How exploration geologists can and should use "soft NSRs" to represent assays of Ni-Cu-PGE mineralization – and introducing the concept of a negative NSR

Abstract as submitted February 29, 2024:

Goldie, R.J.[1]

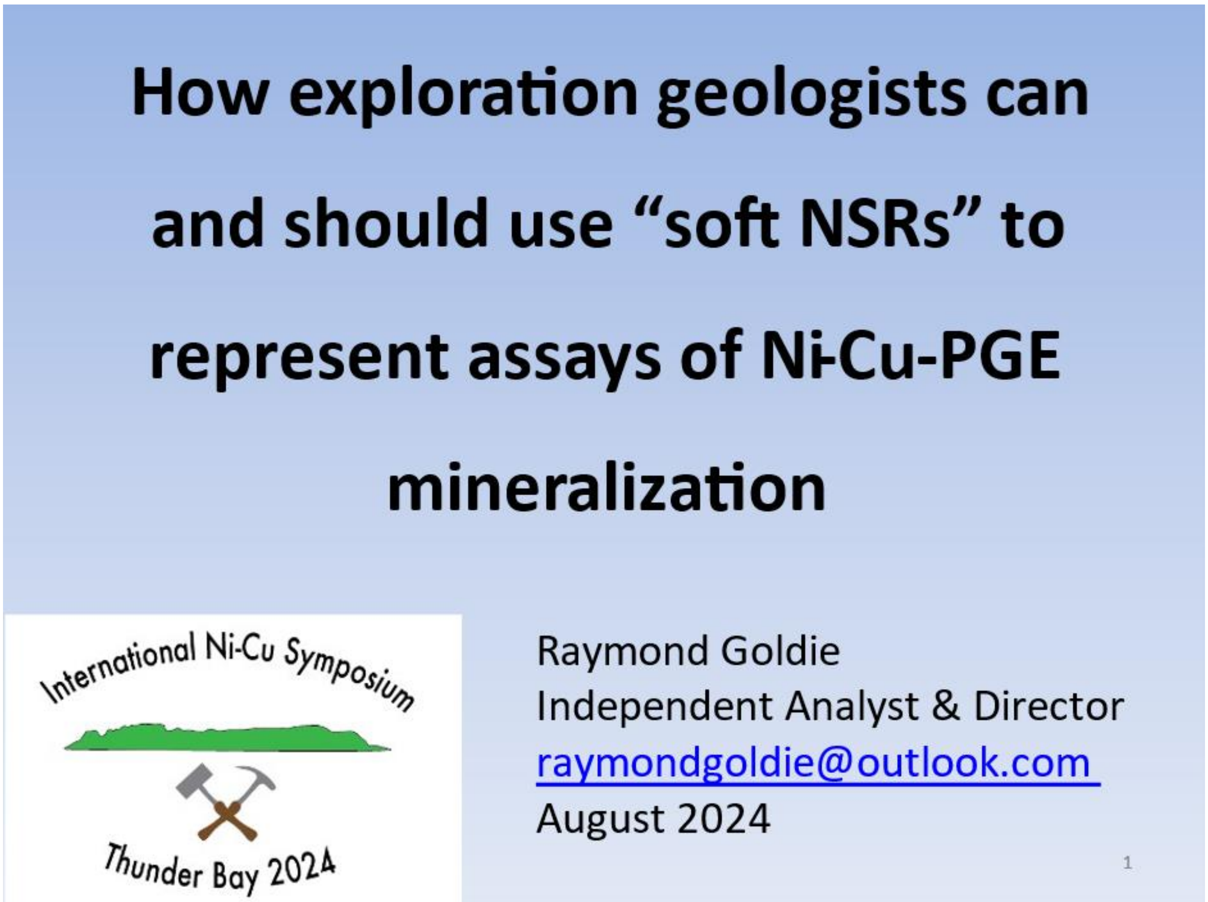
[1] Independent Analyst and Director, 54 Peach Willow Way, Toronto, Ontario, Canada M2J 2B6
Raymondgoldie@outlook.com

