Characterizing Geochemical Impacts of a Low-Sulfur Waste-Rock System:
Diavik Project, Lac de Gras, NT, Canada

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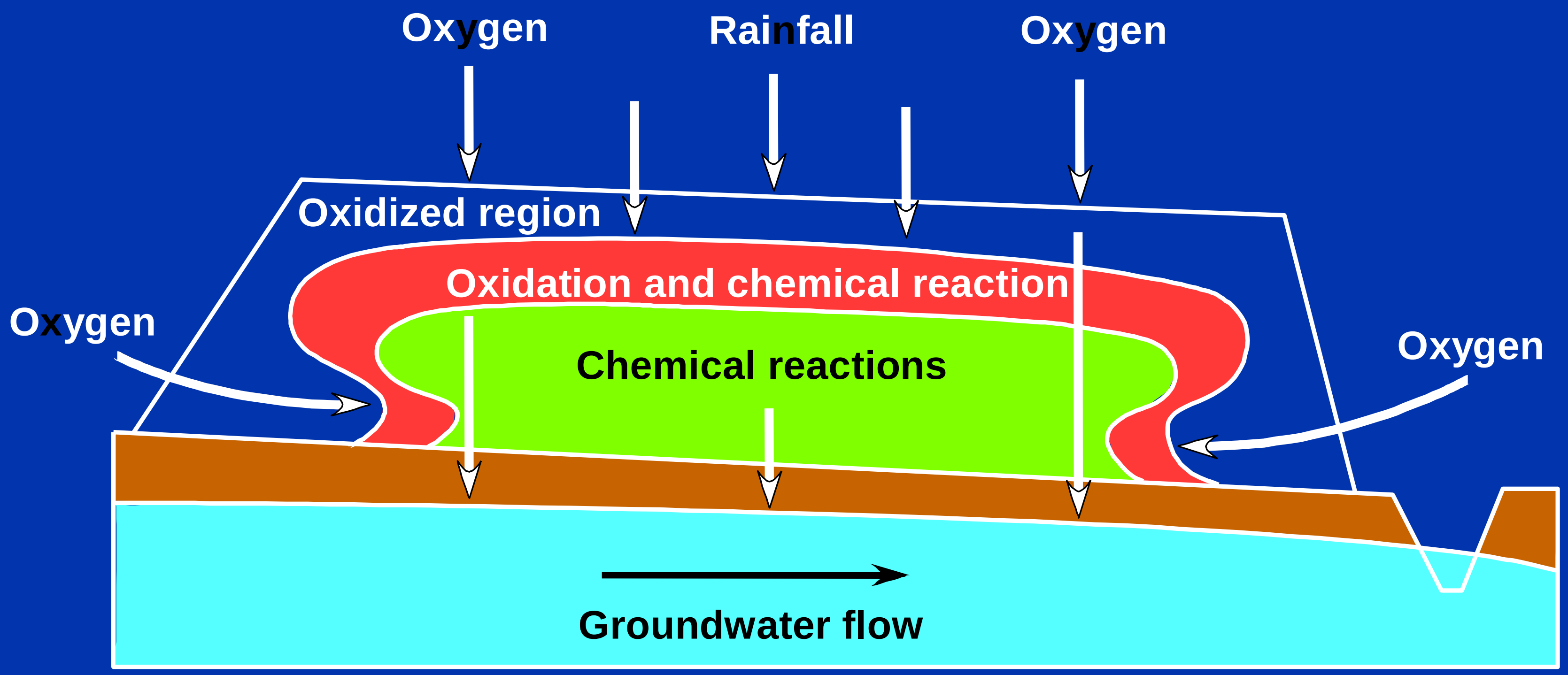
Hydrogeochemistry of Model Facility



Ritchie, 1994

The Challenge: *a priori* Prediction of Water Chemistry

Requirements:

- An accurate conceptual model
- Modeling strategy and tools
- Sufficient data to characterize site
  - Data types
  - “Representative” data
- A reliable approach for scaling laboratory data to field conditions

