

Queen Hill Tin Prospect

Zeehan Tasmania

Technical Review

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Executive Summary

A hard rock tin prospect known as Queen Hill located near to Zeehan in Tasmania is currently under preliminary study for commercial development by Western Metals Limited

Exploration drilling work to carried out by Aberfoyle Ltd in the 1970`s delineated some 7.3 million tonnes of mineralization at an average grade of 0.66% Sn. Higher grade zones within this mineralised envelope were reported as 3.61 Mt @ 1.21% Sn.

The ores are complex and refractory and Aberfoyle put considerable effort into finding process routes to exploit the deposit.

The most promising route seemed to be standard mineral dressing methods to gain acceptable recoveries of the cassiterite into low grade concentrate and upgrade this by a pyro-metallurgical route they called matte fuming.

The project was never taken through to bankable feasibility study level as the development was **halted in 1984** due to **imposition of export quotas** on tin concentrates by the **Association of Tin Producers**.

Aberfoyle was Australia' No. 2 tin producer at that time, but ceased in the late 80`s when reserves in Tasmania and NSW were exhausted or became uneconomic. Queen Hill has remained in Western Metals Ltd portfolio but little work has been done on it in the intervening period. The recent rise in tin price and forecast for future demand has caused attention to be turned on Queen Hill in terms of a preliminary study of all aspects of the deposit.

The writer has reviewed relevant documents in regard to ore treatment of the ore.

The main findings are:-

- ◆ A matte fuming process to treat whole ore, or low grade tin concentrates was successfully developed based on submerged lance technology.
- ◆ An acceptable treatment method for the off-gases was not resolved and remains a major environmental question in any consideration of construction of a fuming plant in current times.
- ◆ The original premise for developing matte fuming changed when more amenable ores were discovered at Queen Hill, and offered an option of processing by conventional mineral processing methods such as those used at Cleveland Tin and Renison Tin mine.

- ◆ The Upper Queen Hill ore is unable to be treated by mineral dressing methods even considering advances in gravity technology such as centrifugal enhanced gravity devices.
- ◆ The addition of a fuming plant to a conventional mineral dressing circuit could be used to improve overall concentrate grades, however, overall recovery would be lower, Capital costs and Operating costs higher.
- ◆ The **maximum mining rate** determined by Aberfoyle, between 150,000-200,000 TPA, **imposes a major constraint** to building a dedicated process plant, as operating costs would be high due to no benefit from economies of scale. However, at current tin prices even at this treatment rate, and by mining ore from the higher grade zones processing at site may be economic.
- ◆ The ores respond to Heavy Media Separation, and although not pursued in the Aberfoyle studies should be borne in mind any future studies as it could be employed to pre-concentrate some of the lower grade ores.

The writer considered requirements for a conventional mineral processing plant and set plant operating parameters at 165,000 TPA @ 1.37 % Sn. tin recovery of 71.5 % and final concentrate grade at 50% Sn. These parameters were based on the ore characterisation and metallurgical test work on drill core from the deposit carried out by Aberfoyle, and the 1983 pre-feasibility study report.

Using a process flow diagram from the test work, a plant incorporating the unit processes shown was developed using standard engineering procedures to estimate **Capital Cost** of plant and equipment to treat the ore at the rate of 165,000 TPA through these processes, and the **Operating Cost** of such treatment.

Fuming

Capex and Opex for a fuming plant was estimated to determine if addition of a 5 tph fuming plant to a conventional process could improve the economics, by increasing recovery and final concentrate grade.

The process plant operating parameters were set at 165,000 TPA at a feed grade of 1.37% Sn. Tin recovery of 76.5 % and final concentrate grade at 5% Sn was used based on Aberfoyle metallurgical test work on drill core from the deposit.

Recovery was increased by 5 % to take into account the requirement to produce only a low grade concentrate.

- ◆ CAPEX for a fuming plant was estimated at \$20 million based on discussion with Ausmelt.
- ◆ OPEX was estimated at \$ 198 / tonne of fuming plant feed based on discussion with Ausmelt

In a **Concentrator / Fuming combination** the Capital cost of the Concentrator would be reduced by around \$1 million as there would be no Gravity Plant. Operating cost would be reduced by around \$3 / tonne due to savings in labor, maintenance, and flotation reagents as a cheaper collector could be used for tin flotation.

Tin recovered from the concentrator would increase by around 100 tonnes per annum compared to the conventional mineral dressing circuit. However when applying a recovery of 90% from the fumer there would be sixty tonnes of tin less than the conventional plant. The Concentrate from the fumer would be 60 % Sn compared with 50% from the conventional plant.

Determination of Mining, Infrastructure and other costs associated with setting up a Greenfield's operation, is not part of the writer's brief. The battery limits and exclusions for the process plant are given in **Section 4** and **5** of this document.

The preliminary **Capital** and **Operating costs** have been estimated based on information available and use of standard engineering methods to a conceptual accuracy of $\pm 40\%$ and are summarised in **Table 1** & **Table 2** below, and detailed in the body of this report. More detailed test work, study and engineering would need to be carried out to refine the process and order of cost accuracy.

The two options are summarized below

Table 1 Conventional Concentrator

Item	Value
Capital	\$15.35 million
Operating Cost	\$ 39 / tonne of ore
Tin Metal in Concentrates	1616 tonnes
Concentrate Grade	50% Sn
Recovery	71.5%

Table 2 Concentrator / Fuming Plant

Item	Value
Capital	\$ 34.3 million
Operating Cost	\$ 75 / tonne of ore
Tin Metal in Concentrates	1556 tonnes
Concentrate Grade	60% Sn
Recovery	69%

Note 1 If a 10 % Tin concentrate was produced, which is what Aberfoyle were planning, this would halve the feed to the fumer and reduce overall operating cost to \$55 / tonne of ore. However the plant would only need to run for half the time, which is not a practical way to run a pyro-metallurgical plant. Halving the size of the plant gets into the area of non-practical design. Aberfoyle planned to treat concentrates from the Cleveland Tin Mine in addition to Queen Hill, and produce a copper matte as well as a tin fume.

Note 2 In regard to whole ore treatment by matte fuming, the handling of the off-gas would be a major cost even if approval was given by the Tasmanian Government. A 10 tph plant would cost in the order of \$35 million, and operating cost would reduce to around \$145 per tonne of ore, but would need to treat the high grade ore to be cash positive at current tin prices

Way Forward Options

- ◆ The information generated in this report be used in a financial model incorporating all aspects being studied by others to assess whether a stand alone operation at site is viable.

