MEMORANDUM

To: Geoff Chapman

From: Ben Grguric

Subject: **Queen Hill tin mineralogy evaluation**

Date: 10th May 2007

Reference: Queen Hill mineralogy memo1.doc

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Below are the results of the desktop evaluation of some key aspects of the tin mineralogy (relevant to processing) of the Queen Hill deposits, comprising Queen Hill, Severn and Montana. The majority of data for evaluation were obtained from existing Aberfoyle Limited data, including geological and metallurgical reports, several hundred thin section descriptions, and approx. 4200 assays of drill core.

GEOLOGICAL CONTEXT
In essence, the Queen Hill deposits are Cleveland/Renison Bell-type tin deposits in which granite-derived hydrothermal fluids carrying Sn, S and other base metals were funneled along structural conduits and reacted with suitable lithologies such as dolomite, chert and tuff horizons to precipitate sulphide-rich lodes containing cassiterite. Typical associated gangue minerals include pyrite, quartz, carbonates (siderite, ankerite, calcite, huntite) and fluorides (fluorite, sellaite). The predominance of pyrite over pyrrhotite is a significant point of difference between the Queen Hill and Renison Bell deposits. In addition to the main high temperature tin mineralizing event, an interpreted later-stage, cooler fluid event has resulted in the formation of Pb-Zn-Ag sulphide lodes (Taylor's and Clarke's Lodes) which are not significantly tin-bearing and thus have been excluded from the May 2007 resource evaluation. These lodes were the focus of early 20th century mining efforts.

KEY MINERALOGICAL ASPECTS
On the basis of existing metallurgical reports the key mineralogical aspects of the deposits which potentially impact conventional processing and tin recoveries in the Queen Hill deposits are:

1. Cassiterite grainsize and association.
2. Importance and distribution of stannite.

These are discussed in turn.

Cassiterite grainsize and association

All previous reports indicate that the most significant hurdle to conventional processing of the Queen Hill deposits is the fine average grainsize of cassiterite in the ores. Grainsizes from various reports and studies are given below:

Deposit	Cassiterite Grainsize	Source
Queen Hill	70wt.% < 20 microns	Foo (1974)
Queen Hill	Av. 20 microns	Young (1982; 1990)
Queen Hill	50% passing 21 microns	Meik (1982)
Queen Hill	Av. of max. in 80 samples = 57 microns	this study
Severn	50% passing 59 microns	Meik (1982)
Severn	Av. of max. in 72 samples = 127 microns	this study
Montana	50% passing 31 microns	Meik (1982)
Montana	Av. of max. in 15 samples = 54 microns	this study

The data for this present study were based on the compilation of all thin section descriptions of samples which contained cassiterite mineralization. In these descriptions, a range of grainsizes (min. to max.) was provided rather than a mean, and thus the mean of the maximum represents an optimistic 'upside' case. Overall a trend can be seen of decreasing cassiterite grainsize in the three deposits in the order Severn > Montana > Queen Hill, which corresponds precisely to the increasing difficulty of processing as found by Meik (1982). By way of comparison, documented cassiterite grainsizes for different ore types from the Renison Bell deposit are given below:

Ore type	Cassiterite Grainsize	Source
Stratabound	Av. grainsize 150 microns	Morland (1990)
Fault ore	Av. grainsize 50 microns	Morland (1990)
Fracture ore	Av. grainsize >150 microns	Morland (1990)
Rendeep	Av. grainsize 100 microns	McQuitty et al. (1998)

Morland (1990) noted that Renison Bell ores averaged 75.2% Sn recovery to concentrate, with Fault ore being the least amenable to concentration, no doubt due to the fine average grainsize of the cassiterite component in this material.

Meik (1982) indicated that of the Queen Hill group of deposits, only Severn ores achieved acceptable recoveries using a relatively conventional flowsheet of milling followed by gravity separation and some flotation. A more complex integrated flowsheet incorporating sulphide flotation, gravity and cassiterite flotation with upgrading by matte fuming was necessary to generate acceptable Sn recoveries from the Queen Hill and Montana deposits. Laboratory testwork showed that Sn recoveries of over 75% were possible using this processing route.

