The exploration history, geology and geochemistry of the polymetallic Highway-Reward deposit, Mt Windsor Subprovince

Simon D. Beams[1], Ed V. Dronseika[2] and Mark G. Doyle[3]

[1]Principal Geologist, Terra Search Pty Ltd, P.O. Box 981, Hyde Park, Townsville, Qld 4812.
[2]Senior Geologist, Aberfoyle Resources Ltd., 27 Mackley Street, Townsville, Qld 4814.
[3]Research Fellow, CODES-SRC and Centre for Strategic Mineral Deposits, UWA, Nedlands 6907.

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Introduction

The Highway-Reward volcanic-hosted massive sulfide (VHMS) deposit is situated 35 km south of Charters Towers in northern Queensland (Figure 1). The deposit is hosted by volcano-sedimentary rocks of the Cambro-Ordovician Seventy Mile Range Group.

The deposit comprises two main discordant pyrite-chalcopyrite pipes: Highway and Reward. Reward is a "blind" orebody and was discovered in 1987 after a long history of exploration by various companies in the area. The Highway pipe was discovered in 1990 and is located approximately 200 m NNW of the Reward orebody beneath the abandoned Highway open pit (Figure 1). The main Reward pyrite-chalcopyrite pipe occurs under 100 m combined thickness of Tertiary fluviatile sediments (Campaspe Formation) and deeply weathered gossanous volcanic rocks. The Highway massive sulphide body lies beneath 100 m of weathered and Au-barite-bearing gossanous rhyolite, the bulk of which has now been mined out.

The mineralisation can be divided into five main types (Beams, et al., 1989; Doyle, 1997). These are: (1) primary pyrite-chalcopyrite pipes; (2) supergene Cu (chalcocite and covellite) and Au above the Reward pipe; (3) gossanous Cu-Au-rich mineralisation above the sulphide zone; (4) disseminated, vein-style and stratabound pyrite-sphalerite-galena-barite mineralisation at the margins of the pipes and in the hanging wall; (5) footwall and hanging wall pyrite-quartz veins.

The Reward pipe is inferred to contain in excess of 5 million tonnes of pyrite with minor primary chalcopyrite-rich zones. Overlying the primary mineralisation, a supergene chalcocite-covellite rich zone contains a resource of around 0.75 million tonnes of 8.7% Cu. An oxide resource of 0.17 million tonnes at 3.7 g/t Au overlies the supergene zone.

The Highway body contains approximately 2 million tonnes of pyrite of which over half is mineralised significantly with interstitial chalcopyrite. This resource amounts to approximately 1.2 million tonnes at 5% Cu.

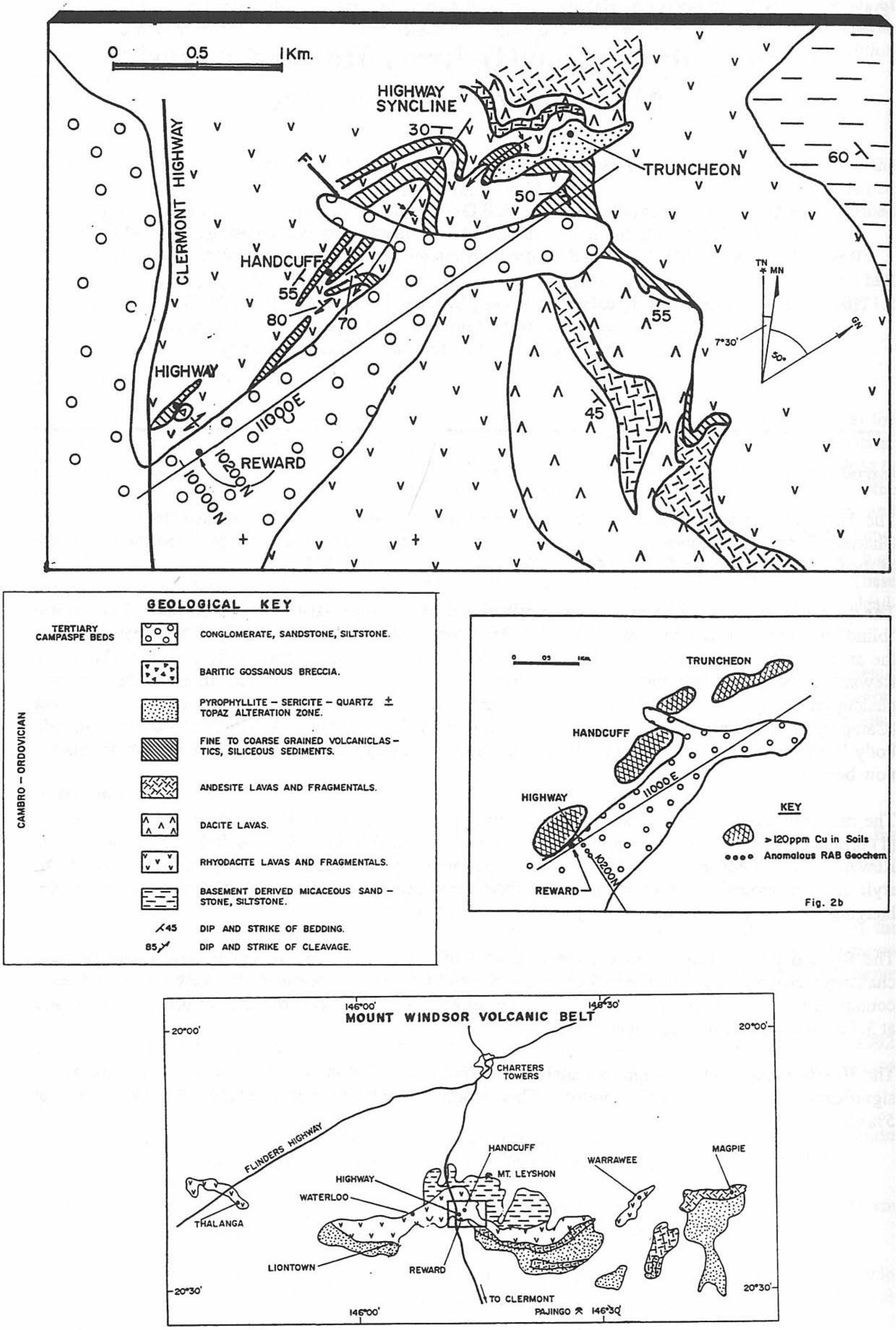


Figure 1 Location, geological setting and Cu soil anomalous zones. Highway, Reward & Handcuff Deposits, Mt Windsor Subprovince, North Queensland. (Beams et al. 1989)

Exploration History

The original Highway mineralisation was discovered in 1953 when Messrs. J.E. Olsen and W.H. Thorne found gold in weathered material exposed in a road metal scraping. The accompanying white mineral, thought by the prospectors to be lead carbonate, was identified by the government geologist in Charters Towers as barite (Banks,1953; Connah, 1954).

Surface and underground evaluation of this mineralisation in 1954, by Mount Isa Mines Ltd, failed to locate a body which could be worked profitably (Connah, 1960). Drilling by Noranda Exploration Company Ltd in 1964 and by Aberfoyle Exploration Pty Ltd in 1983 confirmed the presence of a small gold resource which was interpreted as being the weathered remains of a submarine pyritic exhalite and subsurface stringer zone (Kay, 1985). Further drilling by North Queensland Resources NL indicated an in situ geological resource of 171,000 t averaging 4.4 g/t Au and 5.0 g/t Ag (Russell, 1986). Subsequent drilling and mine development significantly downsized this resource.

