Criteria Used in Material Characterization and the Prediction of Drainage Chemistry: "Screaming Criteria"

Presentation at the 2005 BC MEND ML/ARD Workshop by Bill Price, Natural Resources Canada

Material Characterization and the Prediction of Drainage Chemistry

- Key components of sound environmental and fiscal management.
- Objective is to be both accurate and cost-effective
- Challenges include:
  - The many potentially contributing properties and processes
  - Crude nature of the predictive tools
- Prediction is a complex undertaking and industry, regulators, consultants and the public are always searching for criteria to guide their decision making

Objective of criteria is to provide guidance

- When is sampling and analysis required?
- What information is required?
- How to interpret the results - how to classify materials?

- Criteria should be based on practical and theoretical (scientific) considerations
- Hopefully they provide short cuts – enable cost effective prediction - but one always need to check whether the underlying assumptions or limitations apply to your specific situation.

1. ABA criteria for segregating PAG and non-PAG
2. Minimum mass of material capable of causing a significant impact (when is an assessment required)
3. Minimum %S capable of causing ARD
4. Elemental concentrations required for significant neutral pH metal leaching
5. Number of samples required for material characterization
6. Maximum length of time it could take to produce ARD

1. Criteria for segregating PAG* and non-PAG

Acidic drainage will result if:

- neutralizing minerals are unable to keep up with the rate of acid generation

or

- neutralizing minerals are exhausted prior to the completion of acid generation reactions

*PAG: Potential for ARD generation in the future

- Future balance between acid generating and neutralizing reactions is indicated by NP/AP = NPR = Neutralization Potential Ratio
- NNP = NP-AP is additive rather than a ratio and, while useful in mitigation design, is not recommended for use in characterizing the future potential for ARD.
- The neutralizing reactions used in the calculation of the NPR assume sulphides react ‘like’ pyrite and NP reacts ‘like’ calcite.

There are two basic neutralization reactions for calcite.

1. $CaCO_3 + \underline{2H}^+ \longrightarrow Ca^{2+} + H_2CO_3^0$

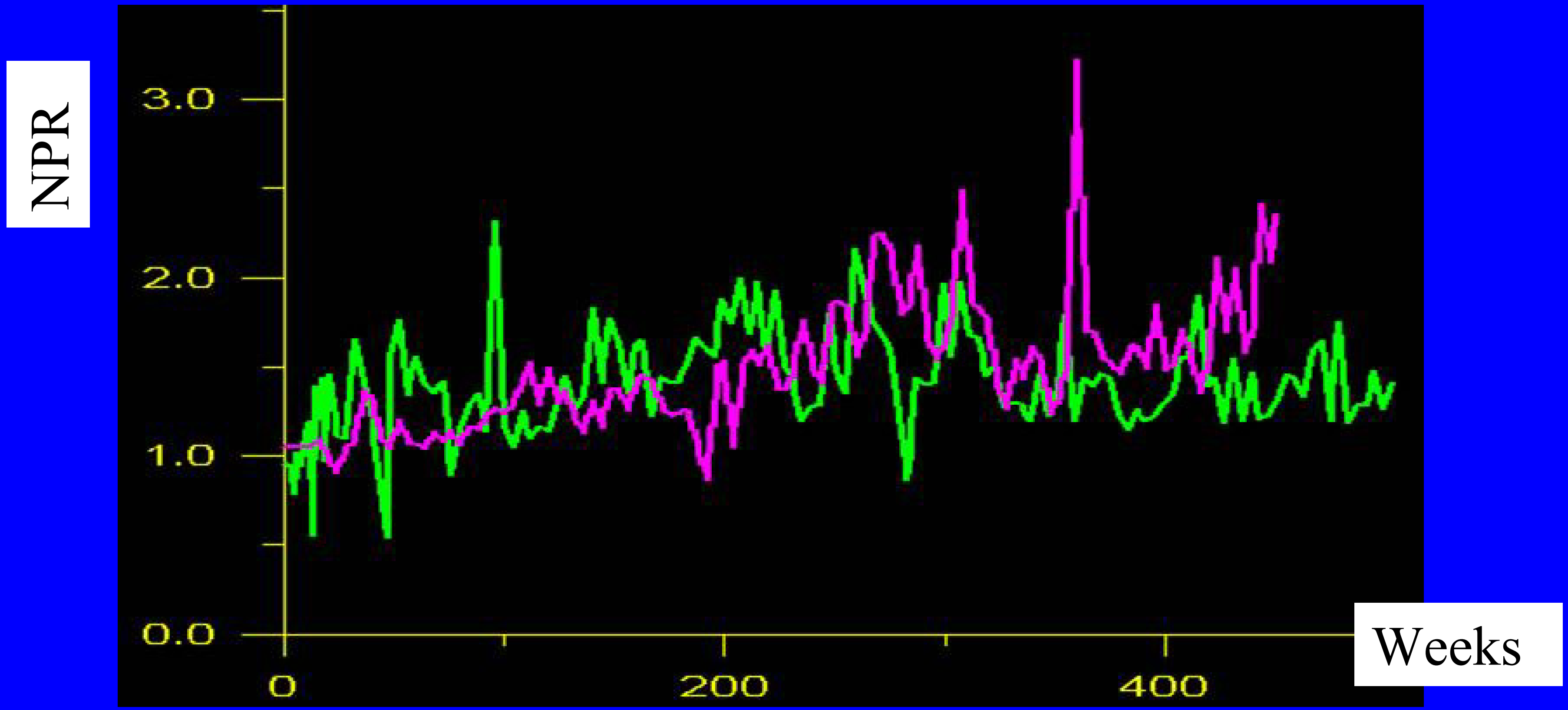
2. $CaCO_3 + \underline{H}^+ \longrightarrow Ca^{2+} + HCO_3^-$

Reaction 1. is assumed in calculation of AP (%S x 31.25) and suggests an NPR < 1 is required for ARD.

