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OPEN CUT POTENTIAL OF THE COPPER CLAYS AREA MOUNT LYELL, TASMANIA

REPORT NO: 1995-50

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1. SUMMARY

This report synthesises 112 years of mining and exploration history at the Mt Lyell Copper Clays. These are a series of native copper in clay deposits located at the head of the Linda Valley, just below the Mt Lyell Saddle. The main deposits are Lyell Blocks, Lyell Consols and King Lyell. They occur in valleys and are generally covered by thin fluvioglacial sediments. The data has been available for the last 25 years but has not been previously reported or interpreted.

During the 1886 Linda gold rush, in addition to gold, up to 1 kilogram per dish, of native copper could be panned from Cooneys Creek (King Lyell) and on Jimmy Watson's Claims (Lyell Blocks). Early copper production commenced with sluicing operations and in 1902, the Blocks commenced gravity treatment of underground ore. The Blocks mine had a large and rambling gravity plant that was visited by metallurgists from all over the Commonwealth, and pronounced first class.

Total production between 1892 and 1910 was 243,000 tonnes of 1.6% ore for 2,750 tonnes of copper. The Blocks and Consols underground mines had severe problems with ground stability and both were closed following collapses and flooding. During its brief life, the Blocks produced a concentrate averaging 69% copper with a recovery of 72%. The Blocks was one of the few mines on the field apart from the MLMRC to declare dividends. The mine was eventually sold to the MLMRC for £5,000 in 1919. Blainey summed up its history succinctly as "a courageous and enterprising company - it deserved a better fate."

Several early factual geological descriptions of the deposits have been very useful. Native copper was found outcropping in 'pug' in the form of: sheets in joints; dendritic masses coated in chalcocite; as pebbles, nuggets, shots and spongles; as masses up to 75 km and as limonite grade fillings of interlayered cuprite and native copper. Batchelor's original 1902 diamond drill logs provide neat and factual descriptions which showed that native copper was the main ore mineral throughout the clay hosted deposits and into the underlying unconsolidated Pioneer Sandstones.

Previous geological descriptions and genetic ideas are reviewed and it is shown that recent workers have suffered from a lack of access to good factual data. This led to unjustified theories which were tested by expensive and unsuccessful exploration programmes. The worst example was the drilling of two long diamond holes in 1984 which showed there was no ore where the Block's main shaft had previously reached the same conclusion in 1915.

Elements of previous genetic ideas have been combined to produce a new model which is factually well supported. It involves the dissolution of copper during weathering into acid oxidising drainage and the neutralisation of solutions during mass formational dissolution of Gordon Limestone. Copper is precipitated by the reducing effects of carbon and hydrocarbons in the limestone residue or pug. The process has been termed natural Cainozoic hydrometallurgy and has a predictive capacity which will hopefully aid future exploration.

Target the pug!

Exploration Justified

A total of 46 diamond drillholes for about 4,000 metres has been drilled during exploration of the Copper Clays between 1902 and 1970. New summary logs have been produced, plotted and interpreted. A sectional resource estimate using a cutoff grade of 0.1% Cu gave global pre-resource mineralisation of 8Mt at 0.6% copper. Core recovery averaged between 56 and 70%. With better recovery, the resource could have been classified as inferred. Simple pit designs lead to an estimated recoverable resource at a waste to ore ratio of 2.3 to 1 of 6.9Mt at 0.6% copper. Estimates of total resource potential including pre-resource mineralisation have also been made. They suggest that 19Mt at 0.8% Cu may be present with a target of potentially recoverable copper in the order of 90,000 tonnes.

Preliminary economics are examined. For contract mining and a gravity copper separation plant, operating costs of $11.28 per tonne are estimated. This equates to a break-even head grade of 0.45% copper. To produce copper with operating costs of 50% of revenue, a head grade of 0.9% is needed, and believed achievable. This suggests that mining of the Copper Clays could be highly profitable. It also justifies an exploration programme to upgrade the status of the resource and provide information for a pre-feasibility study.

A 64-hole, 5,590m programme of vertical air core and face sampling hammer drilling is proposed. This will lead to a better understanding of the deposits and estimation of an Inferred resource. By weighing drill samples, more reliable estimates of recoveries and tonnage factors will be obtained. It is also proposed to commence collecting metallurgical and mining information.

Finally, the long term exploration potential for the entire Copper Clays area is assessed. Four main targets are considered worthy of exploration attention. Firstly, the Copper Clay deposits as described above. Secondly, there are four locations of limited Tabberabberan quartz vein gold known. These suggest leakage from potential gold orebodies in structures at depth. Thirdly, carbonate hosted lead-zinc mineralisation is suggested by the presence of fine-grained galena and honey-yellow sphalerite in concentrates from non cupriferous clays. Fourthly, there is the much greater prize of a continuation of the Mt Lyell Copper-Gold-Silver Field at a depth of about 1,500 metres under the Copper Clay deposits and Owen Conglomerate on the eastern side of the Great Lyell Fault.

Exploration Justified

The Copper Clays are a rare to unique type of ore deposit and their successful evaluation is a challenging task. However, potential rewards are high and it is believed that, like the 1,903 Mt Lyell silver bonanza, the Copper Clays have the potential to produce a significant cash injection during Copper Mines of Tasmania's ("CMT") early years at Mt Lyell.

2. INTRODUCTION

The Copper Clays at Mt Lyell are an unusual group of native copper in clay deposits at the head of the Linda Valley which have been promoted by many but with very little long term effect. The deposits are all located under modern water courses at altitudes of between 300 and 600m above sea level as shown on Figure 1. There are three previous mines and a large area of prospective ground (shown on Figure 1 as Mpc) which may be mineralised.

As part of a brief to examine the future open cut potential of the Mt Lyell area, it became clear in the initial assessment (Wills, 1995a), that excellent potential existed in the Copper Clays area. This was not difficult to conclude as estimates of indicated ore of 1.99 Mt at 1.92% Cu, with additional 6 million tonnes possible, were made by Wade (1957b). Subsequent workers appear not to have been aware of Wade's conclusions as they have not been mentioned again until Flitcroft and McKeown's (1992) report and subsequently by Newnham (1993), Snowden (1994) and Ellis (1994).

After producing a first-pass assessment of the West Lyell Resource, (Wills, 1995b), and while work on an upgrade of the West Lyell resource estimation was under way, an early assessment of the Copper Clays area was requested by Gold Mines of Australia Limited's ("GMA") management so that decisions on future metallurgical and exploration work could be made.

The work for this report has taken about 4 weeks, mostly compiling data, but results have exceeded expectations. It is thought that this has resulted from a situation, particularly during the 1980's, where 'theory' based exploration had gained the upper hand and participants were either unable or unwilling to consider, or unaware of the existence of, the large amount of factual descriptive information which conflicted with their concepts.

This report has been designed to provide a comprehensive overview of the history and economic geology of the Copper Clays deposits. Very little new work other than drawing up and interpreting drill sections has been necessary.

Historical data from the 36 years of operations between 1883 and 1919 is a vital part of the story. Three operations demonstrated that production of high grade copper concentrates by gravity methods was possible. However, underground mining of unconsolidated materials has obvious dangers and after collapses and flooding, the early mines were forced to close. If the deposits are amenable to cheap open cut mining, as well as to gravity concentration, then hurdles to their larger scale development can now be successfully overcome.

3. CONCLUSIONS

3.1 Copper Clays Neglected

Information used in this report has lain dormant at Mt Lyell for 25 years. Between 1902 and 1970, 46 diamond drillholes were completed and neither the results nor their implications have been properly assessed.

3.2 History

The Copper Clays were the first producers of copper metal at Mt Lyell with a total of about 2750 tonnes of copper from 243,000 tonnes of ore averaging 1.6% between 1892 and 1910. The largest mine at Lyell Blocks was in production between 1902 and 1907 with a peak labour force of 282 men. They produced high grade native copper rich concentrate averaging 69% with a recovery of 72% by gravity separation.

3.3 Geology

The Copper Clays are a rare to unique group of mineral deposits hosted in clays formed as a residue after the mass formational dissolution of Gordon Limestone micrite in post landscape-formation times. A natural Cainozoic hydrometallurgical model is proposed for their genesis. In this model, acid oxidising drainage is neutralised by section with limestone and native copper and cuprite are precipitated by reduction with carbon or hydrocarbons within the clays.

3.4 Resource

Resources for the three main deposits total 8.0 mt at a grade of 0.6% copper. Due principally to poor core recovery from unconsolidated sediments, this resource is classified as pre-resource mineralisation. Simple open cuts have been designed and an overall waste to ore ratio of 2.3 to 1 with a recoverable resource of 6.9 mt at 0.6% Cu has been derived. Due to the lack of drillholes in the central higher-grade cores of the deposits, the grade is expected to rise with further drilling.

A number of extensions are likely with a target resource potential of 19 mt at 0.8% Cu containing approximately 90,000 tonnes of recoverable copper.

3.5 Economics

Using preliminary costs for a contract mining and gravity separation type of operation, with waste to ore of 2.3:1, operating costs total $11.28 per tonne. At a copper price of $35 per % Cu this is equivalent to a break even recovered grade of 0.32% Cu and head grade of 0.45% Cu. To operate with costs at 50% of revenue a head grade of about 0.9% Cu is necessary. The clays have the potential to be a highly profitable operation and to justify an exploration programme to upgrade the status of the resource.

4. RECOMMENDATIONS

4.1 Proposed Exploration Programme

A 64-hole, 5,590m programme of mixed vertical air core and face sampling hammer drillholes is proposed. This will lead to a better understanding of the deposit and enable classification as an Inferred resource so that a pre-feasibility study can be undertaken.

4.2 Treatment of Drill Samples

During the programme, careful work collecting, weighing and describing drill samples should lead to more reliable estimates of recoveries, tonnage factors and mineral distribution. Several types of copper analysis such as strong acid, weak acid and gravity recoverable copper will also help in later assessments.

4.3 Metallurgical and Mining Investigations

Representative metallurgical samples can be obtained during the drilling programme. Composite samples should be collected and size analysis and gravity recoverable copper determined. Drilling techniques need to be recorded in detail for each hole to build up a model for the proportion of the orebody which is free diggable and that requiring drill and blast.

5. HISTORY

The original Mt Lyell discovery in 1883 was based on following up alluvial and eluvial gold shed from the Iron Blow. When operating capital became scarce in 1886, the Mt Lyell Prospectors Association received a boost from a very bullish report by the Government Geologist, Gustav Thureau. He claimed the deposit was phenomenally rich in gold and so large that the deposit would be practically inexhaustible (Thureau, 1886, p. 7). In 1887, the Prospectors Association engaged Sydney geologist, J R Robertson, to assess Mt Lyell. He contradicted Thureau by saying that the average ore was poor in gold and silver and rich in copper, and was similar to the Tharsis Mine in Spain (Blainey, 1993, p. 43).

Despite Robertson's assessment, the Prospectors Association was dissolved and the Mt Lyell Gold Mining Company formed in 1888. Capital was raised and an eight-head stamp battery set up to recover the gold bonanza. Both Robertson and Thureau protested that the abundant barite in the ore would severely hinder gold recovery. The battery operation was not viable and in 1891, the company was put up for sale. It was purchased by Bowes Kelly who then floated the Mt Lyell Mining Company in January 1892.

After another bullish, though this time reasonably accurate, report by Peters (1893), the Mt Lyell Mining and Railway Company was formed in March 1893. The company did flourish in its early years from a bonanza; but from silver rather than gold or copper. A rich vein of stromeyerite [(Cu, Ag)S] containing 862 tonnes at 3.1% produced 24.4 tonnes of silver and provided the young company with a windfall gain of some £106,000 and some very credible publicity.

