Voisey's Bay Nickel Mine: A unique approach to mine rock management in the 1990s with a follow-up assessment in 2017

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The Players

- INCO acquire Voisey' Bay deposit in 1996 for $4.3B
- INCO's Voisey's Bay Nickel Company (VBNC)
- Vale acquires INCO in 2006 and operates the Voisey's Bay mine

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The Context

- Discovery of 32 Mt Ovoid Massive Sulphide Ni-Cu deposit
- Identification of significant underground resource
- EIS completed between 1996 – 1999 with a Mine Rock Management plan
  - Using PAG identification of 0.2%S or greater
- Project on hold for due to incomplete negotiation with stakeholders
- Negotiations with stakeholders on necessary agreements concluded in 2002
- Started Mining the Ovoid (open pit) in 2005
  - 0.2%S used in start of operation from 2005 to present
- 2016 Plans expansion to mine underground
- Request from regulator to review mine rock management criteria and plans

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The EIS (1996-99)

- Recognized early that this deposit is sulphide rich and appropriate waste rock management will be required

- Need to identify:
  - non-reactive mine rock that can safely be deposited on-land, and;
  - potentially reactive mine rock that should be stored underwater as a mitigative measure

- All tailings to be stored underwater (PAG)

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Precautionary Principle

- Adopted a precautionary principle regarding PAG rock:

Assume all mine rock is potentially reactive until proven otherwise

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1996-1997 Test Program

- Extensive analyses and testing provided confidence
- Static Tests -more than 500 analyses for:
  - Metal Content
  - Acid Base Accounting (ABA-includes Sulphur)
- Kinetic tests (assess reactivity)
  - 22 Humidity Cells / 18 Column tests
  - 58 Oxygen Consumption Measurements

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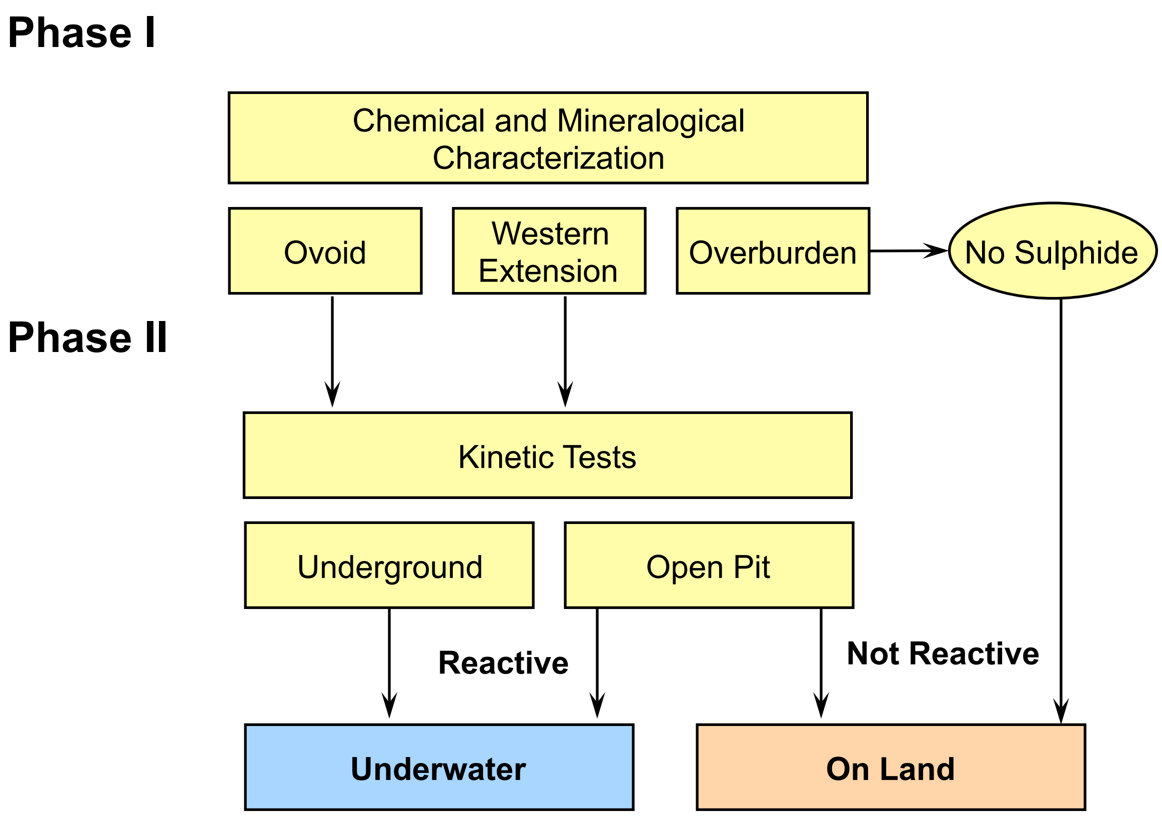
Mine Rock Investigation Flow Chart



Summary of Key Results (1997 EIS)

- Relatively simple geology with two main types of mine rock that are easy to recognize
  - Low-Sulphur "**Gneiss**" (light colored)
  - Sulphur-bearing "**Intrusive**" (dark colored)
- Sulphur content is the KEY indicator of available metals and of reactivity