Reaction 2 suggests an NPR > 2 is required to prevent ARD.

Reaction 1 predominates below pH 6.4. Reaction 2 predominates at higher pH.

- Under neutral pH conditions, both reaction 1 and 2 are likely to occur, and the NPR required to generate ARD will be between 1 and 2.
- This is why the ratio of NP depletion (moles Ca + Mg) to AP depletion (moles sulphate) measured in a humidity cell is typically between 1 and 2.



Criteria: Sample is PAG if $NP/AP < 1$

This is true only if there are no “errors” in the estimation of effective NP and AP. Possible errors:

- at a very low rate of sulphide oxidation, neutralization capacity of silicates may be underestimated by analyses using a relatively short-term acid attack; and
- at neutral pH, many sulphide minerals generate less acidity per unit of S than pyrite.

Pyrite

$$FeS_2 + O_2 + H_2O \longrightarrow Fe(OH)_3 + 2SO_4^{2-} + 4H+$$

Chalcopyrite

$$CuFeS_2 + O_2 + H_2O \longrightarrow Fe(OH)_3 + 2SO_4^{2-} + Cu^{2+} + 2H+$$

Covellite (1:1) similar to Galena (PbS) and Fe-less Sphalerite (ZnS)

$$CuS + O_2 \longrightarrow Cu^{2+} + SO_4^{2-}$$

Chalcocite (2:1)

$$Cu_2S + O_2 + \underline{2H^+} \longrightarrow 2Cu^{2+} + SO_4^{2-} + H_2O$$

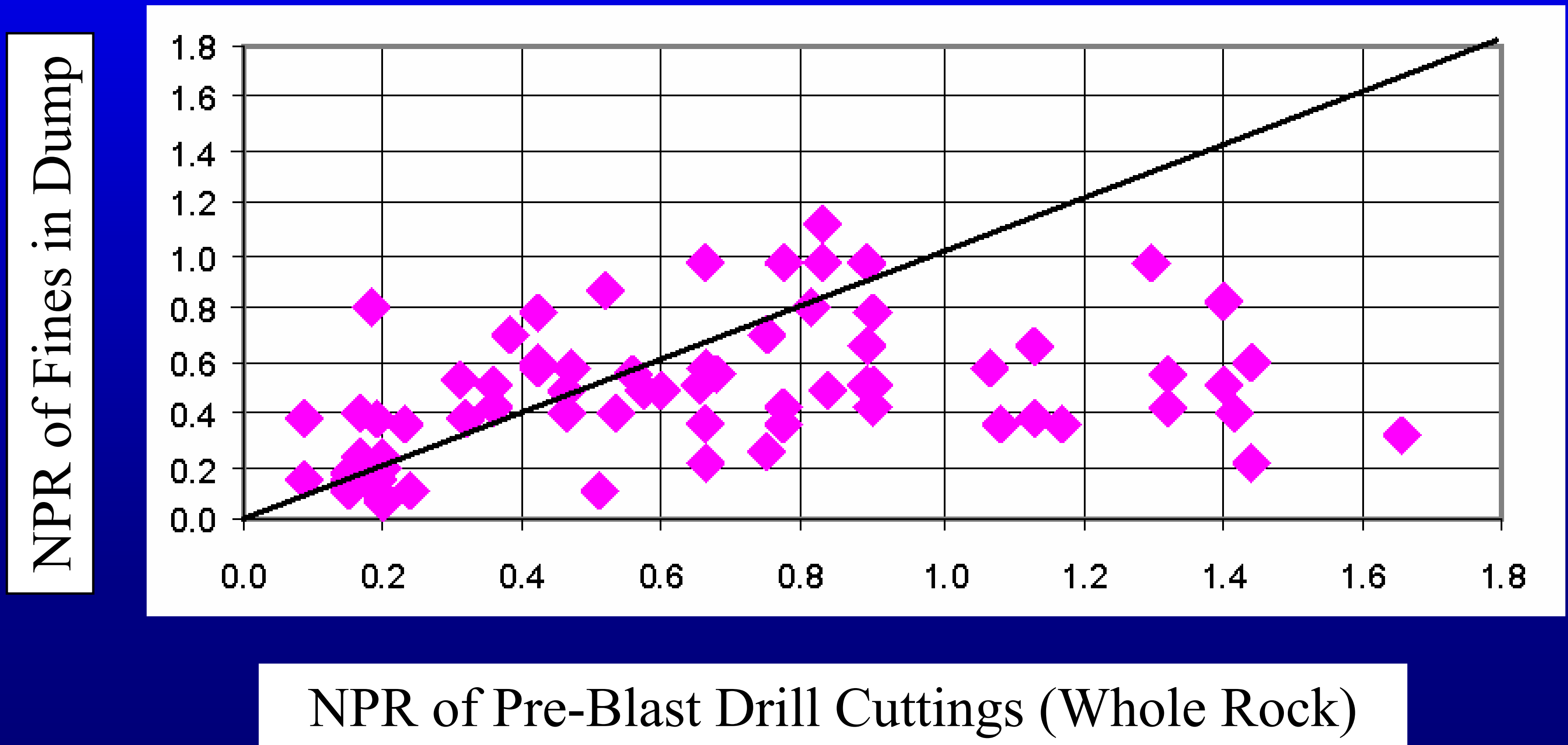
Solution: Conduct mineralogical analysis to check identity of sulphide minerals

