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The mineralogy of gold in the Mt Lyell orebodies (a preliminary report)

by R. S. Bottrill

Abstract

Gold occurs in the Mt Lyell copper ores as electrum grains up to 330 μm in size, usually closely associated with pyrite, chalcopyrite and less commonly numerous other sulphide and non-sulphide minerals. The fineness of electrum grains show a wide range, from about 300 to 997, but most commonly average around 800–900. Silver-rich zones indicate some late-stage remobilisation of silver and/or gold. The characteristics of the different types of electrum grains can be related to various stages in the ore genesis, using a recently developed model.

INTRODUCTION

The Mt Lyell copper orebodies were originally worked for gold, and in total actually still constitute the largest single source of gold production in Tasmania (>40 t; Large *et al.*, 1990). The ores are generally considered to be Cambrian, partly syngenetic and partly epigenetic, consisting principally of disseminated and vein-style mineralisation, with some massive pyrite lenses and rare stratiform mineralisation, hosted in schistose acid lavas and pyroclastic rocks of the Cambrian Mt Read Volcanics (Reid, 1975; Walshe and Solomon, 1981; Hendry, 1981). The ore minerals include pyrite, magnetite, hematite, chalcopyrite and bornite, with minor amounts of tennantite, molybdenite and various other ore minerals (Markham, 1963). Gangue minerals, in approximate order of abundance, include quartz, muscovite, chlorite, siderite, pyrophyllite, apatite, barite, zircon, monazite and florenceite.

Gold has a strong relationship with copper in the orebodies, averaging 0.4 g/t (Large *et al.*, 1990), but little has been published on the actual occurrence of gold-bearing minerals at Mt Lyell. Edwards (1939) noted electrum with galena and bornite which had partly replaced enargite, and somewhat purer and coarser gold or electrum with bornite in quartz veins in the North Lyell orebodies. He also noted gold up to 60 μm in diameter as free particles, and up to 240 μm in size in gold–galena composite particles in panned concentrates. Green (1971) described the occurrence of relatively coarse gold in 'secondary' quartz-chalcopyrite veins in the Cape Horn orebody.

This study was initiated to provide information on the occurrence of gold at Mt Lyell, which could assist in mineral exploration in the area and aid recovery of gold from both the primary ores and also from the "tailings" in the King River Delta. At present about a quarter of the gold is lost to the tailings and the remainder recovered as a by-product of smelting of the copper concentrates.

For the purposes of this paper, "electrum" refers to any gold-silver alloy, rather than only where Ag >20%, as this division is rather arbitrary and irrelevant to this project.

OCCURRENCE

Sample locations and descriptions are listed in Appendices 1 and 2 respectively. Ores from the Prince Lyell, West Lyell, Crown Lyell, Cape Horn, Western Tharsis and Blow orebodies were examined in this investigation, but visible gold/electrum was only noted in samples from Prince Lyell, West Lyell and Cape Horn. Most of this occurs in relatively copper-rich disseminated ores, and is closely associated with chalcopyrite in brecciated pyrite grains; less common associates include sphalerite, galena, hematite, phyllosilicates (muscovite/sericite, chlorite and pyrophyllite), molybdenite and carbonate (siderite?). Association data for the thirty grains observed are shown in Table 1.

Sphalerite and galena are rare in the ores but, where present, appear to be commonly closely associated with electrum (fig. 1 and 2, table 1). Electrum grains in chalcopyrite alone are relatively small and uncommon, and are volumetrically insignificant (table 1). Electrum inclusions in pyrite are more abundant and appear to be related to a secondary, poikiloblastic, generation of pyrite (fig. 3). The inclusions are associated with fine inclusions of gangue, chalcopyrite and pyrrhotite, while bornite occurs in many other similar poikiloblastic pyrite grains. Local pods of massive, granular chalcopyrite contain relatively coarse, brecciated pyrite grains, and some of these are very gold-rich (usually as a fine network of electrum; fig. 4).

In general, however, electrum is difficult to observe in these ores, and the correlation of copper and gold (Large *et al.*, 1990) suggests possible solid solution of gold in chalcopyrite. One ore sample assaying almost 9 g/t showed only two small grains (2 and 4 μm) of electrum in five polished sections, but also contains small quantities of tennantite and a bismuth telluride (fig. 5). These and other minerals could contain significant gold (below the detection limit of the electron microprobe) (Cook and Chryssoulis, 1990). The "nugget" effect is another serious problem in assessment of the gold mineralogy (i.e. a few

Table 1

Size, mass and paragenetic distribution of electrum in Mt Lyell ores

Size range diam. (µm)	Paragenesis/associations				Total	Freq. %	Wt. %	Cum. Wt.%	Cum. Freq. %
	Pyrite	Py + Ccp*	Ccp	Py-Ccp-Sl/Gn					
0.63– 1	0	0	0	1	1	3.33	0.00	0.00	3.33
1 – 1.6	1	0	0	0	1	3.33	0.00	0.00	6.67
1.6 – 2.5	1	1	0	1	3	10.00	0.01	0.01	16.67
2.5 – 4	1	1	2	2	6	20.00	0.05	0.06	36.67
4 – 6.3	0	0	0	1	1	3.33	0.03	0.09	40.00
6.3 – 10	2	1	0	0	3	10.00	0.39	0.48	50.00
10 – 16	1	1	1	2	5	16.67	2.59	3.07	66.67
16 – 25	0	0	0	2	2	6.67	4.37	7.45	73.33
25 – 40	0	4	0	3	7	23.33	59.37	66.82	96.67
40 – 63	1	0	0	0	1	3.33	33.18	100.00	100.00
Totals	7	8	3	12	30				
Mean size	12.93	22.38	7.67	14.08	15.50				
Wt. mean size**	48.54	38.35	15.73	25.12	38.51				
Frequency (%)	23.33	26.67	10.00	40.00	100.00				
Wt. %	29.28	50.06	0.94	19.72	100.00				

* Py: pyrite; Ccp: chalcopyrite; Sl: sphalerite; Gn: galena
** Diameter of particle of mean weight

large electrum grains may be equivalent in weight to several hundred small grains, but be very hard to locate and/or treat statistically).

Nonsulphides are rarely observed in direct association with the electrum, although hematite does occur as an associate of one zoned electrum grain (fig. 6).

For further assessment of the distribution of electrum in these ores, two gold concentrates were prepared by Mt Lyell Mines by tabling copper concentrates and wood pulp from the copper concentrates (Bottrill and Duncan, 1992). Most of this gold (electrum) is free, but a large number of composites were present, and the order of abundance of associates is: chalcopyrite >> pyrite > quartz > carbonates, phyllosilicates and other non-opaques >> hematite > other sulphides (galena, covellite) > magnetite. This indicates that much of this electrum, particularly that associated with nonsulphides, is derived from associations not identified in the ore samples studied. The normal copper concentrate contains 5–6 g/t gold, but systematic searches failed to reveal free electrum. This could indicate gold in solid solution in chalcopyrite as well as electrum, but also is probably related to the relatively coarse size of much of the gold, giving a 'nugget' effect.

Gold-silver tellurides (most probably hessite, calaverite and petzite, the gold-rich species intergrown with electrum) were rarely identified in the concentrates. Hessite was also identified in a bornite-rich ore sample.