From reports by Peters (1893) and Thureau (1886), early gold production of about 4000 ounces can be estimated in the 1880's. This included some 2,200 ounces from the Blow and 1,800 ounces from the Upper Linda Valley alluvials. Thureau (1886, p.8) also noted that native copper was abundant in creeks about 200m east of the Blow (King Lyell) and from Watson's Claim (Lyell Blocks). He noted that: "besides gold, copper is found in its pure malleable state embedded in a kind of hard brown clay. Lumps of pure copper weighing between 1 and 3 kg could be found and up to 1 kg of native copper could be washed in a dish." No records of copper production for the 1883-1897 period have yet been located, but it seems clear that the first significant copper production from the field was actually from the Copper Clay deposits.

Power (1891, p. 32) also examined the alluvial deposits and provided a useful early description of them: "On tracing the alluvial copper to its source, we are led to a zone of decomposed schists forming a pug; grey, yellow and red, some hundred feed broad ...... the copper is found in sheets as if occupying the joints and cleavage planes of the original rock. These sheets of metal which at times are fairly thick, get broken up into small nuggets, shots and spangles which are more or less coated with the black oxide of copper (chalcocite). Below the native copper we come across cuprite which occurs in beautiful crystals, mostly octahedrons. No doubt the native copper has been reduced from this by the agency of the peaty waters. Still deeper than the cuprite, we come across copper pyrites and/or iron pyrites."

Another useful early description from underground observations at Lyell Blocks is by Gregory (1905, P. 140). "From observation, it would appear as if the deposition of the ores had taken place subsequent to some of the transverse faulting as is evidenced by the fact that these smaller dislocations intersect the impregnated areas without any apparent alteration in the peripheral walls (such as they are) of the ore occurrences ....(Later, p. 142) the "eastern orebody" within the North Mt Lyell property .... is quite different from any other in the mine, and is made up of quartzitic boulders and decomposed matter carrying chalcopyrite and bornite. The soft dark decomposed matter is by far the richer in metallic contents, probably being enriched through decomposition of the original ore."

There are also some useful descriptions in W T Batchelor's 1902 drill logs of holes ML8-12 at the King Lyell deposit. Holes 9 and 10 passed through native copper bearing clay over their entire lengths and bottomed in native copper bearing conglomerates. 'Pebbles' of native copper as well as associated 'fossil wood' were also described.

It is clear that the early geologists, some of whose valuable observations are cited, had recognised many features of the Copper Clay deposits which appear to have been overlooked in more recent times.

The early history of the Mt Lyell Field was fiercely competitive and after discovery of rich ironstone-hosted gold at the Blow in June 1886, the news spread fast and sparked a gold rush. By September, over 200 diggers were working in the upper Linda Valley and any remaining ground was blanket pegged. In the years to about 1910, the cumulative effect of hundreds of miners and prospectors working for 40 different companies putting in exploration adits and shafts is thought to have been far more effective than the modern era exploration.

Only four companies have ever paid dividers from activities on the Mt Lyell Field. Of these, MLMRC, Lyell Tharsis and South Tharsis were all dependent on the financial success of the MLMRC for their production. The only company to pay a dividend from its own efforts was the Lyell Blocks Company in 1906. This combination of the first copper production and an ability to generate dividers are the two most notable features of the early history of the Copper Clay deposits.

More detailed descriptions of the mining and production history of the main deposits are given below.

5.1 Lyell Blocks

Native copper mineralisation at the Blocks is mentioned in the first known geological report on the Mt Lyell Field by Thureau (1886). At this time, title was held by Jimmy Watson whose partners had located alluvial copper and gold. This included the largest gold nugget from the field from the topographically highest part of the diggings on their claims. This 6.5 ounce nugget contained 4.5 ounces of gold associated with well-formed quartz crystals. Two creeks draining the southern slopes of Mt Lyell were named Gold and Copper Creeks after their alluvial contents (Figures 1 and 26). To the writer's knowledge, a primary source for the gold in Gold Creek has never been identified and could lie under scree cover along the North Lyell Fault near grid position 6100N-6350E.

Some early workers - eg: Power (1891, p. 30) thought that the source of the gold was the conglomerates surrounding the upper Linda Valley. Power noted that where gold still clings to its matrix, it is sometimes in contact with hematite and sometimes with quartz. He also mentioned that he and local miners Jack Fehey and Steve Karlson had obtained gold from the products of decomposing conglomerate boulders.

After the 1886 rush, Watson's six claims were floated into the North Mt Lyell Prospecting Association who unfortunately found nothing to develop (Blainey, 1993, p. 102). In 1889, the leases came into the possession of a Sydney syndicate known as the Stanley Company (Mining Standard, 1898). They spent £3,000 but were unable to make the property pay. However, they did prove the existence of a large lode of auriferous copper clay. They also held the ground without working it for a long time. Some time before 1892, the leases became owned by the Idaho Copper Mining Company. Two reports by Thureau (1892; 1893) give information on this period. Twenty tonnes of concentrate had been sent to Newcastle (NSW) where they yielded 90% copper.

Some time before 1897 (Russell, 1898), the ground was renamed the Blocks and owned by the Melbourne based Mt Lyell Blocks Copper Corporation. The new manager was Robert Schloesser who placed an emphasis on underground exploration for which he was congratulated by the Press (Mining Standard, 1898). During the period 1897-99 significant sulphide and native Cu ore was discovered and production was said to be imminent (PMIT).

Production did commence during the September 1900 quarter when 3,583 tonnes of bornite ore, said to average 10% Cu, were produced. About the first 10,000 tonnes of bornite ore produced came from the North Lyell orebody on the Blocks leases. However, about the last 8,000 tonnes were stolen from the North Mt Lyell company's ground. The MLMRC were the main benefactors (Blainey, 1993, p. 143). A total of 18,568 tonnes averaging 7.6% copper with similar gold and silver contents to the North Lyell orebody grades were sold to MLMRC between the September 1900 and December 1901 quarters. This production has been included with statistics on the North Lyell Orebody and is not listed in Table 1. Before the end of 1901, probably to avoid legal prosecution, the Mt Lyell Blocks Copper Corporation was dissolved and reformed as the Mt Lyell Blocks Mining Company NL.

Table 1

Copper Clays, Historic Production Details

Mine	Period	Data Source	Tonnes Treated	*Head Grade % Cu	Recovered Grade % Cu	Tonnes Produced Cu
Lyell	pre-1892	T	20.3	Cons	90.0	18.3
Blocks	1902	P	7,500	2.81	2.02	151.7
	1903	P		No production		
	1904	P	17,429	1.72	1.24	215.4
	1905	P	64,410	1.80	1.28	823.2
	1906	P	71,926	1.51	1.09	781.6
	1907	P	45,089	1.14	0.82	368.3
Total Lyell Blocks			206,354	1.58	1.13	2,385.5
Lyell	1909	P	8,700	1.11	0.80	69.4
Consols	1910	P	14,906	1.07	0.77	115.3
Total Lyell Consols			23,606	1.09	0.78	184.7
King	pre 1897	R	10,000	2.08	1.5	150
Lyell	1898	P	2,760	2.08	1.5	41.4
	1899	P	273	2.08	1.5	4.1
	pre 1903	B1	21	56.1	40.4	8.5
	1904	B2	2	1.53	1.1	0.02
	1906	B2	4	2.36	1.7	0.07
Total King Lyell			13,060	2.17	1.56	204.1
Total Copper Clays 1883-1910 (28 years)			243,020	1.56	1.12	2.747.3

* Head grades estimated assuming 72% Recovery as estimated from Table 2.

Data Sources Abbreviations T = Thureau (1892)

P = Progress of the mineral industry of Tasmania quarterly reports 1897-1913.

B = Record of Mining and Treatment operations. "The Black Book" CMT Ref T1991-008. B1 purchased prior to Mt Lyell - North Lyell amalgamation in 1903. B2 during MLMRC ownership.

C = Reid (1970) from G W Blainey's personal records.

Table 2

Available Details of Gravity Concentrates

2.1 Lyell Blocks

Note:
Numbers underlined are reported or calculated from reported numbers. Numbers with superscript ^{e} are estimates based on averages of other reported numbers.

Quarter Ending	Ore Tonnes T	Head Grade % Cu	Recovered Grade % Cu	Conct. Produced T	Conc. Ratio	Con Grade % Cu	Cu Metal Produced	Recovery %
31.03.02	592	4.29^e	3.09	37.4	15.8	48.9	18.3	72^e
30.06.02	3,587	2.90^e	2.09	129.0	27.8	58.1	75.0	72^e
30.09.02	2,399	3.19^e	2.30	85.7^e	28.0^e	64.3^e	55.1	72^e
31.12.02	908	0.51^e	0.37	15.2	59.7	22.4	3.4	72^e
30.09.05	14,242	1.90	1.37^e	267.0	53.3	73.0^e	195.1^e	72^e
31.12.05	19,203	1.90	1.39	335.3	57.3	79.4	266.2	73
1.03.06	12,371	1.58^e	1.13	196.1	63.1	71.5	140.2	72^e
30.09.06	17,927	1.50	1.05	301.2^e	59.5^e	62.0^e	188.2	70
Totals	**71,229**	**1.84**	**1.32**	**1,366.9**	**52.1**	**68.9**	**941.5**	**72**

2.2 Lyell Consols

30.09.09	4,267	1.02^e	6.73	46.7	91.3	67.0	31.3	72^e
31.12.09	4,433	1.19^e	0.86	66.7	66.5	57.2	38.1	72^e
31.03.10	3,338	1.33^e	0.96	49.7	67.2	64.4	32.0	72^e
30.06.10	7,302	1.74^e	1.25	78.7	92.7	61.8	48.7	72^e
30.09.10	4,267	1.13^e	0.81	58.8	72.5	58.8	34.7	72^e
Totals	**23,607**	**1.09**	**0.78**	**300.6**	**78.5**	**61.5**	**184.8**	**72**

Data from progress of the Mineral Industry of Tasmania.

Milling Techniques

During the period of bornite mining, a significant amount of development work had been carried out (Figure 27). Therefore as early as the March quarter of 1902, the new company was able to commence underground production for the first time on copper-clay ore. In this quarter, 592 tonnes of ore was treated by two puddling machines and blanket tables for 34.4 tonnes of concentrates grading 49% copper (Table 2). Over the next two quarters, concentrate grade increased initially to 58.1 and then to 64.3% copper. The entire 1902 production was 7,500 tonnes of ore for 267.3 tonnes of concentrates averaging 57% copper (Tables 1 and 2).

Production was halted in late 1902 by a strike over wages. Eventually, work was resumed with no changes to pay, but with falling copper prices, the result was a loss making situation so the mine was closed and most workers dismissed (Blainey, 1993, p. 201). The copper price from April to December 1901 averaged £71 per tonne and from January to September 1902, it averaged £54 per tonne.

The period to August 1904 was spent reconstructing the company, carrying out underground exploration and development and in constructing a new mill. The mill construction is described in detail by Grayson (1903). The clay was initially desegregated in pudlers and oversize material separated. This was hand sorted and any copper-bearing materials put through a Chillion Mill. The fines and crushed material were then passed over a hydraulic classifier and treated on Wilfley and Ferraris tables. Grayson predicted an 80% recovery and concentrates grading 75% Cu. A second product, largely composed of ironstone, assaying 20% Cu was also produced. The plant was planned to treat 1,500 tonnes per week and for three years from August 1909 to July 1907, it averaged 1,305 tonnes per 50-week year.

The mill was described by Blainey (1993, p. 187) as 'large and rambling' and was visited by metallurgists from all over the Commonwealth and pronounced first class.

During peak production, a maximum of 284 men and an average of 242 men per quarter were employed at the Lyell Blocks Mine. The company recovered at least 70% of the copper and successfully treated about 200,000 tonnes of ore producing concentrates averaging 69% Cu for about 2,200 tonnes of copper (PMIT statistics, listed in Tables 1 and 2). Concentrates were siled to the Kelly Basin and shipped to the Wallaroo smelters. The stock was popular and in 1906 the Blocks paid £15,000 in dividends as well as spending additional funds on exploration properties at Mt Darwin and Zeehan (Blainey, op. cit.).