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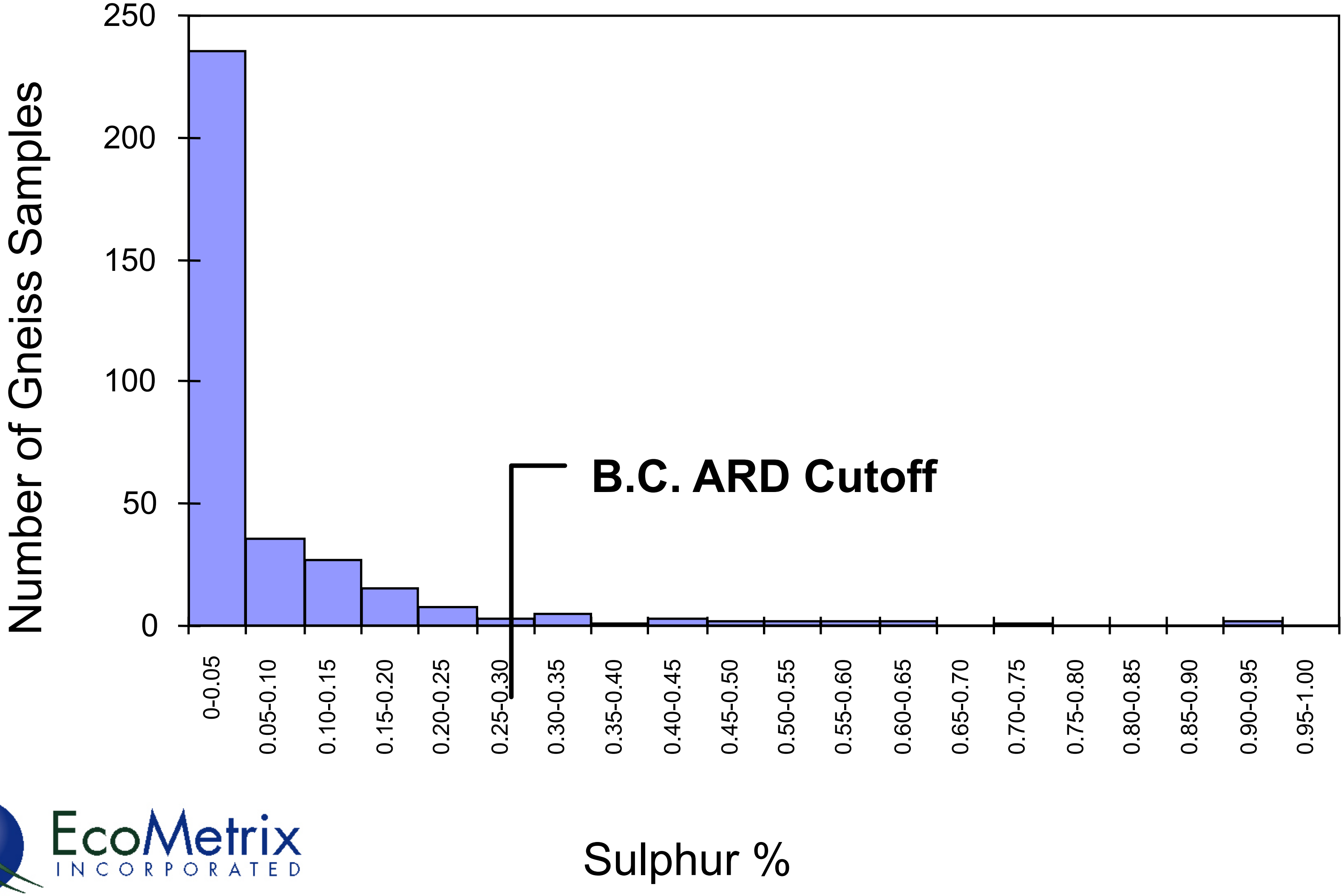
Frequency Analysis of Sulphur in Gneiss



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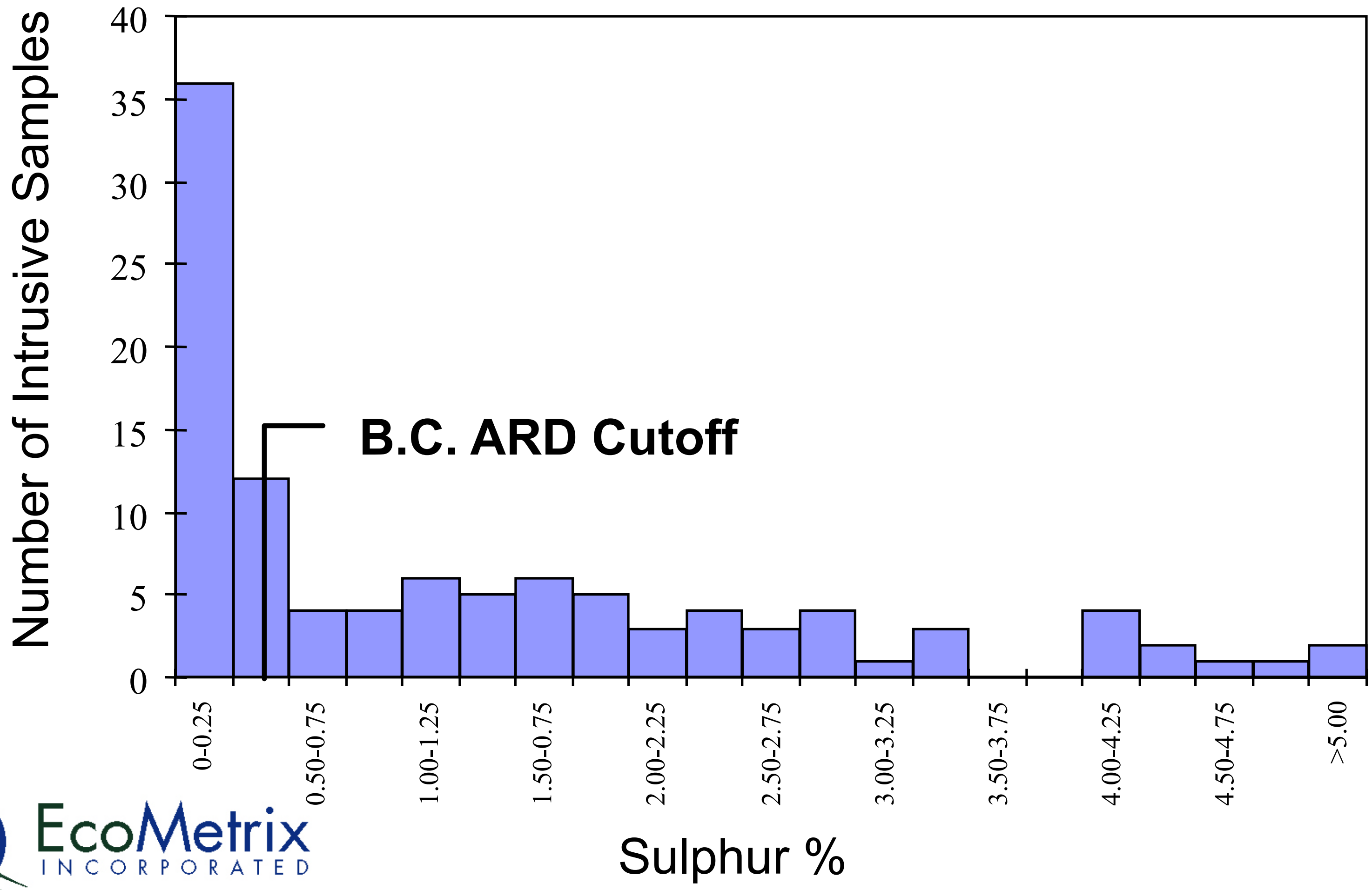
Frequency Analysis of Sulphur in Intrusive Rock