Diavik Diamond Mine, NWT

Proposed Mine

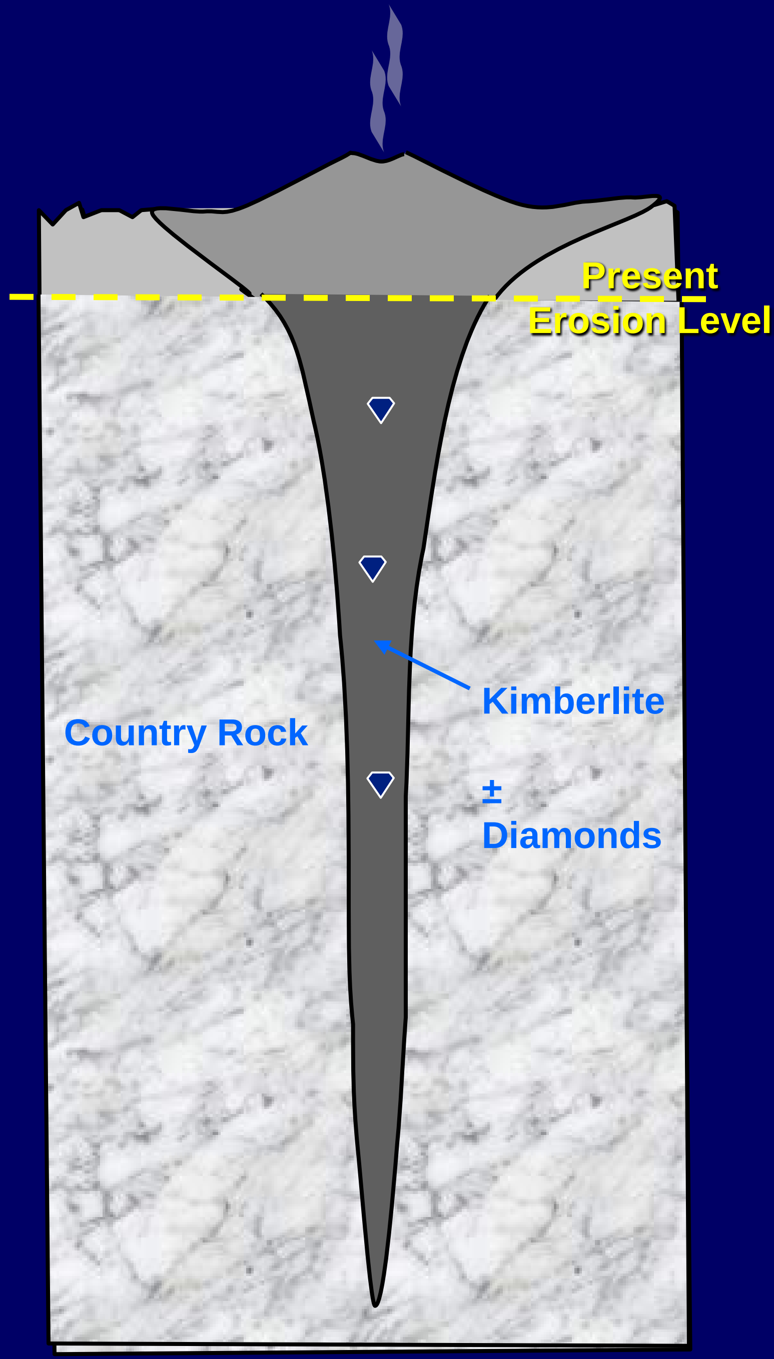
Kimberlite Pipes

Kimberlite is an ultramafic intrusive rock

Commonly found in carrot-shaped “pipes” which represent the roots of ancient, small volcanoes.

Kimberlite pipes average 12 ha in surface area, and may reach depths of several hundred metres or more.

The Diavik pipes range in surface area from 0.9 - 1.6 hectares, and extend below 400 metres

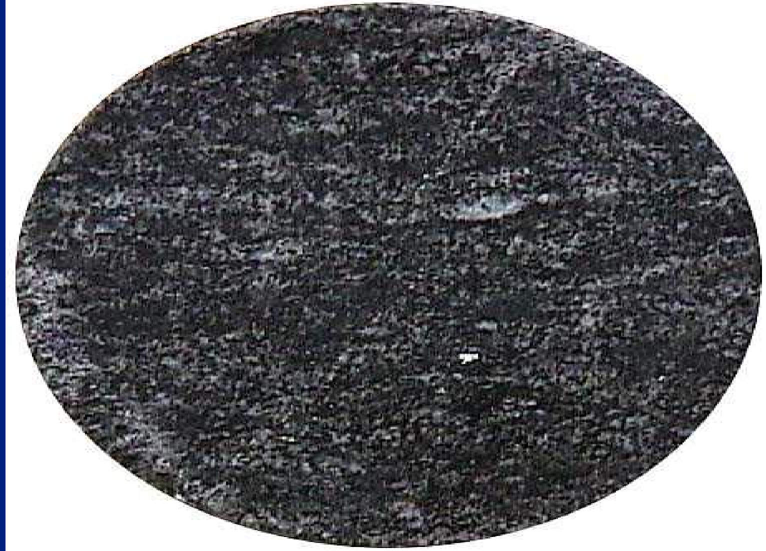


Characterization Approach

1. Lithology/Mineralogy
2. Spatial/Lithologic Distribution
3. Static Testing (ABA/Mineralogy/SWEP)
4. Kinetic Testing (Columns)
5. On-Site Test Pads
6. Hydrogeochemical Modeling