- ◆ The mining rate is a major constraint to the economics of a process plant at site, however there are other tin ores in the area which may be able to be acquired or joint ventured and processed through a central milling facility.

- ◆ In Whyalla, South Australia, Ausmelt have a pyro-metallurgical plant which is available for toll treatment of low grade mineral concentrates, including tin, and could be considered if other methods of upgrading tin flotation concentrates proves difficult or uneconomic.

1.0 Introduction

Western Metals Limited has in their portfolio of assets some tin leases in Zeehan, West Coast Tasmania, which were explored and evaluated by Aberfoyle Ltd in the 1970's. in JV with Gippsland Ltd. Aberfoyle was later acquired by Western Metals.

These tin deposits, known as *Queen Hill, Severn and Montana*, are complex and refractory and for various reasons were not sufficiently attractive for Aberfoyle to proceed with exploitation at the time they established the resources.

The Total Mineralised envelope is Tabled below:-

<i>Deposit</i>	<i>Resource</i>
<i>Queen Hill</i>	<i>1.8 Mt @ 0.6% Sn (inferred)</i>
<i>Severn</i>	<i>5.1 Mt @ 0.82% Sn (indicated)</i>
<i>Montana</i>	<i>0.4 Mt @ 1.22% Sn (inferred)</i>
<i>Total</i>	<i>7.3 Mt @ 0.69% Sn</i>

Higher grade zones within this mineralised envelope have been identified - tabled below:-

<i>Deposit</i>	<i>Resource</i>
<i>Queen Hill</i>	<i>0.93 Mt @ 1.39% Sn (Indicated)</i>
<i>Severn</i>	<i>2.37 Mt @ 0.1.11% Sn (inferred)</i>
<i>Montana</i>	<i>0.31 Mt @ 1.45% Sn (inferred)</i>
<i>Total</i>	<i>3.61 Mt @ 1.21% Sn</i>

These prospects are currently being reviewed by Western Metals Limited to determine if economic circumstances and advances in process technology have changed the outlook for these deposits. There is a significant amount of data available which was produced by Aberfoyle and the Geological, Mineralogical, Mining and Metallurgical aspects are part of the review. It is planned that this be done in-house with the assistance of a small number of consultants

The writer, a consulting metallurgist, has been engaged to assist the team on the ore processing aspects by reviewing the approach adopted by Aberfoyle in the context of current technology, all of which needs to be defined in broad terms to gauge the project economics, and assist Western Metals in their decision making in regard to the future of these deposits.

1.1 Approach

The approach was to carry out a desk top study reviewing documents supplied by Western Metals Limited, on work carried out by Aberfoyle on the Queen Hill Prospect, and offer some options on how to proceed. If any possibilities to process the ore were indicated, determine CAPEX and OPEX costs for a treatment plant / s based on Aberfoyle studies, modified to use any more recent equipment or technology, and current circumstances if applicable

Contact was made with some of the Aberfoyle key players involved with the project to get more details and background - they were:-

- ◆ Kevin Foo – Metallurgist who promoted the Matte fuming approach
- ◆ Chris Young – Aberfoyle Geologist
- ◆ Nick Moony – Metallurgist involved with the ore characterization
- ◆ John Robinson – Aberfoyle Group Metallurgist and a former Mill Manager at Cleveland Tin
- ◆ Brian Lightfoot – Ausmelt - Worked on the pilot plant in Kalgoorlie

The documentation supplied is listed (**Appendix 1**)

2.0 Preamble

It is important to put in context Aberfoyle's presence and activities in Tasmania and the mainland in the 70's and 80's compared to the current situation as this will have a bearing on determining the best way to decide what to do with the Queen Hill prospect.

The exploration effort by Aberfoyle in the 1970's & 80's on the West Coast of Tasmania was a natural extension to their other activities in the State where they operated the Cleveland Tin Mine at Luina, a process plant at Rossarden treating tin – tungsten ores from Storeys Creek and Aberfoyle mines on the East Coast, and mining of copper-lead-zinc ore from Que River Mine for processing by E Z Co Ltd (Pasminco) at Rosebery. Aberfoyle also owned the Ardlethan Tin Mine near Wagga in NSW and were the second largest tin producer after Renison in Australia at that time.

The discovery of Queen Hill caused some disappointment when characterisation of ore from the upper lode showed it to comprise sulphides, (mainly pyrite), carbonates, fluorite and silicates. The tin mineral was mainly cassiterite, but occurred in extremely fine particles (a median D 50 of 15 microns), disseminated throughout the ore, 60% in the sulphide and the remainder in the other gangue.

In 1973 Kevin Foo, who was a project metallurgist with Aberfoyle, decided to further his academic studies and enrolled at Imperial College, Royal School of Mines, London to complete an MSc, DIC.

Kevin Foo chose as his thesis, *Beneficiation of the Queen Hill Ore* and concluded that the best way forward was a pyro-metallurgical route as conventional mineral dressing methods of crushing, grinding, sulphide flotation, gravity and tin flotation would only result in very poor recoveries into un-saleable low grade tin concentrates due to the fine grain size of the cassiterite.

To liberate the cassiterite in Upper Queen Hill ore requires a very fine grind; consequently losses to sulphide flotation concentrate were very high due to mechanical entrainment and some un-liberated composites. The cassiterite in the remaining gangue (sulphide flotation tail) was too fine for gravity separation even at natural grain size, and fine grinding had reduced it further - the only route left was cassiterite flotation which requires considerable de-sliming of the feed, hence resulting in losses to slimes. Cassiterite flotation is not very selective even using the best collectors available, so that saleable concentrates could not be made. The selective tin flotation collectors are also very expensive.

Kevin Foo showed that high recoveries could be achieved by treatment of the whole ore by a pyro-metallurgical process, in which the cassiterite (tin oxide) converts to tin sulphide, which volatilises from the melt, and is converted back to tin oxide + SO₂ by means of oxygen, then captured in a bag house as a high grade tin fume (+60%Sn). The SO₂ passes on and has to be dealt with in some way, e.g. stack to atmosphere, sulphuric acid plant, wet scrubbing, wet scrubbing and neutralisation Kevin referred to this as ***Matte Fuming***.