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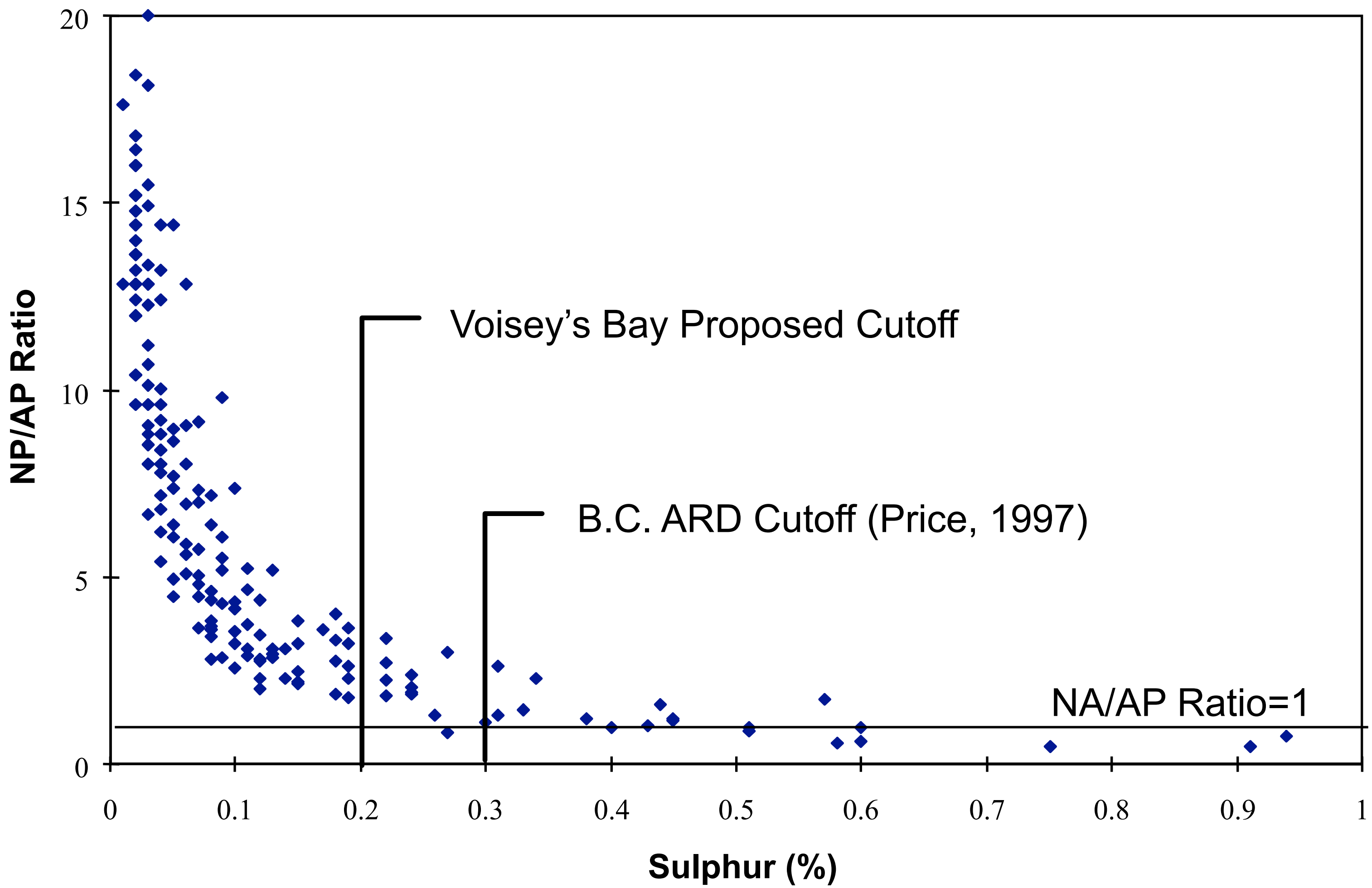
NP/AP Ratio vs. Total Sulphur in Gneiss



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Conclusions of 1997 Study

- Overburden is non-reactive
- **Intrusive** rock is assumed to be reactive and all will be placed underwater
- The non-reactive **Gneiss** represents more than 90% of the mine rock from the open pit that can be safely deposited on-land

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Conclusions of 1997 Study (cont.)

