EXPLORATION
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The Abstract Art of Resource Estimation

Recent news of problems with the grade reconciliation at Pretium Resources' (PVG.T, PVG.NYSE) Brucejack underground gold project in northern British Columbia prompted us to figure out why investors in the mining sector are repeatedly faced with the nightmare of a problematic *resource estimate*.

In this article, with help from our friends at Lions Gate Geological Consulting Inc. (link here) and others that shall remain nameless, we delve into the much-maligned art of *Mineral Resource Estimation* and we offer some advice on how to avoid falling for all-too-common underperforming assets. If Bill Murray can do it, so can we.

(Reliving the nightmare waiting for Punxsutawney Phil)

As mentioned above, our review was motivated by the latest news from Pretium Resources which revealed disappointing ore grade reconciliation (75-80%) and production numbers at the Valley of the Kings deposit—within its wholly-owned Brucejack gold project—in northern British Columbia, Canada.

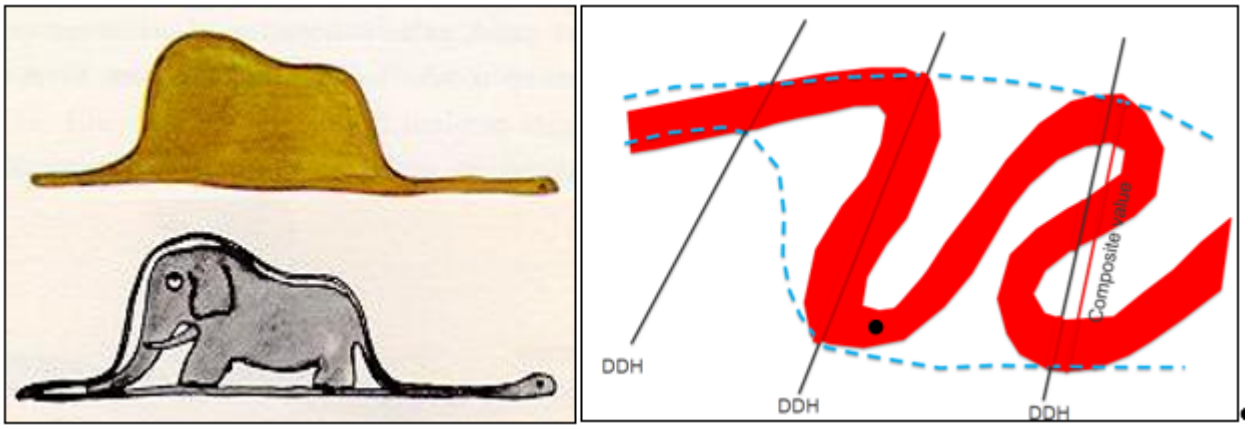
[*Reconciliation* is the process of comparing what was actually mined versus what was estimated. It can be both positive or negative; but the important issue is the magnitude of the difference.]

The news dropped the share price by ~40% and excised ~C$950 million from its market capitalization. Unfortunately, this is not an isolated case. There is no shortage of examples

of resource estimates falling short of expectations despite the fact that reserves had already been declared.

