Geochemical exploration in areas of thick glacial cover

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Presentation Overview

1. What is deep penetrating geochemistry?

2. Things that happen over buried mineral deposits
   - redox responses
   - pH responses (high or low)
   - selective leach metal responses
     - dry terrain
     - peat bogs
   - (soil hydrocarbons)

3. An optimized strategy for exploration in areas of thick cover
   - selective leach; pH; soil gas hydrocarbons
   - sampling: peat terrain; dry terrain
Deep Penetrating Geochemistry

Methods that use surface geochemistry to detect buried mineralization

The methods target a geochemical process characterized by:

1. a hydromorphic dispersion halo
   - i.e. chemical weathering; dissolved transport; deposition

2. a response directly over the deposit
   - transport is primarily vertical, therefore response occurs above

3. a proximal (property-scale) response
   - response is rarely more than twice the width of the buried target

4. both a primary and secondary signal
   - e.g. primary - ore forming elements; secondary: pH responses
Primary vs. Secondary Responses

- in the process of trying to understand how selective leaches can detect a response we discovered a number of other related phenomena.

- some of these are so ubiquitously associated with SL responses that they can be confused with direct responses due to mineralization.

- they can, therefore be used as indicators of mineralization.
Geochemical processes over a buried sulphide

Modified after Cameron et al., 2004

(Hamilton, 1998; 2000)
Marsh Zone, Line 15 - 3D pH & Redox

Subsurface Redox (mV)

Northing - Line 15 (m)

South

North

Boreholes

Line 14 - clay slurry pH

Depth (m)

Hamilton et al., 2004a
Cross Lake, Line 6 - 3D Redox & pH

Hamilton et al., 2004b
Soil Slurry pH 6 m Below Water Table, Cross Lake, Line 6

The graph shows the pH values at various depths below the water table, with different curves representing different depths:

- Yellow curve: above water table (3pt Avg.)
- Red curve: 1.5 m below water table
- Blue curve: 3 m below water table
- Pink curve: 6 m below water table

The x-axis represents the distance south in meters, ranging from 0 to 800. The y-axis represents the pH values, ranging from 6.8 to 8.0.

The data for each depth is plotted across the distance, indicating fluctuations in pH values at different locations.
Development of pH Anomaly Above A Reduced Area in Overburden

Sampling above water table

Soil Samples

$O_2 = \infty$

$O_2 \ll \infty$

Ground Surface

Overburden

Water Table

Acid production

Reduced zone
Development of pH Anomaly Above A Reduced Area in Overburden
1. H\(^+\) anomaly occurs over the reduced chimney
   - most intense above the water table
   - disappears below the water table

2. Intensity of pH response correlates with strength of redox negativity

Conclusion:

Acid is produced by oxidation of reduced metals
pH anomaly is:

1. Highly localized
   - yet $\text{H}^+$ is the most mobile aqueous species

2. Apparently permanent
   - yet $\text{H}^+$ is one of the most reactive of aqueous species

Conclusion:

Acid production is an ongoing process
Acid production by metal oxidation requires precipitation of insoluble metal hydroxides.

Since oxidation must continue, there must be:

1. Continuous upward movement of metals
2. Deposition of metals in the shallow subsurface
Geochemical processes over a buried sulphide

Modified after Cameron et al., 2004 (Hamilton, 1998; 2000)
% CO$_3$ in B-Horizon Soil
Cross Lake, Line 6

% CO$_3$ in B Horizon Soil

Distance South (m)
pH, Line 6, Cross Lake

VMS
Calcium – Line 6, Cross Lake

VMS
Calcium concentration in peat plotted against pH
Marsh Zone Profile Data

Note: the typical background Ca concentration increases gradually with depth from about 0.5% @ 5 cm to 2.5% @ 60 cm.
Geochemical processes over a buried sulphide

Modified after Cameron et al., 2004

(Hamilton, 1998; 2000)
Selective Leach Methods

Most overburden in Canada is exotic
- i.e. it has been transported from somewhere else
- till, glaciofluvial sands, glaciolacustrine clay, etc.

The bulk chemical composition of exotic overburden is not related to that of underlying bedrock or mineralization
Selective Leach Methods

- Any geochemical signal due to mineralization results from hydromorphic transport from below.

- Such transported metals are weakly bound to the mineral matrix.