- Results show that a **0.2% sulphur content** is a conservative cut-off value to separate reactive and non-reactive mine rock

- Segregation procedures and protocols based on sulphur content are practical and achievable during mining

Recommendations of 1997 Study

- Humidity cells and columns continuing
- Underwater testing of;
  - Mine Rock
  - Tailings
  - Potential surface barriers

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Current Operating Parameters

- Use of 0.2%S to identify non-PAG
- Assays blast holes and classify material prior to blasting
- Define non-PAG allowing 5 m buffer from 0.2%S zones
- All PAG material is placed sub-aqueously for final storage
- Non-PAG material to the CRD pile adjacent to the pit
- Approximately 10 Mt of non-PAG rock with an average of 0.06 %S in 2017

2016 Review of Mine Rock Management

- Development Plan for underground expansion submitted in 2015
- Request from regulator to review mine rock management criteria and plans

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The 2016 Review

- Original document by BEAK (1997) and follow up studies
- Reviewed in the context of more recent guidance (Price, 2009; GARD Guide, 2009) and EXPERIENCE since 1997

- Found criteria of 0.2% is reasonable
- Questioned "effectiveness" of NP (Sobek) used in the assessment
- Suggested additional assessment of "effective" NP

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The 2016 Review

- Sobek and Carbonate NP values available in the database
- New samples collected and characterized
- Effective NP assessed in the lab

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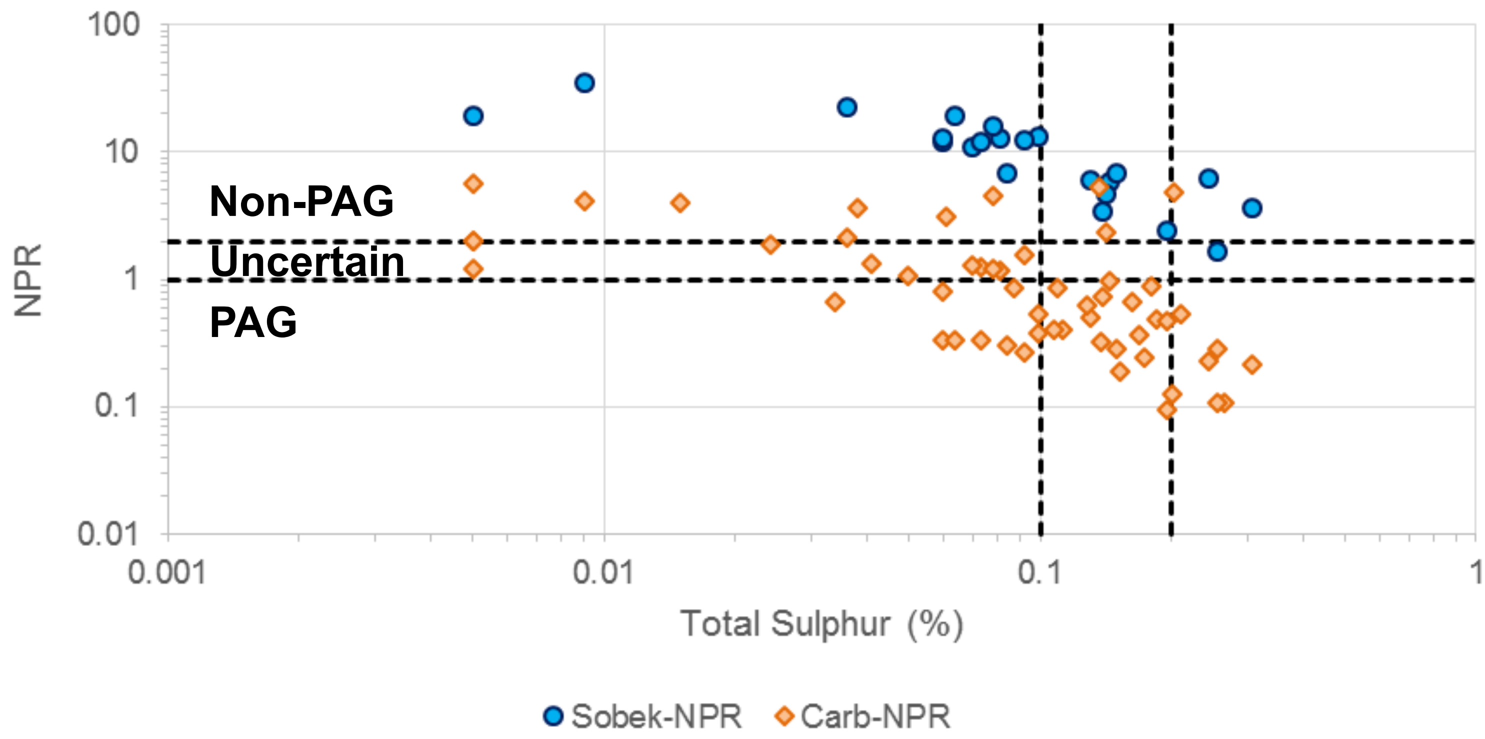
Neutralization Potential Ratio (NPR)

- Effective NP likely between Sobek and Carbonate values



NP Concepts Overview

NP Method	Method Overview
Sobek-NP	• Excess HCl addition (down to pH < 2.0), digestion & back-titration with NaOH to pH 8.3 • Includes carbonates & other potential buffers "outside" relevant environmental of pH < 6.0 (e.g. aluminosilicates); *typically overestimate*
Carbonate-NP	• Based on Inorganic Carbon analysis (as % CO_2) converted to (% CO_3) & Carbonate-NP; *typically conservative*
Assessing "Effective-NP"	Operationally, "readily available" NP able to maintain pH~ 6.0 • Bracket an Eff-NP using two approaches (1) Titrations with Acid (2) Batch Phased Acid Additions

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Recommendations from 2016 Review

- Asses effective NP “available” to maintain pH of 6.0 or greater
- Reassess cut-off criteria based on effective NP
- Test program initiated in 2016, using core samples and rock from open pit