Country-Rock Lithologies

GRANITE

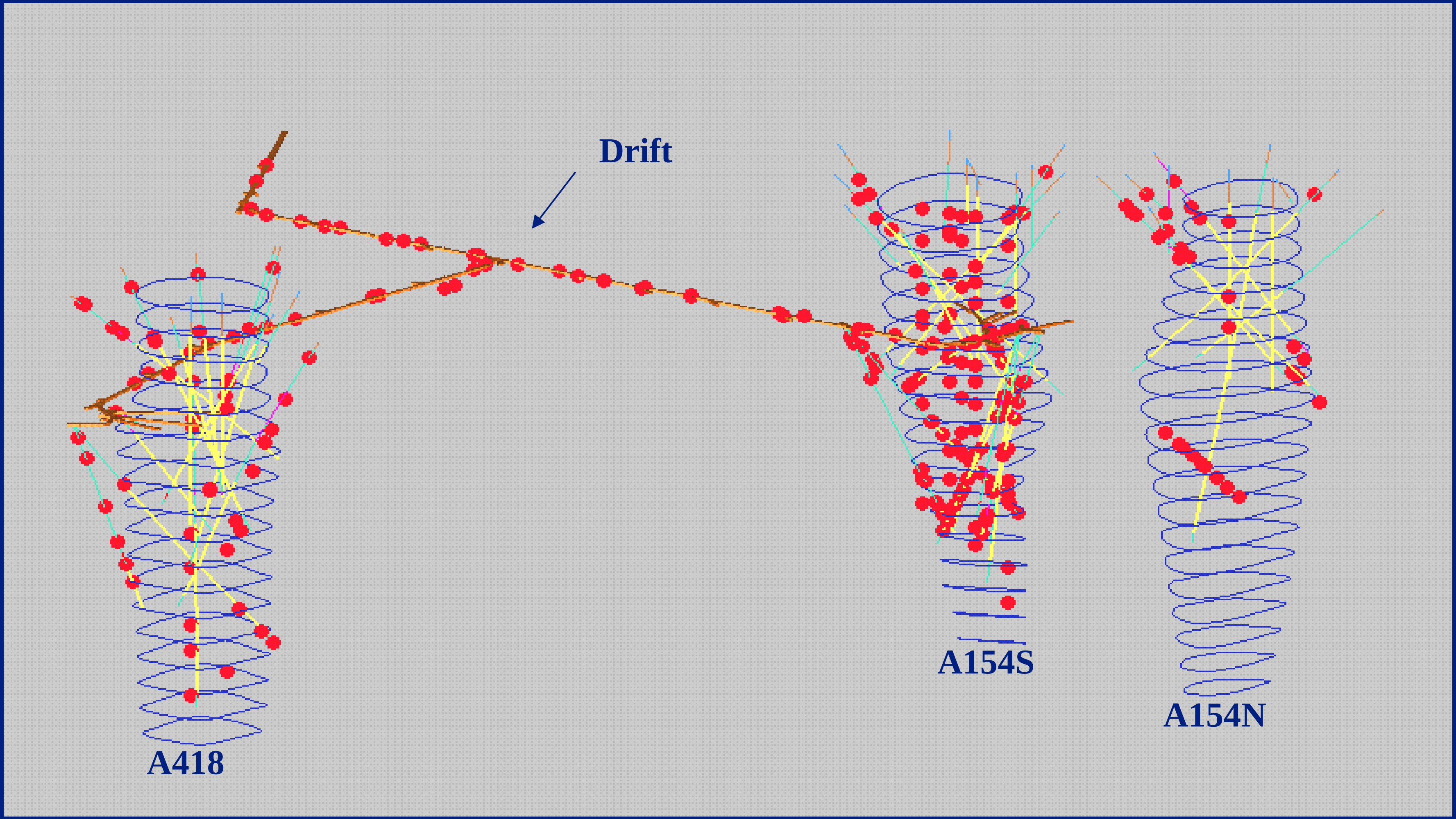


BIOTITE SCHIST

PEGMATITE

DIABASE

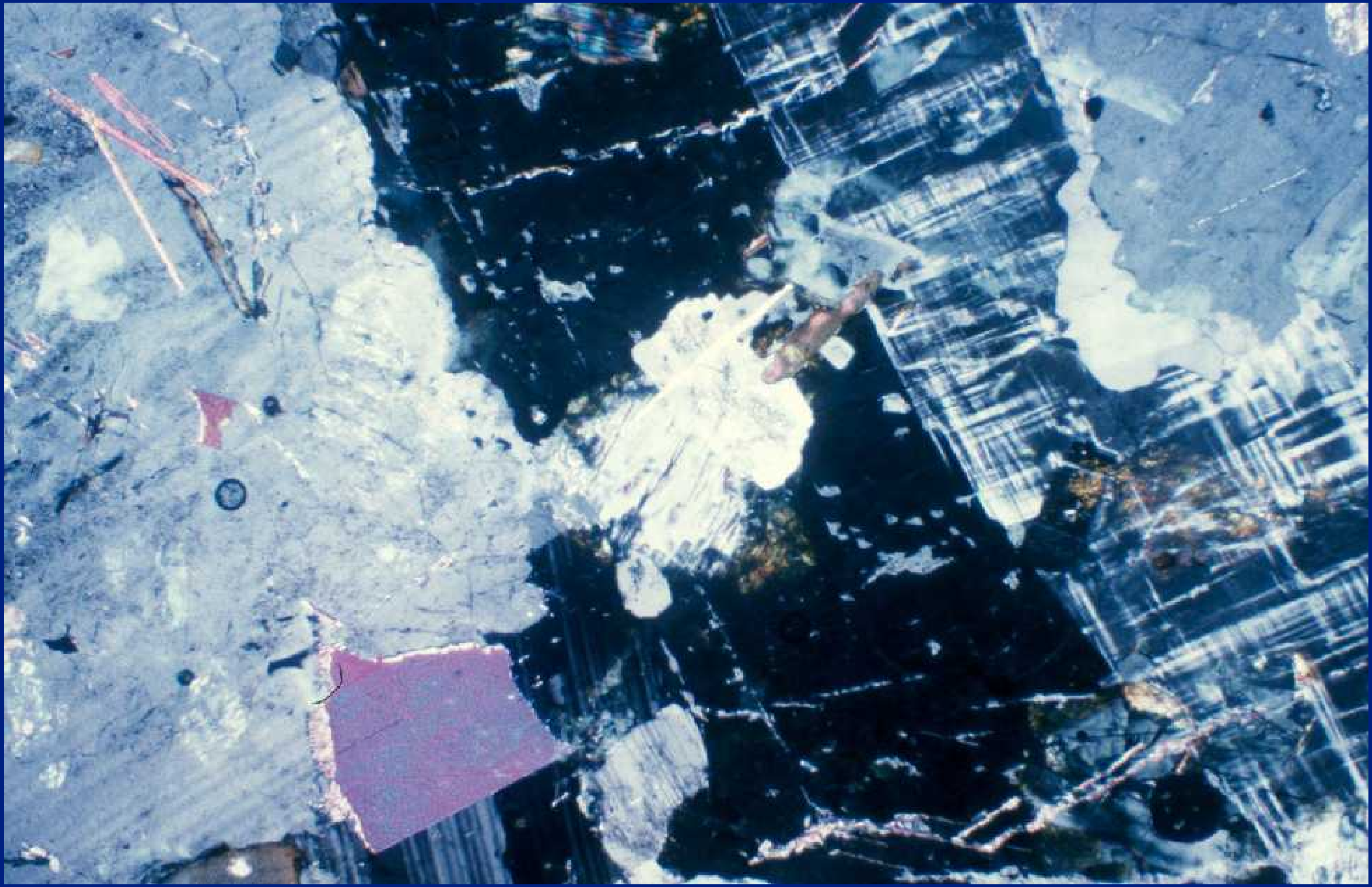
Spatial Distribution (A418 A154)