Returning to Aberfoyle Kevin Foo promoted the idea with management and embarked on an R&D program at the CSIRO Division of Mineral engineering in Clayton, Victoria where Dr John Floyd and others were working on a sub-merged lance smelting process called ***Sirosmelt*** (now called ***Ausmelt*** or ***Isa Smelt*** commercially) (**See Appendix II**)

At CSIRO Foo successfully demonstrated on a small scale that submerged lance smelting could be used to treat the Queen Hill Ore, and then moved on to pilot the process. A 4 tph was built at the Kalgoorlie Nickel smelter – this was chosen as a major cost of any smelter is the gas handling and incorporation of this in a stand alone pilot plant would have been prohibitive. In Kalgoorlie the Sirosmelt furnace was hooked into the nickel smelter off-gas system. For the trials Aberfoyle tested material from Cleveland Tin as well as Queen Hill; the rationale was that Cleveland ore, which contained copper and stannite (copper tin sulphide) could also benefit from Matte Fuming in that a copper matte could be made and sold and tin from the stannite could be recovered. At the time Cleveland were selling a low grade copper concentrate (15%Cu) containing tin from the stannite to a Belgian smelter and getting a poor price.

This program in Kalgoorlie was technically very successful.

Note: Mt Isa bought the pilot plant and set it up at Mt Isa copper smelter for Slag cleaning and subsequently commercialised Isa Smelt.

The potential for use at Cleveland Tin changed Aberfoyle focus, in that they had an operating mine that may have been able to use the technology. In addition the exploration program at Queen Hill had identified ore below Queen Hill and other adjacent ore bodies called Severn and Montana. Metallurgical characterisation test work on these showed them to be more amenable to conventional mineral dressing than the Upper Queen Hill ore. (Amenability was judged on cassiterite grain size and ease of liberation, and response to gravity and flotation separation). In particular the Severn ore responded better than some of the fine grained ores at Renison Bell Tin Mine when subjected to similar unit processes employed in the Renison Concentrator. (Severn had a D50 grain size at 65 microns some of the Renison Fault ores are 50 microns). This offered an option to process these ores by standard mineral dressing methods and produce a saleable gravity concentrate, a low grade tin concentrate to be further upgraded by fuming, and had the advantage of reducing fuming plant feed tonnage for a given output. It also offered an option to considerably reduce SO₂ emission in that concentrates would be much lower in sulphur than the whole ore, in fact sulphur would be added to for the SnO₂ to be converted to the volatile SnS – Kevin Foo refers to this variation as *Slag Fuming* as the process was employed at some world smelters to recover tin from primary slag in the tin smelting process. Other smelters such as Freiberg, East Germany, Novosibirsk, Russia and Capper Pass UK had used it for many years upgrade low grade concentrates. Capper Pass treated low grade tin concentrates from various parts of the world including Renison Tin and Cleveland Tin – as such was well proven technology.

Consequently Aberfoyle adopted a development strategy to carry out a feasibility study into the use of fuming within the Group, the location and whether to be matte or slag fuming would be part of the study. A major part of the study would be what to do with the SO₂ generated. Adding on a sulphuric acid plant would be expensive and could not economic on this small scale even if markets could be found. Discharge to atmosphere via a tall stack was not seen as an option for matte fuming, and wet scrubbing would create a weak acid for disposal, neutralisation of this with lime would be expensive, even discharge into sea water was considered. Location at Cleveland Tin had some advantages in that the tails were alkaline and could be used to aid neutralising of an acid effluent from the wet scrubber.

In regard to the Queen Hill ores three options were considered in November 1982 in a document prepared by Dr SS Meik :-

- ◆ a) A flow sheet along the lines of Cleveland Tin and Renison Tin i.e. Staged crushing, Heavy Media Separation to remove light barren gangue as *floats*, primary grinding of HMS *sinks*, sulphide flotation with inter-stage regrind, hydraulic classification, of the sulphide tails, treatment of the coarse fraction by gravity (spirals and tables), with inter-stage regrind, treatment of the fine fraction by cassiterite flotation. This circuit would result in a saleable gravity conc + 50% Sn and a saleable flotation conc +25%Sn
- ◆ b) A flow sheet along the lines of the above - Staged crushing, Heavy Media Separation to remove light barren gangue as *floats* , primary grinding of HMS *sinks* , sulphide flotation with inter-stage regrind, hydraulic classification, of the sulphide tails, treatment of the coarse fraction by gravity (spirals and tables) with inter-stage regrind, treatment of the fine fraction by cassiterite flotation. This circuit would result in a saleable gravity conc. + 50% Sn and a flotation conc. 10% Sn to be sent to a fuming plant together with 1st cleaner tails from the sulphide circuit.
- ◆ c) A flow sheet along the lines of the above - Staged crushing, Heavy Media Separation to remove light barren gangue as *floats* , primary grinding of HMS *sinks* , sulphide flotation with inter-stage regrind, further grinding of the sulphide tails, cyclone de-sliming, treatment of the coarse fraction by cassiterite flotation. This circuit would result in a flotation conc. 10% Sn to be sent to a fuming plant together with 1st cleaner tails from the sulphide circuit.

A Pre-feasibility study was completed in May 1983 which considered the above options but without HMS plant as this was deemed to complicate the process. Treatment rate in the study was 150,000 TPA @ 1.37 % Sn – achieved by mining the higher grade zones; a fuming plant was included in the study and rated at 4tph with a preferred location at Cleveland Tin although other options were considered.

All of this work came to an abrupt halt when the International Tin Council collapsed in 1984 and was replaced by a committee made of members the *Association of Tin Producing Countries* ATPC. To stabilise tin prices an export quota was imposed which affected new projects around the world.

Cleveland Tin, Ardlethan Tin and Rossarden were all coming to the end of their life and Aberfoyle had discovered the Hellyer lead-zinc-copper deposit in Tasmania and focussed efforts on developing this. A pilot plant for Hellyer was set up at Cleveland tin plant which was close by. Subsequently all of Aberfoyle tin activities ceased and they concentrated on other mineral and base metal prospects.

The situation therefore has changed in the intervening years, and the Queen Hill tin prospect needs to be considered without advantages available when Aberfoyle was a force in tin production. The writer has looked at some options on this basis.

3.0 Way Forward Options at Site

One of the major constraints to developing Queen Hill is that the mining rate is limited to between 150,000 – to 200,000 tpa according to the work carried out by Aberfoyle. At this rate the process operating costs will be high compared to Renison due to fixed cost and overheads.

