1.0 - 5.0	10 - 50	0.5 - 1.0
> 5.0	> 50	> 1.0

Example 3: Mt Garnet area tin exploration

The Bureau of Mineral Resources (BMR) carried out a regional geochemical drainage sampling over the Mt Garnet-Ravenshoe district in the early 1960's. (Zimmerman & Howard, 1962). Historically these drainage systems had been extensively panned by prospectors. Many areas of alluvial and hard rock tin mineralization had been discovered in the 1880's to the 1900's. Alluvial tin dredging was a major operation around Mr Garnet from the 1940's to the 1970's.

Figure 12 illustrates the effectiveness of the panning techniques of the old prospectors. Tin data from BMR stream sediment sampling is plotted in relation to alluvial and hard rock workings. Sampling procedure involved sieving to -80 mesh and spetrographic analysis for tin and other elements (Zimmerman & Howard, 1962). The whole area is regionally anomalous with respect to tin, very high values of 100-2000 ppm Sn were returned in many drainages which also contain alluvial workings. The effectiveness of panning has meant that little advantage is gained from -80 mesh style stream sediment sampling, therefore this is one of the few regional stream sediment surveys in the district.

Future Directions

Detailed surface geochemical surveys coupled with geological mapping and various geophysical techniques have effectively screened a large portion of Northeast Queensland for large scale outcropping base and precious metal deposits. Most future discoveries are likely to be concealed deposits delineated by extensive bedrock drilling under cover, or blind deposits, where vectors to ore are obtained by an understanding of the geochemistry of the hydrothermal system, alteration envelopes and host rocks, together with an appreciation of the nature of geochemical dispersion in the regolith.

It is therefore imperative that historical and future exploration data is properly recorded and fully utilised in order to facilitate discoveries. This requirement is accentuated by the increasing application of sampling procedures emanating from the Yilgarn Block, where CSIRO and AMIRA sponsored research has led to a greater understanding of the regolith and utilisation of innovative sampling media in mineral exploration (Anand and Smith, 1993).

Innovative developments such as partial extraction analysis (eg. BCL) or selective sampling media (eg. lateritic pisolites) have meant that raw assay numbers may no longer be directly comparable. Incorrect interpretations based on spurious comparisons are likely if vital attributes on assay techniques and sampling methods are not recorded with assay data and accessible in a structured data management environment.

Thus, as mineral exploration in North Queensland moves into the next phase of the digital age, it is important to recognise that careful documentation of sample collection methods, analytical procedures and accurate sample location will be as essential in the future as it should have been in the past.

In Northeast Queensland, existing procedures and observations have shortcomings with regard to the recording and interpretation of data on the regolith both from drill and surface observations and geochemical analysis. Some deficiencies are:

- the cover sequence has been rarely logged in drill holes;

- regolith units have been rarely identified;

- information collected by previous explorers is not fully utilised;

- the lower cost of open hole RAB means it is often employed in areas where it returns very low quality geological and geochemical data, to the extent where in some areas it is often uncertain whether bedrock actually has been reached;

- elements such as Fe and Mn are only occasionally analysed, yet they are essential for interpretation of geochemical patterns in the weathering profile.

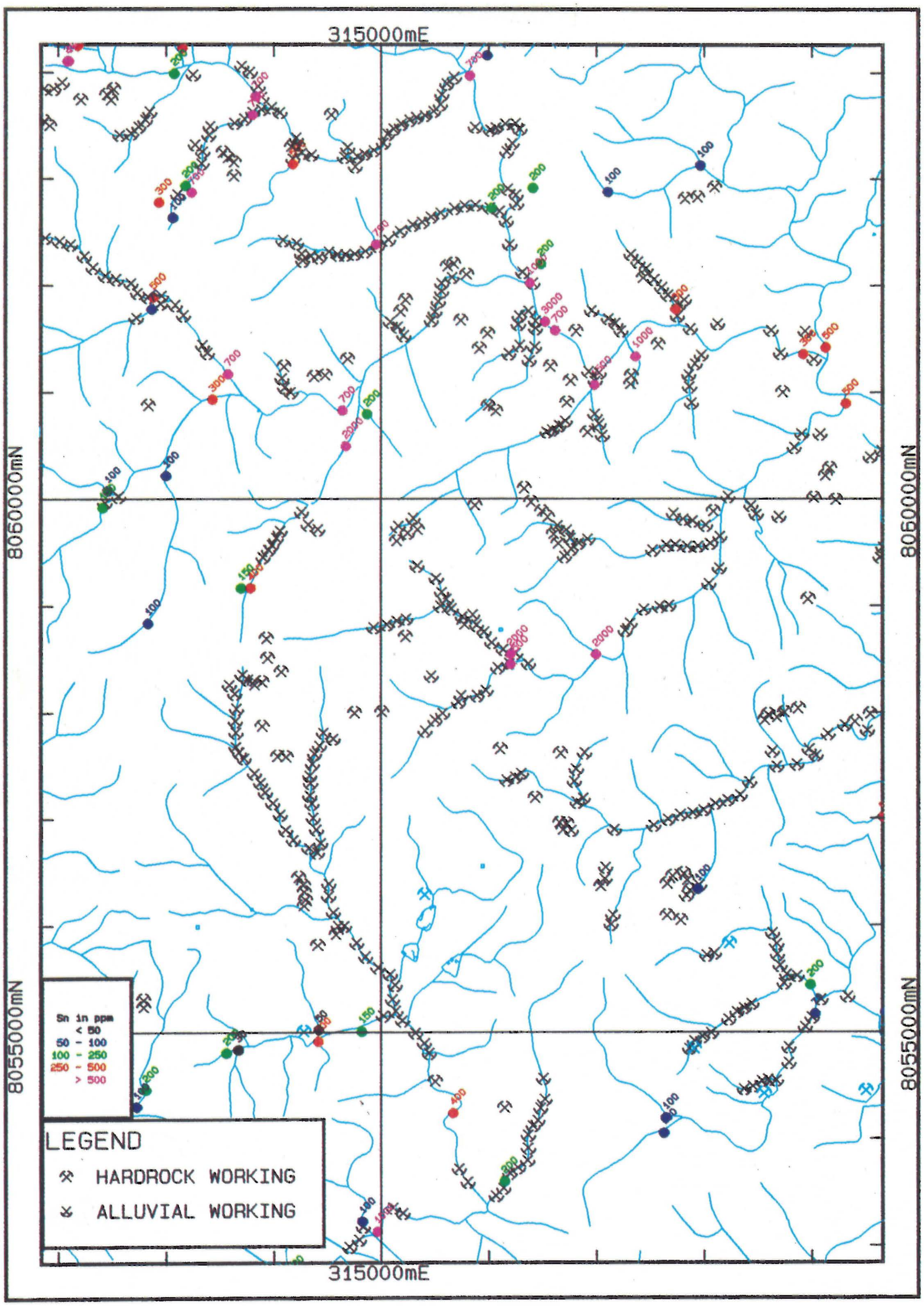


Figure 12 Relationship of tin in ppm from -80 mesh BMR 1962 stream sediment sampling and alluvial and hard rock workings. NE of Mt Garnet.
Data from Zimmerman & Howard, 1962.

In order to optimise exploration efforts it is essential that future procedures overcome these deficiencies. Increasing understanding of the regolith will play a pivotal role in the successful application of exploration geochemistry in Northeast Queensland.

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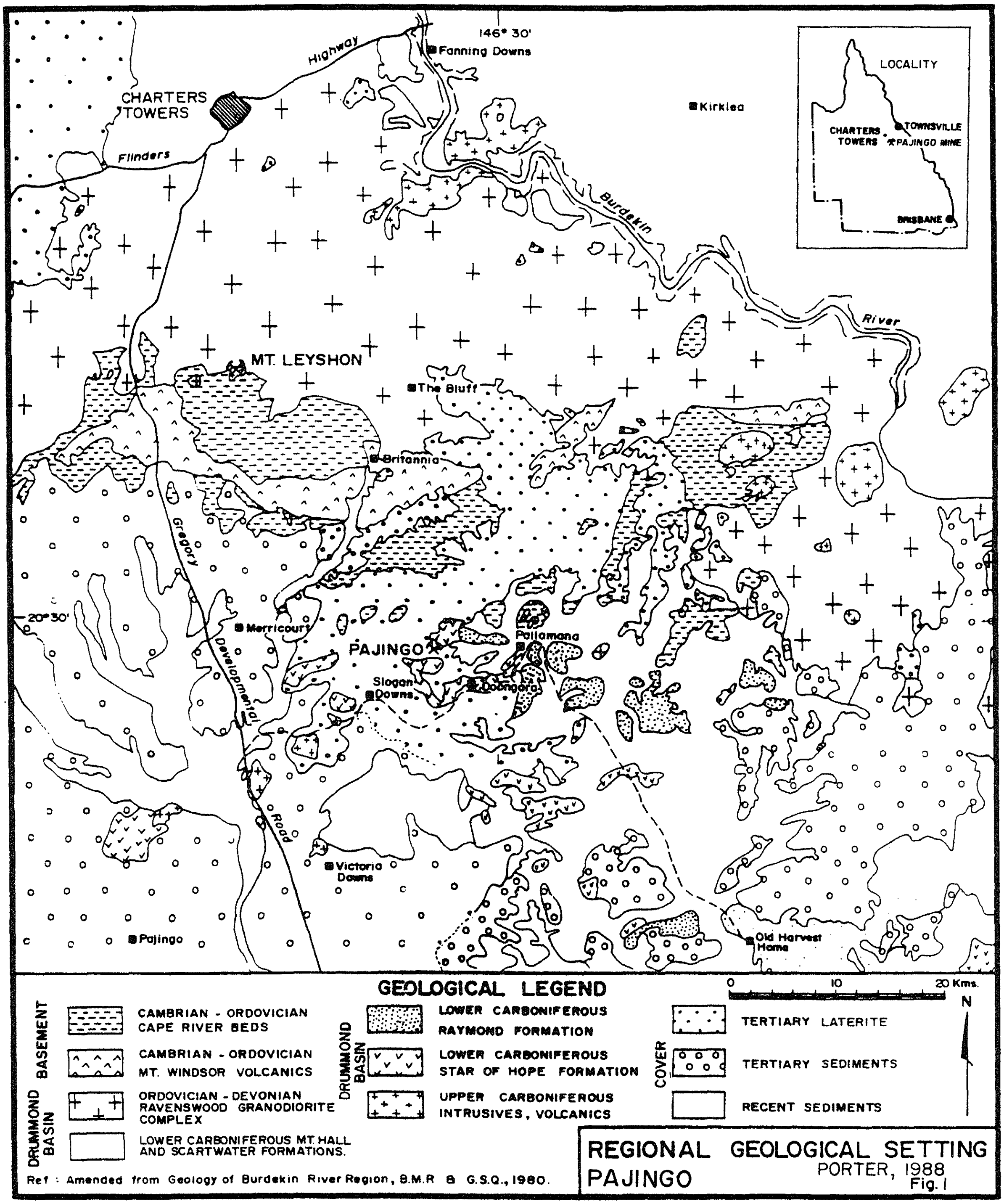

146° 30'
Fanning Downs
Highway
CHARTERS TOWERS
Flinders
Kirklea
LOCALITY
CHARTERS TOWERS
TOWNSVILLE
PAJINGO MINE
BRISBANE
Burdekin
River
MT. LEYSHON
The Bluff
Britannia
Gregory
Developmental
Road
20°30'
Merricourt
PAJINGO
Pallamana
Slogan Downs
Doongara
Victoria Downs
Pajingo
Old Harvest Home
GEOLOGICAL LEGEND
0 10 20 Kms.
N
BASEMENT
CAMBRIAN - ORDOVICIAN CAPE RIVER BEDS
CAMBRIAN - ORDOVICIAN MT. WINDSOR VOLCANICS
ORDOVICIAN - DEVONIAN RAVENSWOOD GRANODIORITE COMPLEX
DRUMMOND BASIN
LOWER CARBONIFEROUS MT. HALL AND SCARTWATER FORMATIONS.
LOWER CARBONIFEROUS RAYMOND FORMATION
LOWER CARBONIFEROUS STAR OF HOPE FORMATION
UPPER CARBONIFEROUS INTRUSIVES, VOLCANICS
COVER
TERTIARY LATERITE
TERTIARY SEDIMENTS
RECENT SEDIMENTS
Ref : Amended from Geology of Burdekin River Region, B.M.R & G.S.Q., 1980.
REGIONAL GEOLOGICAL SETTING
PAJINGO
PORTER, 1988
Fig. 1

Geology and geochemistry and mining of the Pajingo epithermal vein system

Jim Cornwell and Ian Treddinnik

Pajingo Gold Mine, Battle Mountain (Australia) Inc. PO Box 237, Charters Towers, Qld 4820

Location, Access and Project Status

The Pajingo gold mineralisation which includes the Scott Lode gold deposit occurs within the Janet Range which is centred on Latitude 20° 32'S and Longitude 147° 27'E or some 150 km south-southwest of Townsville (Figure 1). It has previously been described by Porter 1988, Porter 1990, Porter 1991, Bobis 1990, Wood et al., 1990. The district has been a gold producer since 1987, mining epithermal quartz vein systems principally from an open cut in the Scott Lode but more recently from small underground operations at Scott Lode and Cindy vein. Three hundred and fifty thousand ounces of gold and 1 million ounces of silver have been produced from 1.2 million tonnes of ore in the project area to date.

Discovery History

The Pajingo mineralization is a grass roots discovery located by geological prospecting. Although it occurs 53 km south-southeast of the historic Charters Towers goldfield and 30 km southeast of the Mount Leyshon gold mine discovered in the 1880's, the Pajingo area has no previous mining history.

At the time Battle Mountain Australia (BMA) acquired the Exploration Permits in 1983 no other official exploration had been recorded on the area (i.e. under a Government permit) and at Pajingo there is no evidence of historical prospecting. The original target styles sought by BMA were porphyry to breccia hosted gold systems; examples of which include Kidston and Mt Leyshon. These deposits are related to Permo-Carboniferous felsic volcano-intrusive complexes (felsic plugs). At the time the 'epithermal' deposit styles were little known and even less sought after as most exploration people believed that erosional levels in Eastern Queensland were too deep for these shallow level hydrothermal systems to survive.

Battle Mountain's interest was drawn to the Pajingo area where Geological Survey of Queensland mapping showed a northeasterly trending "belt" of Permo-Carboniferous felsic plugs extending southwest from the Town Creek (Three Sisters) porphyry Mo (Au) prospect; now referred to as the "Pajingo trend".

In October 1983 in the course of field mapping and prospecting of the felsic plugs and adjacent areas, Battle Mountain geologist Ralph Porter recognised the epithermal style of the outcropping gold bearing quartz veins located 5.3 km southeast of Scott Lode and near Doongara Homestead. Further geological prospecting led to the discovery of the Scott Lode in June 1984. Original rock chip and trench assays of the Janet A vein returned bonanza grades - many in the > 30 g/t Au range. Some of the high grade drill intercepts from the initial drill program in December 1984 were:

PDH-5 54m @ 23.1 g/t Au including
32m @ 32.0 g/t/Au

PDH-7 14m @ 267 g/t Au including
2m @ 1575 g/t Au

DDH-1 57m @ 7.8 g/t Au including
9 m @ 30 g/t Au

These 3 shallow inclined holes were drilled along a 430m strike length.

TABLE 1 Pajingo Mine, Gold-Silver Production 1987-1994.

Year / Operating Data	1987	1988	1989	1990
Tonnes Milled	33621	180750	187006	171087
Au g/t	10.91	11.04	10.73	11.16
Recovery (%)	93.78	95.05	96.06	95.12
Oz produced	11058.08	60928.10	61059.36	59406.17
Ag g/t	26.49	28.50	28.95	27.07
Recovery (%)	90.57	91.78	85.70	77.85
Oz produced	25932.83	152181.77	147630.48	118227.09

1991	1992	1993	1994	PROJECT TO DATE TOTAL
170747	1779953	172287	173657	1267108
9.78	8.78	6.21	5.78	9.14
95.69	94.48	94.48	94.60	95.12
52051.42	47406.65	32481.45	30397.79	354789
26.89	45.38	26.93	14.64	28.36
81.83	83.41	83.64	85.58	84.59
121923.54	212769.98	124980.26	93001.66	996647

NOTES:

1. Reserve Data as at 31/12/87

   Proven, probable reserves 1170000 tonnes at Au 10.0 g/t (376000 cont oz)
   Ag 38.0 g/t (1430000 cont oz)

2. Scott Lode production estimated to end April 1995.

   Cindy lode to provide subsequent mill feed till mid 1996.

Regional geochemical data did not play a definitive role in the Pajingo discovery. However, later orientation work showed that Panned Concentrate, Bulk Cyanide Leach extractable gold (BCL) Stream Sediment and Rockchip Float sampling all successfully locate the main mineralization. (Cameron, 1991 & Beams & Jenkins 1995 this volume).

Development & Mining

An in-situ geological ore reserve was defined by late 1986 based on the results of surface trenching and reverse circulation percussion and diamond core drilling. Mineable reserve data and project to date production is shown in Table 1. BMA began mining at Pajingo in September 1987. Plant construction was completed and dore bullion was first poured at the Pajingo Mine on September 30, 1987, five months after the issuance of the mining lease and start of construction. Full production from the Scott Lode Open Pit was achieved in December 1987. As at end 1994, dore production was 354800 oz (11035 kg) gold and 996600 oz (30998 kg) silver from 1267000 tonnes of ore grading 9.14 g/t gold and 28.36 g/t silver. Metallurgical recoveries, project to date are 95.12% gold and 84.59% silver.

Mining of the Scott Lode orebody was primarily by conventional open pit methods. Due to the high grade narrow vein nature of the deposit (average width 5.5 metres), a hydraulic excavator was utilised to maximise the mining selectivity. The overall stripping ratio of the pit was 14.8:1.

On completion of open cut mining, a small scale underground mining operation was undertaken to extract a high grade narrow vein below the pit floor.

Processing of Pajingo ore is at a rate of 500 tonnes per day in a conventional plant having a single grinding circuit, cyanide leaching, carbon in pulp adsorption and a stripping refining circuit. After mining the treatment process is as follows:

Run of mine ore is fed into a crushing plant which discharges a 16.0 mm product onto a 3000 tonne live capacity stockpile. A stockpile activator discharges onto a conveyor belt, which in turn feeds a 3.83 m diameter x 4.3 m long Allis Chalmers Ball Mill. Accurate tonnage is measured by a Ramsay type electronic belt scale weightometer. Cement is added to the feed conveyor for pH control with fine tuning maintained in the leach tanks using Caustic Soda (liquid). Ball Mill product at 50 micron (P80) is discharged from the cyclone overflow to a pre-aeration tank and subsequent leach tank where cyanide is added. Aeration in these first two tanks is provided by high speed stators fitted to the top of the agitator shaft just below pulp level.

Gold and silver are recovered onto activated carbon in a typical CIP circuit consisting of six adsorption stages. Loading of the carbon is typically 1800 g/t gold and 5500 g/t silver. Carbon is stripped using the Anglo American Research Laboratory (AARL) System. Up to of nine (9) strips per week are conducted in two duplicate electrowinning circuits, precious metals are electrowon onto steel wool which is then calcined and direct smelted in a LPG fired barring furnace.

Geological Setting

The auriferous epithermal quartz veins are in the main, hosted by a sequence of Carboniferous andesitic volcanics and high level intrusive andesite porphyry. This sequence forms part of the northern margin of the Devonian to Carboniferous Drummond Basin which is in fault contract with the Devonian Lolworth-Ravenswood Block (Figure 1).

The Scott Lode host rock sequence is dominantly comprised of andesitic lavas, felsic ignimbrites, block and ash andesite flows, high level intrusive andesite porphyry, and andesite breccias (Figure 2).

The andesites form prominent outcrops within the Janet Range having a peak elevation of some 200 metres above the surrounding relatively flat terrain. The northern most hill within the Janet Range, Mt Molly Darling is composed of quartzo-feldspathic sandstones and siltstones of fluviatile to lacustrine (Bobis 1990). Andesites are present within the sedimentary sequence. Surrounding the Janet Range and prominently developed on the eastern flanks is an erosional peneplain apron composed of locally deposited clastic material cemented during the Tertiary lateritisation event. This unit is referred to as the Southern Cross Formation. On the upper slopes of the Janet Range the Southern Cross Formation unconformably overlies lateritised andesite. The Tertiary sediments are regarded as cover rocks to the Pajingo mineralization. Soil and erosional debris overlie all the preceding units to variable depths and in some instances also act as cover rocks to the mineralised veins.

Figure 3 is a geological summary of the Pajingo area. Figure 4 is a section through the Scott Lode which cuts all units of the andesitic volcanic pile.

