Geochemical exploration in areas of thick glacial cover

Stew Hamilton

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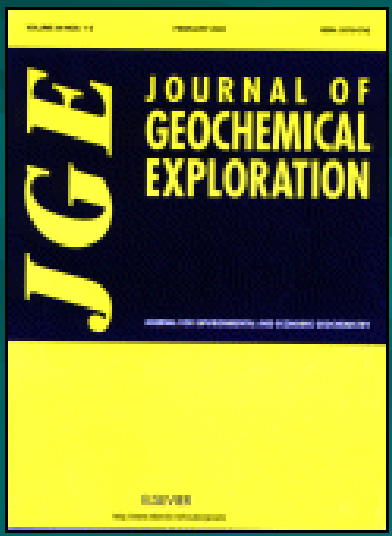
THE ASSOCIATION OF APPLIED GEOCHEMISTS

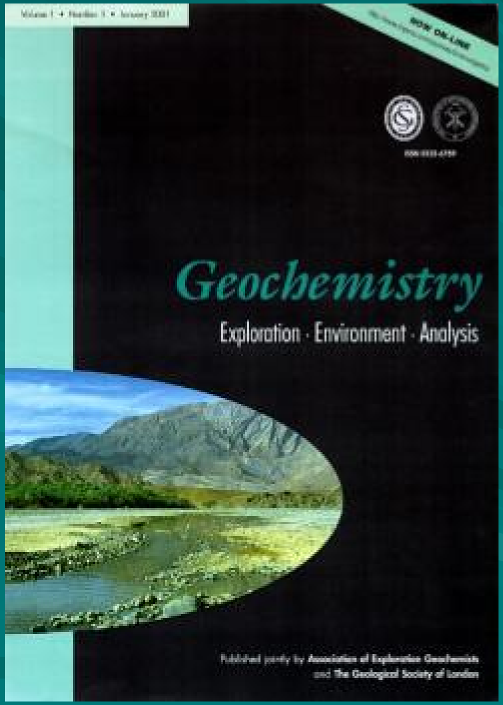
The Association's Journal

Elsevier



1972-1999

Geological Society of London



2001-present

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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

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Deep Penetrating Geochemistry

<u>Methods that use surface geochemistry to detect buried mineralization</u>

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

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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

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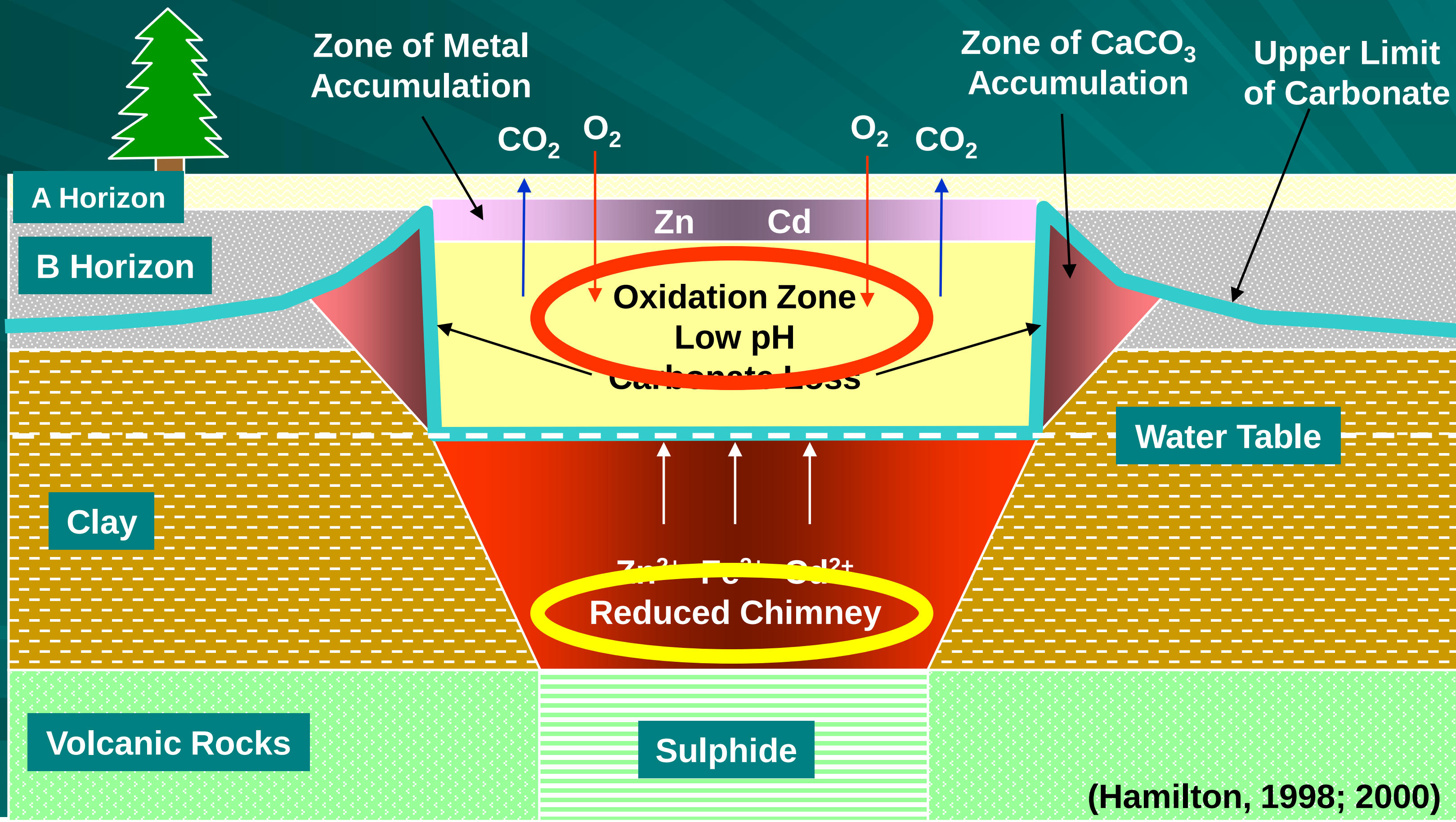
Geochemical processes over a buried sulphide



Modified after Cameron et al., 2004

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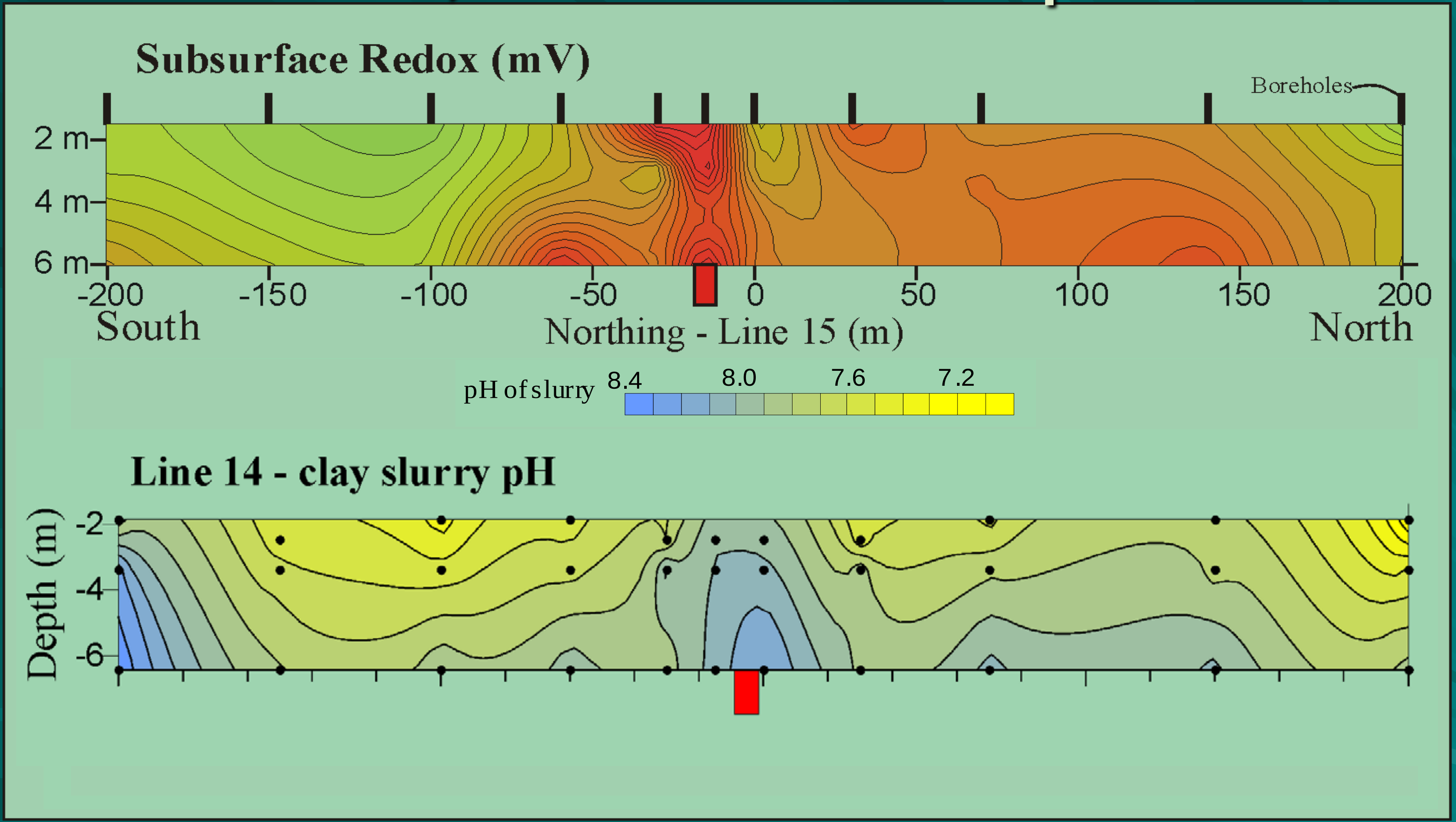
Marsh Zone, Line 15 - 3D pH & Redox



Hamilton et al., 2004a

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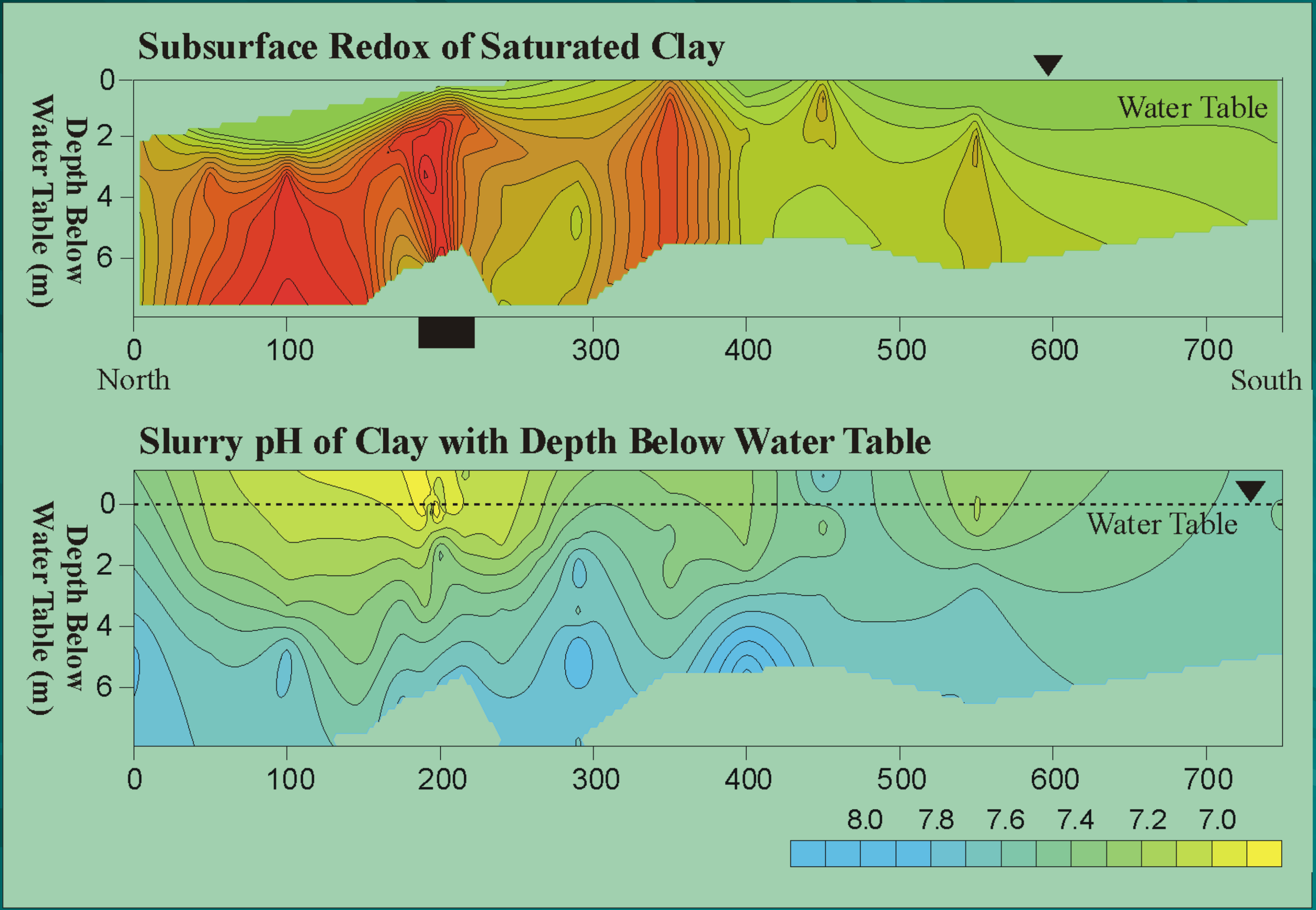
Cross Lake, Line 6 - 3D Redox & pH



Hamilton et al., 2004b

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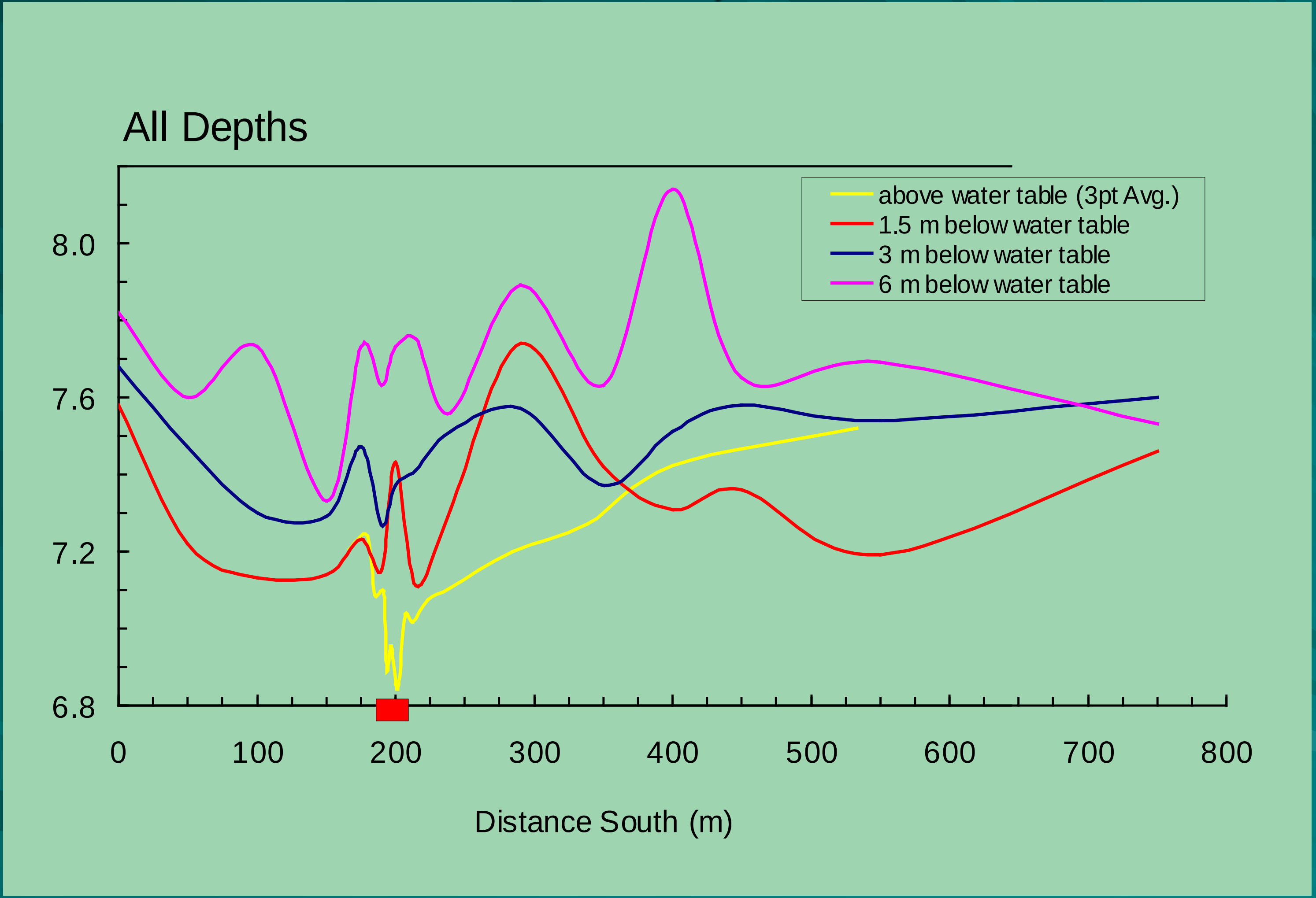
Soil Slurry pH 6 m Below Water Table, Cross Lake, Line 6



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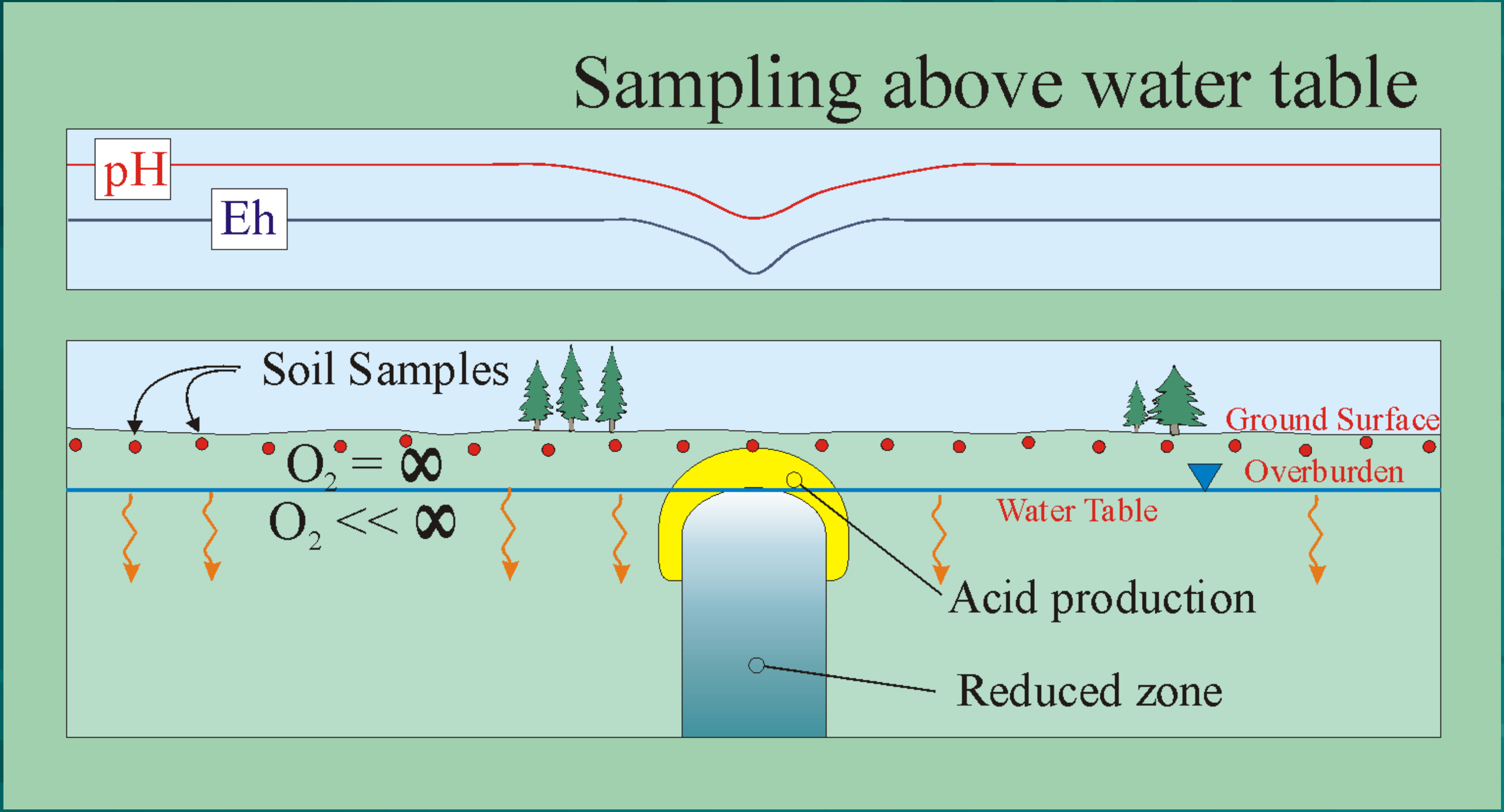
Development of pH Anomaly Above A Reduced Area in Overburden