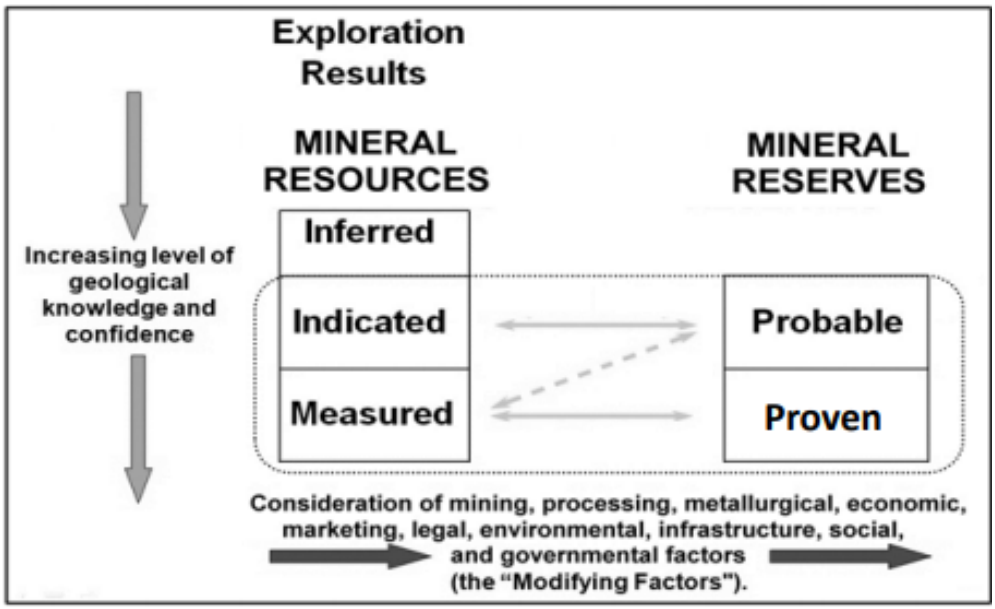
In our discussion on *Fatal Flaws* in September 2016 (link here), we noted that resource estimates are a critical component of a project's valuation and pose a technical risk that can kill a project if not properly carried out.

The calculation of a mineral resource is a fundamental part of a project's evaluation and, ultimately, determines the worth of the company that owns it. The goal of the exercise is to generate a plausible depiction of how the economic fraction of the metallic mineralization is distributed in the ground by combining geology, or at least the interpretation of it based on limited information, laboratory results (assays), and statistics, (Fig. 1).



(Figure 1: Is that a hat or a snake that swallowed an elephant? Case in point: what's going on with the gold mineralization at Eleonore?, *Source: The Little Prince by Antoine de Saint Exupery and Goldcorp*)

An independent Qualified Person (QP) is the person in charge of calculating the resources which are then categorized according to standards established by a governing body (in Canada, it's the Canadian Institute of Mining or CIM) as *Inferred* (lower confidence, higher risk), *Indicated* (higher confidence, lower risk), or *Measured* (highest confidence, lowest risk). Only the two latter can be converted to reserves (*Probable* and *Proven*), which then form the basis of a pre-feasibility (PFS) or feasibility study (FS), whereas the former can only be used in Preliminary Economic Assessments (PEA), (Fig. 2).



(Figure 2: Relationship between mineral resources and mineral reserves, *Source: CIM Standing Committee on Reserve Definitions* [link here])

Easy enough; so, why all the mistakes?

We have to remember that a resource estimate is only an approximation. Even though the geology is unchanging, its interpretation will likely vary depending on the observer.

The truth will only emerge once the deposit is mined (if at all) and the extracted ore is reconciled with the estimate. In the end, if the resource estimate is wrong, the valuation is wrong, and an investment that seemed cheap ends up costing a lot more. In addition, if the mine is already in construction or production, it may be too late for an investor to recover his or her losses.