The recognition of the Mt Windsor Subprovince as a favourable host for VHMS mineralisation was confirmed after reinterpretation of Pb-Zn massive sulphides at Liontown (Jododex, 1974), the discovery of the Thalanga Deposit in 1975 (Gregory & Hartley, 1982) and Pb-Zn mineralisation at Warrawee in 1972 (Layton & Associates, 1973, unpublished data). Since 1972, several companies, notably Jododex (1972-1974) and Esso Australia Ltd in joint venture with EZ Industries Ltd (1974-1986) City Resources/Barrack Mines Limited (1987-1990), Aberfoyle Resources (1991-1995) have carried out comprehensive regional exploration programs over the Seventy Mile Range Group in the Highway-Reward area. Techniques used include: Input (airborne EM), airborne magnetics, -80 mesh stream sediment and soil sampling, RAB, diamond and percussion drilling, IP and surface EM coverage of geochemically anomalous areas combined with geological mapping and interpretation.

The Highway to Handcuff area is located within one of the most clearly identifiable structures in the Mt Windsor Belt (the Highway syncline) and is coincident with large scale Cu, Pb, Zn soil anomalies (Figure 1 and Beams & Jenkins, 1995) and favourable host stratigraphy. Esso geologists recognised it as the most prospective locus for VHMS style mineralisation within the region.

The Handcuff prospect is located 1.5 km along strike from the Reward deposit. At Handcuff, Esso intersected massive sulphide and baritic cherty sediment horizons in drill holes testing Cu, Pb, Zn soil anomalies in 1981 (Castle, 1982, 1983). The mineralisation is hosted in a complex assemblage of siltstone units, volcaniclastic mass-flow deposits, in situ and resedimented hyaloclastite, rhyolitic to dacitic syn-sedimentary sills and lavas. Figure 2 is a 1985 version of the interpretative geology of the Handcuff Prospect.

An intensive drilling program followed the Handcuff discovery, including the drilling in 1983 of a series of 50 m and 25 m spaced vertical RAB holes to depths up to 80 m on line 10200N adjacent to the then Highway Mineral Claims (Figure 1), straddling the boundary between poorly outcropping volcanics and overlying Tertiary sediments. Gossanous and malachite stained rhyolitic volcanics returned assay values up to 0.43 g/t Au over 9m and 0.76% Cu over 9 m (Beams, 1984). In April 1986, North Queensland Resources NL farmed into A to P 3380M, owned by Esso Australia Ltd and EZ Industries Ltd, and surrounding the Highway Mineral Claims. As part of the deal North Queensland Resources NL were given permission to peg a MLA to allow development of the Highway mine. The anomalous RAB holes occur within the lease area. North Queensland Resources NL tested these anomalies with two shallow holes H47 and H2, which intersected gossanous volcanics and breccia, oxidised to a depth of 100m. Values up to 4.7 g/t Au over 4m and 1.5 g/t Au over 5 m were returned.

In 1986, City Resources Ltd acquired Esso Australia Ltd's mineral interests and became operator of the Mt Windsor Joint Venture. In August 1987 the partners sited a deep hole HM034 to test the H2-H47 mineralisation at depth (Figure 6). This hole encountered semi-massive sulphide between 123 m and 137 m which assayed 5.95% Zn, 0.55 g/t Au and trace Ag; 100m of massive pyrite was intersected between 151 and 250 m which assayed 0.77 g/t Au and included a Cu zone between 200 m and 230 m which assayed 3.5% Cu and 0.72 g/t Au. Subsequent to this intersection, mise la masse together with time domain surface EM geophysical surveys outlined a significant anomaly which corresponded to the massive sulphide body as outlined by drilling (Beams et al, 1989), see Figures 3 and 4. At the end of mine life of the Highway open pit, work by Lesh (1989) showed the gossanous baritic and siliceous breccia zones to have an hourglass or pipe-like shape in the oxide zone (Figure 5). This geometry strongly suggested that a sulphide rich pipe-like body was present at depth in the unoxidised portion.

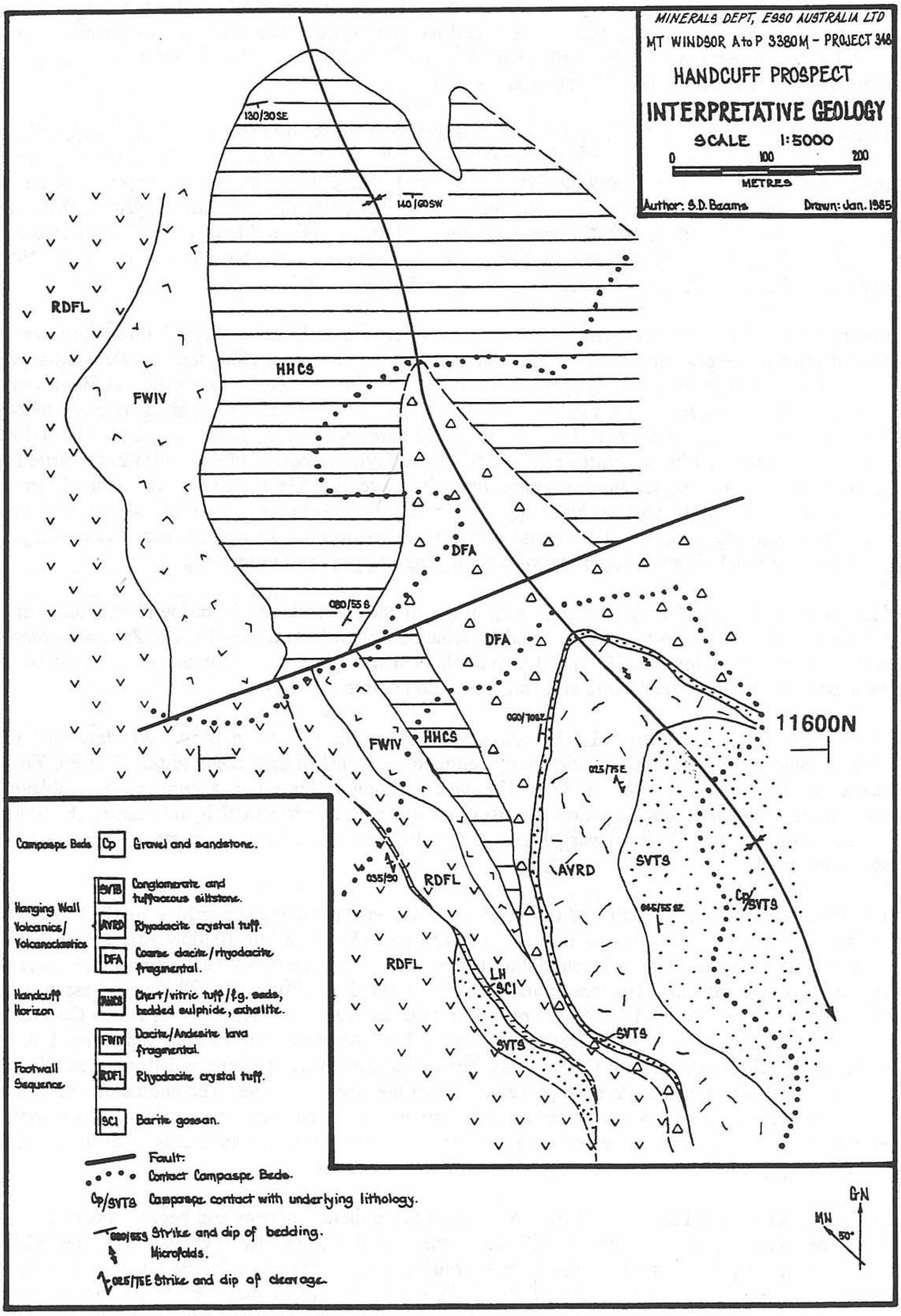


Figure 2 1985 version of interpretative bedrock geology Handcuff Prospect.