Criteria: Sample is Non-PAG if NP/AP > 2

This is true only if there are no "errors" in the estimation of effective NP and AP. Possible errors:

- – the reactivity of a significant portion of the measured NP (silicates) is too slow
- – a significant portion of the measured NP may be Fe and Mn carbonates, which are not neutralizing under aerobic conditions
- – NP is depleted by processes other than the acidity created by sulphide oxidation (see Mattson)
- – measurements are made on 'whole rock' are misleading because after blasting sulphides are preferentially exposed on surfaces, while NP is buried within coarse particles

The NPR of the reactive fines in waste rock is often lower than the pre-blast drill cuttings. In this case the difference is not significant because the pre-blast samples had an NPR < 2, the criteria used to segregate PAG waste rock. But if an NPR < 1 measured on pre-blast drill cuttings had been used for segregation, PAG fines would have been placed in the non-PAG dumps.



Other Considerations:

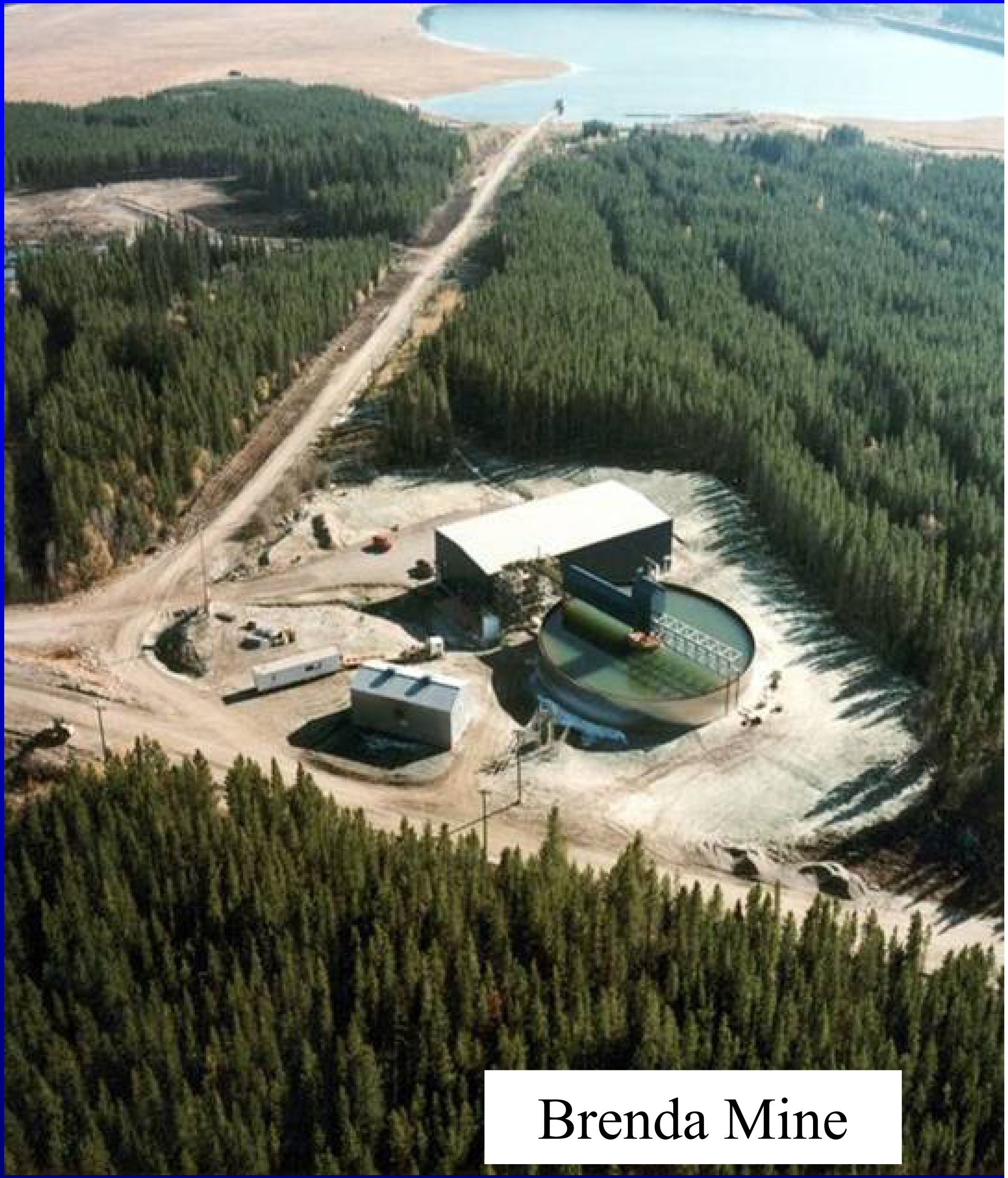
- The ARD potential of material with an effective NP:AP between 1 and 2 will depend in part on the fate of the alkalinity produced by the second pH > 6.4 neutralization reaction.