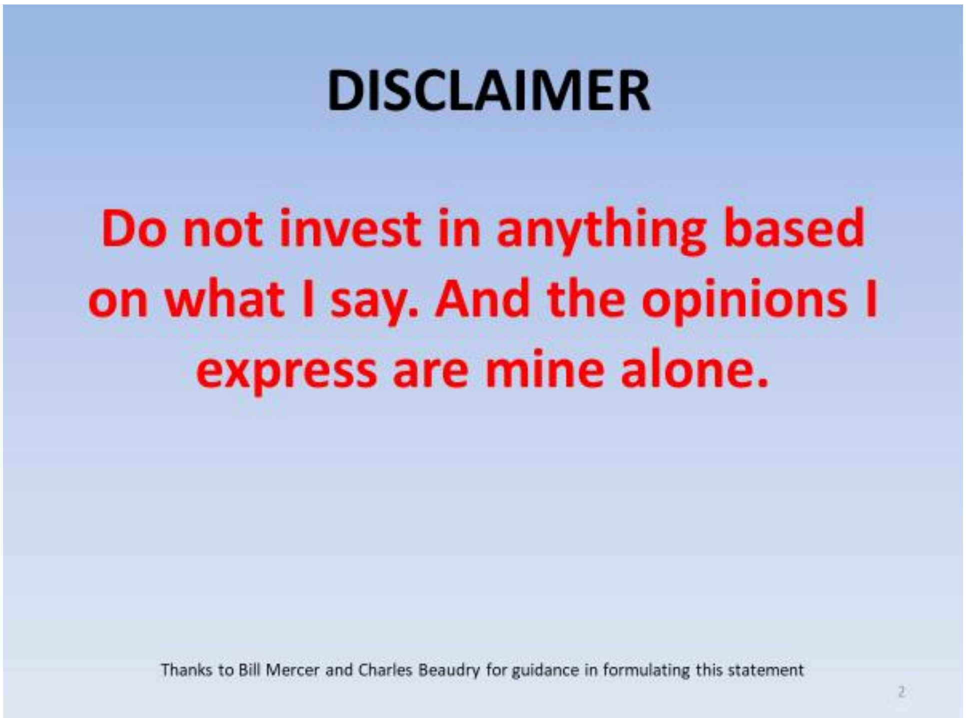
A Net Smelter Return (NSR) is the net revenue generated by a block of mineralization, less offsite costs (Goldie and Tredger [1]). Three procedures for computation of the NSRs of Ni-Cu-PGE sulphide mineralization are in common use: values calculated by accountants; mine-specific estimates, constructed by mine operators, and "soft estimates" (Goldie [2,3]).

Soft estimates of NSRs are useful in representing assays of samples taken during exploration. Their computation is based on statistical analyses of ore grades, metallurgical properties and smelting and refining terms of operating Ni-Cu-PGE mines.

There are three reasons why exploration geologists should express assays of samples as soft estimates of NSRs: (i) representing each assay as a single number facilitates their graphical representation, such as on contour maps; (ii) the computation of soft estimates may reveal that, as is common in mineralization that is rich in PGE, the mineralization contains substances or has mineralogical issues that could lead to a smelter penalizing or even rejecting a potential mine's products (Goldie [3]); (iii) presentation of assays as single numbers not only facilitates their comprehension by investors, but should also reduce the chances that readers of company press releases apply invalid rules-of-thumb to them, resulting in poor investor relations and expensive misunderstandings.

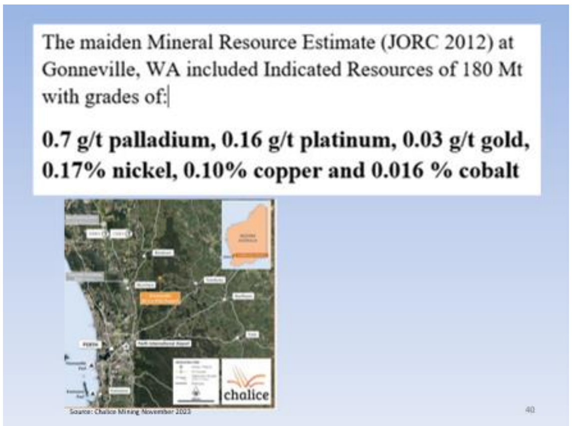
Presentation at Lakehead University, August 8, 2024





Thank you, Dr Sproule for a great presentation [Rebecca Sproule, Principal Geoscientist – Nickel, Rio Tinto had just given a keynote address on “Future research areas to aid in exploration for Ni sulfides”]: I hope that what I’m about to say will also help geologists to find new nickel deposits… deposits like Gonneville, which, as noted by Dr Sproule, is also known as “Julimar”.