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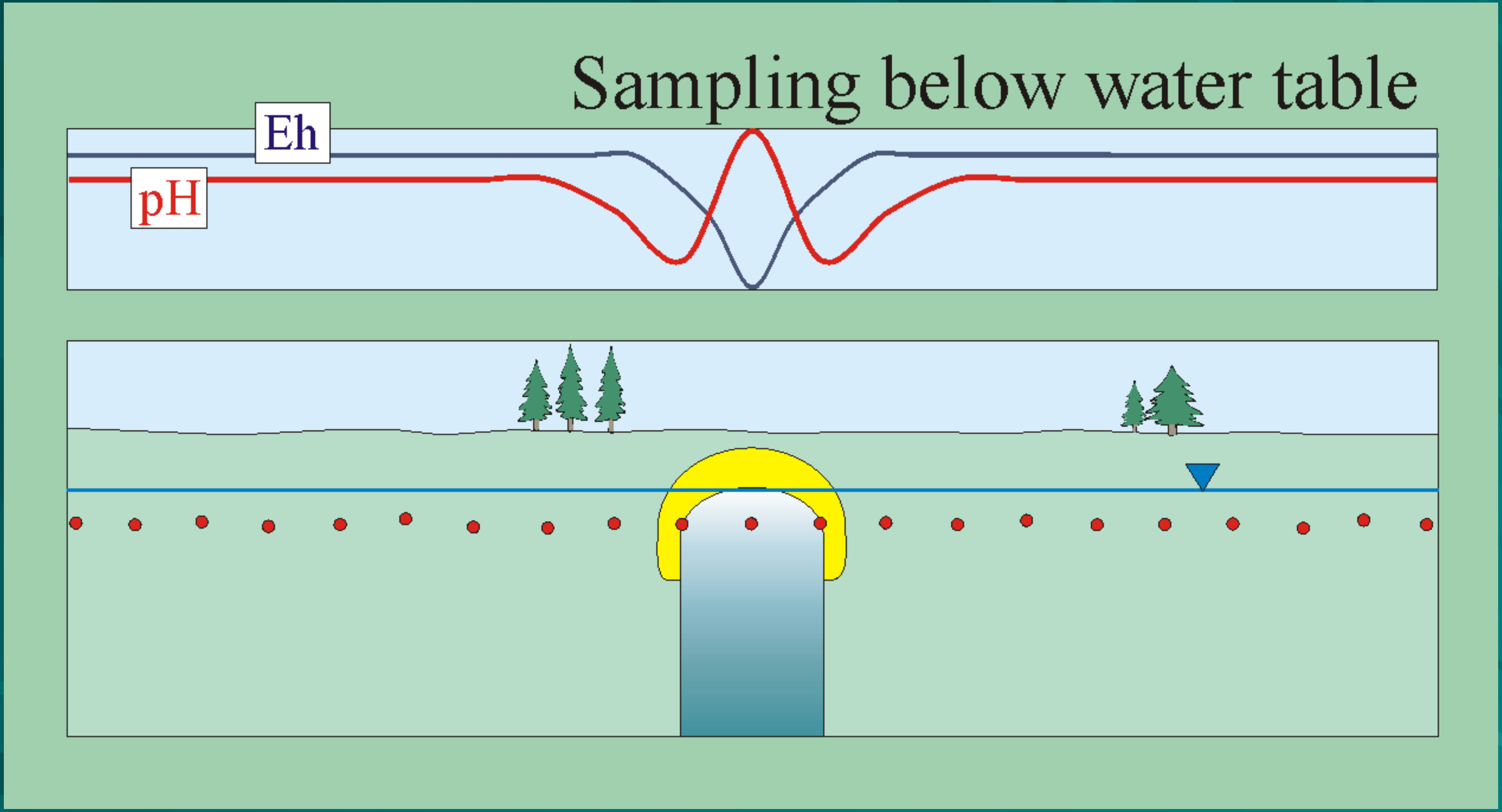

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Acid Production - Implications…1

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:

<u>Acid is produced by oxidation of reduced metals</u>

Acid Production - Implications…2

pH anomaly is:

1. Highly localized
   - yet H^+ is the most mobile aqueous species
2. Apparently permanent
   - yet H^+ is one of the most reactive of aqueous species

Conclusion:

<u>Acid production is an ongoing process</u>

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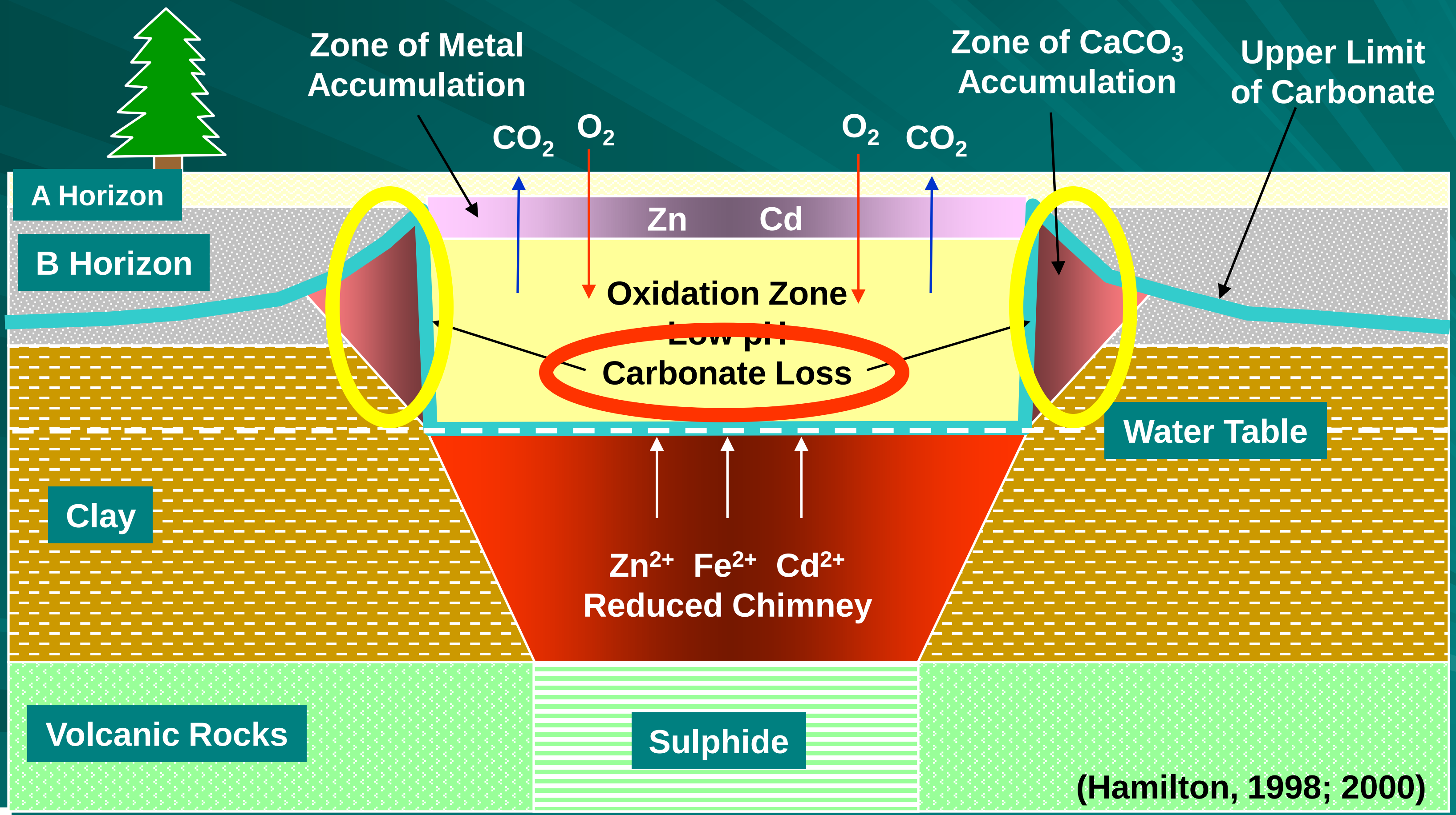
Acid Production - Implications…3

- 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

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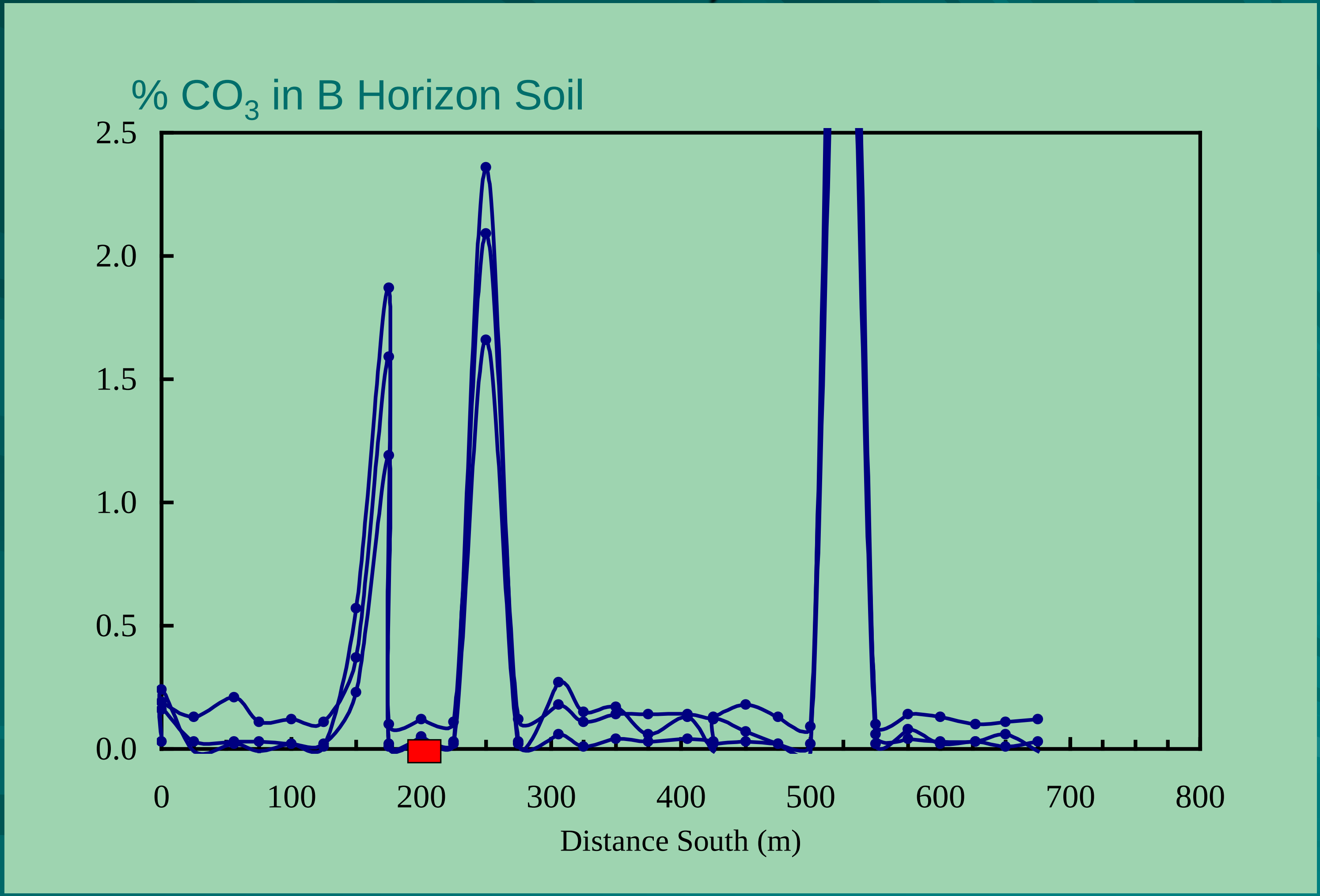
% CO_3 in B-Horizon Soil
Cross Lake, Line 6



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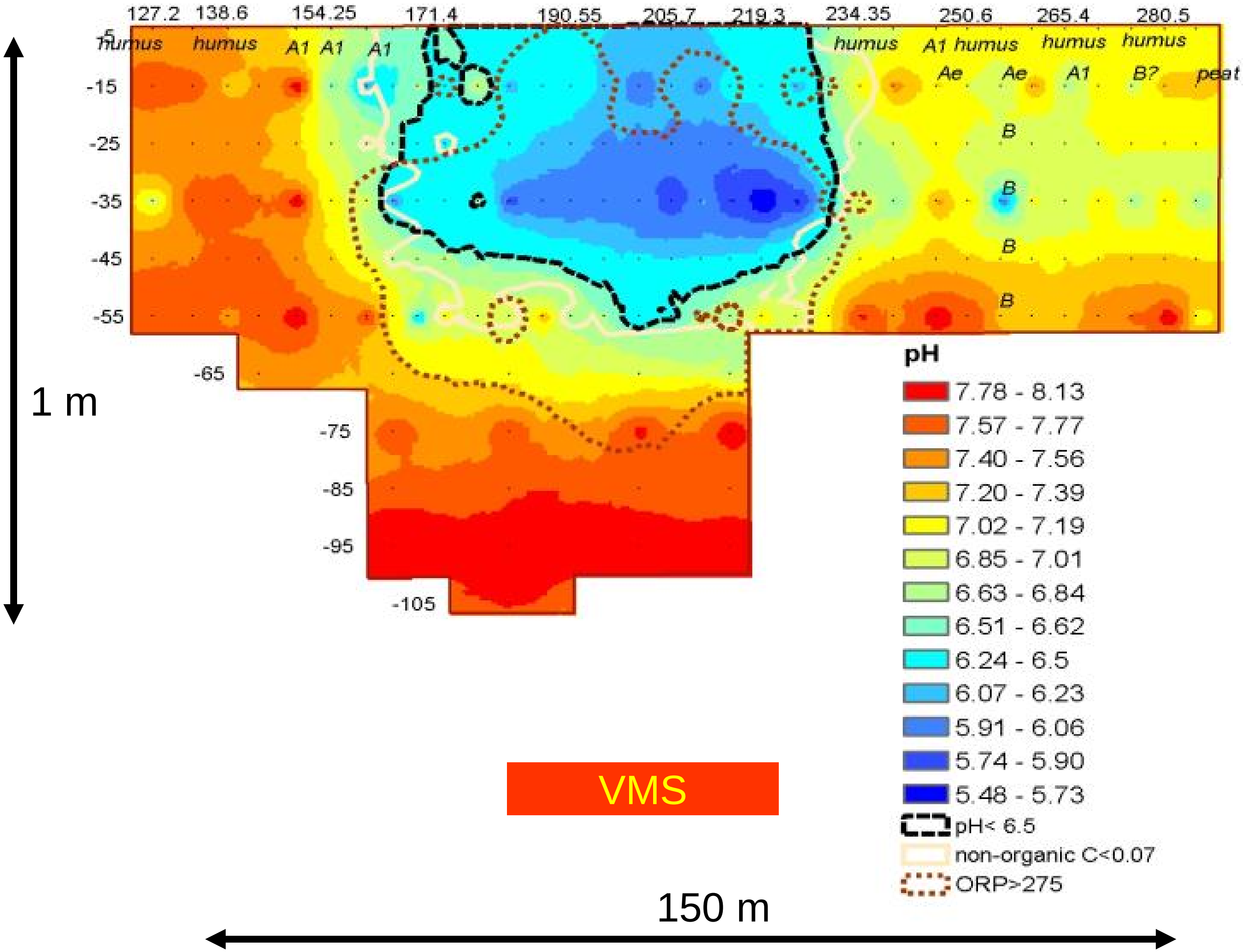
pH, Line 6, Cross Lake



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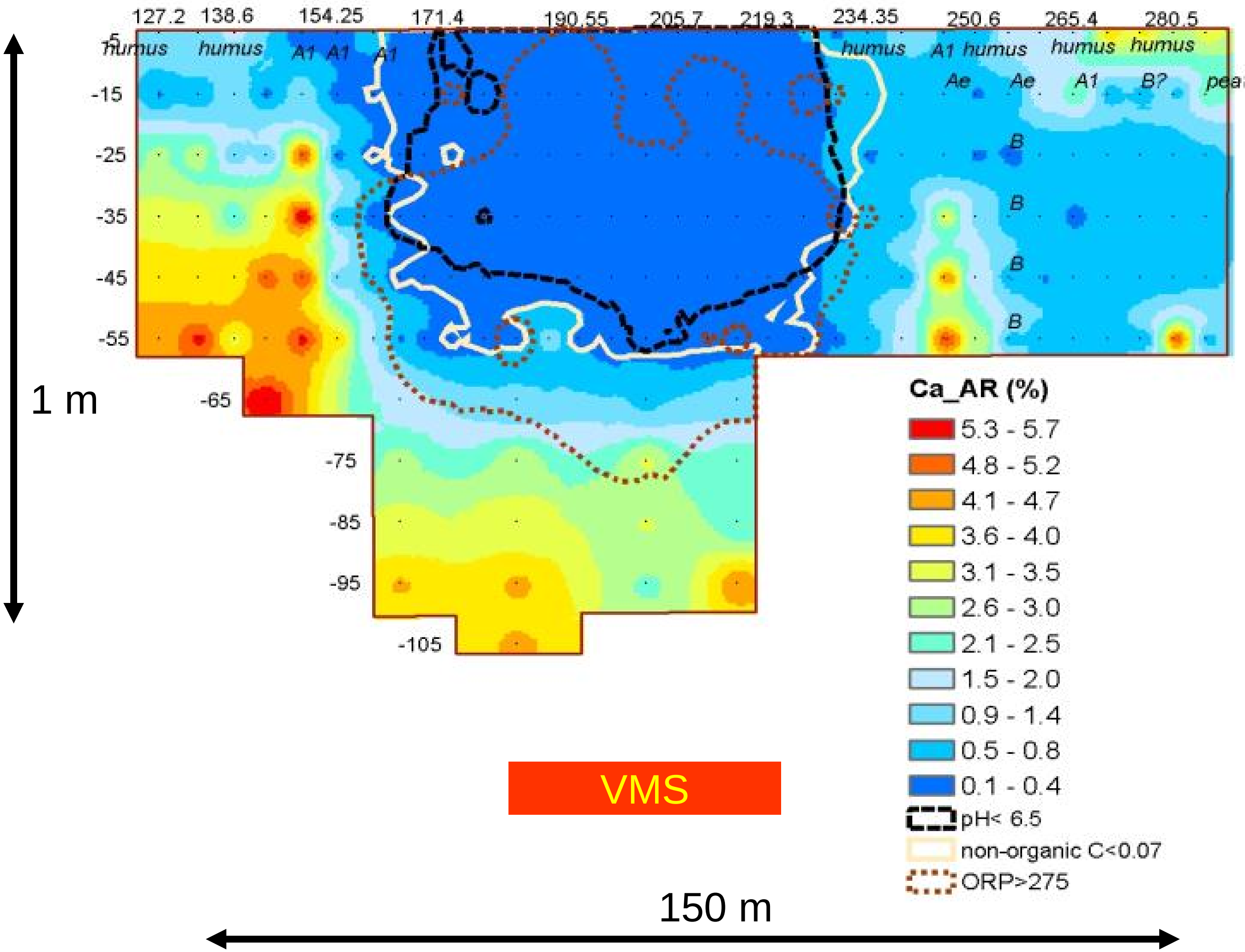
Calcium – Line 6, Cross Lake



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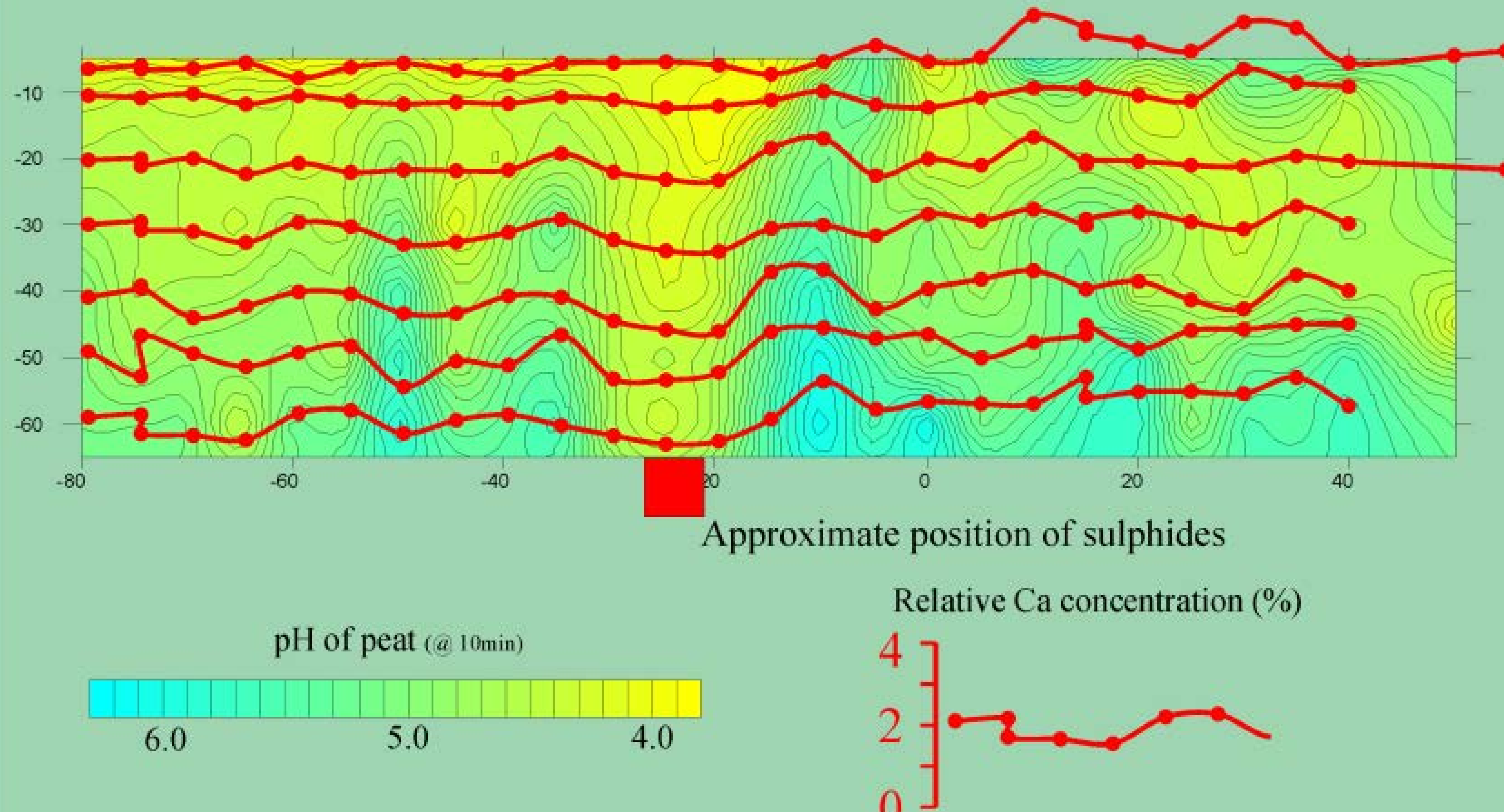
Calcium concentration in peat plotted against pH
Marsh Zone Profile Data



Note: the typical background Ca concentration increases gradually with depth from about 0.5% @ 5 cm to 2.5% @ 60 cm.