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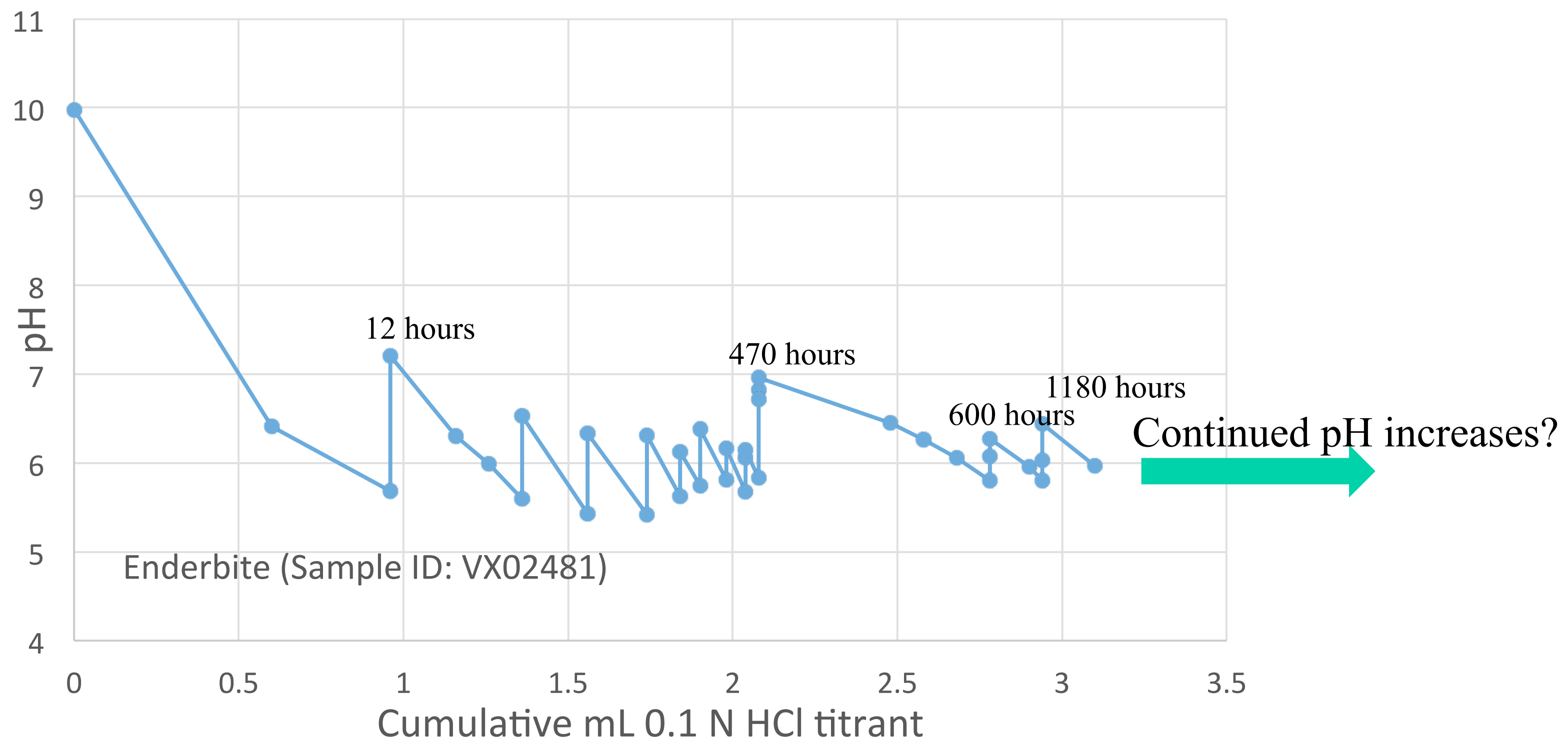
Results 1: Titration-Effective NP

- Rates very slow – not practical to define an Eff-NP
- At 1200 h, sporadic pH increases occur (pH >6.0)
- Enderbite Titration NP at less than 15% Sobek-NP



Results 1: Titration-Effective NP

Rock Type	ABA Analysis		Titration Experiments					
	Carb-NP	Sobek NP (kg CaCO3/t)	Titration Effective-NP	Expressed as Percent Sobek-NP	*pH From Last Acid Addition	Last pH Reading	Total Experiment Time	pH Status From Last Acid Addition
Units	kg CaCO3/t			%	pH unit		Days	
Enderbite	0.4	15	2.0	14	5.74	6.26	53	increasing
	0.6	15	1.7	12	5.74	6.00		
	0.8	17	1.5	9	5.70	6.30		
	1.3	15	3.5	23	5.78	6.44		
Paragneiss	1	6.3	2.2	35	5.86	6.18	52	increasing
	4.3	8.8	1.5	17	5.80	6.25		
	0.5	7.9	3.3	41	5.85	6.30		
Troctolite	0.4	24	3.1	13	5.83	6.26	48	increasing
	2	25	1.9	8	5.76	5.89		
	2.6	22	3.2	15	5.78	6.26		
	2	34	3.5	10	5.91	6.25		
	0.8	29	2.7	9	5.85	6.11		

*Last acid addition done within the last 400 hours (17 days)