On the basis of reports and petrographic descriptions, there is some conflicting data on the association of cassiterite and gangue minerals in the Queen Hill deposits. In his detailed study, Foo (1974) concluded that 60% of the cassiterite in Queen Hill ore was disseminated through pyrite, the remainder associated with

silicates, carbonates and fluorite. This conclusion was based on ore characterisation using a series of techniques including optical microscopy, electron microscopy and selective acid dissolution. Meik (1982) on the other hand, reported no major cassiterite/sulphide association in Queen Hill, Severn or Montana ores. Meik's observations do not make sense from the point of view of the process flowsheets given in his report, which include sulphide flotation to a final concentrate thus indicating a significant Sn component in the sulphide fraction. It is likely that Meik's conclusion on cassiterite associations was drawn from the collated thin section descriptions (Anderson 1987) in which the pyrite/cassiterite association is rarely noted. The concern is that this compilation included some erroneous mineral associations based on transcription of cassiterite associations in transmitted light (i.e. thin section) alone, without mention of reflected light petrography (i.e. polished section). Cassiterite in non-sulphide gangue minerals is readily identified in transmitted light, however fine cassiterite grains embedded in pyrite or pyrrhotite would only be identifiable in reflected light. By way of example:

Report CMS 81/7/53 by H.W. Fander (19-8-1981) is included in Appendix III of Size (1981) and describes the cassiterite association in sample 250399 (Severn sample from drillhole G74 370.3m):

"This contains pyrite as the only sulphide; the pyrite may represent recrystallised pyrrhotite. It contains cassiterite inclusions of all sizes from 10 microns upward."

The entry for the same sample in the compiled petrographic descriptions (Anderson 1987) lists the mineral associations of cassiterite as tourmaline, fluorite and quartz, with no mention of a pyrite association. The suspicion is that only the gangue associations of cassiterite visible in transmitted light were transcribed in this document.

Overall, the weight of evidence based on Foo's (1974) ore characterization and the assays of sulphide flotation concentrates presented in the metallurgical testwork would support a conclusion that a significant proportion of the cassiterite in the deposits is intimately associated with pyrite and pyrrhotite, however, additional confirmation of this using reflected light or SEM methods on a selected suite of samples may be justified.

Importance and distribution of stannite

Stannite is a copper, iron, tin sulphide (Cu_2FeSnS_4), well documented from numerous hard rock tin deposits worldwide. It occurs in all three of the Queen Hill deposits, typically associated with other base metal sulphides containing Cu, Pb, Zn and Ag. With regard to its metallurgical behavior in these deposits, Young (1990) stated that "stannite contributed to poor recoveries" but did not elaborate further or present any evidence. Because of recovery issues associated with stannite in other deposits (mainly gravity separation or cassiterite flotation related), Aberfoyle Limited made efforts to quantify the stannite content of the Queen Hill ores using two methods:

1. Conventional petrographic analysis of polished sections.
2. Partial leach methods.

Of the 167 mineralized samples (Sn > 0.1%) in Anderson's (1987) petrographic description compilation, 35 contained optically identifiable stannite. The distribution is as below:

Deposit	Prop. containing cassiterite only	Prop. containing stannite only	Prop. containing cassiterite and stannite
Queen Hill	79%	16%	5%
Severn	81%	9%	10%
Montana	71%	19%	10%

Although the distribution of the samples has not been examined in 3D, it should be noted that 43% of all the stannite-bearing petrographic samples in the Queen Hill deposit came from Taylor's and Clarke's Lodes (excluded from the resource model), and many of the remainder are described as 'trace' occurrences.