Gangue minerals are rarely in direct association with electrum, and show no significant correlations. Some genetic significance may, however, be placed on the occurrence of pyrophyllite in the most gold-rich sample, and in association with the gold and silver-rich Blow ores. This mineral greatly resembles fine-grained, sericitic muscovite, and was confirmed by X-ray diffraction.

GRAINSIZE AND SHAPE

The size and mass distributions of electrum grains seen in the ore samples are represented in Figures 7 and 8, and Table 1. The largest grain detected was about 50 µm diameter, and most grains are relatively equant. The mean grainsize is 16 µm, the median size is ~10 µm, a particle of median mass is ~35 µm in size, and the weight mean size is 39 µm. There is a wide range of grainsize in all parageneses excepting chalcopyrite-hosted gold, and the overall mean differences in Table 1 are probably not statistically significant.

Examination of the gold concentrates mentioned above indicate median sizes between 95 and 170 µm, with some grains up to 320 µm (Bottrill and Duncan, 1992). This is difficult to compare directly with the ore samples, as the finer grains (<30 µm?) were lost during flotation and tabling, but suggests that a large proportion of the gold in the ores is present as sporadic coarse grains.

The coarser grains in the concentrates are commonly flaky, but many have probably been flattened somewhat during grinding. The finer grains are typically more equant, while the more highly locked grains are quite irregular in shape (fig. 1 to 6). In the ores the grains vary from well-rounded grains to highly irregular networks.

COMPOSITION

Twenty electrum grains were analysed by electron microprobe at the University of Tasmania. The results are listed in Appendix 3 and are discussed below.

The fineness of electrum in the ore samples studied ranges between 660 and 997, with a mean of 803 for the twenty grains (fig. 9 and Appendix 3). Two gold inclusions in pyrite in one sample have very high fineness, while electrum associated with chalcopyrite ± pyrite ± galena ± sphalerite all have a fineness between 800 and 860. Electrum with pyrite and chalcopyrite has a fineness between 650 and 850. This suggests either a compositional gap related to differing genesis, or re-equilibration with silver-bearing chalcopyrite.

The fineness of electrum in the two concentrates is also bimodal, but with different ranges and maxima: one peaks about 800–900, and another around 400–450 fine (i.e. aurian silver) (fig. 10). The concentrate produced in 1978 contains finer electrum, on average, than the 1983 concentrate (855 vs. 774, 26 and 48 analyses respectively), which probably reflects a variation of gold content in different orebodies. The earlier concentrate may have had a contribution from the North Lyell orebodies, while the later concentrate was derived solely from Prince Lyell ore.

Mercury was analysed for in several grains, but only detected in one of eight grains in the concentrates. This silver-rich grain contained almost 10 wt% Hg, and had a composition of $Ag_{78}Au_{16}Hg_6$. The other grains analysed contained much less silver, so there may be some correlation between the two elements. Several other elements were sought in a limited number of analyses, but no other elements could be detected.

Consideration of the fineness ranges and assemblages leads to at least three distinct genetic types of electrum:

1. Highly fine electrum (gold *sensu stricto*), coarse grained, as inclusions in pyrite (>950 fine)

2. Electrum with pyrite and chalcopyrite ± other sulphides (650–950).

3. Coarse-grained aurian silver (300–500).

No correlation was observed between electrum fineness and grainsize in these samples.

ZONING

The only significant zoning of an electrum grain in these ores was noted in a grain with pyrite and chalcopyrite in a high-grade disseminated copper ore (fig. 6). This had a partial pale-coloured rim about 660 fine and a more yellow core about 830 fine. Several other grains showed comparatively slight zoning (<25 in fineness), but the silver-enriched rims appeared consistent.

Many electrum grains in the concentrates show some patchy colour variation, but silver-rich cross-cutting zones and rims are more common than the opposite.

DISCUSSION: GOLD IN MASSIVE SULPHIDE DEPOSITS

Huston *et al.* (1992) have discussed the genesis of gold in base metal sulphide deposits, and have found evidence for two main forms of gold transport: thiosulphide (bisulphide) and chloride complexes. Gold thiocomplexes are most stable at low temperatures (<250°C), low Cl/H_2S, pH >5, and high H_2S/SO_4. Gold chlorocomplexes are most stable at moderate temperatures (>250°C), high Cl/H_2S, pH <5, and low H_2S/SO_4. Gold is apparently deposited differently in different parts of sulphide deposits:

1. In the stringer zone, gold is directly precipitated from the gold chlorocomplexes in solution, largely by a decrease in temperature and increase in pH, forming relatively coarse-grained electrum of high fineness (850–1000).

2. In the main sulphide zone gold is co-precipitated with pyrite, arsenopyrite and perhaps other sulphides, from thiosulphide complexes, as submicroscopic inclusions or solid solution.

3. In the baritic cap, gold directly precipitates as discrete electrum grains of moderate to low fineness (<800), by oxidation and dilution of thiosulphide complexes.

The predicted variation in fineness of electrum with temperature is compatible with data for unmetamorphosed deposits: i.e. electrum deposited from chlorocomplexes has a high fineness and a low fineness range, while electrum deposited from thiosulphide complexes has a low to moderate fineness and a wide fineness range.

Metamorphism and recrystallisation of the ores results in coarsening of electrum and migration into grain boundaries and fractures (particularly in brittle minerals like pyrite). The grainsize is dependent upon the gold grade and metamorphic grade, and the fineness may vary as the electrum or gold re-equilibrates with other sulphides. Thus the grainsize and fineness are both functions of the gold grade, metamorphic grade and style of ore genesis.

CONCLUSIONS

The occurrences of electrum at Mt Lyell, while largely secondary or recrystallised in texture, can be related the the above-mentioned model of Huston *et al.* (1992). Some of the most important points, in this regard, include:

1. the presence of apparently primary gold of very high fineness, as inclusions in pyrite.

2. most electrum occurs as secondary, recrystallised, grains, often with base metal sulphides in fractured pyrite.

3. some electrum exhibits very low fineness, and may contain some mercury.

4. the sporadic presence of pyrophyllite would indicate a low pH, favouring chlorocomplexing of gold, but the more general abundance of muscovite and siderite would indicate higher pH, favouring thiocomplexing of gold.

The various parageneses and fineness ranges, in particular, indicate gold transport in both chloro- and thiocomplexes. The range of associated minerals, including pyrite, pyrrhotite, barite, siderite, magnetite, hematite, muscovite and pyrophyllite, indicate a moderate to wide range of pH and Eh conditions, in accord with this model.

Compositionally-zoned grains are present, and may indicate either:

1. primary grain growth during sulphide deposition under waning temperatures, from gold thiocomplexes;

2. addition of silver from Devonian hydrothermal fluids;

3. or reflect local partial re-equilibration with other sulphides during late-stage recrystallisation (e.g. remobilisation of silver from chalcopyrite, tennantite and other sulphides into electrum).

Similar zoning has been noted in electrum grains in other base metal deposits (Huston *et al.*, 1992). The third option is favoured because:

1. the ores have been deformed and metamorphosed to greenschist grade subsequent to their formation (Walshe and Solomon, 1981), which would probably tend to homogenise any primary zoning in electrum.

2. there is no evidence for other Devonian base metal mineralisation in the ores or immediate surroundings.