- By analyzing only this component, the signal from mineralization can be greatly enhanced.
Zn in Soils - Cross Lake VMS, Line 40

Profile in Sand

Aqua regia (ppm)

Cameron et al., 2004
Zn in Soils - Cross Lake VMS, Line 40

Profile in Sand

Mobile Metal Ion (MMI)®

Enzyme LeachSM

Cameron et al., 2004
Zn in Soils - Cross Lake VMS, Line 40

Profile in Sand

Mobile Metal Ion (MMI)®

“Upper B”

Enzyme Leach℠

“Upper B”

Cameron et al., 2004
Zn in Soils - Cross Lake VMS, Line 6

Profile in Clay

Depth (cm)

original ground surface

30 m

Mobile Metal Ion (MMI)

Enzyme Leach

Cameron et al., 2004
Zn in Soils - Cross Lake VMS, Line 6

Profile in Clay

Depth (cm)

original ground surface

B-Horizon

30 m

Aqua regia (ppm)

North 0 100 200 300 400 500 600 700 800 South

0 20 40 60

Cameron et al., 2004
Zn in Soils - Cross Lake VMS, Line 6

Profile in Clay

Depth (cm)

30 m

Mobile Metal Ion (MMI®)

B-Horizon

Enzyme LeachSM

Cameron et al., 2004
Zn in Soils - Cross Lake VMS, Line 6

Profile in Clay

Depth (cm)

original ground surface

30 m

Mobile Metal Ion (MMI®)

Enzyme LeachSM

Cameron et al., 2004
Zn in Soils - Cross Lake VMS, Line 6

Profile in Clay

Mobile Metal Ion (MMI)

Enzyme Leach®

“Upper B”

“Lower B”

Cameron et al., 2004
Ca in Soils over 3 Kimberlites

**B30 Kimberlite**
- **Ca (AR)**
- Distance East Along Transect (m): 45 m

**95-2 Kimberlite**
- **Ca (AR)**
- Distance South Along Transect (m): 50 m

**A4 Kimberlite**
- **Ca (AR)**
- Distance East Along Transect (m): 30 m

**Dupuis Mag Feature**
- **Ca (AR)**
- Distance West Along Transect (m): ? m

**Legend**
- Peat
- Undifferentiated inorganic soils
Lady’s slippers grow best in well drained, high calcium soils and are extremely profuse over the B-30 and 95-2 Kimberlites (picture).
pH Parameters – Gemini VMS, Line 6450S

Source: Jackson, 2003: Report to CAMIRO & OMET on Gemini VMS
Ca in Upper Peat – Gemini VMS, Line 6450S

25-50 cm peat
Cu in Upper Peat – Gemini VMS, Line 6450S

25-50 cm depth peat
Zn in Upper Peat – Gemini VMS, Line 6450S

Zinc ppm

Grid East (m)

Zinc Zone down-dip extent

sulphide horizon up-dip extent

25-50 cm peat
Development of geochemical responses in a peat bog

Elements input: B, Co, Cs, Fe, K, Li, Mg, Mn, Mo, Na, Nb, Ni, Cu, Pb, S, Sr, Ti, Zn, Zr: predominantly *lithophile* elements

Fen stage: high pH; high nutrient
Development of geochemical responses in a peat bog

External input of elements diminishes

Paludification
Development of geochemical responses in a peat bog

- Input of elements in centre of bog due to airborne fallout in upper peat; diffusion in lower peat.
- Input at edges of bog due to lateral dispersion from adjacent areas; groundwater input.
- Result: **Edge effects** in practically every element.

Bog stage: low pH, low nutrient.

Diffusion and groundwater transport.
Geochemical responses due to bog “edge effects” in upper and basal peat
Geochemical responses due to bog “edge effects” in upper and basal peat

50 cm sample interval

Clastic sediments

Diffusion and groundwater transport
Geochemical responses due to bog “edge effects” in upper and basal peat

Peat by Aqua Regia

Peat by Na-Pyrophosphate

50 cm sample interval

Clastic sediments

Diffusion and groundwater transport

Basal peat sample interval

Ni

Shallow

Deep

Ore Zone
Tillex: Common situation: drastically changing surficial cover
Indiscriminate sampling of uppermost clay results in Cu anomalies related to unweathered clay under the bog.
Vertical Metal Zonation in Peat

As

As (ppm) Marsh Zone
- 14.05 - 18.68
- 11.22 - 14.04
- 9.04 - 11.21
- 7.30 - 9.03
- 5.63 - 7.29
- 4.03 - 5.62
- 2.43 - 4.02
- 1.13 - 2.42
- 0.57 - 1.12
- 0.10 - 0.56
Vertical Metal Zonation in Peat

Zn

Zn (ppm) Marsh Zone
- 158 - 208
- 131 - 157
- 110 - 130
- 90 - 109
- 70 - 89
- 51 - 69
- 31 - 50
- 13 - 30
- 7 - 12
- 2 - 6
Vertical Metal Zonation in Peat