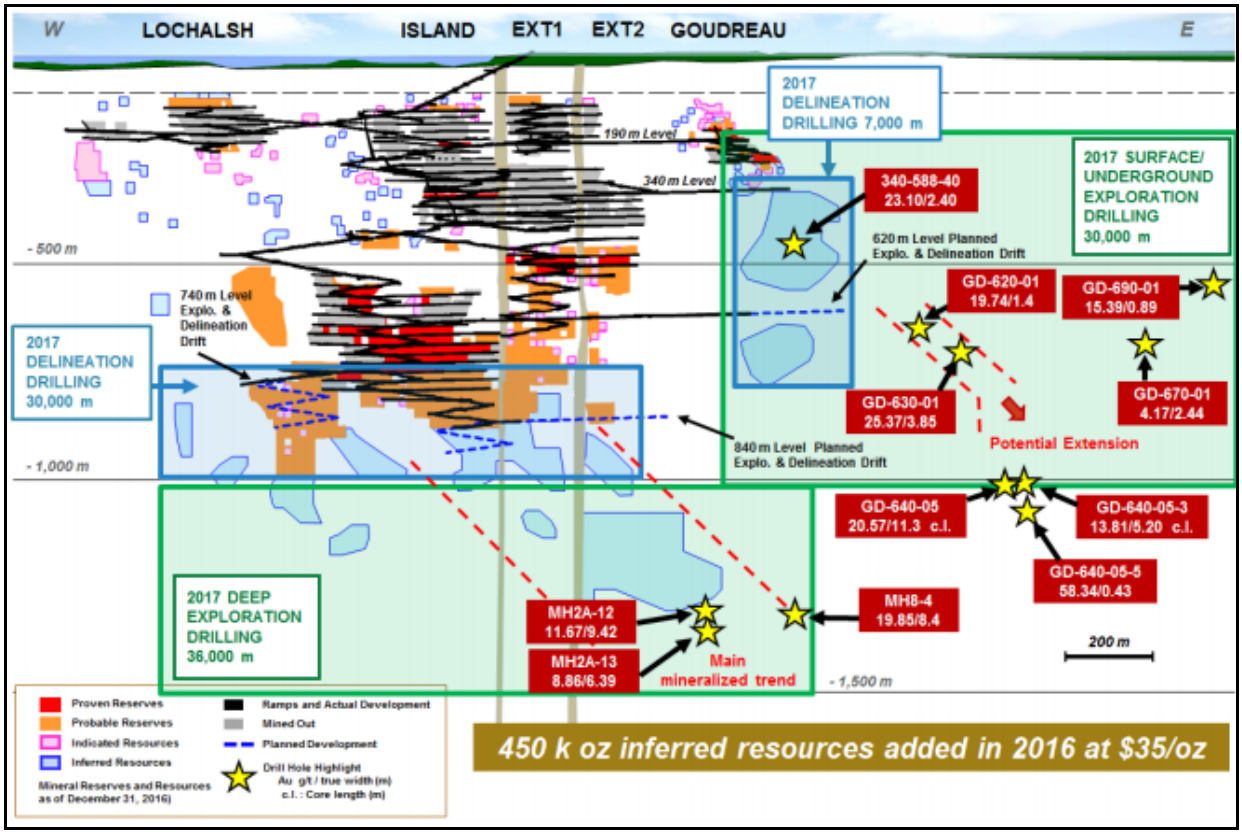
The degree of confidence of a resource estimate is directly related to the quality of the geological interpretation, the sampling protocol, and the statistical methods applied to support a mine plan. The higher the confidence, the lower the risk. Unless, of course, the confidence is misplaced.

As mentioned previously, *Inferred* resources are the riskiest to base economics upon, although many still use them to make or reject an investment decision. That said, not all *Inferred* Resources are created equal; those linked to a mining operation, where the controls on mineralization are better understood, are much less speculative than those from a new project with no open pit or underground development.

In the case of underground projects, it's important to keep in mind that due to depth constraints, these projects have higher cost requirements related to upgrading resources to the *Measured* or *Indicated* categories than open pit amenable projects. Hence, many underground operations have 5-year mine plans that last for decades because the Inferred material is consistently converted to the *M&I* category.

For example, Alamos Gold's (AGI.T, AGI.NYSE) purchase of Richmont Mines (delisted) was no doubt due in part to the upside—*Inferred* resources—at depth and laterally at the Island

Gold Mine in Ontario, (Fig. 3). AGI had more confidence in the potential conversion of the riskier *Inferred* resource from the underground operation so it included it in the valuation.