3. Significant amounts of silver can be held in solid solution in the lattice of sulphide minerals such as chalcopyrite (which may contain up to 0.2 wt% Ag; Cabri *et al.*, 1985).

In summary, four distinct stages in the formation of gold at Mt Lyell can be recognised, using the above model:

1. Syngenetic pyrite, some containing very high gold contents, co-precipitated from thiosulphide complexes. Some of this pyrite may have been originally pyrrhotite (which can contain a higher gold content in solid solution than pyrite; Mironov *et al.*, 1986), which was later altered to pyrite. Some chalcopyrite, bornite and other base metal sulphides probably also formed at this stage.

2. Epigenetic mineralising fluids precipitated relatively free, pure gold from chlorocomplexes, with chalcopyrite, bornite and more pyrite.

3. The syngenetic and epigenetic pyrite was recrystallised, either during the above mineralising event and/or subsequent (probably Devonian) metamorphism, remobilising the electrum into grain boundaries and fractures in pyrite.

4. Silver was probably remobilised from sulphides into electrum during retrograde or low grade metamorphism, although some may have been added to the system by Devonian mineralising fluids.

It is interesting to compare this multiple-stage mineralisation scenario with the widely accepted ore genesis models for the Mt Isa ores (Robertson, 1982; Perkins, 1984), where syngenetic pyrite-pyrrhotite-sphalerite-galena mineralisation appears to have been overprinted, recrystallised and largely replaced by epigenetic, syntectonic chalcopyrite-pyrite mineralisation. Both of these styles of mineralisation contain very low gold contents, but some late-stage, fault-related gold mineralisation is present (Bottrill, unpublished data). An alternative to the two-stage model is a single-stage model of ore genesis with later, metamorphic-induced, hydrothermal remobilisation of ore minerals, which could apply to Mt Lyell as well as Mt Isa (McGoldrick and Keays, 1985). In either case, later metamorphism appears to have affected all of the Mt Lyell ores and the gold mineralogy.

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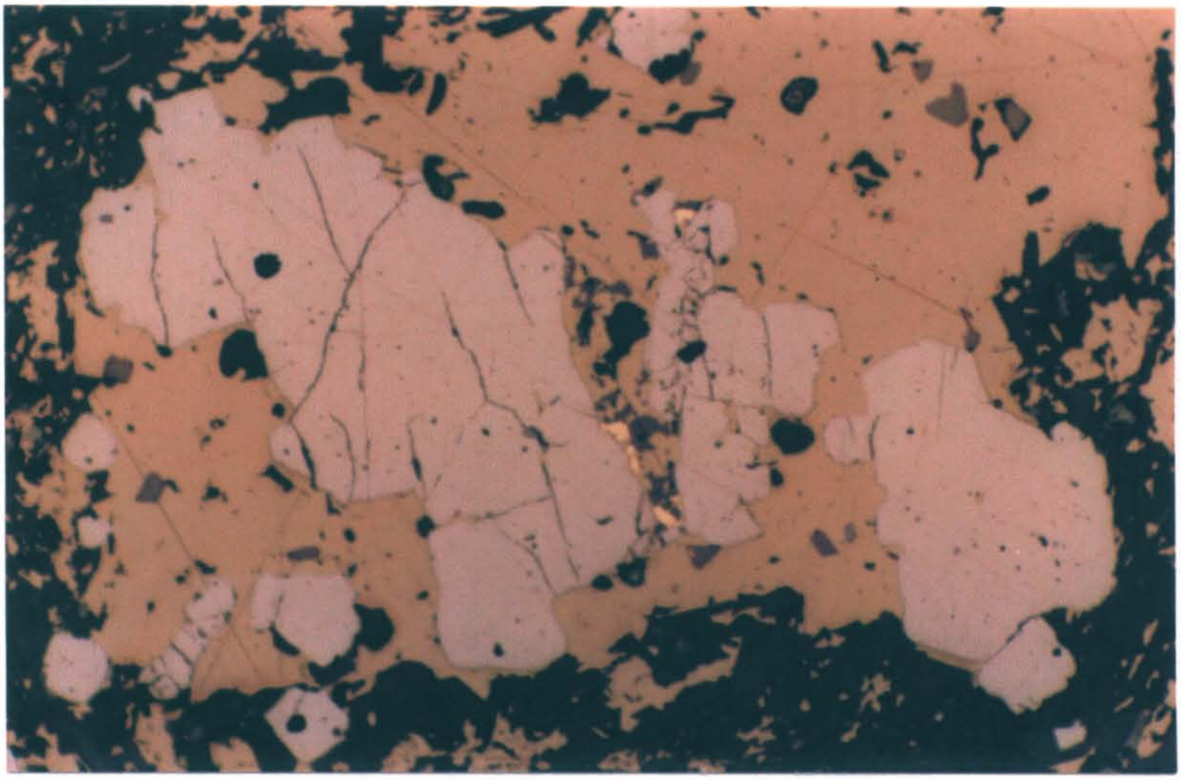


Figure 1

Electrum grains (bright yellow) up to about 30 µm in size, associated with sphalerite (mid grey), galena (not visible), chalcopyrite (yellow-brown) and gangue (dark grey) in a fracture in pyrite (cream). Field of view: 1120 × 750 µm.

