# Estimation of Heavy Mineral Resources in Oil Sands Tailings

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*Titanium containing heavy minerals are present in minute amounts in the McMurray Oilsands formation. An interesting phenomenon occurs in the Syncrude processing facilities where these heavy minerals are enriched and concentrated in a particular tailings stream. Titanium Corporation (TIC) plans to process Syncrude's tailings to recover these heavy minerals.*

*A preliminary study was done with TIC to understand the enrichment process and to develop a methodology for predicting this process. The study showed that the mass fraction of heavy minerals in the tailings could be predicted using an enrichment factor. The methodology presented builds in uncertainty by using a bootstrap approach for the tailings grade and plant enrichment. A classification scheme is proposed that uses the uncertainty from the bootstrap.*

## Background

Titanium Corporation Inc. is developing a world-class heavy minerals project in the Athabasca oil sands region of Northern Alberta, Canada. Through extensive research, including the construction and operation of a pilot facility at the Saskatchewan Research Council in Regina, Saskatchewan and the operation of a Bulk Sampling Plant in Fort McMurray, we have developed proprietary technology to recover titanium-bearing minerals and zircon from oil sands tailings. Titanium Corporation's Oil Sands Project complements sustainable mining principles to create a new, environmentally responsible industry for Canada.

Alberta's oil sands contain an estimated 315 billion barrels (proven and probable reserves) of oil - enough to supply 100 per cent of Canada's petroleum needs for more than 40 years - with an additional trillion barrels soon to be in reach using new retrieval methods. By contrast, the entire Middle East holds an estimated 691 billion recoverable barrels of oil. A recently published roadmap, laid out by the Alberta Chamber of Resources, suggests that Canada's oil sands will soon be capable of producing as much as 5 million barrels per day.

In addition to the immense petroleum resources, the oil sands producers are exploring opportunities to benefit from co-products like the rich deposits of heavy minerals like titanium-bearing sand and zircon, which are concentrated in oil sands mining tailings. In late 2004, Titanium Corporation became the first and only company in the world to recover titanium and zircon minerals from the tailings of the largest crude oil producer in the region [2].

## Process

TIC plans to tap into one of Syncrude's tailings streams to supply feed to its plant. Specifically, they will be targeting the tailings from Plant 6. Syncrude mines oilsands from the North Mine and Aurora. The North Mine oilsands are processed in Plant 5 where the majority of the sand is removed and sent to a tailings pond. Oilsands from Aurora is processed in the Aurora froth plant to remove the majority of the solids. The froth from Plant 5 and the Aurora Forth Plant are then sent to Plant 6 where centrifuges are used to separate the remaining sand from the Bitumen, see Figure 1.

The following table shows a summary of the mass rates available on a monthly basis for the first two quarters of 2005:

| Stream | Tonnes | $\sigma_{Tonnes}$ | Tonnes of Solids | $\sigma_{Tonnes\ of\ Solids}$ |
|---|---|---|---|---|
| North Mine Oil Sands | 8,747,000 | 1,601,000 | 5,558,000 | 992,000 |
| Aurora Oil Sands | 5,616,000 | 2,058,000 | 4,8000,000 | 1,758,000 |
| Plant 5 Froth | 1,112,000 | 199,000 | 122,000 | 21,000 |
| Aurora Froth | 964,000 | 328,000 | 110,000 | 40,000 |
| Plant 6 Tailings | 1,299,000 | 330,000 | 202,000 | 42,000 |

The mass percentage of solids in the oil sands is 63.5% from the North Mine and 85.5% from Aurora. The in-situ mass percentage of THM is estimated to be 0.65 based on available measurements. Some remarks: (1) the North Mine delivered more oil sands than Aurora, but the percentage of solids was higher from Aurora, (2) the mass percentage of total heavy minerals is estimated to be the same, (3) the concentration of THM is significantly enriched in the Plant 6 Tailings, and (4) most of the THM reports to the Plant 6 Tailings, but not all.