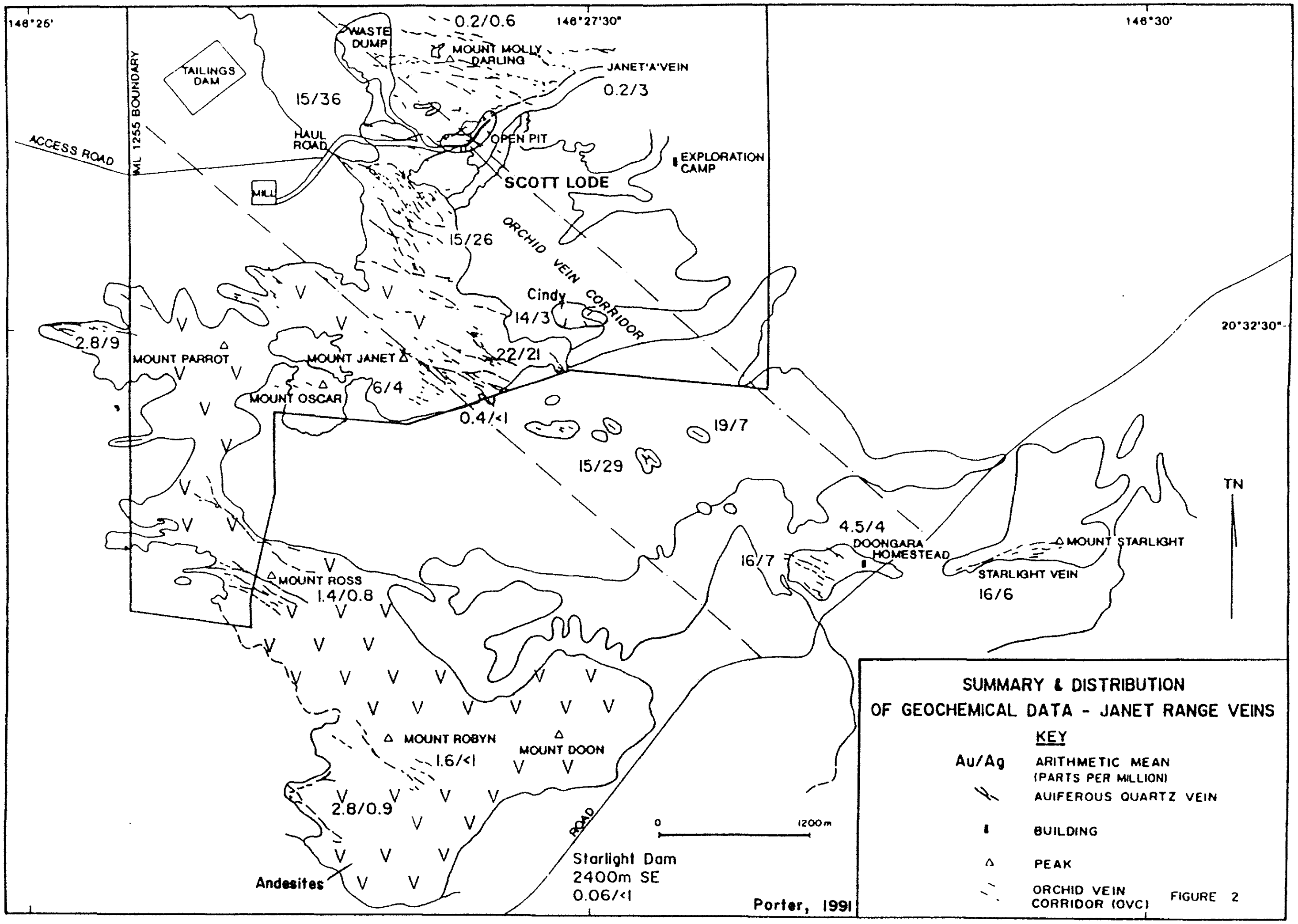
Regional Distribution of Mineralized Veins

Auriferous veins, associated vein breccias and silicification are located throughout the Janet Range (Figure 2). The most economically important structural directions to date are those apparently controlling the emplacement of the Scott Lode. These are an easterly and northeasterly strike direction. The dominant strike direction in terms of vein numbers is the set of structures lying within the northwest compass quadrant. Within this quadrant the structurally emplaced zones of silicification and quartz infill occupy the full spectrum of strike directions from west to north.

The most dense grouping of veins, silicification, silica sealed breccias, and post vein breccias occurs on the northern, eastern and southeastern flanks of Mt Janet. This group lies within the northwest structural quadrant and from evidence such as erosional "windows" in the Tertiary cover rocks southeast of Mt Janet appears to form a structural continuum between Mt Starlight and the Janet "B" Groups veins - a strike distance of some 6,000 metres. There are numerous additional vein sets present throughout the Janet Range. Reactivation of strike slip and normal faults interpreted as bounding the northern margin of the Drummond Basin probably controlled the emplacement of the Pajingo veins.

The Scott Lode

The Scott Lode is a boomerang shaped lode with a strike length of 560 m. The Lode has a maximum width of 23 m in the central bend and tapers to a width of 4 m at each end. The lode plunges steeply to the south at an angle of 70 to 80 degrees and ore extends to a depth of around 140 m from surface (Figures 3 & 4). The lode exhibits features typical of epithermal vein systems such as crustiform, colloform textures and chalcedonic to microcrystalline quartz. The hinge zone is composed of several footwall veins at least one hanging wall vein and lesser veins that form a stockwork within the zone.


146°26'
146°27'30"
146°30'
20°32'30"
TAILINGS DAM
ML 1255 BOUNDARY
ACCESS ROAD
MILL
HAUL ROAD
WASTE DUMP
0.2/0.6
MOUNT MOLLY DARLING
JANET'A'VEIN
0.2/3
15/36
OPEN PIT
EXPLORATION CAMP
SCOTT LODE
15/26
ORCHID VEIN CORRIDOR
Cindy
14/3
22/21
MOUNT JANET
6/4
MOUNT OSCAR
0.4/<1
MOUNT PARROT
2.8/9
19/7
15/29
TN
4.5/4
DOONGARA HOMESTEAD
16/7
MOUNT STARLIGHT
STARLIGHT VEIN
16/6
MOUNT ROSS
1.4/0.8
MOUNT ROBYN
1.6/<1
MOUNT DOON
2.8/0.9
Andesites
ROAD
0
1200m
Starlight Dam
2400m SE
0.06/<1
Porter, 1991
SUMMARY & DISTRIBUTION
OF GEOCHEMICAL DATA - JANET RANGE VEINS
KEY
Au/Ag ARITHMETIC MEAN (PARTS PER MILLION)
AUIFEROUS QUARTZ VEIN
BUILDING
PEAK
ORCHID VEIN CORRIDOR (OVC)
FIGURE 2

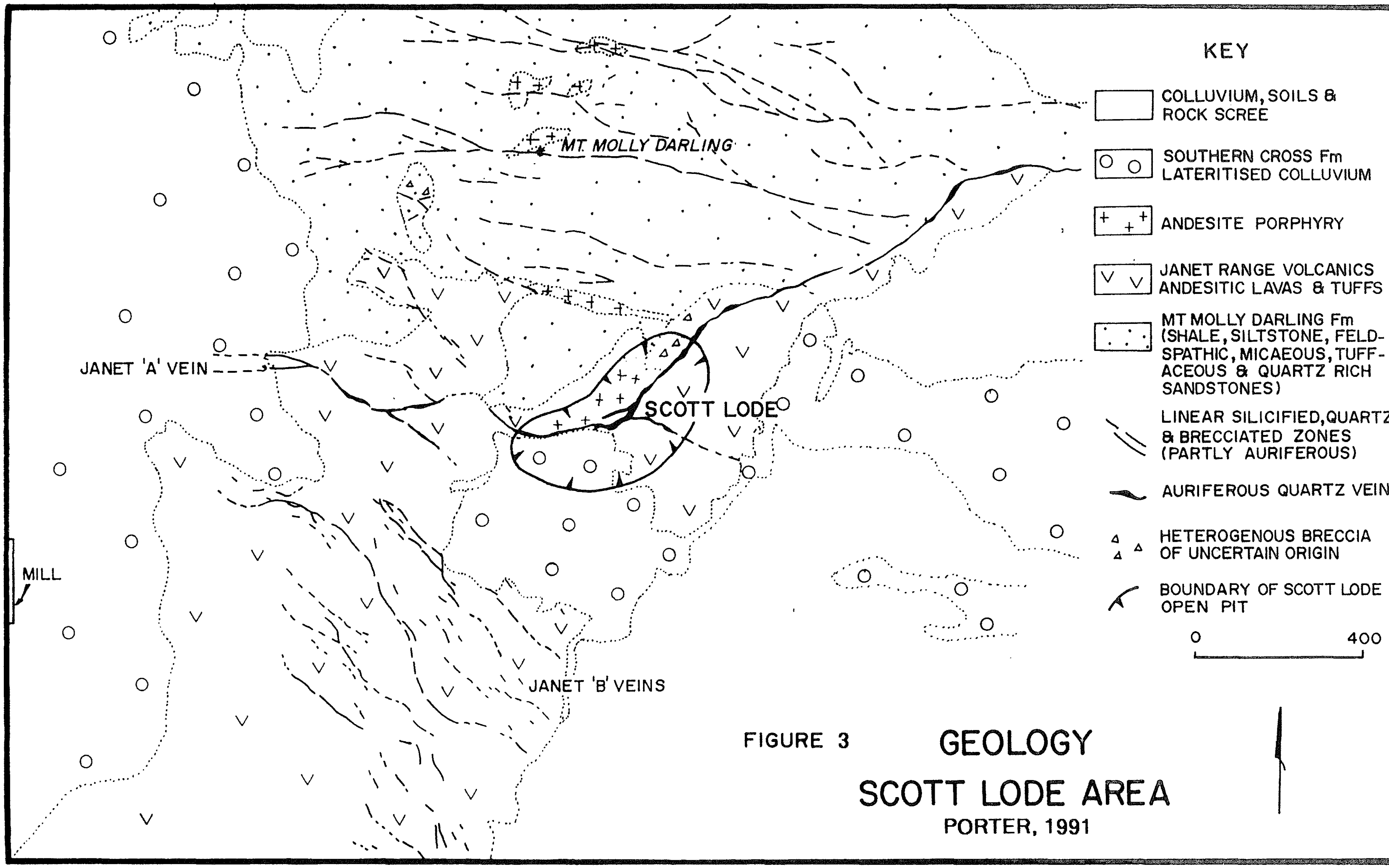


FIGURE 3 GEOLOGY SCOTT LODE AREA
PORTER, 1991

Cindy Vein

The Cindy vein is a blind orebody which was initially identified as a magnetic anomaly 1.5km southeast of the Scott Lode. Initial drill testing was carried out by Battle Mountain. In 1991 A.C.M., as part of the Pajingo Joint Venture, followed up on an adjacent resistivity high which located the main section of the lode which is 10-12m wide and has a strike of at least 1500m. The vein is buried under 5 to 15m of Tertiary sedimentary cover. In 1993 Posgold (replaced A.C.M. in the J.V.) elected to accept a royalty from the Cindy vein production leaving Battle Mountain to evaluate and mine the deposit in their own right.

The Cindy open pit reserve contained 73,000 tonnes @ 4.3 g/t Au (10,000 oz Au). The underground reserve consists of 175,000 tonnes @ 7.1 g/t Au (40,000 oz Au). The silver to gold ratio is approximately 0.8 to 1.

A total of 490,000 BCM (1.25 million tonnes) of material was excavated from the open pit between February and July 1994. The Cindy underground will be accessed via a 650m long decline with the portal located in the southern wall of the open pit. Underground mining will utilise a modified cut and fill technique. Five sub-levels 15m apart will be developed. The average underground mining width will be 4.6m.

The economic section of the Cindy vein is approximately 300m long. Unlike Scott Lode, the Cindy vein is a linear structure with only one minor post mineralisation fault in the central section. The vein system lenses and branches rapidly, hosted within andesitic volcanics (and intrusives?). Gold of economic grade is generally confined to a more continous 2-4m wide footwall vein dipping 80° to the south. The Cindy vein predominantly consists of white sugary quartz and, although minor chalcedony and banded colloform/crustiform quarts is present, there are very few of the classical epithermal textures observed in the Scott Lode.

Alteration and Nature of Ore Fluid at Pajingo

The dominant and ubiquitous alteration type within the Janet Range Volcanics is propylitic characterised by dark green chlorite.

A series of hypogene alteration assemblages is developed with quartz vein lodes and their immediate host rocks. These are referred to as sericite and neutral argillic, which are characterised by light grey, light green and cream rock colouration due to silica and illite, interlayered illite-smectite, and kaolinite (dickite) - Figure 4. Generally, within the wall rocks, these assemblages are overprinted by red, brown or orange-brown colouration due to late alteration by ankerite or dolomite and siderite.

The sericitic type is most closely associated with quartz vein deposition. In this type, feldpsar phenocrysts are replaced by illite, sericite, silica and chlorite. Groundmass alteration consists of fine to medium grained equigranular quartz clouded with disseminated illite, dusty leucoxene and pyrite, and feldspar laths are replaced by illite. Clasts in lithic tuffs are replaced by quartz and illite with pyrite.

Adularia has been identified as quartz vein selvedges in deep veinlets and (Bobis 1990) notes adularia is extensively developed in association with the intrusive andesite porphyry.

The neutral argillic type overprints the sericitic type. Illite is partially to totally replaced by interlayered illite-smectite, however, illite and illite-smectite do co-exist as primary alteration phases.

Kaolinite (dickite), in a well crystallised form, is regarded as a hypogene phase. It commonly overprints the earlier phyllic and neutral argillic phases. Carbonate is the latest alteration assemblage. Often the carbonate obliterates the original alteration assemblages in phenocryst sites but commonly illite, quartz, kaolinite and carbonate coexist in the ground mass. Kaolinite also overprints vein adularia.

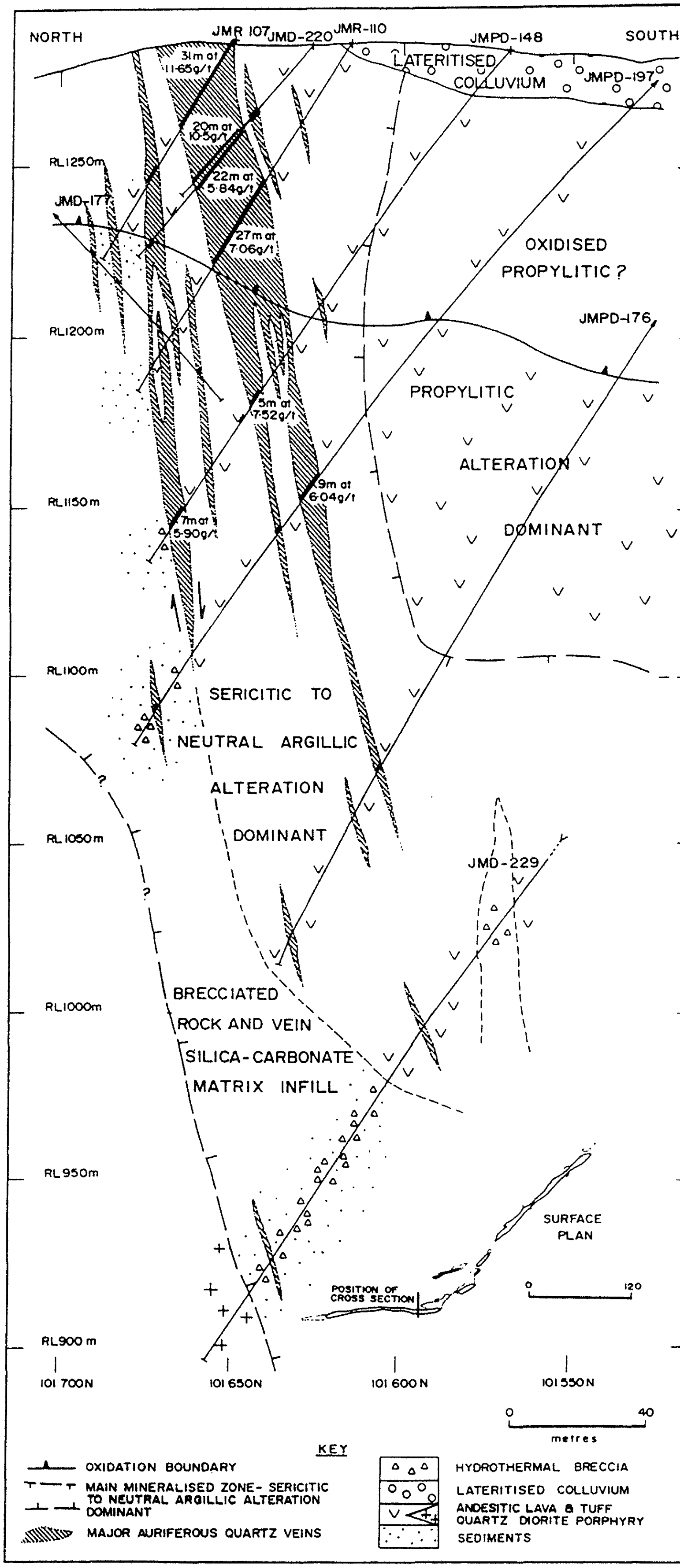


Figure 4 Section Through the Scott Lode Showing Main Alteration Zones

Late stage carbonate alteration is widespread. Pyrite in wallrocks averages 4 vol % with localised zones to 30 vol % which has contributed to the formation in the surface oxidation environment of supergene kaolinite and natroalunite which overprints the above alteration assemblages.

Fluid inclusion data indicates the ore fluids were near neutral, low salinity (maximum 6,600 mg/kg) fluids which had a base temperature of 250 degrees Celsius suggesting a depth of Lode formation of some 300 to 600 m below surface. Oxygen isotope analysis suggest a major meteroic water component in the ore fluid and the wallrock sulphur isotopes values are similar to many comparable modern volcanic hosted systems. Wood et al., 1990; Porter, 1991.

By comparison with New Zealand geothermal systems (Browne, 1985) sericitic alteration is interpreted to have formed at plus 230 degrees Celsius, neutral argillic type at temperatures of 150 to 230 degrees Celsius (generally greater than 200 degrees Celsius).

Geochemical Features of the Pajingo Mineralization

The gold and silver mineralization, as defined by the 1 g/t gold cutoff, is confined to the quartz veins within the quartz vein zone. Mineralisation is dominantly gold and electrum. In the oxidised portion of the vein, gold is sometimes associated with silver halides reflecting the acidic supergene conditions. Below the oxidation base, gold is also associated with galena and sulphosalts, and sphalerite and chalcopyrite. There is little evidence of surficial or supergene enrichment of gold values.

Porter (1991) completed a quartz textural versus gold grade study which showed that in surface samples there is a definite association between crustiform (colloform) microcrystalline milky and to a lesser extent massive microcrystalline milky textured quartz and higher gold grades (Figure 5). In addition from the study of the Scott Lode there is a clear vertical transition in quartz textural types with depth with a coincidental change in gold grades. The most notable change with increased depth is the transition from microcrystalline to crystalline quartz with a predominance of clear to grey over milky quartz. The crustiform textures become broader and less defined. In addition there is a change in the style of sulphide occurrence from dominantly crustiform to irregular clots and disseminations with increasing depth. Therefore quartz textural types are a useful indicator of both gold grades and approximate vertical positions within the Pajingo Epithermal vein system. Overprinting features introduced complexity and hamper symplistic interpretations. Textural relations and gold grade are less clear cut at the Cindy Vein.

Porter (1991) also completed two geochemical studies investigating geochemical variations:

1. with depth in the Scott Lode.
2. over the areal extent of the Pajingo mineralization at surface.

The results of the Scott Lode study are:

- The only element to have a strong correlation with Au is Ag. The ratio of Au to Ag decreases with depth. (Figure 6)
- Sb and As are spatially associated and these elements form a halo to the higher grade Au zone. Both elements tend to be more elevated at depth.
- Cu, Pb, Zn are strongly spatially associated with elevated values towards the base of the gold zone. Values drop rapidly below the Au zone. There may be a subtle Au-Pb association.
- Hg is erratic but there is a vague halo of higher Hg to the Au zone and an increase in Hg with depth.
- Ba forms a broad blanket generally above the oxidation base. There is no apparent relationship to gold.
- Mn displays a broad affinity for the main gold zone and perhaps a link with Cu, Pb and Zn. Generally higher values at depth.