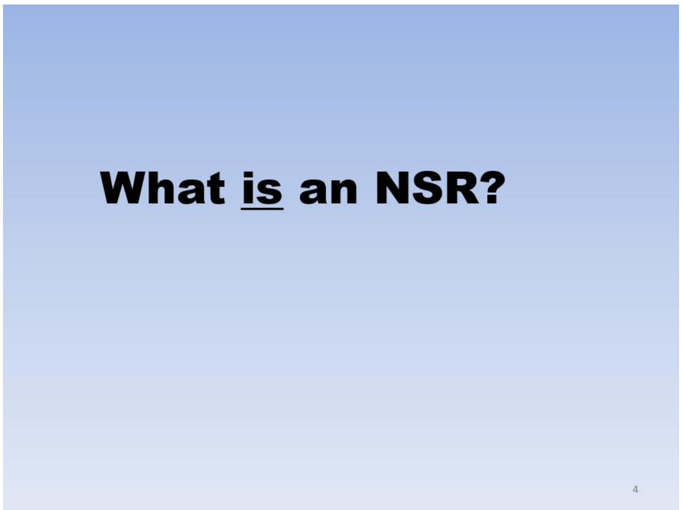
Gonneville is a palladium-platinum-gold-nickel-copper-cobalt deposit, near Perth, Western Australia. In November 2021, Chalice Mining Limited published a maiden Mineral Resource.



The grades of this type of mineralization are unwieldy numbers. It’s hard for geologists to wrap their heads around them, and even harder for outsiders: are these grades good or bad? A single number would make things so much easier, right? And you can contour and krige assays that consist of single numbers. So, how about recasting those figures in terms of a palladium or a nickel equivalent?

I say "No to metal equivalents!" Metal equivalents use rules-of-thumb that may implicitly assume that all metals have equal rates of recovery and payability. Rules-of-thumb caused a stock market disaster last year.

As an alternative to palladium equivalents or nickel equivalents… or gold equivalents, I suggest the NSR.



NSR is a common term in the mining industry. It stands for Net Smelter Return. When Canadian miners present their income statements, the top line is an NSR. It is what a mine receives for its output: the gross revenues from the metals that are recovered and sent to a smelter and get paid for, minus all the costs incurred off the mine site, most notably smelting and refining fees.

There are three ways to compute NSRs:

- actual historic NSRs in financial statements, they're calculated by accountants;

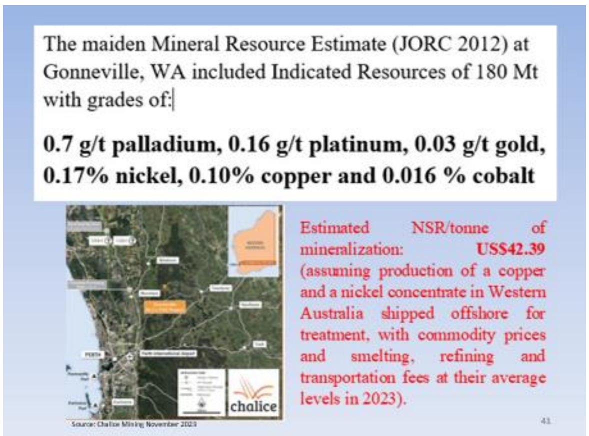
- Soft NSRs are created by and for exploration geologists, and they are estimates, based on analyses of the net revenues generated by similar mineralization world-wide.

- and then there are the “hard” estimates of NSRs that grade-control geologists create for their specific operating mines.

[From my response to a question asked by Prof. David Good: I noted that NSRs are computed as the saleable value of the products produced by a mine at the moment when they leave the mine gate. They do not include any costs incurred on the mine-site. However, when grade control geologists are estimating the "hard" NSR of a block of mineralization, it would make sense to also estimate the on-site milling and mining costs of that mineralization. For example, the technology now exists for grade control geologists to predict the Bond Work Index of a block of mineralization [3]. If the grades of two blocks of mineralization were identical, but they had different Bond Work Indices, the mineralization with the lower Bond Work Index would have a higher economic value.]