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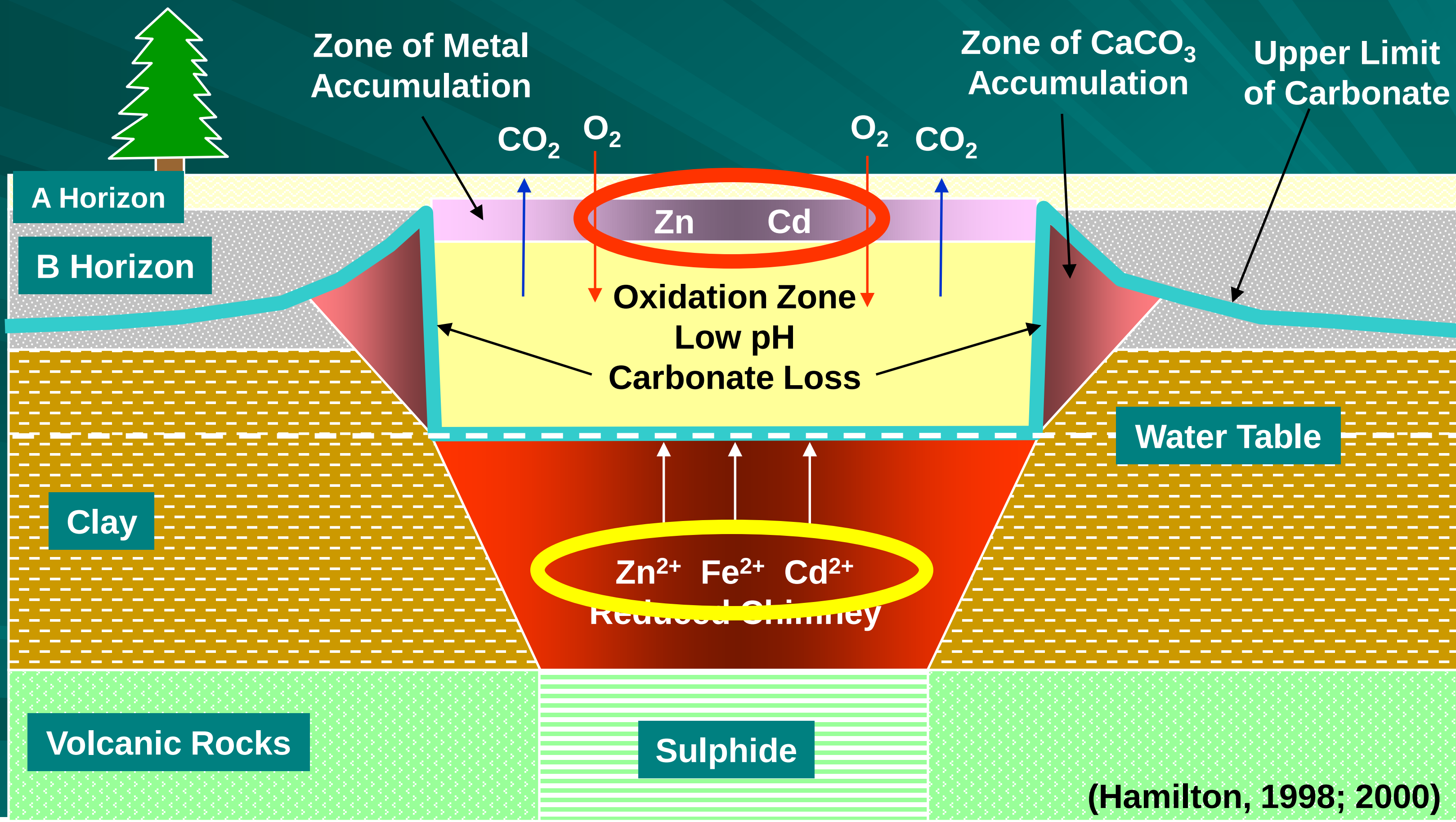
Geochemical processes over a buried sulphide



Modified after Cameron et al., 2004

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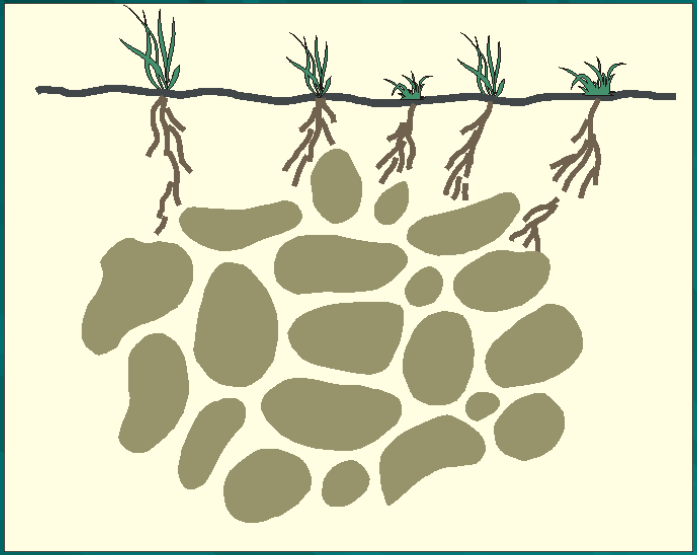
Selective Leach Methods

- 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

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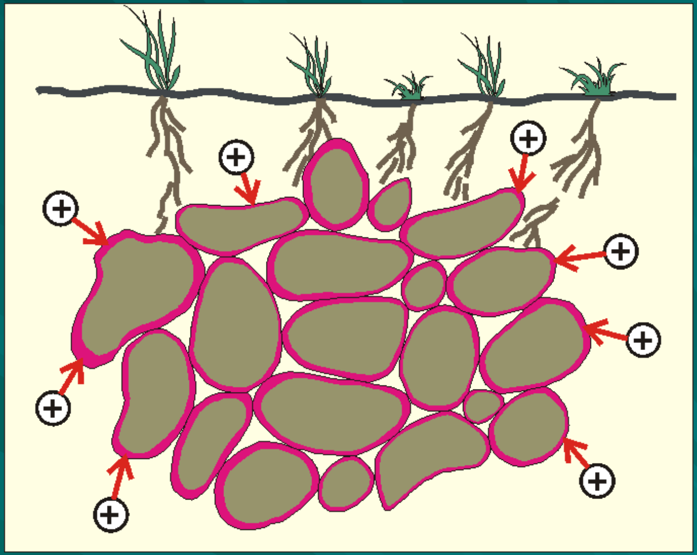
Selective Leach Methods

- 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

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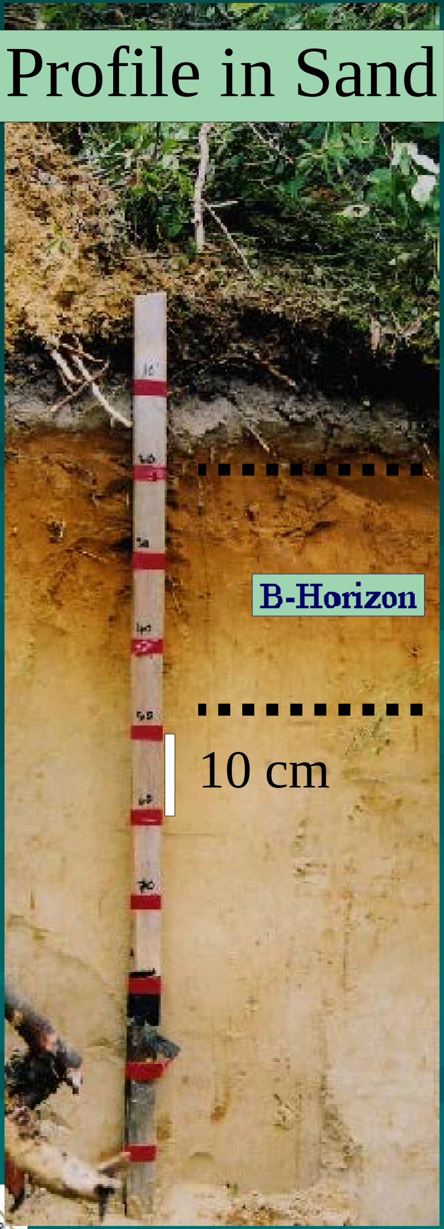
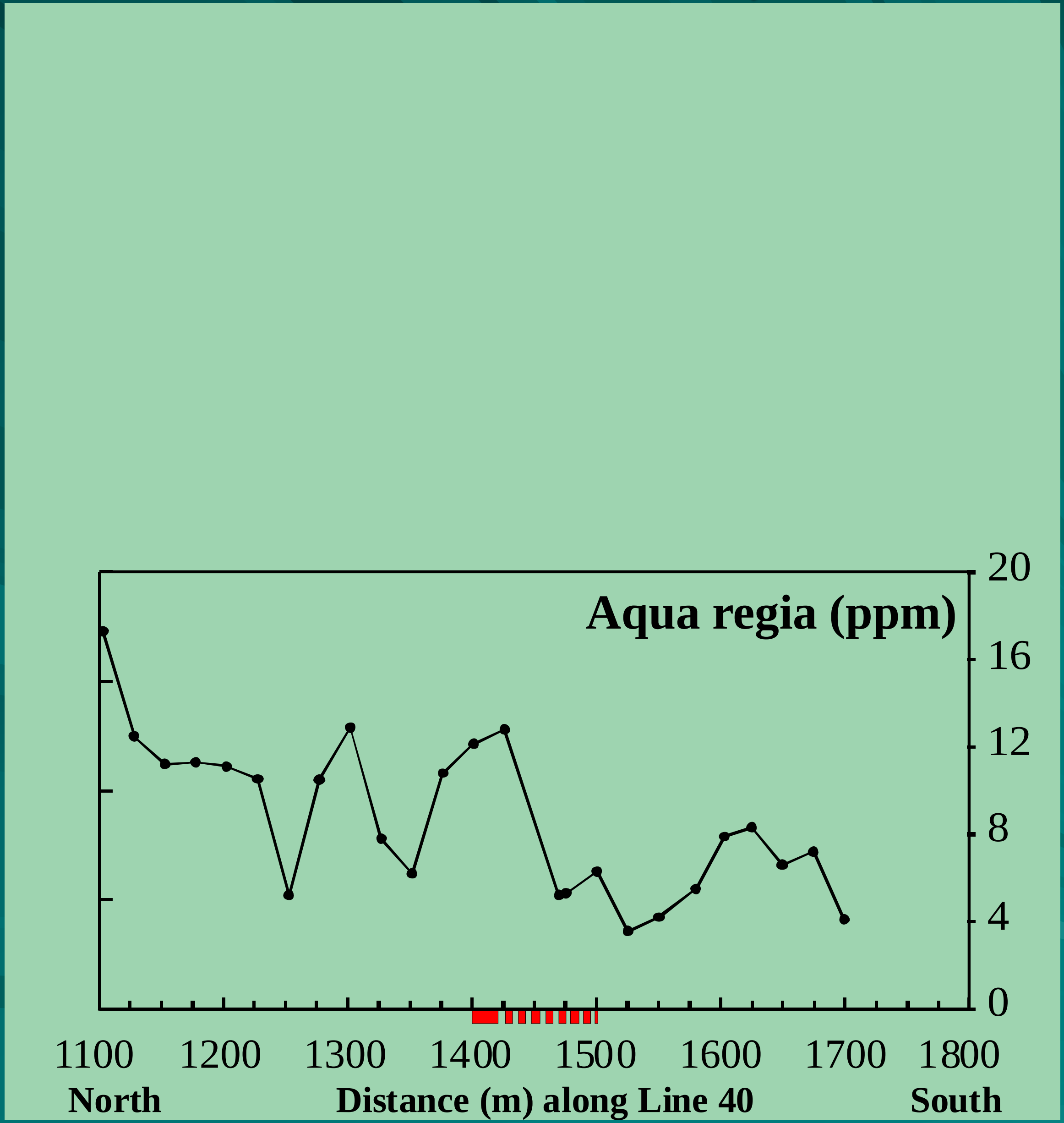
Zn in Soils - Cross Lake VMS, Line 40





50 m

Cameron et al., 2004

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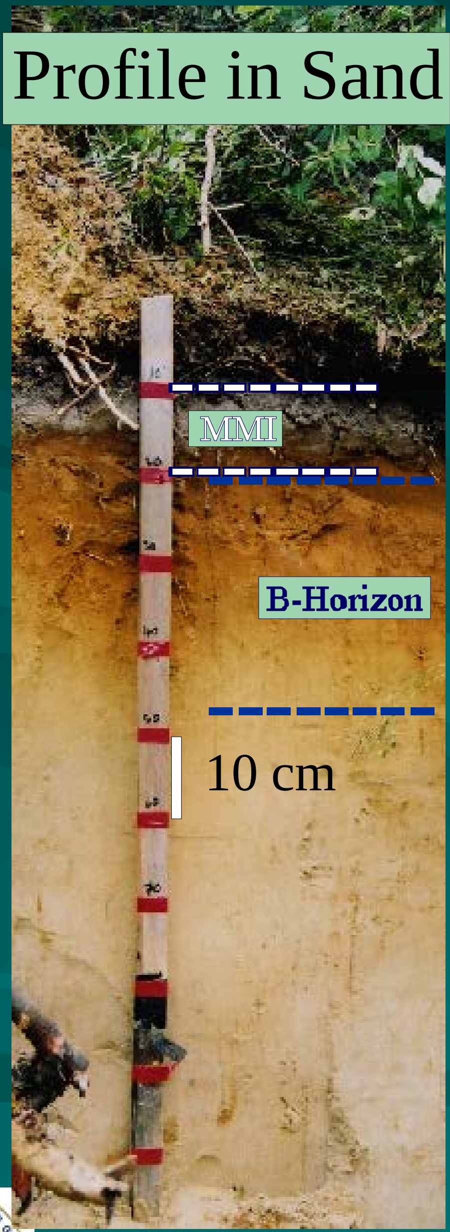
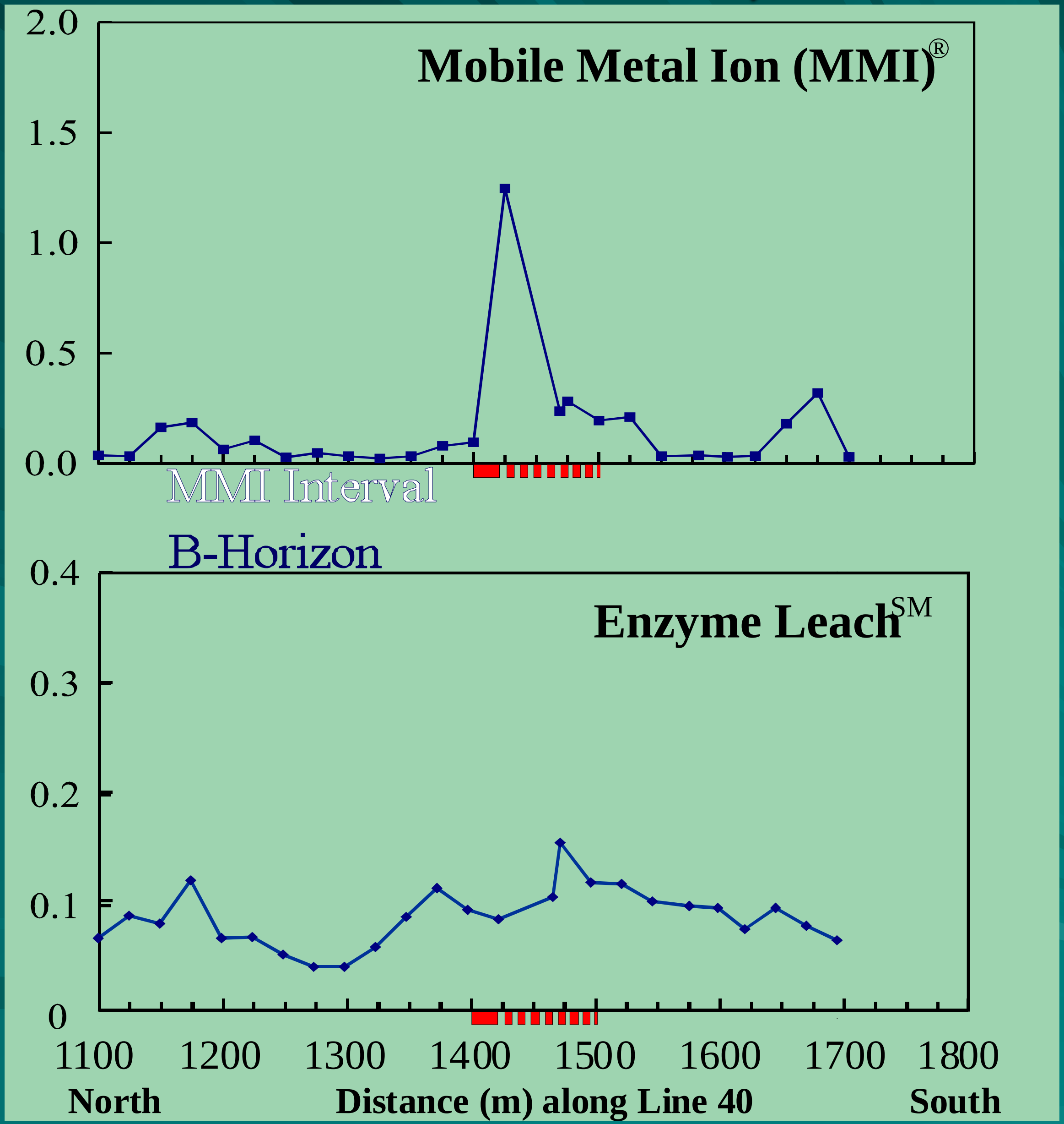
Zn in Soils - Cross Lake VMS, Line 40





50 m

Cameron et al., 2004

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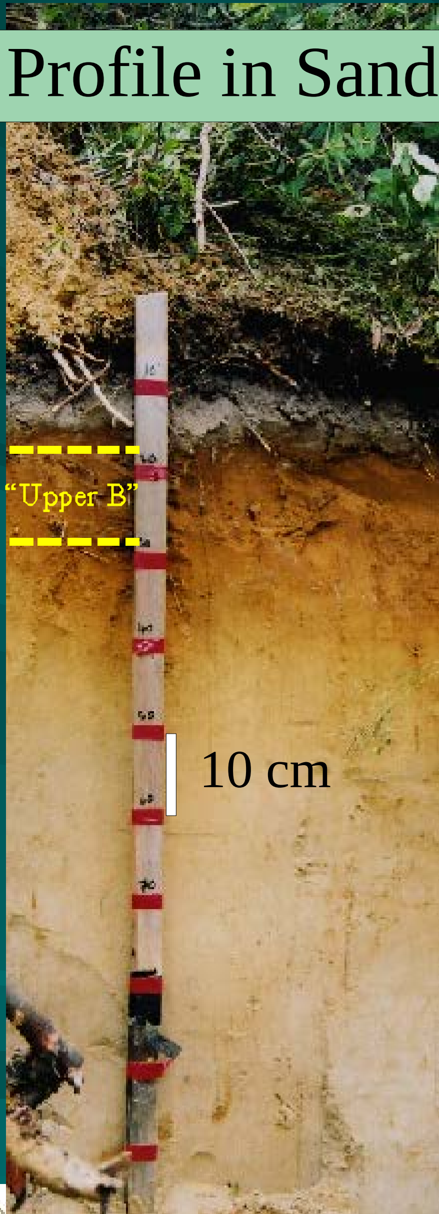
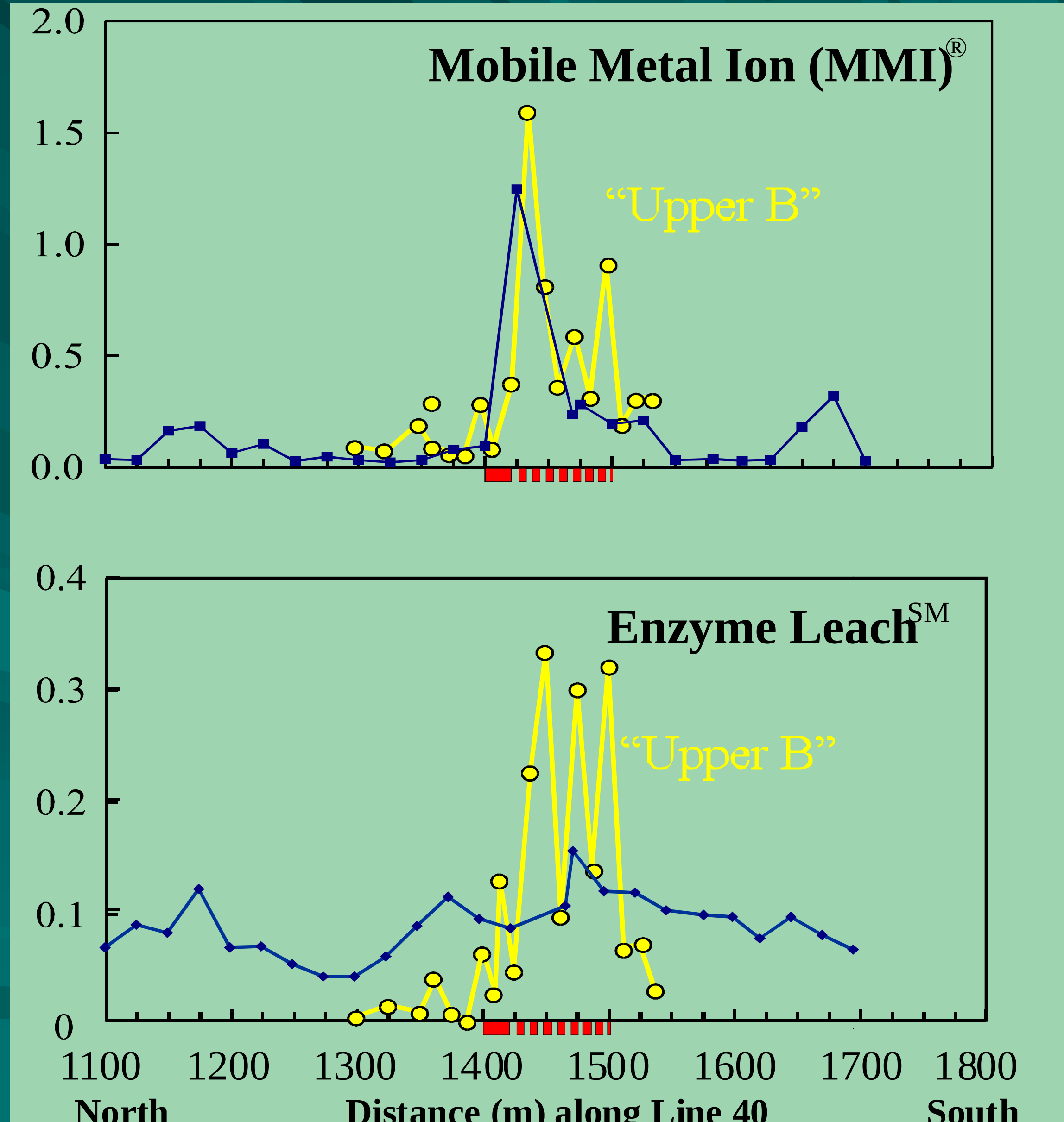
Zn in Soils - Cross Lake VMS, Line 40