Other Considerations in Material Characterization:

To ensure all the PAG rock is correctly identified, safety factors may be used to account for limitations in the precision and accuracy of sampling, analysis, data interpretation, segregation and other aspects of material handling.

Other Considerations:

- The prediction of drainage chemistry should be conducted even if the NPR > 2 because impacts can also occur due to near-neutral pH drainage.



2. Minimum mass of material requiring prediction and /or mitigation

Prediction is required if material is capable of producing a significant environmental impact

Potential for significant impact increases with:

- increasing sulphide and trace element content;
- increasing surface area (volume and mass);
- ARD (increases reactivity, solubility, etc); and
- lack of dilution and/or attenuation prior to sensitive receptor.

Materials Lacking Sulphides and/or Trace Elements

- Glaciofluvial and fluvial materials derived from wide areas and exposed to intense physical and chemical weathering (aggregate and placer mines - unless they use contaminants in the process)
- Dimensional stone quarries are usually sulphide-free because sulphides reduce the quality of the product

Low Surface Area

Drill core and field test pads typically have too low a surface area to be a concern.

For exploration, BC MEMPR has used a criteria of 1,000 tonnes before any prediction is required. For a rock mass smaller than 1,000 tonnes to cause a problem requires:

- significant drainage through the pile;
- a large supply of soluble metals; and
- very little attenuation or dilution between the discharge source and the sensitive environment.

The small size of a pile less than 1,000 tonnes typically limits drainage interception and the environment contributes attenuation.

However, the minimum disturbance criteria should be reduced to 100 tonnes or lower where the excavated rock is highly reactive and is deposited adjacent to a sensitive watercourse.

If in doubt, conduct sensitivity analysis using site data and a few simple assumptions.

		Neutral pH	Low pH
		Zinc	Copper
Downstream Objective	mg/L	0.03	0.004
Background Concentration	mg/L	0.005	0.001
Dump Concentrations	mg/L	2	20
Dump Mass	tonnes	1000	100
Dump Volume	m^3	670	67
Dump Area	m^2	1,531.00	153.00
Required Area for Dilution	m^2	120,663	1,020,629
	ha	12	102

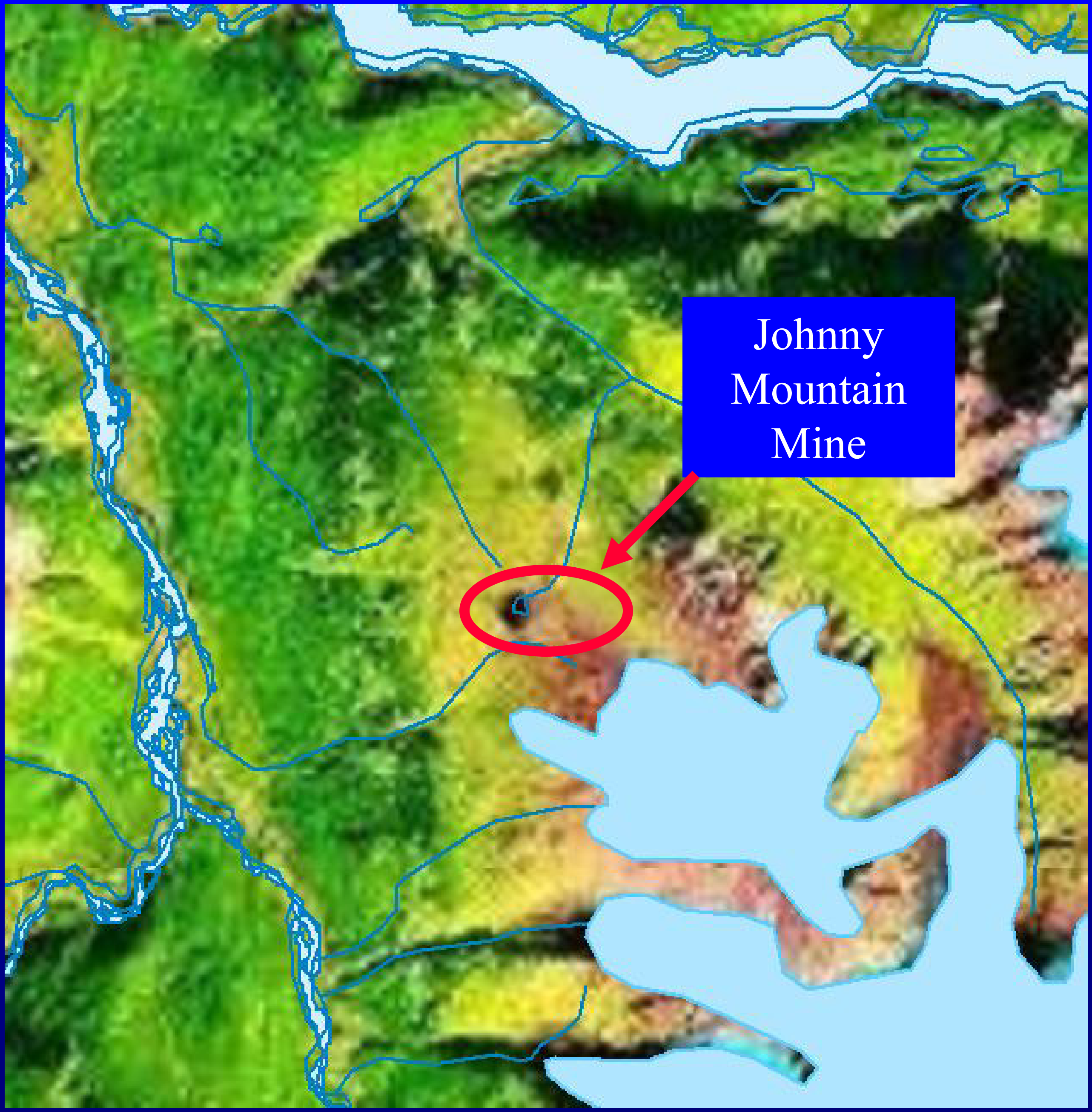
Note: calculations assume dilution is permissible and 4.4 m high dump.