Unfortunately, the clay in the mine tended to swell and smash the heavy timber supports. In July 1907, the timber, clay and slurry caved in over a wide area and buried two men; only one survived. Officially, the mine was closed due to the low copper price and the low ore grade. The recovered grade had gradually dropped from 3.09 to 0.87% Cu between 1902 and 1907. By December 1907, the mine was idle (PMIT, 1907).

The mine remained closed for some time and there was consideration of a merger with the adjacent Consols mine which was preparing for production in 1908. The Blocks was re-opened in December 1909, but copper clay production did not recommence.

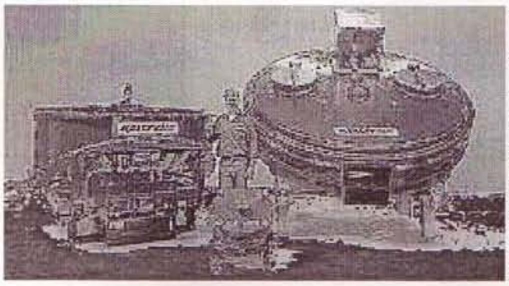
1903 milling

Milling Techniques

Works INFRASTRUCTURE
Downer ENGINEERING
Roche MINING
Century RESOURCES
Downer EDI
CPG

Kelsey Jig and FAG Mill

KELSEY Jig



The Kelsey Centrifugal Jig (KCJ) is departure from the conventional j configurations presently being use concept of the KCJ utilises all the a conventional jig, as well as the a feature of being able to vary the a gravitational field. This gives adde the selectivity of particle accelerat in a conventional jig, the dynamic specific induced movements, the centrifugal jig takes a conventional jig a centrifuge.

This leads to the following key benefits:

- High grade & recovery
- Efficient separation of fine minerals
- Efficient separation of minerals with low sg differentials
- Single-stage processing, with no middlings
- Truly continuous operation
- Environmentally friendly (No reagents)

The models available include:

- J200 KCJ - laboratory test unit, with nominal capacity of 15-100 k
- J1300 MkII KCJ - smallest commercial unit, with nominal capacity solids
- J1800 KCJ - largest commercial unit, with nominal capacity of 5-6

KELSEY Fine Autogenous (FAG) Mill

The development of the Kelsey Fine Autogenous Grinding (FAG) Mill is the first in a projected range of Kelsey comminution equipment. The Kelsey FAG Mill significantly extends fine particle comminution system design with respect to capital and operating cost, maximum feed size, reduction ratios, specific energy consumption, throughput per unit volume and energy utilisation thought to ultra fine sizes.

Between late 1909 and 1915, the Blocks carried out development work in the search for more bornite ore. This was largely by sinking of the 414m deep Blocks shaft. This was located only 10m from the North Mount Lyell companies lease boundary. The search for bornite ore was unsuccessful, as were the two diamond drillholes NL1101 and 1102, which tested the same target area in 1984 (Bird, 1984; 1985). The Blocks Mine was inactive until 1919 when it was sold to the MLMRC for £5,000. Blainey (1993, p. 193) summed up the Blocks Mining Company's history succinctly: "A courageous and enterprising company, it deserved a better fate."

The MLMRC have done little with the ground except for the Corridor mining activities which impinge on the Blocks western boundary and the drilling of 16 diamond drillholes between 1963 and 1984, most of which were not plotted up or reported on. In contrast, a very useful report on the Copper Clays which concentrates on the Blocks was completed by Wade (1957B), but this appears to have been temporarily mislaid until it was mentioned by Flitcroft and McKeown (1992). The MLMRC's work is described in later sections of this report.

5.2 Lyell Consols

The Mt Lyell Blocks Mining Company was the most successful company on the field after the MLMRC. Other Copper Clay mining companies fared badly by comparison with the Blocks and much less information is available.

The first mention located of the Lyell Consols Mining Company NL is by Russell (1898). This was one of James Crotty's companies and preliminary work was being undertaken in 1897. It appears from early publicity that Crotty expected to find additional North Lyell type rich bornite ore on the leases, but despite tunnelling, this was unsuccessful.

Schloesser (1900) reported that hematite and gossan carrying native copper were found in the Consols tunnel under the Linda Valley Creek but the value bulked under 2% Cu. Location is shown on Figures 1 and 8 and the extent of underground workings on Figure 24. There were rumours of a production start from early 1906 and a similar mill to that at Lyell Blocks was built during 1907.

The Consols Plant consisted of puddling machines, a 5-lead battery and Wilfley concentrating tables. Commissioning began in the September quarter 1907 but alterations were necessary and underground development continued until production commenced in the September quarter of 1909. The mine remained in production for two years until 10 September 1910. A total of 23,600 tonnes of ore for 185 tonnes of copper was produced. Production statistics are shown in Table 1 and the concentrate information in table 2.

The average treatment rate of 236 tonnes per week is significantly less than the 1,250 predicted which must have made the operation a financial failure. It is of interest that actual concentrate grades averaged 61.5% and that the Consols did not show a similar gradually declining grade trend to the Blocks. It is thought that problems with one supply or plant performance were the main reasons for their financial position.

However, mine closure was again caused by ground weakness. One day in August 1910, the miners heard the ground creeping and the timbers groaning so they promptly left the mine. A few hours later, creek water broke into the workings which were so badly damaged that the mine had to be abandoned (Blainey, 1993, p. 193). Development including diamond drilling for which we have no records was continued until about June 1911, after which there are no entries in the PMIT records.

Reserves at closure were estimated to be 95,600 tonnes at 3.0% Cu (Wade 1957b). The grade is thought to be over-stated, but a much larger area was mineralised than the reserves suggest.

5.3 King Lyell

The history of King Lyell is also not very well covered by available documents. The presence of Native Copper was mentioned by Thureau in 1886 so the ground was probably pegged soon after the discovery of the Iron Blow in 1883. The Blow is located only 200 metres uphill to the southwest (Figure 1). Reid (1970) mentions that the King Lyell company was sluicing copper from Cooney's Creek as early as June 1895. The deposit was well described geologically by Power (1891, p. 32), and Schloesser (1900) mentioned that the deposit had been mined by hydraulic sluicing by the King Lyell Gold and Copper Mining Company NL for the previous 3 years.

The main areas sluiced to shallow depth were on the Southern Slopes of Pioneer Spur (Figure 30). Reid (1970) comments that Blainey's personal records amount to a total of at least 150 tonnes of copper on a very conservative reckoning (estimate ?). Like the Blocks, King Lyell was also probably selling copper before the MLMRC commenced production on 25 June 1896 though they had produced Ag-Cu-Au concentrates from the Mt Lyell Bonanza in 1893/5.

In November 1901, King Lyell was purchased by the MLMRC for £2,600 as a prospective overburden dump. They set about exploration by the diamond drilling of four holes, ML8-12, in 1902 and the development of the No. 5 Adit for the Iron Blow Mine (Figure 15).

Apart from the diamond drillholes, trenches, sluicing, 2 tunnels and several shafts help to define the mineralised area. There was also Mr Batchelor's prospecting shaft, recommended by Thureau (1899; 1900), put down in 1903 and collapsed soon after. Thureau (1900) also suggested that "the boys in the district might be induced to collect scrap iron for copper precipitation from the mineral waters impregnated with dissolved copper."

Production statistics are recorded in Table 1 from which it can be seen that King Lyell has been the second largest copper clay producer despite its lack of underground mining. Reid (1970) wrote a comprehensive review of King Lyell in which he recognised the potential and recommended an initial programme of 10 vertical diamond drillholes on 122m centres for a total of 945 metres. If encouragement was obtained, the second phase was to consist of 61m spaced holes. Four of these holes were drilled in 1970/71 (KL1, 2, 13 and 16) but the results were disappointing and have never been written up.

Reid (1970) was aware of problems of high core loss in the 1902 drillholes and also of contamination by material falling down the holes. He concluded that with unrepresentative sampling and errors in assay techniques, the information should not be used for evaluation purposes. Despite the

White's Creek

unreconcilable factors, Reid thought that the results were of considerable interest.

5.4 Balance Shaft

The Balance Shaft is shown as a separate deposit on the Queenstown 1:25,000 geology map and receives some separate comments in PMIT. However, it was really part of the Lyell Blocks orebody to which it may still be connected by undiscovered ore.

5.5 McDowell's Prospect

This prospect has been included with the Copper Clays Group for geographic rather than geological reasons. The old open cut is located just east of Figure 1 at about 5600N/7500E. The prospect is shown on the Queenstown 1:25,000 sheet as lying on the North Lyell Fault and is similarly described by Silletoe (1984, p. 21).

The prospect was explored by Bird (1985), who decided that the North Lyell Fault was really 400m further up the hill. He suggested the epithermal mineralisation was associated with a hydrothermal explosion crater which created free-standing Owen Cliffs perhaps 1,000m high. Together with Bird's other explosion crater at Gormonston, these rocks were thought more likely to be glacial sediments by Arnold (1985), Silletoe (1985) and Flitcroft and McKeown (1992).

Silletoe's (1984) description of McDowell's appears realistic, that the gold mineralisation is associated with quartz vein stockworks parallel to the North Lyell Fault. There have also been suggestions that similar features are present on the south boundary faults of the Linda Craben. Together with the Gold Creek alluvials, there appears to be a gold source in the area related to the North Lyell Fault Zone. This is a valid gold exploration target which would be best tracked down by bedrock gold geochemistry. The writer does not rate this target very highly in the near surface zone as it is thought that any large-scale mineralisation would be more obviously apparent from the distribution of alluvial gold workings. However, the mineralisation could improve at depth or conceivably be covered by recent glacial or mountain scree deposits. It is an important aspect of the metallogenic history of the area.

5.6 Lyell Pioneer

Until a recent discovery of old reports, virtually nothing was known about this prospect. It's location was known from Figure 24, but it seemed to be more an alluvial gold working than anything else. The report by Cundy (1901a) included a very useful map which has been redrawn as Figure 23. Cundy explained that there was no major mineralisation in either the main or in Calligan's Tunnel. However, he did report quartz veins with traces of gold near the contact of the Owen Conglomerate with the Lyell Schists.

Also Cundy reported a gossan zone near the entrance to the main Tunnel (Figure 23) which he compared with the mineralisation at the Lyell Blocks. A shaft had been sunk to 100 feet on the eastern part of the property through surface clay, pug and loose boulders, but the ground proved too heavy for the timbering and collapsed.

In this area, the clays have been washed off the Spurs (Wade, 1957a) and the flanking valley to the north which may turn out to be as prospective as that to the south (which hosts the King Lyell deposit). The Lyell Pioneer area is an exploration target, particularly along the Zeplin Fault zone as shown in Figure 1.

Sample along Zepplin fault
Whites Creek

5.7 Mt Lyell Extended

This area has been named as a separate prospect, mainly by virtue of it's tenure history, being in James Crotty's stable at the turn of the century (Russell, 1898). the property contained two prospecting tunnels. The property location is shown on Figure 23, but no detailed map of the workings has yet been located.

Cundy (1901b) mentions that in the 183m long lower tunnel, minor chalcopyrite ? schist and a 2 foot wide vein with galena were located but did not persist more than a few feet. A gossan is present at the entrance to the lower tunnel containing shows of native copper but the workings had collapsed by 1901. PMIT makes mention of Lyell Extended in 1901, 1908 and 1909, but apart from mentions of appreciable native copper, no production is known.

6. GEOLOGY

Some previous geological descriptions have suffered from being a mixture of fact and theory. The best descriptive accounts are by Thureau (1886), Power (1891), Batchelor (1902; 1904), Gregory (1905), Wade (1975b), Solomon (1969) and Reid (1970). It is thought vital to distinguish between observation and deduction so sections 6.1 on host rocks and 6.2 on mineralisation are as factual as possible and any deductions are made in section 6.3 on ore genesis. The writer has studied any information available, visited the deposits, looked at drill core and produced summary drill logs and drill sections for most of the holes drilled. In this section, the Copper Clays are treated as a group as similar features have been observed at many deposits and the report would otherwise be too repetitive.