The writer estimated the CAPEX and OPEX cost of a plant at 165,000 TPA @ 1.37%Sn by mining from the higher grade zones, and producing a saleable gravity concentrate and a saleable tin flotation concentrate upgraded by centrifugal gravity methods – similar to **Option a)** above. Metallurgical results were based on the S.S Meik Document

The writer estimated the CAPEX and OPEX cost of a plant at 165,000 TPA @ 1.37%Sn by mining from the higher grade zones, and producing a low grade tin flotation concentrate for fuming – similar to **Option c)** above, and the CAPEX and OPEX of a fuming plant to upgrade the concentrate. An increase in recovery of 5% was applied to the mineral process plant due to the requirement to only produce a low grade concentrate.

3.1 Metallurgical Test Work

For this hard rock primary tin prospect, the objective was to produce saleable tin concentrates at an acceptable recovery. The early stage of investigation comprised basic ore characterisation tests necessary prior to metallurgical beneficiation tests to develop a process flow sheet. This initial test work was regarded as *sighter* or *scout* testing to characterise the ore and comprised:-

- Sizing and assay of crushed samples of the drill core to determine particle and mineral distribution within sized fractions.
- Specific Gravity
- Subjecting the fractions to heavy liquid separation to give a guide to valuable mineral liberation size and amenability to gravity concentration.
- Mineralogical examination of selected fractions to determine the mineral suite present, mineral association and degree of association (composites of gangue and valuable minerals).
- Assay for a range of elements to determine if other metals were present at a level which could be economic.

Following this further work aimed at determining the amenability to beneficiation processes was carried out on the three ores. The work comprised liberation and separation testing using grinding and gravity methods together with assay and mineralogy of separated products,

The practical mineral dressing options to achieve a separation using the properties of minerals are size, specific gravity, magnetic susceptibility, conductivity, colour, floatability and solubility;

From the initial characterisation work the best options to achieve the targeted outcome was regarded as the use of certain combinations of sulphide flotation, gravity and oxide flotation following comminution to liberate the valuable mineral.

The drill core was reduced by crushing microns and heavy liquid separation was carried out on

Beneficiation test work carried out comprised removal of sulphides by flotation, assessment of cassiterite liberation in the sulphide tail and gravity response, de-sliming and flotation of cassiterite from the de-slimed fraction.

3.2 Process Logic and Design Philosophy

Based on samples tested Queen Hill ores may be described as a complex, of medium hardness. The tin occurs mainly as cassiterite (SnO_2) and there are significant iron sulphides mainly as pyrite FeS_2 - other gangue present, fluorite, carbonates and silicates. There are no other minerals present in commercial quantities. The cassiterite is fine grained and disseminated throughout the ore, needs to be ground initially below 200 microns to achieve sufficient liberation to allow concentration to saleable tin grades. Further reduction of the ores needs to be carefully staged to minimise over-grinding and maximise the amount of cassiterite which can be recovered by natural gravity methods, (spirals and tables). Cassiterite particles below 30 microns needs to be recovered by flotation with final upgrading by centrifugal gravity methods such as a Mozley Multi Gravity Separator (MGS) Centrifugal concentrator were not available when Aberfoyle did their test work – since a number of centrifugal devices have been commercialised and allow recovery of finer cassiterite by gravity means to be considered, such as Falcon, Knelson, or Kelsey separators. Of these Mozley MGS is probably the most appropriate. **(See Appendix III)** The upgrading of cassiterite flotation concentrate was not finalised in the Aberfoyle test work and there may be other options such as acid leaching if carbonates are present.

To achieve a reasonable recovery of the tin, a process involving 3 stage crushing to – 12 mm followed by ball mill grinding to reduce the sulphides to a size for flotation and liberate cassiterite from the rest of the gangue. To minimise over-grinding of cassiterite the ball mill needs to be closed with fine screens to ensure early removal of liberated cassiterite from the grinding circuit. Flotation of the sulphides, and concentration of the tin by a combination of classification, gravity separation, and tin flotation, with inter-stage regrinding should result in a medium grade concentrate, acceptable to tin smelters.

The test work indicated that **pre-concentration** was a possibility with Queen Hill ore but as the heavy liquid work was done at fine sizes it could not be considered in this exercise, and Aberfoyle also discounted as an unnecessary complication. However, in any subsequent work assessment of pre-concentration between the crushing and grinding circuits should be carried out. Heavy Media Separation or possibly Jigs could be used in the process flow sheet if the ore is shown to be amenable at coarse size i.e. good weight rejection to floats with minimal loss of valuable mineral.

3.3 Process Plant

Based on the characterisation work and the requirements mentioned above the **Process Plant** proposed would comprise

- 3-stage Crushing of Run-of-Mine ore
- Ball mill grinding to a particle size which liberates the sulphide and tin mineral from the gangue and to a size where the sulphides will float (< 200 microns).
- Flotation to remove pyrite which will interfere with down stream gravity processes
- Hydraulic classification to separate the sulphide flotation tails into feed for natural gravity, tin flotation and enhanced circuits, plus a slime tail (-6 microns) which would be discarded as being too fine for gravity or tin flotation beneficiation methods.
- Ball mill regrinding of selected tailings streams which include sulphides
- De-watering of the tin concentrates in thickeners, followed by filtration to within transportable moisture limits, and storage in a concentrate shed
- Tailings from the process plant would be thickened and delivered to a tailings storage facility – sulphides may need to be stored separately.

3.4 Assumptions

For the purpose of this preliminary cost study the following assumptions have been made based on the S. S. Meik Document.

- The treatment plant will be located on a level Greenfield's site
- Access to the site to be via roads suitable for the use of heavy lifting equipment
- The treatment rate is 165,000 tonnes per annum @ 1.37% Sn, 50 % Sn gravity concentrate a 25 % Sn flotation concentrate and 71.5 % tin recovery.
- The basis of the design has been made based on practice at a number of other operations - equipment sizing and selection is preliminary only.
- The treatment plant will operate 24 hours a day for 365 days a year and 90% availability.
- Workforce numbers have been determined to cover for 4 operating crews working 12 hour shifts on a suitable roster; an appropriate number of management, supervisory and technical staff has been included, and a **site organisation** suggested.

