D.3 Release and Mobility of Nickel from Mine Waste: Theory and Case Histories

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Nickel Geochemistry

- Sources of Nickel
  - Pentlandite $(Fe,Ni)_8S_9$
  - Millerite (NiS)
  - Gersdorfite, Annabergite and other exotics
  - Impurity in Pyrrhotite (up to 1% by Mass)

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Geochemistry

- Simple cation in water
- Ni^{2+}
- pH controlled (Ni-hydroxide for pH> 8)
- Sorption onto Iron Hydroxides (pH> 7.5)

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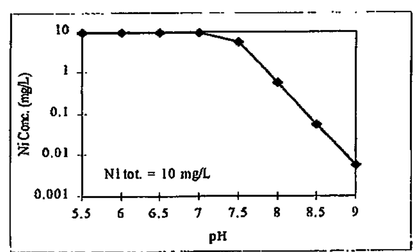
$Ni(OH)_2$ Control



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Nickel in Mine Wastes

- Related to sulphur content
- Variable and site specific
- Because of simple geochemistry and high mobility,
  - RELEASE RATES are critical

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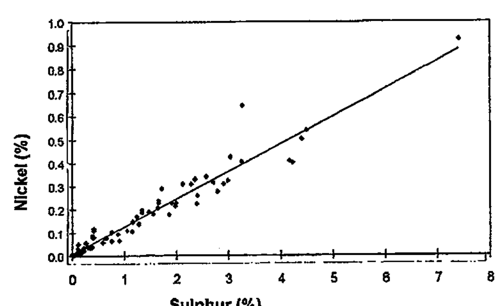
Voisey's Bay - Nickel versus Sulphur in Waste Rock



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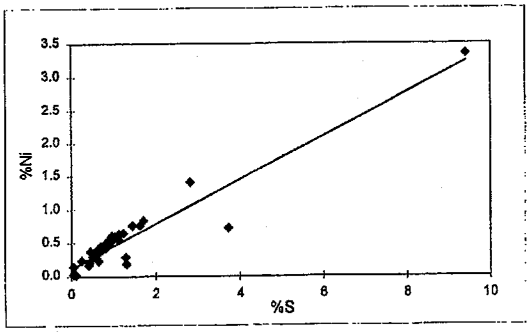
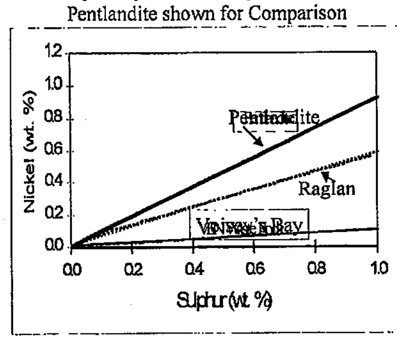
Raglan – Nickel versus Sulphur in Waste Rock



Nickel versus Sulphur by mass for Raglan and Voisey's Bay rock. Pentlandite shown for Comparison



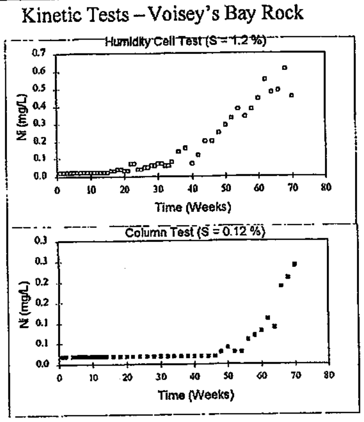
Kinetic Tests

- Provide an estimate of rates of oxidation / leaching
- Requires careful interpretation
  - "One Size" does NOT fit ALL
- Consider "Lag Times" – time between observed metal leaching (or acid generation) and time of deposition (or exposure)

Voisey's Bay Waste Rock

- Standard Humidity Cells (1 kg rock)
- Column tests (5 to 8 kg)

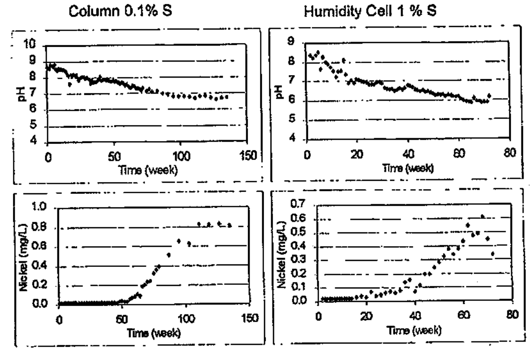
Kinetic Tests – Voisey's Bay Rock



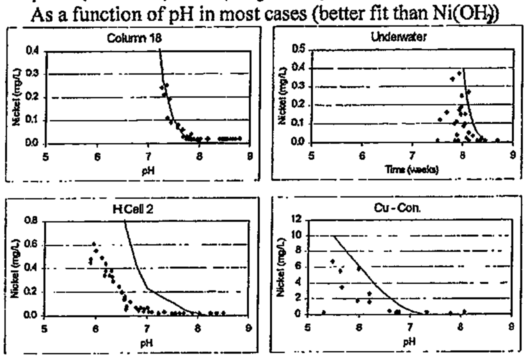
Voisey's Bay Rock

Column 0.1% S

Humidity Cell 1 % S



Sorption (solid line) on $Fe(OH)_3$ can explain nickel concentrations As a function of pH in most cases (better fit than $Ni(OH)_2$)