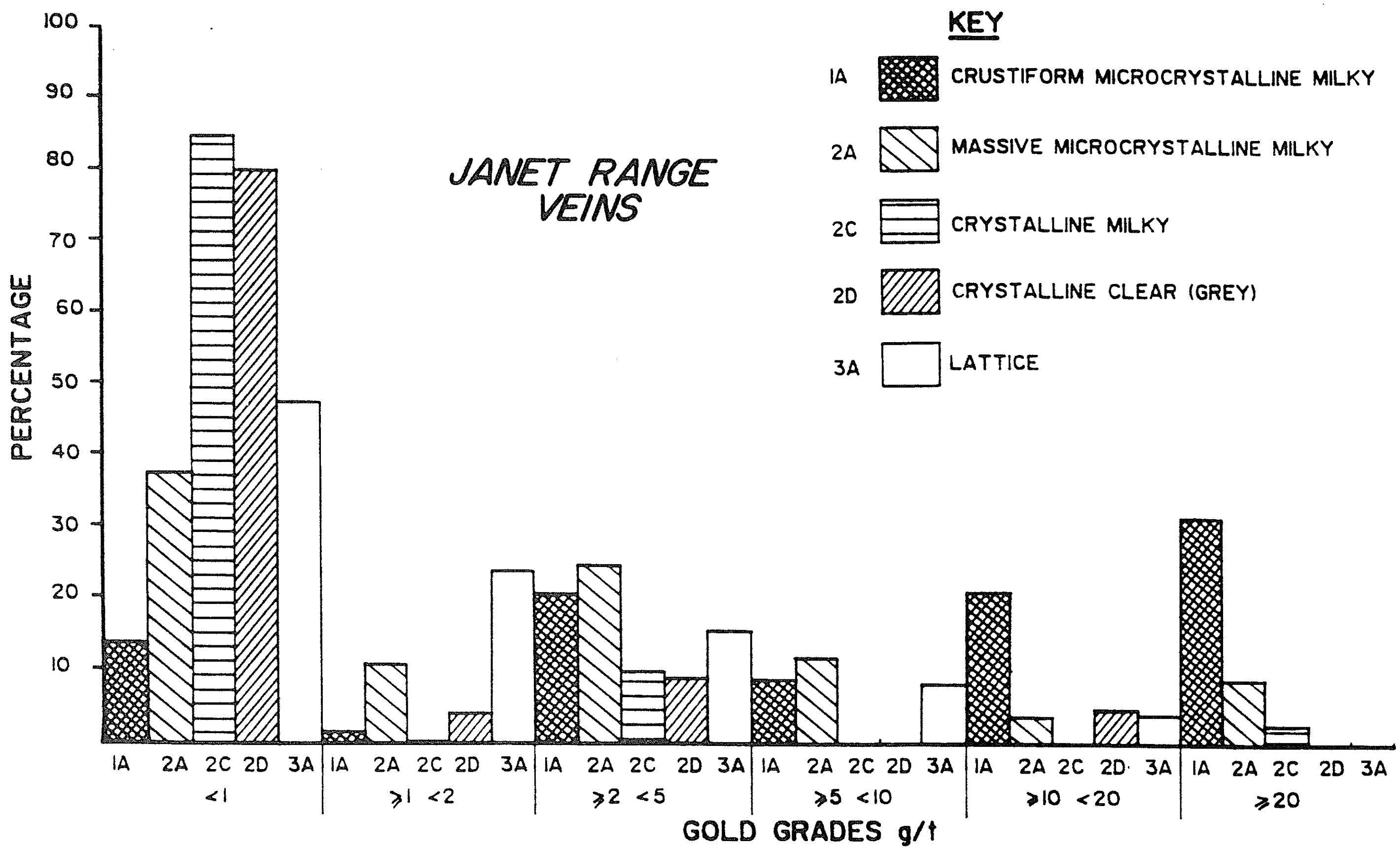
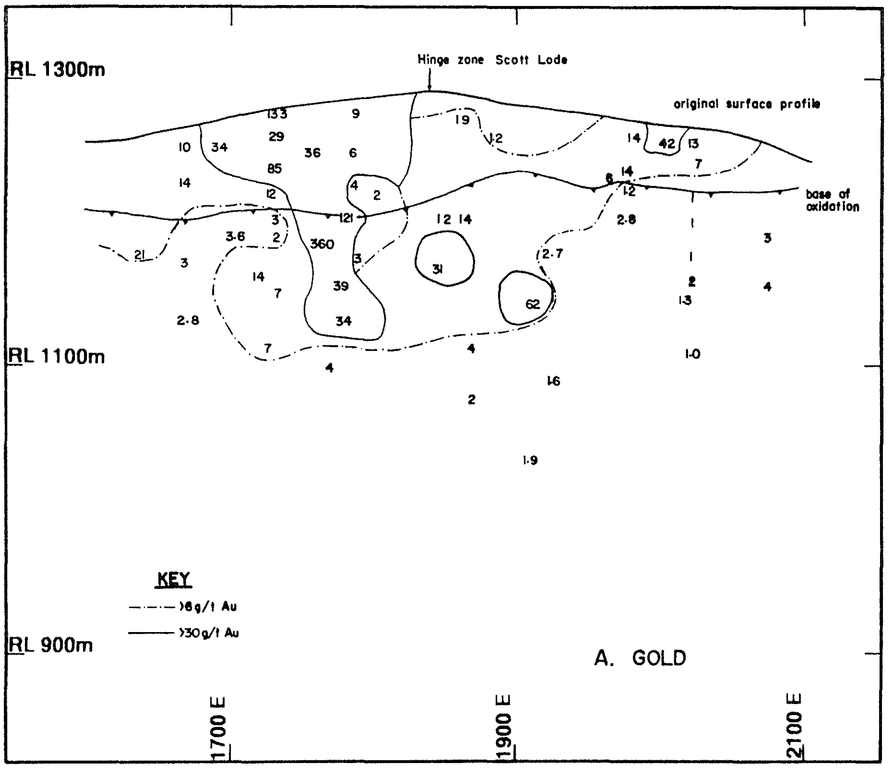


Figure 5 Janet Range Veins
Distribution of the Five Dominant Textural Types (Crustiform Ia, Massive Microcrystalline Milky 2a, Crystalline Milky 2c, Crystalline Clear 2d and Lattice) by Gold Grade As A Percentage of the Total of Non-Brecciated Samples in Each Textural Type.
Porter, 1991



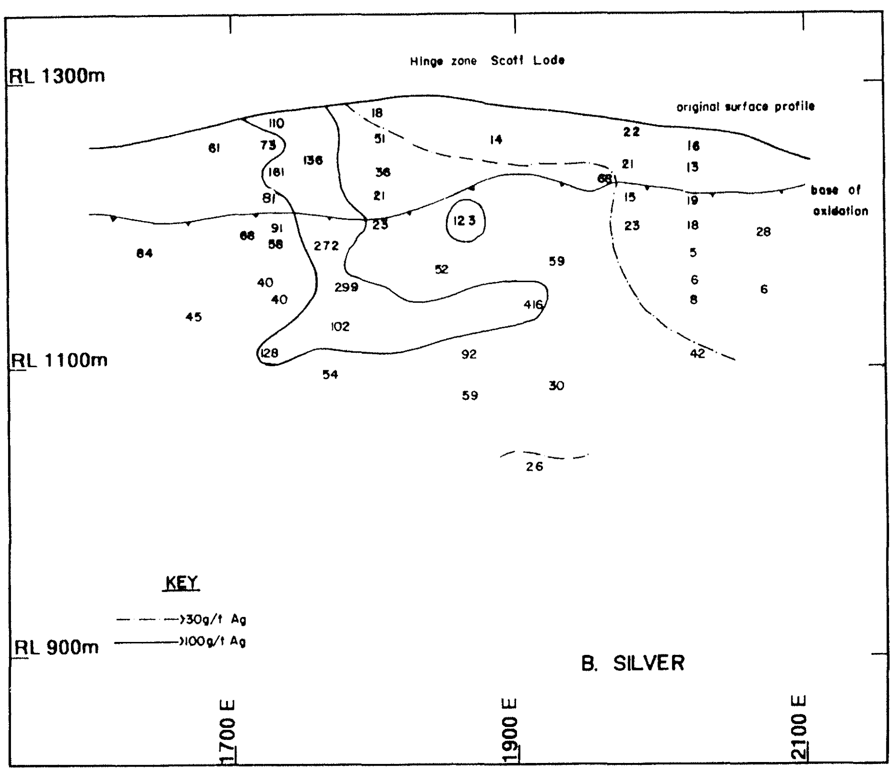


Figure 6 Distribution of Elements Associated with Ore Zone.
A. Au Zones & Values (Ppm)
B. Ag Zones & Values (Ppm)
For Location of Long Section See Figure 3.

Overall the main trends are a decrease in the Au:Ag ratio with depth, an increase in base metals with depth to the base of Au zone. As, Sb and Hg tend to be elevated at depth and form halos to the high grade zone.

The results of the geochemical study of the surface veins showed the following features and trends:

- There is a defined 6 km long north-west to south-east striking corridor where; within the main gold bearing veins, there is little change in average Au grades.
- There is an increase in the Au:Ag ratio towards the southern end of the Janet Range.
- Sb, Hg and Ba tend to be elevated to the south of Mt Janet.
- Cu, Pb, Zn and Mo are generally low in value and the results inconclusive.

Overall Au and Ag ratios and Cu, Pb, Zn values are considered to be the most reliable geochemical guides to position within a vein system.

Quartz textures appear to be a very useful indicator to higher grade Au zones and provide:

- a useful guide to vertical position within a vein/lode; and
- are a good indicator of potentially higher grade shoots within a vein/lode system.

Scott Lode Zoning Model

The Scott Lode sampling provided depth information which highlighted a systematic distribution of quartz types and vein textures which not only correlate with grade but vary with depth and with respect to relative position to the higher grade portions of the vein. Several zones based on quartz types vein textures (plus the form of sulphide and adularia) were identified. (Figure 7). Porter (1991) developed a zoning model which can be used to identify potential high grade vein infill and provide a means with which to estimate relative depth. The model provides a useful guide with which to evaluate other similar vein systems.

Acknowledgments

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The authors acknowledge the numerous geologists who have contributed to the understanding of the Pajingo ore deposits.

Terra Search Pty Ltd helped produce the paper. Deirdre Rodwell typed the manuscript, Adam Scott helped with figures. Simon Beams reviewed and edited the paper.

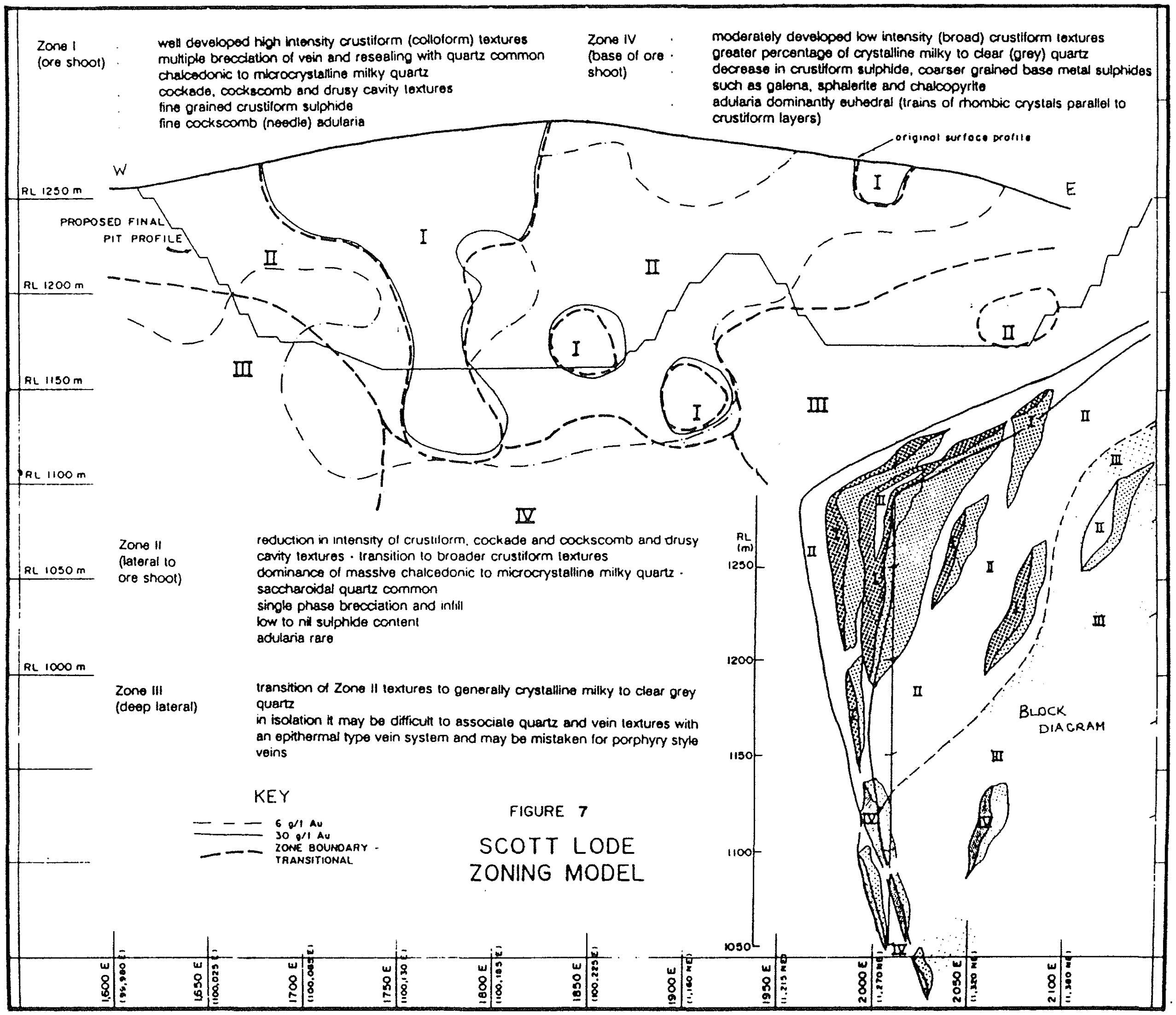

FIGURE 7

SCOTT LODE ZONING MODEL

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Environmental Geochemistry of the Pajingo Gold Mine

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Battle Mountain (Australia) Inc., PO Box 237, Charters Towers, Qld 4820

Background

Battle Mountain (Australia) Inc. has adopted a proactive approach to environmental management at the Pajingo Mine. Much of this has revolved around a co-ordinated program of waste characterisation based upon both static and kinetic geochemical test work. This has been supported by a program of physical characterisation of waste material. The above test work has resulted in different management practices for the three sources of waste generated to date from the Pajingo operation. Distinctive (geochemically) wastes have been generated from:

- Scott Lode open pit: 14 million tonnes
- Cindy open pit/underground: 1 million tonnes
- Mill tailings: 1.5 million tonnes will be generated based upon current reserves.

The geology and mineralogy of the Pajingo deposits indicated that Acid Rock Drainage (ARD) could be significant. Geochemical test work focused upon this and potential management strategies. Figure 1 shows the plan of operations for the Pajingo Gold Mine.

Predictive Test Work Results - Scott Lode Waste Rock

The Scott Lode is hosted by a sequence of intrusive and extrusive rocks of andesitic composition. Fresh samples can contain up to 5% fine disseminated pyrite. Minor galena, sphalerite, chalcopyrite and arsenopyrite can be present.

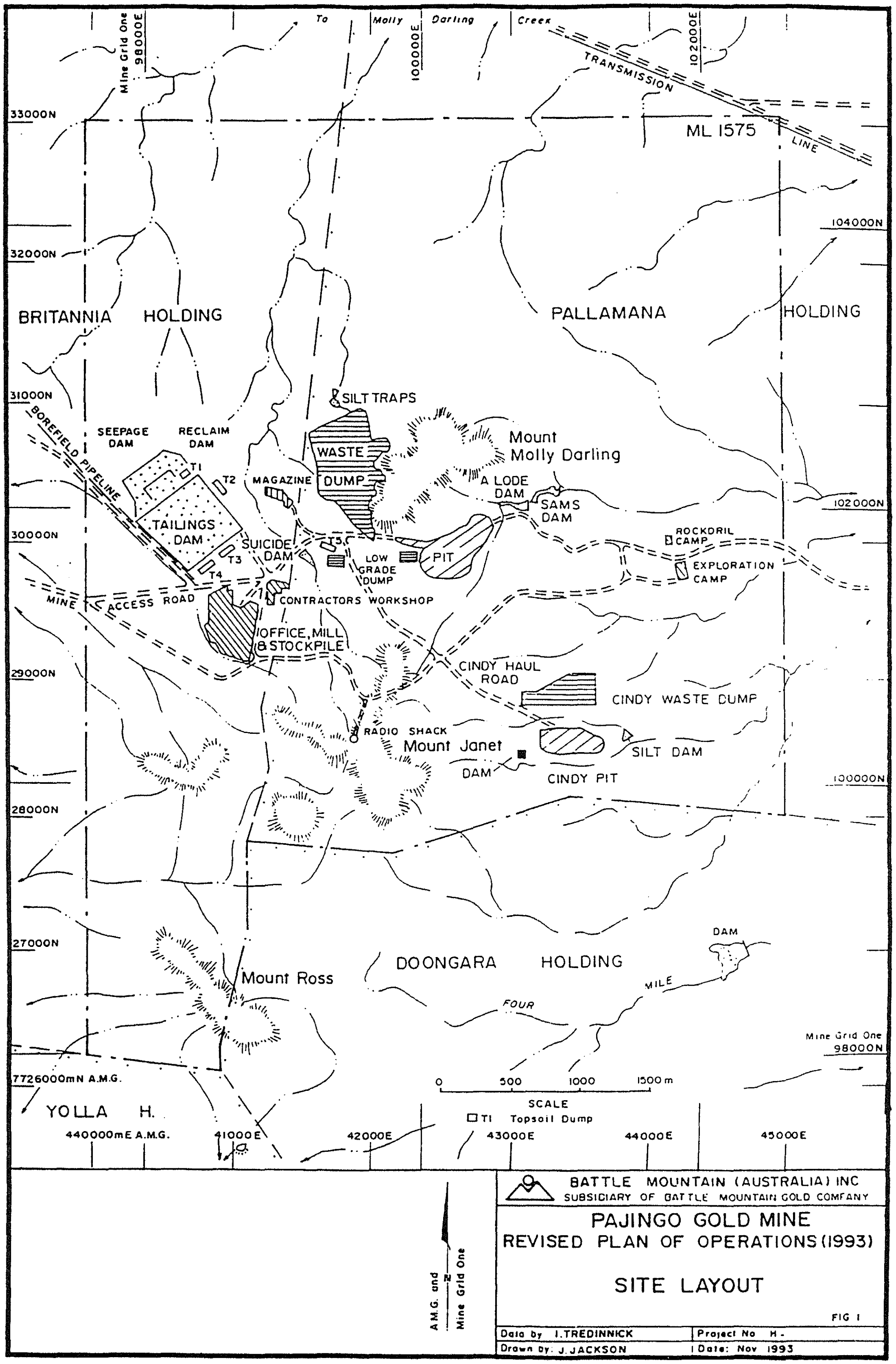
Waste rock samples can be visually differentiated into oxidised waste (OW) and fresh/sulphide bearing waste (SW). Sampling and analysis of the various geological units within the above subdivisions showed there was no requirement to further subdivide the classes of waste rock.

Static Test Work

Static test work showed that both the OW and SW have very low Acid Neutralising Capacity (ANC). The ANC is the natural neutralising ability of a sample. The associated minerals contributing to the overall ANC include carbonates, exchangeable cations on clays, and silicate minerals. The ANC ranged between 0.0 and 18 kg H_2SO4/tonne with an average value of 3.7 kg H_2SO4/tonne.

Total sulphur values for OW ranged from 0.01 - 2.56%, with an average concentration of 0.36%. Sulphide waste averages 2.03% sulphur with a range of 0.39% - 4.8%.

The above equates to a Maximum Potential Acidity (MPA) of between 0.3 - 78.4 kg H_2SO4/tonne and an average of 11.2 kg H_2SO4/tonne for OW. The MPA for SW ranged between 2.2 - 145.4 kg H_2SO4/tonne with and average MPA of 62.1 kg H_2SO4/tonne. Whole rock analysis of samples returned higher than "normal background" levels of Pb, Zn, As, Cu, Fe, and Mn. Shake tests on Scott Lode SW returned neutral to alkaline pH's. However increased concentrations of sulphate indicated that acid generation was occurring but was not sufficient at this point to counteract the natural buffering capacity of the material. The neutral to alkaline conditions greatly reduced the solubility of metals in the short term.



BATTLE MOUNTAIN (AUSTRALIA) INC
SUBSIDIARY OF BATTLE MOUNTAIN GOLD COMPANY
PAJINGO GOLD MINE
REVISED PLAN OF OPERATIONS (1993)
SITE LAYOUT
FIG 1
Data by I. TREDINNICK
Drawn by: J. JACKSON
Project No H-
Date: Nov 1993
To Molly Darling Creek
TRANSMISSION LINE
ML 1575
BRITANNIA HOLDING
PALLAMANA HOLDING
DOONGARA HOLDING
YOLLA H.
BOREFIELD PIPELINE
SEEPAGE DAM
RECLAIM DAM
TAILINGS DAM
SUICIDE DAM
MAGAZINE
WASTE DUMP
SILT TRAPS
Mount Molly Darling
A LODE DAM
SAMS DAM
PIT
LOW GRADE DUMP
ROCKDRIL CAMP
EXPLORATION CAMP
MINE ACCESS ROAD
CONTRACTORS WORKSHOP
OFFICE, MILL & STOCKPILE
CINDY HAUL ROAD
CINDY WASTE DUMP
RADIO SHACK
Mount Janet
SILT DAM
DAM
CINDY PIT
Mount Ross
FOUR MILE
DAM
T1 T2 T3 T4 T5
T1 Topsoil Dump
SCALE
0 500 1000 1500 m
33000N
32000N
31000N
30000N
29000N
28000N
27000N
7726000mN A.M.G.
104000N
102000N
100000N
Mine Grid One 98000N
Mine Grid One 98000E
100000E
102000E
440000mE A.M.G.
41000E
42000E
43000E
44000E
45000E
A.M.G. and Mine Grid One N

The static test work indicated that the OW was naturally acidic with low sulphur and low metal concentrations. Significant generation of acidic metal bearing leachate was unlikely based upon the above data. The sulphide waste has a significant net acid producing potential but although the more environmentally sensitive metals (e.g. arsenic, zinc, copper) are present, the concentration of these metals are not as high as those for other projects reported in the literature where ARD has been of concern.