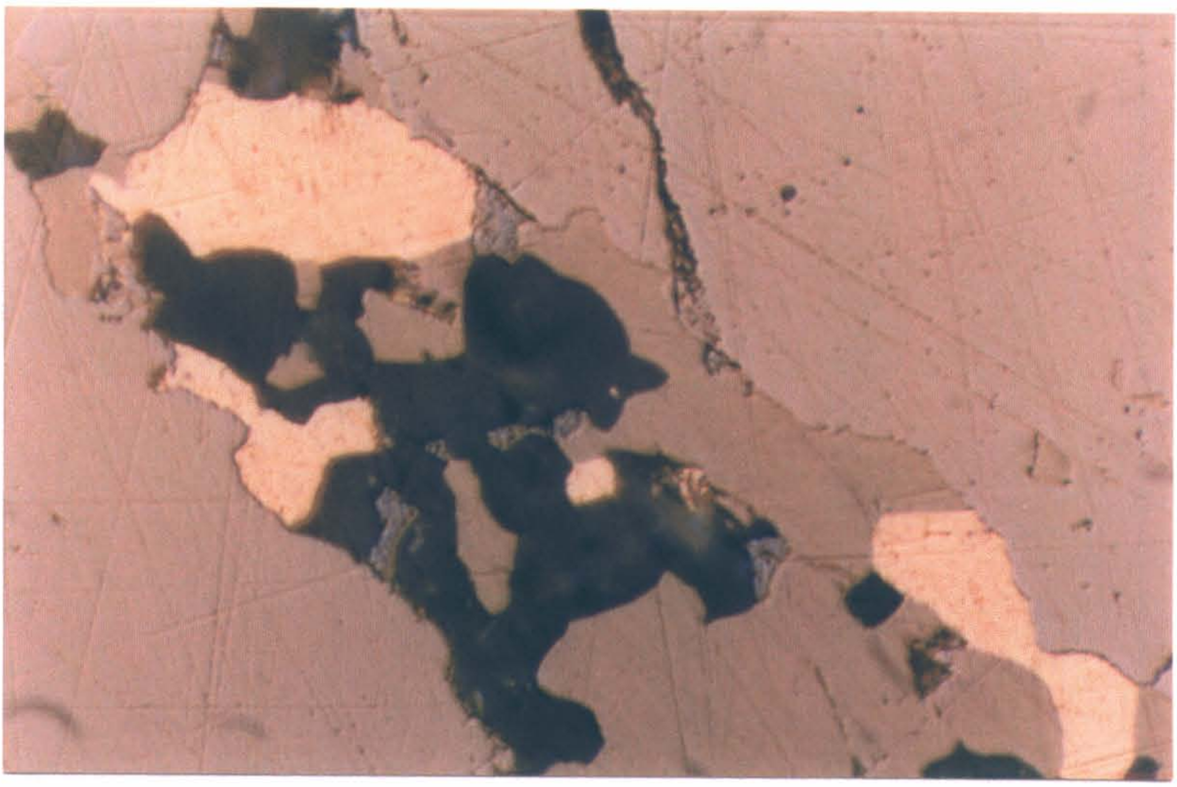


Figure 2

Electrum grains (bright yellow) up to about 30 µm in size, associated with sphalerite (dark grey), galena (light grey) and chalcopyrite (yellow-brown) in a fracture in pyrite (cream). Field of view: 90 × 60 µm.

5 cm

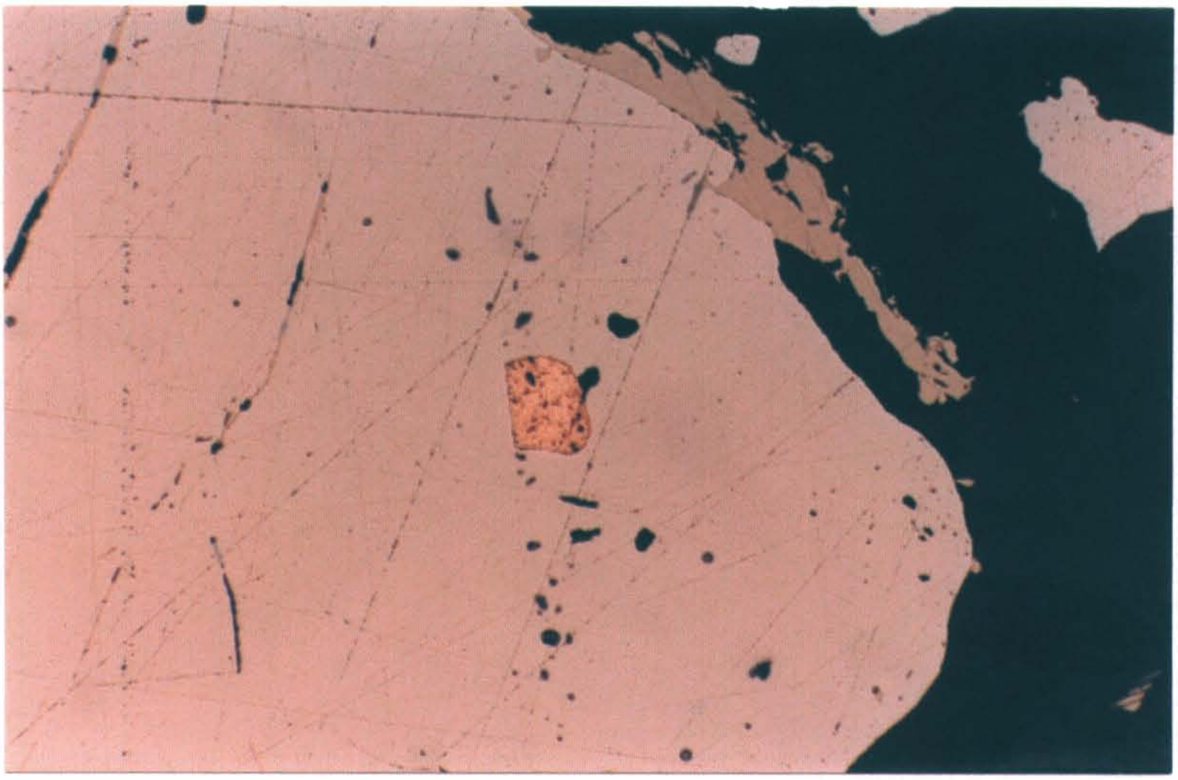


Figure 3

An electrum grain 50 µm in size, occurring as a primary inclusion in pyrite. The gold is in a poikiloblastic zone, overgrowing earlier formed, euhedral pyrite. Field of view: 560 × 375 µm.

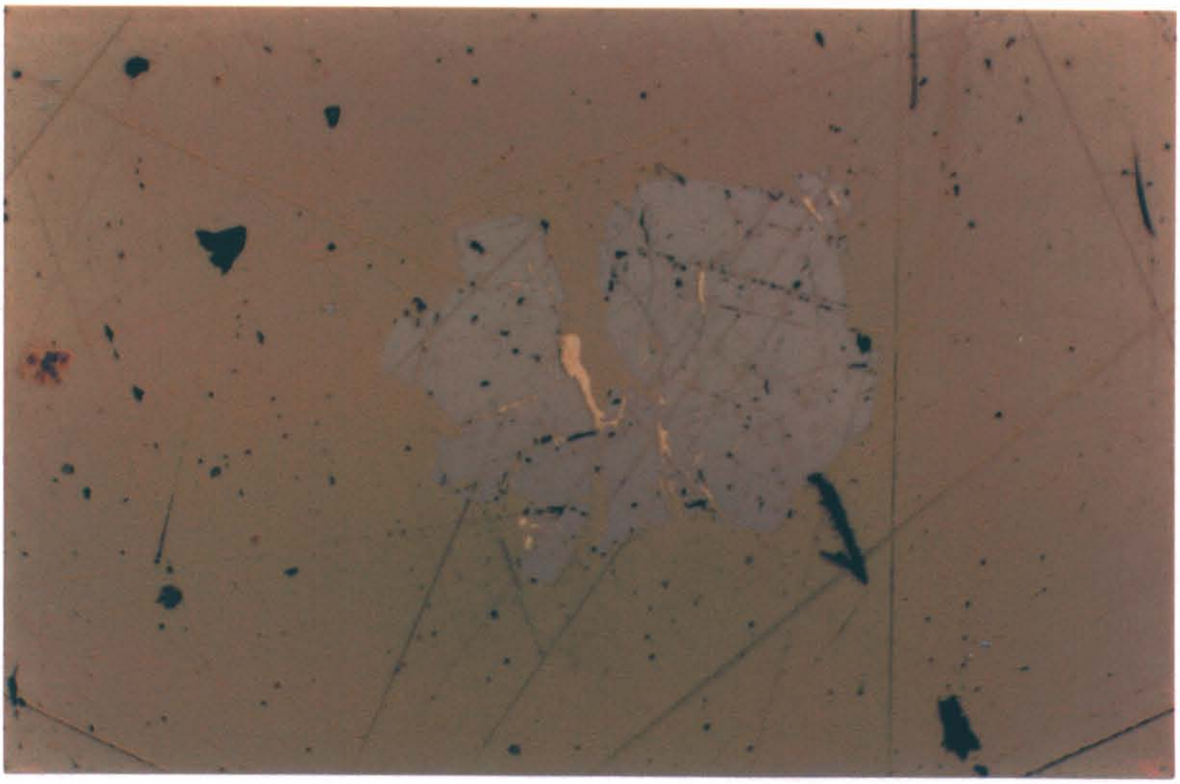


Figure 4

Electrum network up to about 10 µm in thickness, and partly submicroscopic, in fractured pyrite enclosed in a massive chalcopyrite matrix. Field of view: 560 × 375 µm.