6.1 Host Rocks

Regional

The known Copper Clay deposits are restricted to altitudes of between 200 and 600m at the Western and of the Linda Valley or against the eastern flank of the Lyell Saddle. They are located in the Western Linda Graben, east of the Great Lyell Fault, south of the North Lyell Fault and north of the Owen Spur Fault. The deposits are located under water courses in valleys coincident with synclines and WNW trending Tabberabberan faults.

Ore Host

The immediate host to ore is clay, thought to be remnant clay after the dissolution of the calcium carbonate component of the Gordon Limestone. There are references to mineralisation in the Gordon Limestone itself, but these do not form a large part of the mineralisation in sight. There is a tendency, best seen in the long sections of Figures 14 and 19 for the better grade clays and undissolved Gordon Limestone to be incompatible.

Gordon Limestone

Regionally, the Gordon Limestone shows a comparable sequence of basal interbedded limestone and sandstone followed by 300-500m of micritic limestone (Banks and Baillie, 1989; Calver, 1995). Recent work by Morrison (1995) at the Halls Creek Quarry has shown that this micrite typically consists of about 40-70% calcium carbonate and 25-50% clay. The formation is not typically pyritic. Also, the sequence is mainly massive micrite with few shaley interbeds. A middle Ordovician age has recently been established for the Pioneer Sandstone (Calver, pers. comm., 1995) which is similar to the Gordon Limestone. This suggests a time gap of some 10-20 Ma associated with the haulage unconformity.

Ore Footwall

Assays of interest normally cut out in the Pioneer Sandstone which acts as a footwall to copper clay mineralisation. Often, the sands are poorly consolidated. Anomalous chromium to 0.43% has been recorded, for instance, in LB09 at the Consols. In the vicinity of the Copper Clays, the Pioneer Sandstone is generally only 10-15m thick with a basal conglomerate. This passes unconformably into either conglomerates or sandstones of the Owen Conglomerate which are usually strongly hematitic.

Ore Hanging Wall

In the mineralised positions, upper parts of the Gordon Limestone are not seen. If present, the overlying stratigraphy is the Crotty Quartzite of the Silurian Eldon Group, but this has not been mapped in the Linda Valley.

There is often no hanging wall or only recent fluvioglacial sediments present, making it likely that part of the copper clay mineralisation was eroded during the Pleistocene glaciations.

6.2 Mineralisation

Ore Minerals

From the drill logs and mining history, it is concluded that there is one dominant ore mineral, namely native copper and two minor ore minerals, namely cuprite and chalcocite. No thorough work has been undertaken to quantify the various minerals present and this will be a difficult process as the ore is not homogenous. Although the sulphides covellite, bornite, chalcopyrite and pyrite are present, they are often contained in variably sized sub-angular to sub-rounded clasts suggesting they represent detrital material from the orebodies up slope.

Markham (1966; 1968) made heavy mineral concentrates from drillholes LB13, 26, 28 and 31 as it was impossible to prepare polished sections. The concentrates included the following minerals:

> <u>*Pyrite*</u> was the most abundant sulphide mineral occurring as discrete euhedral crystals averaging 0.03mm in size. They may show partial replacement by chalcocite, digenite or covellite. The textural features suggest a process whereby copper in solution is precipitated by reaction with sulphides.

<u>Chalcocite</u> occurs as marginal replacements to pyrite and as framboidal aggregates of spherical, oval and crescent-shaped grains. Digenite, covellite and bornite are also present in the framboidal aggregates.

<u>Native Copper and Cuprite</u> are claimed by Markham to be more typically observed in the near surface portions of the deposits and grade into sulphides at depth. This was also suggested by Power (1891). However, this is not true from the drill logs nor from the Lyell Blocks production concentrate grades. In his own samples from depth, Markham observes native copper and cuprite and assumes that they have formed by oxidation from primary copper sulphides.

<u>Sphalerite and Galena</u>; a few isolated grains occur which are not associated with copper sulphides. The sphalerite is typically a honey-yellow in colour. Wade (1957b) also noted block clays derived from the Gordon Limestone containing fine, widely disseminated grains of galena.

Other mineralogical descriptions by Edwards (1939, 1958) are also useful. During a field visit in March 1958, Edwards collected some limonite nodules from King Lyell with internal cavities up to 2cm across encrusted with interlayered seams of native copper and cuprite up to 0.5mm wide. Open or filled cracks lined with these minerals lead into the cavities. There are also sheets of native copper filmed by malachite. Another group of specimens from the Blocks consisted of porous sheet-like slightly colloform bands of cuprite studded with minute inclusions of native copper.

Other relevant previously mentioned descriptions include the native copper occurring as films infilling joints and cleavages, including joints in the footwall Pioneer Sandstone and as chalcocite encrusted dendritic masses. Massive nuggets of native copper of up to 75kg were encountered at the Blocks (Blainey, 1993, p. 187). In his drill logs, Batchelor (1902) records pebbles of native copper and in hole ML12, the only mineralised Gordon Limestone interval with no associated clay mineralisation, fine pyrite-chalcopyrite and native copper are disseminated in silicified limestone.

Determination of the relative quantities of each mineral is difficult as they are not spread homogenously through the deposits. However, the best evidence is from the deposit's metallurgical history. To be able to produce concentrates averaging 69% Cu with 72% recovery, the minerals involved must be high copper species.

Since the chalcocite is very fine and hard to recover, this indicates that native copper and cuprite are the main minerals present which agrees with the drill logs. An educated guess at the proportions would be 70-90% native copper, 5-20% cuprite and 5-10% chalcocite.

Associated Lithologies

Not all of the Copper Clays consists of clay. There are two other major components which tend to be unmineralised. These are Limestone and detrital sediments. The limestone may be massive or vughy limestone or limestone gravels. Dolomite has been logged, but this may be ironstained limestone. Various unconsolidated detrital sediments are mixed with the clays. They vary from silt to sand, grit, pebbles, cobbles and boulders. Examples of all major local lithologies have been seen, including sub-angular to rounded clasts of cleaved and mineralised Lyell Schists, hematite, quartzite, quartz, conglomerate, sandstone, bornite and gossan. These lithologies may occur as wide intervals, eg: up to 100m of hematitic sand in LB37 or as isolated boulders in clay.

Where limestone is present, there are no descriptions of any typical skarn mineral assemblages or any clay mineral hydrothermal alteration. Occasional quartz veins containing sulphides are present under the Gordon Limestone. For instance, in hole NL1102, in a zone of altered Owen Conglomerate under Lyell Blocks, an interval of 46m at 30% $BaSO_4$ contains narrow quartz-barite-galena veins assaying up to 0.37% Pb and g/t Ag over 2m. The assays are diluted by their host rocks. Galena and chalcopyrite bearing quartz veins are present in Owen Conglomerate at Mt Lyell Extended. Gold is present in quartz veins at Lyell Pioneer.

There is insufficient Gordon Limestone core available to be sure if the fresh limestone normally carries sulphide minerals. There are several holes with long lengths of unmineralised limestone, eg: LB6, 7, 32, 33, 34, 35 and NL1101.

Of the 48 holes drilled at the Blocks, Consols and King Lyell only 16 have intersected limestone and clay. Of these, only 5 have some mineralisation in limestone, whereas 15 contain mineralised clay. Only one hole, ML12 (Batchelor, 1902), near the eastern margin of the King Lyell deposit, had mineralised limestone with no associated mineralised clay (Figure 19).

Relationship to Structure and Metamorphism

The deposits are hosted predominantly by poorly lithified to plastic clay (cf. history of ground support collapse) and no descriptions of the effects of metamorphism such as schistocity or metamorphic mineral development in the deposits themselves have been sighted.

The limestone precursors were present in synclines with common axial planar faults which have similar orientations to the S2 schistocity in Lyell Schists and Owen Conglomerate; where it can be determined (Figure 1). These synclines have acted as hosts for topographic lows which have allowed limestone and clay to be preserved.

It is thought, for instance, by Wade (1957b), that former limestone on the Whaleback, Linda, Pioneer and Gormanston Spurs has been converted to clay by carbonate dissolution and then either scraped off by ice or washed off by the heavy rainfall. This process has left unusual exposed fold surfaces as if they had been carefully excavated.

6.3 Ore Genesis

Review of Previous Ideas

Various theories have been advanced to account for the copper clay mineralisation. Gregory (1905, p. 140) pointed out that the ore deposition at the Blocks was subsequent to the main transverse faulting. At the turn of the century, Power, Batchelor and Cundy promoted the view that the deposits were products of in situ decomposition. There was a long gap before anyone even commented on the Copper Clays until Alexander (1953) claimed that their relationship to structure indicated a hypogene origin. Wade (1957a) and Wade and Solomon (1958) thought that the deposits occurred in shales of the Gordon Formation that had been mineralised by hypogene hydrothermal activity and then oxidised. However, Wade (1957b) noted that native copper is forming at the present time, particularly after rain by adsorption of copper on the clay from acid solution.

Markham (1966) suggested that the textural features strongly suggested the precipitation of iron and copper sulphides in a low temperature environment. He said that in view of their proximity to major sulphide deposits, it was reasonable to assume that they were the source of the iron and copper. The primary orebodies could have contributed metals to the Ordovician clay sediments by processes of leaching and transportation as soluble iron and copper sulphates. Markham thought it was difficult to decide when the process occurred, either syngenetically in the Ordovician or epigenetically in present day climatic and topographic conditions. A syngenetic Ordovician genesis was his preferred model.

Solomon (1967) suggested that the Iron Blow and associated hematites were gossans formed by oxidation during the early Ordovician. His descriptive paper on the Copper Clays (Solomon, 1969) is, in the writer's opinion, the best available summary; though Solomon seems unaware of the results of the 1963-65 drilling of holes LB1-37. Solomon's genetic views were multifaceted and included an enrichment of copper and iron sulphides during sedimentation. He thought a Tabberabberan age via hydrothermal remobilisation could not be ruled out. Solomon also considered that modern low-temperature precipitation and exchange with iron and/or limestone from copper in groundwaters derived from the deposits uphill was possible. In summary, he concluded that "the Copper Clay deposits are a combination of indigenous and transported gossans."

Reid (1970; 1975) followed the views of Markham (1968) and Solomon (1969).

In the early 1980's, a group of geologists from the new mine owner, RGC, soon dispensed with many of the views established after years of careful mapping, research and debate.

Bird (1982a; b), Brook (1984), Sillitoe (1984; 1985) and Arnold (1985) resurrected many dormant Tabberabberan epigenetic ideas and applied them to most of the orebodies on the field; including the Copper Clays. Sillitoe asserted that much of the mineralisation was structurally controlled by faults and that the Lyell Blocks mine exploited a steep 10-15m wide structure. If the mineralisation was structurally controlled, then Markham's (1968) syngenetic limestone-shale concentration model was unlikely. Also, any Tertiary supergene addition presupposed pre-existing sulphides. Sillitoe concluded that the Copper Clay deposits support hydrothermal sulphide mineralisation at Mt Lyell in post Gordon Limestone, probably Tabberabberan, times.

Bird (1984) stated that recent work at Mt Lyell had shown that volcanogenic models were erroneous and that the mineralisation is related to hydrothermal events that post-date the Gordon Limestone and Crotty Quartzite and is therefore of probable Devonian age. The two main styles of deposit likely in the Gordon Limestone were vein or replacement mineralisation. Vein deposits were likely to be of native copper-silver type with 2-4% Cu, 30-100 g/t Ag and possibly 1-2 g/t Au. Potential for up to 20 million tonnes of this style of material was recognised. Bird tested his model by drilling diamond holes NL1101 and 1102, totalling 1,024 metres, under Lyell Blocks. Apart from retesting the zone where the Lyell Blocks main shaft had terminated in 1915, the holes intersected very little mineralisation. The Copper Clays sections were not assayed and the best results were from the 46m of 30% barite section reported above.