Kinetic Test Work
To further evaluate the potential leachate quality produced by sulphide waste a series of column leach tests were carried out. Column leach tests were carried out on samples of SW for a period of 31 months. The principal features of the results were:

• *pH* - the pH was initially in a range between 3 to 4. After approximately eights weeks this reduced to pH 2.5 and eventually levelled of to approximately pH 2 (Figure 2).

• *Electrical Conductivity (EC)* - the EC is a measure of the concentration of dissolved salts (salinity). The EC increased from approximately 1000 uS/cm to peak above 10,000 uS/cm at twelve months. By the end of the test period electrical conductivities had declined to approximately 7000 uS/cm (Figure 2).

• *Sulphate and Iron* - sulphate and iron concentrations were initially in the order of 800 mg/l and 35 mg/l respectively and peaked at approximately 17,300 mg/l and 4,420 mg/l after 18 months. They then decreased to approximately 920 mg/l iron and 3700 mg/l sulphate by the end of the test period. At pH less than 2 the iron and sulphate concentrations in the leachate greatly increased (Figure 3).

• *Other Metals* - concentrations of copper in the leachate ranged from 0.34 mg/l to 52 mg/l and consistently exceeded the livestock (cattle) water quality guide-line standard of (0.5 mg/l). The data indicated that copper depletion or unavailability was occurring during the second half of the test period.

Concentrations of zinc (0.20 mg/l to 5.9 mg/l) were consistently below the live stock (cattle) standard. Arsenic and cadmium results were generally within livestock (cattle) guide-line values (0.2 and 0.01 mg/l respectively). At low pH (less than pH 2.0) arsenic and cadmium content in leachates exceeded these guide-line values, ranging between 0.01 and 6.0 mg/l for arsenic and between <0.01 and 0.81 mg/l for cadmium.

Concentrations of lead in the leachates analysed tended to peak above livestock (cattle) water quality guideline values.

Predictive Test Work Results - Cindy Waste Rock

The Cindy Lode is located approximately 2.5 km from the Scott Lode pit. It is hosted by the same geological sequence and contains similar mineralisation. Geochemical waste characterisation consisted of whole rock analysis of Cindy oxide and sulphide waste and comparison with Scott Lode waste rock.

Table 1 is a comparison of the concentrations of potential pollutants in Scott Lode and Cindy waste rock. In all cases (except Cindy SW Mn concentration) the Cindy waste rock contained lower concentrations of metals and sulphur than the corresponding Scott Lode waste rock. Assuming the same low to very low ANC for Cindy waste as for Scott Lode waste then the NAPP and metals concentrations in leachate for Cindy would be lower than for Scott Lode material.

COLUMN LEACH TESTS SULPHIDE WASTE

pH & Electrical Conductivity (EC)

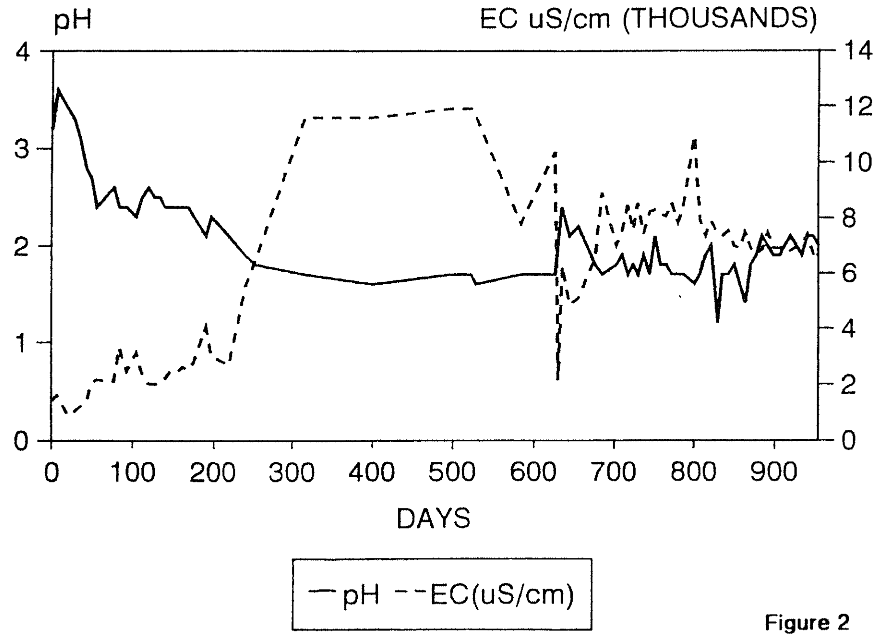


Figure 2

COLUMN LEACH TESTS SULPHIDE WASTE

Fe & SO4

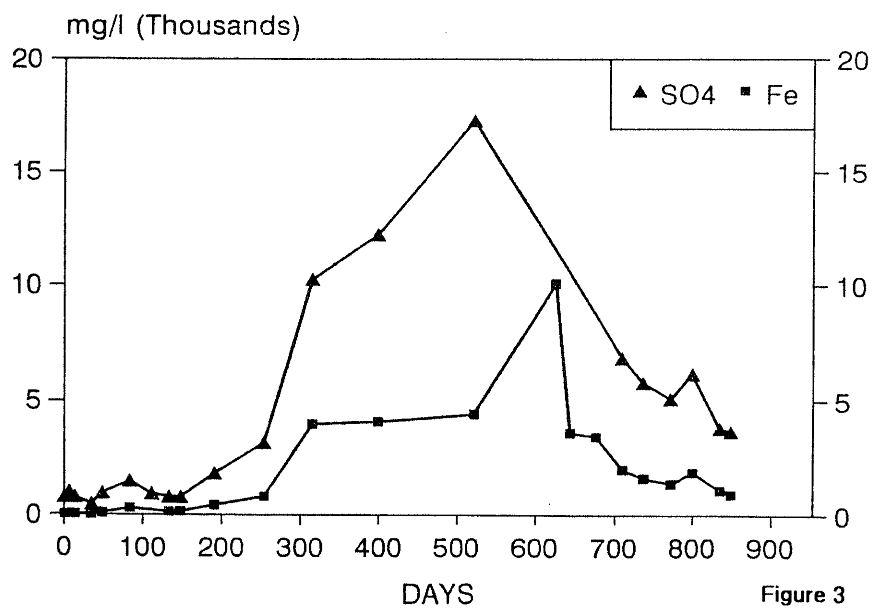


Figure 3

	Cu	Pb	Zn	As	Fe(%)	Cd	Mn	S(%)
Scott Lode OW	53	18	119	62	5.08	BLD	1202	0.36
Cindy OW	28	9	59	40	3.36	BLD	307	0.10
Scott Lode SW	62	29	73	47	3.97	BLD	611	2.03
Cindy SW	43	15	56	34	2.70	BLD	1014	0.43

Table 1. Cindy and Scott Lode Waste Rock Chemistry
(All values in ppm except where shown; BLD = Below Level of Detection)

Predictive Test Work Results - Tailings

The Pajingo ore consists of fine grained gold/silver bearing quartz. The quartz veins are the local aquifers and as such the only sulphides present (<1%) are those encapsulated in the quartz. The majority of sulphides present in the tailings is due to the inclusion of sulphide waste as mining dilution. This dilution is estimated to be in the order of 5-15% of the total material presented to the mill. The milling process involves the addition of cyanide, caustic soda and lead nitrate (CIP/CIL Circuit).

The tailings facility is divided into 3 cells (Figure 4). Cells 2 & 3 and the base of cell 1 have had Scott Lode oxide tailings deposited into them. The middle layers of Cell 1 will contain sulphide Scott Lode and Cindy tails while the top layers will consist of Cindy oxide tails (Figure 4).

Geochemical characterisation of the tails to date has concentrated upon the calculation of the NAPP and the Net Acid Generation (NAG) along with whole sample geochemistry of the different composition tailings. Limited shake solubility test work has also been carried out.

The MPA based on total sulphur (average = 0.28% S total) for "oxide" tails from cells 2 & 3 ranged up to 28kg H_2SO4/tonnes (Figure 5). However when calculated using sulphide sulphur the MPA for cells 2 & 3 was generally below 10kg H_2SO4/tonne (Figure 6). The marked decrease being due to a high proportion of sulphate sulphur in the oxide tails. However the "sulphide" tails (average = 0.53% S total) from cell 1 showed only a minor reduction in MPA when calculated using Sulphide sulphur only. The smaller reduction reflecting the predominance of sulphide sulphur in the tails.

The higher ANC reported for the Cell 1 tails is a reflection of the alkaline milling conditions. The freshly deposited Cell 1 tails having had insufficient time to consume this neutralizing capacity. NAG test results (Figures 7 and 8) show a good correlation with the NAPP values calculated using sulphide sulphur values.

Analysis of the tailings revealed similar metal concentrations to those in the corresponding Scott Lode waste rock. The exception being Pb which returned elevated levels due to the addition of lead nitrate in the milling process.

PAJINGO TAILINGS DAM

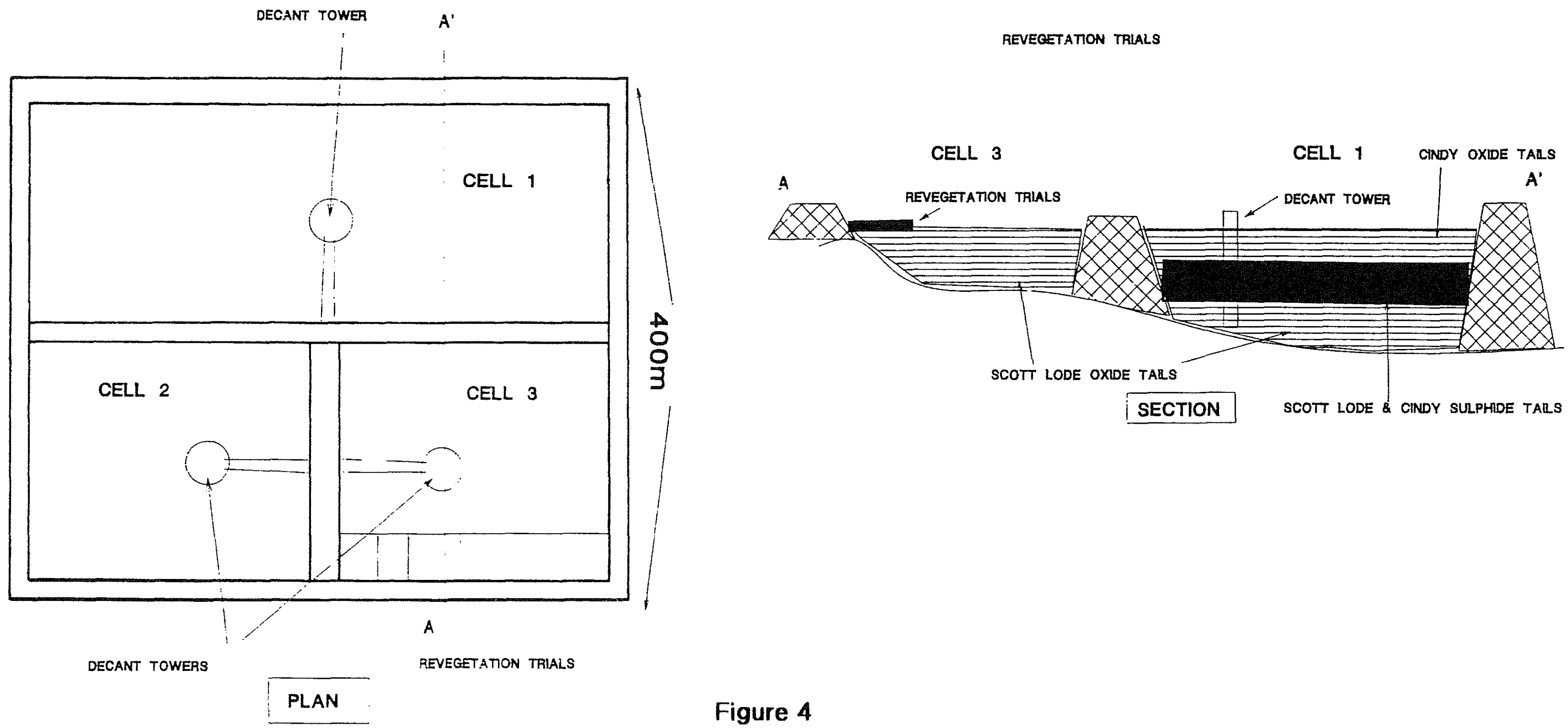
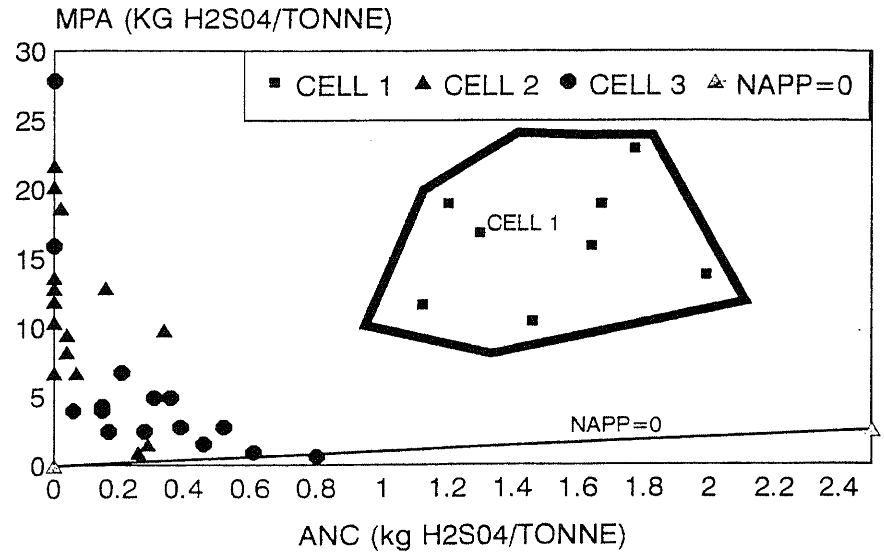


Figure 4

PAJINGO TAILINGS

NET ACID PRODUCING POTENTIAL: TOTAL SULPHUR

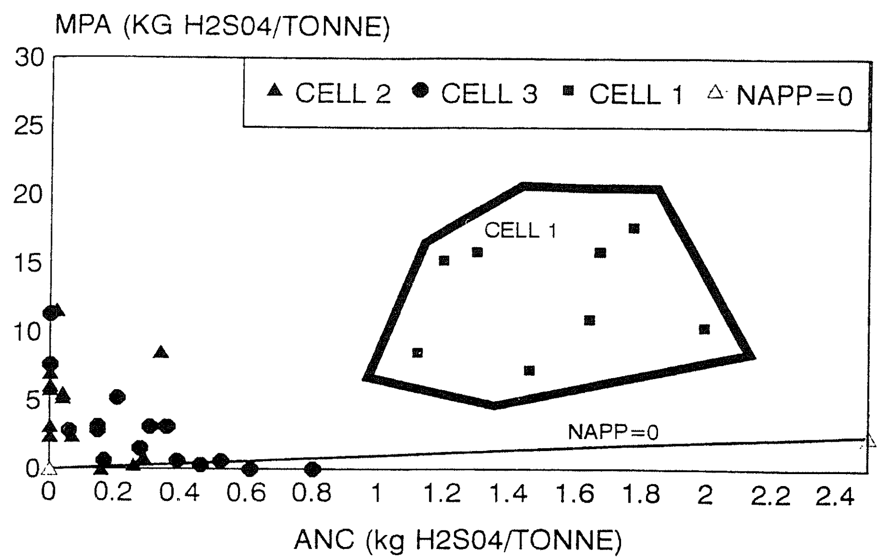


MPA = MAXIMUM POTENTIAL ACIDITY
ANC = ACID NEUTRALIZING CAPACITY

Figure 5

PAJINGO TAILINGS

NET ACID PRODUCING POTENTIAL: SULPHIDE SULPHUR



MPA = MAXIMUM POTENTIAL ACIDITY
ANC = ACID NEUTRALIZING CAPACITY

Figure 6

PAJINGO TAILINGS

NET ACID GENERATION TEST RESULTS
(pH 5.5)

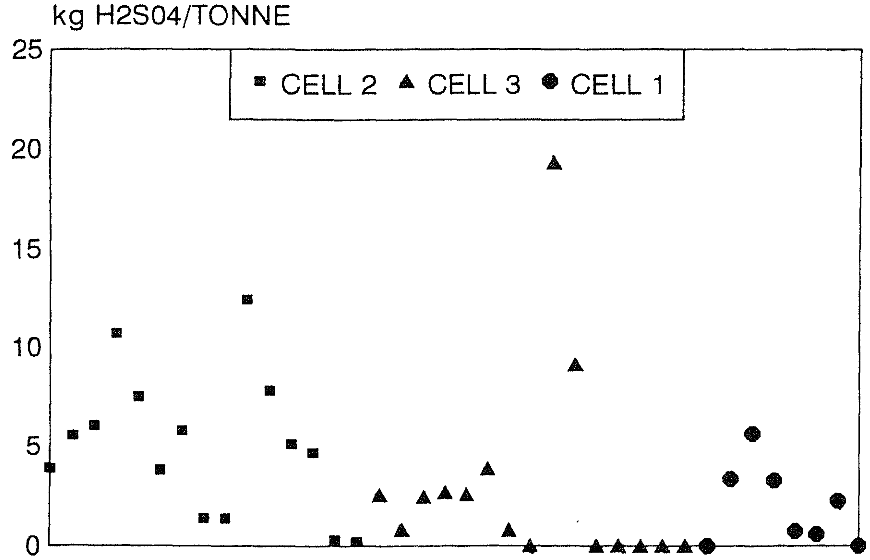


Figure 7

PAJINGO TAILINGS

NET ACID GENERATION TEST RESULTS
(pH 7.0)