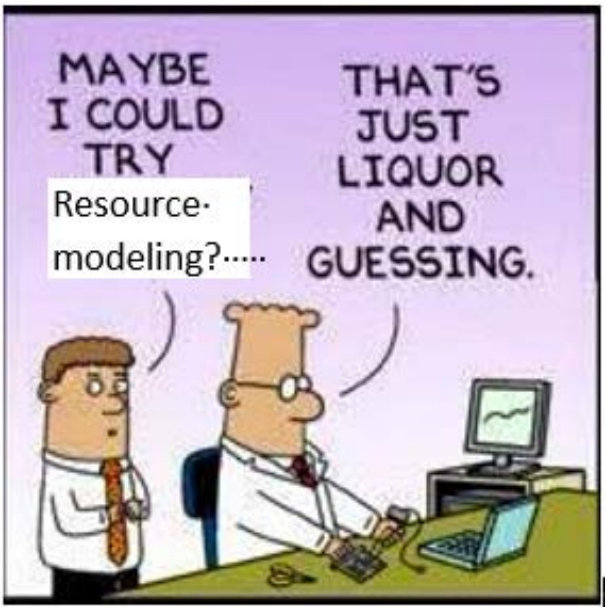


(Figure 3: Island Gold Mine long section highlighting the potential of the 450,000 ounces of *Inferred* resources added in 2016 at a low cost of C$35 per ounce, *Source: Alamos Gold*)

Upgrading a resource from the *Inferred* to the *Indicated* category requires increased confidence in the available "geoscientific information" and assumed "technical and economic factors likely to influence the eventual prospect of economic extraction" (CIM). Finally, the highest level of confidence is the *Measured* category, which relies on the ability of the estimate to form the basis of a more detailed mine plan that supports the final evaluation of the project.

Again, all of this sounds straightforward, but the reality is that in many cases the focus of the company is on making sure the lab gets the assay results right rather than accurately documenting and interpreting the stratigraphy, alteration, mineralization, and structure of the project. As we pointed out, if the geological constraints on the mineralization are incorrectly interpreted, the resource estimate will be wrong. In other cases, even if the geologic interpretation is close to reality, if it is never embedded into the resource model, the resulting estimate ends up being wrong as well.

Attempting to generate a resource estimate on a project where either the geological constraints are not well understood, the laboratory results are unreliable, or the statistics employed are flawed—or any combination of those—is a recipe for failure.



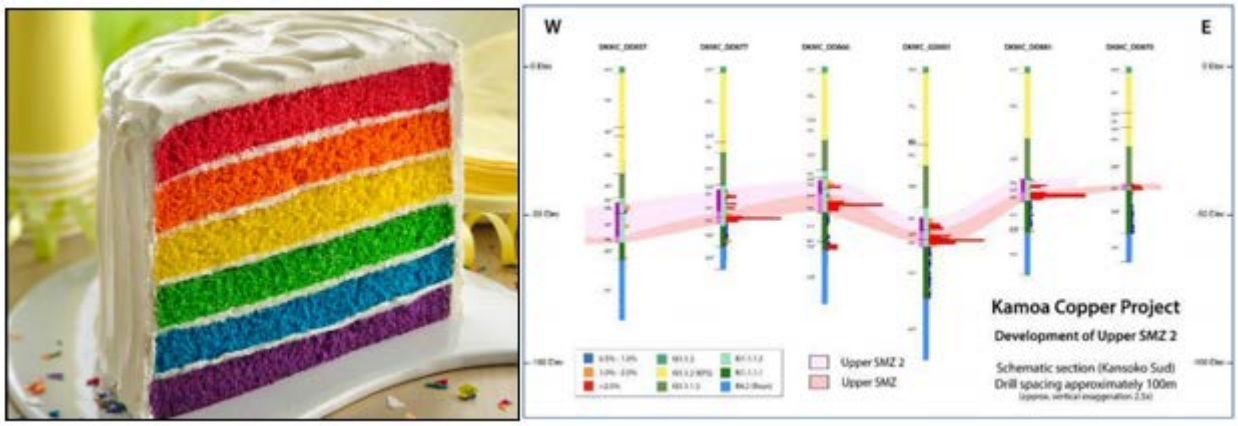
(*Source: Dilbert and Exploration Insights*)

Below, we illustrate the case with a few recent examples of faulty estimates.

Valley of the Kings - Recipe for failure?

We know that the process of resource estimation is not a cakewalk as the models rely on the interpolation of grade and tonnage between drill holes that have the diameter of a good bottle of Malbec or less and realistically represent anywhere from one in a million (0.0001%) to one in tens of millions (0.00001%) of the actual tonnage.

Deposits with good continuity are more predictable and easier to model. A good example is the Kamoa sediment-hosted copper deposit in the Democratic Republic of Congo operated by Ivanhoe Mines (IVN.T). Its layer-cake-like mineralization can be observed over hundreds of meters, (Fig. 4).