TIC does not control any of the Syncrude processes that they depend on. Syncrude will make operational changes and upgrades to their facilities. These changes, both short and long term, will impact the amount of heavy minerals reporting to the tailings.

**Heavy Mineral Concentration**

The heavy minerals are concentrated in the Plant 6 tailings during processing; however, not all of the heavy minerals present in the oilsands report to the Plant 6 tailings. Some of the heavy minerals report to earlier tailings streams. A mass balance for THM could be written:

$$T_{mine} \cdot Z_{mine} = T_{floatation\ tails} \cdot Z_{floatation\ tails} + T_{plant\ 6\ tails} \cdot Z_{plant\ 6\ tails} \qquad (1)$$

where $T$ is the mass flow rate of the solids only and $Z$ is the mass percentage of heavy minerals in the different streams. The tonnes and grade in the flotation tails are calculated with:

$$T_{floatation\ tails} = T_{mine} - T_{plant\ 6\ tails}$$

$$Z_{floatation\ tails} = \frac{Z_{mine} \cdot T_{mine} - Z_{plant\ 6\ tails} \cdot T_{plant\ 6\ tails}}{T_{floatation\ tails}}$$

For the first and second quarter of 2005:

$$Z_{mine} = 0.63\% \qquad Z_{mine} = 0.67\%$$

$$T_{mine} = 24{,}650{,}000 \qquad T_{mine} = 37{,}490{,}000$$

$$Z_{plant\ 6\ tails} = 23.0\% \qquad Z_{plant\ 6\ tails} = 24.6\%$$

$$T_{plant\ 6\ tails} = 508{,}400 \qquad T_{plant\ 6\ tails} = 702{,}600$$

$$Z_{floatation\ tails} = 0.16\% \qquad Z_{floatation\ tails} = 0.21\%$$

$$T_{floatation\ tails} = 24{,}142{,}000 \qquad T_{floatation\ tails} = 36{,}787{,}000$$

Note that the concentration of THM in the flotation tails is significantly less than the ore coming from the mine, but it is nearly 0.2%, which is significant. There are different ways to account for the enrichment of heavy minerals in the Plant 6 tailings. Perhaps the simplest is to consider an enrichment factor. The enrichment factor is defined as the ratio of the mass fraction of heavy minerals in the Plant 6 tails to the fraction in the mine:

$$E_{plant\ 6\ tails} = \frac{Z_{plant\ 6\ tails}}{Z_{mine}} \qquad (2)$$

For the first and second quarter of 2005:

$$E_{plant\ 6\ tails} = \frac{23.0\%}{0.63\%} = 36.5 \qquad E_{plant\ 6\ tails} = \frac{24.6\%}{0.67\%} = 36.7$$

Note that the enrichment factor of 36 is very stable for both quarters. This is based on two data points and there could be significant areal and temporal variations due to a wide range of factors. Nevertheless, the stability of this factor makes it suitable for uncertainty assessment and resource classification.

**Model of Uncertainty**

The key property for classification purposes is the concentration of THM arriving in the Plant 6 tailings. TIC's resource consists of the mass rate of this tailings stream processed by TIC ($T_{TIC}$) and the concentration of THM in the tailings stream ($Z_{mine\cdot} \cdot E_{Plant\ 6\ Tailings}$):

$$M_{THM} = T_{TIC} \bullet Z_{mine} \bullet E_{plant\ 6\ tails} \qquad (3)$$

The mass rate of the tailings stream ($T_{TIC}$) is controlled by Syncrude and the capacity available by TIC to process the tailings. The key uncertainty addressed by this report is the mass fraction of THM in the tailings stream ($Z_{mine\cdot} \cdot E_{Plant\ 6\ Tailings}$). The two key variables are (1) the concentration of THM in the mine, and (2) the enrichment of this concentration in the stream processed by TIC.

Uncertainty is scale dependent. There is less uncertainty in large volumes / long time periods than small volumes / short time periods. Volumes should be chosen that are relevant for technical and economic evaluation. Both monthly and quarterly time scales have been used in practice. Monthly is the most common for measured or proven designations. We use a nominal monthly time period or volume.