Arnold (1985) recognised that the puggy ex-Gordon Limestone clays are clearly much modified from Paleozoic precursor limestones. He recognised, as did Sillitoe (1985), that pre-glacial deep weathering and periglacial and fluvioglacial processes have caused additional complications in the area. Arnold commented that the 'black pug' showed evidence of slumping, mixing and resedimentation with the glacial sediments. He provides a concise review of various models, but, apart from supporting Bird's ideas, he makes no firm conclusions.

Conclusions from Previous Ideas

Previous workers' ideas can be grouped into the four most popular models:

1. Decomposition
2. Syngenetic
3. Epigenetic - Hydrothermal
4. Natural Hydrometallurgy

1. <u>In Situ Decomposition of Lyell Schists</u>

The decomposition model was accepted by most of the early workers, including Power (1891), Cundy (1901) and Batchelor (1904). The model involved in situ decomposition of schist to pug and near surface oxidation of chalcopyrite to native copper. This process is untenable because Lyell Schists do not decompose; stable detrital schist clasts are present in the copper clays. Pug is now widely accepted as a residue after weak acid dissolution of Gordon Limestone calcite.

2. <u>Ordovician Syngenetic Deposition with Gordon Limestone</u>

Markham (1966; 1968) and Reid (1970; 1975) were the main protagonists of this model which was also considered possible by Solomon (1969). The syngenetic model involved sulphide deposition during sedimentation in a shaley or mudstone horizon at the base of the Gordon Limestone. Metal-bearing solutions are in part derived by low-temperature leaching from the adjacent large deposits (Blow, West Lyell, Corridor). Flitcroft and McKeown (1992, section 6.4) wanted to carry out lead isotopic work to determine if the ores were Cambrian in age, ie: older than their host rocks.

This model is based on several misconceptions on the nature of the deposits:

(a) that the surface native copper grades into primary sulphide mineralisation at depth (drilling and mining have shown that it does not);

(b) that there was a shaley zone at the base of the Gordon Limestone. This is unsupported by regional stratigraphic evidence and the 'clays' are thought to be residues from mass formational dissolution; and

(c) the ore has formed in a zone which is of post landscape, probably Cainozoic, age.

3. Devonian Epigenetic Hydrothermal Models

The epigenetic model was mentioned by Alexander (1953), Wade (1957a; b), Wade and Solomon (1958), but principally developed by Bird (1982a; b; 1984), Brook (1984) Angus (1984) and Sillitoe (1984; 1985). The model proposes primary epigenetic vein-type mineralisation associated with strong barite-hematite metasomatism during late stages of the Devonian Tabberabberan Orogeny. The model also predicts vein mineralisation in structural zones cutting the Owen Conglomerate. Later, in situ oxidation has produced native copper at surface.

This model also fails to take account of the drill log and mining evidence of predominant native copper. Furthermore, there is little evidence for the associated veins. Practically all the Gordon Limestone drilled is unmineralised and the barite-galena veins discovered under the Blocks and Mt Lyell Extended can hardly have been responsible for copper mineralisation.

With the process suggested, either some skarn or clay mineral hydrothermal alteration would be expected, but has not yet been identified. Also, Cainozoic mass limestone dissolution is not compatible with the Tabberabberan timing of this model. Markham's (1966) recognition of low temperature framboidal textures is another problem. In fact, there is so much conflicting evidence that this model is regarded as unacceptable. If the model is invalid, ore potential in the Owen Conglomerate is also downgraded.

4. Natural Cainozoic Hydrometallurgy

Elements of this model have been suggested as a possibility by Wade (1957b), Markham (1966), Solomon (1969), Arnold (1985) ??? and Hills (1990), though none of these authors chose recent concentration as their preferred option. The model proposed here involves a source of copper and acid solutions from oxidation of primary deposits such as the Blow, West Lyell and the Corridor on the Lyell Saddle. The solutions are then transported downhill until they meet carbonate from the Gordon Limestone which neutralises the solutions. This makes the dissolved copper unstable and it is readily precipitated by reducing agents in the clay such as carbon, kerogen, bacteria or iron oxides.

Objections to this model have been based on presumed structural control, the presence of sulphides at depth and difficulties with low temperature copper precipitation mechanisms.

Evidence for the hydrometallurgical model is the distribution of native copper throughout the clay formed by Cainozoic non dissolution of Gordon

Limestone. This process chemically aids copper precipitation at low temperatures, producing minerals and textures consistent with the model and observations. Precious metal contents in the Copper Clays are generally low (see Tables 4 and 5) which would be expected in the low temperature model, but not in the higher temperature syngenetic or epigenetic models. The lack of associated mineralised limestone, veins and metamorphic features are all also consistent with the natural hydrometallurgical model which is considered the most acceptable current theory.

Timing of Mineralisation

The sheets of copper in joints, dendritic copper nuggets and pebbles of native copper all suggest copper deposition post landscape formation. The mass dissolution of calcium carbonate of the Gordon Limestone is also likely to have occurred after the formation of the landscape. The process would be much slower, if at all possible, if the limestone was below a poorly oxygenated fresh water table.

The abundant oxidising sulphides on the Lyell Saddle are naturally producing both surface and groundwater solution flow which is acid, oxygenated and cupriferous. The reaction of pyrite, chalcopyrite, water and oxygen produce goethite (gossan with residual precious metals), sulphuric acid, copper sulphate and iron sulphate. The recent CMT environmental management report showed that a daily mean of over two tonnes of copper is being transported downstream from Mt Lyell (Thompson and Brett, 1944, Figure 4.22). Mining has caused accelerated copper transport rates, but even at 0.1 tonnes per day and only a 5% of total copper precipitation rate, it would only take some 27,000 years to accumulate the 50,000 tonnes of copper identified in the three main deposits to date (Appendix 3).

Since glacial deposits of up to 0.8 Ma age overlie but do not contain interesting copper intersections (Appendix 1), the mineralising process is thought to be mainly of pre-Quaternary age. As the current landscape is thought to have developed during the Cainozoic, it is likely that the Gordon Limestone dissolution and copper deposition took place during this period, and is probably currently continuing.

Limestone Dissolution Process

While trying to understand the dissolution process, the writer contacted Dr Armstrong Osborne of Sydney University who is an expert on limestone caves. He is currently working on a model for major cave system formation which suggests the rate of dissolution is exponentially increased if oxidising sulphides (generally pyrite) are present in the groundwater catchment. The mass dissolution of Gordon Limestone at Mt Lyell is clearly an extreme example of Osborne's model.

In fact, it is surprising there is any limestone left in the Linda Valley. This can be explained by the channeling effect of groundwater flow through established open space. It is highly likely that during the dissolution process a complex and constantly evolving cave system developed which included major collapse and breccia formation. Another common feature of cave systems is their sediment content, including boulder beds if a source and access are present. During Pleistocene glaciations, it is even likely that diamictic sediments were squeezed through subterranean cave systems under pressure (K Kiernan, pers. comm., 1995).

The gradual dissolution of limestone can be likened to the gradual melting of ice during a glacial retreat. Examples of the complex types of sedimentary accumulations developed are illustrated by Fitzsimmons and others (1993, Figure 32).

Implications of the Model

As the deposits occur in faulted synclines, some may claim they exhibit structural control, though this is an inherited control on valley position. The important control on mineralisation is thought to be by natural hydrometallurgy, ie: the dissolution, transport and precipitation mechanisms that have allowed the economic concentrations to be formed.

The model has a predictive capacity for orebody location, shape and grade variation. The deposits will have an overall synclinal chute-like geometry with major variations in grade caused by the copper nugget effect and paleofluid channeling zones. The highest grades may be expected near source with a gradual tapering off in grade with depth. Zones of potential mineralisation are present all along the western limit of clays as shown on Figure 1.

The deposits will be very complex in detail having evolved through a cave stage where irregular channels and collapse followed by dissolution have occurred. Before and during glacial stages, sediments of varying grainsize will have been transported through caves and mixed up with collapsing limestone debris.

Ore fluid channelling will have led to adjacent high and low grade zones. Correlation between adjacent drillholes will be very difficult and numerous voids are still likely to be present. Isolated boulders in clay and porous gravel zones will present severe drilling difficulties.

6.4 Comparisons With Other Native Copper Deposits

Although copper is one of the commonest native elements, this is generally as a supergene oxidation product rather than as the major mineral in an ore deposit. In order to gain helpful insights from other native copper deposits, a search was made on the main international computer data bases at the AMF.

The most common deposits of native copper are associated with low-grade metamorphism of basic volcanics. The best example is the Michigan Native Copper District on the Keweenan Peninsula, USA (Lindegren, 1913). Since 1845, over 5 million tonnes of copper have been produced from the 1095 Ma Portage Volcanics and interbedded sediments. Hosts for this production are approximately 58% volcanics, 40 conglomerates and 2% veins with 96% coming from a 45km long, 3km wide zone. Ore is principally mined underground, historically at grades of up to 4% copper, but more recently at grades of between 0.5 and 1.0% copper.

Most authors have concluded that the deposits formed at about 1050 Ma during prehnite-pumpellyite regional metamorphism at 250°C and depths up to 3.5km. Copper has been leached from boric volcanics containing about 70 ppm Cu during dehydration reactions and transported as chloride complexes containing 1500 to 2000 ppm Cu. Solutions have percolated upwards towards lower temperature levels where hydration was dominant. Open space in both amygdaloidal basalts and porous conglomerates has been filled to produce 'pseudo' stratiform 'manto' (blanket) type orebodies. The deposits are silver rich and contain some native silver. Where constrictions have concentrated fluid flow through, grades are higher.

Neither the Keweenawan deposits, nor any others for which descriptions have been located, seem similar to the Mt Lyell Copper Clays. They are therefore thought to be a very rare to unique type of ore deposit.

7. RESOURCE ESTIMATES

It is surprising that with 48 diamond drillholes completed, and many significant intersections (Table 3), that nobody appears to have yet carried out a resource estimate. In the most recent MLMRC report, Reid (1970, p.7) claims that as the data is unrepresentative and contains errors, it should not be used for evaluation purposes. While there are certainly problems with the data quality, this is the case with all resource estimations and geologists have a responsibility to make the most of the information available. Also, since 1970, the AIMM resource reporting code has been developed and this gives guidelines for dealing with Copper Clay type situations.

The procedure adopted here is to analyse resource assessment criteria with a view to suggesting improvements. Detailed results for each main deposit are then reported in sections 7.1 to 7.3.

Estimation Technique and Interpretation

A total of 48 diamond drillholes for 4,900 metres have been completed between September 1902 and July 1984. Drill logs are stored in the Lyell Blocks blue book in the geology office safe. Summary logs have been produced for this work (Appendix 1) and lists of intersections compiled as Table 3 and Appendix 2.

These logs have been plotted on a series of 13 sections at the most appropriate intervals to reduce the length of projection onto each section. Intersections have been bulked as much as possible and a low cutoff grade of 0.1% Cu has been used to simplify the interpretation. Cross sections have been interpreted and areas of mineralisation on each section measured by planimeter. Average grade assigned is a length weighted average of the intersections inside each perimeter. A tonnage factor of 2.1 tonnes/m^3 has been used to account for the low density clays and voids. Tonnages for each section have then been added. Resources obtained are detailed in Appendix 3 and summarised on Table 7.

The orebodies have been defined by clustering of holes with significant drill intersections and orebody perimeters drawn to divide ore bearing holes from barren holes. All holes within the mineralised perimeter for each orebody have been included in the estimate.

If it were not for the problems of core recovery, the resource might be able to be classified as inferred. However, the recovery is so poor that a classification as pre-resource mineralisation is preferred. The AIMM is currently reviewing the use of this term (Stephenson, 1995). The term is not fully appropriate as there is sufficient continuity of mineralisation to be confident we are dealing with a resource. In the writer's experience, poor core recovery sledim 'makes' or 'breaks' an orebody. In detail, the recovery is quite variable and available estimates for each intersection are given in Appendix 2. The term low confidence resource or preliminary resource would be preferred by the writer.