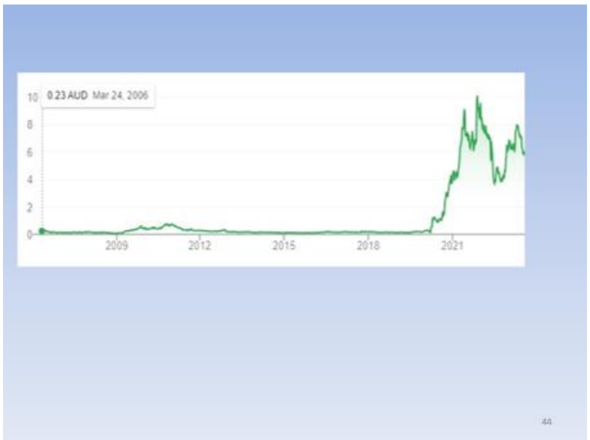
In this presentation, I'm focussing on why exploration geologists should express sample assays as soft NSRs.

Here's what my own soft NSR estimate of Gonneville would have been based on average prices and smelter fees in 2023:

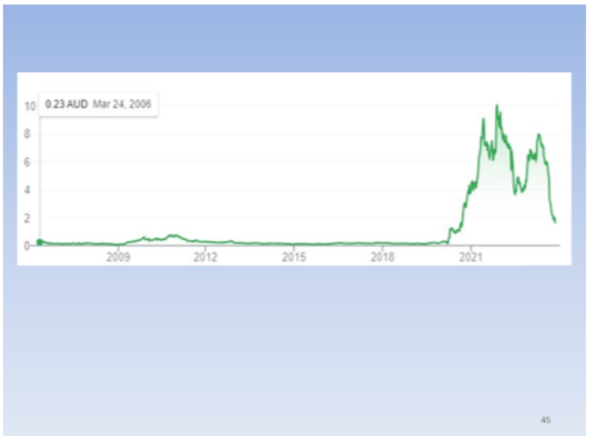


About $US42 per tonne: that's calculated from an Excel workbook that I've been compiling and maintaining since 1990.

Here is the price of Chalice's shares up to August 28, 2023, 9 months after the Maiden Resource.



On August 29, Chalice released its Scoping Study of Gonneville. Here's what happened next:



In the week after the release of the Scoping Study, the stock price dropped by 42%.

Why was Chalice's Scoping Study such a surprise to the market?

Before the Scoping Study came out, investors and analysts would have been valuing Gonneville by forecasting its NSRs, its capital costs and its operating costs. I infer that investors in Chalice had been estimating those NSRs using a well-known rule of thumb, which is that, after metallurgical losses at the mill, the smelter and the refinery; copper-gold mines get paid for about 82% of the copper and gold in the ore that they mine. Perhaps the investors applied 82% as a rule-of-thumb for Gonneville's recovery of payable palladium, platinum, nickel and cobalt, as well as the copper and gold in the ore. However, this 82% rule of thumb emphatically does <u>not</u> apply to Ni-Cu-PGE mineralization.

Here are the estimates, they're soft estimates, of recoveries of payable metals that Chalice published in its Gonneville Scoping Study.

Recoveries of payable metals, %
as in Chalice's Scoping Study, 15 Mtpa case

Ni	43.0
Cu	80.0
Pd	78.0
Pt	45.0
Au	66.0
Co	42.0

The key point of showing this chart is to illustrate that the determination of the payable metals, and hence, the NSRs of Ni-Cu-PGE deposits are <u>not</u> like those of copper-gold deposits. Using a rule-of-thumb that assumes an 82% recovery of payable metals is just wrong. I encourage exploration geologists to turn assay results into soft NSRs, which are based on statistical (regression) analyses of mill recoveries and smelter payabilities in comparable mineralization from around the world.

Not only are soft NSRs more reliable than rules of thumb, they recognize two important issues. These issues are: nickel that you mine but don't get paid for; and stuff that you get dinged for.

- nickel in ore that the mine does not get paid for;
- penalty materials in concentrates

Let's look first at the nickel you don't get paid for.