***Uncertainty in $T_{TIC}$ or $T_{Plant\ 6\ Tailings}$***

The uncertainty in the mass rate of the tailings stream can be estimated from actual measurements. Six monthly values were provided by TIC. This data is inadequate to provide a distribution of uncertainty, but the mean and variance are calculated (see also the table on page 2) as 1.30 million tonnes with a standard deviation of 0.33 million tones. If necessary, the distribution could be assumed to follow a Gaussian shape.

***Uncertainty in $Z_{mine}$***

The uncertainty in the concentration coming from the mine can be calculated analytically or with the well established bootstrap technique. Analytical methods make strong assumptions related to the independence of the samples. The bootstrap technique provides identical results and is more flexible in its ability to handle spatial correlation. Although we do not have a good understanding of the spatial continuity of the in-situ THM grades at this point, the bootstrap was used for future flexibility.

The distribution of uncertainty in this variable is Gaussian in shape. The Gaussian shape is a theoretical and practical result. Averages of independent values tend to a Gaussian shape because of the central limit theorem. Minor deviations from a Gaussian shape are expected, but are of second order importance relative to data quality and inference of the mean and standard deviation.

Although we are interested in monthly volumes, the data are separated by quarters. The bootstrap results of uncertainty in the quarterly grades are given in Figure 2. Assuming that the monthly grades are independent would entail that the monthly variance is three times that of the quarterly variance. The distribution of uncertainty in $Z_{mine}$ is Gaussian with mean and standard deviation:

$$m_Z = \frac{0.630 + 0.666}{2} = 0.648\%$$

$$\sigma_Z = \sqrt{3 \bullet \left( \frac{0.0318^2 + 0.0380^2}{2} \right)} = 0.0607\%$$

This mean and standard deviation could be refined with additional data. The standard deviation could be increased to account for additional uncertainty not reflected in the current data. This calculation assumes the data are independent. The standard deviation could be significantly (as much as three times) higher if the data are found to be highly correlated.

***Uncertainty in $E_{Plant\ 6\ Tailings}$***

There are only two calculated enrichment values (36.5 and 36.7 for the first and second quarter of 2005, respectively), which makes it difficult to calculate the uncertainty in this factor. We calculate the mean and standard deviation assuming (1) the two values are the 45th and 55th percentiles of the distribution of quarterly values, and (2) the months are independent of the quarters. This leads to the following parameters:

$$m_E = \frac{36.5 + 36.7}{2} = 36.6$$

$$\sigma_E = \sqrt{3 \bullet \left(\frac{36.7 - 36.6}{0.12566}\right)^2} = 1.38$$

Note that the value of 0.12566 comes from the standard normal distribution. There is considerable uncertainty in the standard deviation. A history of measurements would provide more confidence; however, these values are the most reliable at this time.

***Combined Uncertainty in $Z_{mine} \cdot E_{Plant\ 6\ Tailings}$***

The individual uncertainty in each parameter has been established. The uncertainty in these two factors can be combined analytically or with Monte Carlo Simulation (MCS). MCS is fast and flexible. The combined uncertainty leads to a near-Gaussian distribution with a mean and variance:

$$m_{Z \bullet E} = 23.7\%$$

$$\sigma_{Z \bullet E} = 2.43\%$$

The units are percent THM in the Plant 6 tailings (the feedstock to TIC).

***Verification***

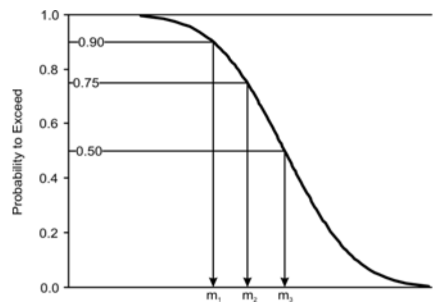
The product of ($Z_{mine\cdot} \cdot E_{Plant\ 6\ Tailings}$) is available in the monthly scale data. The mean and standard deviation are 23.9% and 2.02%, which compare favorably with the derived values of 23.7% and 2.4%.