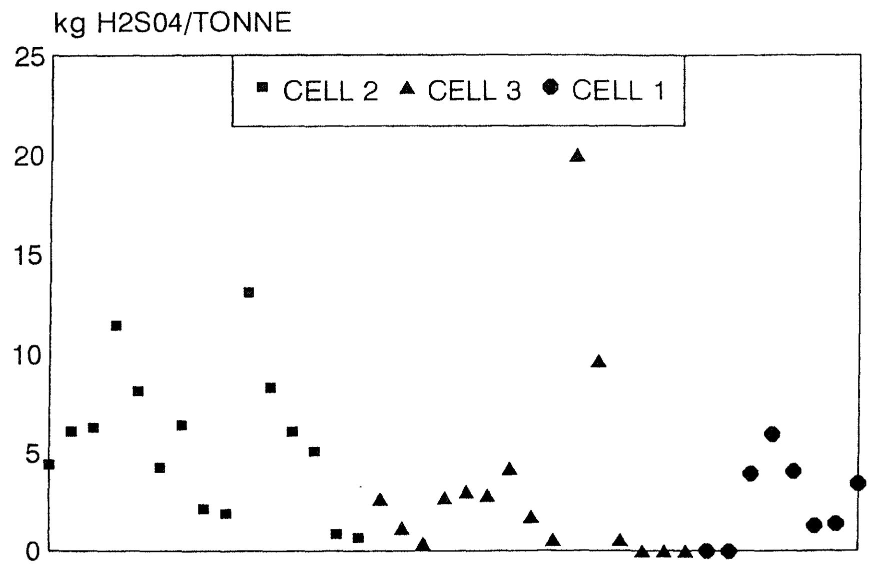


Figure 8

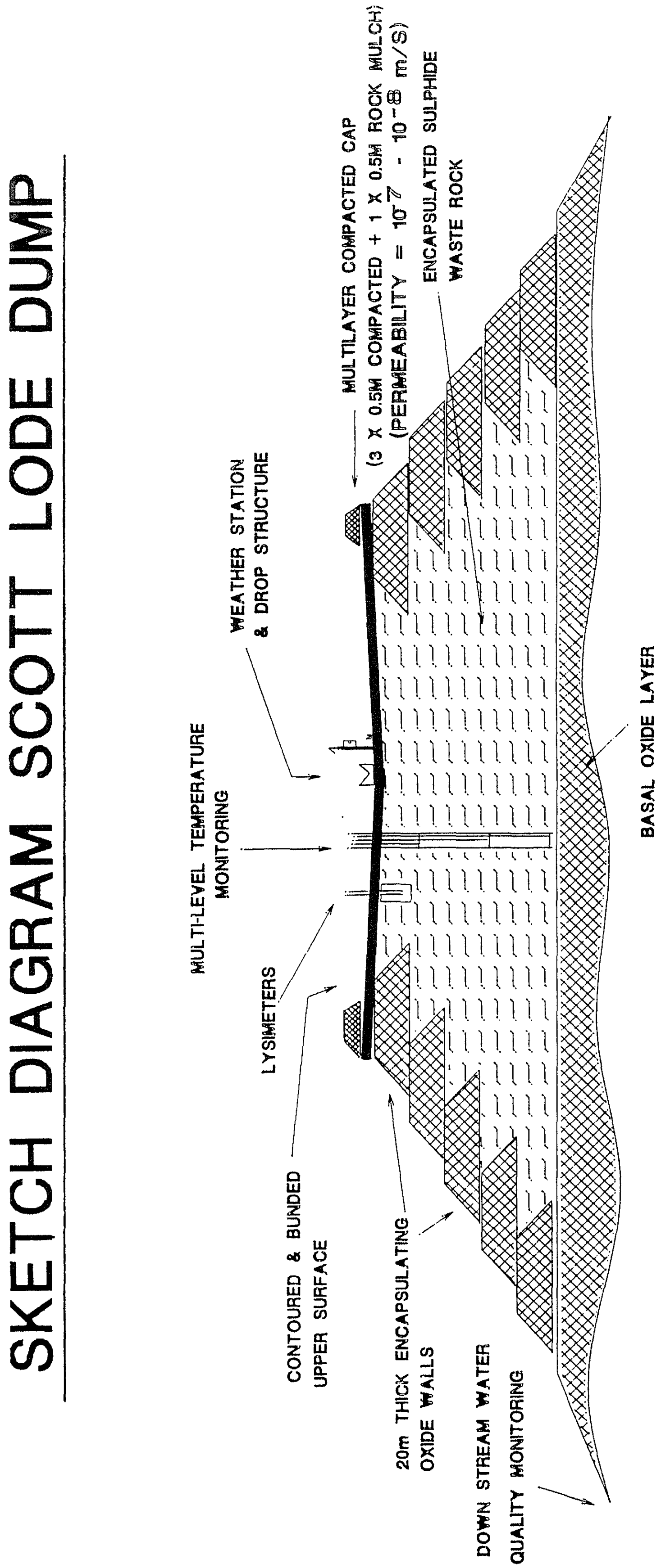

SKETCH DIAGRAM SCOTT LODE DUMP
MULTILAYER COMPACTED CAP
(3 X 0.5M COMPACTED + 1 X 0.5M ROCK MULCH)
(PERMEABILITY = 10⁻⁷ - 10⁻⁸ m/S)
ENCAPSULATED SULPHIDE
WASTE ROCK
WEATHER STATION
& DROP STRUCTURE
MULTI-LEVEL TEMPERATURE
MONITORING
LYSIMETERS
CONTOURED & BUNDED
UPPER SURFACE
20m THICK ENCAPSULATING
OXIDE WALLS
DOWN STREAM WATER
QUALITY MONITORING
BASAL OXIDE LAYER

Figure 9

Management Strategy

Scott Lode waste rock
The Scott Lode waste rock was disposed of in an encapsulating waste dump. Modelling of the volumes and extraction schedule for oxide and sulphide waste was carried out to allow specific design parameters to be calculated. The principal features of the dump are:

- basal oxide waste rock layer;
- 20m thick encapsulating oxide walls;
- sulphide waste placed within oxide walls;
- minimum of 3 x 0.5m thick compacted cap layers;
- 0.5m loose rock mulch surface layer;
- contoured top surface to a central discharge point;
- monitoring of dump physics, surface runoff (quantity & quality), vegetation and erosion (Figure 9).

Cindy waste rock
Modelling revealed that only oxide waste would be produced from the Cindy pit. As such encapsulation was not required. The dump was constructed with 1:3 slopes, maximum slope lengths of 20m and drains grade at 1%. Sulphide waste mined from the underground operation will be used as underground backfill and not left exposed on the surface.

Tailings
Initial results of the tailings geochemistry study reveal that despite being low in sulphur there is the potential for ARD to be generated. Further evaluation will be conducted into various capping options. Revegetation trials have been conducted for the past 3 years.

Monitoring
Monitoring of surface water quality, downstream of the Scott Lode waste dump indicates that the sulphide waste has been successfully isolated. Analysis of water samples downstream of both the Cindy and Scott Lode waste dumps are within the compliance limits. Water currently collected in the tailings dam is recycled to the treatment plant. Water will not be discharged from the dam until it is decommissioned.

Acknowledgements

Peter Ryan (Principal - Environmental Scientist), Peter Scott (Senior Environmental Scientist): AGC-Woodward Clyde. AGC-Woodward Clyde provide ongoing advice to BMAI and conducted the Pajingo waste characterisation and management studies.

Discovery history, geology and geochemistry of the Yandan Gold Deposit

Mike Seed

Ross Mining N.L., Yandan Gold Mine, PO Box 242, Collinsville, Qld 4804

Introduction

The Yandan adularia-sericite (low sulphidation) epithermal Au deposit is located in North Queensland, Australia, approximately 225 km south of Townsville at latitude 21°18'S, longitude 149°58'E. Main road access is via Collinsville (Figure 1).

The Yandan deposit is situated in the basal sequence (St Anns Formation) of Late Devonian-Carboniferous sediments and volcanics of the Drummond Basin (Figure 1). Basement to these sediments consists of the Ordovician metamorphics of the Anakie Inlier and the overlying, locally preserved, Mid Devonian Ukalunda Beds. Sedimentation in the Drummond Basin ended with the Early Carboniferous Kanimblan Orogeny. St Anns Formation sediments were subsequently unconformably overlain by Permian and Triassic sediments of the Bowen and Galilee Basins, and intruded by numerous later Carboniferous, Permian and Tertiary stocks, volcanic plugs and domes. Extensive sheets of Tertiary sediments of the Campaspe Beds and Suttor Formation obscure much of the Drummond Basin sequence north and west of Mt Coolon. North and east of Clermont, Tertiary basalts cover both the Anakie Inlier and the Drummond Basin sequence.

The deposit is amenable to standard open pit mining, carbon in pulp and dump leach processing techniques. Mining commenced in September 1993 on the basis of a published ore reserve of 8.16 Mt at an average grade of 1.35 g/t gold (354,000 contained ounces), comprising 4.72 Mt at 2.00 g/t gold of CIP ore and 3.44 Mt at 0.46 g/t gold of run of mine dump leach ore. Forecast life of mine strip ratio and CIP recoveries are 0.22 and 93% respectively.

Historical Perspective

There were no historical diggings associated with the Yandan Deposit; the nearest historical gold diggings are at Mt Coolon, 45km to the east. The Yandan Deposit was discovered in 1985 as a result of a grass roots regional stream sediment sampling program in a area that had not been previously tested by systematic "modern exploration". Brief reviews of the project history, geology and alteration and mineralisation are given by Western Mining Corporation (WMC) in 1989, and Johnston (1994).

Systematic follow up stream sediment sampling, rock chip and soil sampling led to the targeting of five percussion holes, the second of which intersected the main orebody (59m at 3.04 g/t Au). Gold was the main element used to discover Yandan at all stages of the exploration program. Geological and geophysical input were only used at the prospect scale, once the geochemistry had highlighted the area of prospectivity.

A standard ore reserve delineation drilling program was carried out on a 50m x 25m pattern using 75% reverse circulation percussion and 25% diamond core techniques. An initial proved and probable reserve of 2.7 million tonnes at 2.3 g/t gold using a 1.5 g/t cut-off was established by WMC (Sharpe and Goss, 1992).

Ross Mining acquired the deposit in 1992 and commenced production in September 1993.

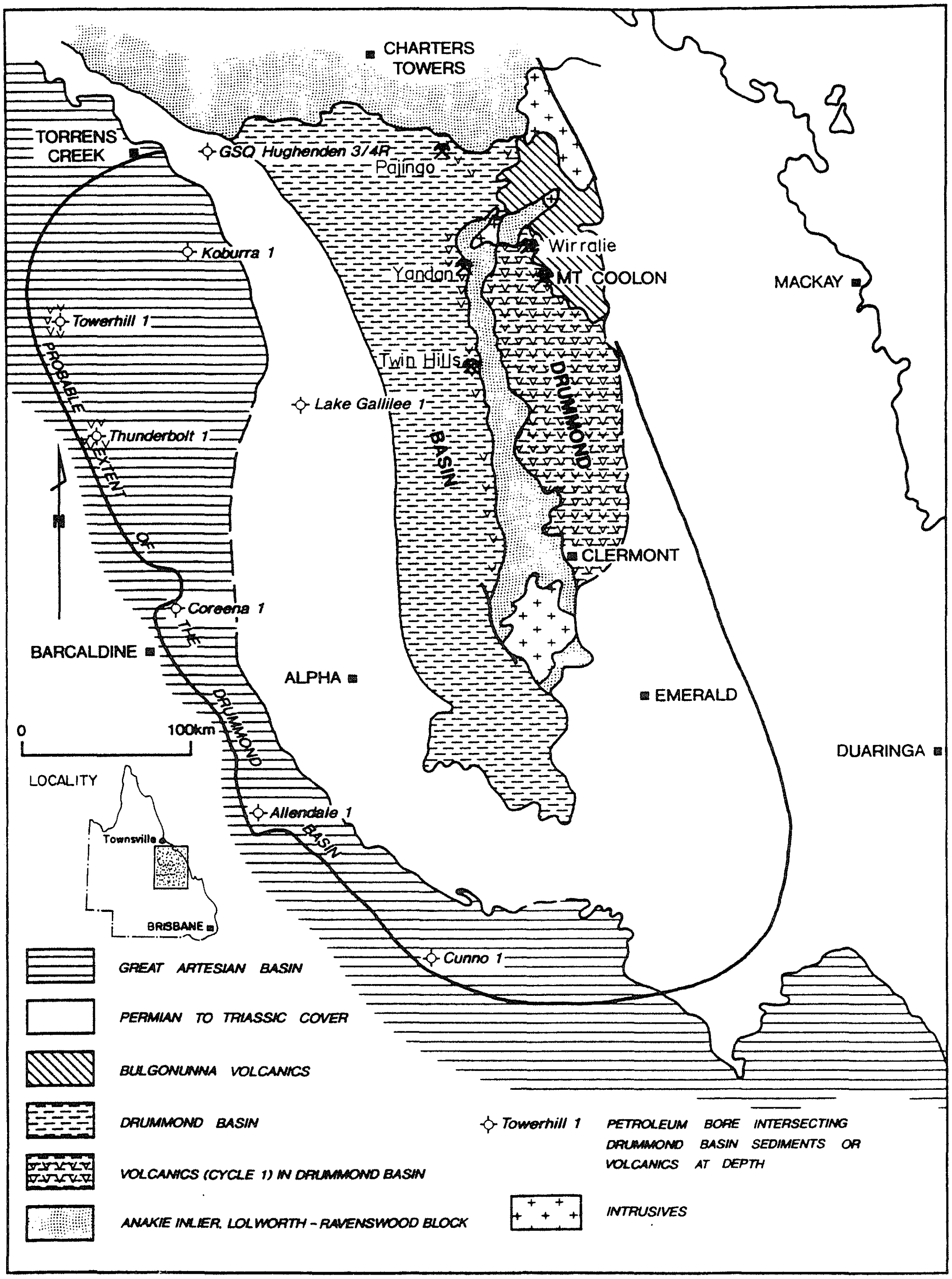


Figure 1. Map of central Queensland showing distribution of the Drummond Basin

Yandan Deposit Geology

Mineralisation at Yandan outcrops as three small hills which rise some 30m above the surrounding plains, and cover in total a surface area of approximately 1.0km x 0.8km. The main economic mineralisation is confined to an area called Main Hill.

Mineralisation is within the Upper Devonian - Carboniferous tuffaceous sediments of the St Anns Formation (Figures 2 and 3). St Anns Formation sediments in the mine area represent a broad upwardly fining cycle of sedimentation, passing upwards from andesitic flows, volcanic breccias and agglomerates of the informally named Yandan Andesite Unit, into tuffaceous sediments and siltstones of the Yandan Host Units, and finally into dirty algal limestones of the Yandan Limestone.

Sediments in the Mining Lease have a general east-north-east strike and a gentle north-westerly dip of 15 to 20°. A series of east-north-east and north-south faults truncate the local stratigraphy and are thought to be important in the development of the mineralisation.

The East Yandan Fault is a normal fault which locally bounds the St Anns Formation to the east against the Anakie Inlier. The Yandan Creek Fault truncates the mineralisation at the western end of Main Hill. There is also a possible north-south fault between East Hill and Main Hill.

Superimposed on the block between the Yandan Creek Fault and the East Yandan Fault is a series of east-north-east striking faults; the Yandan Fault zone is the most significant of these. It is a normal fault with a downthrow to the north. The South Yandan Fault is also a normal fault with a downthrow to the south. Other structures have been identified in the Main Pit which parallel the Yandan Fault and bound the mineralisation.

A number of hydrothermal "sandy breccias" and mosaic breccia zones have been identified within the pit, cross-cutting the local stratigraphy, and are probably spatially related to faulting.

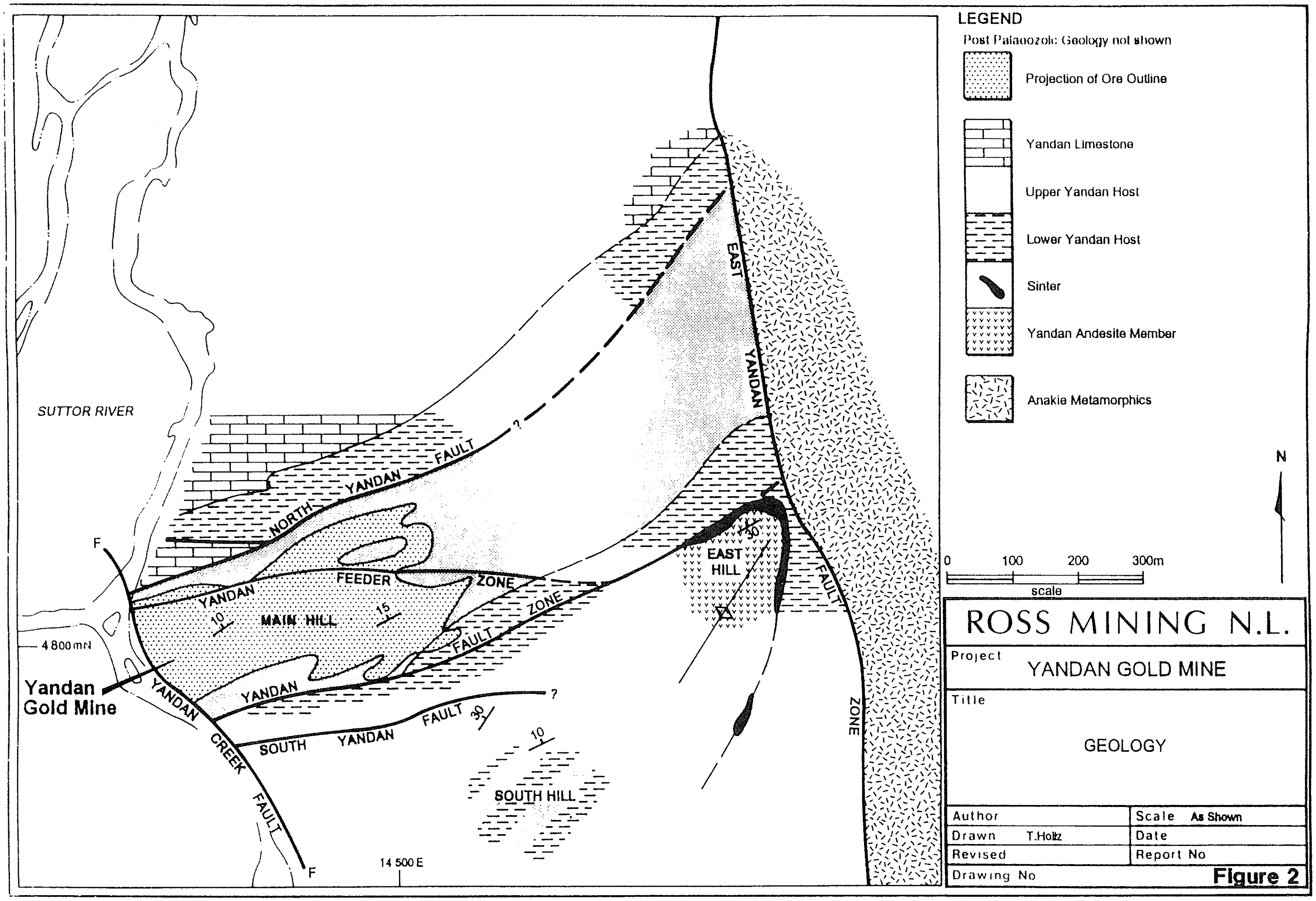
Pervasive alteration of the largely clastic host rock lithologies was probably facilitated by both primary permeability, inherent in most fragmental rocks, and secondary permeability (e.g. due to leaching, brecciation). Early quartz and adularia alteration is pervasive and "primary" cavities (within the matrices of the host lithologies) are infilled with interlocking adularia and quartz. Minor illitic clay occurs intergrown with some of the early quartz and replacing adularia.

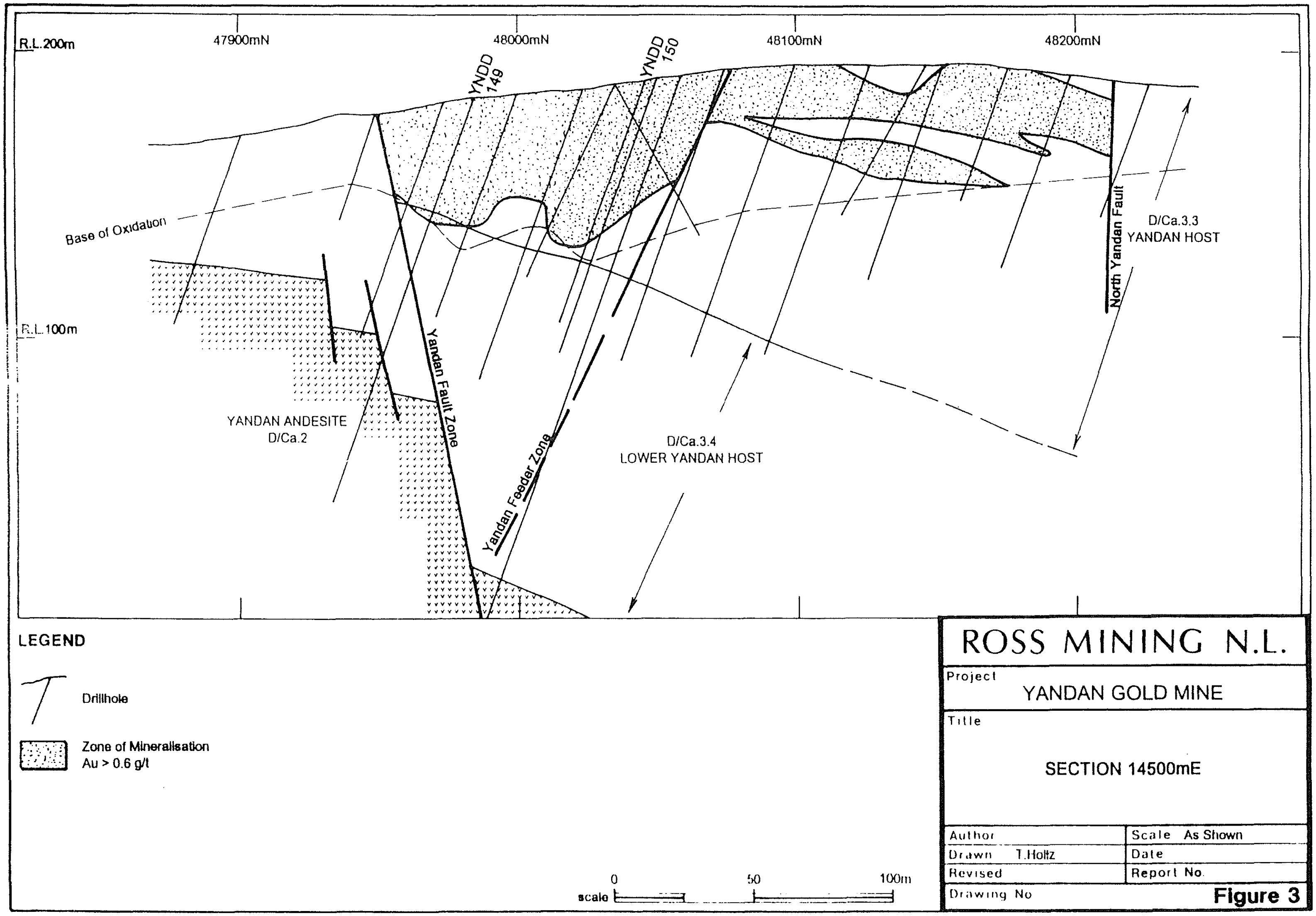
Where silicification is strongest, primary permeability is lost and secondary permeability is established as a result of fracturing of the silicified host rock (leading to boiling), and it is in these zones that mosaic-type hydrothermal breccias have developed. Deposition of bladed calcite occurred in the early stages, but with decreasing temperatures as a result of continued boiling, early precipitated carbonate will have gone to solution, leaving leached cavities or quartz replacement textures. Where significant brecciation did not occur, secondary permeability and subsequent deposition is manifested by microfracturing and leaching. With continued development of the system, alteration of adularia to illite is pervasive.