Drill Hole Density

Currently, a total of 36 holes and various underground workings define the three resources. Spacing is somewhat irregular, possibly due to severe difficulties of site access, but from the sections and workings, our confidence in ore continuity is good. This is also because there are no examples of unmineralised holes within ore perimeters. Holes KL16 at King Lyell and LB37 at the Blocks are closest to being negative. There are sufficient holes and continuity for an inferred resource.

Hole Location Accuracy

For all but the old ML holes, locations have been surveyed. The five Mt Lyell holes drilled in 1902 are probably only accurate to ±5m, but this will not affect the current conclusions.

Table 3

List of Significant Drill Intersections

Deposit	Hole No	Intersection			Cu	Au	Ag	Recovery
		From (m)	To (m)	Length (m)	%	g/t	g/t	% Est
Lyell Blocks	LB28	16.5	181.4	164.9	0.64	0.13	4.1	50
	including	74.8	143.3	68.5	1.33	0.08	6.7	50
	including	77.0	85.5	8.5	2.20	0.07	1.2	67
	LB30	0.0	48.8	48.8	0.37	Tr	3.1	50
	including	32.3	39.6	7.3	0.80*	Tr	3.2	36
Lyell Consols	LB18	10.7	41.7	31.0	1.56	nd	Tr	60
	including	27.1	29.9	2.8	10.5	nd	Tr	84
	LB23	55.0	90.0	45.0	0.62	nd	Tr	80
	including	59.4	70.1	10.7	1.38	nd	Tr	91
King Lyell	ML09	2.4	43.0	40.6	2.16	nr	nr	low
	including	2.4	6.1	3.7	9.5	nr	nr	low
	ML11	48.8	85.3	36.5	0.67	bld	bld	poor
	ML12	62.5	111.3	48.8	0.52	bld	bld	poor
	including	94.5	106.7	12.2	1.05	bld	bld	poor
	KL01	30.5	38.1	7.6	1.69	nd	nd	37
	KL13	42.7	70.1	27.4	1.08	nd	nd	46

* = Includes 3.1m of office tunnel void - otherwise probably 1.5% Cu
Tr = Trace
nd = not determined
nr = not recorded in logs, existence unknown
bld = below limit of detection
= detection limits for Au and Ag
= for ML holes - Au 0.3 g/t Ag 15 g/t
= for other holes - Au 0.15 g/t Ag 0.3 g/t

Drilling Techniques and Recovery

All holes, except the five 1902 holes, have been drilled with modern types of diamond drill equipment. There is probably no ideal rig to drill the difficult mixture of limestone, clay, running sand, gravel and boulder clay that is present. In observing the core that has been recovered, it is surprising to see how much unconsolidated sand, gravel and some cored boulders has been recovered. Overall recoveries over mineralised intervals vary from 20 to 100% with an average from Appendix 2 of 56%. A void space of 20% has been assumed to reduce the tonnage factors so that the real recovery may be 56/80, ie: up to about 70%.

Such a recovery could still give a good representation of what is in the ground, depending on whether the 30% lost core was of lower, similar or higher grade than the material recovered. In the general absence of sludge assays, there is no way of knowing whether the lost core is of consistently higher or lower grade.

The only sludge assays located were from the 1902 drilling on hole ML09 and these are reported in Table 4. Surprisingly, these sludge assays are significantly higher grade than the recovered core. However, it is doubtful if the sludge assays are representative - so they do not really help.

The writer believes the most likely lost material is unconsolidated sediment; which is generally unmineralised. This would have the effect of increasing the average grade of material recovered. Because of the difficulties of drilling copper clay type mineralisation, it is likely the problem will not be able to be eradicated. However, it should be possible to do better and quantify the errors so that risk can be reduced.

Sampling Techniques

These are not well documented. From drill core remaining, it can be seen that it was not always cut in half, even if it was possible to do so. As much of the core is unconsolidated, it can only be assumed that the samplers attempted to select a representative sample for analysis.

Assay Techniques

These were similar to others in use At Mt Lyell. It is clear from the logs that if native copper is present, it can be visually seen down to very low levels of 0.1% Cu, though for some intervals of plus 0.5% Cu, no copper minerals are mentioned. This could be caused by the problem of identifying chalcocite which is hard to distinguish from black clay, carbon and manganese staining.

The main problem, illustrated on Table 4, is reproduceability due to difficulties in preparing a homogenous pulp from malleable native copper. The only data available are from the 1970 King Lyell drilling. They show poor comparability, so it is concluded that there is an assay reliability problem. It is not known whether this would lead to generally higher or lower results. This would depend on how the assay charge was taken. It is thought most likely that with unpulverised native copper present, the charges would be generally of lower grade than the bulk pulp.

Table 4

Details of Sludge Assays and Re-Assays

From 1902 drilling recorded in drill logs for Hole ML09

Interval (m)			Core Assay	Sludge Assay	Difference
From	To	Length	% Cu	% Cu	%
19.8	21.3	1.5	1.9	8.7	+ 358
21.3	22.9	1.5	2.4	15.0	+ 525
22.9	24.4	1.5	2.9	12.9	+ 345

No details on core recovery available.
No details of sludge collection method available.

Note That from 13.7 to 16.8m in Batchelor's Prospecting shaft located 15m to the northeast of ML09, a gossan zone was recorded and was estimated to contain 20% copper!

Re-Assays

Only carried out on 1970/71 King Lyell drilling

Hole No	Interval (m)			Original Cu Assays	Re-Assays	Difference
	From	To	Length	% Cu	% Cu	%
KL01	30.5	38.1	7.6	1.69	0.85	- 50
KL02	74.5	78.5	4.0	0.86	1.60	+ 86
KL16	19.8	42.7	22.9	0.049	0.042	- 14

Note These are bulked intervals. Individual assays may show more variation.

Tonnage Factor

Tonnage factors will vary from 0 for voids to 8.9 for native copper. The SG of the clay is probably about 2.6, but with the possibility of up to 20% voids on SG of 80% of 2.6, that is 2.1 tonnes/m^3 has been used in the estimation. Wade (1957b) reports work by Batchelor in 1902 who measured the SG of King Lyell clay at 2.08. However, Wade used a figure of 2.4 in his estimations. If he was right, the current estimate is up to 15% or 1.2 million tonnes low on tonnes.

SG Weighted Assay Averaging

Another factor which can have a major influence on contained copper is whether composite assays are SG and length weighted rather than the normal length only weighting which has been used here. For instance, one meter of native copper and 1 meter of barren clay average 77% (8.9/8.9+2.6)not 50% Cu.

A more realistic example is to average 4m of clay at 0.1% Cu with an SG of 2.6 and 1m of mineralisation at 10% Cu with an SG of 3.3. Normal length weighted averaging gives 5m at 2.08% Cu, but the correct average is 5m at 2.48% Cu; which is a 16% increase in grade. It is thought likely that the average grade would be increased from 10-15% if SG weighted averaging were used.

Nugget Effect

Another effect which is difficult to evaluate is the nugget effect. It is likely that, as in gold deposits, a large proportion of contained copper is present in a small proportion of the volume. To properly evaluate this would require geostatistical knowledge of the range and nugget effect from a much higher drill density. This is not likely to be available. The factor is important if there is a desire to maximise copper production in the short term.

From the model developed, it is anticipated that the high grade zones of plus 3% copper are likely to be paleo fluid channeling zones. Deposits with high nugget effects are difficult to evaluate and some cutting of high grades may be appropriate.

Cut-Off Grade

A cut-off grade of 0.1% copper was chosen arbitrarily. The decision can be justified as follows: At a revenue of $35 per % Cu recovered, if treatment cost is $1.0 to $1.5 per tonne, then in an open cut situation, recovered copper needs to be over 0.03 to 0.04% to justify treatment as ore rather than waste. At this grade, recovery can be expected to be only 30 to 50%, so a cut-off head grade of 0.08 to 0.1% Cu is appropriate.

Quality of Data Description

Unfortunately, this leaves a lot to be desired as hardly any information or reports describing what has been done are available. The blue drill log books are vital, and do systematically record the most important data. However, logging has been carried out by many geologists and a degree of inconsistency is inevitable.

On check logging, the only problem found was an interval in the most recent King Lyell holes logged as quartzite which was found to be silicified vughy limestone with a fizzy reaction to 10% Hcl. It is hoped that by simplification to only a few lithologies, the summary logs are as reliable as possible.

As no reports on drilling of 46 of the 48 holes were produced (or have not been referred to or located), it is thought that the MLMRC were not impressed by the results. When they did carry out metallurgical testing, it is suspected they were considering treating the copper clays through their normal flotation process. As the flotation test results were disappointing, it is easy to see how they become disenchanted with the copper clays and did not regard a resource assessment as necessary.

7.1 Lyell Blocks

Blocks mining history is reasonably documented, but more detailed period reports are probably available through State Archives. Previous stoping history suggests a zone of higher grade mineralisation parallel to and under the gossan zone which was exposed in Copper Creek (Figure 26). Assuming mineralisation between the Blocks and Balance Shaft area is really continuous, the Blocks orebody is up to 400m long, 140m wide and 160m deep. Strike is NW which is not parallel to either the North Lyell Fault of the set of WNW trending Tabberabberan D2 faults to the south. The body appears to be controlled by the topography and the natural hydrometallurgy model previously described.

Nine of the 16 holes drilled for 2569m outline the orebody. Of the 7 remaining, 2 were abandoned (LB3 and 36), 2 were not assayed (NL1101 and 1102) and 3 are some distance to the southeast of the orebody (LB1, 2 and 4). Of the 9 holes defining the orebody, only one, LB28, was drilled in the central higher grade zone. It achieved an intersection of 165m at 0.6% Cu which is the highest m% accumulation in all clays holes. The other 8 holes intersected significantly less mineralisation (Appendix 2.1).

There is good evidence for strong mineralisation on the old long projections (Figures 28 and 29) and from the complexity of the underground workings (Figure 27). It is anticipated that despite the ore extracted, after more holes are drilled, the average grade will be increased by relatively more strong intersections from the central core.

The Blocks resource of 4.7 mt at 0.5% Cu contains 23,700 tonnes of copper which is 48% of the pre-resource mineralisation recognised in this report. Without the benefit of the 1960's drilling, Wade (1957b) estimated probable reserves of 1.63 mt at 1.75% Cu containing 28,500 tonnes of copper. He also recognised potential for an additional six million tonnes of ore above the Crown Lyell Quarry. Since this is largely outside the current pre-resource mineralisation, a total resource potential of 10 mt at 1% Cu is recognised.

The few mildly anomalous silver and gold assays from copper clays are mainly from Lyell Blocks (Tables 5 and 6). There is a suggestion, at least with the anomalous Ag, that it correlates with higher sulphur assays. This implies that detrital clasts of bornite and chalcopyrite ore from North Lyell form a part of the Blocks mineralisation as recognised by Batchelor (1904).

Table 5

Copper Clays Ore, Gold and Silver Contents from Production Records

Ore Source	Period	Tonnes	% Cu	g/t Au	g/t Ag	Note
North Lyell	Pre 1903	101,978	7.8	0.32	85	1
Lyell Blocks	1900/01	18,537	7.6	0.29	47	2
King Lyell	1903	21	40.42	bld	19	
	1904	2.0	1.09	Tr	3.4	
	1906	3.6	1.68	bld	Tr	
North Lyell	1904	59.1	0.50	bld	13.8	3
	1906	34.6	0.34	bld	11.0	3

Notes:

Tr	= Trace.	
bld	= below limit of analytical detection.	
1	Bornite-rich ore mined by the North Lyell Company.	
2	Bornite-rich ore mined from Lyell Blocks - see Blainey (1993, p. 143).	
3	Probably Blocks are sold to MLMRC, possibly from the Copper Clays north of Lyell Blocks.	