In 1989, Barrack Mines (BML Holdings) acquired a 25% interest which increased to 55% in 1990. As operators of the joint venture they continued to define the supergene and oxide resources at Reward.

Recognising the possible relationship between oxide Au and primary Cu-Au at Reward, a series of diamond holes were designed to test for primary sulphide mineralisation beneath mined out oxide ore of the Highway open-pit (M. van Eck pers. comm.). In January 1990, hole REMM 119 intersected the Highway massive pyrite body. In 1991, Aberfoyle acquired a 65% interest with BML Holdings (35%). BML Holdings interest was acquired by Sabminco NL in 1992. RGC Thalanga Pty Ltd have since acquired Aberfoyle's interest and are currently developing the Highway-Reward deposit in joint venture with Grange Resources (formerly Sabminco NL).

Regional Geology

The Highway-Reward deposit is hosted within the Trooper Creek Formation (Fig. 1), one of four formations within the Seventy Mile Range Group (Henderson, 1986). The Trooper Creek Formation comprises a complex suite of rhyolitic, dacitic and andesitic lavas, syn-sedimentary intrusions, volcaniclastic rocks and volcanic and non-volcanic siltstone. Combined, features such as andesite pillow lavas, sandstone turbidites, hyaloclastite, peperite and fossils suggest a submarine below-storm-wave-base depositional setting for the bulk of the Trooper Creek Formation (e.g. Berry et al., 1992; Doyle, 1994, 1997). However, parts of the succession were deposited above storm wave base and may have been partly emergent (Doyle, 1997).

The Seventy Mile Range Group has been metamorphosed to lower greenschist facies and affected by three deformations of equivocal age (e.g. Berry et al., 1992). In the east, the syn-deformational early regional metamorphic assemblage has been overprinted by hornblende hornfels assemblages, which form contact metamorphic aureoles around post-kinematic granitoids of the Lolworth-Ravenswood Batholith (Berry et al., 1992).

The Trooper Creek Formation hosts two significant massive sulfide deposits (Thalanga, Highway-Reward) and several small sub-economic prospects including Liontown, Waterloo, Handcuff, Magpie and Warrawee (Fig. 1). Thalanga is the largest known VHMS deposit in the Seventy Mile Range Group and occurs within the Trooper Creek Formation at the contact with the underlying Mount Windsor Formation (Gregory and Hartley, 1982; Gregory, et al., 1987). The remaining VHMS deposits, including Highway-Reward, occur within the Trooper Creek Formation.

Host Stratigraphy

The host succession to the Highway-Reward deposit was originally interpreted to comprise rhyolitic lavas separated by three horizons of volcaniclastic and sedimentary facies (VS1, VS2, VS3; Figures 3 and 6). However, detailed drill core logging and mapping has subsequently demonstrated that the deposit is hosted in the proximal facies association of a syn-sedimentary intrusion-dominated volcanic centre (Doyle, 1994; Doyle & McPhie, 1994; Doyle, 1997; Doyle, 1998).

Massive coherent rhyolite, rhyodacite and dacite and associated in situ or resedimented hyaloclastite and peperite are the principal facies in the environment of mineralisation. The distribution and arrangement of these facies is the basis for determining the mode of emplacement. Upper contact relationships are critical in evaluating intrusive versus extrusive emplacement, as basal contacts can be similar. The peperitic upper margins of many porphyries demonstrates that they intruded wet poorly consolidated sediment. Syn-sedimentary sills, cryptodomes and a single partly-extrusive cryptodome have been recognised (Figure 8A). Contact relationships and phenocryst mineralogy, size and percentages indicate the presence of thirteen distinct porphyritic units in a volume of 1 x 1 x 0.5 km (Doyle, 1994, 1997).

Porphyries intruded or were overlain by a volcaniclastic and sedimentary facies association comprising suspension-settled siltstone, graded turbiditic sandstone and thick, non-welded pumice- and crystal-rich sandstone and breccia units. Pumiceous and crystal-rich deposits record episodes of explosive silicic volcanism in an extrabasinal or marginal basin environment, and were emplaced by cold, water-supported, high-concentration turbidity currents. Andesite dykes cut across the massive sulfide and altered host rocks. The sedimentary facies that indicate a submarine, below-storm-wave-base environment of deposition for the volcanism and massive sulfide deposition. At Highway-Reward, beds generally dip (10-30°) and face southeast.

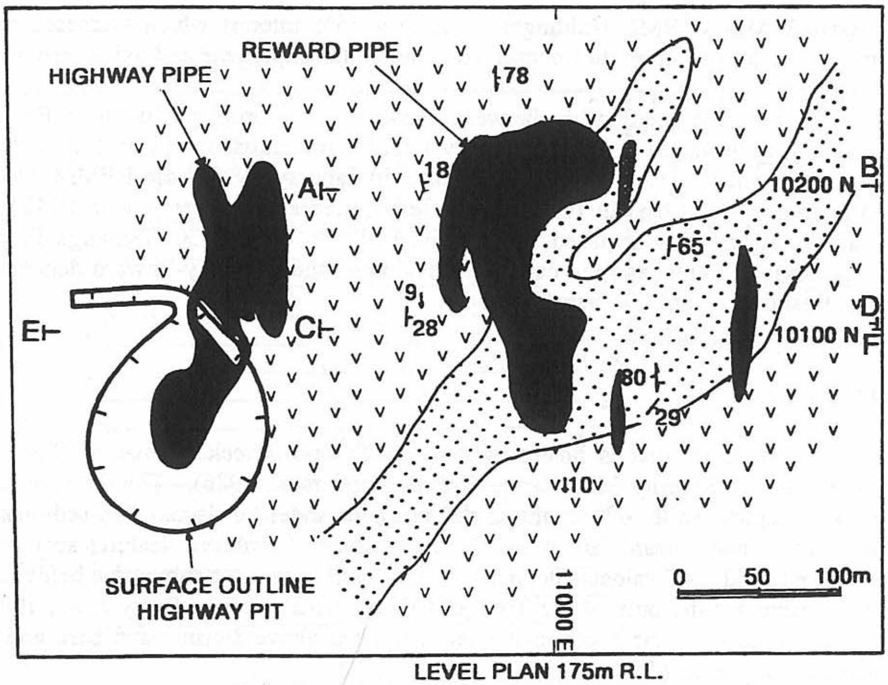
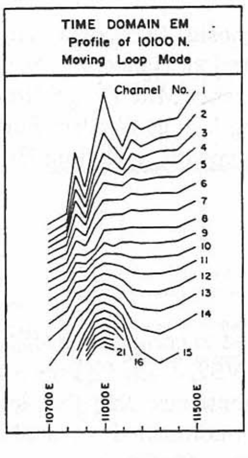
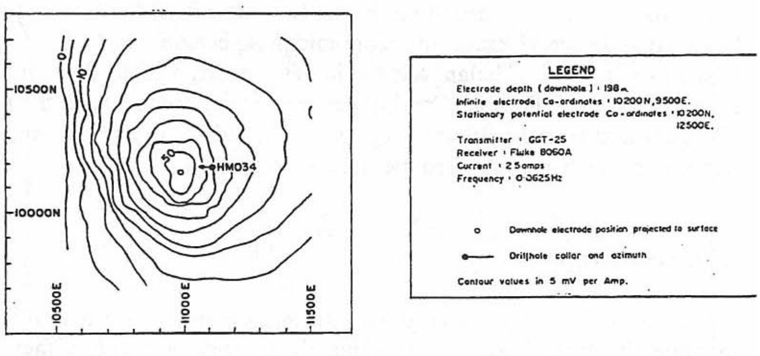


Figure 3 Schematic level plan 175m R.L. (150m below surface) of Reward and Highway massive sulphide pipes. Dips and strikes deduced from drill core measurements. Sections A-B (10200N) and C-D (10100N) refer to Figure 6. Section E-F (10100N) refer to Figure 8.