5 cm

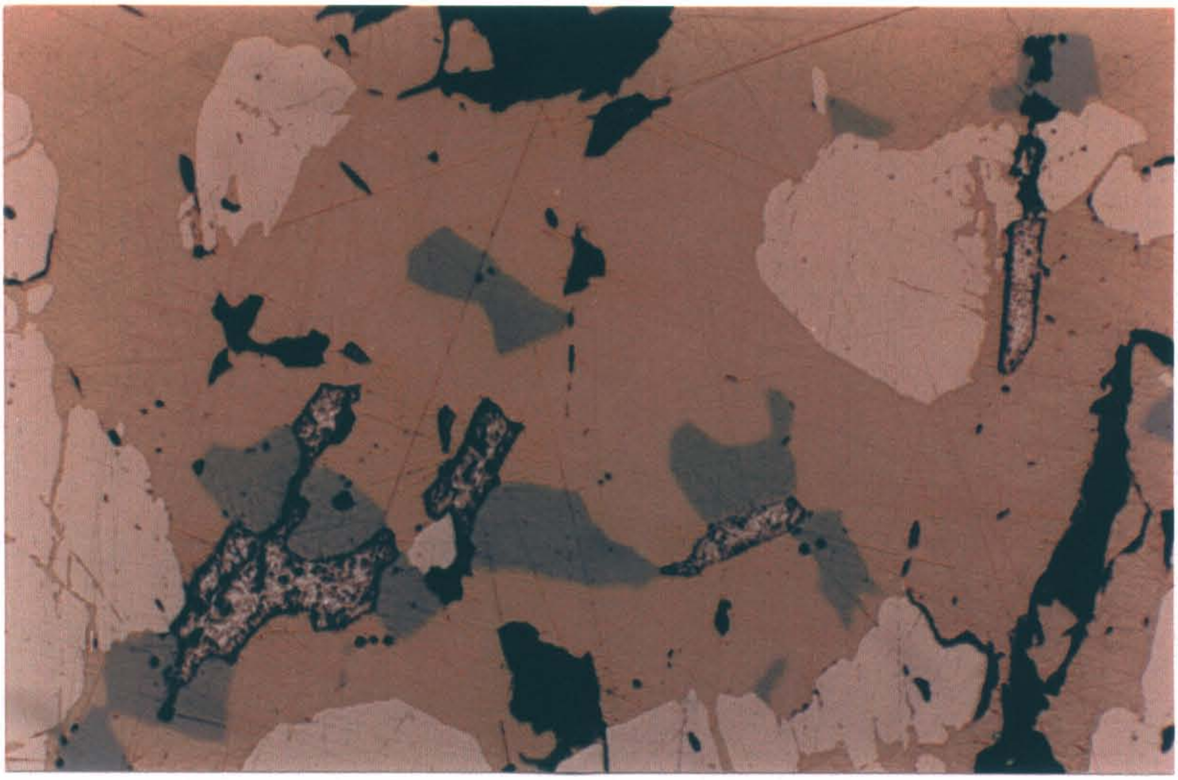


Figure 5

Bismuth telluride grains (mottled, white) up to 70 μm in size, with chalcopyrite (yellow-brown), pyrite (cream), gangue (black) and tennantite (mid grey). Field of view: 560 × 375 μm.

Figure 6

An electrum grain, associated with pyrite (cream), hematite (grey) and chalcopyrite (yellow-brown), about 10 × 20 μm in size, showing compositional zoning (about 660-830 in fineness). Field of view: 90 × 60 μm.

5 cm

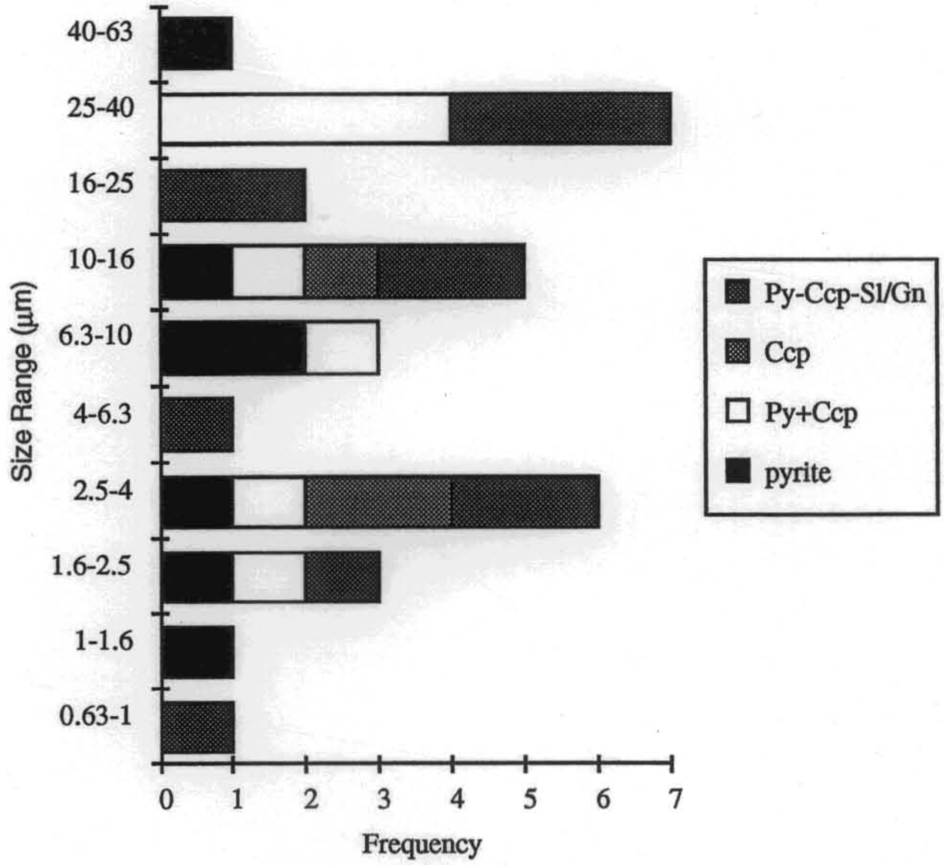


Figure 7

Size distribution, by paragenesis, of electrum grains in the ores.
Py: pyrite, ccp: chalcopyrite, Sl: sphalerite, Gn: galena.