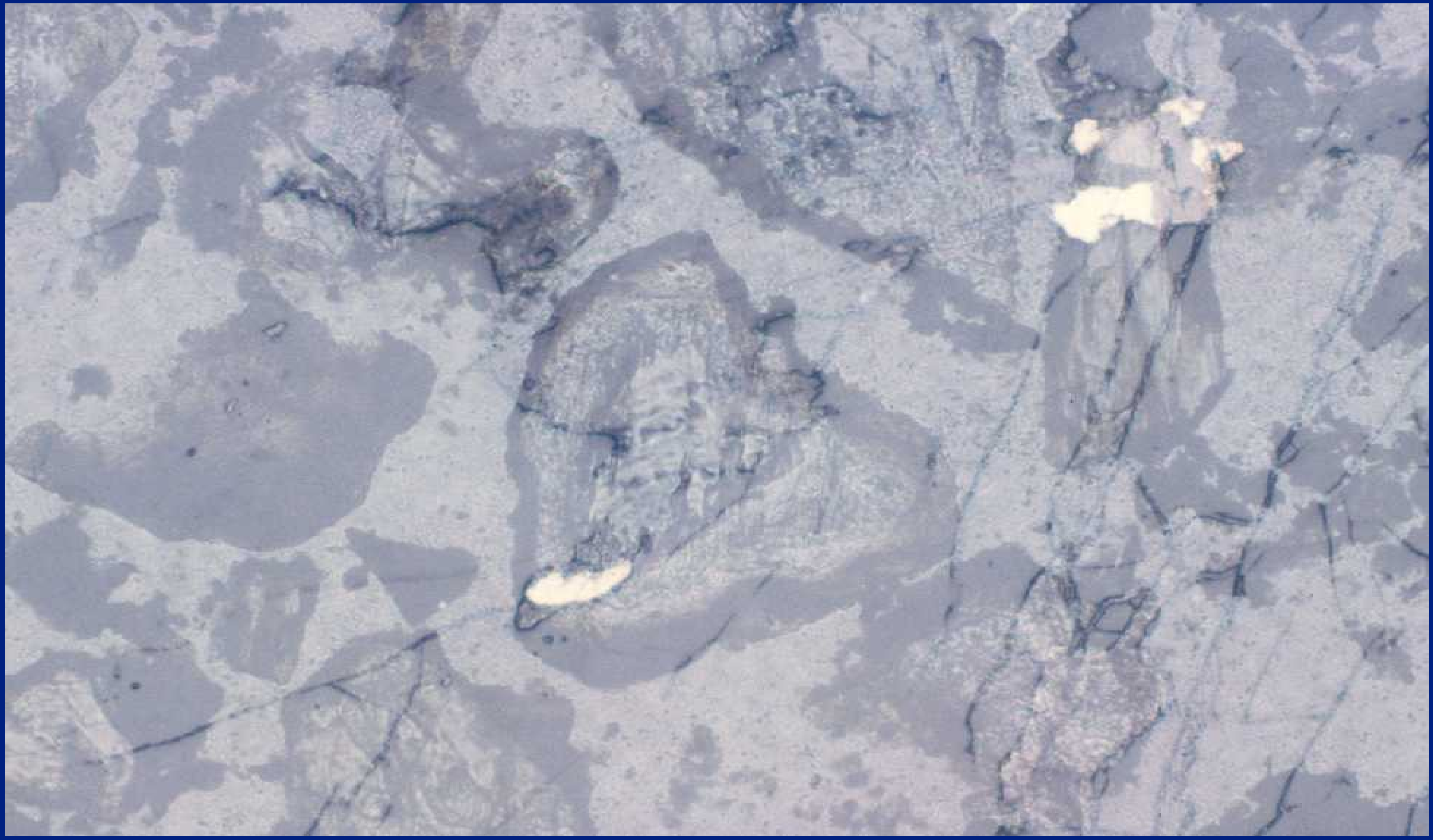
Rock-Type Summary – Static

Characteristic	Granite + Pegmatite (85%)	Biotite Schist (13%)
Total S <0.05 wt%	98%	20%
Total S: Max (wt%)	0.14	0.56
Total S: Avg (wt%)	0.015 (Py)	0.16 (Po)
NP/MPA > 3:1	97%	32%
NP/MPA <1:1	0%	20%
Avg Ni (ppm)	6.64	66.1