Negative Site Features:

- Drainage from upstream enters waste – add diversion ditches, and avoid adits and depressions
- High background concentrations from natural metal source or cumulative effects of other developments minimize the assimilative capacity

Advantageous Site Features:

- Enhanced geochemical attenuation, such as precipitation or adsorption
- Large drainage source upstream (e.g., glacier)


Johnny Mountain Mine

3. Minimum % sulphide-S capable of causing ARD

- The ‘minimum %S capable of causing ARD depends on magnitude of the effective NP.
- For example, if the effective NP is 20 kg/t, <0.3% sulphide-S will result in an NPR > 2.
- Mined rock often has an extremely low NP.
- At the East Kempville Mine, coarse tailings in humidity cells with a sulphide-S as low as 0.09% produced ARD.
- Conclusion: Do not use a %S cut-off when assessing the ARD potential.

4. Elemental concentrations required for significant neutral pH metal leaching

- Determination of which trace elements occur in relatively high total concentrations can be made by comparing results with the normal range of concentrations found in rock.
- However, total concentrations provide no information about the source in which the element exists, its solubility or reactivity. In many cases, the mineral source will be inert or only sparingly soluble and therefore a total concentrations is not in itself a measure of the threat to the environment.
- Further mineralogical analysis and static and kinetic testing is required to determine the mineral source(s), present solubility and predict future weathering rates and drainage chemistry.

Exceedance of the upper concentration of total trace elements normally found in rock (mg/kg) is not a measure of the environmental concern.

Ag 0.1	Cu 90	Pb 20
As 2	Hg 0.1	Sb 0.2
Cd 0.2	Mn 1500	Se 0.1
Co 100	Mo 2	Sn 5
Cr 170	Ni 200	Zn 100

5. Number of samples required for material characterization

- Sufficient samples should be taken to accurately characterize the variability and central tendency over the entire area of disturbance and for each geological unit.
- The actual number of samples required for a particular area or material will depend on the variability of critical parameters, the questions being asked and the degree of accuracy required.
- Ideally sampling will be an iterative task involving several phases of sampling and analysis, with each phase informed by the results from the previous campaigns.

The following arbitrary number of samples from each rock unit or a mine component based on tonnage of disturbed rock is recommended for use in the first phase of testing, if no other guiding information is available.

Minimum Number of Samples for first Phase of Testing	
Tonnage of Unit (tonnes)	# of Samples
< 10,000	3
< 100,000	8
< 1,000,000	26
<10,000,000	80

- Sampling density used to determine ore grades is a better initial guide.
- Check whether adopted sampling frequency is sufficient by sampling more frequently.
- Check the variability of the result, the questions being asked the degree of accuracy required and the variability of the geology to check whether sampling is too frequent.

6. Maximum delay prior to ARD occurring

- "If this rock was potentially ARD generating, we would have already seen ARD in the dumps, some of which are over 50 years old."
- Absence of ARD does not prove it will not occur in the future. Depletion of effective NP may take 10s to 100s of years.

Humidity cell coupled with ABA results provide rough estimates of NP depletion.

An NP depletion of 5 kg $CaCO_3$/tonne measured in cells suggest it would take 36 years to exhaust an NP of 180 kg/t in the backfill in the Snip Mine.

At colder site temperatures, the depletion of neutralizing minerals required for the onset of ARD may take far longer.

It is important to set up field test pads ASAP and check field weathering in materials at the site, such as older dumps and drill core.

Conclusions

It is important to recognize that generic numbers in prediction criteria cannot substitute for:

- an understanding of the natural environment, the project, the geological materials and the protection requirements; and
- the development of site-specific criteria based on measurable parameters and a well-informed assessment of the limitations of the results.