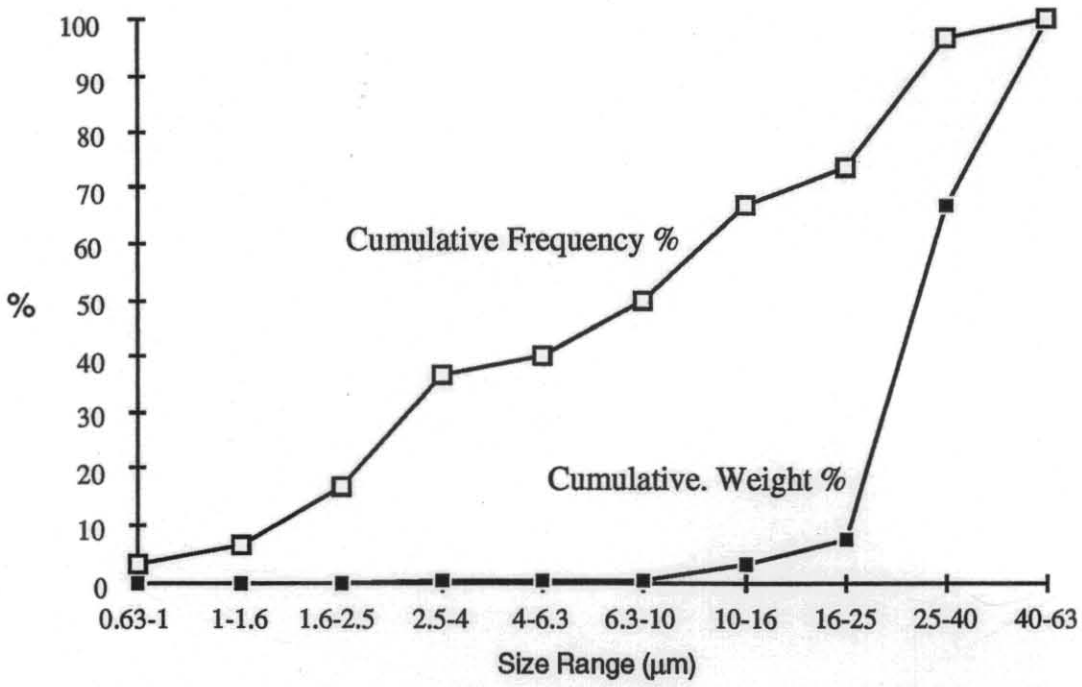


Figure 8

Size and mass distribution of electrum grains in the ores.

5 cm

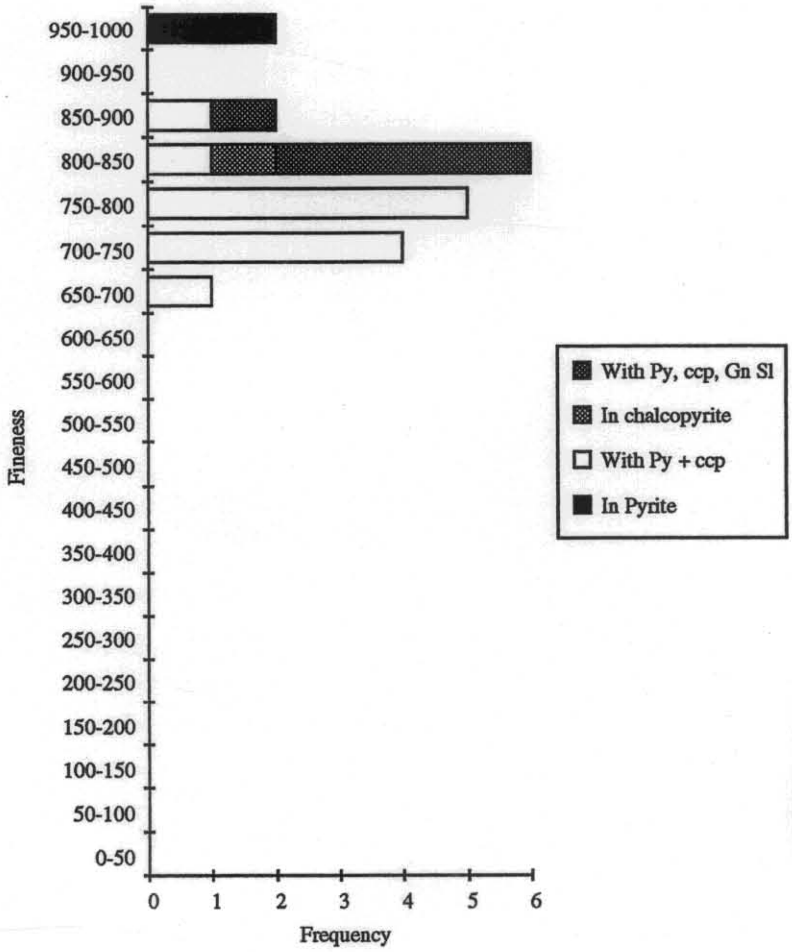
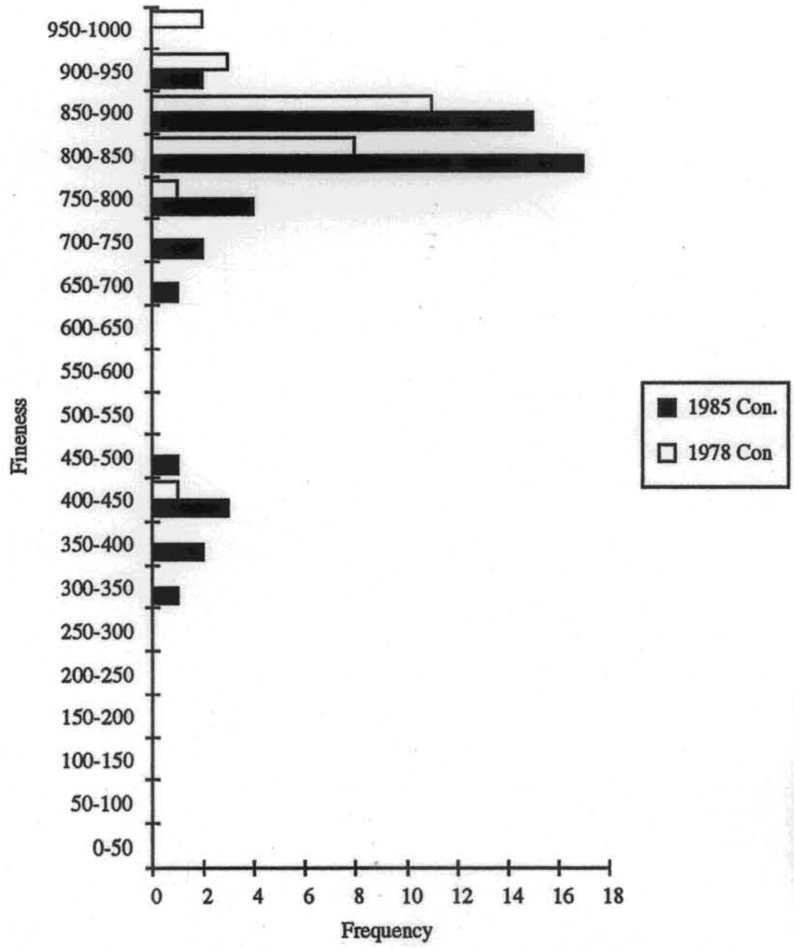


Figure 9

Fineness distribution of electrum grains in the ores. Py: pyrite, ccp: chalcopyrite, Sl: sphalerite, Gn: galena.



5 cm

Figure 10

Fineness distribution of electrum grains in the gold concentrates, from Bottrill and Duncan, 1992.