A.



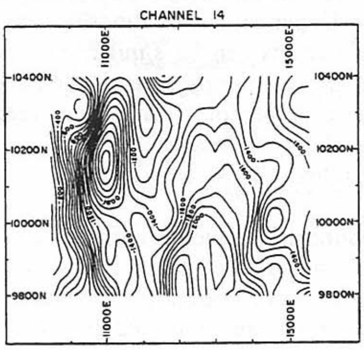
C.

Figure 4 Geophysical Response Reward Deposit. From Beams et al., 1989.

A. Time Domain EM Profile of 10100N.

B. Contours of Surface EM (Horizontal Component Channel 14 Sirotem) Large Fixed Loop Survey.

C. Contours of Mise à la Masse Survey, HM034 198m.



B.

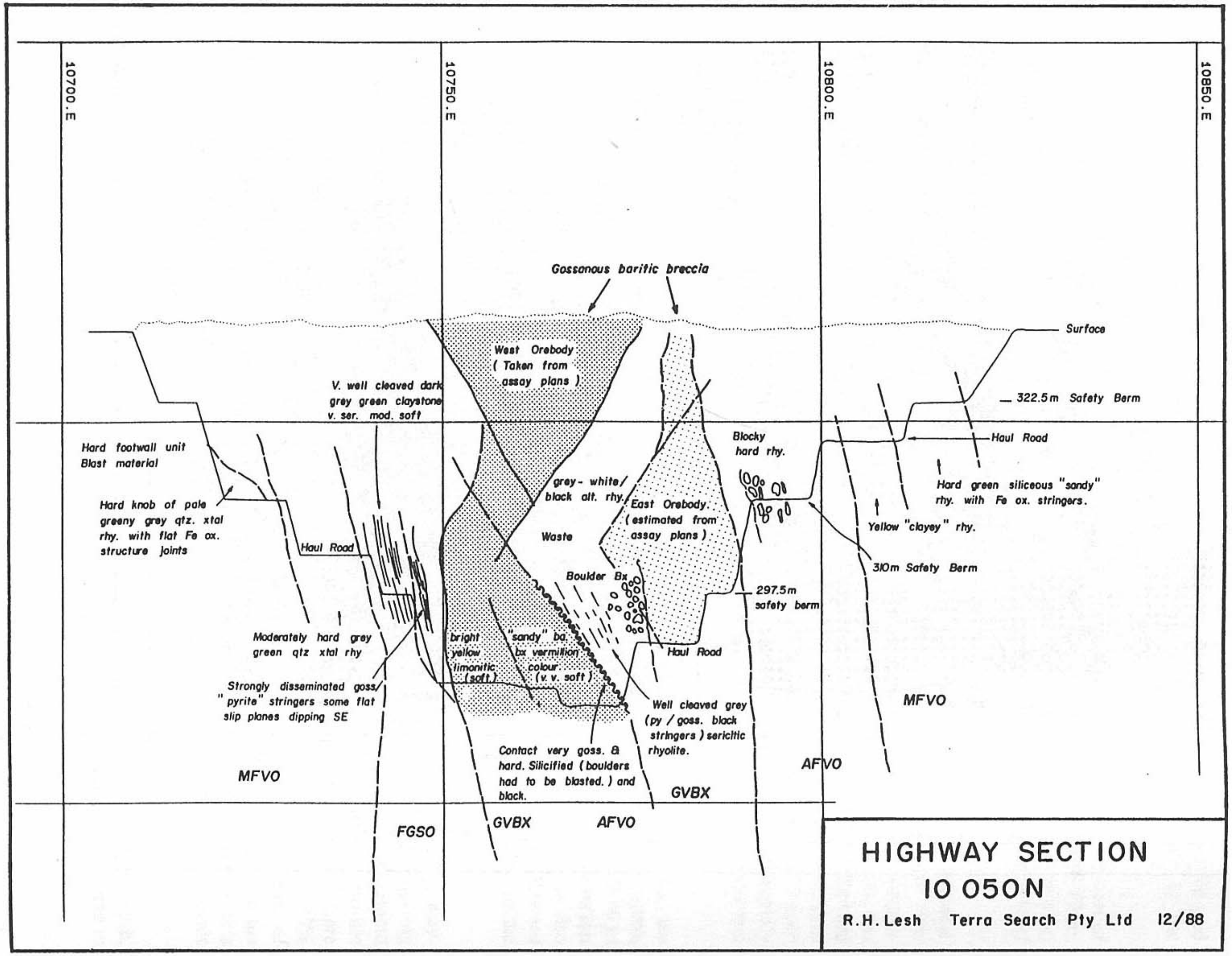


Figure 5
Section of the oxide portion of the Highway breccia bodies, as determined from mapping of pitwalls and level plans.
End of pit life.
R.H. Lesh, Terra Search report November 1988.