Table 6

Copper Clays Mineralisation, Copper, Pyrite, Gold and Silver Contents from Drill Intersections

Deposit	Hole No	Intersection (m)			Cu	F_eS_2	Au	Ag	Description of Interval
		From	To	Interval	%	%	g/t	g/t	
Blocks	LB28	16.5	30.8	14.3	0.15	1.07	0.15	1.4	sand, clay, py cubes
Blocks	LB28	30.8	45.7	14.9	0.13	1.14	0.30	2.6	clay
Blocks	LB28	45.7	65.2	19.5	0.21	1.36	0.30	4.3	hematitic schist
Blocks	LB28	65.2	72.9	7.6	0.11	0.23	Tr	0.8	decomposed schist
Blocks	LB28	72.9	76.7	3.8	0.59	0.51	0.15	1.4	clay
Blocks	LB28	76.7	85.5	8.7	2.94	0.64	Tr	1.2	clay, fine diss NCu
Blocks	LB28	85.5	100.6	15.4	0.27	1.41	Tr	2.1	clay, limestone, py cube
Blocks	LB28	100.6	112.8	12.2	1.09	1.17	Tr	1.2	clay, NCu
Blocks	LB28	112.8	121.9	9.1	2.37	1.63	Tr	12.4	clay, NCu
Blocks	LB28	121.9	129.5	7.6	1.06	0.78	0.15	27.7	coloured clay, NCu
Blocks	LB28	129.5	139.0	9.5	1.81	1.56	Tr	2.9	grey clay fine NCu
Blocks	LB28	139.0	152.4	13.4	0.35	2.05	Tr	3.5	grey clay NCu & py
Blocks	LB28	152.4	167.3	14.9	0.15	1.33	Tr	1.2	(clay with fine py in darker
Blocks	LB28	167.3	181.1	13.7	0.10	1.74	Tr	Tr	layers)
Blocks	LB30	9.0	21.3	12.3	0.21	0.20	Tr	2.9	clay
Blocks	LB30	21.3	35.1	13.8	0.34	0.45	Tr	3.1	clay with NCu
Blocks	LB30	35.1	45.7	10.6	0.45	2.67	Tr	3.4	clay with NCu
Blocks	LB30	45.7	54.5	8.8	0.30	3.58	Tr	2.8	clay with py
Blocks	LB32	12.5	24.4	11.9	0.16	0.01	Tr	1.2	clay with NCu
Consols	LB13	5.5	17.4	11.9	0.10	2.46	Tr	2.5	coloured clays, diss py
Consols	LB13	58.5	75.9	17.4	0.68	bld	0.15	3.1	clay, limestone, py, NCu
Consols	LB18	27.1	29.9	2.8	10.5	bld	Tr	Tr	grey clay, NCu
Consols	LB23	53.3	59.4	6.1	0.27	4.0	Tr	0.9	clay with fine diss NCu
Consols	LB23	59.4	67.1	7.7	1.54	bld	bld	Tr	clay with fine NCu

Abbreviations: Tr = Trace bld = below limit of detection
py = pyrite
diss = disseminated
NCu = Native Copper

The main problem with the Blocks, particularly during the exploration stage, is the presence of waste dumps from the various Corridor pits. This comprises Crown 3 and North Lyell waste which together cover the northwestern part of the orebody.

7.2 Lyell Consols

Mining history is not well documented, but ore was developed on several levels and over a considerable strike length (Figure 24). In 1907, reserves were estimated at 95,627 tonnes at 3% copper (Wade, 1957b). The orebody trends approximately east-west at a similar orientation to the Consols and Whaleback Faults. It is up to 400m long, 160m wide and 70m deep and opportunities for immediate extensions are not obvious.

Lyell Consols is the most densely drilled of the three deposits, with 23 holes for 1646m (Appendix 2.2). Again, one hole, LB18, had by far the best intersection of 31m at 1.56% Cu and the mineralised body appears to be strongly zoned around a high-grade core. The total resource of 1.9 mt at 0.5% Cu contains 8,700 tonnes of copper which is 18% of the global resource. It is again predicted that after a more representative drilling pattern is established, a higher grade though lower tonnage resource of about 1.5 mt at 1% Cu will be established.

The long section view of Lyell Consols (Figure 14) is remarkably similar to that at King Lyell (Figure 19). It is expected that the overall geology is also very similar. The higher grade predicted for King Lyell may be a function of hole location to date, or, if it is real, it is probably caused by King Lyell's closer proximity to a source of high grade solutions derived from the Iron Blow.

There are no known mine dumps overlying the Consols deposit which, apart from general site access difficulties, should be the easiest of the three main deposits to develop.

7.3 King Lyell

Although the mining history of King Lyell is different, with all previous production coming from sluicing operations, there are still sufficient shafts and tunnels to again be confident of ore continuity. These workings are shown on a beautiful plan from about 1903 (Figure 30). In plan view, King Lyell is the most erratic of the three deposits and although it is the smallest, it is also the highest grade containing 16,500 tonnes of copper or 34% of the current resource. The orebody as defined is up to 300m long, 180m wide and 45m deep, containing 1.5 mt of 1.1% Cu. There is a good chance that mineralisation will be found over an area of up to 400m long, 260m wide and 45m deep. This could lead to a doubling of the current resource to about 3 mt of 1.0% Cu.

The King Lyell resource is defined by only 7 holes of the total of 9 drilled. Of the other two, KL1 was not a good intersection, but it was not assayed over the whole hole and ML12 achieved an intersection at 62.5m depth of 49m at 0.52% Cu. This hole is near the Lyell Highway (Figure 19) and has been previously mentioned as the only hole to have a significant intersection in Gordon Limestone and not in clay. Further drilling in this area is recommended.

The 9 holes drilled are not well sighted to outline the entire deposit. Reid (1970) proposed a more extensive programme, but for some unknown reason, the 4 holes completed only achieved an average 44% recovery and Reid may have given up in disgust. Despite the poor recovery and poor assay reproduceability (Table 4), hole KL13 located 75m from Batchelor's Shaft achieved a good intersection of 27m at 1.10% Cu.

The other holes were disappointing, but the logger did not recognise some of the copper and the holes were not assayed over their entire length. Core condition has deteriorated since they were drilled and many core trays are missing, so it is not thought possible to correct this problem.

Strong zones of native copper rich mineralisation were intersected in the 1898/9 adit (55m at 4.6% Cu), in hole ML09 (40m at 2.2% Cu) and in Batchelor's Shaft (45m at 1.1% Cu; "excluding a zone between 45 feet and 50 feet which probably went 20% Cu"). At the base of Batchelor's Shaft, cross cuts were driven. The north cross cut passed through 0.2-0.3% copper before reaching the conglomerate contact and the south cross cut averaged 1.98% Cu over 26m (Reid, 1970).

King Lyell has a problem from two of the Iron Blow waste dumps (Figure 15) though these are only thought to be up to about 10m thick and may contain grades of interest. King Lyell is likely to be the second easiest mining proposition once the current aggregate operation is terminated. It contains a large area of prospective untested clay on its southern side between Cooney's Creek and the Gormanston Fault (Figure 15).

8. OPEN CUT POTENTIAL

The aim of this section is to take a preliminary look at economic factors to make sure that an exploration programme can be justified. This also encourages foresight during the exploration programme so that logging and assaying is suitable for future needs, and samples can be collected for metallurgical assessment. As the clays have been classified as pre-resource mineralisation, they are not strictly an identified mineral resource and economic assessment should not be taken too far. However, the AIMM guidelines are slightly contradictory, for although pre-resource mineralisation and inferred resources are not reserves, when reporting a resource, there is an "implication that there are reasonable prospects for eventual economic exploitation."

8.1 Waste to Ore Ratios

An exercise was undertaken where simple pit outlines were drawn on photocopies of each resource cross section. That is on Figures 3-6, 9-13 and 16-19. To avoid an extra 13 figures in this report, these are kept on file at Mt Lyell if required. In these simplistic pits, walls were drawn at 45° if in clay and at 50° if in conglomerate. Floors are not at the same RL, as all pits slope downhill parallel to the topography, but they are geometrically sensible. Deep or isolated ore was excluded to give figures for in pit resources. No adjustment has been made for end effects, so the volume of waste is probably slightly high. No dilution has been applied.

Results are summarised in Table 7 and detailed in Appendix 4. Waste to ore ratios on individual sections vary widely from 0.61 to 1 to 5.5 to 1, but overall ratios from each orebody are more consistent in varying from 1.9 to 1 to 2.8 to 1, with an overall average of 2.3 to 1. The waste was higher than expected due to deposit location in valleys. In Appendix 5, the proportion of copper in resources recovered is listed. On individual sections, this varies from 66 to 100% and averages 83%.

Since more control is possible via detailed pit planning, the degree of waste removal is not thought to be a major hurdle to development. In fact, it presents an opportunity to develop a considerable production of construction aggregate materials for on mine use and off mine sale.

8.2 Metallurgy

Since the copper clays have been previously profitably treated, there is good reason to believe that as long as a substantial resource is outlined, it should be economically viable to treat. Grayson's (1903) description of the Blocks plant is given in section 5.1. Sufficient information on mineral distribution from the existing 48 drill holes to believe that a gravity concentration plant would again be most appropriate. However, all options need to be considered during any feasibility study as follows:

1. Gravity concentration
2. Flotation
3. Solvent extraction and electrowinning

Previous gravity treatment at the Blocks and Consols gave recoveries of 72% with concentrate grades of 69% copper. This should be able to be improved with modem experience and technology. As the ore contains some gossan and some mineralised clasts, crushing and grinding for the estimated 20-25% that is not clay would be necessary. The Blocks also produced a secondary iron-rich product averaging about 20% copper.

Some metallurgical testwork was carried out by MLMRC from the 1964/65 Blocks and Consols drilling. As only the work sheets could be located, John Geoghegan, MLMRC's final Mill Superintendent, kindly provided a commentary on the work which is given in Appendix 6. He concluded that high slime contents would probably preclude flotation treatment and that fine chalcocite is likely to be the most troublesome component.

Table 7

Summary of Copper Clays Resources

Deposit	Global Resource			In Pit Resource		
	Mt	% Cu	Tonnes Cu	Mt	% Cu	Tonnes Cu
Lyell Blocks	4.71	0.50	23,757	4.18	0.49	20,590
Lyell Consols	1.86	0.47	8,698	1.69	0.48	8,084
King Lyell	1.47	1.13	16,570	1.05	1.12	11,810
Totals	**8.04**	**0.61**	**49,025**	**6.92**	**0.59**	**40,484**

Deposit	Waste	In Pit Resource	Waste to	Recovered % of	
	Mt	Mt	Ore Ratio	Tonnes	Cu
Lyell Blocks	7.92	4.18	1.89	89	87
Lyell Consols	4.77	1.69	2.82	91	93
King Lyell	3.00	1.05	2.86	71	71
Totals	**15.69**	**6.92**	**2.27**	**86**	**83**

As far as metallurgical testwork is concerned, it is thought that should a drilling technique such as air core/hammer be utilised, then for the mineralised sections, gravity recoverable copper as well as total chemical copper should be determined. Such work could be carried out in a diamond indicator mineral laboratory. It is thought that this type of analysis would be of great value in assessing the deposit. Five, ten or more meter composites could be treated so the metallurgical response of the whole deposit can be determined.

Collection of metallurgical samples by surface sampling is not recommended as it would be very hard to ensure representativeness. Regular size fraction analysis of uncrushed materials would also be necessary to determine the proportion of oversize that would need crushing. A small heavy-media plant could also be considered as this would effectively separate crushed oversize and create a useful aggregate by-product.