**Classification**

TIC is listed on the Toronto Stock Exchange Venture list. They will eventually require an NI 43-101 or NI 53-101 compliant resource disclosure. TIC is in an interesting position. Most oil sands operations, both mining and insitu, have exemptions from the Canadian securities administrators and report under the US disclosure requirements. We present an introductory framework for classification based on quantitative uncertainty [1].

An implicit assumption throughout the work documented above is that the uncertainty in the concentration of THM is a reasonable basis for classification. In many mining cases (NI 43-101), the basis is geologic confidence in a local estimate of grade. We have no local estimates; we have global data related to six months of production and other corroborating data from the pilot plant. The basis for petroleum classification (NI 51-101) is more likely related to global uncertainty, e.g., a proven reserve has greater than 90% chance of being recovered.

A basis for classification could consist of the probability to achieve a certain result. For example, there should be a 90% probability to exceed the measured concentration of THM ($Z_{mine\cdot} \cdot E_{Plant\ 6\ Tailings}$), a 75% probability to exceed the indicated concentration and a 50% for inferred. Anything above 50% cannot be classified. This would lead to the following results:




Given the distribution of uncertainty established above, there is a 90% probability to exceed 20.6% THM, a 75% probability to exceed 22.1% THM and a 50% probability to exceed 23.7%. The uncertainty in the throughput must also be considered; however, these results must simply be expressed as a grade.

With a prediction of 23.7% THM, there is 86.9% measured, 6.3% indicated and 6.8% inferred. This leads to a relatively high percentage of measured given the relatively sparse data. The standard deviation could be higher in presence of spatial correlation and from area to area.

As mentioned above, the standard deviation could be three times higher in presence of spatial correlation between the measurements. In this case, there is a 90% probability to exceed 15.1% THM and a 75% probability to exceed 19.21% THM. In this scenario, 63.7% of the predicted tonnes of THM are measured, 17.3% are indicated and 19.0% are inferred. These numbers are more conservative.

There are other considerations including the mass rate of tailings, significant changes to the geological setting and in-situ concentrations of THM and changes to the enrichment factor based on the process.

**Conclusions**

Data from the first two quarters of 2005 have been examined. The mass fraction of total heavy minerals (THM) was considered from a statistical perspective. The THM resource available to TIC consists of (1) the mass flow rate of solids available to a TIC plant, and (2) the mass concentration of THM in those solids. There is significant uncertainty in the mass flow rate of solids; however, the capacity of the proposed TIC plant was not considered in this analysis. The uncertainty in the mass concentration of THM in the feed (the *grade*) was quantified. Uncertainty in the grade is attributed to the geological variability of the in-situ concentration of THM and the enrichment of that grade due to processing. We used analytical and simulation methods to assess the uncertainty. Classification could be based on the *probability to exceed a specified grade*. We suggest that the measured resource available to TIC is computed with a grade estimate that has a 90% probability to exceed the estimated resource. We also suggest that there be a 75% probability to exceed measured plus indicated and 50% to exceed measured plus indicated plus inferred. Two estimates are proposed. The first estimate is based entirely on the data – with a great deal of trust in the data provided. The second conservative estimate is based on an inflated uncertainty (standard deviation multiplied by three) that accounts for unforeseen factors and correlations among the data measurements. Assuming an average grade of 23.7% THM to the plant:

| | Data-Based | Conservative |
|---|---|---|
| Grade for Measured | 20.6% | 15.1% |
| Percentage Measured | 86.9% | 63.7% |
| Grade for Indicated | 22.1% | 19.2% |
| Percentage Indicated | 6.3% | 17.3% |
| Grade for Inferred | 23.7% | 23.7% |
| Percentage Inferred | 6.8% | 19.0% |

Establishing the measured/indicated/inferred resource of tonnes of THM would require a specification of the solids rate, in-situ grade and the enrichment factor.