At a still later stage, pervasive replacement of adularia by kaolinite, and of pyrite by haematite, and the deposition of kaolinite, haematite, and rare jarosite in vughs and veinlets, suggests cool, downward-moving, low pH oxygenated fluids. The frequent occurrence of illite intergrown with kaolinite suggests a hydrothermal origin to the late stage alteration, rather than weathering.

The late stage alteration has produced the bleached zones down to approximately 50m where fresh sulphides and more carbonaceous material are encountered. This boundary has been designated as the base of oxidation.

Distribution of the alteration types grade out from a core of silicification, plunging to the west to illite-smectite, adularia and kaolinitic zones, which host the best gold grades. Peripheral to the dominantly argillic zone is propylitic-style chlorite-calcite-pyrite alteration.


LEGEND
Post Palaeozoic Geology not shown
Projection of Ore Outline
Yandan Limestone
Upper Yandan Host
Lower Yandan Host
Sinter
Yandan Andesite Member
Anakie Metamorphics
N
0
100
200
300m
scale
ROSS MINING N.L.
Project
YANDAN GOLD MINE
Title
GEOLOGY
Author
Scale As Shown
Drawn T.Holtz
Date
Revised
Report No
Drawing No
Figure 2
SUTTOR RIVER
NORTH YANDAN FAULT
YANDAN FEEDER ZONE
FAULT ZONE
MAIN HILL
EAST HILL
EAST YANDAN FAULT ZONE
YANDAN CREEK FAULT
SOUTH YANDAN FAULT
SOUTH HILL
Yandan Gold Mine
4 800mN
14 500E
F



R.L.200m
47900mN
48000mN
48100mN
48200mN
YNDD 149
YNDD 150
Base of Oxidation
R.L.100m
D/Ca.3.3
YANDAN HOST
North Yandan Fault
Yandan Fault Zone
YANDAN ANDESITE
D/Ca.2
Yandan Feeder Zone
D/Ca.3.4
LOWER YANDAN HOST
LEGEND
Drillhole
Zone of Mineralisation
Au > 0.6 g/t
0
50
100m
scale
ROSS MINING N.L.
Project
YANDAN GOLD MINE
Title
SECTION 14500mE
Author
Scale As Shown
Drawn T.Holtz
Date
Revised
Report No.
Drawing No

Figure 3

Gold deposition is associated with an early quartz + adularia + illite + pyrite ± bladed carbonate, graphite and chalcopyrite alteration assemblage. Gold occurs within matrix alteration assemblages of both clasts and "sandy" hydrothermal breccias. Higher grade mineralisation is generally associated with cross-cutting chalcedonic quartz + pyrite veinlets and pervasive adularia (- kaolin) alteration, and celadonitic faults; both tend to be spatially related to "sandy" hydrothermal breccia and fault zones.

The high grade core to the deposit appears to comprise a large east-north-east trending fault-related "sandy" hydrothermal breccia zone in the west at 14200E, changing in character in an easterly direction to become a complex fault link system by 14500E (this was described by WMC as the Yandan Feeder Zone, Figure 2).

Gold within Main Hill is very fine, with 50% being less than 4.5 microns and 92% less than 30 microns. Silver content is very low, and bullion fineness is around 900 (Sharpe and Goss, 1992).

Fluid inclusion studies from Main Hill indicate homogenisation temperatures of 205 to 215°C, and support the epithermal origin proposed for the deposit (Leach and Coote, 1988).

East Hill

Mineralisation at East Hill is significantly different to that at Main Hill, and is characterised by narrow (<1m) sub vertical colloform/crustiform banded quartz adularia veinlets, and narrow vein breccias with high silver to gold ratios (up to 30 : 1) occurring in the footwall of a large sinter horizon.

South Hill

Mineralisation at South Hill appears to be related to a large weakly pervasively mineralised "sandy" hydrothermal breccia zone centred on the western portion of the hill.

Geochemistry

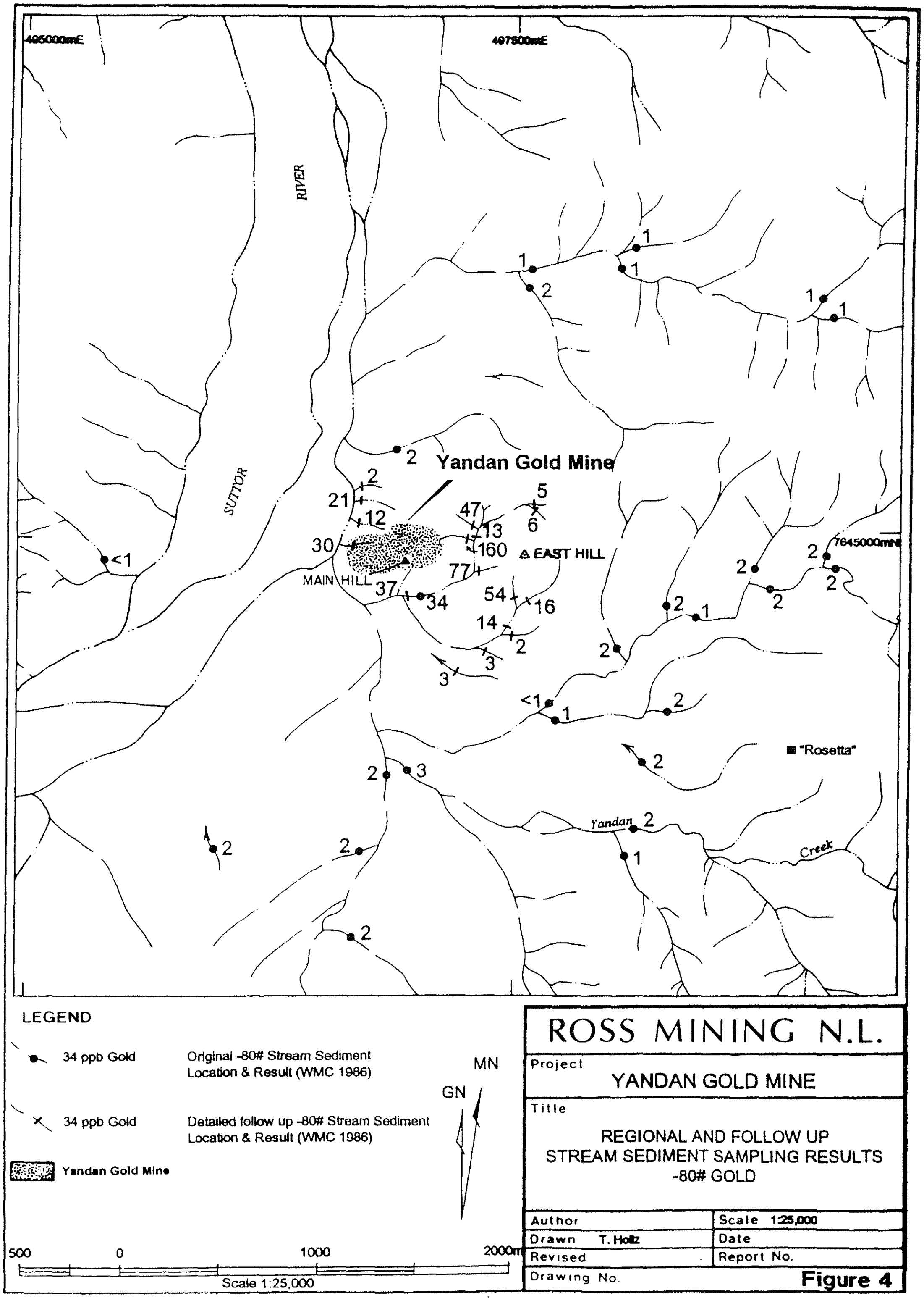
The Yandan Deposit was discovered by follow-up to a single anomalous stream sediment sample (-80#) which was part of a broad regional stream sampling program conducted by Western Mining Corporation in 1986. Figure 4 shows the position and results of both the regional and follow-up stream sediment sampling. Samples were sieved to -80# and split to 5 to 25g prior to an aqua regia digest. Analysis involved solvent extraction (DIBK), and an AAS finish with carbon furnace.

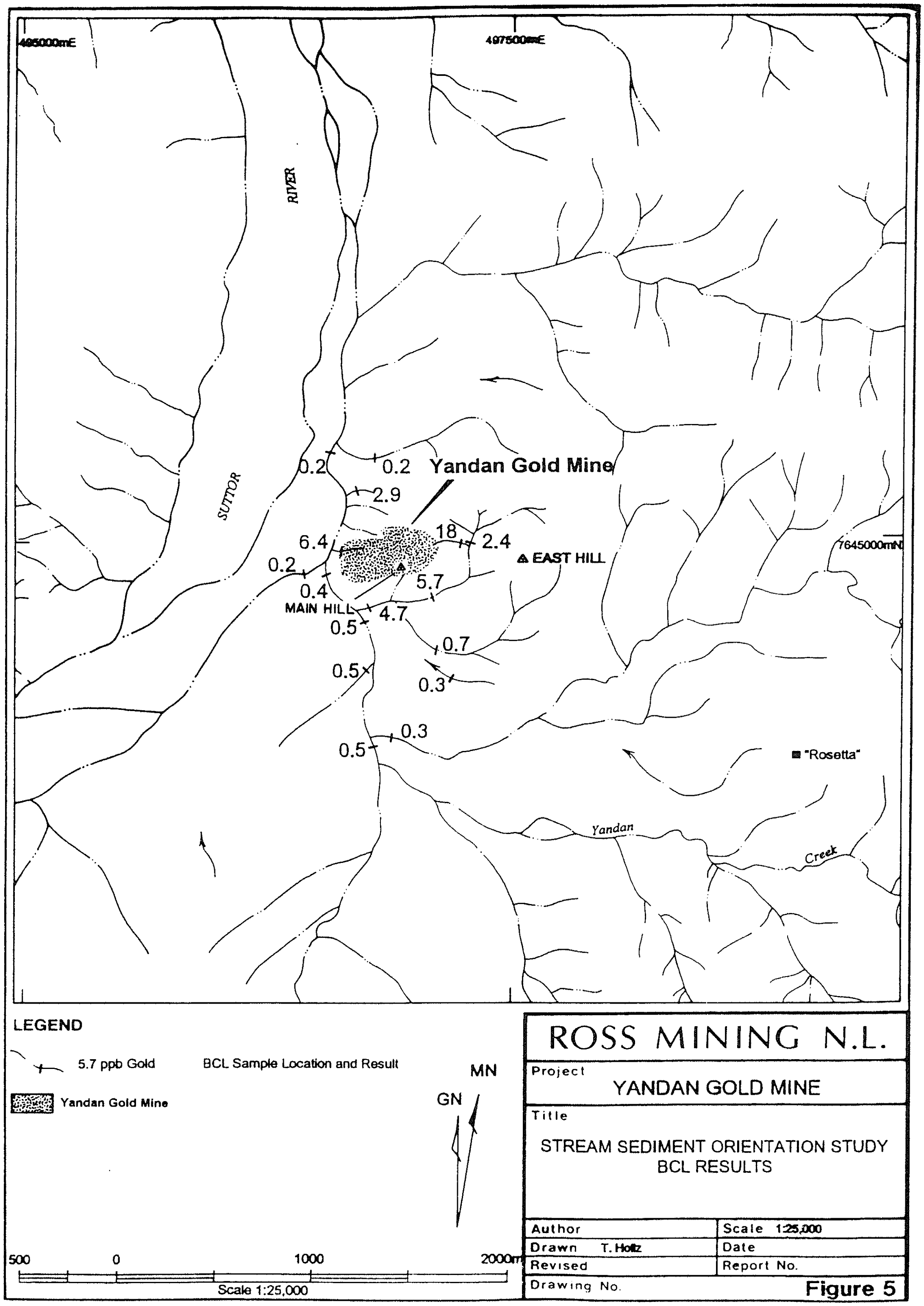
Only two samples from the regional program were taken in streams which drain the Yandan Hills, and only one of these was anomalous (34 ppb Au). This sample was collected in a small unnamed dry creek located between what are now known as Main Hill (location of Yandan Orebody) and South Hill.

The more detailed follow-up -80# sampling, carried out soon after, was highly successful, with most of the 18 samples returning anomalous results of up to 160 ppb Au (Figure 4).

At a later stage an orientation survey was conducted which involved the collection from 19 stream sediment sites around the Yandan deposit a 5kg sample of -2mm material for determining bulk leach extractable gold (BLEG; Figure 5) and 3kg of -6mm active sediment for size fractionation and more conventional studies. The fractions sieved were -6+2mm, -2mm+400µm, -400µm +200µm, -200µm+125µm, -125µm+75µm, and -75µm.

Size fractionation of the active stream sediment samples indicated that Au and As are mostly enriched in the -6+2mm fraction. For more details of the orientation study please refer to Chenoweth (1995).


495000mE
497500mE
SUTTOR
RIVER
Yandan Gold Mine
EAST HILL
MAIN HILL
7645000mN
"Rosetta"
Yandan
Creek
LEGEND
34 ppb Gold
Original -80# Stream Sediment Location & Result (WMC 1986)
34 ppb Gold
Detailed follow up -80# Stream Sediment Location & Result (WMC 1986)
Yandan Gold Mine
MN
GN
500
0
1000
2000m
Scale 1:25,000
ROSS MINING N.L.
Project
YANDAN GOLD MINE
Title
REGIONAL AND FOLLOW UP STREAM SEDIMENT SAMPLING RESULTS -80# GOLD
Author
Scale 1:25,000
Drawn T. Holtz
Date
Revised
Report No.
Drawing No.
Figure 4


495000mE
497500mE
RIVER
SUTTOR
0.2
0.2
Yandan Gold Mine
2.9
6.4
18
2.4
EAST HILL
0.2
5.7
0.4
MAIN HILL
4.7
0.5
0.7
0.5
0.3
0.3
0.5
7645000mN
"Rosetta"
Yandan
Creek
LEGEND
5.7 ppb Gold
BCL Sample Location and Result
Yandan Gold Mine
MN
GN
500
0
1000
2000m
Scale 1:25,000
ROSS MINING N.L.
Project
YANDAN GOLD MINE
Title
STREAM SEDIMENT ORIENTATION STUDY
BCL RESULTS
Author
Scale 1:25,000
Drawn T. Holtz
Date
Revised
Report No.
Drawing No.
Figure 5

A reconnaissance soil sample traverse was carried out along 525 line meters east-west across East Hill, which was assumed to be the source of the stream anomaly. Twenty-two samples were analysed for Au and As. The entire line was anomalous but significantly the highest Au values (120 and 180 ppb) were at the western end close to Main Hill. East Hill produced a broad Au (14 to 84 ppb) and As (30 to 310 ppm) anomaly.

Twenty-five rock chip samples were collected and analysed for Au, two from the Main Hill and the rest from East Hill. The two best results were from East Hill (1.06 and 1.83 ppm Au), and were probably collected from quartz veins, which are more prominent than those at Main Hill. The best Main Hill sample was 0.16 ppm Au.

During early 1987, a 100m x 25m grid-based soil sampling program was conducted over all three hills (Figure 6); samples were analysed for a suite of epithermal associated elements (Au, Ag, As, Hg, Sb, Tl, Te,). The largest Au soil anomaly, with a peak value of 1400 ppb, was found on Main Hill. East Hill had a more prominent As (maximum 145 ppm), Sb (maximum 50 ppm), Hg (maximum 2020 ppb), Tl (maximum 2490 ppm) and moderate Au (maximum 620 ppb) soil anomaly in comparison to Main Hill, which had weaker As (maximum 32 ppm), Sb (maximum 7 ppm), Hg (maximum 130 ppb) and Tl (maximum 850 ppm) responses. Tellurium was not anomalous at either location.

A further soil orientation study was carried out across two lines, 14300E and 14500E; samples were sieved to the same size fractions as the stream sediment samples (see above). Results indicated Au was concentrated in both the -75u and -6+2mm fractions, and As was concentrated in the -6+2mm fraction. Again, for more details of the orientation study please refer to Chenoweth (1995).

In conjunction with the grid-based soil sampling, 1:5 000 scale geological mapping and rock chip sampling (returning results up to 9.8 g/t Au) were carried out and confirmed the Main Hill area to be the most prospective.

Gold was the only element assayed systematically in the delineation drilling program, so a three dimensional geochemical picture of the deposit for any associated elements has not been established.

There does not seem to be any significant depletion or enrichment of gold in the near-surface environment at the main Yandan deposit.

Geophysics

A number of geophysical techniques have been used at Yandan, including IP, airborne and ground magnetics, and TEM. Of these, IP was certainly the most successful but was somewhat overshadowed by the success of geochemistry as an exploration tool.

The chargeability results from the gradient array survey shown in Figure 7 show a reasonable correlation with the known mineralisation on Main Hill. Both South and East Hill also produced anomalies. The results of the dipole-dipole surveys correlate well with the gradient array. The high resistivities due to silicification are also apparent at each area.

Both the airborne and ground magnetics were found to be of limited use in defining the prospective zones.