50 m

Cameron et al., 2004

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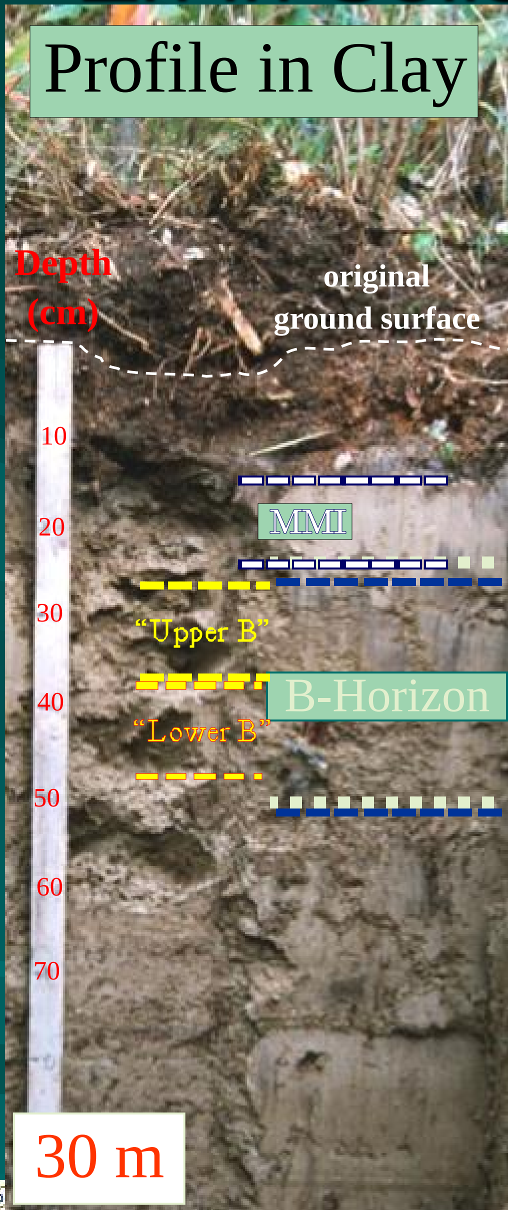
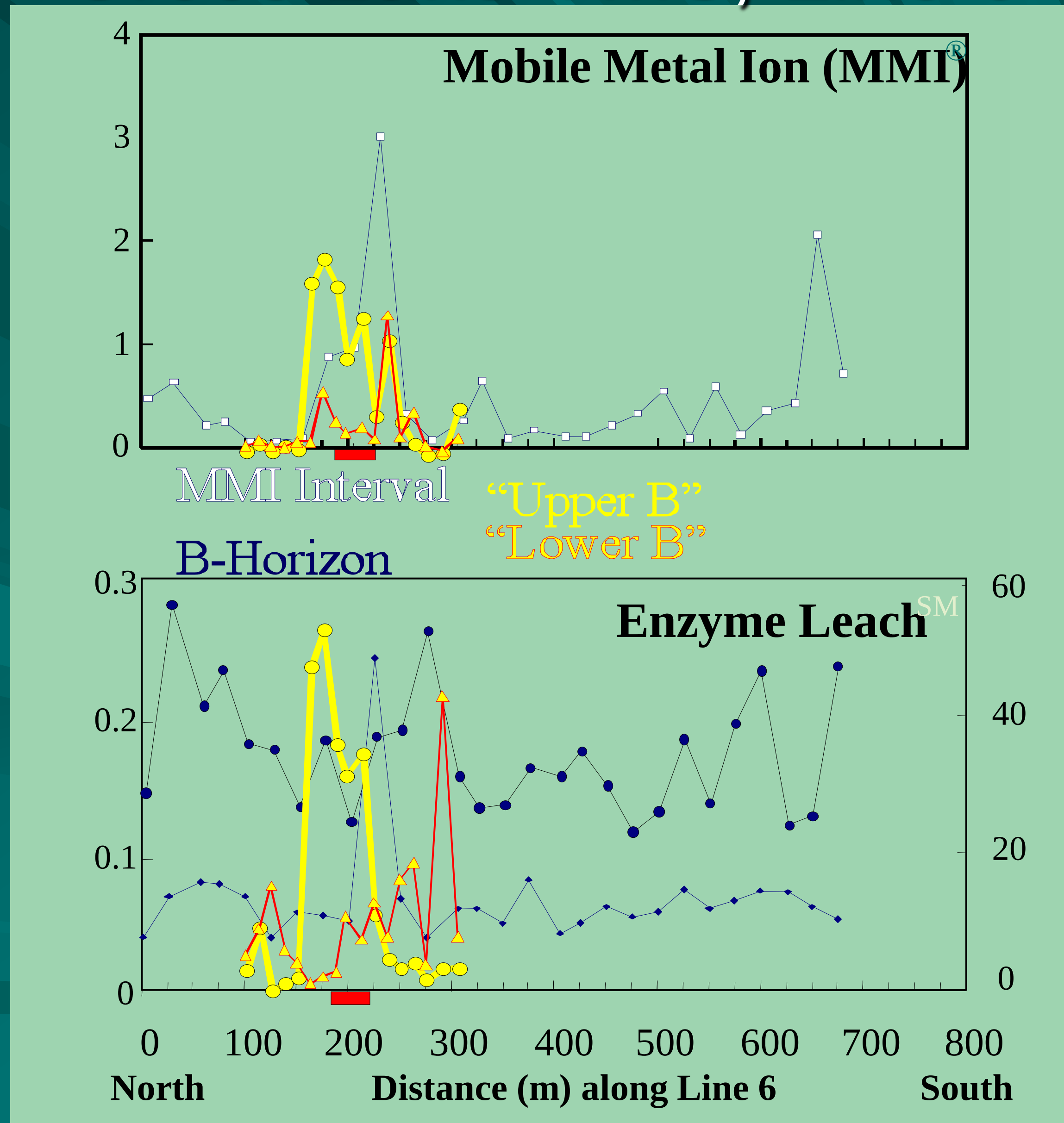
Zn in Soils - Cross Lake VMS, Line 6





Cameron et al., 2004

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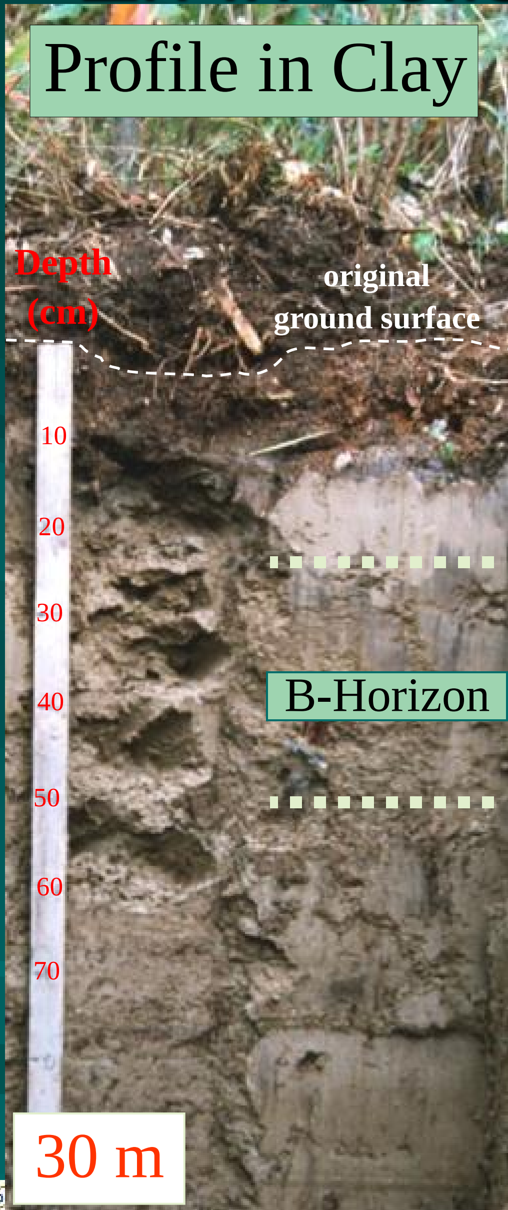
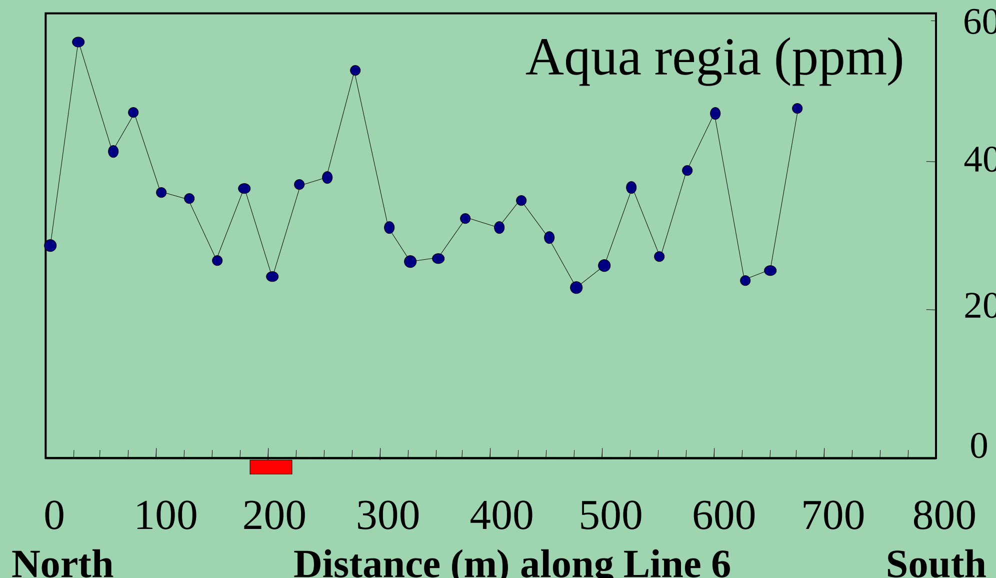
Zn in Soils - Cross Lake VMS, Line 6





Cameron et al., 2004

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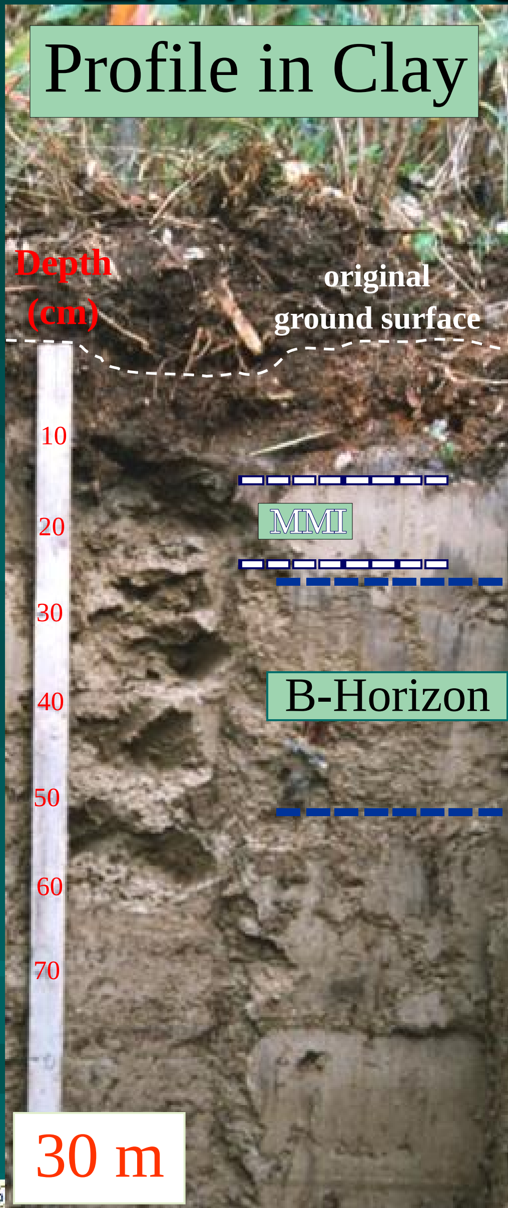

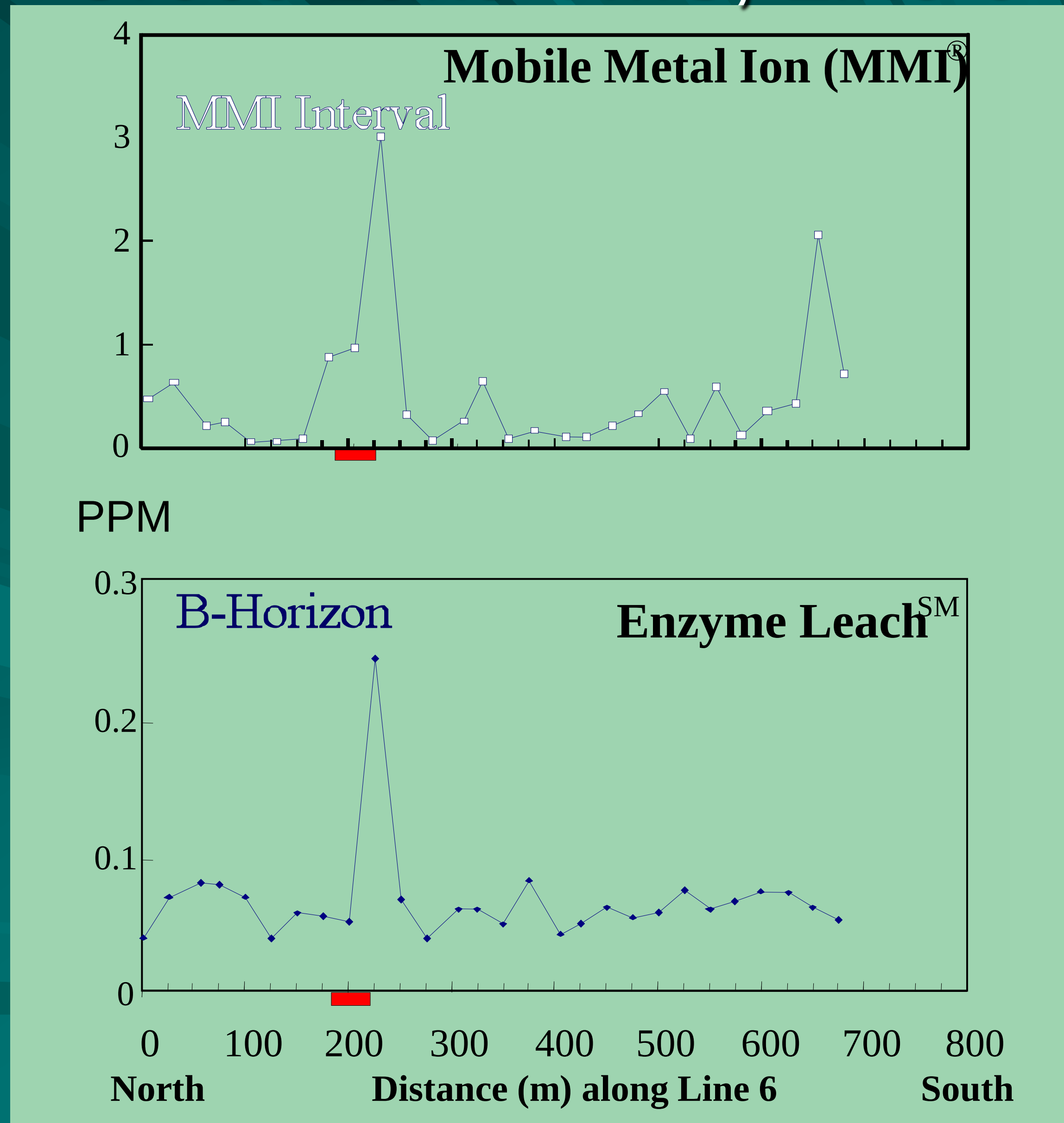

Cameron et al., 2004

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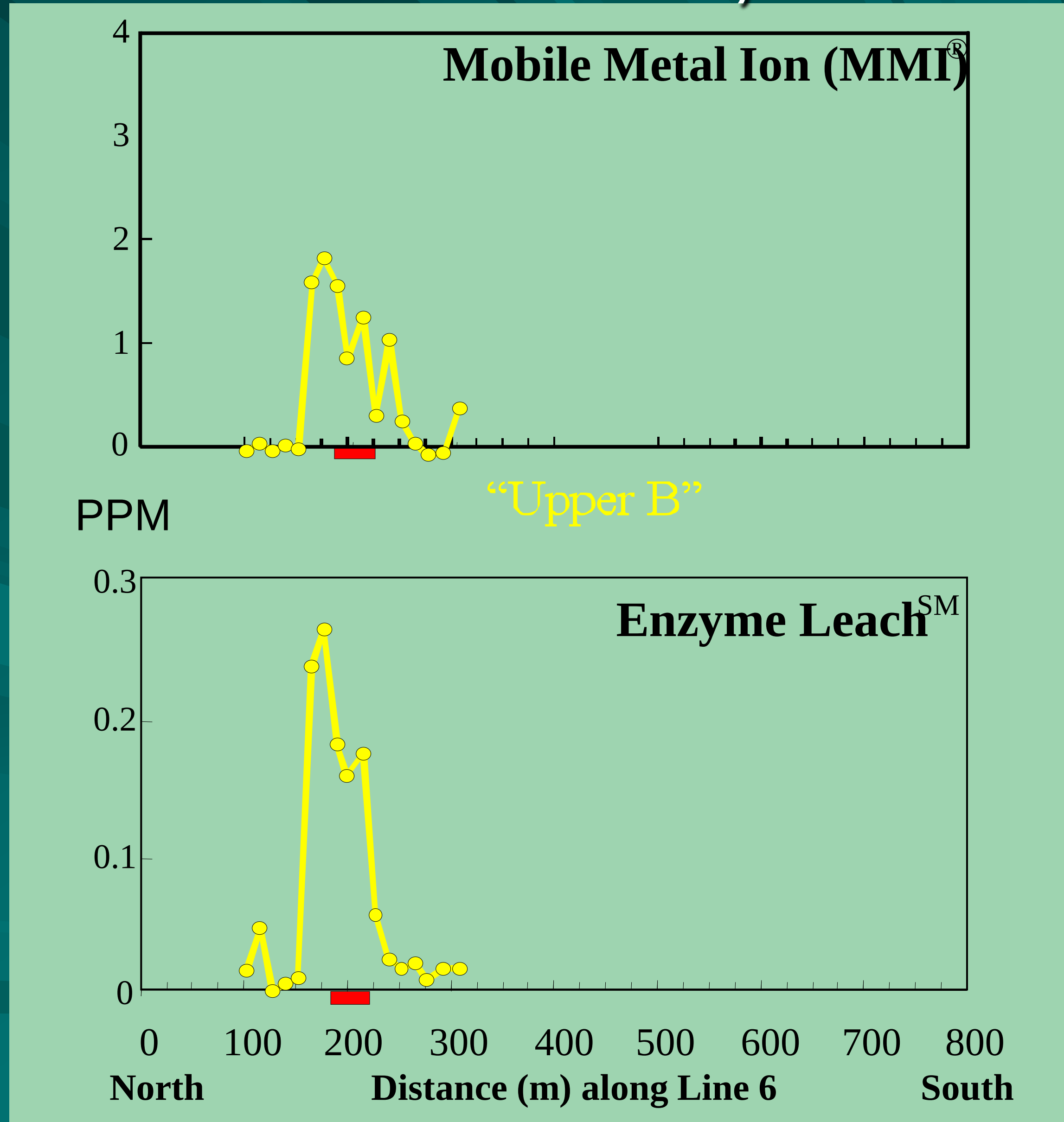

Cameron et al., 2004

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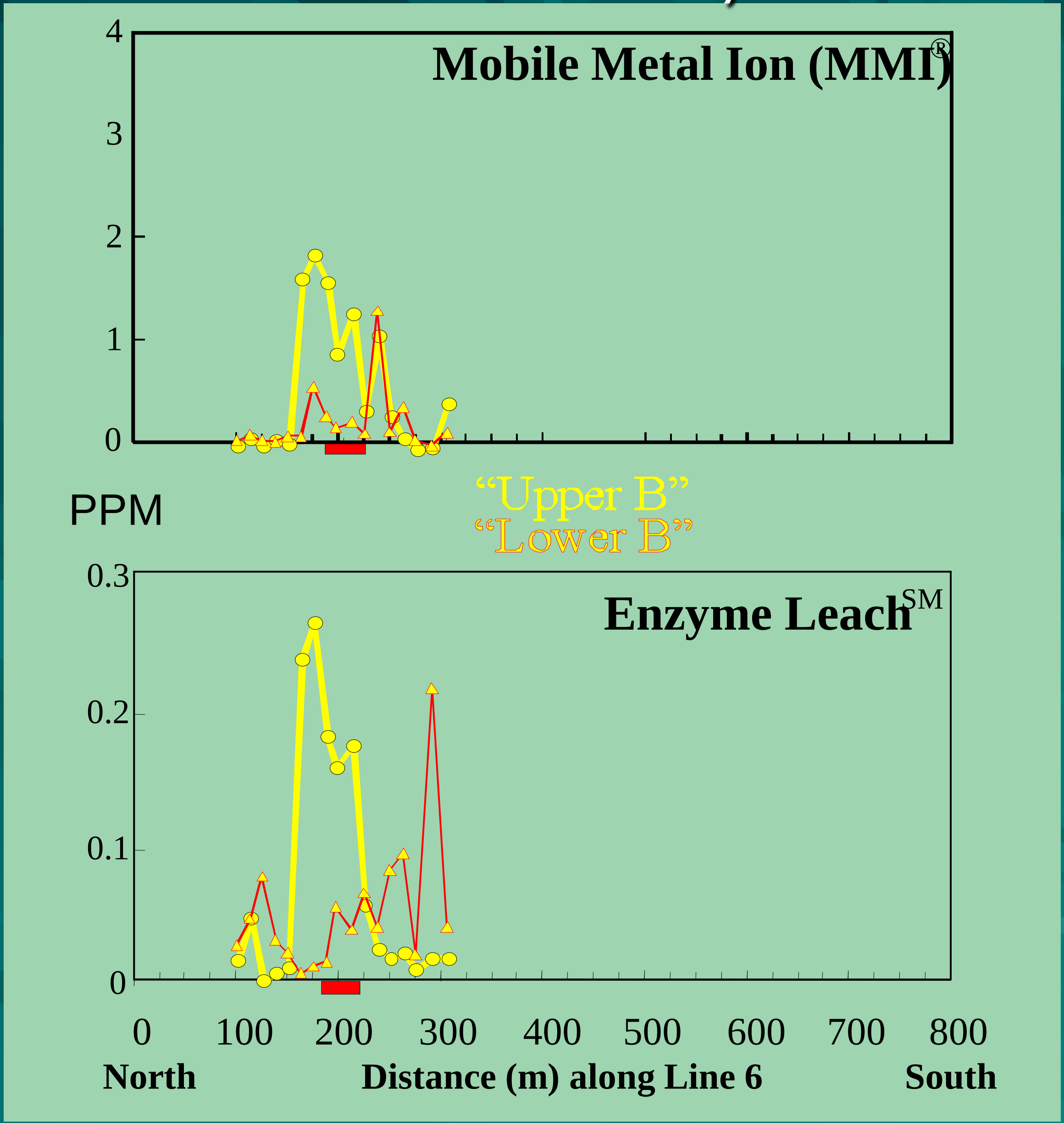