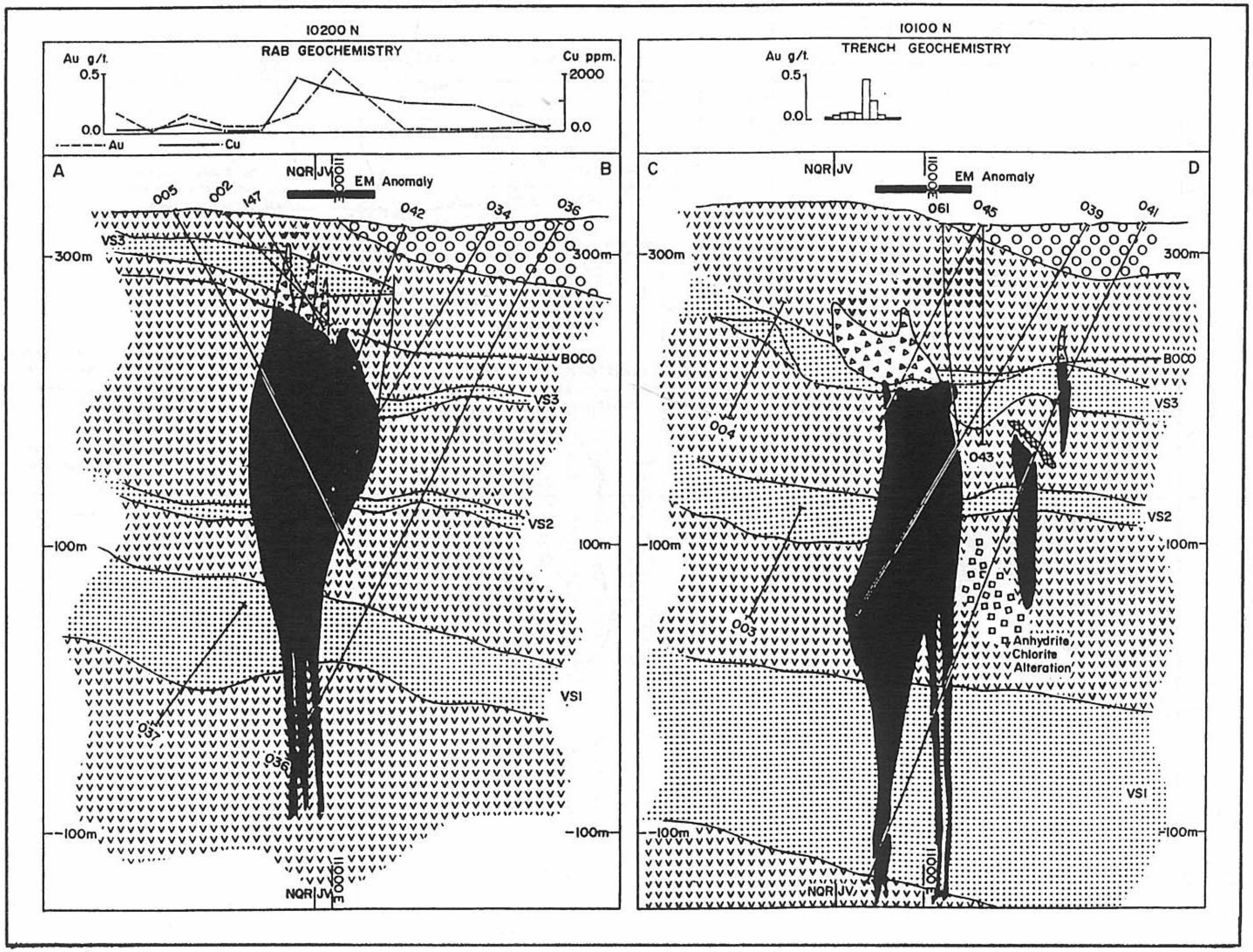


Figure 6
Schematic geology sections
10100N and 10200N
Reward Deposits,
RAB geochemistry from
1983 drilling by Esso,
25m spaced holes 10-50m deep in outcrop areas, 50-80m deep in covered areas.
Trench Geochemistry from
5m sampling City Resources, 1987.
From Beams et al. 1989

Geochemical Implications of the Regolith

A cover sequence of coarse boulder conglomerate, ferruginous clay rich grits and silts, lap onto the grid eastern side of the Reward orebody (Figure. 1). The cover rocks have been ascribed to the Tertiary Campaspe Beds (Wyatt et al., 1971).

In the Highway-Reward area, the volcanic sequence is completely oxidised to vertical depths in excess of 100 m. This contrasts with the Handcuff area where depth of oxidation is approximately 10 to 20 m. Acid groundwaters generated by the large massive pyrite bodies together with the current exposure level being close to the deeply weathered pre-Tertiary land surface, could be responsible for the very deep level of oxidation.

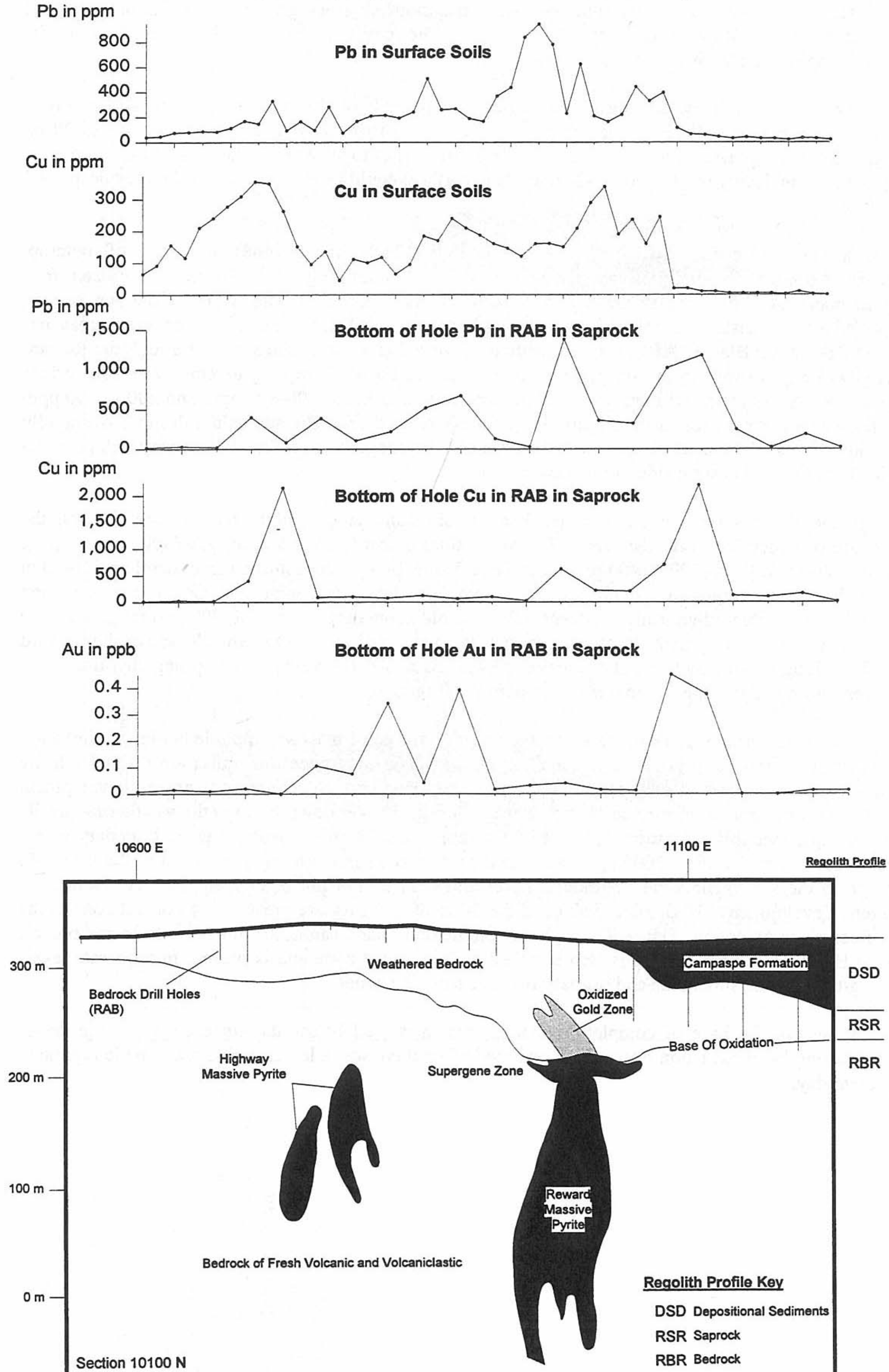
Soil sampling has been effective in delineating high base metal zones in areas of outcrop. Major 300 m x 800 m anomalies with Cu greater than 120 ppm (Figure 1) Pb and Zn greater than 500 ppm occur at Highway, Handcuff and Truncheon. Where onlap onto areas of outcrop occurs, transported cover masks the soil values. Bedrock geochemical sampling in the covered areas has involved Rotary Air Blast (RAB) or Auger drilling. Figure 7 is a composite section through the Reward and Highway pipes showing the surface Pb values obtained by soil sampling together with sub-surface sampling by RAB bedrock drilling. Elevated Pb and Cu values in the 400-800 ppm and 200 to 300 ppm range respectively were present in soil sampling of the outcrop areas. The soil values dropped off rapidly to very low levels where a cover sequence of coarse boulder conglomerate, ferruginous clay rich grits and silts, lap onto the grid eastern side of the Reward deposit.