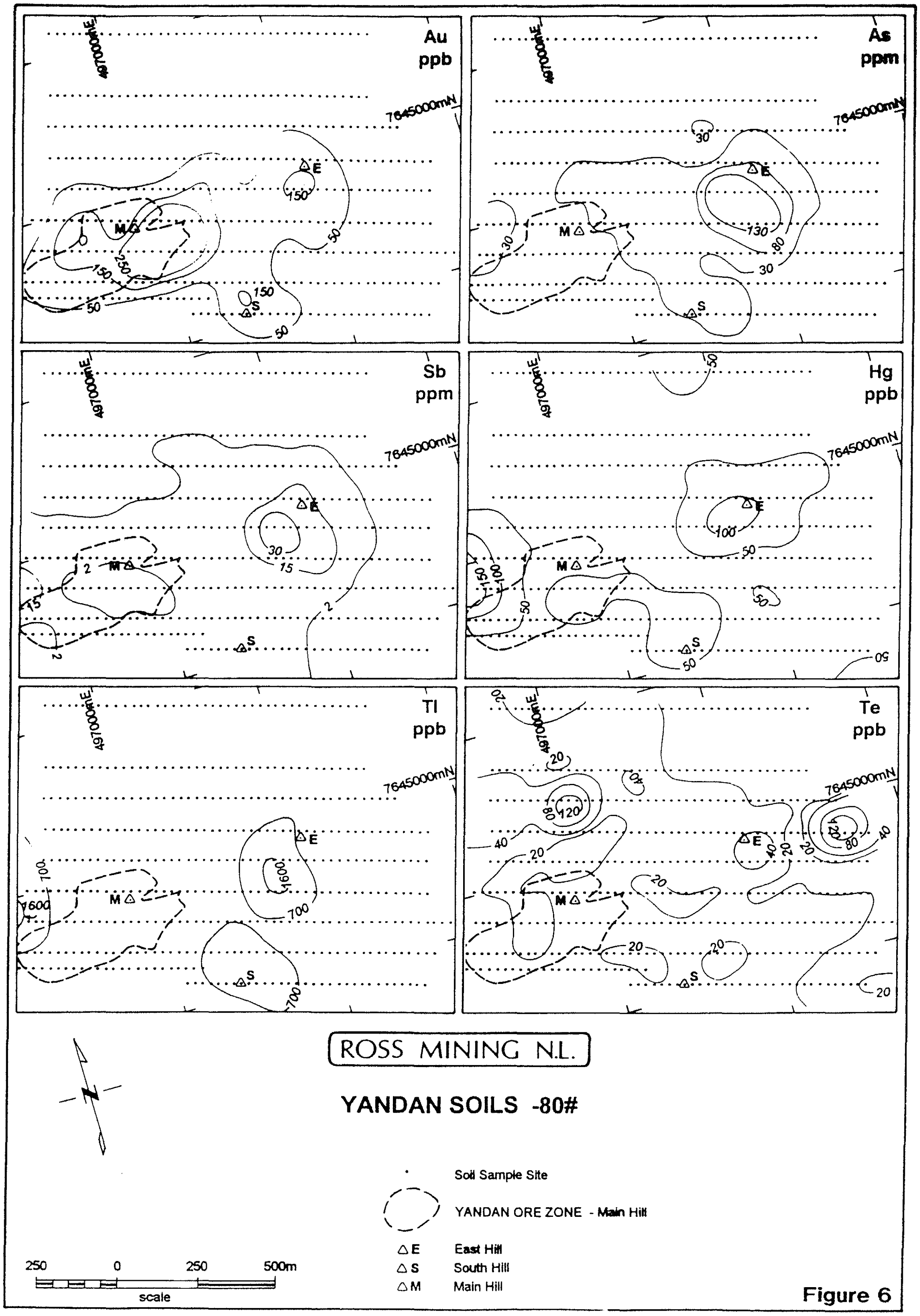
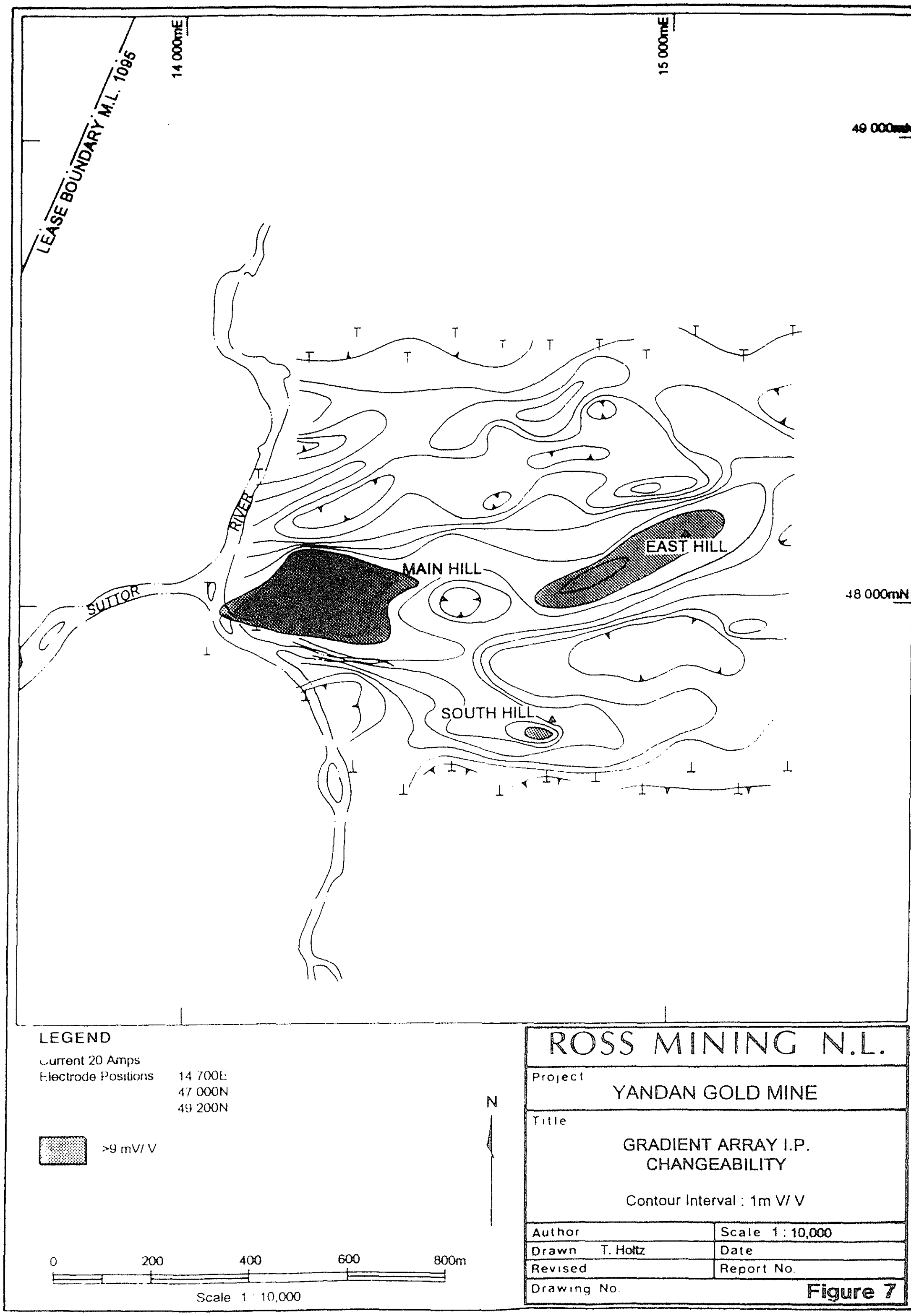

Au
ppb
As
ppm
Sb
ppm
Hg
ppb
Tl
ppb
Te
ppb
497000mE
7645000mN
ROSS MINING N.L.
YANDAN SOILS -80#
Soil Sample Site
YANDAN ORE ZONE - Main Hill
△E East Hill
△S South Hill
△M Main Hill
250 0 250 500m
scale

Figure 6



14 000mE
15 000mE
49 000mN
48 000mN
LEASE BOUNDARY M.L. 1095
SUTTOR RIVER
MAIN HILL
EAST HILL
SOUTH HILL
LEGEND
Current 20 Amps
Electrode Positions
14 700E
47 000N
49 200N
>9 mV/ V
N
0
200
400
600
800m
Scale 1 : 10,000
ROSS MINING N.L.
Project
YANDAN GOLD MINE
Title
GRADIENT ARRAY I.P.
CHANGEABILITY
Contour Interval : 1m V/ V
Author
Scale 1 : 10,000
Drawn T. Holtz
Date
Revised
Report No.
Drawing No.
Figure 7

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Discovery history, geology and geochemistry of the Wirralie gold deposit

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Introduction

The Wirralie epithermal style gold deposit, located 210km SSE of Townsville at latitude 21°7'S and longitude 147°16'E, occurs in the basal sequence (Mt Wyatt Formation) of Late Devonian-Carboniferous sediments and volcanics of the eastern Drummond Basin (Figure 1). The basement to these sediments is formed by the Ordovician metamorphics of the Anakie Inlier and the overlying locally preserved Mid Devonian Ukulunda Beds.

Extensive sheets of Tertiary peidmont fluviatile and lacustrine deposits capped by silcrete and ferricrete occur near the Wirralie deposit; these are assigned to the Suttor Formation. These sediments are deeply eroded, with remnants of the Tertiary land surface being preserved as mesas and plateaux.

The exploration history, regional geology and deposit features of the Wirralie deposit were previously described by Fellows and Hammond (1988, 1990).

Development of the Wirralie project, by Australian Consolidated Minerals Limited (ACM), began in November 1987 and was based on a zone of oxidised ore which was amenable to open pit mining. Published ore reserves were 3.65 Mt at 2.75 g/t gold (cutoff 1.0 g/t gold). Operations ceased in 1992.

Historical Perspective

Mineralisation at Wirralie outcrops over a surface area of 0.6 km x 0.6km. Drainage of the area is reasonable, however the mineralisation does not "stand out" above the surrounding areas and has probably only recently been exposed from beneath the Tertiary Suttor Formation. Discovery of mineralisation at Wirralie was a grass-roots exploration success. There were no historical diggings associated with the Wirralie deposit; the nearest area of recognised gold diggings is 11 km to the north-east at Bimurra.

Based on geological concepts developed by J.E. Thompson, AUSTAMAX Resources Limited (ARL) acquired Authorities to Prospect covering some 600 km^2 to the north of Mount Coolon in November 1984 (ARL merged with ACM in March 1986). Initial work over these tenements consisted of an airborne magnetic and radiometric survey and photogeological interpretation. The Wirralie prospect appeared as a circular feature with two airphoto colour anomalies (Fellows and Hammond, 1990).

The deposit was discovered in early 1986 as a result of a grass-roots regional Bulk Leach Extractable Gold (BLEG) stream sediment sampling program in an area that had not undergone any previously recorded systematic "modern exploration". Systematic follow-up stream sediment sampling, rock chip sampling and geological mapping led to drilling in August 1986. The first hole intersected 55m at 2.57 g/t.

Gold was the main element used to discover Wirralie at all stages of exploration. Geological and geophysical input was only used at the prospect scale once geochemistry had highlighted the area of prospectivity.

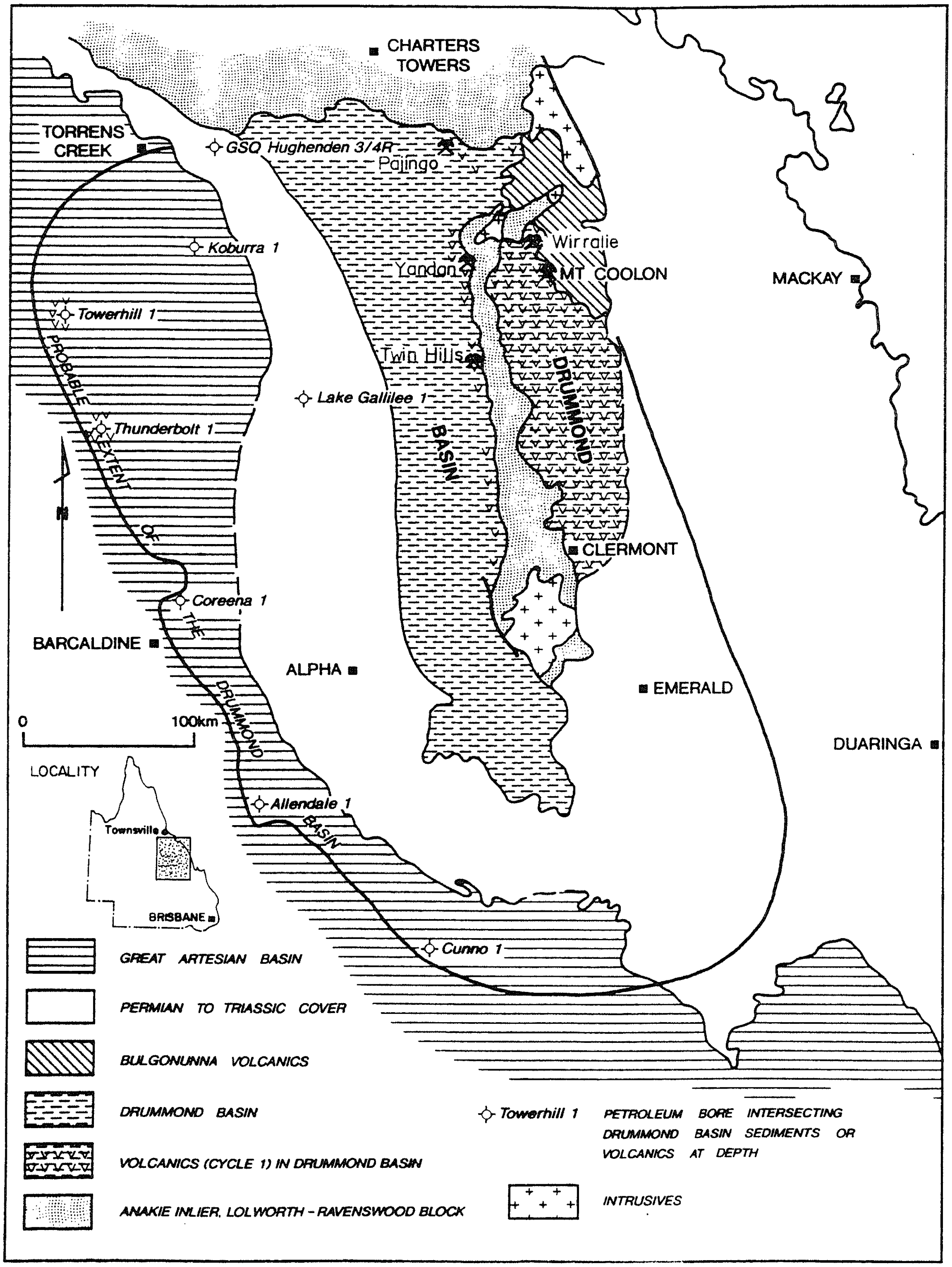


Figure 1 Map of Central Queensland showing distribution of the Drummond Basin

By April 1988, 136 reverse circulation percussion and 41 diamond drill holes had outlined a mineable reserve of 3.7 Mt at 2.7 g/t gold.

Ross Mining acquired the property in July 1992 and have since extended the known oxide resource and are looking at a potential heap leach operation. Stockpile milling ceased in June 1993.

Wirralie Deposit Host Rocks and Structure

Mineralisation at Wirralie is within the Late Devonian - Carboniferous Mt Wyatt Formation/Bimurra Volcanics (Figures 2 and 3). The host rocks within the mine areas comprise two distinct stratigraphic units which are recognised principally on the basis of volcanic component and relative structural orientation. The hangingwall sequence consists of pyroclastic units interbedded with associated epiclastic sediments; the footwall sequence consists of siltstones and sandstones, with a relatively high proportion of carbonaceous material, interbedded with thin fiamme tuff units and medium- to coarse-grained sandstones. In both pits, east-west structures separate the defined hanging wall volcaniclastic units from the footwall sedimentary units.

Based on descriptions given by Hutton (1989) and Olgers (1972), the hangingwall and footwall units can be tentatively equated with the Bimurra Volcanics and Mt Wyatt Formation respectively.

The volcaniclastic sequences in the hanging wall unit have an overall northerly dip of 20 to 30°, and strike 280° to 300°. In contrast, the footwall sequence dips 10° to 40° to the west and strikes around 170° to 180°.

A major structure, the north-east striking Juggler Fault, separates Pit A from Pit B (Figure 2). It also separates two different stratigraphic sequences and two different styles of mineralisation either side of the fault. This structure is unmineralised but contains clasts of mineralised material set in a gouge matrix of mainly clay. North of 10 000N, the fault narrows abruptly and breaks up into a series of listric faults dipping to the west.

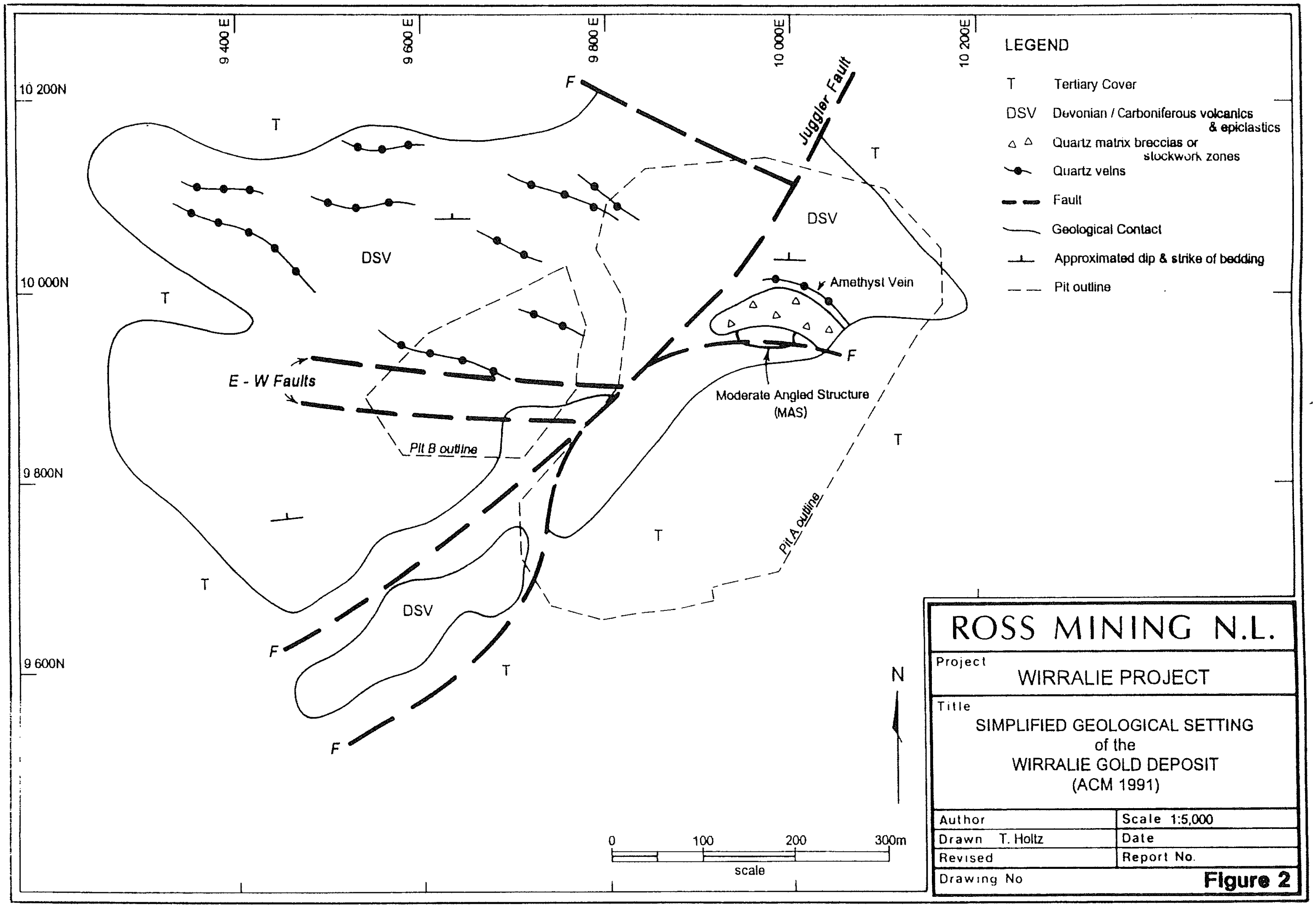
Mineralisation and Alteration

The mineralisation in Pit A is controlled by the Moderately Angled Shear (MAS) which strikes east-west, dips to the north at 45°, and varies in thickness from a few meters to over twenty meters (Figures 2 and 3). The MAS separates upper volcaniclastic units from the lower sediments; its main effect has been to create open space above the shear through which ore forming fluids moved. The maximum dilation zone occurs where the MAS changes direction from east-west to north-east. Disruption of rock between splays of the MAS gave rise to network-stockwork fractured and brecciated mineralised zones.

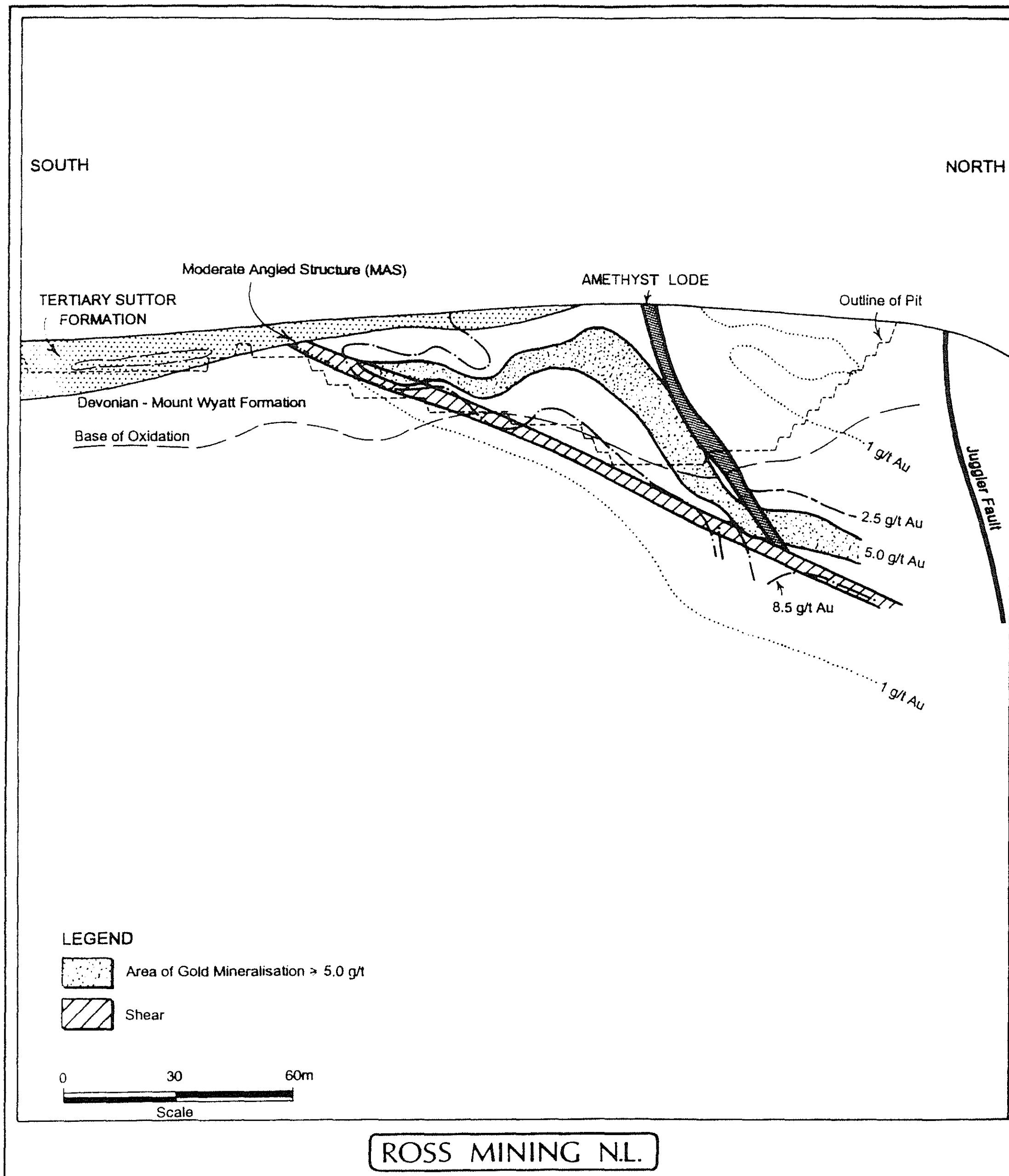
West-north-west and east-west veins, breccia zones, and mineralised faults are important ore bearing structures above the MAS. These structures are, for the most part, steep and southerly dipping. Late in the mineralising episode, amethystine quartz filled through-going structures, which mainly dip to the north and mark the northern limit of higher grade material. They are offset along the northerly splays of the Juggler Fault.