(Figure 4: The continuous and layered nature of the sediment-hosted copper mineralization at Kamoa resembles a layered cake, *Source: Ivanhoe Mines*)

Conversely, the variability of the gold mineralization at the Valley of the Kings (VOK) deposit is extreme. Brent discussed it at large back on June 16, 2013 where he concluded that "*The deposit's geological and structural complexity makes it virtually impossible to precisely predict where the economic gold grades will occur on the drill hole scale*." Several years later, our opinion remains unchanged.

Compared to the 2013 mineral resource estimate, the most recent estimate dated July 2016 reported an increase of ~60% in the *Measured* category to 1.9 million ounces plus an ~5% increase in the *Measured* and *Indicated* to 9.1 million ounces, (Table 1).

Category	Tonnage (Mt)	Gold (g/t)	Silver (g/t)	Gold (Moz)	Silver (koz)
Measured	3.5	17.0	15.3	1.9	1.7
Indicated	13.0	17.3	15.0	7.2	6.3
M&I	16.4	17.2	15.0	9.1	7.9
Inferred	4.6	21.0	26.9	3.1	4.0

(Table 1: Valley of the Kings mineral resource estimate, July 2016, based on a gold-silver cut-off grade of 5 grams per tonne gold equivalent [defined as Au+Ag/53]. Note: we could not find a technical report related to this resource estimate on the company's website or SEDAR, only a press release, *Source: Pretium Resources*)

But that's not the whole story. The maximum recorded grade from the ~79,700 drill samples used in the 2013 resource was >16,550 grams per tonne; however, the average grade was only 2.5-2.6 grams per tonne and the coefficient of variation (CV), which would be considered extreme at 5, was ~27, (Table 2).

[The coefficient of variation (CV) is the ratio of the standard deviation to the average of the assay results. In this case, 69.54/2.57 = 27. The higher the CV, the more variable and erratic the distribution of the mineralization is, the more difficult it is to model.]

Statistic	Gold g/t	Silver g/t
Samples	79,699	79,699
Minimum	0.00	0.25
Maximum	16,552	9,383
Mean	2.57	8.59
Standard deviation	69.54	41.94
CV	27.03	4.88
Variance	4,836	1,759
Skewness	109.40	70.11

(Table 2: Summary statistics from assays underpinning the Valley of Kings resource, *Source: Pretium Resources*)

Due to the high degree of variability, the resource at VOK is clearly driven by the top percentile of the grade (>99.5th percentile or >85 g/t Au). Based on the results from the bulk tonnage sample, we calculate that ~85% of the gold must reside within only 0.5% of the estimated tonnage.

A comparison of resource estimation methodologies on the bulk tonnage sample with and without top cuts, which limits the influence of the high grade samples, suggests any significant top cut slashes the grade considerably, (Table 3). Note that a resource is only reliable if various geostatistical methods generate similar results, which is apparently not the case for the VOK resource.

Model	Mill	Top cut (Au g/t)				
		No top cut	2000	1500	700	85
ID1	16.08	28.78	15.99	13.59	9.51	2.86
ID2	16.08	29.57	16.31	13.85	9.69	2.82
ID3	16.08	28.91	16.05	13.70	9.71	2.77
OK	16.08	24.00	13.58	11.90	8.92	2.71
December 2013 Mineral Resource		12.20				

(Table 3: Grade of the bulk tonnage sample based on drilling at various top cuts [top row] and estimation methodologies [far left column] versus the actual result from the plant and the 2103 resource estimate, *Source: Pretium Resources*)

A colleague has likened the gold mineralization at VOK to raisin bread: slice it too thin (low throughput rate), and you might not get any raisins (gold). To avoid missing out on extracting enough ounces, the underground throughput rate for the VOK deposit is fairly high (2,700 tonnes per day) and may get even higher (+40%, 3,800 tonnes per day). Although the bigger the slice, the higher the probability one will get a raisin, this comes at a cost with more dilution.