3.5 Exclusions

To develop the capital and operating cost estimates the following exclusions have been made:

- Metallurgical test work and further process investigations
- Geotechnical test work. Cost of process equipment foundation is based on suitable ground conditions available for large equipment.
- Allowance for the variation in head grade, ore type and hardness.
- Mining, geology, administration, environment, occupational health and safety costs
- Tailings storage facility, raw water dam, and water reticulation
- Site Power and water supply.
- Handling and transportation costs
- Royalties
- Personnel accommodation costs
- Refinery and treatment charges
- Marketing and warehousing
- First Fill Consumables
- Any scope changes
- Owner's costs
- Fire fighting equipment
- Plant mobile equipment, new or used – loaders, trucks, forklift, cranes
- Interest during construction, project financing costs and financing fees
- Import duties, Corporation taxes and Royalties
- Permitting costs
- Schedule delays
- Sunk costs Escalation
- Preparation of Development Proposal and Environmental Management Plan Any other statutory legal requirements

3.6 Battery Limits

The limits of the preliminary cost study are:

- ROM pad
- Delivery side of tailings disposal pumps
- Concentrate storage at the process plant
- Power supply to on-site sub-station
- Process water from the tailings storage facility and the raw water dam

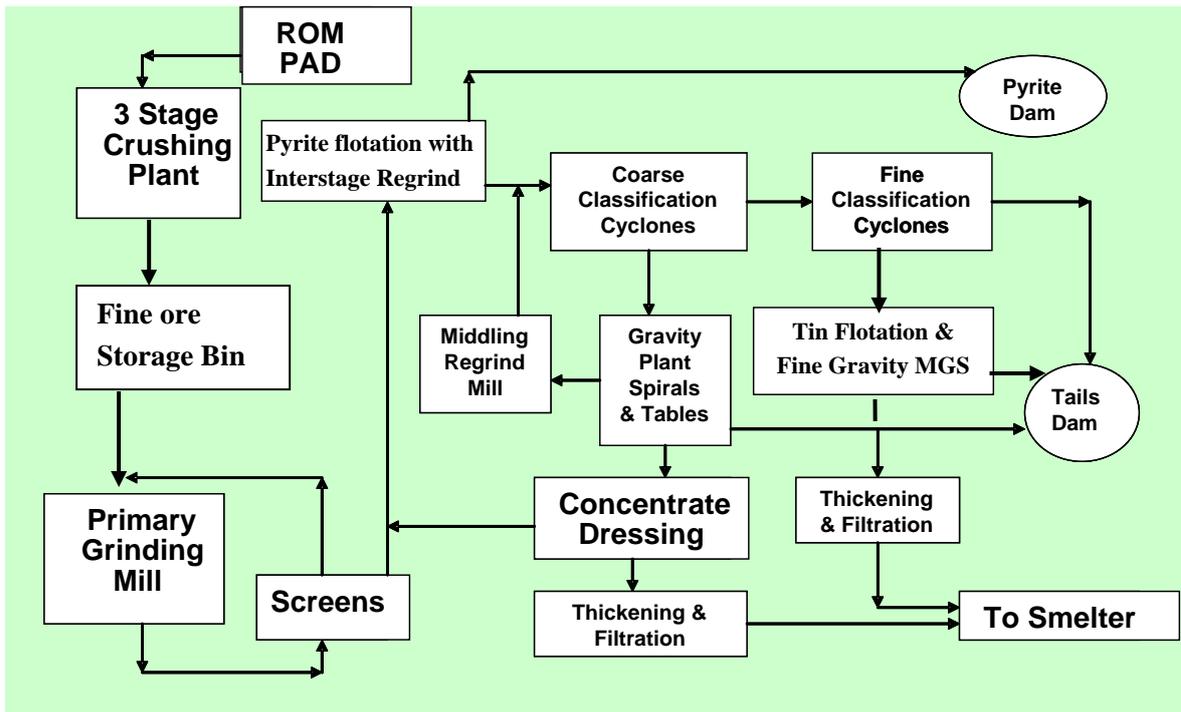
3.7 Data and Information

The basis of the capital and operating cost estimate encompasses the following:

- Basic design criteria, current labour and power costs.
- Process description from conceptual flow sheet based on Aberfoyle test work
- Major Mechanical Equipment List comprising: -
 - ROM Stockpile Feeders
 - 3-stage Crushing plant including screens, conveyors - assumes a top size of 600mm for the ROM Ore -- important as this affects the primary jaw crusher selection a smaller size is better in this case as will result in a cheaper crushing plant
 - Fine ore storage - 1000 tonne bin
 - Ball Mill
 - Fine Screens
 - Hydro-cyclones / Slurry Pumps
 - Sulphide flotation
 - Sulphide regrind Mill
 - Spirals
 - Shaking Tables
 - Tin Flotation
 - Mozley Multi Gravity Separator (MGS)
 - Regrind Ball Mill
 - Concentrate Thickener
 - Concentrate Filter
 - Tailings thickener

3.8 Process Flow Sheet

The process flow sheet below shows 3 stage crushing to – 12 mm followed by ball mill grinding to liberate the cassiterite from the gangue, sulphide flotation with inter-stage regrind to remove pyrite, and concentration of the tin by a combination of classification, gravity plant and tin flotation to produce concentrates acceptable to tin smelters.



3.9 Design Parameters for processing Queen Hill ores

Ore Characteristics

Specific Gravity	t/m3	3.0
Run-of-Mine moisture	% H2O	5.0 %
Bulk Density broken rock	t/m3	1.6
Compressive Strength	Kg/cm2	n/a
Work Index	kWhr/t	Assumed 18.0
Abrasion Index		n/a
Run-of-Mine top size	.mm	Say 600mm

Crushing Plant Operations (3 stage crushing)

Annual throughput target	Tonnes per annum	165,000
Hours per shift	-	8
Shifts per day	-	1
Days per week	-	6
Weeks per year	-	52
Plant utilisation	%	40
Nominal Throughput	Tonnes per hour	100
ROM Top size	Mm	600
Crusher Product size	P80 mm	12
ROM ore storage	Tonnes	5,000
Crushed ore bin storage	Tonnes	1000

Concentrator Operations

Annual throughput target	TPA	165,000
Operations	Hours per shift	12
“	Shifts per day	2
“	Days per week	7
“	Weeks per year	52
Utilisation	%	90%
Treatment rate	Tonnes per day	500
Treatment rate	Tonnes per hour	20

Metallurgical Parameters

Ore Grade	% Sn	1.37
Annual Feed Tonnes	TPA	165,000
Tin Recovery	%	71.5
Tin metal in conc.	TPA	1616
Gravity Tin Metal	TPA	1293
Flotation Tin Metal	TPA	323
Gravity Conc. Tin grade	%Sn	50
Gravity Concentrate	Dry tonnes per annum	2586
Flotation Conc. Tin grade	%Sn	25
Flotation Concentrate	Dry tonnes per annum	1292
Total Tin metal in Conc.	TPA	1616