Although the Reward pipe is blind, a geochemical signature is present in the overlying rocks, the recognition of which led to its discovery. Elevated values of Au (0.2 - 0.5 ppm), Cu (300 - 2200 ppm), Pb (200 - 1200 ppm), Zn (200 - 1400 ppm) and Ba (0.1% to 1.4%) were returned from depths of 10-80 m in RAB drill holes (Figure 6) which penetrated into both the outcropping and Campaspe Formation covered deeply weathered volcanics (Beams, 1984). Gold anomalism in the 100-200 ppb range was also detected as secondary dispersion in the Campaspe Formation sediments immediately above the Reward pipe. Trenching of silica-altered and jarosite-boxworked and barite-veined outcropping rhyolite in the same area returned Au values up to 5 m @ 0.5 ppm Au (Figure 6).

A long-lived weathering regime operated on the massive and semi-massive sulphide bodies at Highway-Reward resulting in strong gossan development, leaching and supergene mineralisation. The Highway pipe has a gossanous breccia developed at the present day land surface, whereas the gossan development above the Reward pipe is subsurface. Leaching of copper and silver down through the weathering profile produced supergene mineralisation. The base of complete oxidation delineates a sharp boundary where copper is present in the 200 - 2000 ppm range in the oxide zone and extremely enriched in the 8 to 40% Cu range in the supergene zone. Although silver and gold do not mirror copper, there is evidence of supergene development. High silver values in the 50 to 80 ppm Ag are present in a contact zone at the base of complete oxidation (Figure 9). High Au, on the other hand can occur in the oxide baritic breccia zones at Highway-Reward. Gold is also enriched in the contact zone and is present in moderate levels (0.5 - 1 g/t Au) in the supergene and primary massive sulphide zones.

The sharpness of the base of complete oxidation, which is well below the current water table depth, suggests a long lived oxidation front which operated when there was a lower, stable water table regime to the present day.

Figure 7: Composite Cross Section Reward and Highway Surface Soil and Subsurface RAB Geochemistry



See also Beams, 1998

Mineralisation Styles

Assay intersections of the different styles of mineralisation at Reward and Highway are presented in the Table 1.

TABLE 1: Assay intersections of the mineralisation styles, Reward Deposit (Modified after Beams et al., 1989)

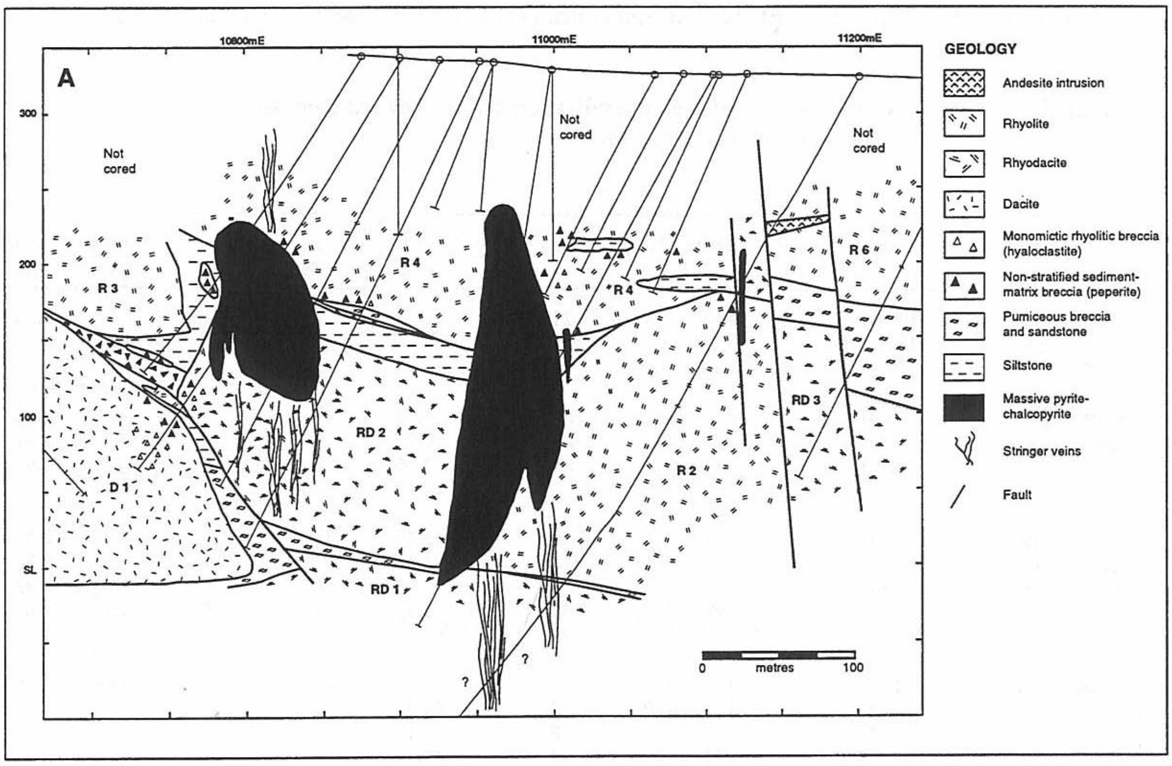
Reward Pipe	Hole No.	From To (m) (m)	(m)	Cu %	Pb %	Zn %	Ag g/t	Au g/t
Oxide generally gossanous and baritic	HM045	102 - 123	21					6.26
	HMH006	72 - 133.5	61.5				10	5.06
Massive pyrite chalcopyrite	HM034	151 - 251	100					0.72
	HM038	223 - 327	104	0.95				0.81
	HM039	178 - 312	134	0.76				0.64
Chalcopyrite rich sections in massive pyrite	HM034	200 - 230	30	3.49	<0.01	0.02	3	0.57
	HM038	313 - 325	12	3.44	0.01	0.06	<1	0.87
	HM039	190 - 202	12	3.32	<0.01	0.01	4	0.48
	HM039	292 - 312	20	2.53	0.02	0.13	5	1.03
Chalcocite rich supergene	HM039	127 - 150	23	8.24	0.12	0.05	18	1.56
	HM051	119 - 140	21	22.47				
	HM045	119 - 147	28	5.17				
	HM061	104 - 128	24	18.36				
Massive lead-zinc-barite lenses	HM040	166 - 178	12	1.86	2.78	13.39	127	0.94
	HM047	245 - 250	5	0.64	5.54	25.38	234	34.49
	HM047	260 - 265	5	1.07	8.70	19.82	193	26.18

Highway Pipe	Hole No.	From To (m) (m)	(m)	Cu %	Pb %	Zn %	Ag g/t	Au g/t
Massive pyrite/ chalcopyrite	REMM142	183 - 240	57	9.1	0.01	0.12	4	0.63

The Highway and Reward pyrite-chalcopyrite pipes are discordant to bedding, but parallel to S4, and have a plunge subparallel to a sub-vertical mineral lineation (cf. Berry et al., 1992; Doyle, 1997). The Highway orebody comprise two to three pipes spaced less than 3 to 10 m apart or a single "dome" or "tooth-shaped" massive sulfide body. The Reward orebody consists of one main and several smaller subvertical, massive pyrite pipes. The largest pipe is saddle-shaped in plan, with a bulbous top (Figyre 8).