(Figure 4: Raisin bread [left] and very high grade gold mineralization from the Valley of the Kings [right], *Source: Pretium Resources*)

Pan gold project - Whiskey, Tango, Foxtrot

Midway Gold's (delisted) Pan project is a good example of a resource estimate failing to support the mine plan after declaring commercial production, (Fig. 5). The case of the Pan project is unusual because Midway Gold had partially funded its development with bank debt. This is usually a good sign from an equity investor perspective, but it was surprising in this case given that banks tend to send an independent consultant to verify the resource and the mine plan before making a move. It would seem that their review was also okay with the resource estimate which led to the flawed mine plan.

(Figure 5: Mining lower gold grade than modeled at the Pan project, *Source: Fiore Gold*)

The drilling, blast hole sampling, and in-pit geological mapping that informed the revised May 2015 resource estimate indicated that the Carlin-style gold mineralization was much less continuous than previously modeled. The updated resource pushed down the majority of the *Measured* and *Indicated* tonnage—24% (11 Mt) from the 2011 estimate—into the *Inferred* category and lowered the overall grade 15% to 0.44 g/t Au, hence negatively impacting the reserve calculation, (Table 4).

	2011 Feasibility	Updated 2015 Resource	Delta	% Delta	Updated 2017 Resource	Delta	% Delta
M&I – Tonnage (kt)	47,300	35,937	-11,363	-24%	27,275	-8,662	-24%
M&I – Au grade (g/t)	0.52	0.44	-0.08	-15%	0.48	0.04	9%
M&I – Contained Au (koz)	788	504	-285	-36%	434	-69.80	-14%
Inferred – Tonnage (kt)	633	13,971	13,338	2107%	5,144	-8,827	-63%
Inferred – Au Grade (g/t)	0.50	0.31	-0.19	-38%	0.45	0.14	45%
Inferred – Contained Au (koz)	10	141	131	1283%	72	-69.10	-49%

(Table 4: Comparison of revised resource at Pan gold project in Nevada, *Source: Midway Gold and Exploration Insights*)

To add insult to injury, management had seen fit to ignore the Feasibility Study and avoided crushing the run of mine ore before placing it on the heap leach. The result was a low grade heap leach pad that couldn't be leached as it was not crushed.

[Low grade open pit heap leach deposits live on the margin and are highly sensitive to the grade placed on the leach pad, the metallurgical recoveries, and the time required to complete the recovery. Link here for an in-depth discussion on heap leach gold projects.]

Needless to say, the company defaulted on its debt and went bankrupt. But hope springs eternal. Fiore Gold (F.V) took over the asset and issued a new resource in July 2017 that depleted the *Measured* and *Indicated* resource by another ~70,000 ounces, (Table 4), which has an implied grade of ~0.25 grams per tonne gold (!)—some of it was no doubt mined and now lays on the heap leach pad.

Soledad Mountain gold-silver mine - Not so golden queen

Another colorful example of a project that was funded to build based on a feasibility study and then changed its resource during construction is Golden Queen Mining's (GQM.T) Soledad Mountain low sulphidation epithermal gold-silver mine in California, (Fig. 6).

(Figure 6: Soledad Mountain open pit, heap leach gold-silver project in California, *Source: Golden Queen Mining*)

Unlike the Pan project, (1) the funds were derived from private equity and, (2) the company continued operating the mine even after the revision of the resource estimate.

Although the continuity of the epithermal gold-silver mineralization was not an issue, further studies interpreted the veins' widths to be narrower than previously modeled. The revised estimate dropped the *Measured* and *Indicated* resource by ~60 million tonnes or ~40% and the contained ounces of gold by ~860,000 ounces or about one third, (Table 5).