Cameron et al., 2004

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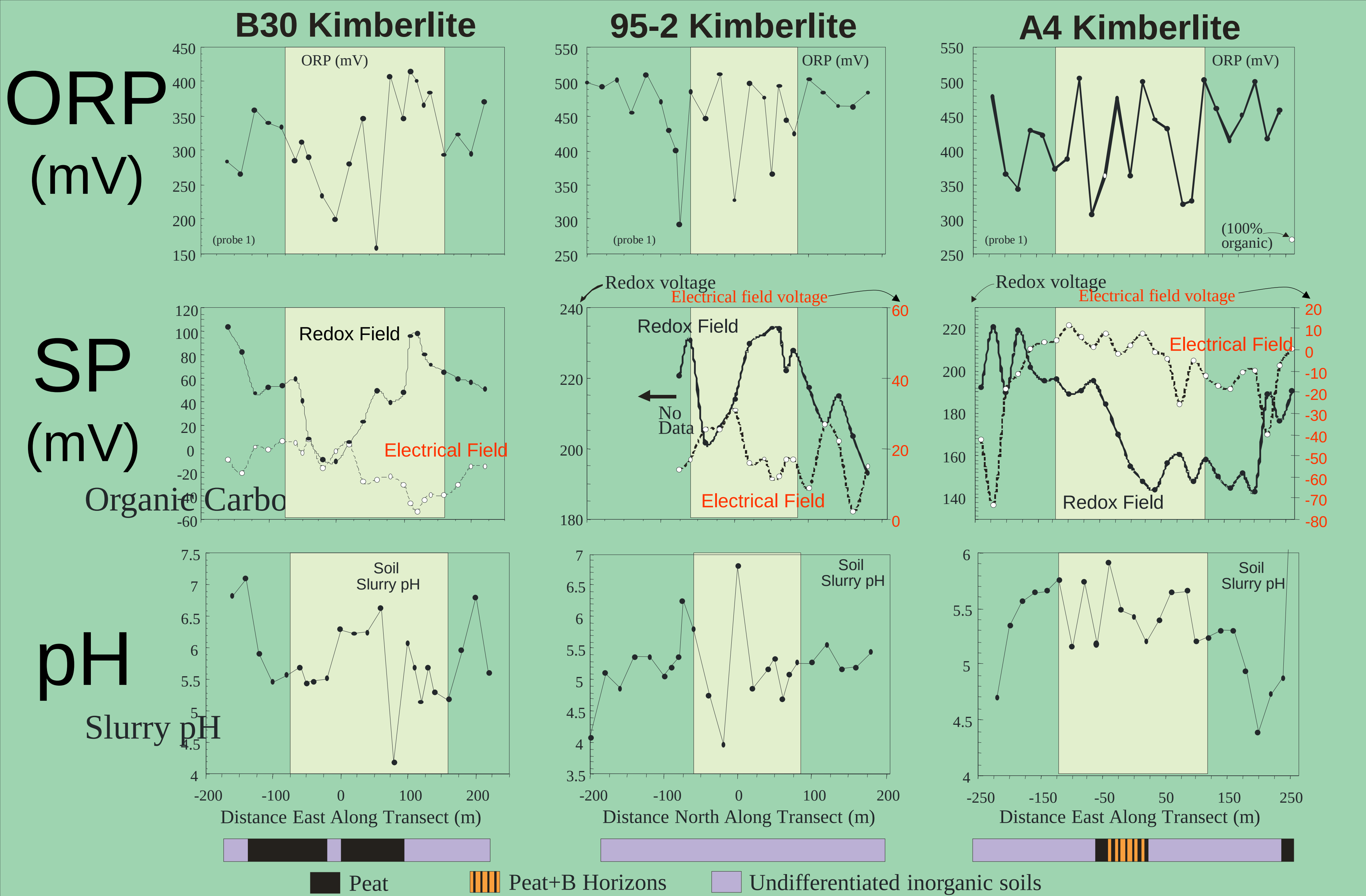

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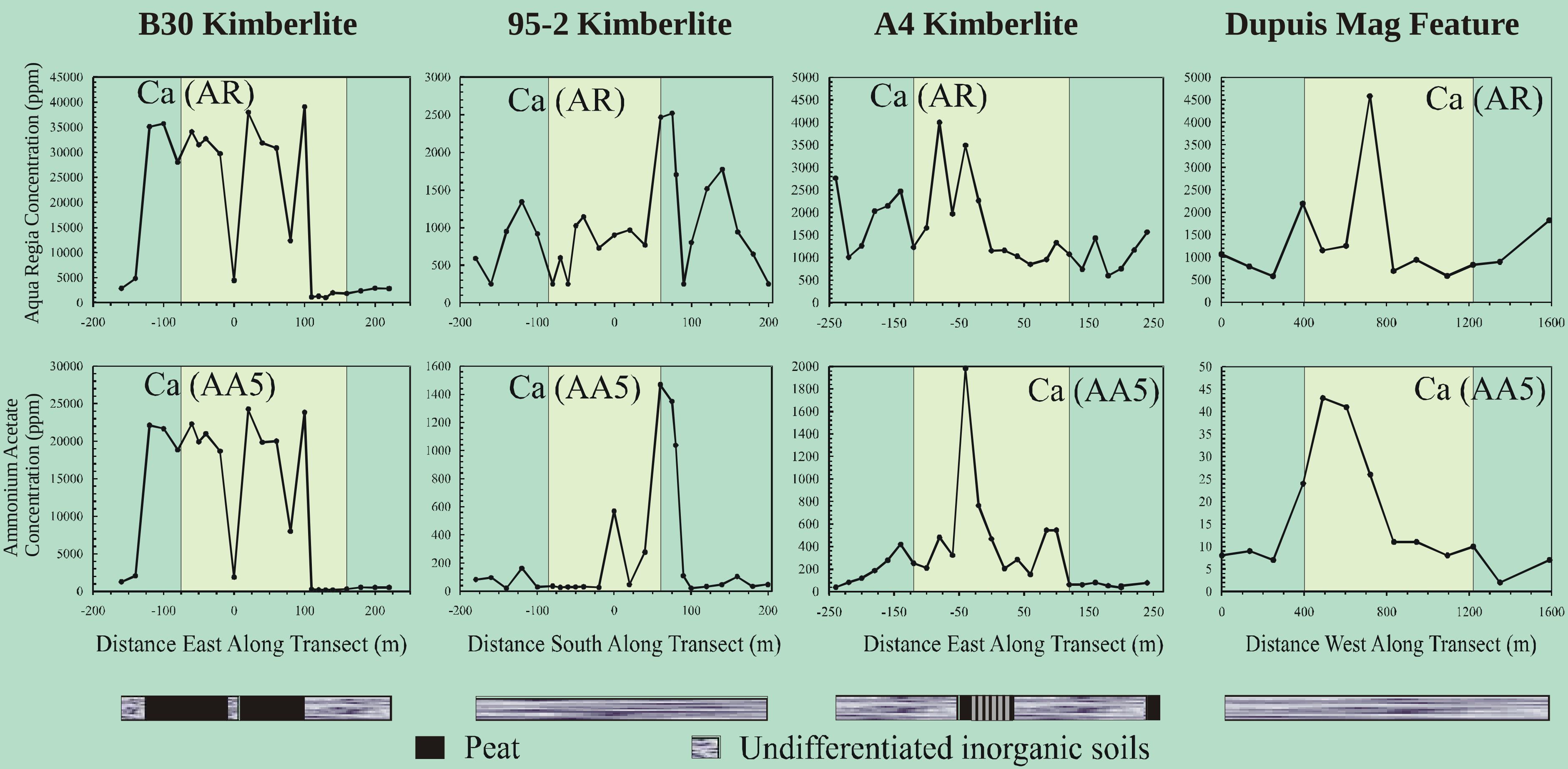
Ca in Soils over 3 Kimberlites



45 m

50 m

30 m

? m

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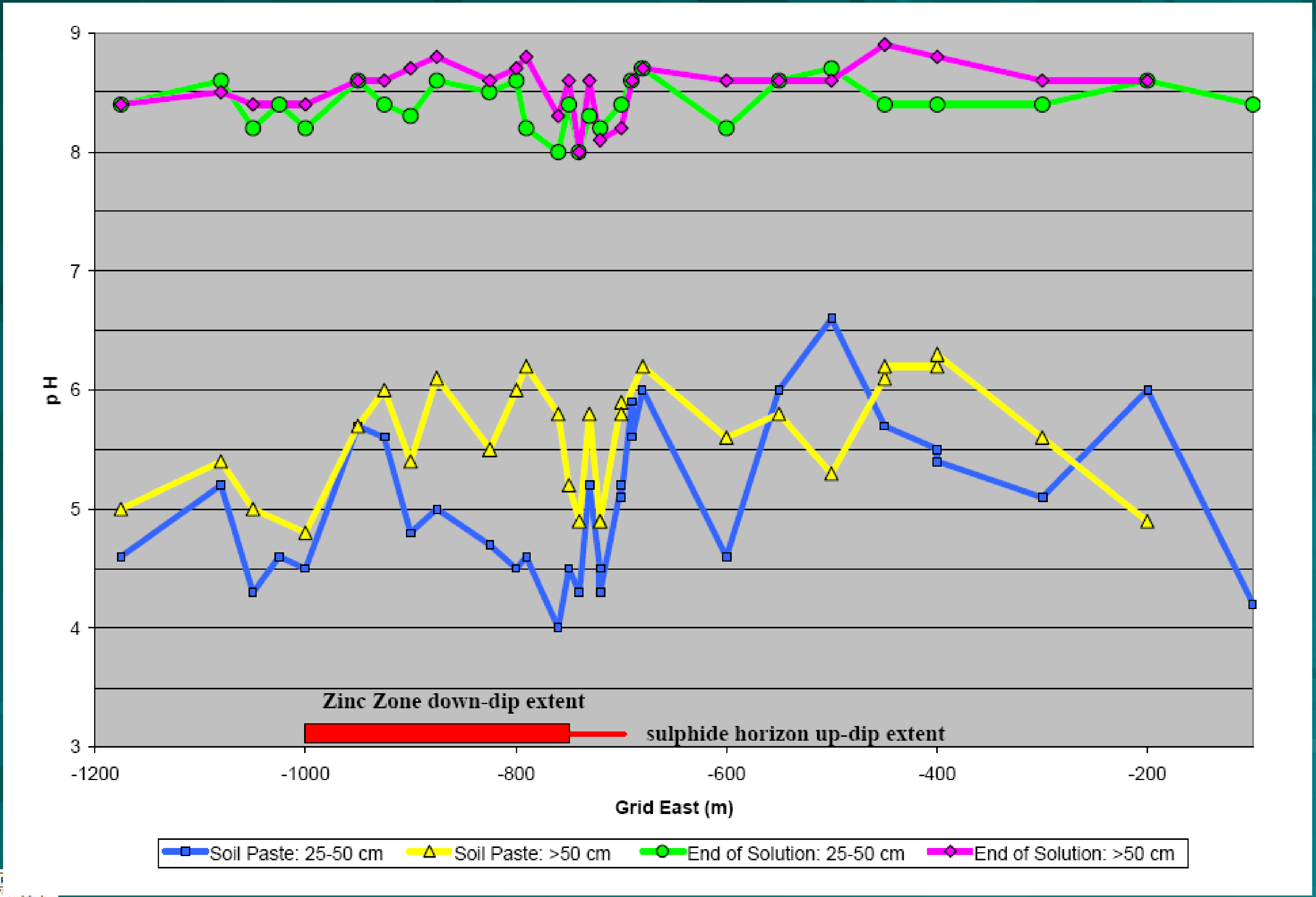
Lady’s slippers grow best in well drained, high calcium soils and are extremely profu over the B-30 and 95-2 Kimberlites (pictur

pH Parameters – Gemini VMS, Line 6450S



Source: Jackson, 2003: Report to CAMIRO & OMET on Gemini VMS

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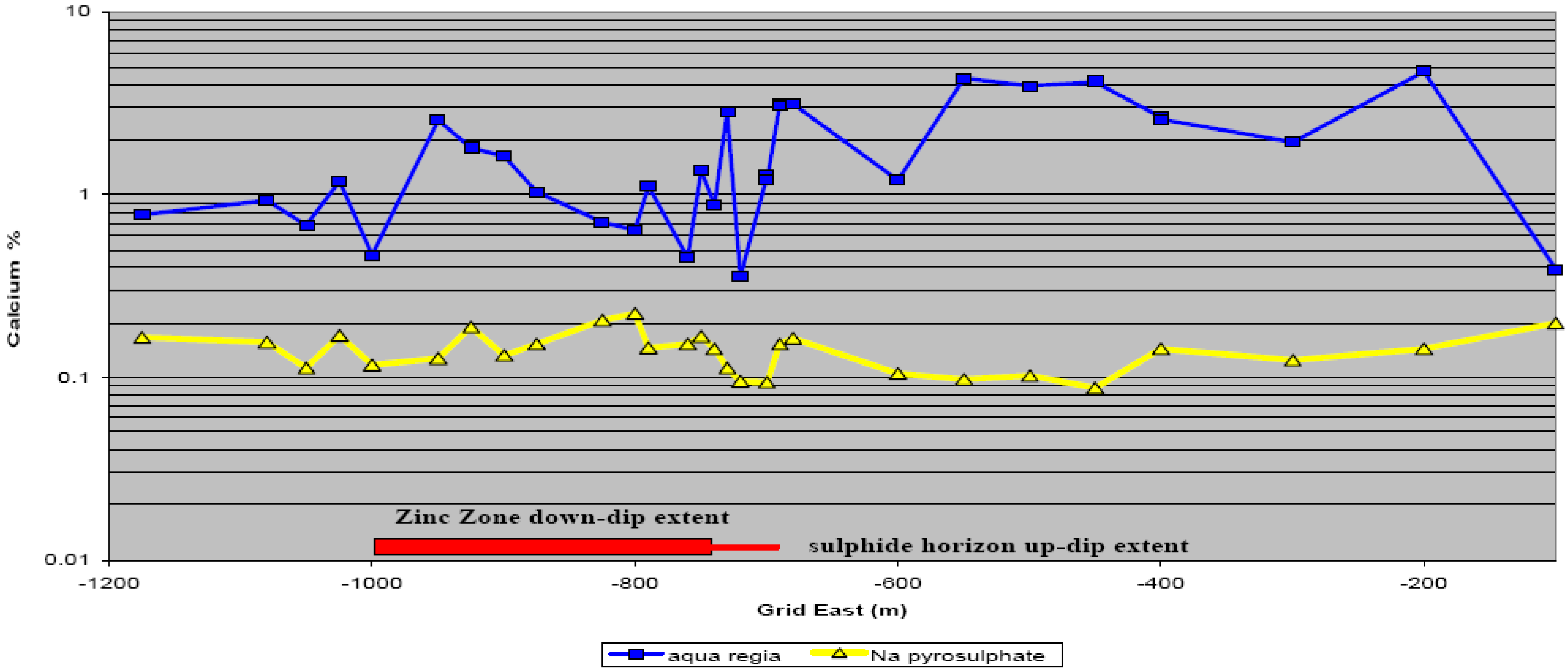
Ca in Upper Peat – Gemini VMS, Line 6450S



25-50 cm peat

Source: Jackson, 2003: Report to CAMIRO & OMET on Gemini VMS

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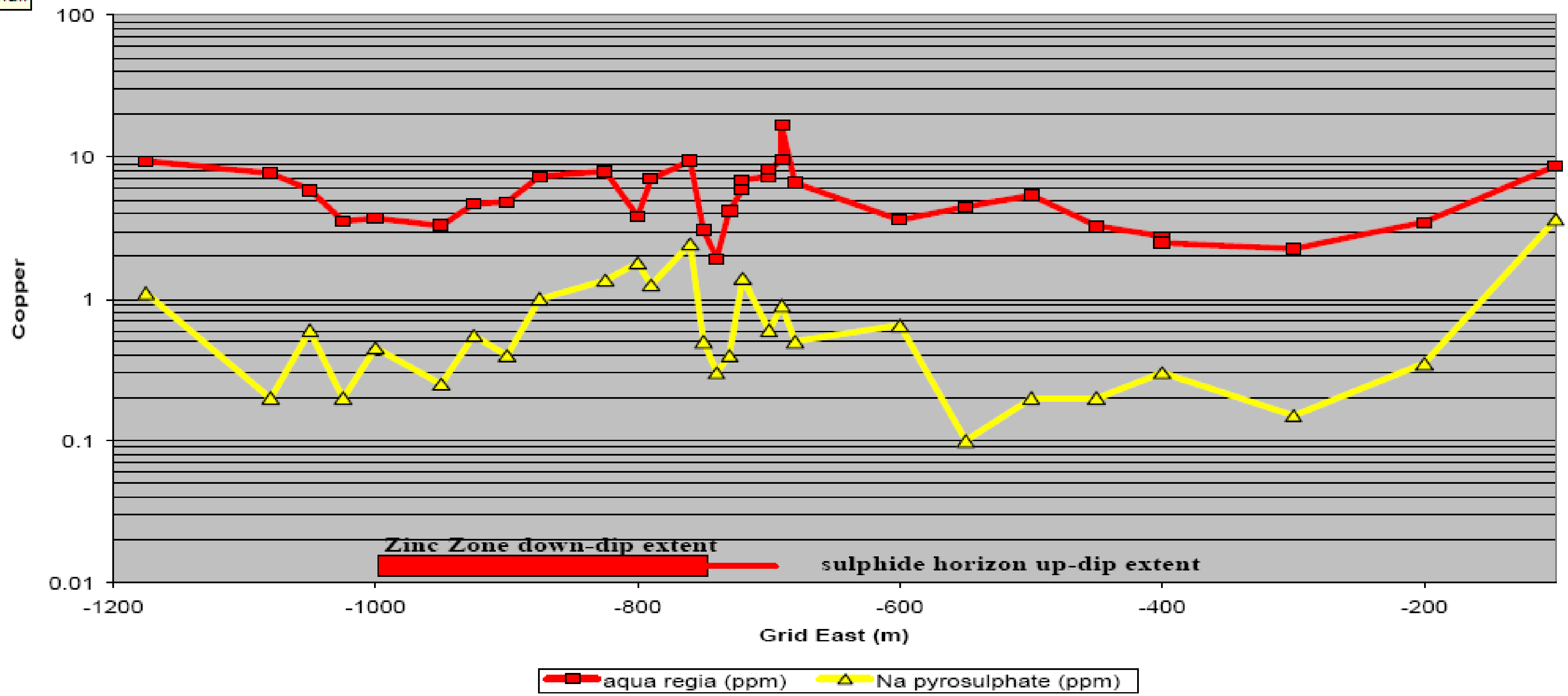
Cu in Upper Peat – Gemini VMS, Line 6450S

Email



25-50 cm depth peat

Source: Jackson, 2003: Report to CAMIRO & OMET on Gemini VMS

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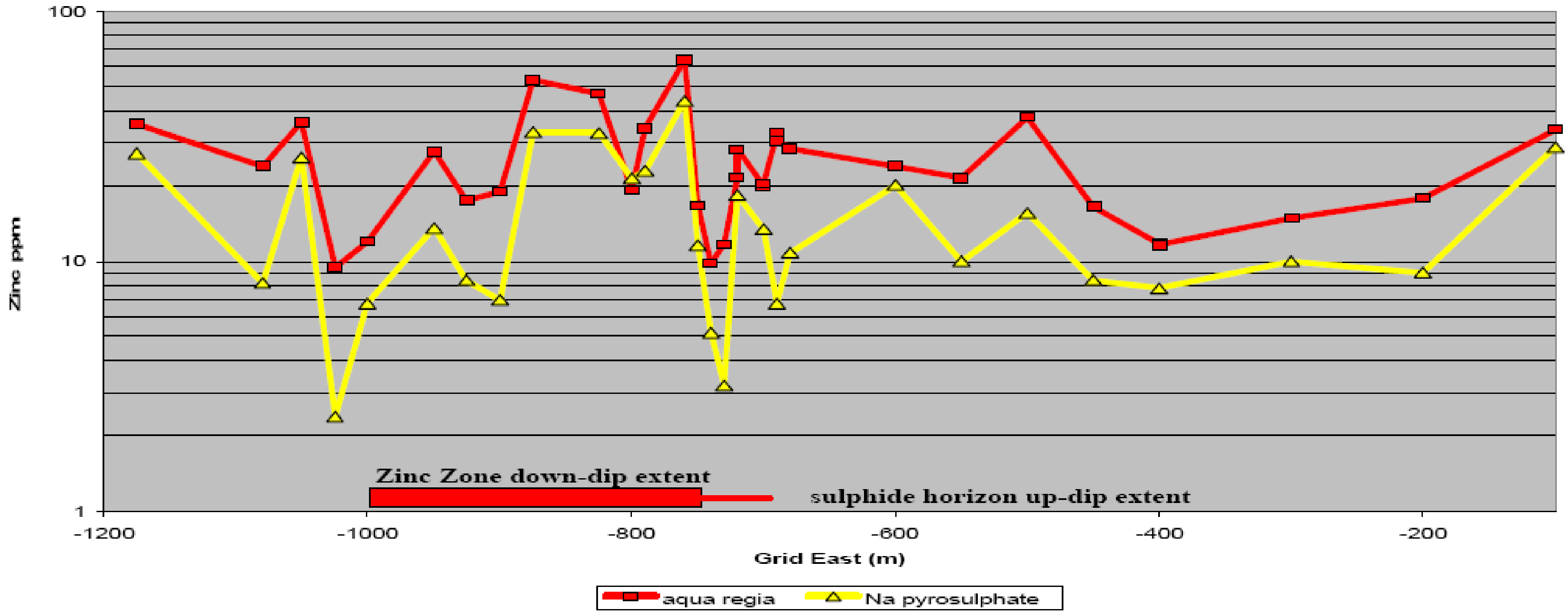
Zn in Upper Peat – Gemini VMS, Line 6450S



25-50 cm peat

Source: Jackson, 2003: Report to CAMIRO & OMET on Gemini VMS

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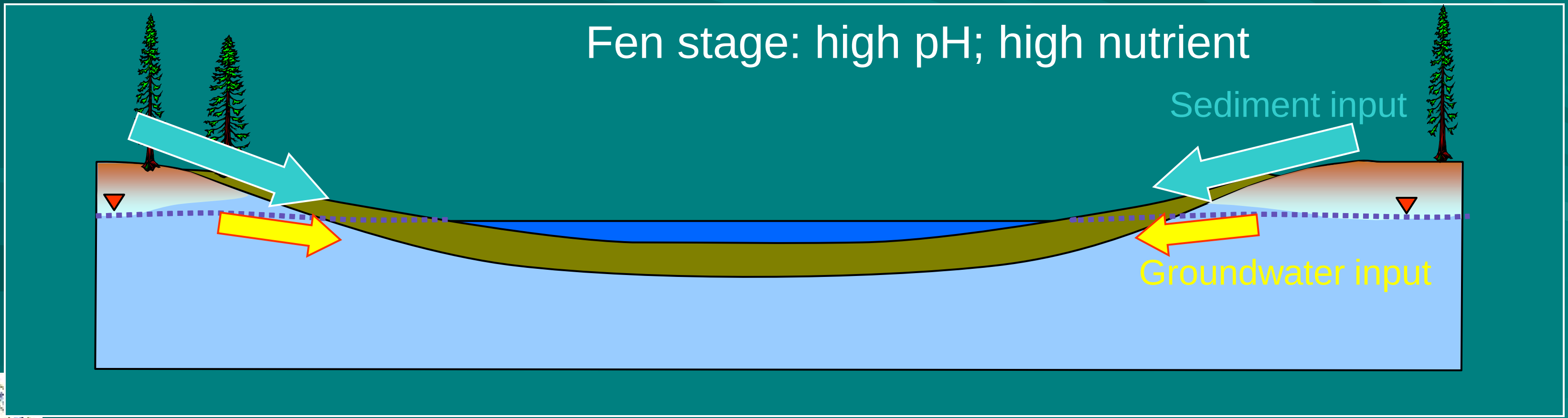
Development of geochemical responses in a peat bog