The pyrite-chalcopyrite pipes have a mineralogy dominated by pyrite and chalcopyrite, with minor tennantite, sphalerite, quartz and sericite. Pyrite is typically fine to medium grained (20-300 μm) but is coarse grained (2-5 mm) near shear zones. Pyrite is euhedral, has a lath-like habit or exhibits spongy, shreddy, framboidal, or snowflake texture (Huston, 1992; Doyle, 1997). Fine-grained annealed chalcopyrite fills the interstices between pyrite crystals.

Relict patches and segments of altered coherent and peperitic rhyolite and rhyodacite occur in a 1 to 10 m wide zone at the margins and top of the pipes. Relict quartz phenocrysts are rarely preserved within the sulfide, but quartz and/or feldspar are common in relict volcanic intervals. Interstitial anhedral quartz constitutes up to 20 to 30% of the pipe along some contacts with the altered host rock. The quartz is intergrown with pyrite, forms patches up to 2 cm across, or occurs in bands of pyrite-quartz±barite. Contacts with the host succession are often sharp, but many are sheared. A halo of disseminated and patchy pyrite extends out into the surrounding altered rhyolite, rhyodacite, dacite or peperite.



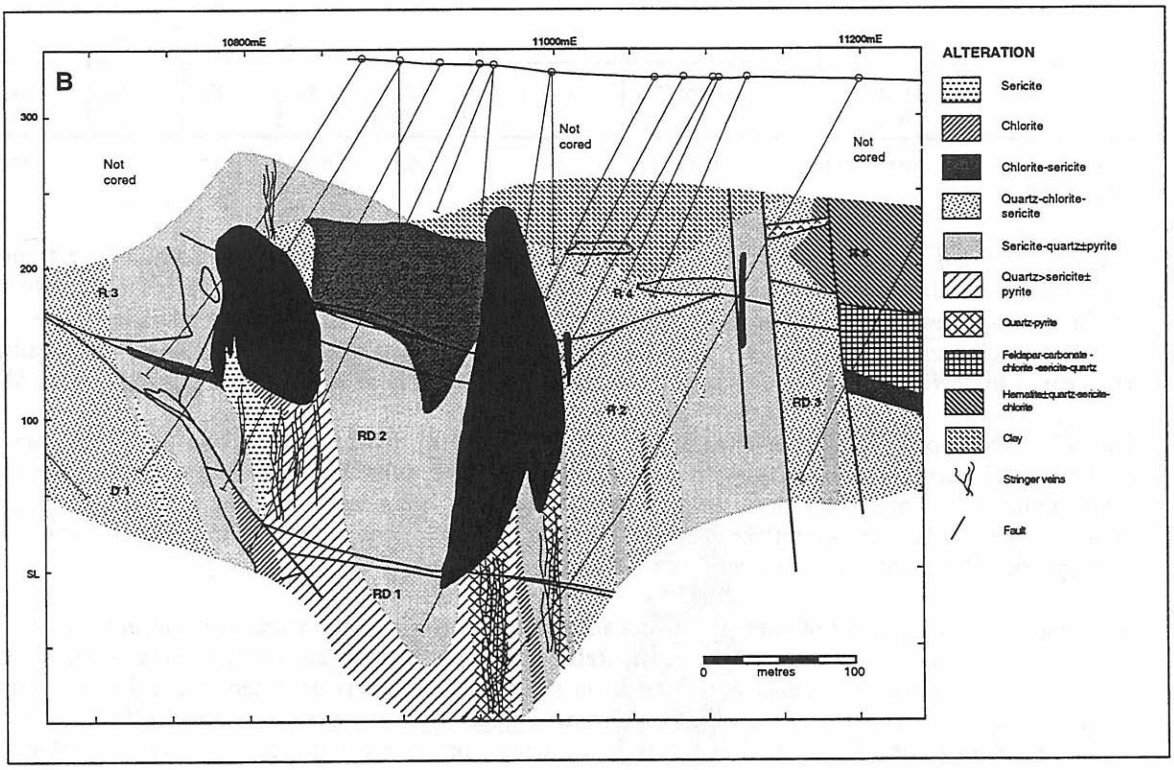


Figure 8. Simplified geological cross section showing the distribution of (A) lithofacies and (B) alteration at 10150N. The position of the massive sulfide bodies is also shown. Dacite D1, rhyodaictes RD1-RD3 and rhyolites R2-4 and R6 are exposed on section 10150N (after Doyle, 1997).

The pyrite-chalcopyrite pipes are surrounded by a halo of Pb-Zn-Ba-rich mineralisation containing four styles of mineralisation. These are: (1) veins and veinlets of sphalerite±galena-barite within altered volcanic rocks along the margins and tops of the pyrite pipes; (2) disseminated, patchy and spotty sphalerite within sericite-quartz-chlorite-altered rocks at the tops of the pipes; (3) lenses of strata-bound massive pyrite-sphalerite-chalcopyrite-barite closely associated with volcaniclastic mass-flow units in the hanging wall to the Reward pipe; and (4) massive to semi-massive pyrite-sphalerite-chalcopyrite±barite at the margins of the pyrite pipes.

The southern part of the stratabound Zn-Pb-rich lens comprises massive and finely banded sphalerite-rich massive sulfide. The northern part of the lens has a progressively thickening pyrite-rich base and grades into a discordant massive pyrite pod. The pod occurs around 20-50 m above the southern margin of the Reward pipe. Strong quartz-sericite±pyrite alteration occurs above the pod suggesting that the hydrothermal fluids transgressed the rhyolite intrusion which overlies the lens/pod. The sulfides and peperitic base of the intrusion are not mixed, implying that the sulfides deposited sub-seafloor (Doyle, 1997).

A supergene zone occurs immediately below the base of complete oxidation (Figures 6 and 9). In this zone volcaniclastic units and coherent rhyolite are partially to almost completely replaced by sooty black or grey chalcocite and blue-grey covellite. Supergene mineralisation extends downwards into the massive pyrite where copper contents up to 40% occur over some 1 m intervals indicating semi-massive development of chalcocite and covellite.

At Reward, a gold oxide zone is sporadically developed above the base of oxidation. It consists of fine-grained siliceous breccias and orange coloured baritic gossan. Much of the silica is probably introduced during downward percolation and leaching of groundwaters. A larger pipe like baritic gold bearing gossanous breccia body is present at Highway (Figure 5). This resource was calculated by North Queensland Resources NL to contain a western zone of 45,400 tonnes @ 7.84 g/t Au and an eastern zone of lower grade 22,220 tonnes @ 1.42 g/t Au. Total production from mining in the period April to November 1988 was in the vicinity of 9,000 ounces of Au (Lesh, 1989).

Alteration

The Highway and Reward orebodies occur within a well-developed discordant alteration envelope. The envelop extends from at least 150 m below the orebodies to over 60 m above the Highway pipe (Figure 8B). The alteration envelope has a mineralogical zoning which is defined by assemblages of chlorite-sericite±quartz, chlorite±anhydrite, quartz-sericite±pyrite, sericite-chlorite-feldspar-quartz and hematite±chlorite-sericite-albite-quartz (Doyle, 1997).