The methodology developed is preliminary; there are a number of alternatives that could be considered. There are many areas for future work including: (1) Analysis of the different mineral species – statistics and spatial statistics of the concentrations of Ilmenite, Leucoxene, Rutile, Zircon as well as important ratios such as the Leucoxene to Ilmenite and (Leucoxene plus Rutile) to Ilmenite should be considered. Much of the data is available for this analysis. (2) Integration with Syncrude mine plan. TIC resources are linked to the Syncrude mine plan. It would be reasonable to review that plan, collect samples for THM and mineral concentrations for upcoming years and consider calibrating the concentrations to routinely mapped variables such as the bitumen grade, facies, and particle size distribution. (3) The enrichment factor is very important. An additional study could be considered to understand the enrichment factor and considerations that may cause it to be different in different areas or for different processing options. There is a possibility that the enrichment depends on the mass rate. (4) The THM and other variables almost certainly have important spatial variations that should be understood and built into a locally varying resource model. Assuming a constant feedstock of 24% THM (solid basis) is naïve.

It is important to note that the processes TIC is depending on are not under their control. Syncrude will make operational changes and upgrades to their facilities. These changes, both short and long term, will impact the amount of heavy minerals reporting to the tailings. This will have to be considered in the future as part of any resource or reserve statement.

### References


[1] Canadian Oil Sands Trust. 2006 Annual Report. www.cos-trust.com

[2] Titanium Corporation Website. http://www.titaniumcorporation.com

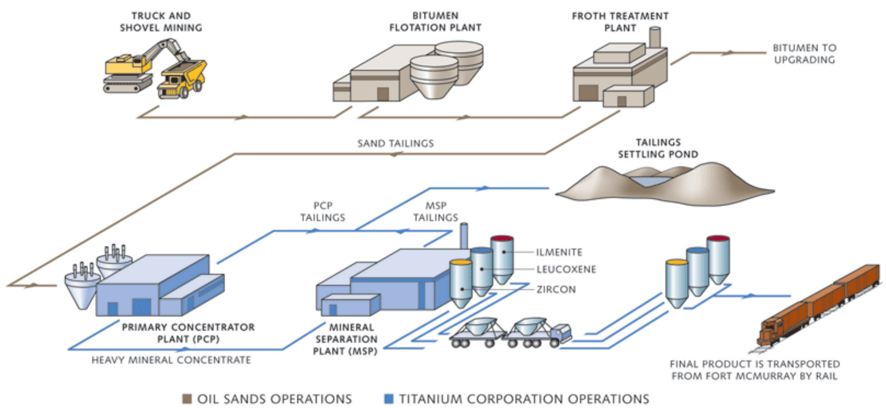




**Figure 1:** Titanium Corporation process diagram (http://www.titaniumcorporation.com/).

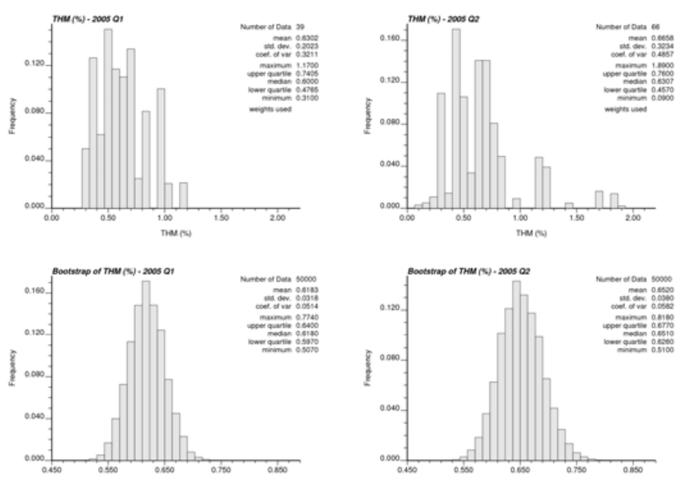



**Figure 2:** Bootstrap results for the uncertainty in THM grade in the mine. The top histograms are from the data, the bottom histograms are from the bootstrap, the left figures are for the first quarter and the right figures are for the second quarter of 2005.