The second method of quantifying the stannite content, or more correctly the 'non-cassiterite Sn content' of Queen Hill ores, was by partial leach. Total Sn in the drill core samples was determined by XRF, and the 'stannite' content determined by performing atomic absorption spectroscopy on a nitric + hydrochloric acid digest of the sample. The leach solution attacked sulphides (and other phases) but left cassiterite in the filtrate. These partial leach assays are recorded in the Queen Hill data base as "Stannite ppm" which refers to the non-cassiterite Sn content of the sample. A description of the method is given in an Aberfoyle Limited file note by R.V. Sale dated 13-2-1972, and is included in document No. 1826. Discussions with assay chemists from ALS indicate that the method is perfectly valid and has been utilized by other tin producers (in some cases with modifications) in their ore characterization programmes.
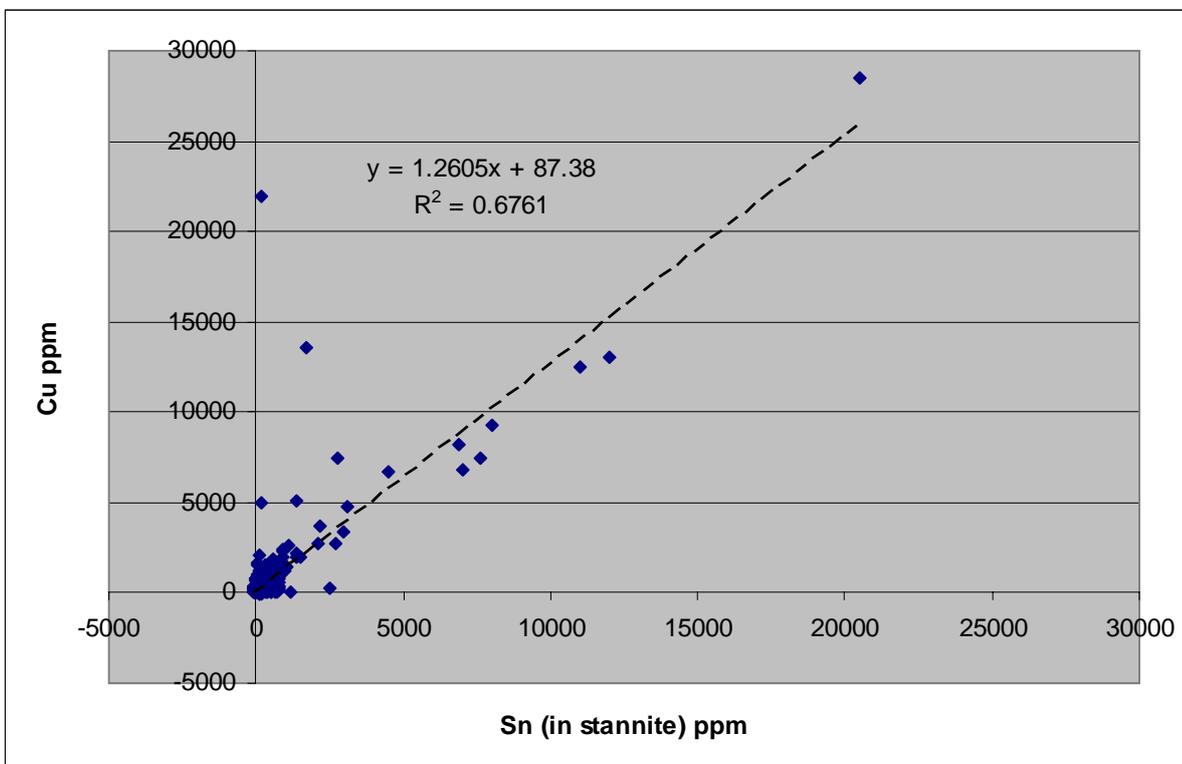
Of a total of 4286 assayed samples in the complete Queen Hill database (only 1870 of these have > 0.1% Sn), 1304 have Stannite analyses, and of these only 429 are from samples with total Sn contents > 0.1%. Although not complete, the available Stannite assays give a good indication on the distribution of the non-cassiterite Sn content of the ores. The distribution is indicated in the histogram below.
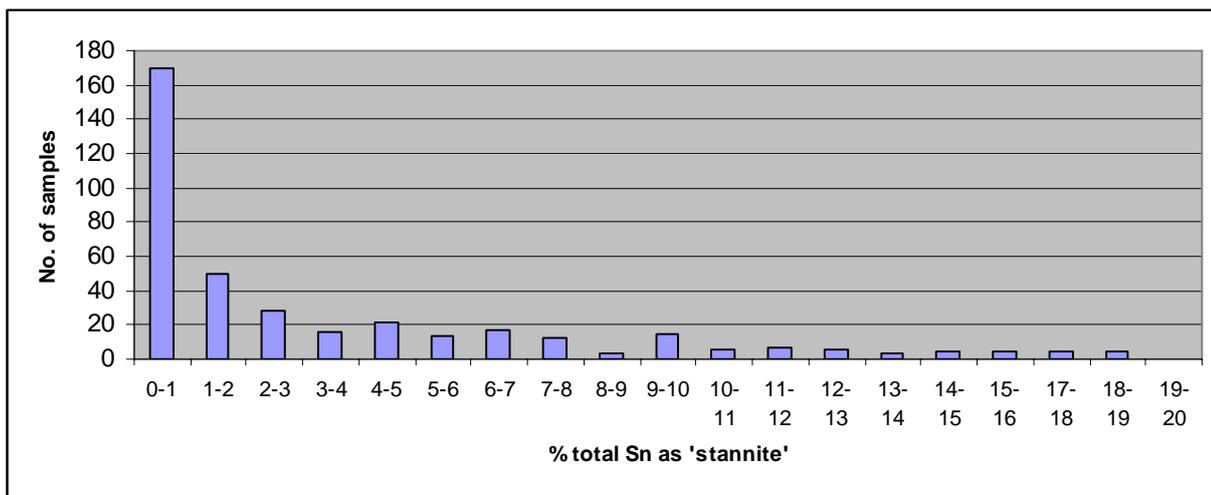
The partial leach data presented in the histogram is not broken down by individual deposit, but it serves to illustrate that a significant number of samples above the 0.1% Sn cutoff have less than 3% of their total Sn content in non-cassiterite form.