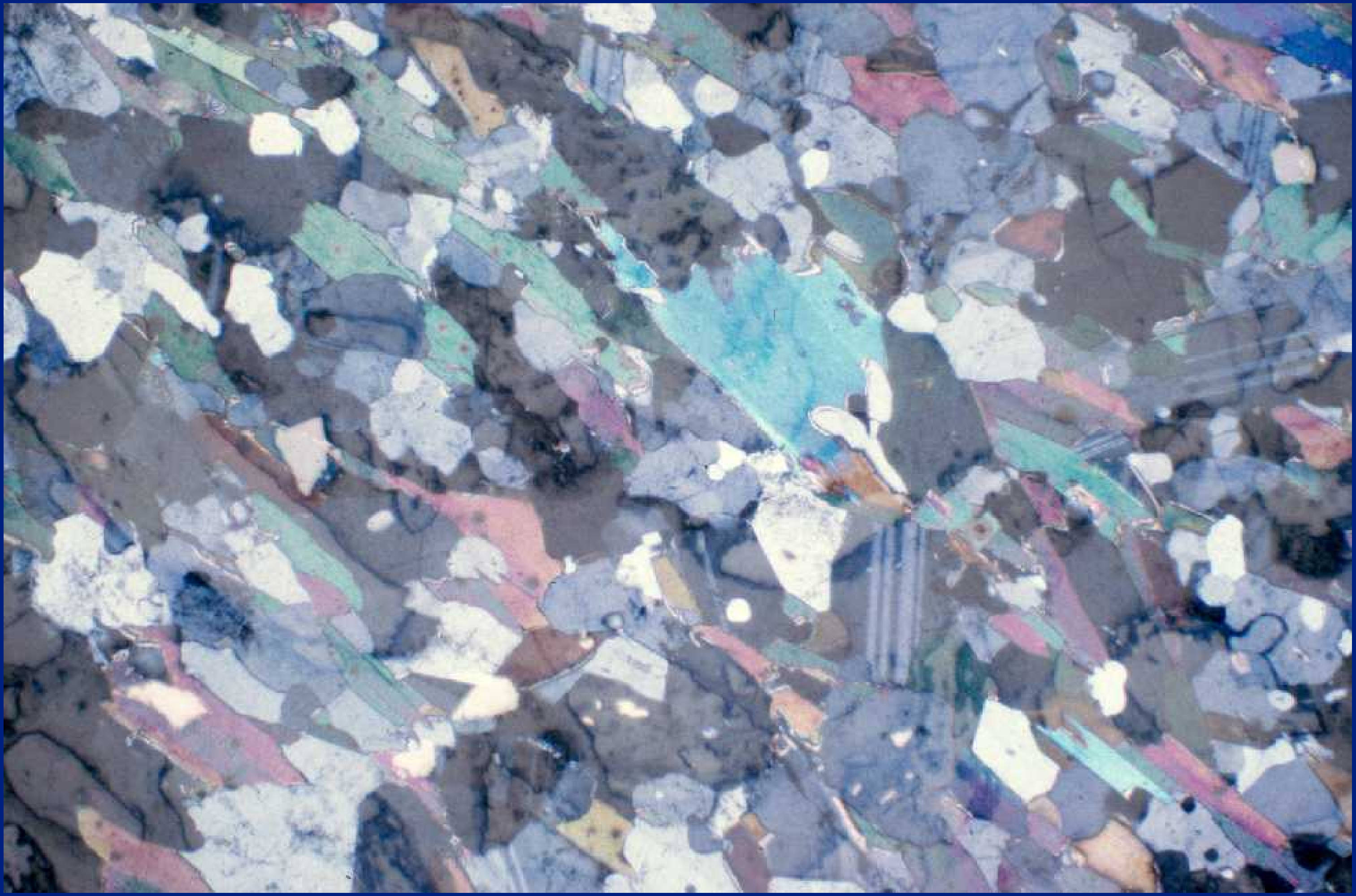
Granite - Silicates



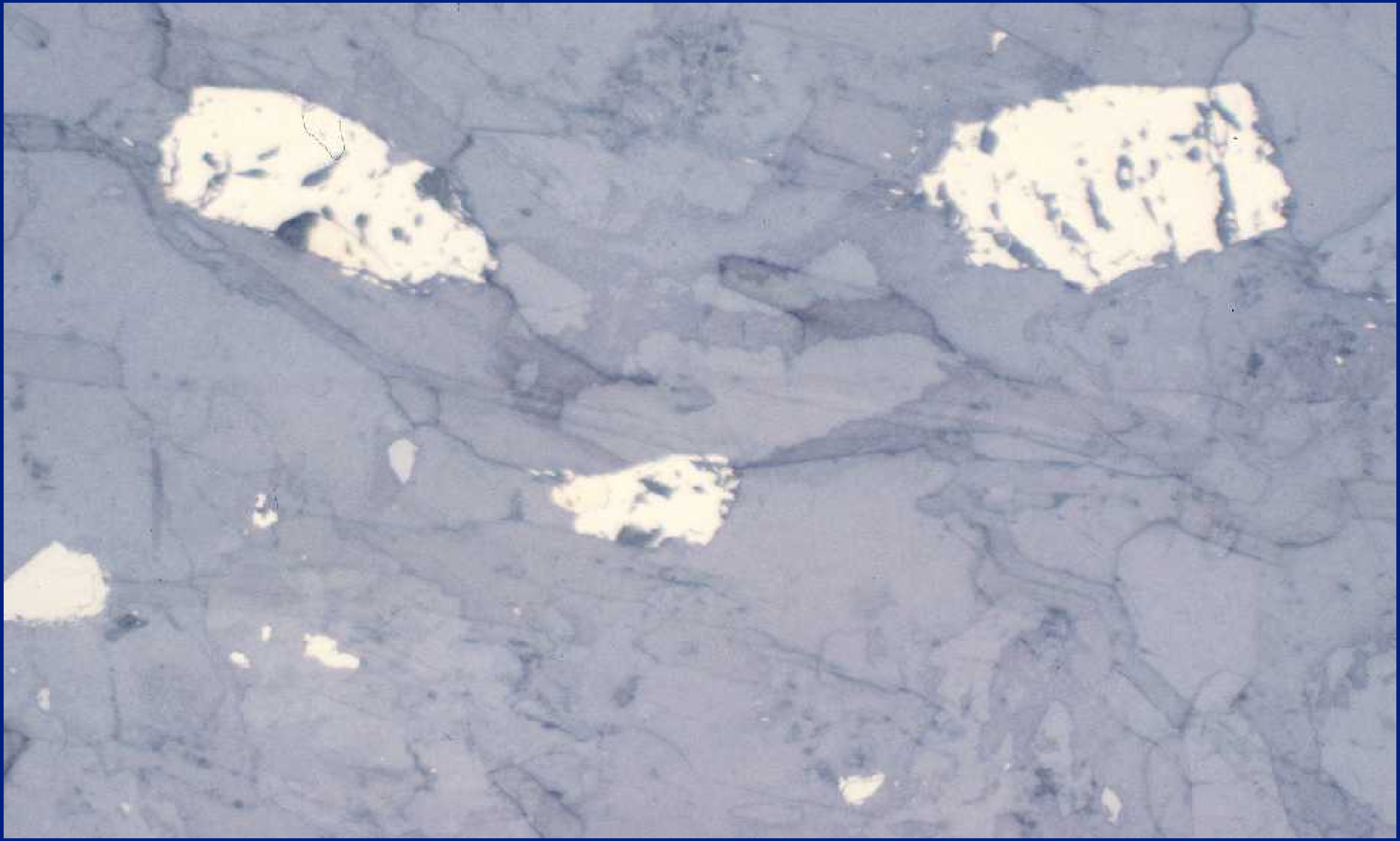
Granite - Sulfides



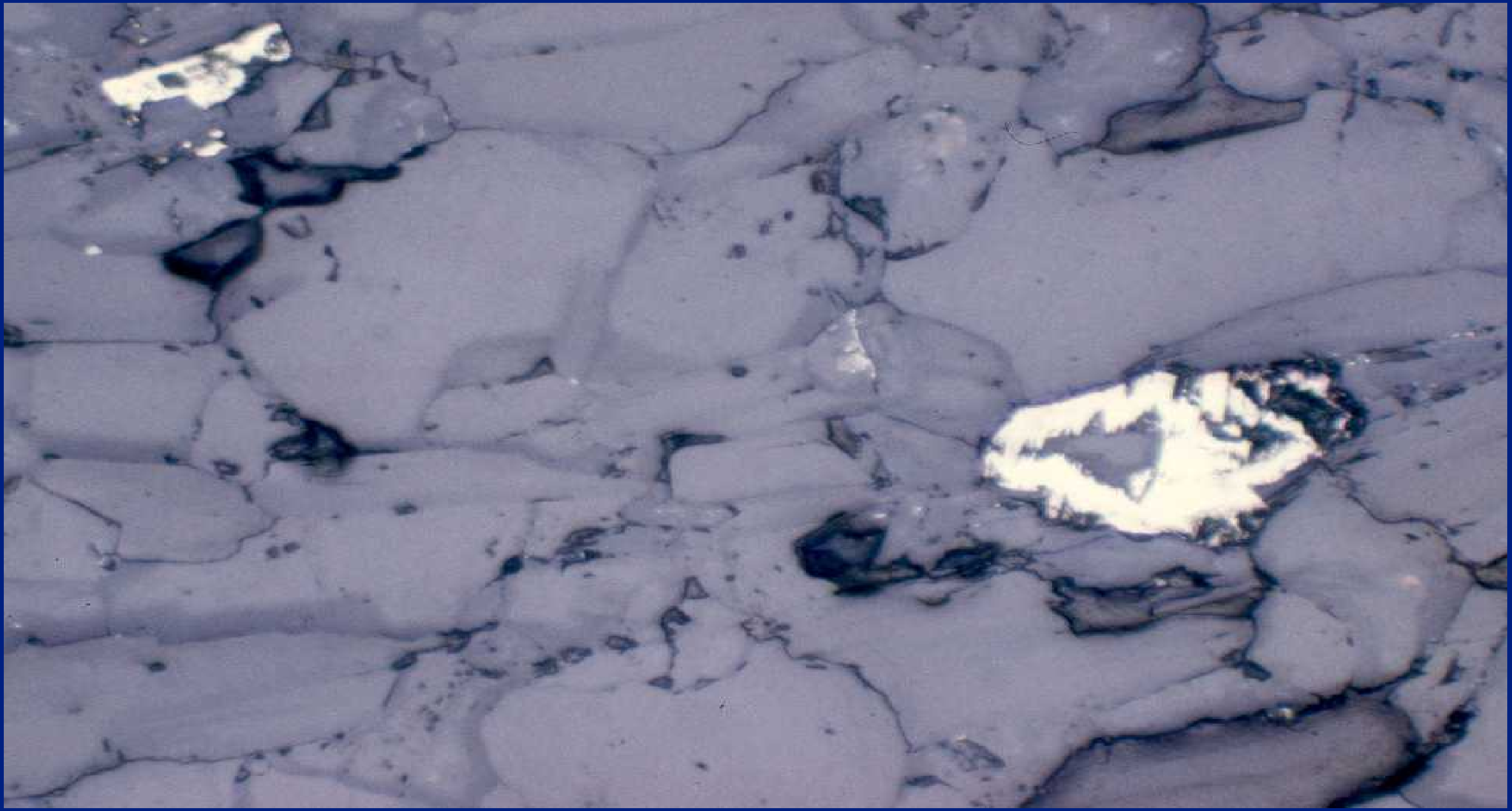
Biotite Schist - Silicates



Biotite Schist: Pyrrhotite



Biotite Schist: Marcasite After Pyrrhotite



Rock-Type Summary - Kinetic

Long-Term	Granite	Biotite Schist
pH (su)	6.8 – 8.2	3 – 4