4.0 Process Plant Capital Cost Estimate

Major Equipment	Capital Cost Estimate (\$M)
A 1 - Crushing Plant - 3 Stage comprising a primary jaw, secondary cone and two tertiary cone crushers plus associated screens and conveyors – note top size of ROM ore fixes the size of the jaw crusher – assumed 600mm	\$3.0
A2 Concentrator	
Primary Grinding Ball Mill	0.6
Sulphide Flotation Plant	0.75
Sulphide Re grind Ball Mill	0.3
Gravity Plant - Spirals, Tables	0.3
Gravity Re grind Mill	0.4
Tin Flotation + Mozley MGS	0.75
Concentrate thickeners	0.35
Concentrate Filters	0.25
Tailings Thickener	0.4
Agitated tanks (including reagent mixing)	0.4
Cyclones / Pumps / Motors	0.5
Item A2 Sub-total	\$5.0

B – Other Items by Factoring	A 2 x factor	\$
Instrumentation / samplers/ reagent feeding	A2 x 0.08	0.40
Plant services Compressors water pumps etc	A2 x 0.08	0.40
Concentrate handling system	A2 x 0.08	0.40
Main Process building	A2 x 0.25	1.25
Auxiliary Buildings	A2 x 0.11	0.55
Electrical installation	A2 x 0.19	0.95
Piping Installation	A 2 x 0.14	0.70
Equipment Installation	A2 x 0.21	1.05
	Items B Sub Total	5.7

Item C - Total Installed Cost

Equipment & Installation	A1 +A2+ B	\$13.70
EPCM – Engineering Procurement & Construction Management	A1 + A2 + B x 0.12	1.65
	Grand Total	\$15.35

4.1 Process Equipment Inclusions

The estimate includes crushing, grinding, fine screening, sulphide flotation, cyclone classification, gravity, tin flotation, thickening and filtration of concentrates, thickening of plant tails sized to treat 165,000 TPA. Major process equipment costing is from recent vendor quotations for similar projects based on preliminary design parameters and test data. These costs need to be firmed up in later study stages – it should be noted that with the current global activity in the mining mineral and metal industry all project costs are escalating on a short term basis.

4.2 Engineering, Procurement and Construction Management

Based on in-house information for a number of projects similar in scope and scale. The EPCM costs do not cover geotechnical testing, surveying, material testing, warehousing and the contractor's direct construction supervision and other owner's costs.

5.0 Process Plant Operating Cost Estimate

Preliminary Operating Cost Estimates exclude:

- Tailings storage facility wall lifts
- Transport handling charges
- Marketing, refinery and treatment charges for concentrates
- Effluent treatment
- Royalties
- Interest charges and tax
- Mining, geology, administration, environment, occupational health and safety costs.

Indicative Operating Costs composition

Consumables

- Crusher wear parts
- Grinding mill liners
- Grinding media
- Flotation reagents
- Filter Cloths
- Labor
- Power (installed estimated at 2 MW)
- Maintenance

5.1 Labour

The list below is an estimate of the Management and Labour required to operate the proposed concentrator – wages, salary and on-costs based on current rates in Tasmania

Number	Position	Salary	On Costs 40%	Annual Cost \$
1	Mill Manager	150,000	210000	210000
1	Planner / Met Clerk	60,000	84000	84000
1	Plant Met	120,000	168000	168,000
1	Mill Foreman	100,000	140000	140,000
4	Shift Boss	80,000	112000	448,000
20	Shift Operators	60,000	84000	1680,000
4	Day Team Crushing	50,000	70000	280,000
1	Maintenance Supt	120,000	168000	168,000
1	Electrical Supt	120,000	168000	168,000
2	Elect /Instr Tradesmen	70,000	98000	196,000
4	Mechanical Tradesmen	70,000	98000	392,000
1	Chemist	70,000	98000	98,000
2	Assay Technicians	50,000	70000	140,000
2	Met Technicians	50,000	70000	140,000
45	Total			4,312,000
	Cost per Tonne			\$26.13

5.2 Consumables

The reagent and grinding media costs were estimated in \$ per tonne based on similar operations

Item	Tonnes per annum	Cost per tonne \$	Total Cost \$
S Float Collector	20	1600	32,000
Copper Sulphate	30	3000	90,000
Frother	12	3000	36000
Tin Float Collector	30	9000	270,000
Flocculants	15	5000	75,000
Grinding Media	165	1200	198,000
Jaw Crusher liners			10,000
Cone Crusher Liners			10,000
Screen Panels			40,000
Ball Mill Liners			70,000
Cyclone Parts			20,000
Filter Cloths			10,000
Total			\$861,000
Cost per tonne treated			\$5.2

5.3 Power

Power demand has been based on an estimate of the installed equipment as shown in the equipment list above. The estimate of the consumed power has been made to determine the annual power costs based on equipment operating hours. Unit cost of Power (8 Cents per kWh) and is typical for this region.

Item	MW	Cost per kWhr \$	Total Cost \$
Installed Power	2.00		
Total consumption = Load Factor 0.70 and plant running Time 90 % x Installed Power	1.26	8cents	1,008,000
Cost per tonne treated			\$6.10

5.4 Maintenance

Item	Basis	Total Cost \$
Maintenance Materials	4% of installed equipment	320,000
Cost per tonne treated		\$1.94

5.5 Operating Cost Summary

Area	Unit Costs \$ / Tonne	Total costs per annum \$
Labour	26.13	4,312,000
Consumables	5.20	861,000
Power	6.10	1,008,000
Maintenance	1.94	320,000
TOTAL COSTS	39.37	\$6,501,000

6.0 Fuming Plant Capital Cost Estimate

The process plant operating parameters these have been set at 165,000 TPA at a feed grade of 1.37% Sn. Tin recovery of 76.5 % and final concentrate grade at 5% Sn has been inferred based on Aberfoyle metallurgical test work on drill core from the deposit. This would be along the lines of Option c) flow sheet, no gravity plant; recovery increased by 5 % due to the requirement to produce only a low grade concentrate.

- ◆ Assume a feed rate at 5 tonnes/hr of flotation concentrates at 5 %Sn content.
- ◆ Annual capacity 34,000 tonnes of concentrate per annum.

This gives in excess of 1700 tonnes of tin metal contained in 34,000 tones of low grade concentrate feed to the fuming plant. A 60%Sn content fume will be produced at 90% recovery.

A fuming plant based on Ausmelt sub-merged lance technology would cost in the order of \$ 20 million which would comprise

- ◆ \$ 8 million for Furnace, Design Engineering and Licence.
- ◆ \$ 12 million for gas handling system, bag-house, scrubber and stack.