Important controls on the stannite content of a Sn-bearing hydrothermal deposit are the temperature and activity of Cu in the depositing hydrothermal fluid; stannite being a Cu-bearing sulphide. It follows then that the more Cu enriched parts of the ore system have the potential to host more Sn mineralization in the form of stannite. This is a key reason why the base metal-rich Taylor's and Clarke's Lodes in the Queen Hill deposit contain significant stannite. Correlations between the Cu content and 'Stannite' ppm in the dataset (below) show a positive trend, indicating Cu assays may be of some use in roughly predicting Stannite content in the absence of partial leach data.

The chart shows the trend line equation $y = 1.2605x + 87.38$ with $R^2 = 0.6761$, plotting Cu ppm against Sn (in stannite) ppm.

Use of other trace elements as proxies for stannite content is unlikely to work as stannite in most occurrences is essentially stoichiometric.

Overall, the Queen Hill deposits appear not to host markedly significant amounts of non-cassiterite Sn, particularly if the separate base metal lodes are not included in the ore reserve. More importantly the whole issue of stannite being deleterious may be irrelevant if the process flowsheet for the deposits originally designed by Aberfoyle Ltd is followed. Stannite, being a sulphide, will report to the sulphide flotation concentrate together with cassiterite/pyrite composites and will be decomposed in the matte fuming process.

DISCUSSION

The employment of matte fuming appears to alleviate recovery problems associated with fine, not easily liberated cassiterite grains embedded in iron sulphides, and any significant stannite content of the Queen Hill ores. The matte fuming process involves feeding crushed ore or concentrate to a smelting vessel containing a copper sulphide matte overlain with a thin layer of iron silicate slag at 1200°C. Cold air is injected through the matte via a slag-protected steel lance, causing rapid matte oxidation and turbulent mixing of the bath. These reactions can create sufficient exothermic heat to drive the process, provided enough sulphides are present in the feed. Iron oxides from matte oxidation combine with silicates from the feed to form a slag which can be tapped as required and discarded. Tin is rapidly fumed off from the molten bath as stannous sulphide and is collected as tin oxide in a baghouse. Matte remains in the vessel as a heat and chemical reservoir and gradually accumulates copper and any precious metals. The matte can be tapped when the matte grade is high enough for sale or possibly blown through to blister copper (Anon. 1978).

As mentioned it is expected that stannite will be readily decomposed during matte fuming, with Sn released as stannous sulphide and Cu reporting to matte. Any precious metals in the sulphide assemblage (e.g. Ag) will also report to matte and add to the revenue stream.

Previously, the stumbling block to treatment of Queen Hill ores has been the cost of processing when a matte fuming step is included in the process flowsheet, but recent hikes in the Sn price may have changed the overall economics to the point where treatment is feasible.

CONCLUSIONS AND RECOMMENDATIONS

- **The main issues associated with the conventional processing of Queen Hill and Montana ores relate to the fine grainsize of cassiterite. Severn ores appear to more closely resemble Renison Bell ores (i.e. coarser cassiterite grainsize) and are thus less problematic.**
- **Stannite is present in all three deposits in small amounts, but its importance (if any?) as a cause of tin losses to tailings is called into question if a processing flowsheet involving sulphide flotation and matte fuming is employed.**

Recommendations would be to:

- **Reassess the cost/tonne of processing Queen Hill ores using matte fuming.**
- **Perform a desktop metallurgical review to evaluate any possible improvements to the original Aberfoyle flowsheet with the benefit of present-day processing technology. This may then require resampling of core for benchtop testing as a next 'proof of concept' step.**
- **Confirm the cassiterite/sulphide association in a small suite of selected drill core samples using SEM element mapping.**
- **If stannite is still considered problematic, its distribution in 3D can be modeled, as a stannite database has been assembled as part of this study.**

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