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Raglan Waste Rock

- Modified test to avoid Lag Times for Nickel
- pH adjusted to 5 to 6 range to avoid pH control on Ni release

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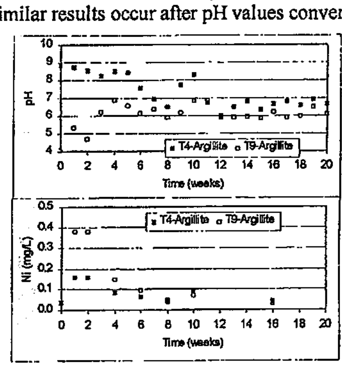
Standard (filled squares) and pHadjusted (open squares) Kinetic test Results on Raglan Waste Rock. Similar results occur after pH values converge



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Water Quality Example for Ni from Waste Rock Piles Showing Water Quality in Pile, Flow and Drainage Areas Needed to Avoid Guideline Exceedence

	Pore[1] Water (mg/L)	Flow[2] per MT rock for 25ppb ($x\ 10^6\ m^3a^{-1}$)	DrainageArea[3] per MT rock for 25ppb (km^2)
Waste Pile[4]	28	6.4	14
Fines	140	32	70

1-Assumes 200 mm/a infiltration in waste rock pile
2- Assimilative flow per Million Tonnes of waste rock to remain below 0.025 mg/L (25 ppb)
3 - Runoff of 450 mm/a
4 Assumes Rates are 1% and 5% of lab values for Pile and Crushedmaterial, respectively

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Uranium Mine Rock

- Elevated Ni, As, Co and U
- 0.2 % S
- 7 Mt Pile
- 20 to 30 m thick
- Field Samples of rock collected to 20 m depth
- 6 Trenches / 60 samples
- Pile age was approximately 15 years

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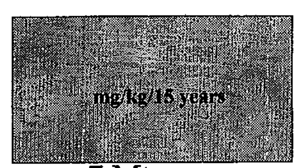
Reaction rates can be measured in the lab and in the field using similar concepts for cost-effective results. In this case, most infiltration was retained in the pile and dissolved mass was conserved.

Humidity Cells

?

1 kg

mg/kg/week



7 Mt
Rock Pile

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Soluble masses of selected constituents rinsed from waste rock samples. All values in **mg/kg**

Samples	SO_4^{2-} (as S)	Ni
SWEP 1(n=7)	585	7.4
SWEP 2 (n=4)	355	1.4
Average SWEP	**501**	**5.2**
Kinetic 1	587	14
Kinetic 2	681	17
Kinetic 3	691	12
Kinetic 4	382	1.7
Kinetic 5	544	2.0
Average Kinetic	**577**	**9.3**

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Estimated Percent of Constituents Leached over 15 Year History of Pile Masses expressed in "mg/kg"

Constituent	Mass in Solids (1999)	Soluble Mass (1999)	Estimated Original Mass (1985)	% of Mass Leached in 15 Years
SO_4^{2-} (as S)	2,522	577	3,099	19
Ni	46	9.3	55	17

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Calculated Pore Water Concentrations in the Rock Pile (mg/L) – Based on measured Water Content values and Soluble Mass of Constituents and Observed Concentrations In Groundwater Adjacent to the Pile

Constituent	Ni	SO_4
Estimated Porewater Concentrations in the Pile	**190**	**34,600***
Maximum Observed in wells near Pile (rising trend)	**30**	**6,200**

*Porewater sulphate is unrealistic because of the presence of Gypsum that formed on the rock

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Modelled Loadings

- Geochemical model developed to assess loading rates for metals and pH of leachate
- Measured inventory of soluble loads included in model
- Provides estimates of loads to environment that can form the basis of a Risk Assessment

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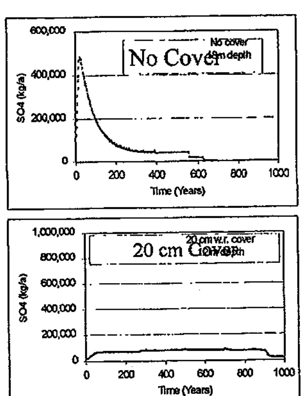

Calculated Sulphate Loadings With Time From 7 Mt Pile.

Values in kg/year

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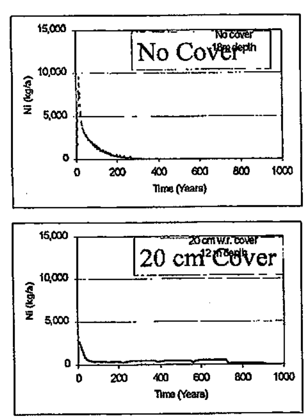

Calculated Nickel Loadings With Time from 7Mt Pile.

Values in Kg/year

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Conclusions

- Nickel leaching can occur at neutral pH
- Time dependent processes must be clearly identified (eg. Time Lags) especially for short test periods (weeks to a few months)
- With careful measurements and interpretation, Mass Balance calculations (and simple models) can be used to provide CONSERVATIVE estimates of loadings of many metals from mine wastes for Risk Assessment and Mitigation purposes

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