Ni (ppm) Marsh Zone
- 39.5 - 52.9
- 29.8 - 39.4
- 23.3 - 29.7
- 18.1 - 23.2
- 13.6 - 18.0
- 10.2 - 13.5
- 7.8 - 10.1
- 5.9 - 7.7
- 3.5 - 5.8
Vertical Metal Zonation in Peat
Vertical Metal Zonation in Peat

Hf

Hf (ppm) Marsh Zone

- 0.13 - 0.17
- 0.11 - 0.12
- 0.10 - 0.10
- 0.09 - 0.09
- 0.07 - 0.08
- 0.06 - 0.08
- 0.05 - 0.05
- 0.03 - 0.04
- 0.01 - 0.02
Vertical Metal Zonation in Peat

Ca

Ca (%) Marsh Zone
- 2.9 - 3.4
- 2.6 - 2.8
- 2.3 - 2.5
- 2.0 - 2.2
- 1.7 - 1.9
- 1.4 - 1.6
- 1.1 - 1.3
- 0.8 - 1.0
- 0.2 - 0.7
Pb at MZ - 5 cm depth
Ontario Geological Survey

Pb at MZ - 10 cm depth

Graph showing Pb by Aqua Regia ppm at 10 cm depth.
Pb (AR, ppm) at MZ - 20 cm depth

ppm Pb by Aqua Regia

-100 -80 -60 -40 -20 0 20 40 60 80

-100 -80 -60 -40 -20 0 20 40 60 80

1 10 100
Pb at MZ - 30 cm depth

ppm Pb by Aqua Regia
Pb at MZ - 40 cm depth

Graph showing Pb concentration in ppm by Aqua Regia at various depths.
Pb at MZ - 50 cm depth

ppm Pb by Aqua Regia

-100 -80 -60 -40 -20 0 20 40 60 80

100

10

1
Conclusion:

1. The top-down zonation of metals at the Marsh Zone is due to airborne fallout of contaminants into the peat; probably dust from gold tailings less than 1 km to the south.
2. The bottom-up zonation is due to clastic matter entrained in the peat.
Determining source of Pb anomalies using isotopes

Line 6 trench: best profile for is by AA7, selecting top of B and Ae samples

Pb (Ae & B) AA7

Pb (Ae & B) AA5

30 m
Unoxidised clay in alluvial area, 270 and 280-6
Pb isotopes, Line 6

Unoxidised samples at depth

Surface organic-rich samples

Weak AA leaches, sample right over deposit

Unpublished GSC/OGS data
Kidd Creek Tailings – 26 km to the northwest of Cross lake
Recap - Geochemical processes over buried features

1. Apical or “rabbit-ear” commodity element responses in shallow soils
2. Acid responses either immediately over or flanking the deposit near surface
3. A negative redox anomaly centred above mineralization (reduced chimney)
4. Secondary elemental responses due to the redox / pH anomaly (e.g. CO$_3$, Ca, etc.)
Soil Gas Hydrocarbons

- Measurable increases in the concentration of hydrocarbon compounds occur in soils above mineral deposits.
- Somewhat similar suites of hydrocarbons in the pulped rock of the same deposits suggested they might be originating from the deposits.
- **Problem:** thick, young clays would restrict movement of large, sticky hydrocarbon molecules to surface.
Soil Gas Hydrocarbons

Cross Lake Line 6 (expanded)
SGH & Redox

Soil Gas Hydrocarbon
(2nd PC - inverted)

Plate Count - Sulphate Reducing Bacteria

Distance south (m) on Line 6
The source of hydrocarbons

Hydrocarbon anomalies correlate with:

- Mineralization (spatially)
- Reduced chimneys (spatially)
- Redox variation
- pH anomalies in soil
- \( \text{O}_2 \) depletions / \( \text{CO}_2 \) enrichments in soil gas
- Organic carbon depletions
- Metal enrichments
- Increased bacterial populations
Conclusions:

1. Source of hydrocarbons is bacterial biomass and microbial exhalation above the reduced chimney

2. Increased hydrocarbons result from increased microbial activity

3. Increased microbial activity results from enhanced redox gradients and a greater availability of essential nutrients over the chimney

4. SGH & SDP should therefore be an excellent proxy for redox
SRBs - Cross Lake - 14 m from line

Distance (m)

Depth (cm)

Log units

-70
-60
-50
-40
-30
-20
-10
0
0.1
0.2
0.3
0.4
0.5
0.6
-230 -220 -210 -200 -190 -180 -170 -160 -150

Slide courtesy of Gordon Southam
SRBs - Cross Lake - 12 m from line

Distance (m)

Depth (cm)

Log Units

Slide courtesy of Gordon Southam
Aerobic Heterotrophs - Cross Lake - 12 m from line