	2012 Feasibility	2015 Feasibility	Delta	% Delta
M&I – Tonnage (kt)	144,817	83,535	-61,282	-42%
M&I – Au grade (g/t)	0.52	0.575	0.06	11%
M&I – Contained Au (koz)	2,404	1545	-859	-36%
Inferred – Tonnage (kt)	14,545	21,392	6,847	47%
Inferred – Au Grade (g/t)	0.36	0.34	-0.02	-5%
Inferred – Contained Au (koz)	169	245	76	45%

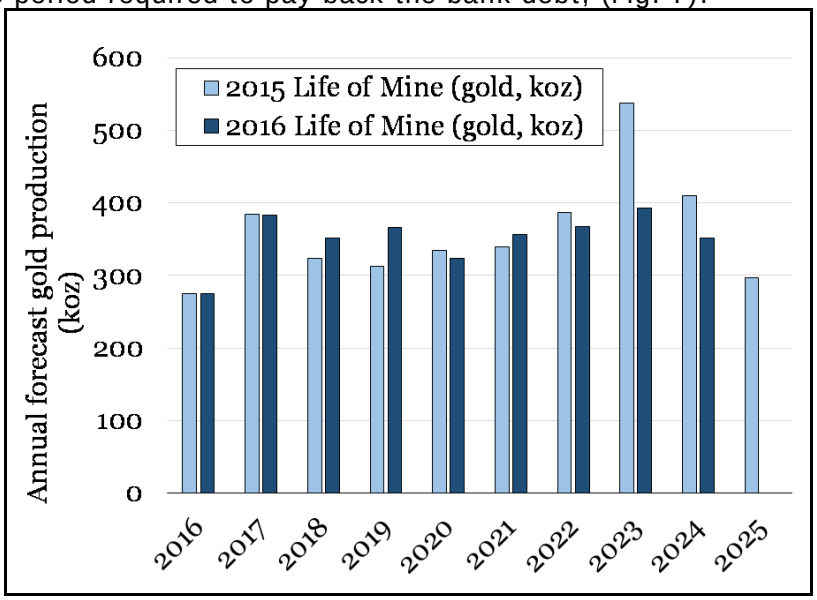
(Table 5: Comparison of revised resource at Soledad Mountain gold project in California, *Source: Golden Queen Mining and Exploration Insights*)

Unlike the Pan project, the lost *M&I* tonnage did not get relegated to the *Inferred* category and instead was eliminated as this was an issue with the thickness of the veins and not their continuity.

A few more examples - Too many to cover!

- A more recent instance illustrating the vagrancies of resource estimation is the Bombore open pit gold deposit owned by Orezone Gold (ORE.T), which we dissected in a previous letter (link here). In the late summer of 2016, the old resource was thought to have been overestimated by 30%, but unlike the previous examples, the project had not been funded to production. The stock fell by about 50% at the time and is slowly recovering.

- In mid-2016, the discovery of post-mineral dikes that diluted the resources at Torex Gold's (TXG.T) El Limon-Guajes open pit gold project in Mexico, shrunk its life of mine plan by 1.5 years to 8.5 and lowered the life of mine production by 433,000 ounces. Thankfully, the major impact was late in the mine life and did not materially affect the period required to pay back the bank debt, (Fig. 7).



(Figure 7: Annual production profile change for the life of the El Limon-Guajes open pit gold mine in Mexico, *Source: Torex Gold and Exploration Insights*)

- We have also previously discussed the controversial resource estimates put forward

by Rubicon Mineral's (RMX.T) at its Phoenix gold project and the Barkerville gold project, which first-time subscribers may find a useful read to better understand the art of resource estimation. Regrettably, there are many more examples, but you get the point.

Trust no one, check everything

After spending the time reviewing these cases and discussing the topic with people that estimate mineral resources for a living, we put together a list of factors that we think directly impact mineral resource estimates and can serve as a guide for investors looking for potential flaws in a project:

- Failure to understand the geological controls on mineralization - It is not a good sign when one visits a project and the technical staff in charge has a hard time relaying the nature of the mineralization. Geological controls on mineralization (structural, chemical, stratigraphic) exist on every ore deposit. It is critical for the Qualified Person (and the company!) to recognize these critical features and how they impact the grade distribution.

- Lack of practical experience - Many estimates are often generated by resource modelers that have little or no field experience and, therefore, rely strictly on numbers. As one of our colleagues has pointed out: "until somebody has been taught to be a pragmatic geologist, logged core, mapped underground, mapped the surface, run reverse circulation and core drilling programs, sampled in all kinds of environments, been in production and been at a face when the ore wasn't there, they can't do a proper estimate. And then still it takes close to 10 years to fully appreciate what's needed."