In a roughly central position, coinciding with the MAS, the mineral assemblage is dominated by quartz and pyrite, with minor quartz pseudomorphing calcite and adularia. This assemblage is enveloped by an assemblage dominated by carbonates, particularly calcite and siderite; quartz veining and pervasive silicification are minor in this peripheral zone. Illite and illite-smectite overlap the carbonate dominated assemblage.

Mineralisation in Pit B, west of the Juggler Fault, is controlled by two steeply dipping east-west faults and associated splays. The thickest and best gold grades occur where the east-west faults intersect the Juggler Fault. The character of mineralisation is different in Pit A and Pit B.



LEGEND
T Tertiary Cover
DSV Devonian / Carboniferous volcanics & epiclastics
Quartz matrix breccias or stockwork zones
Quartz veins
Fault
Geological Contact
Approximated dip & strike of bedding
Pit outline
9 400 E
9 600 E
9 800 E
10 000E
10 200E
10 200N
10 000N
9 800N
9 600N
Juggler Fault
Amethyst Vein
E - W Faults
Moderate Angled Structure (MAS)
Pit B outline
Pit A outline
DSV
T
F
N
0
100
200
300m
scale
ROSS MINING N.L.
Project
WIRRALIE PROJECT
Title
SIMPLIFIED GEOLOGICAL SETTING of the WIRRALIE GOLD DEPOSIT (ACM 1991)
Author
Scale 1:5,000
Drawn T. Holtz
Date
Revised
Report No.
Drawing No
Figure 2



CROSS SECTION AT 10 000E THROUGH THE WIRRALIE GOLD DEPOSIT LOOKING WEST

Figure 3

In Pit B there are no large volumes of mineralised breccias and network-stockwork fractured rocks. Instead the mineralisation occurs mainly in chalcedonic quartz veins, breccia veins, and tabular breccias flanking the veins. Pit B high grade assays are confined exclusively to the veins which are more chalcedonic. The alteration is less pervasive but has a similar zonation to that in Pit A.

The principal sulphide minerals are pyrite, marcasite, sphalerite, arsenopyrite and chalcopyrite; pyrite is dominant and generally arsenical, and fine bladed marcasite is common. Up to 5% sulphides by volume occur in the high grade zones, decreasing to approximately 2% in the peripheral areas.

In the oxidised zone, gold occurs in hematite and geothite along quartz grain boundaries, and in relict pyrite. Below the base of oxidation, at about 40m, gold occurs principally with bladed pyrite. Gold has an average grain size of 25um and a fineness of 670 to 841 (Dong, 1995).

Fluid inclusion studies indicate homogenisation temperatures of 172°to 232°C (Grant, 1991).

Geochemistry

The Wirralie Deposit was discovered by following up two anomalous regional BLEG stream sediment samples collected by AustAmax/ACM in 1986. Previous explorers had not detected any anomalism in -80# stream sediment samples in the general area (Mike Fellows, pers. comm., 1987). Figures 4 and 5 show the position and results of both the regional and follow-up stream sediment sampling.

Stream sediment sampling, both regional and follow-up, consisted of a 5kg BLEG sample (-6mm sieved in the field) for gold analysis, and a -80# sample analysed for pathfinder elements As, Sb, Cu, Pb, and Zn.

Two regional BLEG samples from Sugarbag Creek, which drains the Wirralie deposit, returned highly anomalous gold values: 6.79 ppb and 8.96 ppb. Follow-up BLEG samples nearer to the deposit gave higher results: 16.8 ppb and 42.8 ppb Au.

The best pathfinder element in the -80# stream sediment samples was arsenic, with values of 8 and 13 ppm in the samples from Sugarbag Creek; no other elements were anomalous.

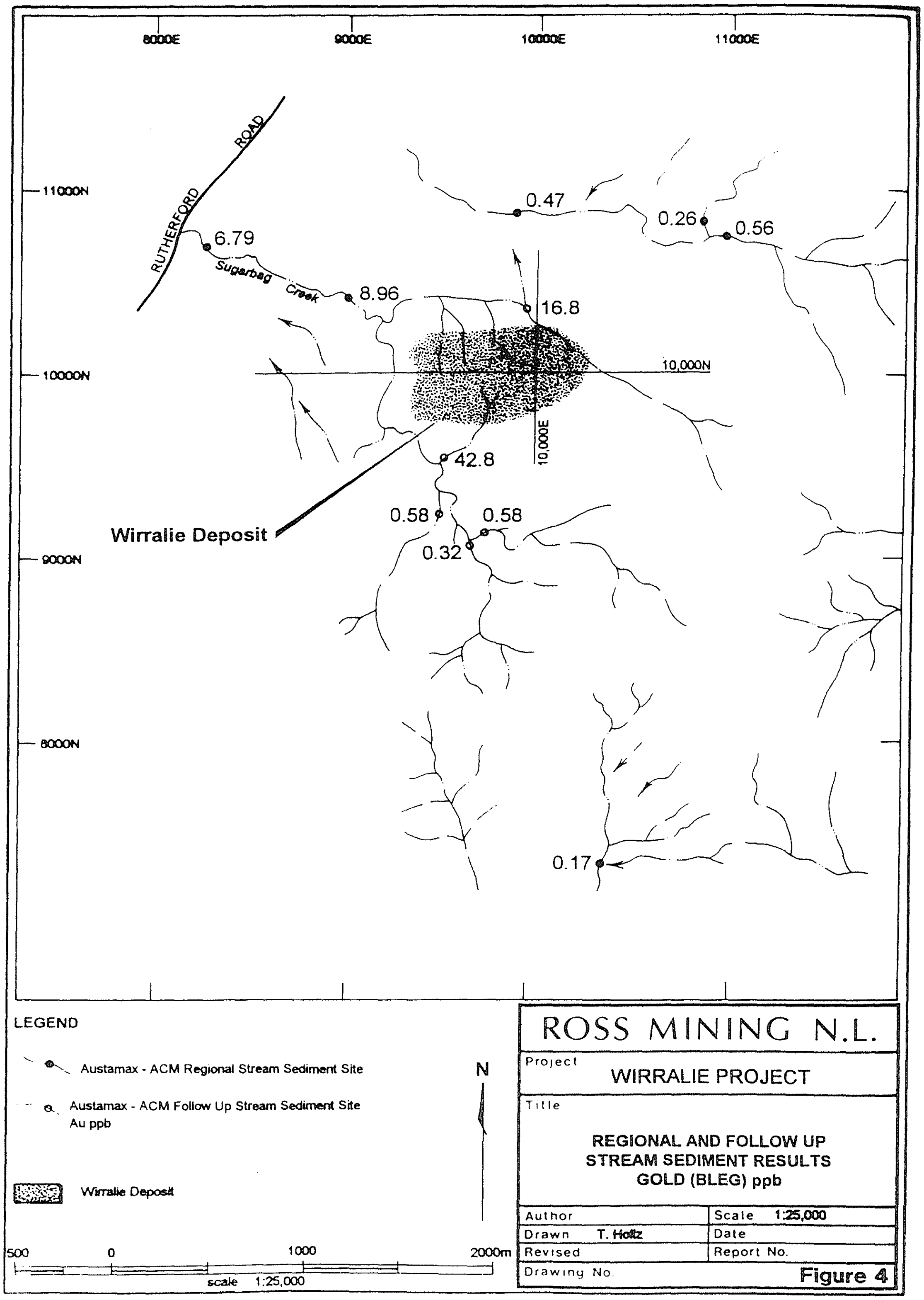
Float analysis along the anomalous streams led to semi-detailed rock chip sampling (30 samples) over the obvious outcropping alteration and mineralisation; Pits A and B were subsequently centered on these outcrops. Results were encouraging, with Au values up to 7.14 ppm and anomalous pathfinder elements such as Hg (up to 3370 ppb), As (up to 1010 ppm) and Sb (up to 115 ppm). Grid based mapping and rock chip sampling at 1:1 000 outlined the area of interest. The first drill hole intersected 55m at 2.57 g/t Au.

No soil sampling was undertaken, and there also no record of orientation stream sediment or soil sampling work carried out over the deposit area.

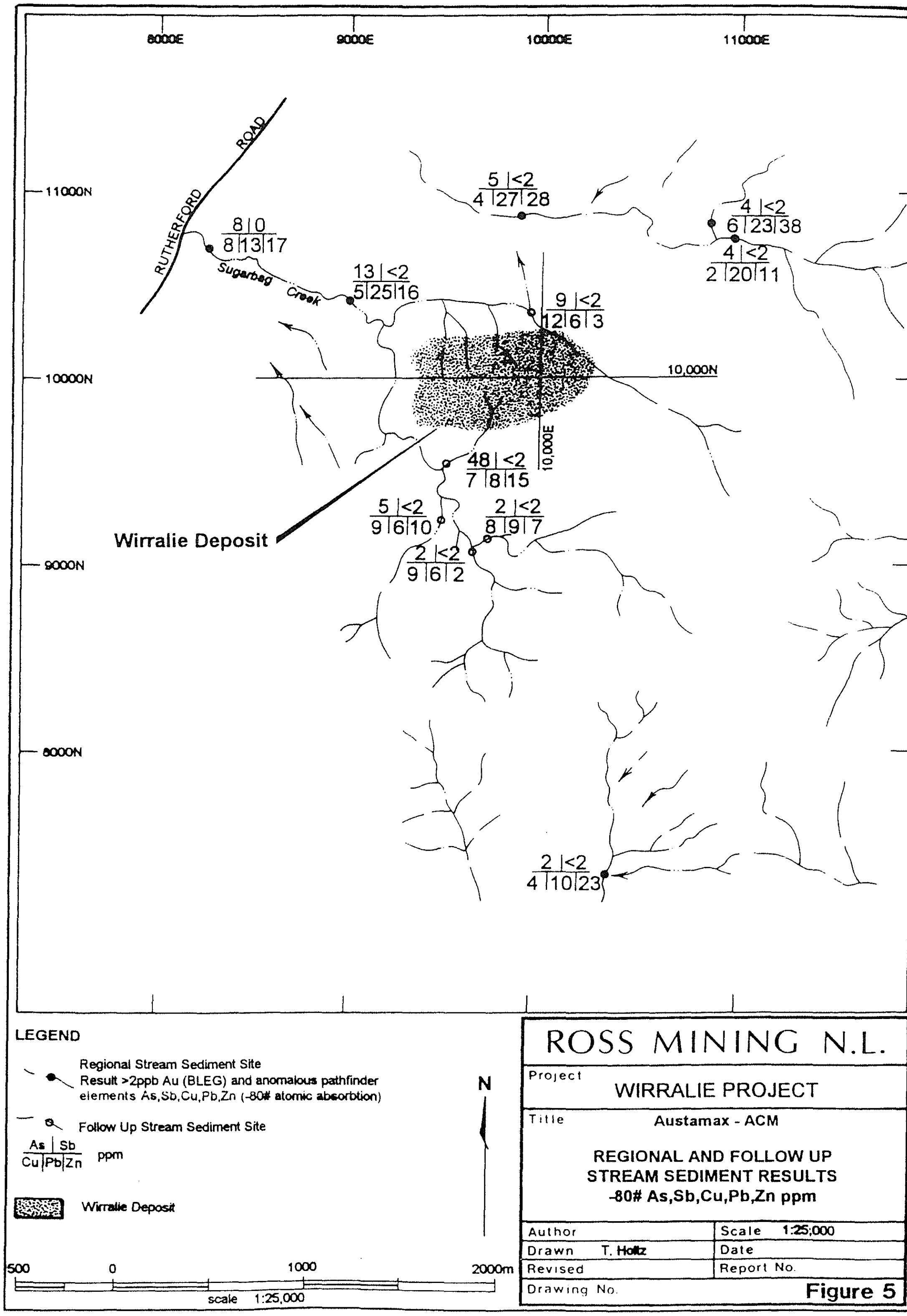
There does not appear to be any significant depletion or enrichment of gold in the near-surface environment at the Wirralie deposit, however no detailed research has been conducted to evaluate any secondary redistribution.

Geophysics

During 1986 an airborne magnetic survey was conducted over the exploration permit containing Wirralie. Though some regional stuctures were identified, Wirralie occurs in a magnetically featureless area.



8000E
9000E
10000E
11000E
11000N
10000N
9000N
8000N
RUTHERFORD ROAD
Sugarbag Creek
6.79
8.96
0.47
0.26
0.56
16.8
10,000N
10,000E
42.8
0.58
0.58
0.32
0.17
Wirralie Deposit
LEGEND
Austamax - ACM Regional Stream Sediment Site
Austamax - ACM Follow Up Stream Sediment Site
Au ppb
Wirralie Deposit
N
500
0
1000
2000m
scale 1:25,000
ROSS MINING N.L.
Project
WIRRALIE PROJECT
Title
REGIONAL AND FOLLOW UP
STREAM SEDIMENT RESULTS
GOLD (BLEG) ppb
Author
Scale 1:25,000
Drawn T. Holtz
Date
Revised
Report No.
Drawing No.
Figure 4


8000E
9000E
10000E
11000E
11000N
10000N
9000N
8000N
RUTHERFORD ROAD
Sugarbag Creek
8 | 0
8 | 13 | 17
13 | <2
5 | 25 | 16
5 | <2
4 | 27 | 28
4 | <2
6 | 23 | 38
4 | <2
2 | 20 | 11
9 | <2
12 | 6 | 3
10,000N
10,000E
48 | <2
7 | 8 | 15
5 | <2
9 | 6 | 10
2 | <2
8 | 9 | 7
2 | <2
9 | 6 | 2
2 | <2
4 | 10 | 23
Wirralie Deposit
LEGEND
Regional Stream Sediment Site
Result >2ppb Au (BLEG) and anomalous pathfinder elements As,Sb,Cu,Pb,Zn (-80# atomic absorbtion)
Follow Up Stream Sediment Site
As | Sb
Cu | Pb | Zn ppm
Wirralie Deposit
N
500 0 1000 2000m
scale 1:25,000
ROSS MINING N.L.
Project
WIRRALIE PROJECT
Title
Austamax - ACM
REGIONAL AND FOLLOW UP STREAM SEDIMENT RESULTS -80# As,Sb,Cu,Pb,Zn ppm
Author
Scale 1:25,000
Drawn T. Holtz
Date
Revised
Report No.
Drawing No.
Figure 5

Four lines of gradient array Induced Polarization were carried out over the deposit after the resource was outlined by drilling. Resistivity identified the intense silicification as highs, and the sulphides at depth gave a good chargeability anomaly.

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Ravenswood Gold Deposits

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Introduction

The gold deposits at Ravenswood are located at latitude 20°06'S, longitude 146°53'E, within and adjacent to the town of Ravenswood approximately 90 kilometres south of Townsville in north Queensland.

Carpentaria Gold Pty. Ltd. (CG), a wholly owned subsidiary of MIM Holdings Limited, commenced mining operations at Ravenswood in 1987. Total production since 1987 is 165,000 ounces of gold from 1.8 million tonnes of ore at an average head grade of 3.2 g/t.

Gold mineralisation at Ravenswood is contained within veins and shears hosted by the Jessops Creek Tonalite, an Early to Middle Devonian unit of the Ravenswood Batholith.

History

The Ravenswood goldfield was declared in 1868 following the discovery of alluvial gold in gullies in the area.

The earliest production was from the mining of alluvial and eluvial sources, and later, after the discovery of auriferous quartz reefs, from shallow workings in the oxide zone. By 1872 most of the oxide ore had been mined out. The more difficult metallurgy of the sulphide ore and water flows made deeper mining difficult at that stage.

At the turn of the century a systematic and organised exploitation of the primary quartz sulphide veins commenced. Dominated by the New Ravenswood Company Ltd., operations and mining of the Duke of Edinburgh, General Grant, Sunset, London, Mellaneur, Shelmallier and Black Jack lodes continued up until 1917. Most of the mines were worked within 250m of the surface, but the deepest workings extended to a depth of 458m from surface.

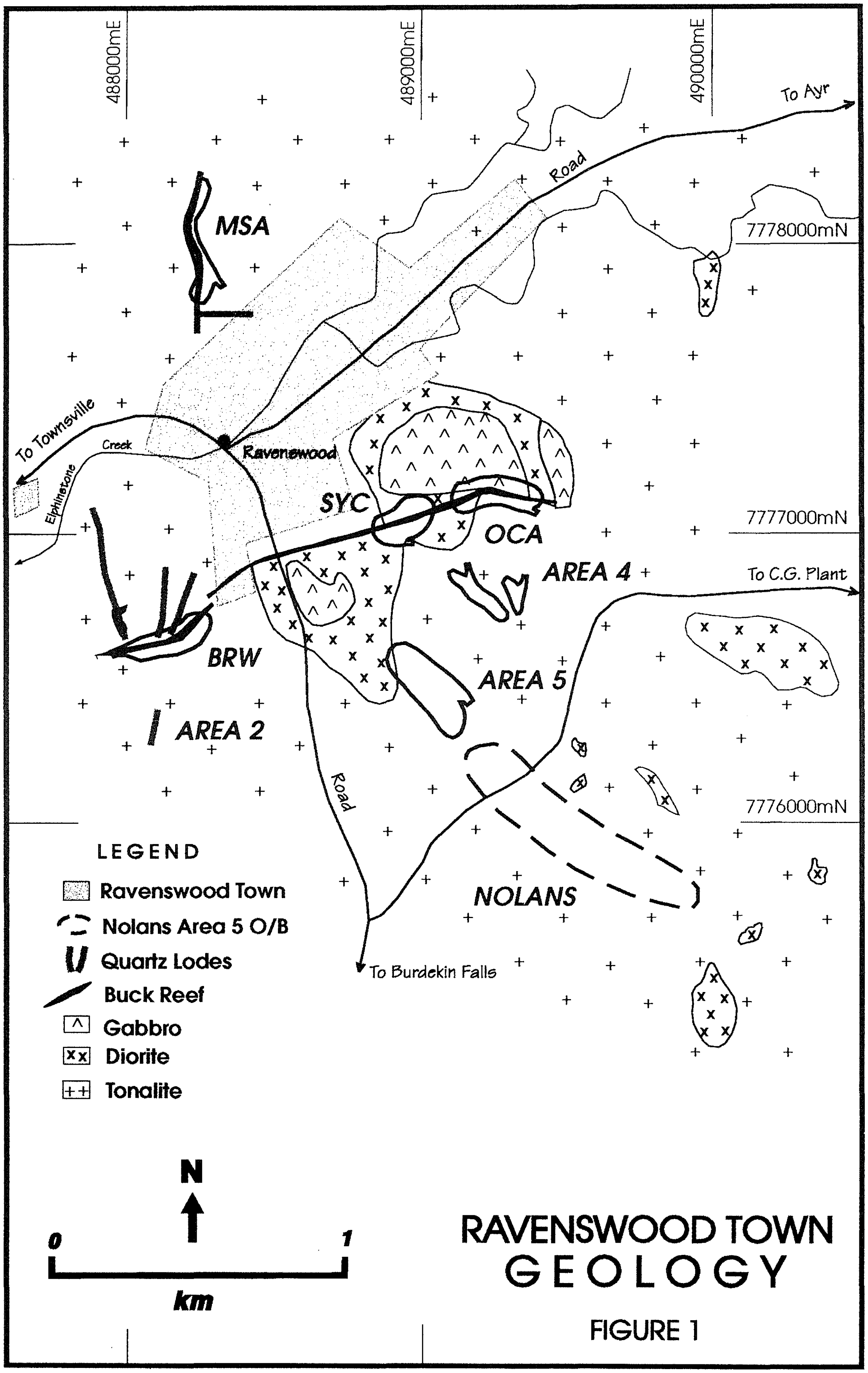
Only limited production followed this early activity until 1983, when the North Queensland Company recovered gold from the treatment of old mullock dumps and from open cut mining of oxide material on the Buck Reef.

CG commenced gold mining operations during 1987 following the definition of reserves on the Buck Reef at Buck Reef East, and developed open cut mines at SYC, OCA and BRW. Continued exploration by MIM Exploration Pty. Ltd. (MIMEX) defined further open cut ore bodies at Area 4, Area 5 and MSA, and underground orebodies at OCA and Area 2. These have all subsequently been mined. Current mining is from the Nolans deposit 1 km south of Ravenswood where operations will continue beyond the year 2000.

Total recorded production of gold from Ravenswood is now about 1.1 million ounces.

Geology and Mineralisation

The Ravenswood gold deposits are hosted in an Early to Middle Devonian tonalite intrusive unit of the Ravenswood Batholith known as the Jessop Creek Tonalite, a grey medium grained biotite hornblende tonalite (Figure 1). Unnamed diorite and gabbro bodies intrude the tonalite.



RAVENSWOOD TOWN GEOLOGY

FIGURE 1