Cu: typical recovery, ore to concentrate: 85%

typical payability of Cu in concentrate: 96.25%

thus, **payable copper in ore =** 85% x 96.25% = **82%**

Ni: typical recovery, ore to concentrate: 69.5%

typical payability of Ni in concentrate: 72%

thus, **payable nickel in ore =** 69.5% x 72% = **50%**

A mine's mills will typically recover, into a copper concentrate, about 85% of the copper in its ore. And a smelter will typically pay for just over 96% of the copper in that concentrate. So, a miner will be paid for 85% times 96.25%, or 82% of the copper in its ore.

But for nickel, a typical recovery from ore into a nickel concentrate is 69.5%, and a smelter will pay for about 72% of that nickel. So a miner would get paid for only 50% of the nickel in its ore.

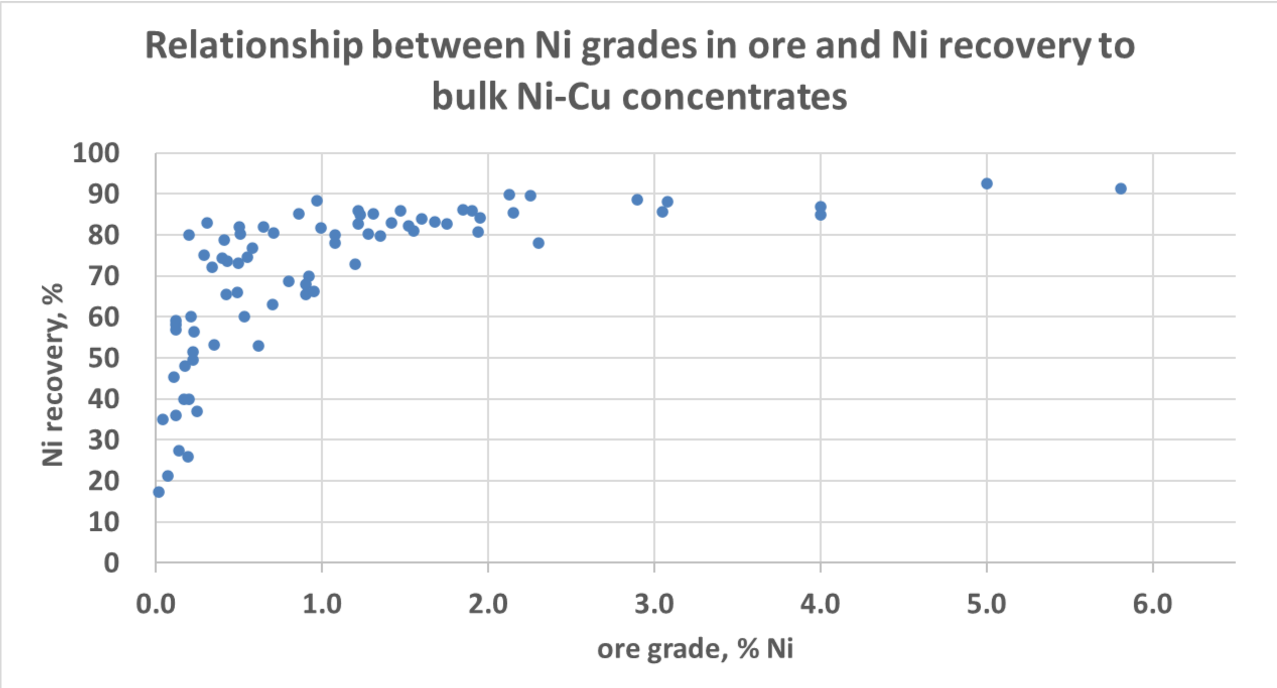
Why the difference between copper and nickel payabilities?

The biggest reason is that copper usually occurs in sulphides, and sometimes carbonates and oxides, all of which the smelter is able to recover and pay for.

Smelters can recover nickel in sulphides and in metal alloys such as awaruite. But nickel also often occurs in silicates, mostly substituting for iron or magnesium in olivine and serpentine. Smelters cannot profitably recover silicate-hosted nickel, so it goes into slag and they don't pay for it. Yet nickel assays of exploration samples usually include the nickel in silicates. Assay lab.s do not routinely provide geologists with nickel assays that exclude silicate nickel. Determining the nickel content of silicates requires studies of mineralogy [4].