A quartz-sericite±pyrite zone is centred beneath the pyrite pipes and on some sections extends into the hanging wall succession. The relative proportions of sericite and quartz within the zone varies considerably. Quartz-dominant alteration is associated with strong development of disseminated and vein-style pyrite-quartz mineralisation. Small domains of intense chlorite±anhydrite-gypsum alteration occur within the footwall quartz-sericite±pyrite zone and along some margins of the pipes. These zones consists of lilac-coloured anhydrite crystals (up to 1.5 cm) mantled by white gypsum, and studded through a schistose matrix of green-black chlorite. The foliation wraps around the anhydrite, which indicates a pre- or syn-kinematic timing for anhydrite crystallisation (Huston, 1992; Doyle, 1997). The anhydrite is interpreted to represent the products of reactions between hydrothermal fluids and sea-water during the waning stages of hydrothermal activity. Quartz-sericite±pyrite alteration gives way laterally and vertically to domains of sericite-chlorite±quartz alteration. Beyond the hydrothermal alteration halo, rocks of rhyolitic to dacitic composition contain various assemblages of feldspar (albite), calcite, sericite, chlorite, quartz and hematite (Figure 7B).

Contacts between the alteration zones are typically gradational. The strongest alteration, as indicated by destruction of feldspar and volcanic textures, occurs in the footwall stringer zone and on some sections in the hanging wall quartz-sericite±pyrite zone. Less intense alteration, occurs marginal to the orebodies and within the outer alteration zone (Doyle, 1997).

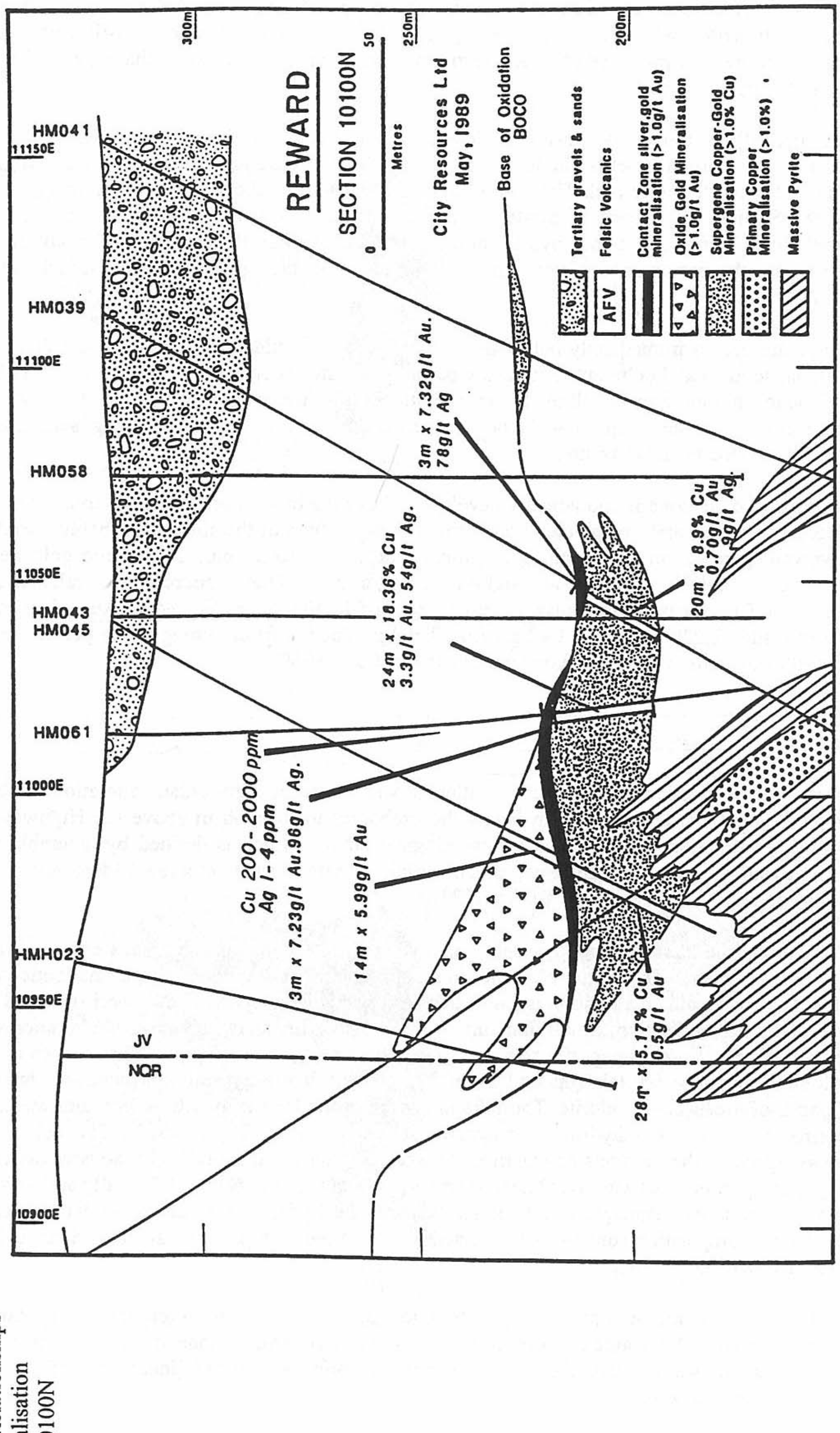


Figure 9
Reward, Relationships
of Mineralisation
Styles, 10100N

Discussion

Beams et al. (1989) favoured emplacement of the massive pyrite pipes by fluid mass transfer processes during deformation, in a similar fashion to Elura and The Peak in NSW (Schmidt, 1990, Hinman & Scott, 1990). Nisbet (1992) reveals that cleavage consistently overprints all alteration and mineralisation and is therefore likely to be pre-cleavage or at latest very early syn-cleavage in timing. More recent work by Aberfoyle, McPhie and Large (1992) and Doyle (1994, 1997) suggests that the pyrite-chalcopyrite pipes and associated sphalerite-rich mineralisation formed at the same time and are syn-genetic VHMS in origin.

Doyle (1997) demonstrated that most of the massive sulfide ores at Highway-Reward formed by sub-seafloor replacement of rhyolite to dacite and volcaniclastic units because: (1) the mineralisation is hosted by intrusive or mass-flow emplaced units; (2) discordant and strata-bound ores contain relict patches of coherent facies or precursor volcanic particles; (3) peperite and massive sulfides are not mixed, implying sulfide deposition postdated emplacement of the enclosing succession; (4) pyrite pipes are discordant to bedding; (5) there are replacement fronts passing from strata-bound sphalerite-rich ores into discordant pyrite-pipes; (6) zones of strong quartz-sericite-alteration and pyrite veining extend into the hanging wall without any abrupt break in intensity. The distance below the seafloor at which infiltration and replacement took place is difficult to interpret, but was probably at least 60 m.

Ascending high temperature (300-350°C) hydrothermal fluids are interpreted to have been focussed within feeder zones (McPhie & Large, 1992) localised along the fractured glassy margins of the cryptodomes in the host succession (Doyle, 1997). The pyrite-chalcopyrite mineralisation progressively replaced the rhyolite to dacite intrusions, peperite and sediment. Lower temperature fluids that moved out from the margins of the pyrite-chalcopyrite pipes deposited a halo of Zn-Pb-Ba mineralisation.

The supergene (and probably oxide) mineralisation developed by downward concentration of metals during weathering of sulphide in the uppermost rhyolite unit above the pyrite-chalcopyrite pipes. At Reward, high-grade supergene copper mineralisation is attributed to local enrichment by weathering of chalcopyrite rich lenses.

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