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



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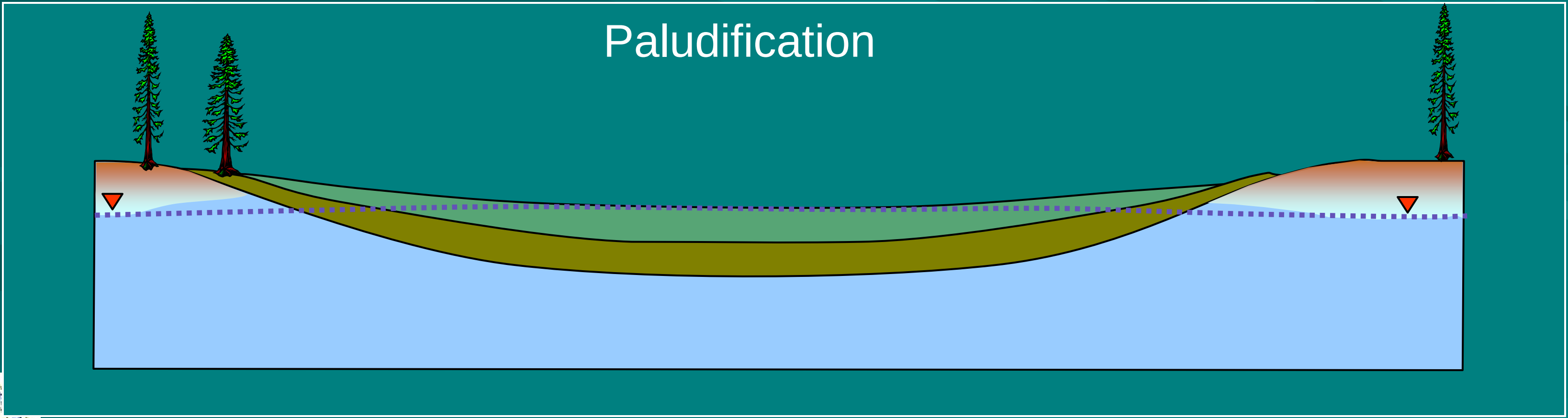
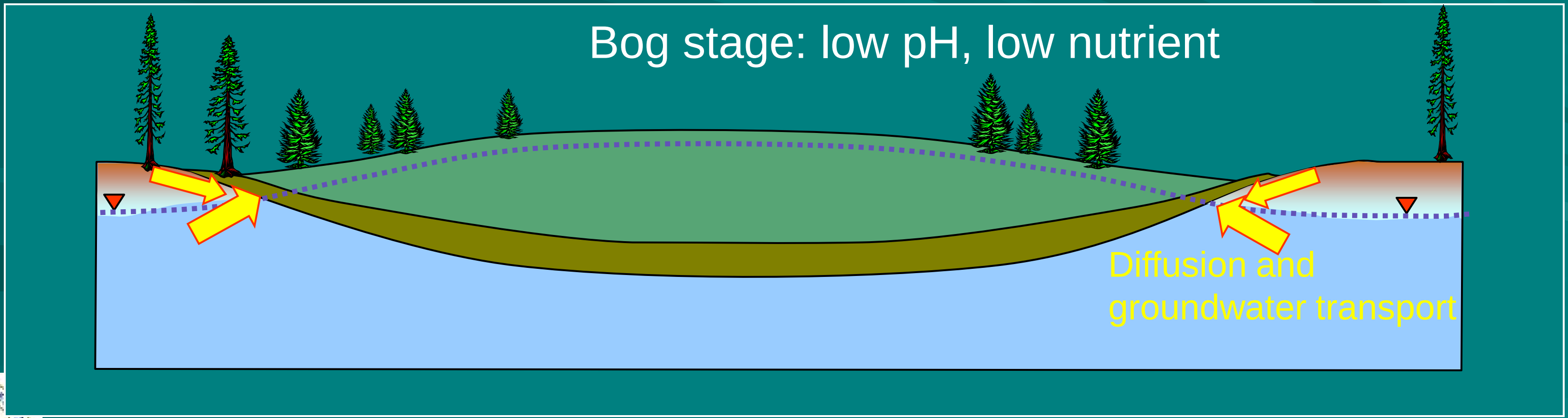
Development of geochemical responses in a peat bog

- External input of elements diminishes



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



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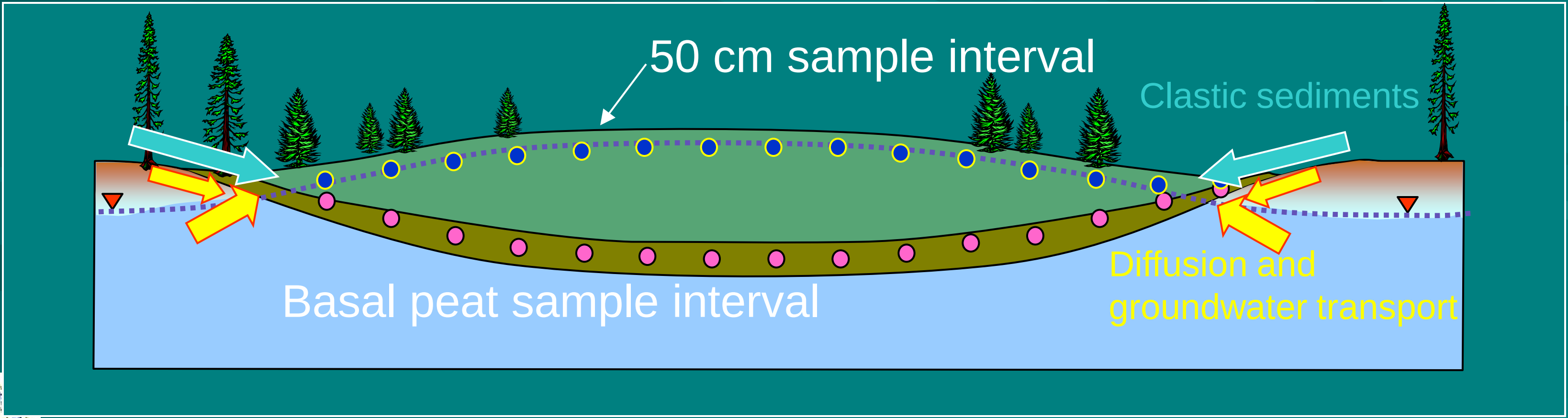
Geochemical responses due to bog “edge effects” in upper and basal peat



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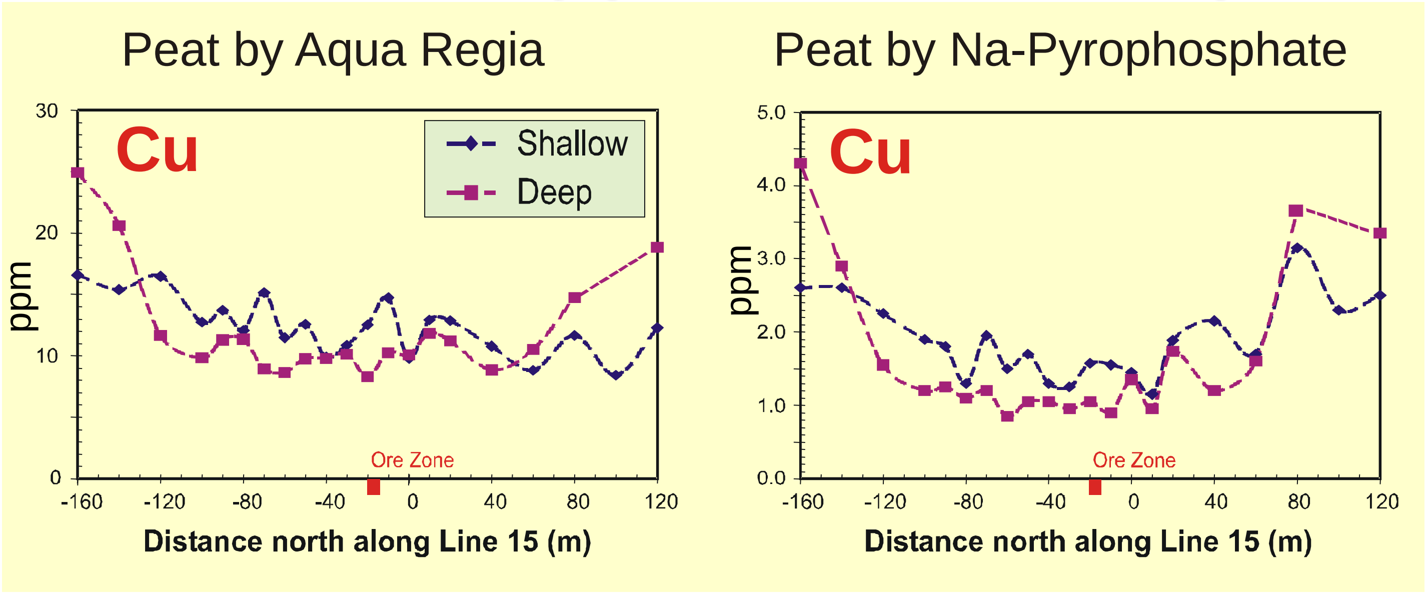

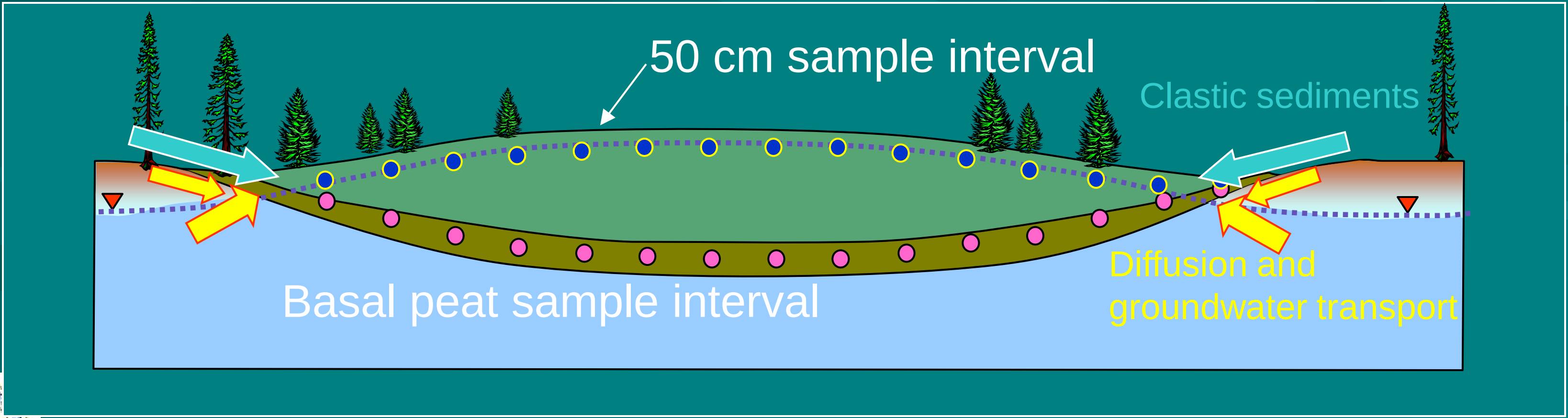

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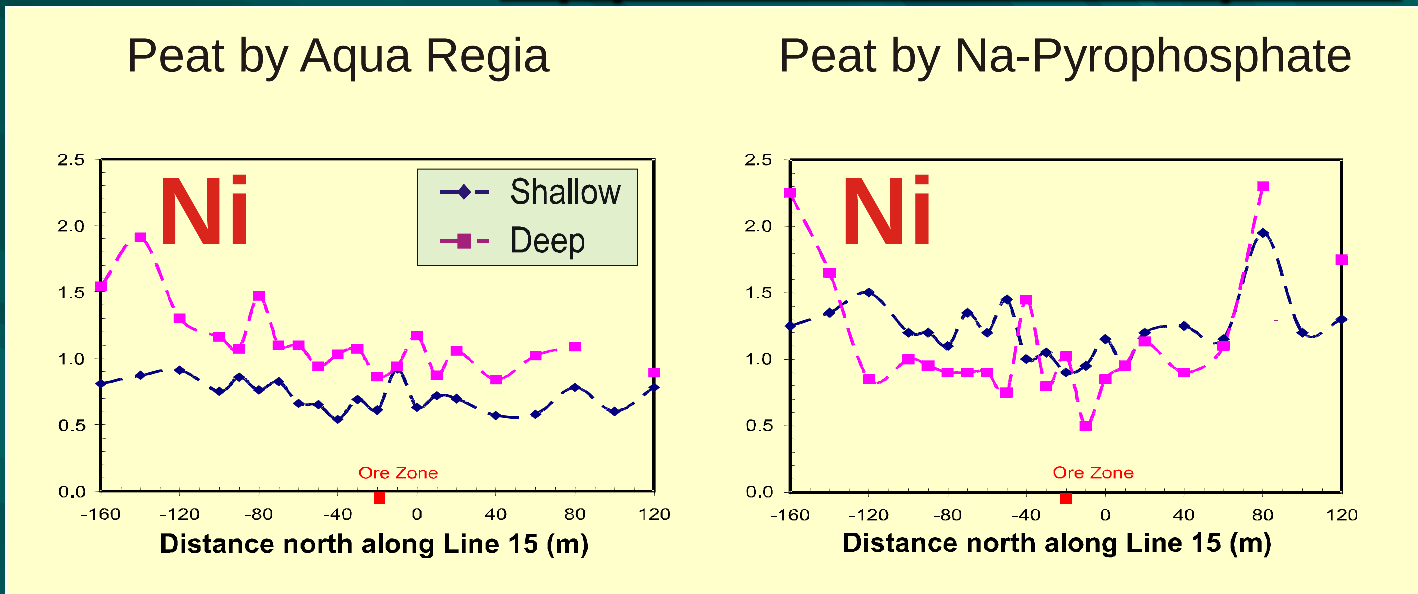

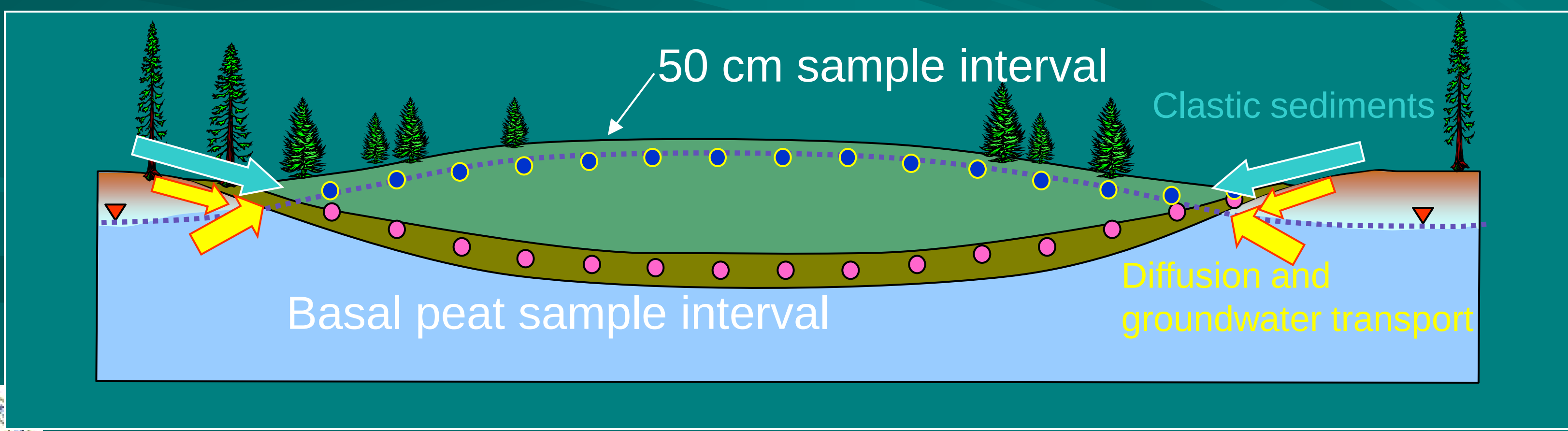

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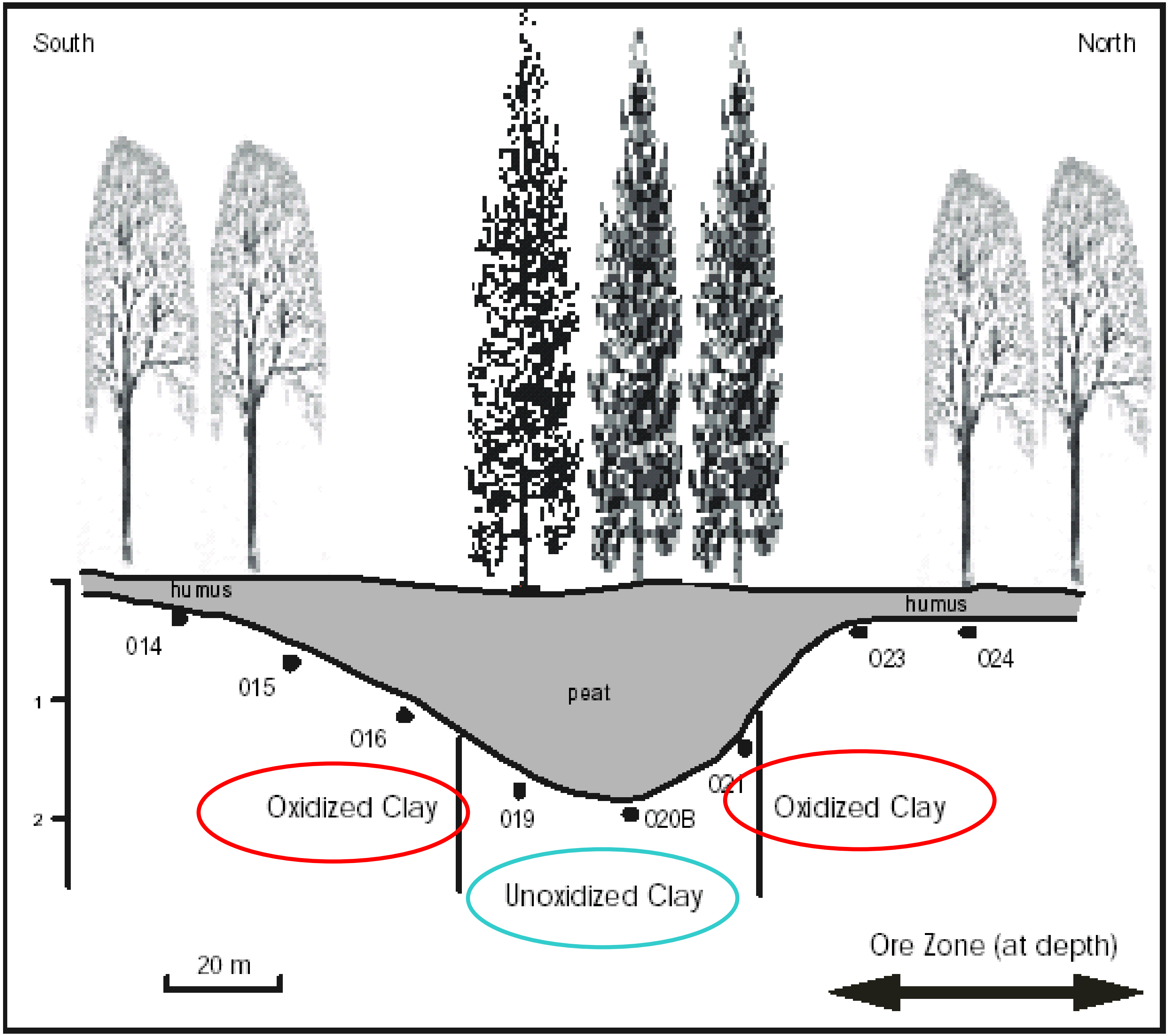
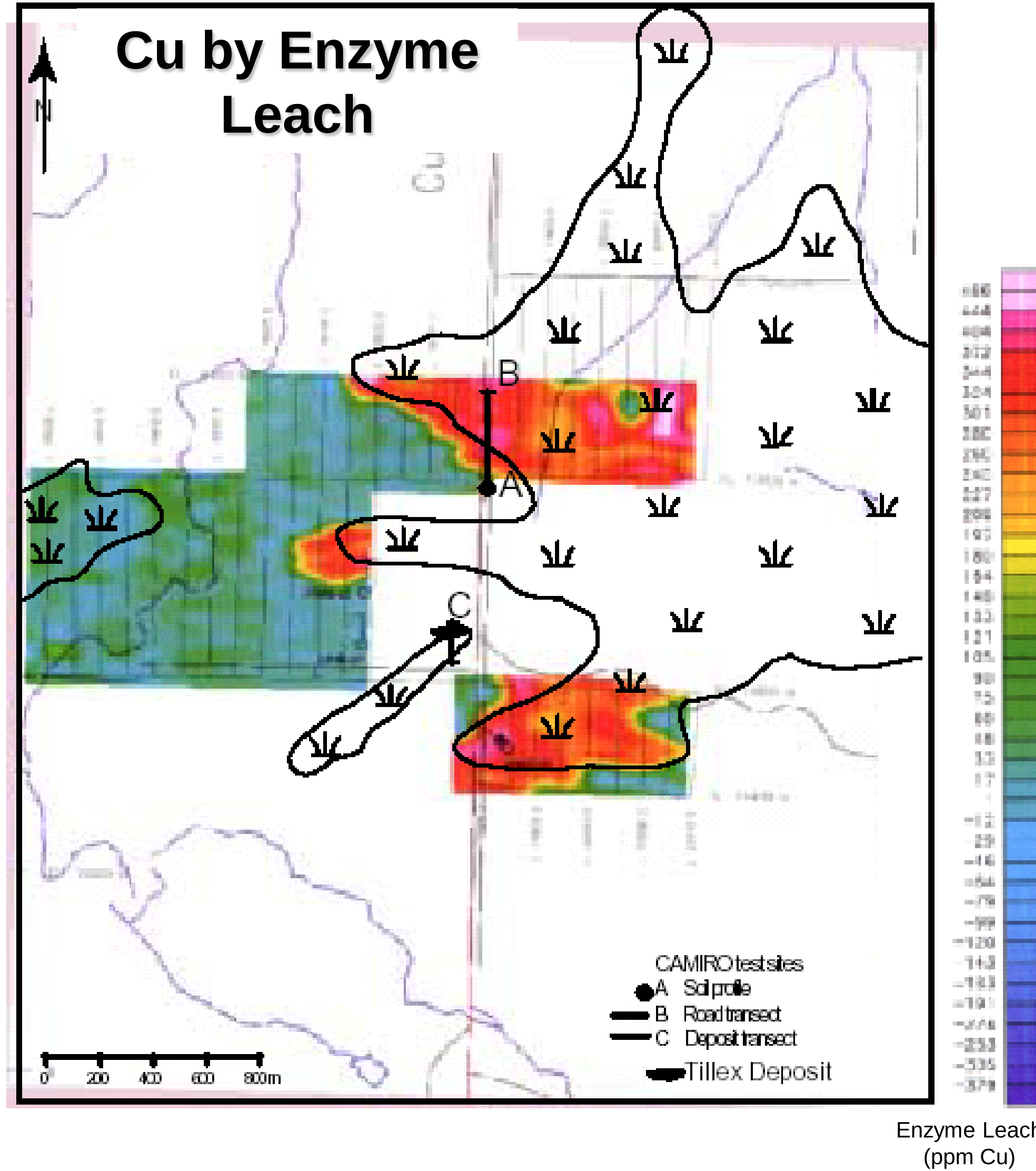
Tillex: Common situation: drastically changing surficial cover