So, exploration geologists should recognize when the nickel grades in their assays represent the total nickel content of the sample. Soft estimates of the NSRs of those samples depend on estimates of the recovery of that nickel into a concentrate, and of what the smelter would pay for it.

Here is the arithmetic of nickel assays. The commonest nickel ore mineral, pentlandite, contains about 22% nickel whereas olivines have no more than 0.5% nickel [5]. So, when whole rocks assay at better than 1% nickel, most of that nickel must be in sulphides. But when whole-rock assays are below 1%, much of that nickel could be in olivine or serpentine.



This chart shows recovery rates collated from 90 mill operations and locked-cycle tests. Mills are tuned to collect sulphides and to reject silicates. You'll see that, at ore grades of above 1%, recovery rates are steady at around 85% and the nickel is mostly in sulphides. But for ores containing less than 1% nickel, recoveries of nickel to concentrates are very variable because much of that nickel could be in silicates and unrecoverable. For example, a dunite consisting purely of olivine could contain as much as 0.5% nickel, none of which would be recovered by a mill or be payable by a smelter. So if, in exploration, you are consistently getting nickel assays under 1%, work with the lab. to find out how much of that nickel is in silicates.

What if there is nickel present that occurs in neither sulphides nor silicates? I'm thinking of you, gersdorffite, a common nickel arsenide.

Gersdorffite is the devil in disguise. Yes, the smelter will recover and pay for the nickel in gersdorffite. But if the gersdorffite takes the arsenic levels in the nickel concentrate to levels greater than …. well, it depends on the smelter …. greater than 2,500 ppm arsenic … then the smelter will add arsenic penalties to the fees that it charges the miner.

- nickel in ore that the mine does not get paid for;
- penalty materials in concentrates

Which takes us to considering other penalty substances that a mine may send to the smelter.

Here is a list of what may cause a smelter to penalize – or even reject – copper or nickel concentrates:

PENALTY SUBSTANCES IN COPPER AND NICKEL CONCENTRATES

alumina antimony arsenic bismuth
cadmium chlorine chromite cobalt
copper fluorine iron lead magnesia
manganese mercury nickel selenium
silica tellurium thallium zinc

yellow: oxides; blue: amphoterics; green: metals; red: halogens

Why are these substances potential penalty materials?

Well, in most cases, not only do penalty substances adversely affect the physical properties of the smelter's major product, be it copper or nickel or PGE; they also may be toxic to humans and require special handling. Accordingly, the smelters send as much as possible of the penalty materials to waste repositories, while protecting people and the environment from potentially toxic materials.

Now, why does this slide show cobalt, copper, lead, nickel, tin and zinc as penalty materials? Sometimes, the metals whose presence is touted by stock promoters may have a negative value.

For example, other than at smelters in the heart of the African Copper Belt, cobalt is a penalty in copper concentrates, not a credit. And copper smelters may penalize nickel while nickel smelters may penalize copper.

But the two most important penalty materials in nickel-copper-PGE deposits are arsenic and magnesia.

Arsenic is the most powerful human carcinogen [3], which is why Chinese smelters are forbidden to import concentrates that contain more than 5,000 ppm arsenic. Ship operators may refuse to transport concentrates grading over 2,000 ppm arsenic and Vale's Sudbury smelters prefer arsenic to be less than 80 ppm in its feedstock.

Table 1: Avebury Mineral Resource estimate, reported from all blocks within Ni > 0.4 % envelope

JORC classification	Tonnage (Mt)	Ni (%)	Co (ppm)	As (ppm)
Indicated	8.7	1.0	244	378
Inferred	20.7	0.8	223	297
TOTAL	**29.3**	**0.9**	**229**	**321**

Notes: Due to effects of rounding, the total may not represent the sum of all components. All resources quoted as total nickel, a nickel recovery of 75 to 80% is expected using conventional flotation processes.

Source: listcorp.com 8 April 2022

Arsenic is the reason that the Avebury nickel mine in Tasmania, owned by Mallee Resources, has tried twice to go into sustained operation but has been unable to produce nickel concentrates acceptable to a smelter.

Table 1: Avebury Mineral Resource estimate, reported from all blocks within Ni > 0.4 % envelope

JORC classification	Tonnage (Mt)	Ni (%)	Co (ppm)	As (ppm)
Indicated	8.7	1.0	244	378
Inferred	20.7	0.8	223	297
TOTAL	**29.3**	**0.9**	**229**	**321**

Notes: Due to effects of rounding, the total may not represent the sum of all components. All resources quoted as total nickel, a nickel recovery of 75 to 80% is expected using conventional flotation processes.