Practitioners need to decide:

- What information is required to make assessment
- Under what conditions are ‘short cuts’ permitted
- When conditions deviate from the ‘expected’

- Sensitivity analysis and risk assessment are required to determine the sufficiency of the information. The devil is usually in the details; so check them!
- Safety factors may be required to account for limitations in the precision and accuracy of sampling; analysis; data interpretation; segregation; and other aspects of material handling.

Why "Screaming Criteria"?

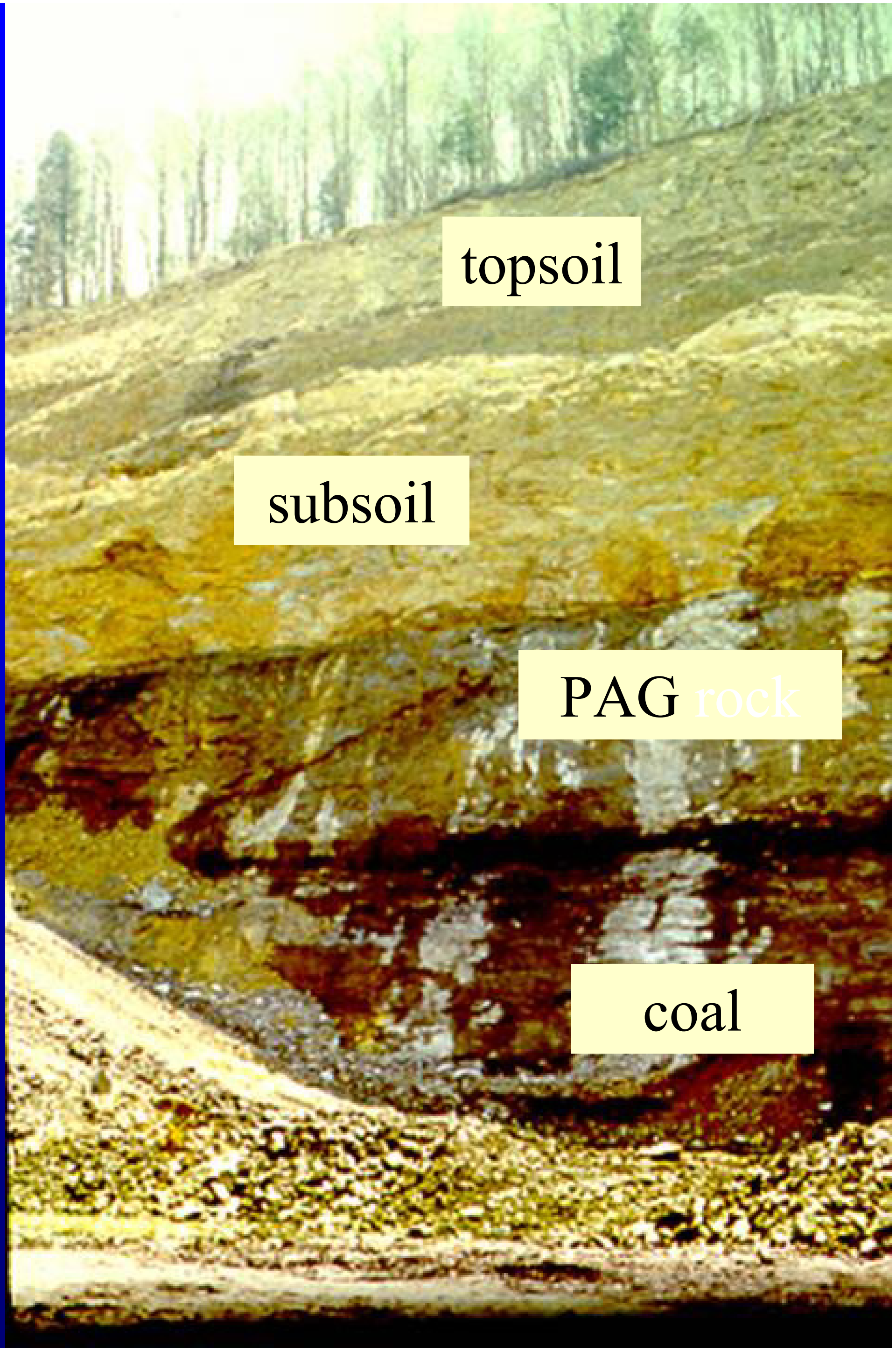
Because the numbers provided in guideline documents are commonly:

- misunderstood,
- used inappropriately or
- quoted out of context.