APPENDIX 1

Sample Locations and Grades

Registered No.	Field No.	Description	Location	Mine Co-ordinates	RL (m)	Cu grade (%)	Au grade (g/t)	Inferred Au grade (g/t)
C100027	ML1	WL 590, 96–98 m	Prince Lyell	4778 mN 5460 mE	-166	1.4	8.8	
C100028	ML2	Blow Main Lens	Mt Lyell	4420 mN 6180 mE	350	<0.2		2–3
C100029	ML3	Blow F/W lens	Mt Lyell	4420 mN 6180 mE	350	<0.2		2–3
C100030	ML4	High grade Cu, 45N X/C	Prince Lyell	4630 mN 5665 mE	-10	~7		1.5
C100031	ML5	Cu-Mo ore, 45N X/C	Prince Lyell	4630 mN 5665 mE	-10	~2.5		1.5
C100032	ML6	CH174, 24–26 m	Cape Horn	6898 mN 4737 mE	-22	4.3	1.7	
C100033	ML7	CH173, 44–46 m	Cape Horn	6884 mN 4738 mE	53	4.1	3.2	
C100034	ML8	WT65, 320–322 m	Western Tharsis	5990 mN 4925 mE	-290	2.57	1.9	
C100035	ML9	WL582, 184–186 m	Prince Lyell	4675 mN 5516 mE	-186	4.1	2.4	
C100036	ML10	Mo-rich ore	Crown Lyell III	6280 mN 5730 mE	555	~6	1.5	
C100037	ML11	Massive chalcopyrite	Prince Lyell			~35		8
C100038	ML12	Massive chalcopyrite	Prince Lyell			~17		4
C100039	ML13	Massive chalcopyrite	Crown Lyell			~30		
C102020		Massive pyrite	West Lyell open cut			<0.2		<0.6
C102023		Massive pyrite	West Lyell open cut			<0.2		<0.6
C102910		Hanging wall schist	Prince Lyell			~1		0.3
C102911		Magnetite-apatite rock	Prince Lyell			~0.4		0.1

APPENDIX 2

Petrographic Descriptions

Reg. No. C100027 (ML1): Au-rich ore, Prince Lyell

The rock is a highly sulphidic, quartz-sericite schist. Much of the rock is a sericitic, pyritic "chert", with quartz phenocrysts and sericitised feldspar phenocrysts indicating a volcanogenic origin. It is highly brecciated and sheared, with veinlets and blebs of sulphides ± sericite ± quartz ± chlorite ± apatite. The rock was probably an acid lava or pyroclastic which has been highly altered (mostly to quartz-sericite), brecciated and mineralised.

The pyrite is mostly medium to coarse-grained (rarely colloform), and frequently brecciated, with sporadic inclusions of various minerals. Some of the trace sulphides (e.g. bornite, pyrrhotite, galena and mawsonite) only occur as such inclusions. Chalcopyrite occurs as highly irregular medium-grained, disseminated grains, inclusions and veinlets. The tennantite occurs as coarse-grained veinlets, the molybdenite as rare flakes, and the tellurides as sporadic grains in and adjacent to pyrite. Florenceite occurs as fine-grained aggregates and veinlets, apatite occurs as highly poikiloblastic coarse-grained crystals. Rare kaolinite patches occur, and may represent altered feldspar.

Constitution, approximate volume %

Quartz:	40–60
Sericite:	10–30 (including pyrophyllite and muscovite)
Chlorite:	tr–10
Apatite:	tr–5
Pyrite:	10–45
Chalcopyrite:	5–10
Tennantite:	tr–1

Traces: hematite, zircon, monazite, rutile, clinozoisite(?), fluorite(?), molybdenite, bornite, pyrrhotite, bismuth tellurides, sphalerite, galena, mawsonite, florenceite and gold.

Reg. No. C100028 (ML2): Massive pyrite, Blow main lens

The rock is a massive sulphide, consisting mainly of medium to coarse-grained pyrite with minor barite and sericite, and only traces of other sulphides. Barite occurs as crystals and aggregates in sericite.

Constitution, approximate volume %

Sericite:	5–15 (including pyrophyllite and muscovite)
Barite:	10–20
Pyrite:	70–80
Chalcopyrite:	tr

Traces: rutile, pyrrhotite, sphalerite, galena.

Reg. No. C100029 (ML3): Massive pyrite, Blow footwall lens

The rock is a massive, banded sulphide, consisting mainly of medium to coarse-grained pyrite (sometimes colloform) with very minor quartz and sericite, and only traces of other sulphides.

Constitution, approximate volume %

Quartz:	2–5
Sericite:	tr–1 (including pyrophyllite and muscovite)
Tennantite:	tr–2
Pyrite:	95
Chalcopyrite:	tr

Traces: bornite, pyrrhotite, galena, tellurides?

Reg. No. C100030 (ML4): High grade copper ore, Prince Lyell

The rock is a highly sulphidic, quartz-sericite schist, very similar to C100027 in nature and origin, except for the greater presence of iron oxides, and minor poikiloblastic carbonate (siderite) rhombs in the chert.

Constitution, approximate volume %

Quartz:	20–35
Sericite:	20–45
Chlorite:	5
Carbonate:	5
Apatite:	tr–2
Pyrite:	5–20
Chalcopyrite:	10–30
Magnetite:	5–6
Hematite:	tr–3

Traces: rutile, pyrrhotite, zircon, barite, tennantite, monazite, epidote, galena and gold.

Reg. No. C100031 (ML5): Copper-molybdenite ore, Prince Lyell

The rock is a sulphidic, quartz-sericite schist, very similar to C100030 in nature and origin, except for the traces of molybdenite.

Constitution, approximate volume %

Quartz:	20–45
Sericite:	40–50
Chlorite:	tr–5
Carbonate:	5
Pyrite:	tr–5
Chalcopyrite:	5–10
Magnetite:	5

Traces: hematite, rutile, pyrrhotite, monazite, molybdenite, galena, sphalerite.

Reg. No. C100032 (ML6): Copper ore, Cape Horn

The rock is a sulphidic, quartz-sericite schist, similar to C100031 in nature and origin, except for more abundant chlorite and apatite, less sericite, and hematite being dominant to magnetite. It may have been derived from more mafic volcanic rocks.

Constitution, approximate volume %

Quartz:	30–55
Sericite:	10–20
Chlorite:	10–20
Carbonate:	tr–5
Apatite:	1–10
Pyrite:	1–5
Chalcopyrite:	6–20
Hematite:	2–10

Traces: zircon, rutile, pyrrhotite, monazite, barite and gold.

Reg. No. C100033 (ML7): Gold-copper ore, Cape Horn

The rock is a sulphidic, quartz-sericite schist, similar to C100032 in nature and origin, except for being more siliceous and less hematitic. The carbonates include siderite and calcite.

Constitution, approximate volume %

Quartz:	50–65
Sericite:	5–25
Chlorite:	5–15
Carbonate:	5
Apatite:	tr–3
Pyrite:	tr–10
Chalcopyrite:	5–15
Hematite:	tr–1

Traces: zircon, rutile, pyrrhotite, monazite, molybdenite, anhydrite, tellurides and gold.

Reg. No. C100034 (ML8): Gold-copper ore, Western Tharsis

The rock is a sulphidic, quartz-sericite schist, similar to C100033 in nature and origin, except for containing some particularly carbonate-rich zones. Traces of anhydrite, apparently primary, are present.