7.0 Fuming Plant Operating Cost Estimate

The plant will require 20 operators on a 4 shift basis and will be supervised by a Manager, a Non-technical supervisor and a Plant Metallurgist.

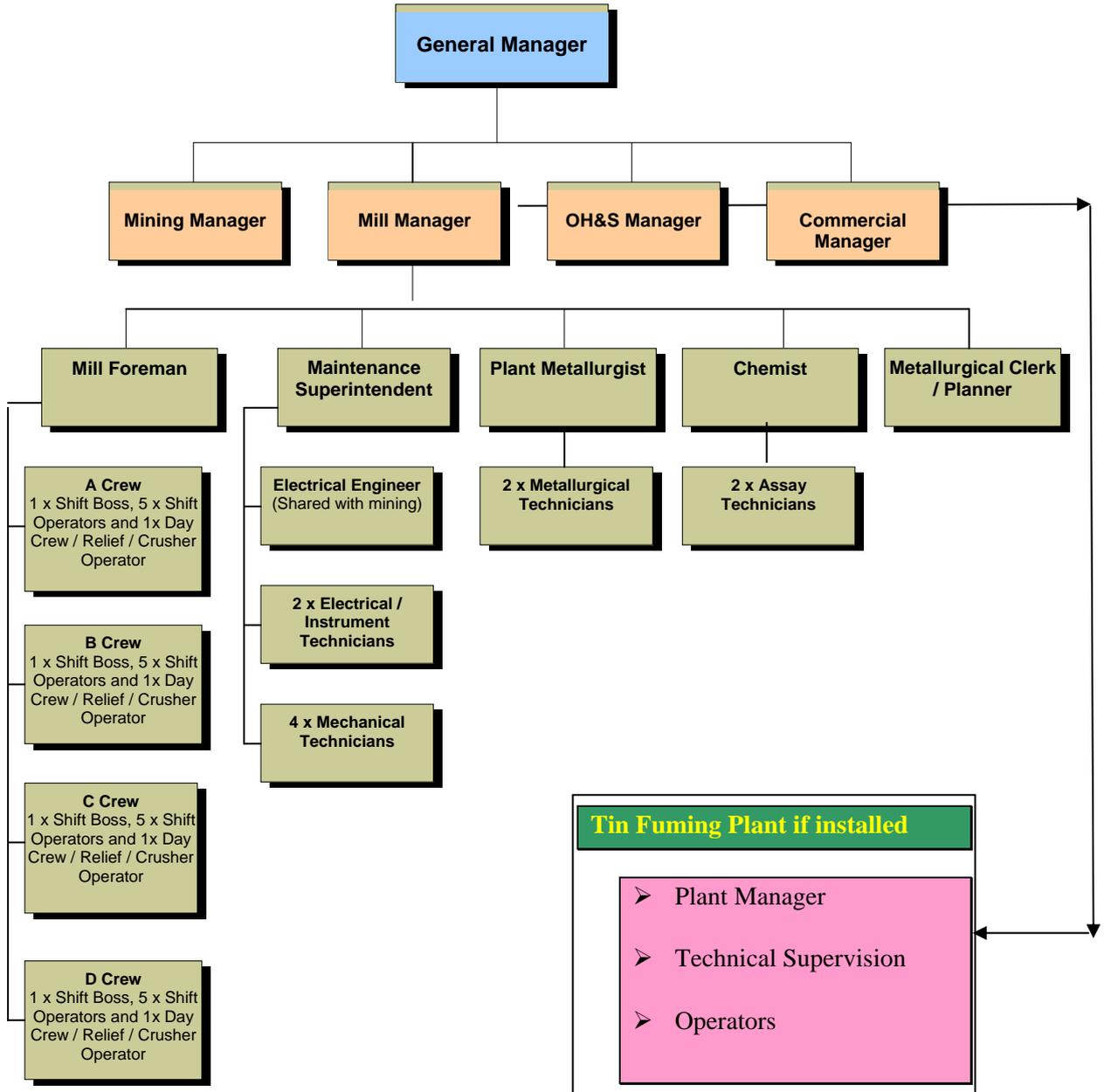
The furnace will consume the following materials + power:

- ◆ Coal - as a reductant and heat source
- ◆ .pyrite - sulphidiser for SnO₂ conversion to Sn S
- ◆ Magnetite- iron flux for SiO₂ content.
- ◆ Limestone- CaO flux for slag.
- ◆ Slaked lime- for gas scrubber to fix SO₂ and Fluorine from stack emissions.
- ◆ Refractory consumption estimated to cost \$500,000 per annum allowing for one full reline of furnace per annum.

Fuming plant Operating Cost Estimate for 34,000 tonnes of low grade concentrate per annum

Item	Quantity Per Annum	Unit cost	Total cost	Cost per tonne
Labour	20	100000	2000000	
Supervision	3	150,000	450000	
Power	0.5MW installed	8cents	250,000	
Coal	10,000	\$75 /tonne	750,000	
Sulphide	12,500	\$40	500,000	
Magnetite	7000	\$130	910,000	
Limestone	2250	\$80	180,000	
Slaked Lime	3500	\$230	800,000	
Refractories	1		500,000	
		Total	6,340,000	186