8.3 Preliminary Economics

A brief and simplistic look at the economics of a copper clay operation is considered necessary to allow debate on the project's relative importance. Ball park cost figures have been obtained after discussions with Richard Winby and Hamish Bohannan. If contract earthmoving and an alluvial type concentration are utilised, capital cost is not expected to be a major hurdle. The type of operating cost scenario envisaged is as follows:

	per tonne ore $
• Mining (earthmoving) at $2.25/tonne and 2.3:1 waste to ore (3.3 tonnes per tonne ore)	7.43
• Cu recovery by gravity, including comminution	1.50
• Cu transport and recovery	2.10
• Administration	0.25
Total	**$11.28**

Thus, to break even, recovered grade at a revenue of $35 per % Cu would be 0.32% Cu. This equates to a head grade of 0.45% Cu at a recovery of 72%. For current resources, with an average grade of 0.61% Cu, an operating surplus of about $4 per tonne could be expected. However, the current grades at the Blocks and Consols would be marginal. To have operating costs as 50% of revenue with a 2.3 to 1 waste to ore ratio, a recovered grade of 0.64% Cu and head grade of 0.9% Cu would be required. This is thought to be possible by modification of pit designs.

For the King Lyell orebody (1.5 mt at 1.13% Cu) and a 2.9 to 1 waste to ore ratio, the figures are:

per tonne ore

	$
• Mining per tonne of ore treated (3.9 x 2.25)	8.78
• Concentrate production	1.50
• Cu recovery and transport	3.95
• Administration	0.25
Total	**$14.48**
Revenue from 1.13% head grade is 0.81% recovered grade at $35 per % Cu	+ 28.48
Surplus	**$14.00**

or for 1.5 mt, a total surplus of $21.0m

From these figures, it is concluded that a copper clays operation has the potential to be highly profitable. An exploration programme designed to increase confidence in resource knowledge is therefore justified.

9. EXPLORATION PROPOSALS

In order to enable a pre-feasibility study to be carried out, it is necessary to upgrade the resource classification to an inferred resource. Due to the unconsolidated nature of the Copper Clays, the resource estimation has similar problems to those evaluating alluvials and it may never be possible to estimate a measured resource. Any development may have to proceed on the basis of an indicated resource and probably reserve. This is possible with a two-stage drilling programme, the first stage of which is proposed here.

The main improvements to resource assessment factors which are necessary are:

1. Greater drillhole density.
2. Significantly improved recovery.
3. Minor improvements in assays, tonnage factor, size fraction analysis, quantitative mineralogy and documentation.
4. Commencement of systematic metallurgical investigations.
5. Commencement of mining investigations.

1. Greater Drillhole Density

A 64 hole, 5590m drilling programme is proposed as illustrated in Figures 20, 21 and 22 and tabulated in Appendix 7. A nominal spacing of 40m along lines 80m apart is proposed. This is slightly more dense than the 122 x 61m pattern proposed by Reid (1970) for an imperial grid. Holes average 87m in length which is similar to the historical average for the 46 holes to 1971 for 3876m at 84m per hole.

Hole depths have been predicted by reference to the cross section interpretations and are expected to be reasonably reliable. Only 8 holes (7 at the Blocks, 1 at King Lyell) are expected to be between 120 and 200m in length so their may have to be some compromise on these by leaving all difficult holes for the second phase.

It is important to complete holes to the Pioneer-Owen contact if possible as the Pioneer Sandstone is generally only about 10m thick and often carries good native copper grades.

Some holes will have to be drilled through Blow and North Lyell waste dumps, but this is unlikely to be more difficult than drilling through unconsolidated boulder beds. For best cross section interpretation, hole collars should be reasonably close to those planned.

This will involve considerable time and earthmoving cost for site preparation.

The grids at King Lyell and the Consols are the mine grid, whereas at the Blocks, a new local grid may be necessary. Holes on each traverse have been sighted so that at least one hole is outside the presumed orebody. If follow-up drilling is carried out it may be necessary to vary the hole spacing so there are more holes in the higher grade-width zones.

If drilling funds are scarce, holes could be drilled on the current cross sections. However, it would be necessary to redrill most holes for better recovery so the new pattern might as well be used. Also, one deposit such as King Lyell could be drilled first to check that objectives are being met.

2. Significantly Improved Recovery

Improved recovery is so important that a drill contractor and drillers with patience to experiment and a desire to improve will be necessary. It is likely that no one technique will be suitable for every situation and a combination of air core for clay and sand and a face sampling hammer for waste dumps, gossan, boulders and limestone may be necessary. A technique with casing advancing behind the bit may also be worth trialing.

It may be worth bringing in one or more experienced drilling consultants, showing them a selection of available clays core, and seeing what they recommend.

The air core technique is likely to create a big improvement in recovery in all unconsolidated zones with pebble size or less. A large diameter system may recover cobble size materials too and would create larger samples for metallurgical testing. It should be possible to retain 1 or 2m samples in large porous bags so that they can be drained and weighed. This will enable more reliable estimates of recovery and tonnage factor to be derived.

3. Minor Improvements

Assays: more duplicate work and screening of pulps to see if there is a copper smearing problem should be carried out.

Tonnage factor: weighing dry materials recovered from each meter should enable better data to be obtained. Clay samples are unlikely to dry and would have to be weighed damp and on H_2O^+ determination carried out.

Size fraction analysis: *this is necessary to make an estimate of the proportion of oversize that will be generated and hence crushed to liberate* its copper.

Mineralogy: more quantitive estimates of the proportions of each copper mineral are necessary. A combination of whole rock and XRD analysis of concentrates on a suite of representative composites should enable a reliable model analysis. The previous practice of estimating pyrite contents from sulphur assays when the main mineral is native copper, not chalcopyrite, needs to be discontinued.

Drill logging: drill logging by a competent mineral observer with a binocular microscope on panned concentrates is thought to be desirable for semi-quantitive determinations.

Documentation: it is taken for granted that CMT would not recreate the problems MLMRC have be lack of documentation of work for 25 years.

4. Metallurgical Investigations

As long as samples are kept in porous bags, loose water will drain out and the samples retained until assays are available. Composites for metallurgical or any other analysis can then be produced. In the next exploration stage, an attempt to determine total copper and gravity recoverable copper should be made. Some leaching and flotation tests can also be carried out so that a likely treatment route is known. This will influence later exploration.

5. Mining Investigations

There are not thought to be great problems here, but the proportion of the resource which can be freely dug or scraped compared to that requiring drilling and blasting needs to be known for an improvement in the quality of mining cost estimates. If a driller, an engineer and a geologist discuss the problem, it should be possible to devise a method of recording the ground type during drilling. For instance, air core drillable could indicate free digging and hammer drillable could indicate a need for drill and blast. Some work on suitable pit wall angles also needs to be carried out.

The Copper Clays evaluation is a challenging task on the boundary between alluvial, soft and hard rock evaluations. There will be many opportunities to improve evaluation techniques.

10. EXPLORATION POTENTIAL

In this section, the exploration potential of the whole copper clay's area is considered. This includes the head of the Linda Valley to AMG easterly co-ordinate 384000mE which is the eastern boundary of 1M/95 and ELA5/95. It can be sub-divided into four main possibilities:

1. Copper Clays and extensions.
2. Tabberabberan quartz vein gold.
3. Carbonate hosted lead-zinc.
4. Volcanic hosted copper-gold-silver.

10.1 Copper Clays and Extensions

The three deposits identified are not closed off by drilling and are likely to have extensions. Such opportunities have been termed Mpc or mineralisation-potential copper clays on Figure 1.

This includes the potential identified by the author of Figure 24 (probably Wade) in 1957. These areas are listed from north to south below with estimates of resource potential (rp) or pre-resource mineralisation at an average grade of between 0.6 and 1.2%, say 0.8% copper.

Area	Category	Resource Mt
North of Blocks (Wade, 1957b)	rp	6.0
Lyell Blocks (this work)	prm	4.7
Gap between Blocks and Balance Shaft	rp	1.0
North of Consols (Fig 24)	rp	0.5
West of Consols (Fig 24)	rp	0.5
Lyell Consols (this work)	prm	1.9
Lyell Extended/Pioneer (Fig 24)	rp	1.5
King Lyell (this work	prm	1.5
South/surrounding King Lyell	rp	1.5
Total	rp	**19.1**

If 83% of this potential is converted to a reserve and 72% of this is recovered, then potential copper production is about 91,000 tonnes.

10.2 Tabberabberan Quartz Vein Gold

The gold potential of the Linda Valley area has been addressed by Sillitoe (1984; 1985), Angus (1984) and Jones (1984; 1985). Evidence has been given in section 5.5 of gold-bearing quartz vein stockworks at McDowels, parallel to the North Lyell Fault. There are four areas currently known and possibly worthy of evaluation. These are:

1. McDowel's PA.
2. North flank of Mt Owen, Moore's and Gormanston Gold Mines.
3. Lyell Pioneer Gold workings.
4. Source of Jimmy Watson's old creek alluvials.

There is thus sufficient evidence to believe that Tabberabberan quartz vein stockworks, and associated processes, represent an important part of the metallogenic history of the area. However, to date, none have been large enough to warrant long-term exploitation. If larger deposits were present near the surface, we could expect to see some evidence in the distribution of alluvial workings.

Geoff Cordery (pers. comm., 1995) has suggested that these systems may develop into sulphide-rich systems, such as the Henty deposit, at depth. This is a much more attractive target. As Tabberabberan D2 quartz veins show evidence of local derivation (Cox, 1979, p. 63), the most likely location for pyritic veins is in the Lyell Schists of depth.

10.3 Carbonate Hosted Lead-Zinc

Markham (1966) recovered small isolated grains of honey-yellow sphalerite and galena from his copper clays drill composites. The minerals were not associated with the copper sulphides. Since the Owen Conglomerate hosted galena-barite veins reported by Bird (1984) do not contain anomalous zinc, the Markham Pb/Zn is thought to be from carbonate hosted mineralisation developed in the Gordon Limestone.

Banks and Baillie (1989) and Calver (1995) both report common secondary dolomitisation processes in Gordon Limestone Micrites. Therefore, given the regional linears indicating long-term deep fractures, an anomalous metal basement and the observed galena and sphalerite, it is highly likely that carbonate hosted Pb-Zn mineralisation of unknown dimensions is developed.

The location of such deposits would be difficult. If a geophysical signature is present, it could be targeted. This is unlikely and mapping and sampling followed by reconnaissance drilling would be a favoured exploration strategy. As sulphides are stable in pug derived from Gordon Limestone, a search for galena and sphalerite in heavy mineral concentrates from shallow pug could be a very sensitive technique.

10.4 Volcanic Hosted Copper-Gold-Silver

The gold mineralisation mentioned above may be a leakage indication from a much greater prize; namely an extension of the Mt Lyell Field on the east side of the Great Lyell Fault (GLF). This idea will be more fully developed in a later report. The GLF is thought to be a Tabberabberan DI reverse fault generated at a depositioned/lithological/rheological boundary due to overturned folding generated by the weak hydrothermal alteration zone in the Central Volcanic Complex.

Orebodies such as the Blow, A Lens, Prince Lyell, Lyell Tharsis and North Lyell appear to be truncated by the GLF. Due to the reverse movement on the GLF, the extensions of these orebodies can be expected on the east side of the GLF under the Lyell Saddle - Western Linda Valley area. Unfortunately, depths are likely to be in the -1000 to -1500 RL range, so any orebodies here are probably propositions for the second half of the 21st Century. However, if their existence was confirmed, it would surely have a positive long-term effect on the Company's market profile.

The time to execute such a programme would be when Prince Lyell development is down to the 90 or 100 series. A 1km easterly cross-cut at say, -600 RL and a drilling development drive parallel to and approximately 1.5 km beneath the Copper Clays would be necessary.

11. KEYWORDS

Literature Review; Mine History; Open Cut Potential; Native Copper; Clay; Limestone; Ordovician; Devonian; Cainozoic; Glaciation; Ore Fluids; Mineralisation; Diamond Drilling; Mineralogy; Metallurgy; Mining; Economic Evaluation; Resources; Exploration Potential.

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