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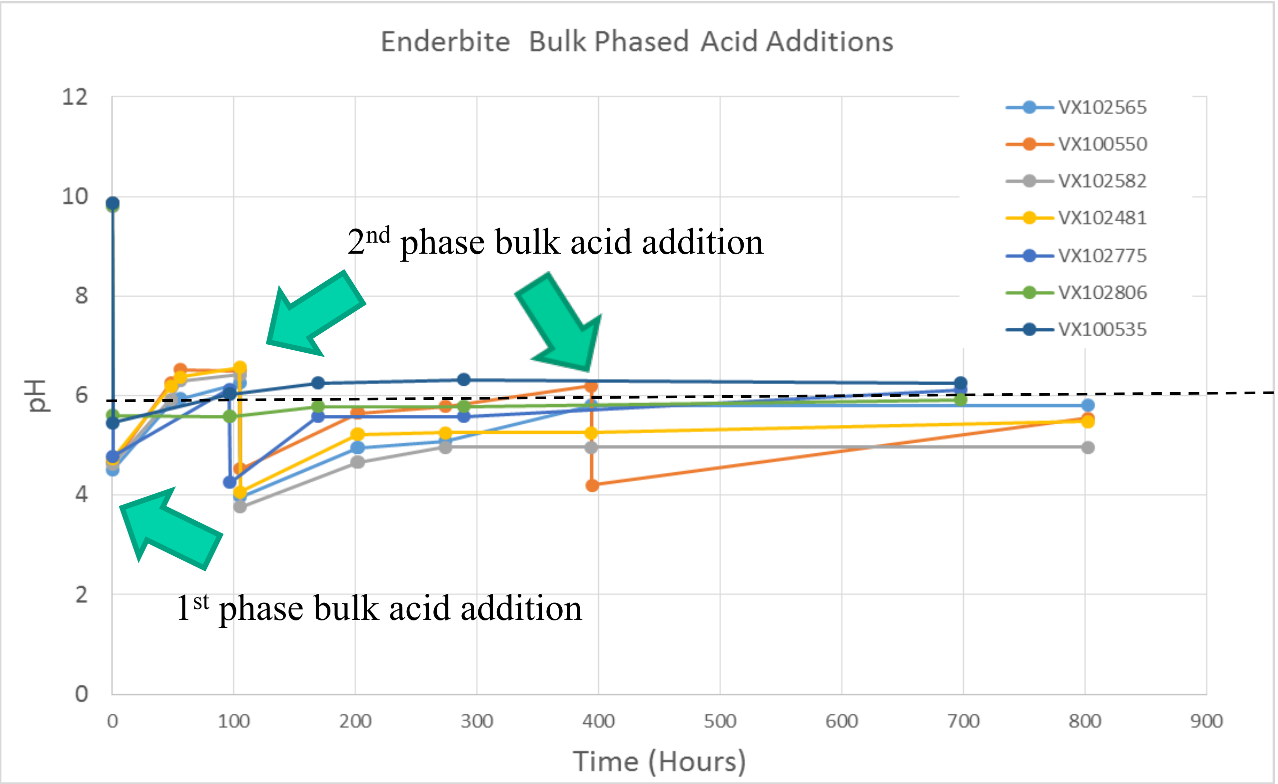
Results 2: BPAA-Effective NP

- 2 phase Bulk Acid Additions
- Only able to recover (pH > 6.0) from 1st bulk acid addition; plateaued (pH < 6) after 800H
- *Enderbite* pH vs. Time sample plot



Results 2: BPAA Eff-NP

- Batch Phased Acid Eff-NP (as % Sobek-NP)

Rock Type	Sample Location	ABA Analysis		1st Phase Batch Acid Addition			2nd Phase Batch Acid Addition			
		Carb-NP	Sobek-NP	BPAA - ENP	Percent Sobek-NP	Recovered to pH>6?	Cumulative BPAA - ENP	Cumulative Percent Sobek-NP	Recovered to pH > 6?	Terminal pH (Within approx. last 200 hours)
	Units	kg CaCO3/t		kg CaCO3/t	%		kg CaCO3/t	%		pH unit
ENDERBITE	SE Extension	0.4	15	4.8	32	Yes	6.6	44	No	5.15
		0.6	15	4.8	32	Yes	8.4	56	No	4.96
		1.3	15	4.8	32	Yes	6.5	44	No	5.25
	RB Ramp	0.8	12	4.6	39	Yes	5.2	43	Yes	6.12
		1.3	14	4.2	30	*No*	*4.2*	*30*	--	*5.92*
	ED Conveyor	0.8	17	4.8	28	Yes	6.0	35	No	5.78
		2.0	17	6.0	36	Yes	6.0	36	--	6.25
PARAGNEISS	RB Ramp Churchill Province	4.3	9	2.4	27	Yes	4.8	54	No	5.64
		0.5	8	2.4	30	Yes	4.7	60	No	4.95
		1.1	6	2.4	38	Yes	4.8	75	No	5.4
		2.1	10	3.5	37	Yes	3.5	37	--	6.37
		1.8	11	3.5	32	*No*	*3.5*	*32*	--	*5.75*
		1.1	12	4.7	39	*No*	*4.7*	*39*	--	*5.97*
TROCTOLITE	Reid Brook	1.6	43	9.7	23	*No*	*9.7*	*23*	--	*5.54*
		1.9	25	6.9	28	Yes	7.5	30	No	5.89
		2.6	22	5.8	26	Yes	8.1	37	No	5.89
	SE Extension	0.4	24	5.9	25	Yes	5.9	25	--	6.02
		0.8	29	8.1	28	*No*	*8.1*	*28*	--	*5.2*
		2.0	34	8.4	25	Yes	10.8	32	No	5.28
		1.3	32	9.6	30	*No*	*9.6*	*30*	--	*5.36*