Constitution, approximate volume %

Quartz:	50–60
Sericite:	15–20
Chlorite:	5–10
Carbonate:	tr–20
Epidote:	tr–1
Apatite:	tr–1
Anhydrite:	tr–3
Pyrite:	5–10
Chalcopyrite:	5–10

Traces: zircon, rutile, hematite, pyrrhotite, monazite, molybdenite, tennantite, sphalerite, galena and gold.

Reg. No. C100035 (ML9): Gold-copper ore, Prince Lyell

The rock is a sulphidic, quartz-sericite schist, similar to C100034 in nature and origin, except for containing carbonate-rich zones. Traces of anhydrite, apparently primary, are present.

Constitution, approximate volume %

Quartz:	50–70
Sericite:	5–25
Chlorite:	5–15
Carbonate:	1–5
Apatite:	tr–5
Anhydrite:	tr–3
Pyrite:	5–10
Chalcopyrite:	5–10

Traces: zircon, rutile, hematite, clinozoisite, magnetite, monazite, molybdenite, pyrrhotite, sphalerite, galena and gold.

Reg. No. C100036 (ML10): Molybdenum-rich ore, Crown Lyell

The rock is a relatively massive sulphidic chert with small bands of molybdenite and massive, granular pyrite. Most of the quartz is recrystallised, with a comb-like or fine-grained quartzitic texture, and there is a suggestion of recrystallised quartz phenocrysts. The rock may be of volcanogenic origin, but has been highly deformed, silicified and pyritised, probably in two or more stages. Some of the pyrite is framboidal or atoll-like, and is probably diagenetic. Some of the other sulphides occur as inclusions in pyrite, but most are paragenetically later, veining pyrite.

Constitution, approximate volume %

Quartz:	60–90
Sericite:	1–5
Molybdenite:	tr–2
Pyrite:	5–30
Chalcopyrite:	tr–5

Traces: apatite?, rutile, albite?, molybdenite, bornite, covellite, mawsonite, digenite, sphalerite, galena and gold.

Reg. No. C100037 (ML11): Massive chalcopyrite, Prince Lyell

The rock is a massive sulphide, composed almost entirely of medium-grained chalcopyrite.

Constitution, approximate volume %

Quartz:	tr
Sphalerite:	tr
Siderite:	tr
Chalcopyrite:	100

Reg. No. C100038 (ML12): Massive chalcopyrite, Prince Lyell

The rock is a massive sulphide, composed almost entirely of medium-grained chalcopyrite and coarse-grained pyrite. The pyrite is usually highly brecciated and poikilitic, and some may be colloform.

Constitution, approximate volume %

Quartz:	5
Siderite:	5
Chalcopyrite:	50
Pyrite:	40

Traces: hematite, phyllosilicates, pyrrhotite, sphalerite and gold.

Reg. No. C100039 (ML13): Massive chalcopyrite, Prince Lyell

The rock is a massive sulphide, composed almost entirely of medium-grained chalcopyrite and coarse-grained pyrite. The pyrite is usually highly brecciated and poikilitic, and some may be colloform.

Constitution, approximate volume %

Quartz:	tr
Siderite:	tr
Chalcopyrite:	85
Pyrite:	15

Traces: hematite, phyllosilicates, pyrrhotite, sphalerite and gold.

Reg. No. C102020: Hanging wall sub-ore, Prince Lyell

The rock is a sulphidic, quartz-sericite schist, similar to C100034 in nature and origin, except for containing more magnetite and less sulphides.

Constitution, approximate volume %

Quartz:	60
Sericite:	15
Chlorite:	10
Carbonate:	5
Magnetite:	10
Pyrite:	tr
Chalcopyrite:	5

Traces: rutile, hematite.

Reg. No. C102023: Magnetite-apatite rock, Prince Lyell

The rock is a coarse-grained aggregate of quartz, magnetite, apatite and carbonate. The origin is possibly modified hydrothermal-exhalative: it is probably similar in bulk chemistry to the banded iron formations in the Broken Hill area, but is quite different texturally. Some of the quartz appears pseudomorphic, perhaps after feldspar or an evaporite mineral.

Constitution, approximate volume %

Quartz:	30
Magnetite:	20
Chlorite:	3
Carbonate:	15
Apatite:	30
Pyrite:	1
Chalcopyrite:	1

Traces: muscovite, hematite.

Reg. No. C102910: Massive pyrite, West Lyell open cut

The rock is a massive sulphide, composed almost entirely of medium to coarse-grained pyrite. The pyrite is usually highly brecciated and poikilitic, and some may be colloform. Much of the quartz is fibrous and strained.

Constitution, approximate volume %

Quartz:	35
Micas:	15 (muscovite and pyrophyllite)
Pyrite:	50

Reg. No. C102911: Massive pyrite, West Lyell open cut

The rock is a massive sulphide, composed almost entirely of medium to coarse-grained pyrite. The pyrite is usually highly brecciated and poikilitic, and some may be colloform. Much of the quartz is fibrous and strained.

Constitution, approximate volume %

Quartz:	2
Micas:	20 (muscovite and pyrophyllite)
Pyrite:	78

Traces: rutile, zircon

APPENDIX 3

Electron microprobe analyses of electrum from Mt Lyell ores

Grain No.	Ag (wt. %)	Au (wt. %)	Total (wt. %)	Fineness
G6A-C	17.86	81.4	99.26	820.07
G6A-R	34.06	66.59	100.65	661.6
G6A-C, RPT	17.19	82.46	99.65	827.5
G6-SMALL	32.05	62.62	94.67	661.46
G6	13.12	51.13	64.25	795.8
ML4C#1	17.25	82.03	99.28	826.25
ML4C#1B	16.82	83.01	99.83	831.51
ML4C#2	15.88	87.34	103.22	846.15
ML4C#2A	15.16	87.79	102.95	852.74
ML4C#2B	14.97	77.62	92.59	838.32
ML4C#2D	14.53	84.47	99	853.23
ML4C#2E	15.53	83.14	98.67	842.61
ML4C#2F	21.82	76.35	98.17	777.73
ML4C#3	15.75	77.88	93.63	831.78
ML4C#3A	15.77	78.54	94.31	832.79
ML4C#3b	15.97	83.27	99.24	839.08
ML4C#3C	14.89	72.79	87.68	830.18
ML4C#4	16.43	84.82	101.25	837.73
ML4C#4A	16.02	81.67	97.69	836.01
ML4C#5	19.19	79.9	99.09	806.34
ML7D#1	17.36	81.98	99.34	825.25
ML7D#1-rim	18.92	75.95	94.87	800.57
ML9B-C	1.13	97.21	98.34	988.51
ML9B-R	1.33	97.72	99.05	986.57
ML9B-SMALL	0.26	96.34	96.6	997.31
ML12#1	20.26	80.04	100.3	798.01
ML12#2	22.6	73.11	95.71	763.87
ML12#3	22.09	64.49	86.58	744.86
ML12#4	22.86	72.9	95.76	761.28
ML12#5	18.52	55.9	74.42	751.14
ML12A#1.1	23.01	57.79	80.8	715.22
ML12A#1.2	24.45	59.75	84.2	709.62
ML12A#1.3	22.36	54.02	76.38	707.25
ML12A#1.4	23.45	68.76	92.21	745.69
ML12A#2.1	21.56	57.76	79.32	728.19
ML12A#3.1	24.91	63.3	88.21	717.61
ML12A#4.1	19.85	72.76	92.61	785.66
average	17.98	75.53	93.51	804.74