Alk./Acid. (mgCaCO3/L)	25 - > 150 / nil	Nil / 10 - 200
Rate –SO_4 (mg/kg/wk)	5 E-02	1E+01
Rate – Al (mg/kg/wk)	5 E-03	5 E-01
Rate – Ni (mg/kg/wk)	5 E-04	1 E-01

Approaches to Predictive Modeling

1. Numerical modeling of oxidation coupled with geochemical modeling (ANSTO/DDMI)

2. Surface-area scaling of laboratory test data plus geochemical modeling (DDMI)

3. Reactive solute transport modeling (Research Follow-up: Blowes & Mayer)

ANSTO Modeling Approach

1. Measure average laboratory leach rates and calculate oxygen consumption rates (kg(S) m^{-3} s^{-1}) for each lithology.

2. Adjust leaching rates by appropriate temperature correction factor

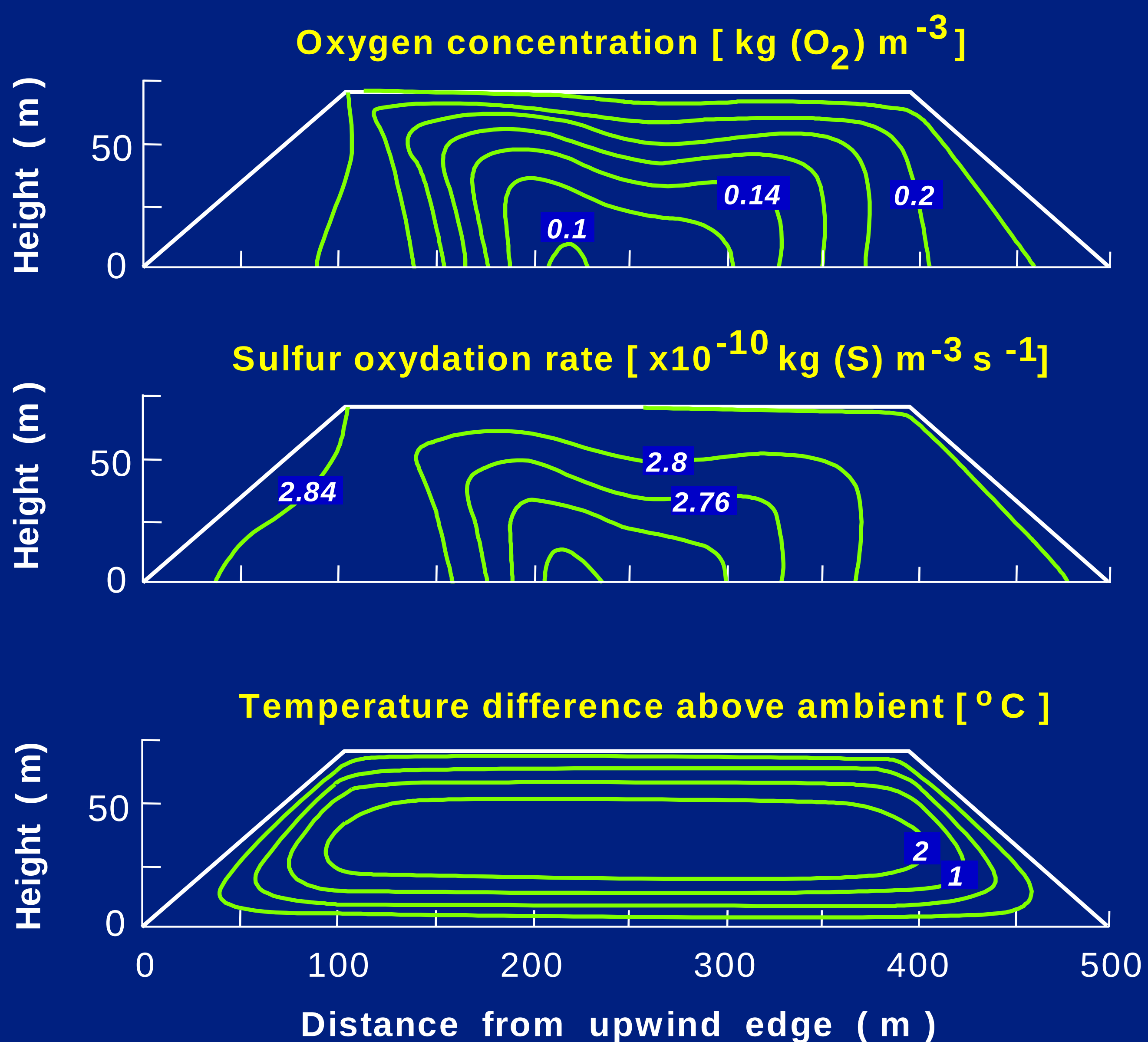
3. Calculate oxidation and sulfate release using FIDHELM model