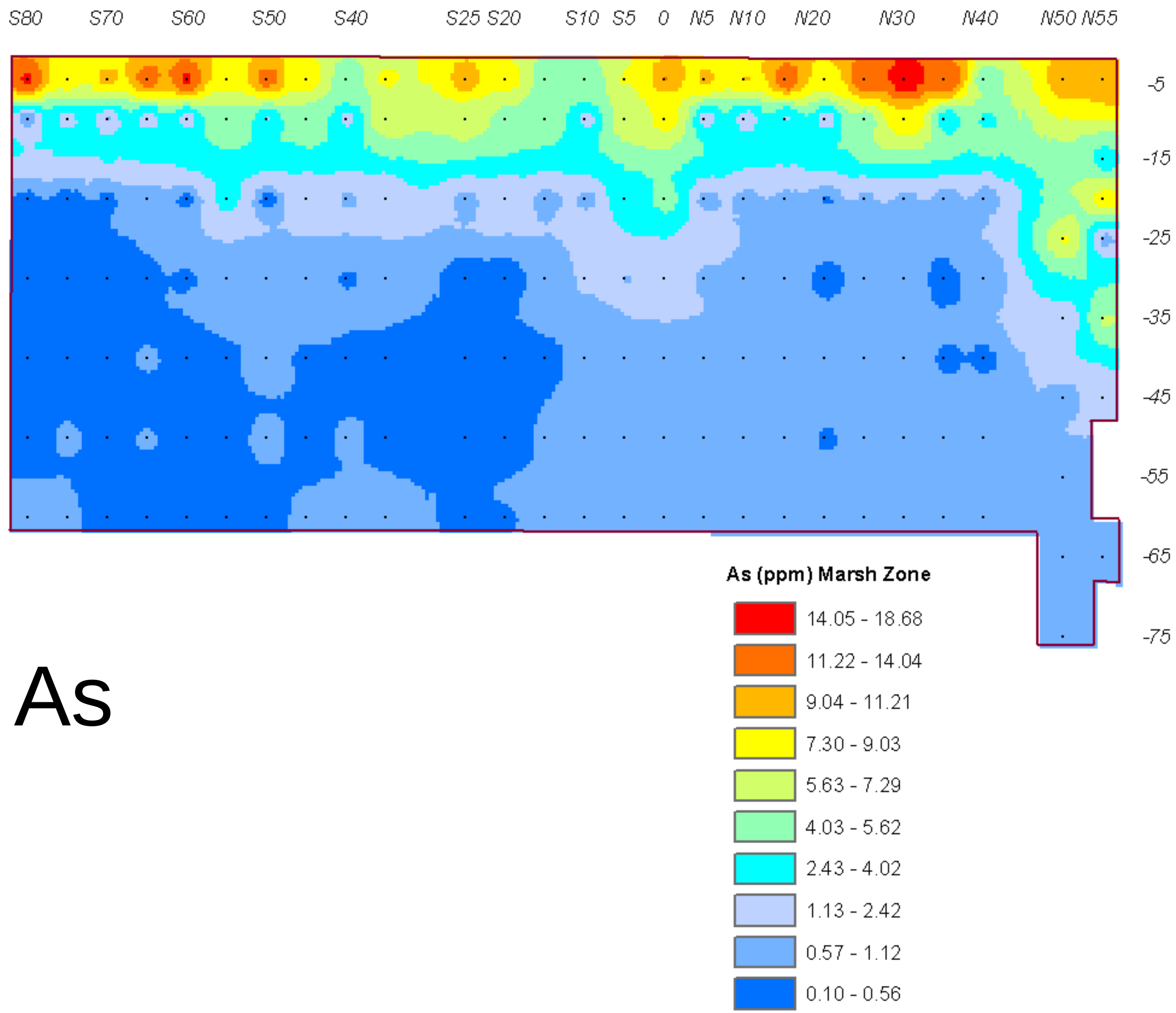


How **NOT** to collect samples

Indiscriminate sampling of uppermost clay results in Cu anomalies related to unweathered clay under the bog



Vertical Metal Zonation in Peat



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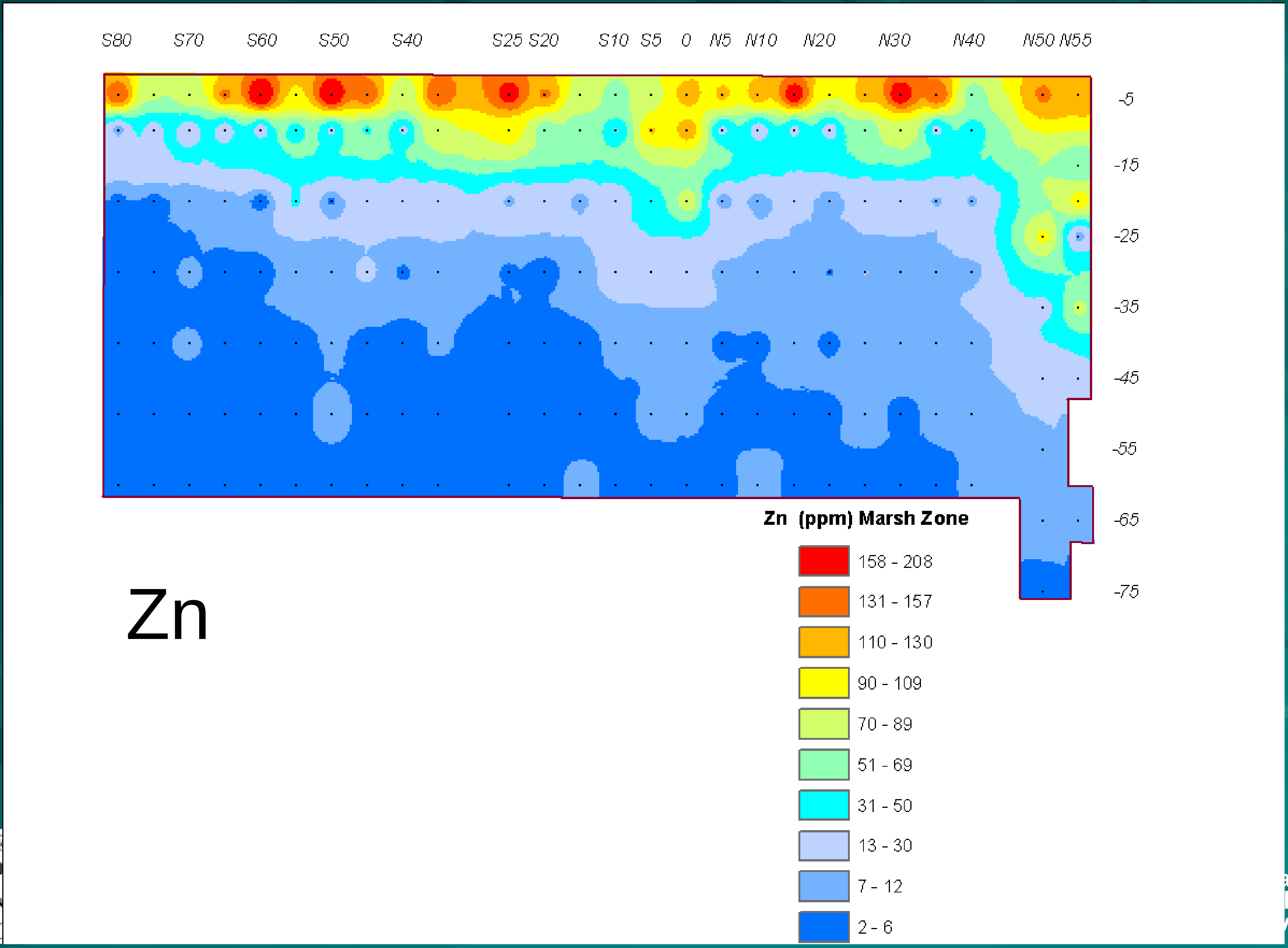
Vertical Metal Zonation in Peat



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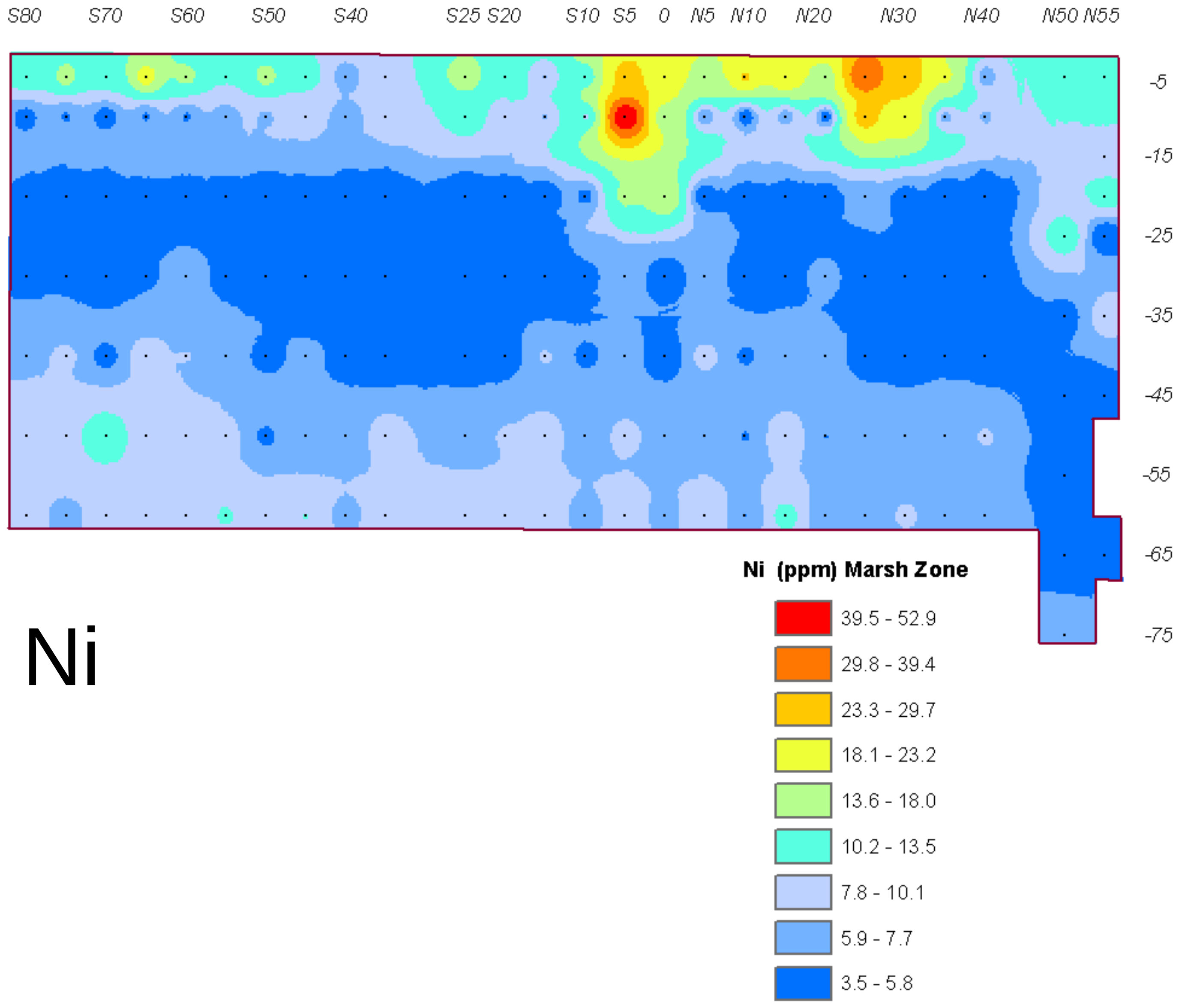
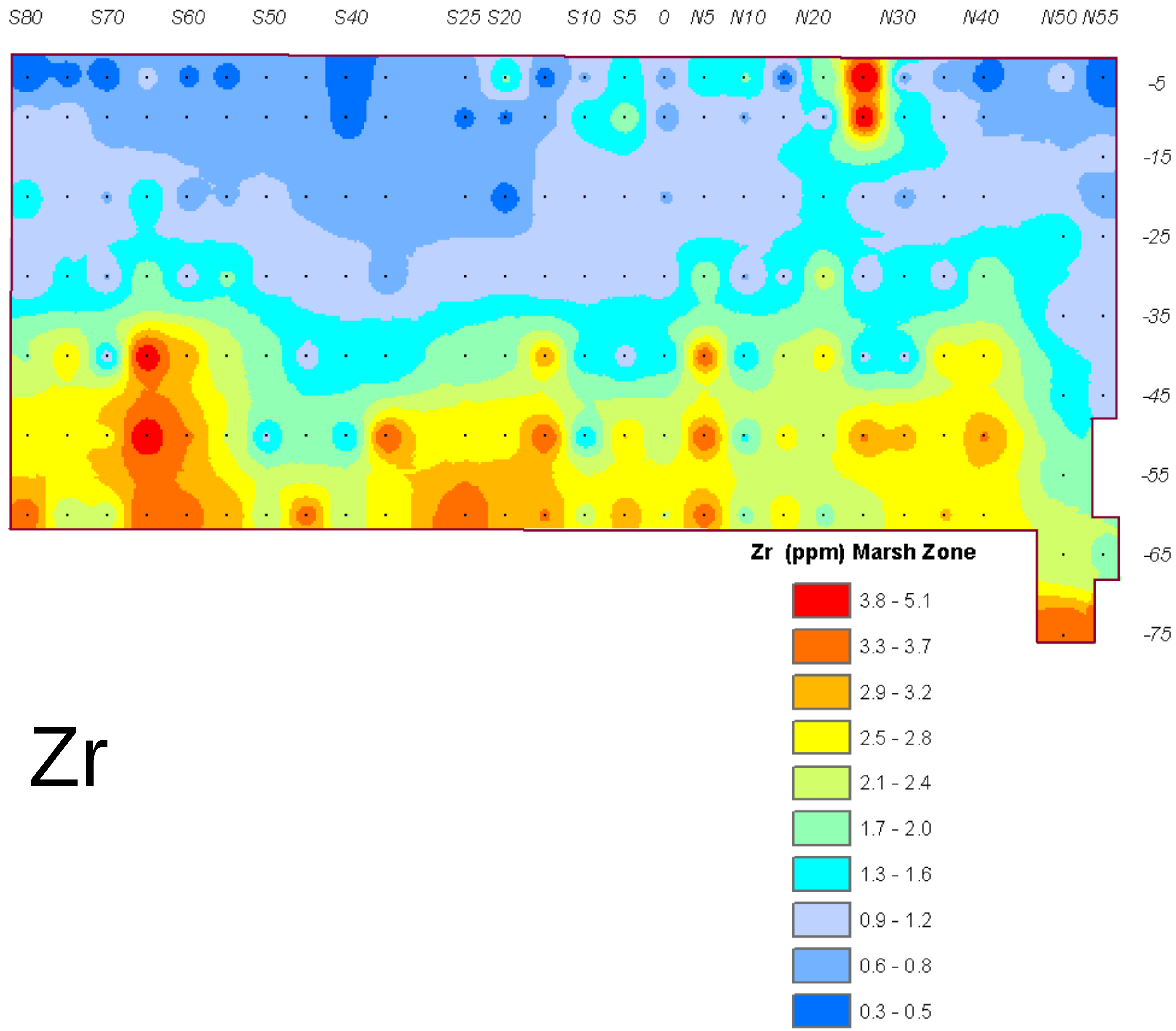
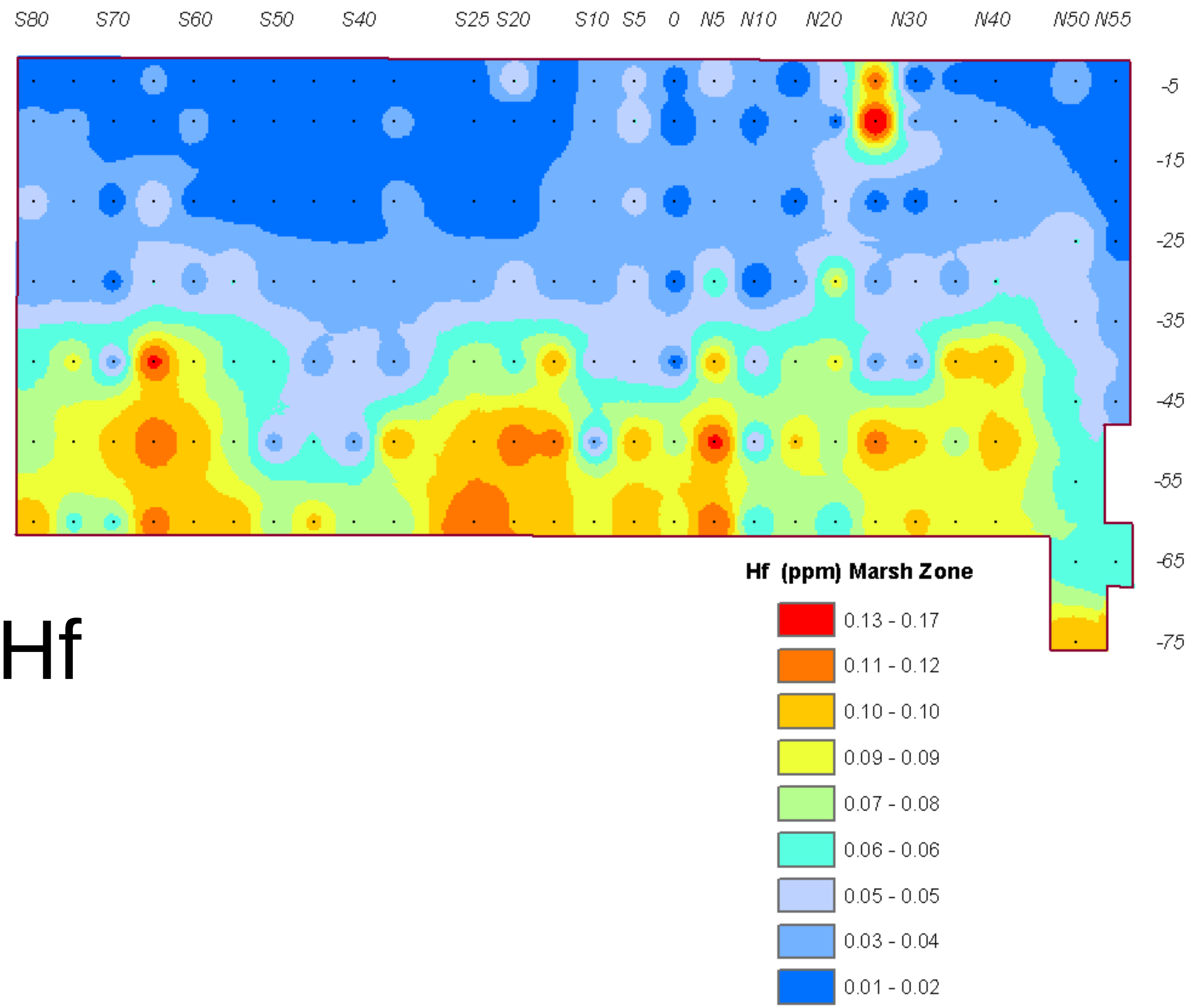