7.0 Suggested Site Organisation Chart



Appendix I

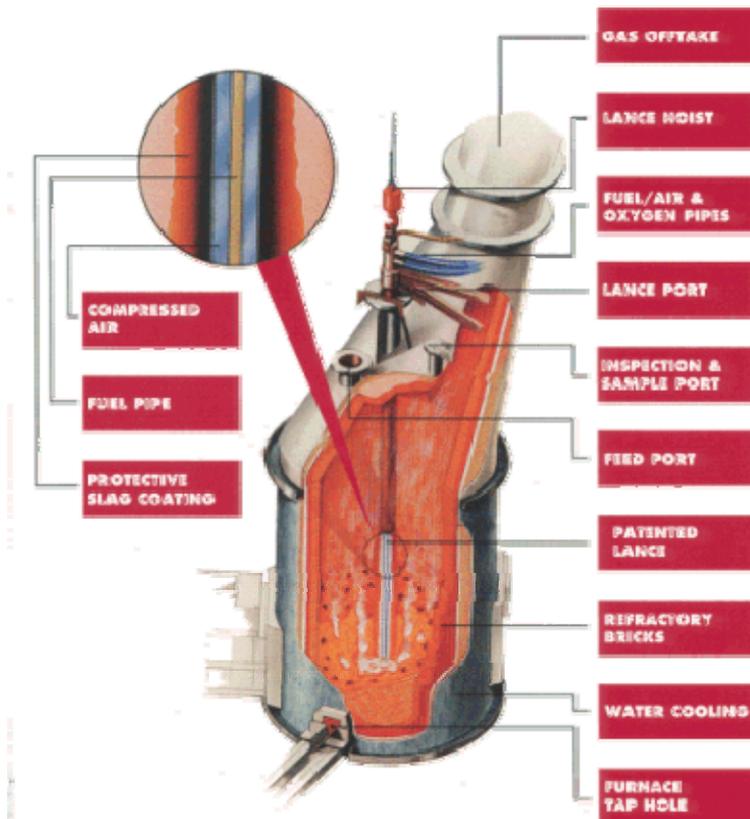
Documents Reviewed

Title & File Number
1799 Process Design Study for beneficiation of a tin ore from Queen Hill Tasmania by Kevin Foo September 1974
1805 Matte Fuming Appropriation requisition support document August 1978
1806 Economic Feasibility Cost and Marketing study August 1978
1822 Matte Fuming Appropriation requisition support document March 1979
1826 Memo Queen Hill Drill Core Assays November 1979
Presentation to Aberfoyle Board 21 /9/ 81 Kevin Foo
1836 Pelletisation and pre –reduction of Queen Hill Fume Concentrates with Coal Powders –Dr V .N Mishra September 1981
1837 Progress Report – Queen Hill Joint Venture December 21 st 1981 J Sise
1839 Progress Report – Queen Hill Joint Venture June 21 st 1982 Richardson & Sise
1840 The Zeehan Tin project Tasmania. Tim Hopwood October 1982
1843 Queen Hill Upper – Progress Report No 1 S Meik October 1982
1844 Zeehan Deposits – Progress Report No 1 S Meik November 1982
1848 Annual Report Exploration Licence 47/71 Queen Hill, Tasmania. December 21 st , 1982
ABR/MET10 Tin Beneficiation in Aberfoyle feasibility Study Volume 2 Task Force Final Report M Walton. March 1983
ABR/MET 11 Tin Beneficiation in Aberfoyle feasibility Study. Volume 3. Economic study of Possible Commercial Applications D S Conochie March 1983
1849 Zeehan Project Pre feasibility Study Report. K G Palmer May 1983
1858 Zeehan Tin Deposits Tabulated Petrological Descriptions. J A Anderson September 1987
1864 Zeehan Tin Deposits, Tasmania C H Young , April 1990

Appendix 11

Ausmelt Furnace

The Ausmelt furnace is a totally enclosed refractory lined vessel that uses a lance to inject fuel and air into the bath. The fuel combusts at the tip of the lance, thereby heating the furnace contents, while the injected gases cause vigorous agitation and rapid process reactions.



Feed and fluxes are dropped into the furnace through a feed port in the roof and the off-gases are ducted from the top of the furnace and delivered to a gas handling system .

As the reactions in the furnace are rapid, only a short residence time is required to process most materials. This means furnaces can be much smaller than more conventional designs, leading to specific operating and cost advantages.

Conditions in the furnace can be controlled precisely by adjusting feed, fuel and airflow rates.

Appendix 111

Gravity Equipment Options

The choice of gravity separation equipment for use on Queen Hill ores is limited to a few options due to the size range of the liberated cassiterite, cassiterite distribution within the size range identified for treatment, and the low sg differential between pyrite and cassiterite.

Conventional jigs such as Yuba-Richards, Pan American, Bendalari, Denver, and Gekko IPJ, will not work on this size range but could be considered for pre-concentration of the ore at coarse size ranges - between the crushing plant and the primary grinding plant. Heavy Media Separation could also be applied here

Flowing film concentrators such as spirals and shaking tables will work down to about 30 microns, but will also beneficiate some of the sulphides and any other heavy minerals present such as rutile and will need dressing prior to sale to smelters.

Natural gravity devices which go below this size such as vanners are no longer an option having ceased being manufactured due to replacement by other devices and processes such as flotation.

To separate down to say 10 or 20 microns cassiterite, the selection is currently limited to devices that enhance natural gravity forces through high-speed rotation of the machine or the pulp. It can be expected that other heavy minerals present will also concentrate to some extent

Equipment in this category includes the: -

- Knelson Concentrator
- Falcon Concentrator
- Kelsey Jig
- Mozley MGS
- Hydro-cyclones

Considering the above list the **Knelson concentrator** is not regarded as a possibility, the combination of centrifugal force and back-pressure water that keeps the mineral bed open should achieve a good separation but they operate on a batch basis. If the latest commercial semi-continuous unit can be demonstrated to be industrially robust the Knelson may find use in this type of application - the units are compact and high capacity but are not installed in tin anywhere at this time.

In regard to **Falcon**, they also produce a simple continuous unit, which is essentially a centrifuge with a provision to remove heavies through a slot from the bottom of the bed formed in the spinning bowl. The lights in the top layer of the bed travel across to a second slot or launder. More recently Falcon has introduced a semi-continuous unit which is having some success at TANCO in Canada on very fine material. Renison have been testing them and they may have place in the Tailings re-treatment plant

The **Mozley Multi Gravity Separator (MGS)** has the necessary features to achieve a separation on fine cassiterite however, to determine the optimum conditions for the MGS requires an extensive test program, as there are many variables on the machine such as the drum angle, vibrator frequency and amplitude, and dressing water. The double drum units can be operated in parallel or in series, which provides another set of variables.

The commercial Mozley units available are low capacity; application would be limited to about 2 tonnes per hour per drum and would be suitable for upgrading tin flotation concentrates

The Kelsey Jig is probably the best device currently available capable for treatment of the material on a continuous basis. The unit is compact and high capacity. As with the Mozley there are number of variables and extensive test work is necessary to optimise the parameters. Selection of the most appropriate ragging is a prime objective in the preliminary test work program. It is likely that a two-stage process would be necessary to achieve the metallurgical objective.

Due to capital cost and operating cost the Kelsey Jig to be considered in a circuit with other devices which could reduce the amount of material sent to Kelsey Jigs and therefore the total number required.

There are a number of Kelsey Jig installations on tin beneficiation at several mines around the world eg Renison Tin Mine Tasmania, and Minsur San Rafael Mine, Peru consequently Roche MT, the supplier, has amassed a great deal of experience on a variety of tin ore types.