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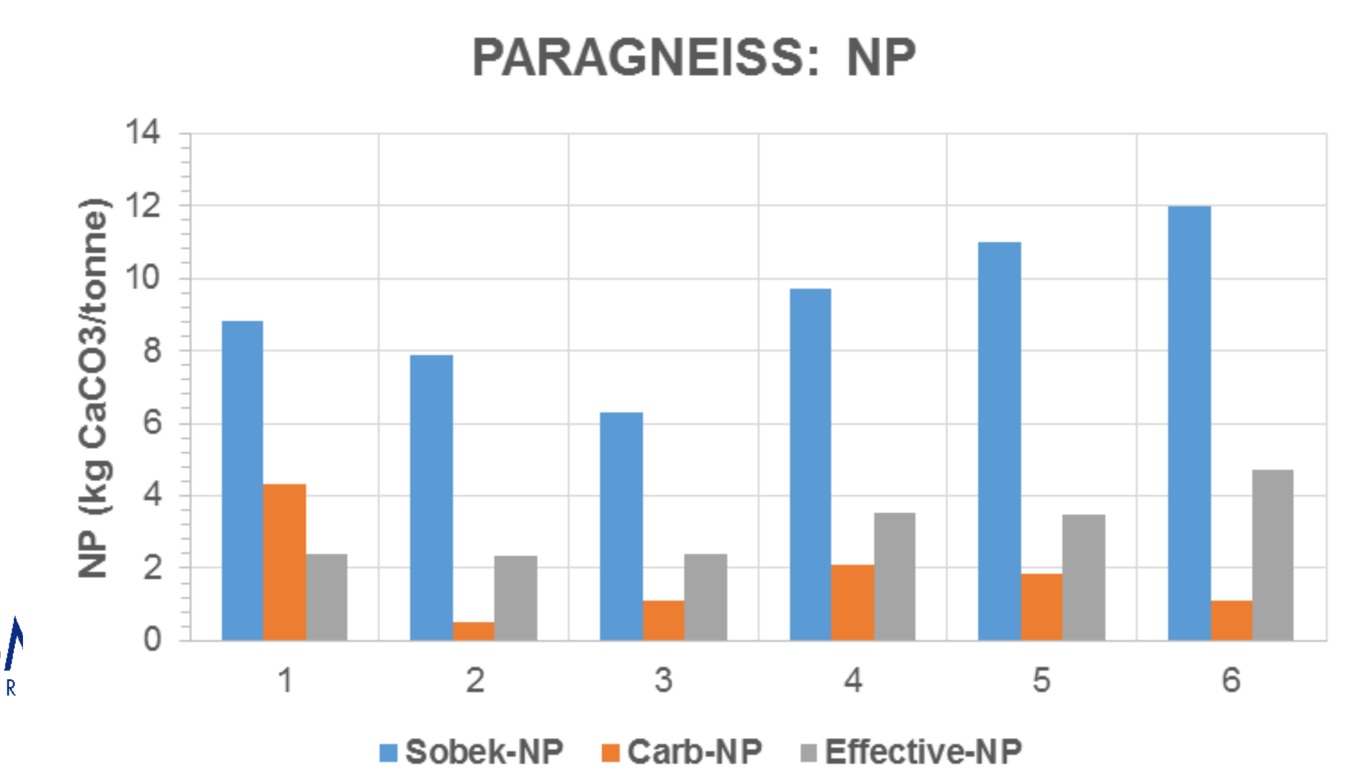
Batch Acid Titrations - Paragneiss

- Batch acid addition of a portion of the Sobek-NP
  - 6 Paragneiss Tests



Sobek-NP to Effective-NP

- Enderbite
  - 30% of Sobek-NP is effective
- Paragneiss
  - 30% of Sobek-NP is effective
- Troctolite
  - 20% of Sobek-NP is effective

- Further investigations can use Sobek-NP to estimate Effective-NP

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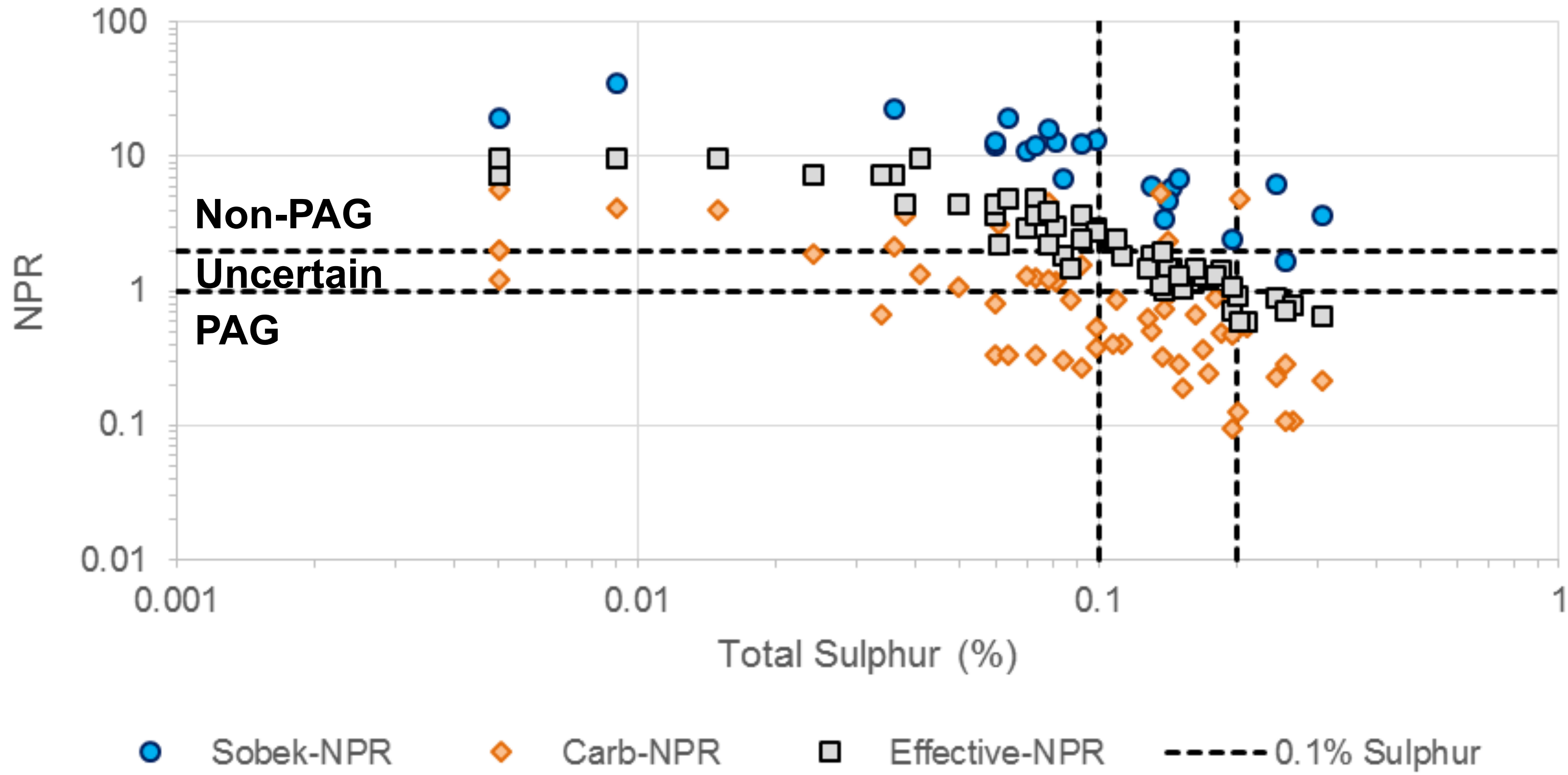
Neutralization Potential Ratios