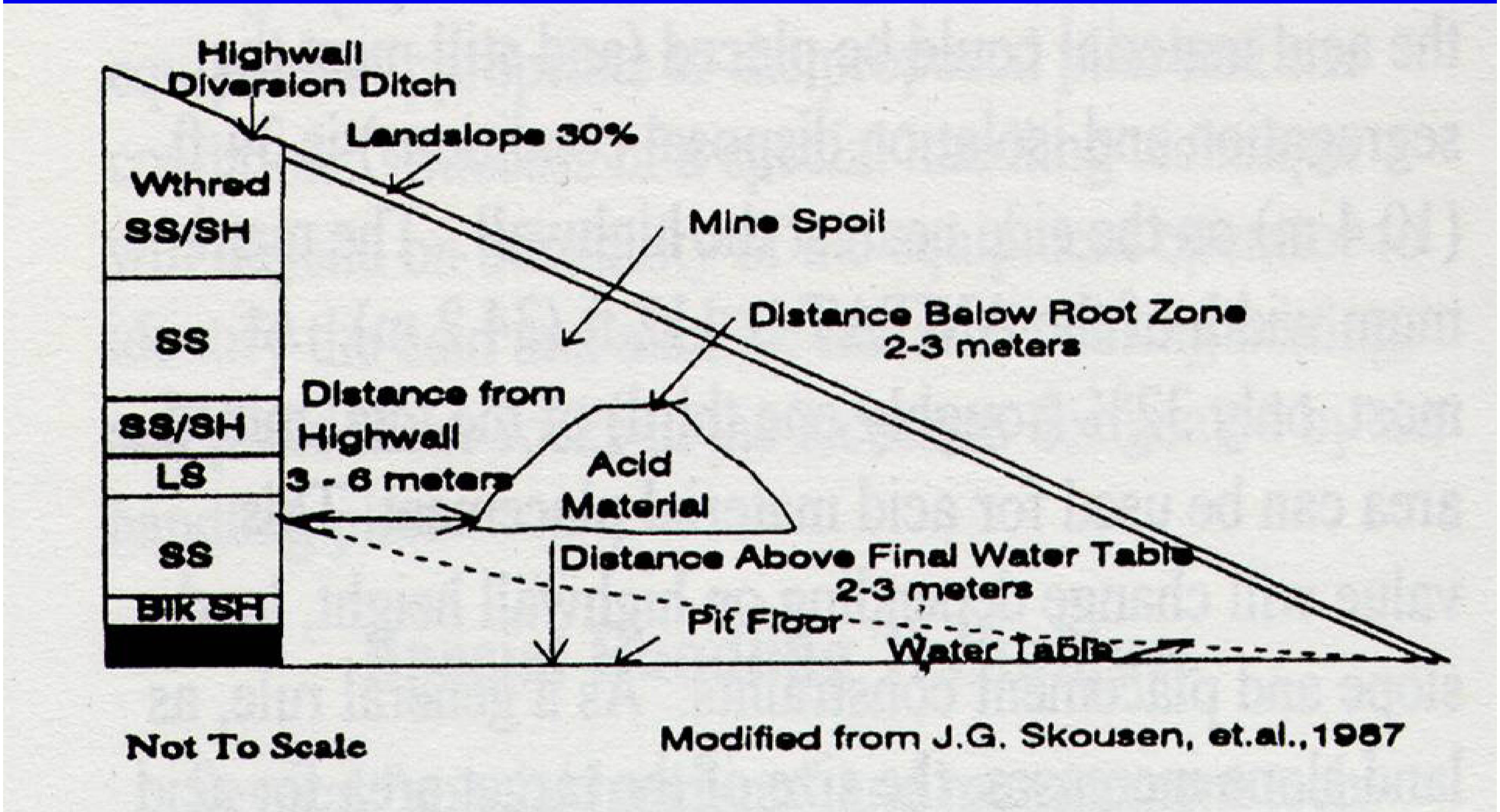
Always need to consider the specific situations to which the criteria apply and the details concerning there use.

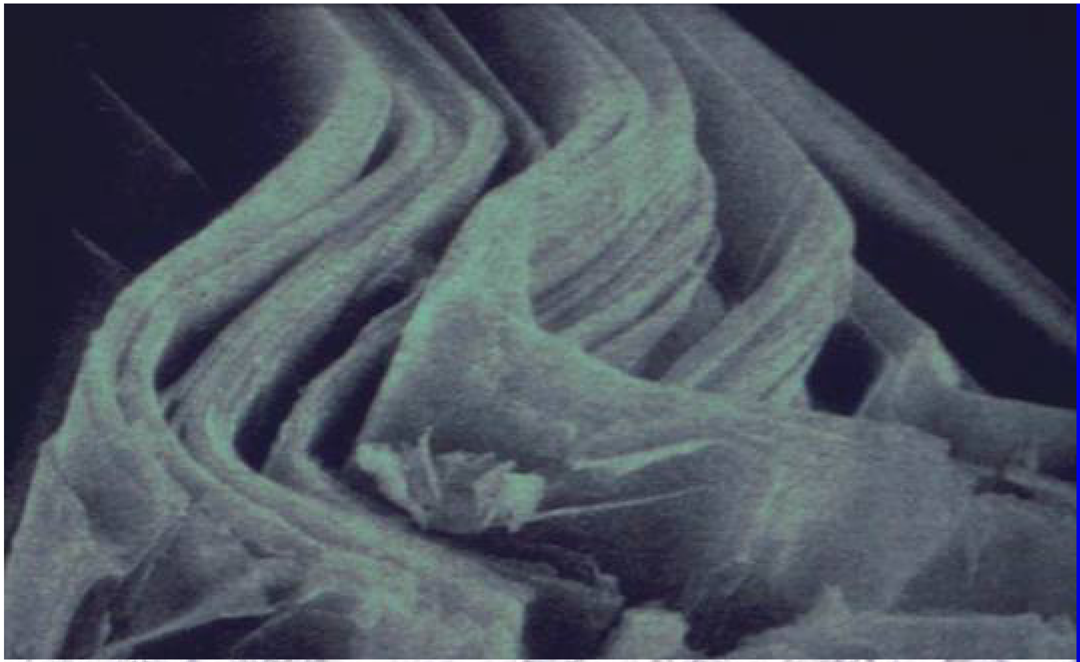
Numbers rarely tell the whole story. For example, the blending procedure adopted by one BC mine in the late 80s was based on the 2:1 blending ratio supposedly used by coal mines in the Eastern US.