4. Calculate the total mass of each element released based on ratio to sulfate release rates

5. Calculate the final concentrations of each element using best hydrological estimates

6. Equilibrate the water chemistry to allow precipitation of oversaturated solids.

ANSTO Simulations



Results of ANSTO Modeling

- Entire waste rock pile will remain oxic
- Oxidation will continue for >100 a
- Thermally driven convection limited to dump margins
- Mass-density driven advection may occur in the center of the pile

Surface-Area Modeling Approach

1. Measure average laboratory leach rates (mg m^{-2} day^{-1}) for each lithology.

2. Adjust leaching rates by appropriate temperature correction factor

3. Weight calculated leach rates by total surface area and lithological composition of project facility (e.g. country rock stockpile)

4. Calculate the total mass of each element released

5. Calculate the final concentrations of each element using best hydrological estimates

6. Equilibrate the water chemistry to allow precipitation of over-saturated solids.

Reactive Transport in Mine Wastes: the Model MIN3P

- Geochemical batch systems
- Reactive transport in variably-saturated media
- Partial equilibrium formulation
- Global implicit approach (direct substitution)
- Site-specific geochemical system

MIN3P Modeling Approach

1. Estimate reaction rates based on literature values.
2. Adjust leaching rates for temperature and according to mineral masses
3. Scale reaction rates to account for reactive surface area
4. Calculate the water flux using hydrological estimates
5. Equilibrate the water chemistry to allow dissolution and precipitation of solids

Comparison of Model Results – Full (200MMT) Pile

	Surface Area Model	ANSTO	MIN3P
pH	6-8	6-8	7.3
SO_4	3,400	4,400	4,330
Fe	0.002	<0.002	0.02
Ni	50	7.49	3.2
Co	18.3	17.3	3.2
Cu	2.6	1.48	0.25
Zn	36.7	26	13

Summary of Model Results

- Discharge at gypsum saturation
- pH of a mixed pile near neutral
- Low pH may be present in biotite schist rich zones
- Ni and Zn concentrations > 10 mg/L
- High concentrations continue past mine closure

On Site Test Pads

- Erected on site in 1997
- Contain approx. 10 tonnes of rock each
- Contain samples of individual rock types
- Country rock test pad similar to expected pile
- Sampled 9 times since installation
- Precipitation records maintained
- Paired to kinetic tests

Onsite Testpad : Country Rock Mixture

	Alk (mg/L CaCO3)	pH	SO_4 mg/L	Fe mg/L	Al mg/L	Cu mg/L	Co mg/L	Ni mg/L	Zn mg/L
Maximum	62	7.6	284	0.22	0.053	0.134	0.017	0.521	0.266
Minimum	10	6.7	47.3	< 0.005	0.006	0.009	0.023	0.116	0.003
S.A. Model Estimates									
Equilibration	*58*	*7 to 8*	*276*	*0.0002*	*0.005*	*0.87*	*0.66*	*0.14*	*0.86*
No equilibration	*58*	*7 to 8*	*276*	*8.9*	*3.0*	*1.11*	*0.66*	*2.45*	*0.86*
MIN3P Model Predictions - Year 4									
	44	*7.85*	*432*	*0.013*	*0.032*	*0.40*	*0.23*	*0.91*	*0.94*

Implications for Waste Rock Management

- Near neutral effluent on average
- Potential for some zones of low pH water
- Moderate concentrations of dissolved metals
- Effluent waters will require management
- Effluent management or engineered closure required at the cessation of mining

Comparison of Model Results

- **Reasonable agreement between approaches**

***N.B*:**

- **Surface-area weighted and mass-weighted models based on the same laboratory data**

- **Specific concentration estimates vary with approach**

- **All modeling and scaling approaches lead to similar recommendations for this case:**

  Management Needed

Research Questions

1. Characterization methods
   - Do existing test methods supply data suitable for new modeling approaches?
   - Should new testing methods be developed?
2. Scaling methods
   - Is sufficient data available to evaluate scaling methods?
   - Is adopting a uniform approach valid?
3. Economic considerations
   - Is the cost of improved precision warranted?