  In our case, we tend to avoid pointing fingers at the consultants when a resource estimate goes wrong and instead prefer to lay the blame squarely on the company that hired them.

- Independence is bought and paid for - There are companies that can't handle the truth and hence employ an "independent" consultant who can come up with a resource closer to their number (the one they promised the market). This problem becomes more pronounced when work is scarce, and time is tight; consultants may dilute their final product to keep the lights on.

  To minimize this impact, a solution would be to have the regulators (Investment Industry Regulatory Organization of Canada, IIROC) pay for an independent review of the NI 43-101 technical report. Also, since the Qualified Person that signs off on the resource is critical, IIROC could suggest a few consultants that have the experience in the type of deposit being assessed.

- Dilution of responsibility - Unfortunately, a well-integrated team that generates a resource estimate on a project based on solid geological interpretation is more the exception than the rule. The norm is a dysfunctional group of professionals with varying degrees of input and responsibility in different parts of the chain with no one owning the entire process. A company must own its data and pick the right consultants for the job; the buck stops there.

Summary — Getting a handle on resource estimation

Flawed estimations of mineral resources are one of the primary causes of investor strife and recurring nightmares. Many investors in the mining sector, especially the gold sector where the goal is to extract parts per million, don't recognize the impact of this risk when looking for new opportunities.

To avoid repeatedly falling for flawed projects in a Groundhog-Day kind of way, we base our decisions on the following points when it comes to resource estimates:

- Management team - If there are more technical advisors than geologists on the ground, we will think twice before investing.

- Choice of Qualified Person (QP) - The QP should be truly independent, objective and have enough relevant experience in the deposit type and evaluation of mining projects to add value not just be available, inexpensive or pliable.

- Site visits - If possible, go on a site visit to verify the continuity of grade and mineralization, keeping in mind that an exceptionally high grade deposit has a higher risk of grade smearing than a low grade one. Looking through maps and sections should provide some comfort (or lack thereof). If they don't exist, that is another major problem, and the company is one you want to avoid.

  At Exploration Insights, we consider site visits a fundamental part of our due diligence; nothing beats being on site to understand the issues related to the geology and how they might affect the valuation of a project. If we don't see continuity of grade and mineralization within and in-between cross sections, we will reject the project. Such was the case in the sale of Erdene Resources, Nighthawk Gold, and Dalradian Resources.

- Project stage and type - Evaluating a resource estimate is usually easier in an operating mine than in a greenfield project since there is more data available for cross-checking. We also have more confidence in an estimate from a greenfield project with outcropping mineralization than in one with a blind target (no surface exposure) since the mineralization model in the former is easier to visualize.

- Other points of view - Hearing the perspective on the project from our network of fellow geologists and engineers is always an eye-opener and an excellent source of independent information.

Even though mineral resource estimation is not an exact science, it is possible for a qualified professional to produce a realistic and reliable estimate (under the guidelines of reporting standards) that can be used confidently by the company to further a project. We hope this review will help you determine the reliability of a resource calculation when choosing a project to invest.

That's the way we see it,

Joe Mazumdar and Brent Cook

Disclosures

Of the companies mentioned in this week's letter, Exploration Insights does not own shares of Alamos Gold, Fiore Gold, Golden Queen Mining, Ivanhoe Mines, Orezone Gold, Torex Gold, Pretium Resources and Rubicon Minerals.

[Note that our trading activity is based on our investment thesis, which can be short-(tactical) or long-term (strategic), but the timing will not always be perfect due to market volatility and share price liquidity. As a subscriber, you may want to purchase/sell a stock sooner or later than we do. As we need to justify our purchases and sales while allowing our subscribers to trade with us, we, unfortunately, cannot always act as quickly as we would like. We also want to remind all our subscribers that they have access to the open and closed positions in the EI Portfolio via the website. As soon as we execute a trade, we update the price and date of the open and closed positions, depending on whether the position was purchased or sold. There can be delays due to the illiquidity of some of the junior mining stocks and the time needed to link a new stock to our website. Our site visit expenses are covered by the company.]

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