Mistakes occurred due to misleading terminology, a failure to check the details and inadequate material characterization.



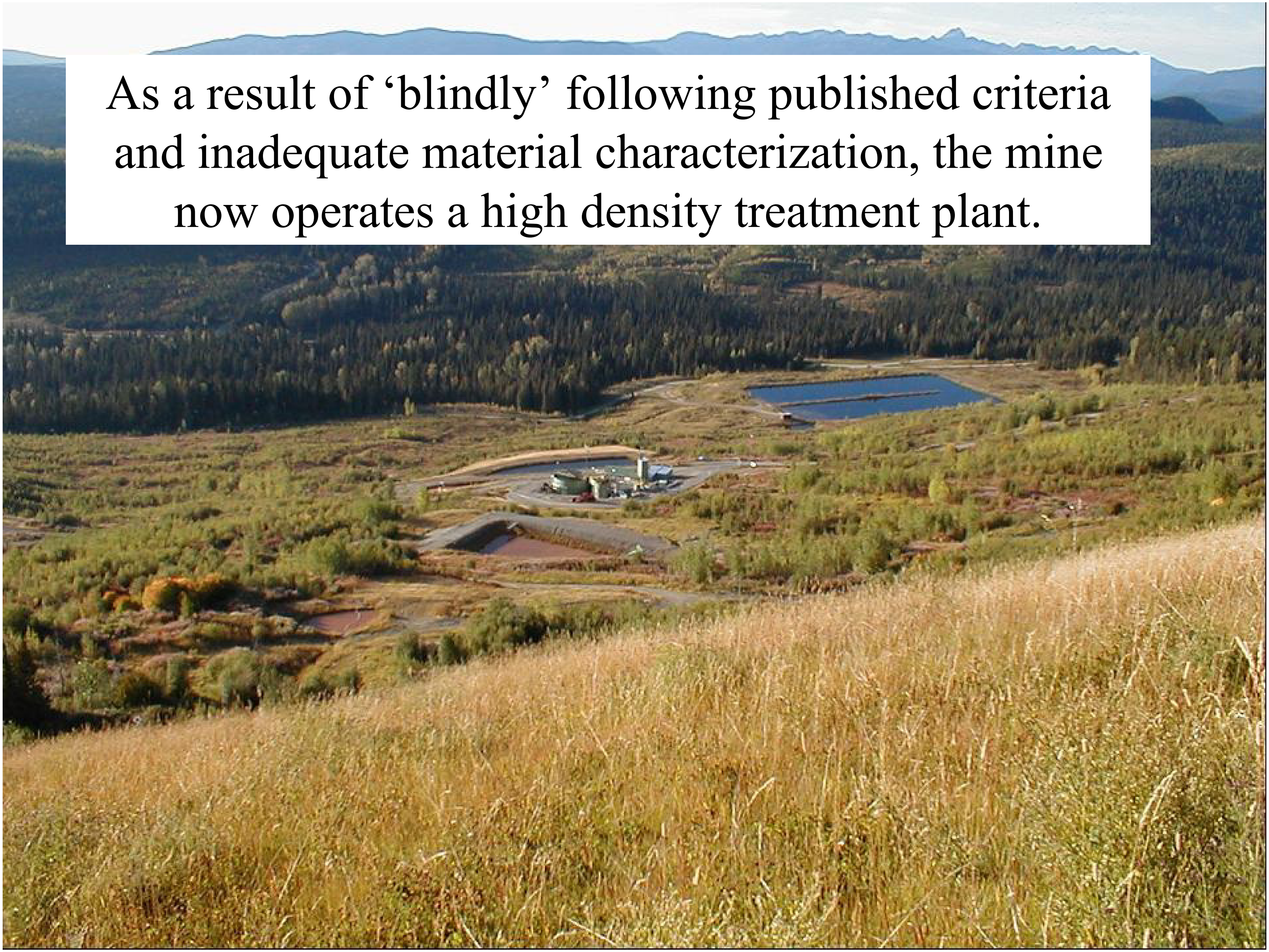
Although an overall average ABA was calculated, the actual mitigation measures used in the Appalachia relied primarily on measures to reduce leaching (hydrological isolation - rather than blending) and there was no discussion of a potential for elevated metals in drainage at neutral pH.





Furthermore the PAG rock at the BC mine was highly sericitic and had a large surface area, whereas the non-PAG rock was far more competent. As a result the surface area and therefore the reactivity of the PAG was >> non-PAG.

As a result of 'blindly' following published criteria and inadequate material characterization, the mine now operates a high density treatment plant.



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