Slide courtesy of Gordon Southam
Ontario Geological Survey

A Horizon

B Horizon

Autotroph (chemotroph) abundance

Aerobic Heterotroph abundance

High redox gradient

Redox equipotentials
increasing redox potential

Outside ring (Oxidizing)

Inside ring (reducing)

Outside ring (Oxidizing)

Very high gradient

Autotroph abundance

Aerobic Heterotroph abundance

Increase redox potential

High redox gradient

Outside ring (Oxidizing)

Inside ring (reducing)

Outside ring (Oxidizing)
Optimizing an Exploration Strategy for the Abitibi
Methodology, Deep Penetrating Geochemistry

- Selective leach geochemical methods
  - targeting commodity metals and secondary responses

- pH measurement
  - targeting the “acidic cap” or “basic chimney”

- Redox measurement
  - targeting the reduced chimney
  - direct measurement of redox impractical; indirect methods must be used (i.e. hydrocarbons)
Selective Leach Sampling in Variable Terrain

Problem: peat thickness > 20 cm but < 35 cm

1. If available between 10 and 25 cm sample mineral soil
2. If not available due to peat or thick organics, sample the organics at a consistent depth of > 30 cm
3. These are treated as 2 different media from sampling right through to data interpretation
Sampling in Oxidized Sand and Clay

- Sample inorganic media if available between 10 and 25 cm from "ground surface".
- "Ground surface" is defined as the base of A0 (leaf litter) and Ae and B horizons are considered one medium.
- Clay, sand and alluvium should be differentiated in the notes.
- Moisture is the primary source of false positives.

Clay, sand and alluvium are shown in the images.
Peat Sampling Protocol

- Sample at a consistent depth between 30 and 50 cm from ground surface.
- "Ground surface" is defined as the beginning of the decomposed peat under the brown sphagnum.
- Sample shallower if peat is consistently thin.
- Clastics are primary source of false positives.
- Airborne fallout possible at <30 cm depth. (always record depth of clastics if within 1 auger length.)
pH Measurement

- pH should be measured either in the field or later in camp on the day of sampling.
- Never mix media! Organics are almost always more acidic than inorganics; humus is more acidic than peat.

Line 40

- B-Horizon pH - Sand
- pH of Humus
- Wet & Peat

Line 6

- B-Horizon pH - Clay
- pH of Humus
pH Measurement – contd.

False positives (i.e. acidic responses):
- Organic matter is the most likely cause of false positives in mineral soil.
- Sandy clastic matter (paradoxically) is the most likely cause of false positives in peat.
- Dry soils in an otherwise wet area

False negatives (i.e. alkaline responses):
- Poor soil drainage is the most likely cause of false positives in humus & mineral soil.
- Clayey clastic matter a likely cause of false negatives in peat (often an edge-of-bog effect)

Mineralization-related responses are acidic, sometimes accompanied by flanking “rabbit-ear” alkaline responses (occasionally the reverse occurs)

Kimberlite-related responses are alkaline
Redox Measurement Techniques

- **ORP slurries**
  - Extremely subject to analytical errors; instrument failure & sample oxidation
  - Almost useless except in fully saturated, very homogenous media

- **CO₂ / O₂ soil gas measurements**
  - Works well in deserts; requires low soil moisture

- **Bacteriological measurements**
  - SRBs; aerobic heterotrophs; anaerobes
  - Very time consuming and expensive

- **Soil gas hydrocarbons**
  - SGH (Actlabs); SDP
Note Taking

Station:
- Moisture conditions
- Thickness of peat, which helps to identify “edge effect” false positives
- Site disturbance (drill pad, etc.)
- Slope; vegetative cover

Sample:
- Sample: i.e. organic or inorganic
- Soil horizon: B-horizon, Ae horizon, C-horizon, mixture
- Soil type: clay, sand, silt, alluvium
- Depth of sample
- Obvious contamination or mixing (e.g. sand present in peat)
Uses of Deep Penetrating Geochemistry

- **Target discrimination**: determining the nature of previously identified targets prior to drilling
  - Discriminating sulphide from graphite
  - Characterizing sulphide as barren or metalliferous

- **Target prioritization**: ranking of many possible geophysical targets in the most appropriate order for drilling
  - Significantly increases the value of geophysics

- **Target generation**: the discovery of previously unknown targets for drilling

Summary

1. Selective leaches should be used in conjunction with pH and some form of redox measurement.
2. In the Abitibi, soil hydrocarbon measurement (SGH, SDP) appears to be a good proxy for redox.
3. Deep penetrating geochemistry is appropriate for target discrimination and prioritization.
4. DPG is less successful in target generation because of the effort required to differentiate real from “false” anomalies.