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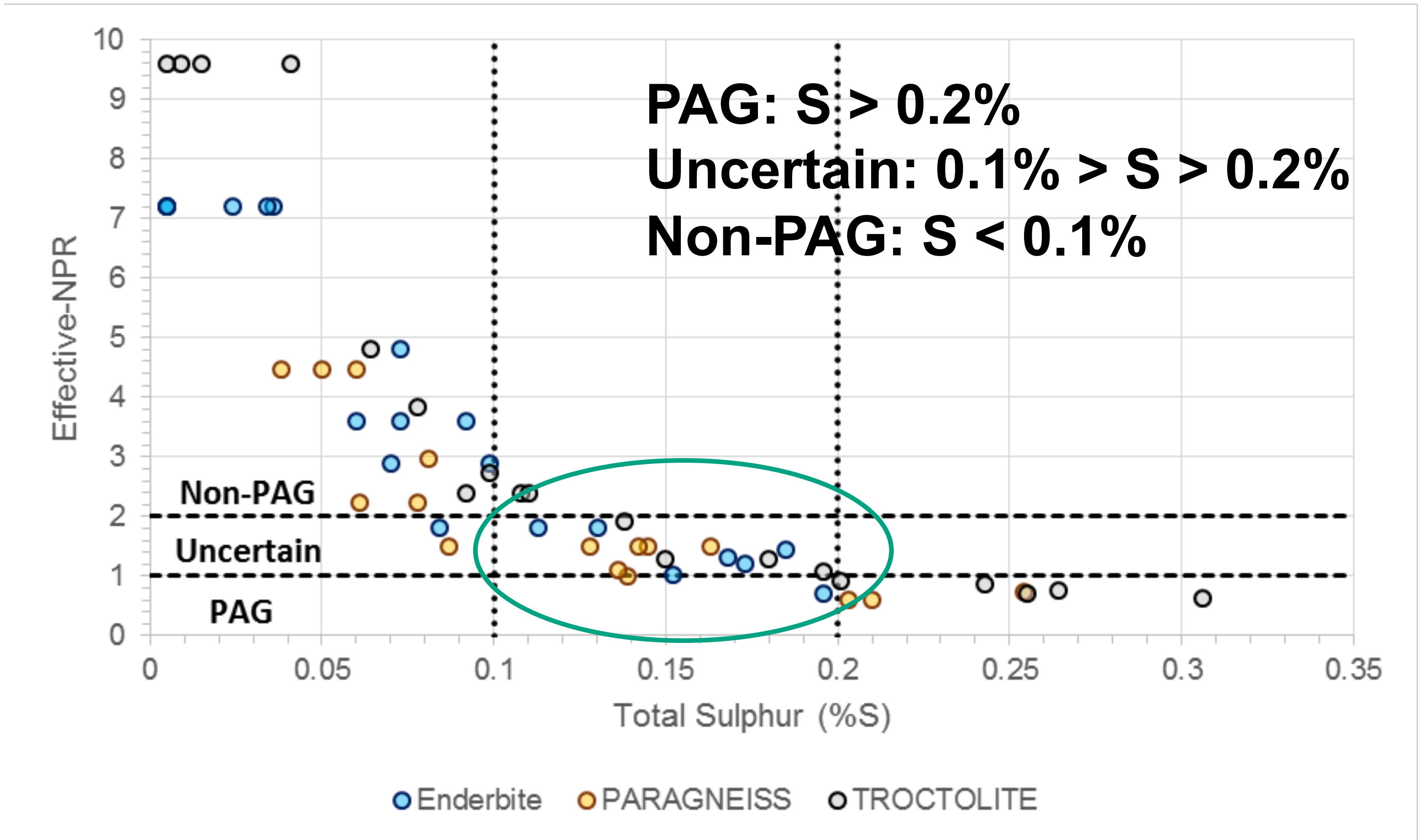
Effective-NPR and Sulphur



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Mine Rock Management Conclusions

- Total sulphur content used as a standalone predictor of ARD
- The sulphur content of 0.2% S appears reasonable based on effective NP
- A 0.1%S value to identify PAG and non-PAG materials will be more conservative
- Carbonate content not a reliable predictor of Effective-NP at Voisey's Bay
- Should assess metal leaching characteristics to confirm low risk for rock with less than 0.1%S

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The Work Continues

- Field investigation in progress to evaluate the behaviour of the non-PAG rock in the CRD
- Confirmation of S criterion and investigation of metal leaching within the field "kinetic test cell"

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