Source: listcorp.com 8 April 2022

Australian nickel miner Mallee Resources enters receivership

September 17, 2023 — 09:51 pm EDT

Written by →

MELBOURNE, Sept 18 (Reuters) - Australian nickel miner Mallee Resources has appointed receivers after failing to pay a debt relating to its Avebury nickel-cobalt mine in Tasmania state to commodities trader Hartree Partners, the miner said in a notice on its website.

Insolvency firm KordaMentha was appointed joint receiver and manager of all property belonging to Mallee Resources, rounding out a process that began earlier in the month, the notice posted on Friday said.

17

o

Source: www.nasdaq.com

Similarly, the Armstrong nickel deposit in Western Australia has so much arsenic that its mineralization has a potentially negative NSR. You'd have to pay someone to take it away. That's why Armstrong has never been developed.

The concept of a negative NSR is a useful guide to would-be developers of mines, and it's another reason why NSRs are superior to metal equivalents in assessing the viability of a mineral deposit. I've never seen anyone publish a metal equivalent that is a negative number.

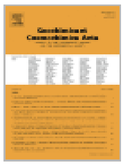
The other most important penalty material in nickel smelting is magnesia, MgO, which can make the slag more viscous, forcing furnaces to operate at higher temperatures, thus requiring more frequent rebricking of the smelter. Smelters typically start penalizing magnesia at levels above 5%, and they may reject concentrates containing more than 6% magnesia.

Explorers for nickel-copper-PGE deposits usually assay for the "TABSS" elements because they may be pathfinders for PGE.

ELSEVIER

Geochimica et Cosmochimica Acta

Volume 272, 1 March 2020, Pages 235-258



The role of Te, As, Bi, Sn and Sb during the formation of platinum-group-element reef deposits: Examples from the Bushveld and Stillwater Complexes

Eduardo T. Mansur, Sarah-Jane Barnes

Abstract

The distribution of platinum-group element (PGE) and Te, As, Bi, Sb and Sn (TABS) in whole-rock samples, and in disseminated base metal sulfides (BMS) pentlandite, pyrrhotite and chalcopyrite from the Bushveld and Stillwater Complexes are reported.

TABSS elements can suggest the presence of PGEs, but they are also a nuisance. As well as arsenic - tellurium, bismuth and antimony can also cause penalties.

In summary:

Nickel in ore is worthless if it's in silicates. This is one of the reasons why explorers should include "soft NSRs" in their tabulation of data. Soft NSRs are a measure of the revenues that could be produced from mineralization, and they are based on statistical analysis of data from comparable situations around the world.

Company press releases should specify the assumptions behind soft NSRs. This would reduce the chances of expensive misunderstandings that may result when investors apply invalid rules-of-thumb to assays.

Soft NSRs make allowances for penalties on deleterious materials, so they may alert geologists to mineralogical issues that could even cause rejection of a mine's products.

I recommend against using metal equivalents. They are often based on unreliable rules of thumb.

And, even though the presence of deleterious materials may result in a soft NSR that is a negative number – information very important to an exploration team deciding whether to drill or drop a project - I have never come across anyone presenting negative metal equivalents.

I've referred to the compilation of data and formulas that I use to estimate NSRs; they are available free to anyone, and thank you, everybody.

To receive, at no charge, a pdf of my NSR paper in *Mineral Economics*, or a copy of the Excel workbook containing data I have compiled and methods of computing NSRs (It's big: 9.8 MB), write to me at raymondgoldie@outlook.com

References:

[1] Goldie R and Tredger P (1991) Geosci Canada 18:159-171

[2] Goldie R (2023) Min Economics https://doi.org/10.1007/s13563-023-00400-3

[3] Goldie R (2022) Aust Inst Mining & Metal, Int Mining Geol Conf: 222-235

[4] Kerr, A (2003) Current Research Newfoundland Dept. Mines & Energy 03-1: 223-229

[5] Herzberg C, Vidito C and Starkey, N (2016) American Mineralogist http:dx.doi.org/10.213R/am-2016-5538