Vertical Metal Zonation in Peat



Zr

Vertical Metal Zonation in Peat



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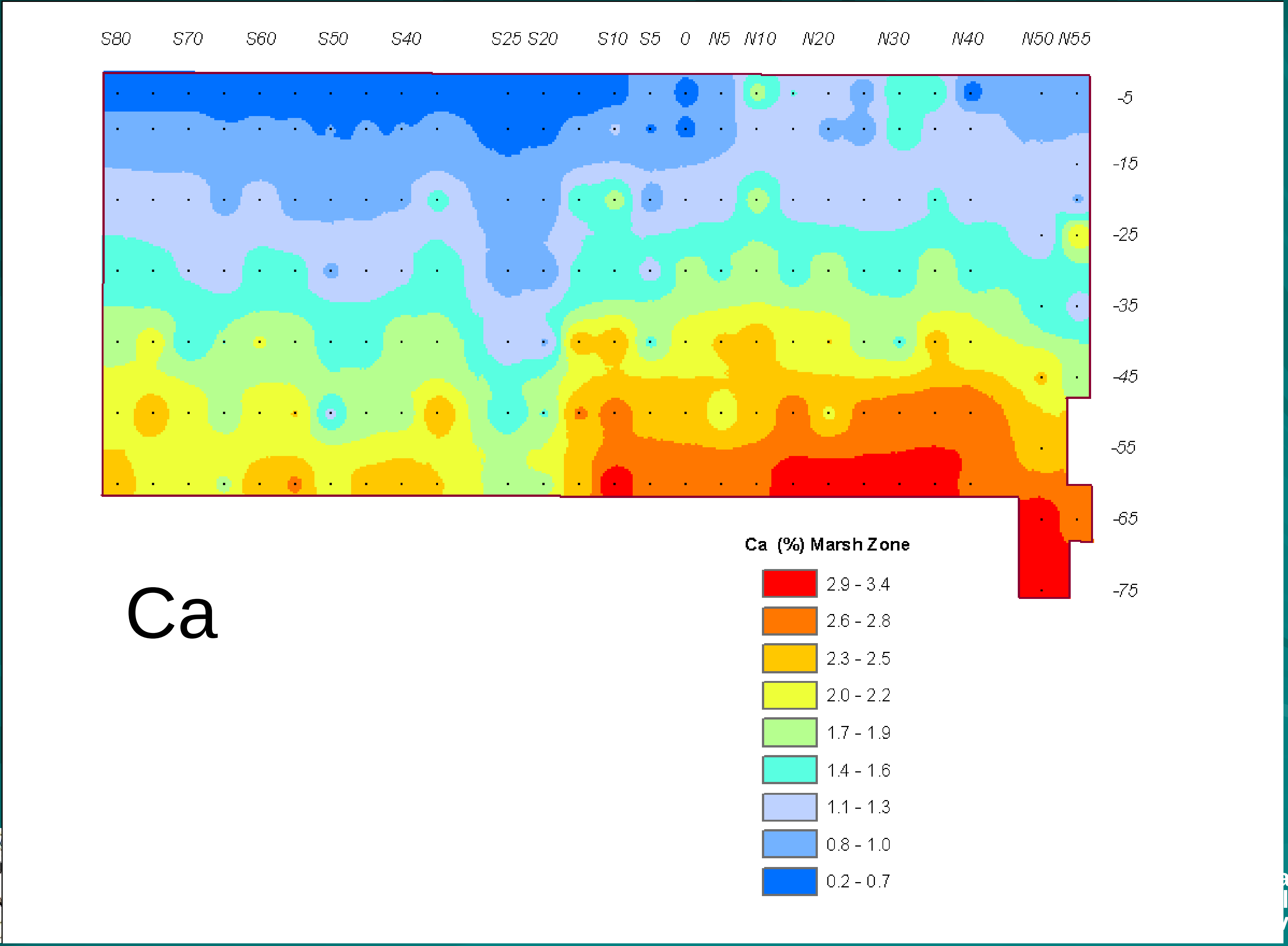
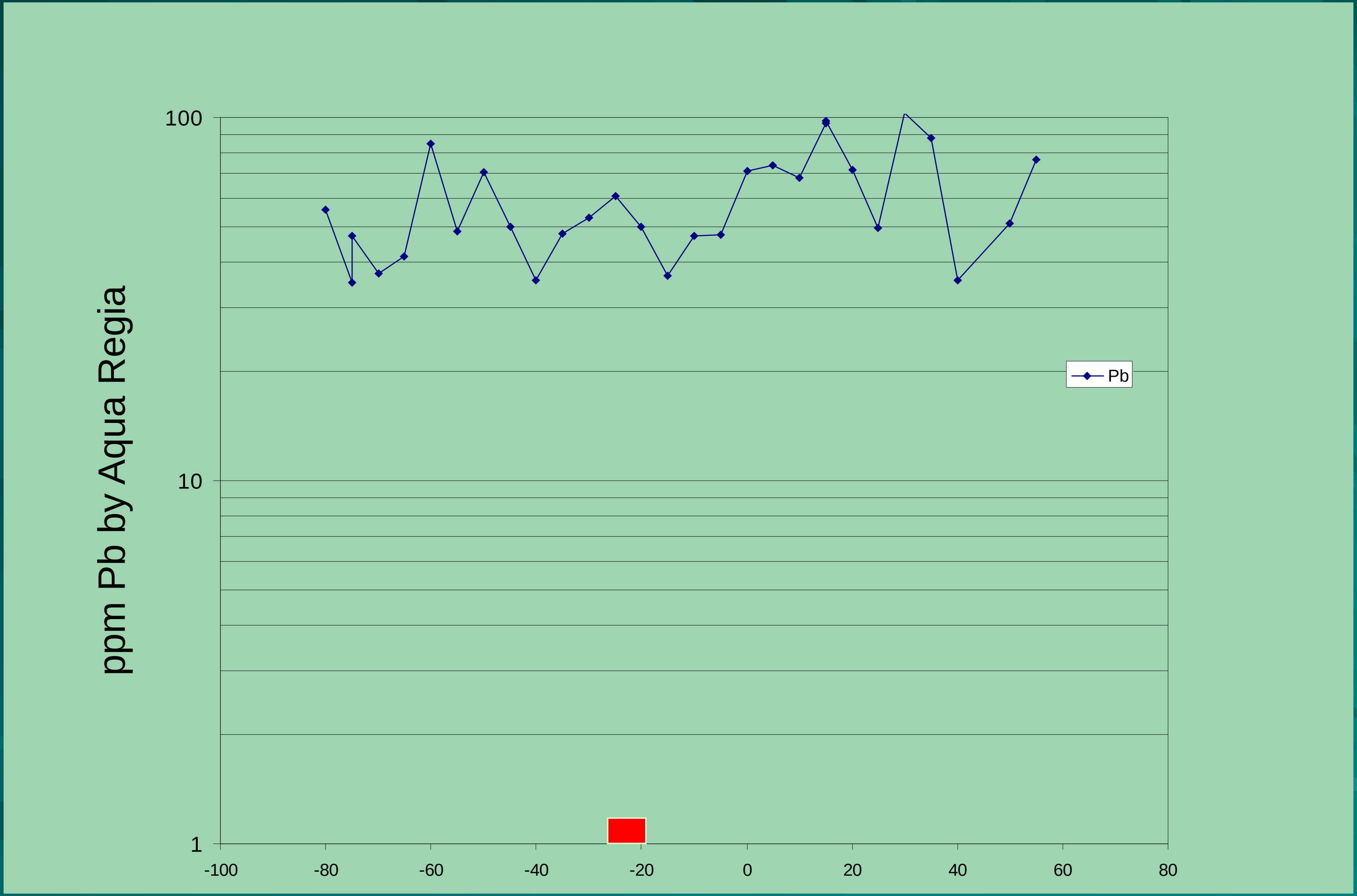
Vertical Metal Zonation in Peat



Pb at MZ - 5 cm depth



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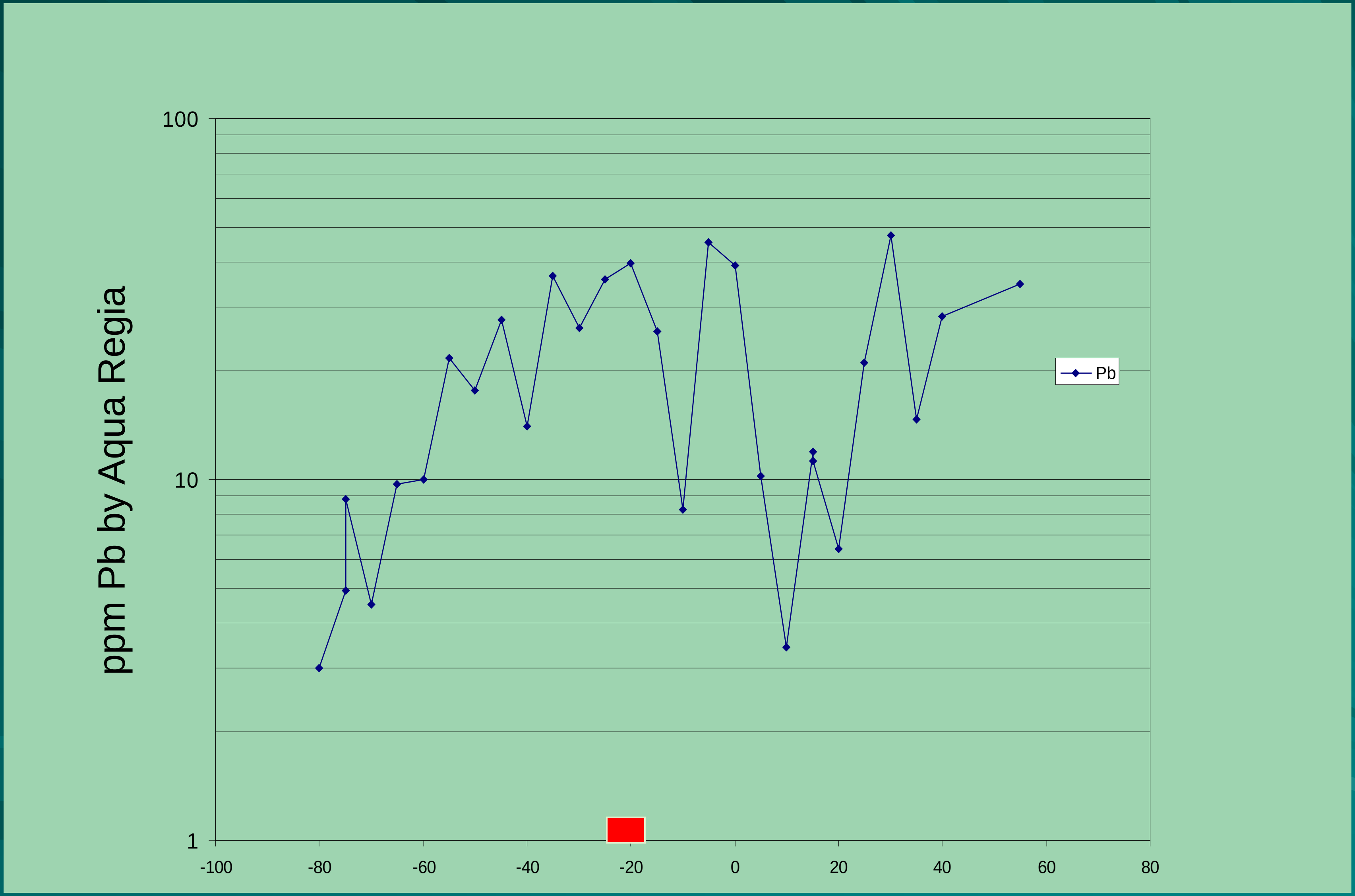
Pb at MZ - 10 cm depth



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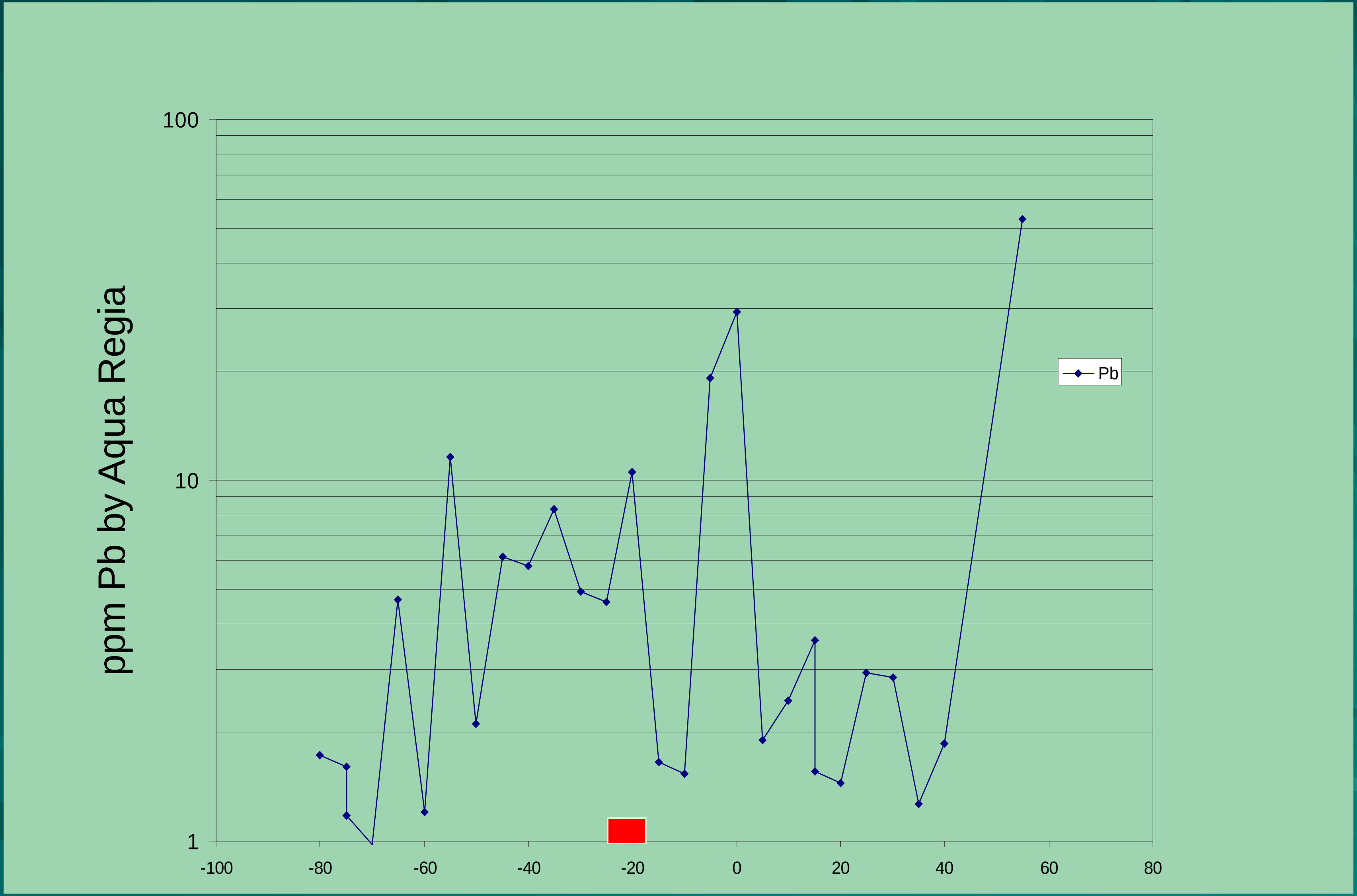
Pb (AR, ppm) at MZ - 20 cm depth



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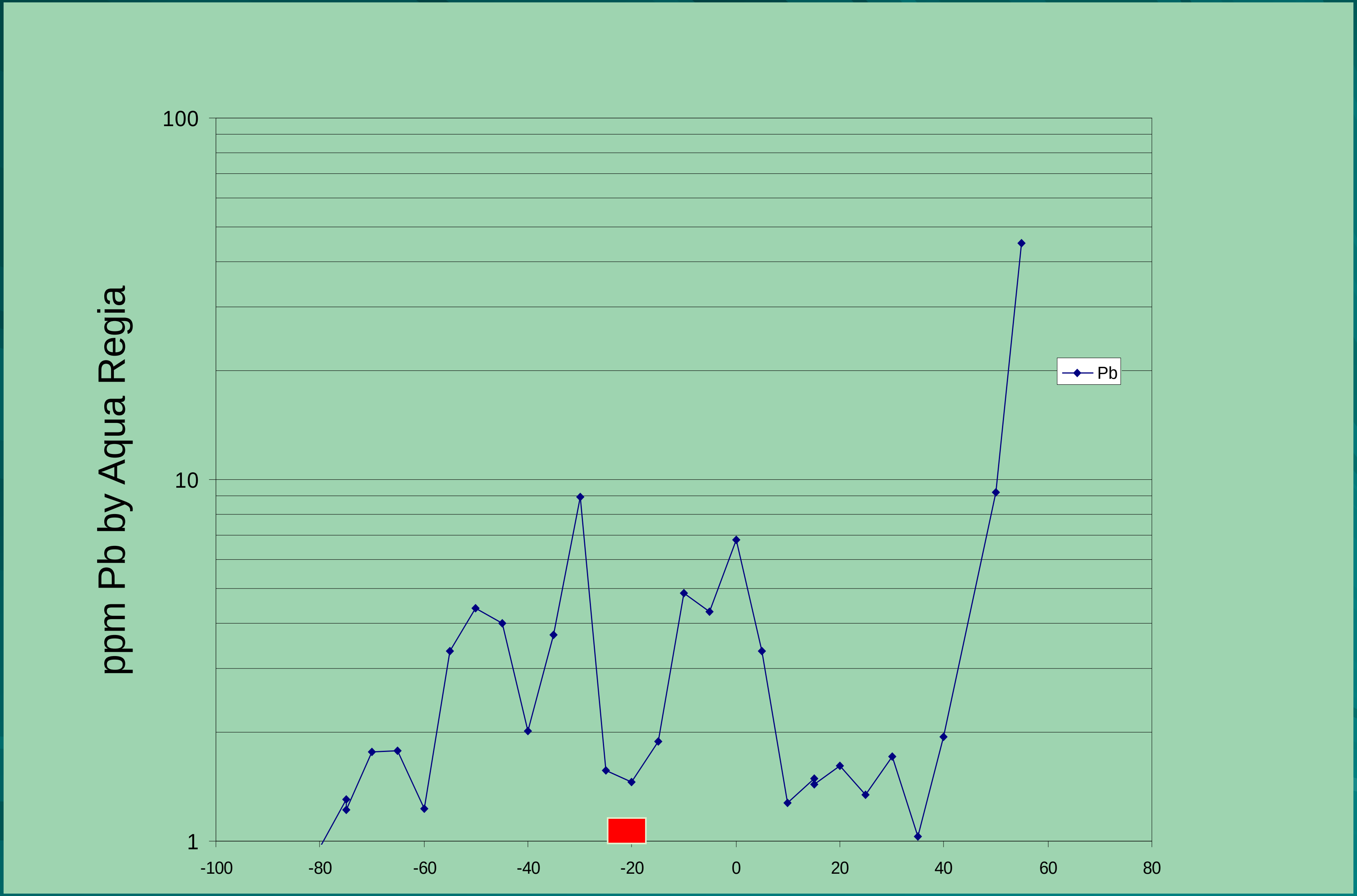
Pb at MZ - 30 cm depth



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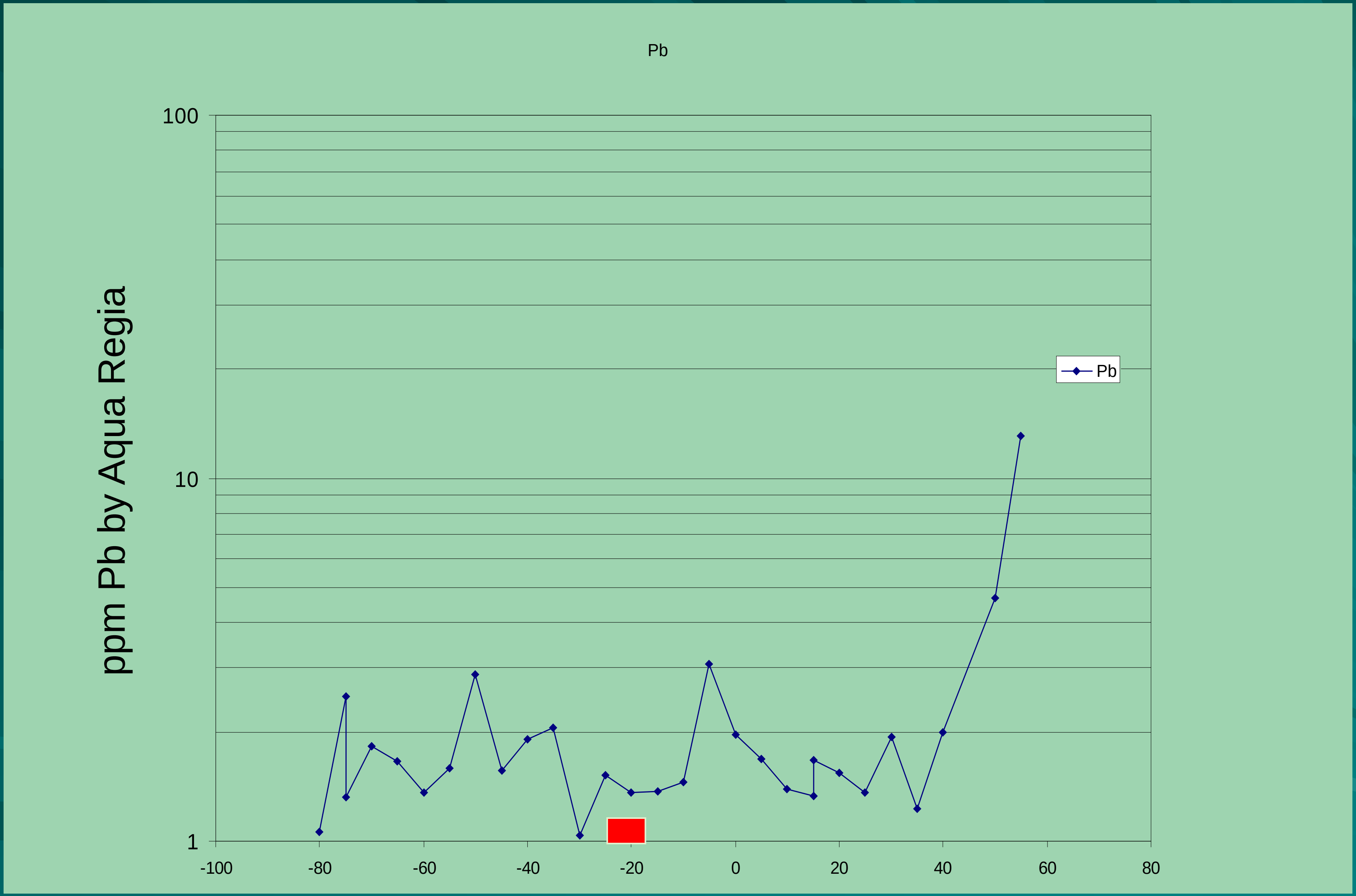
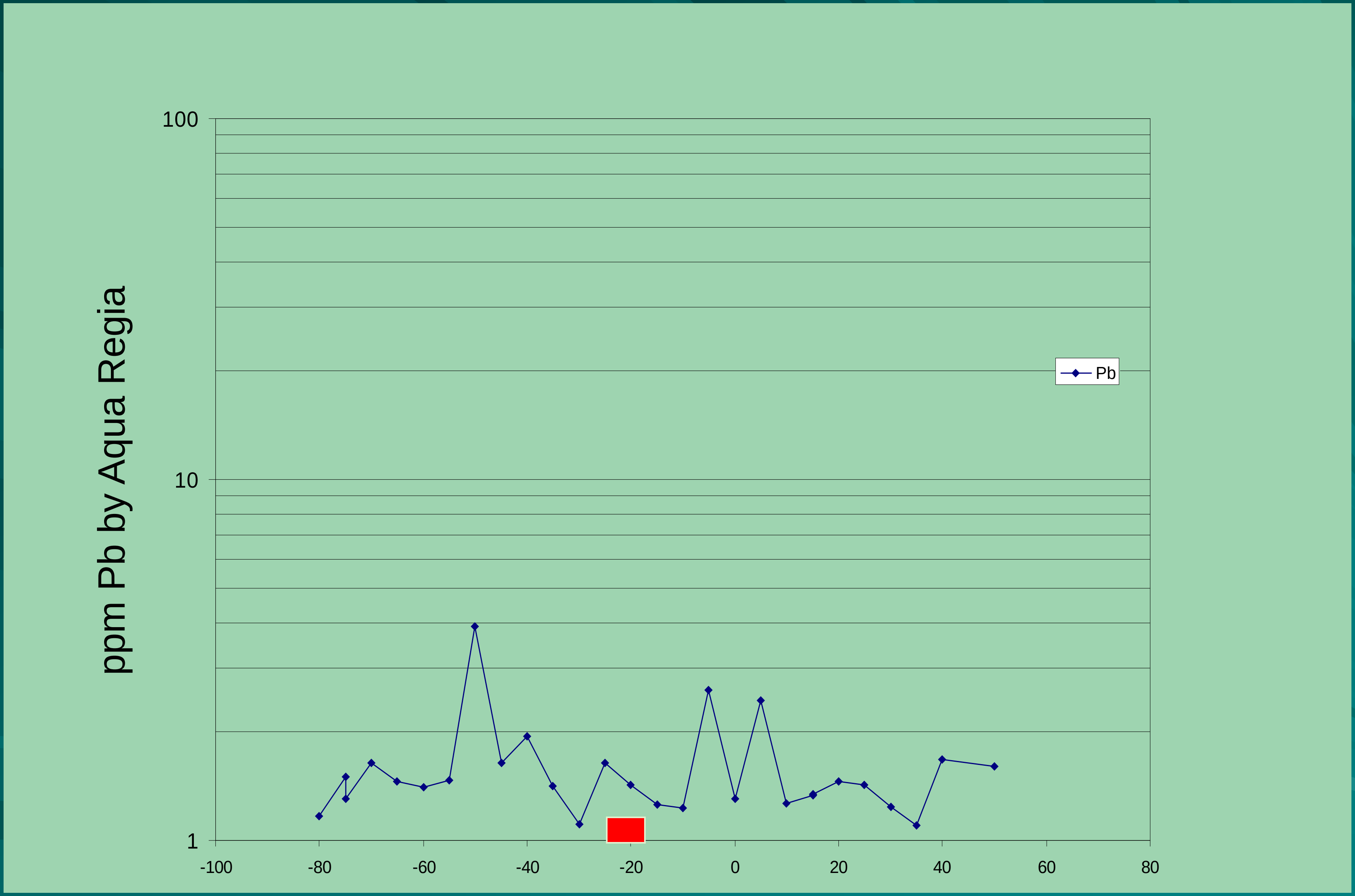
Pb at MZ - 40 cm depth



Pb at MZ - 50 cm depth



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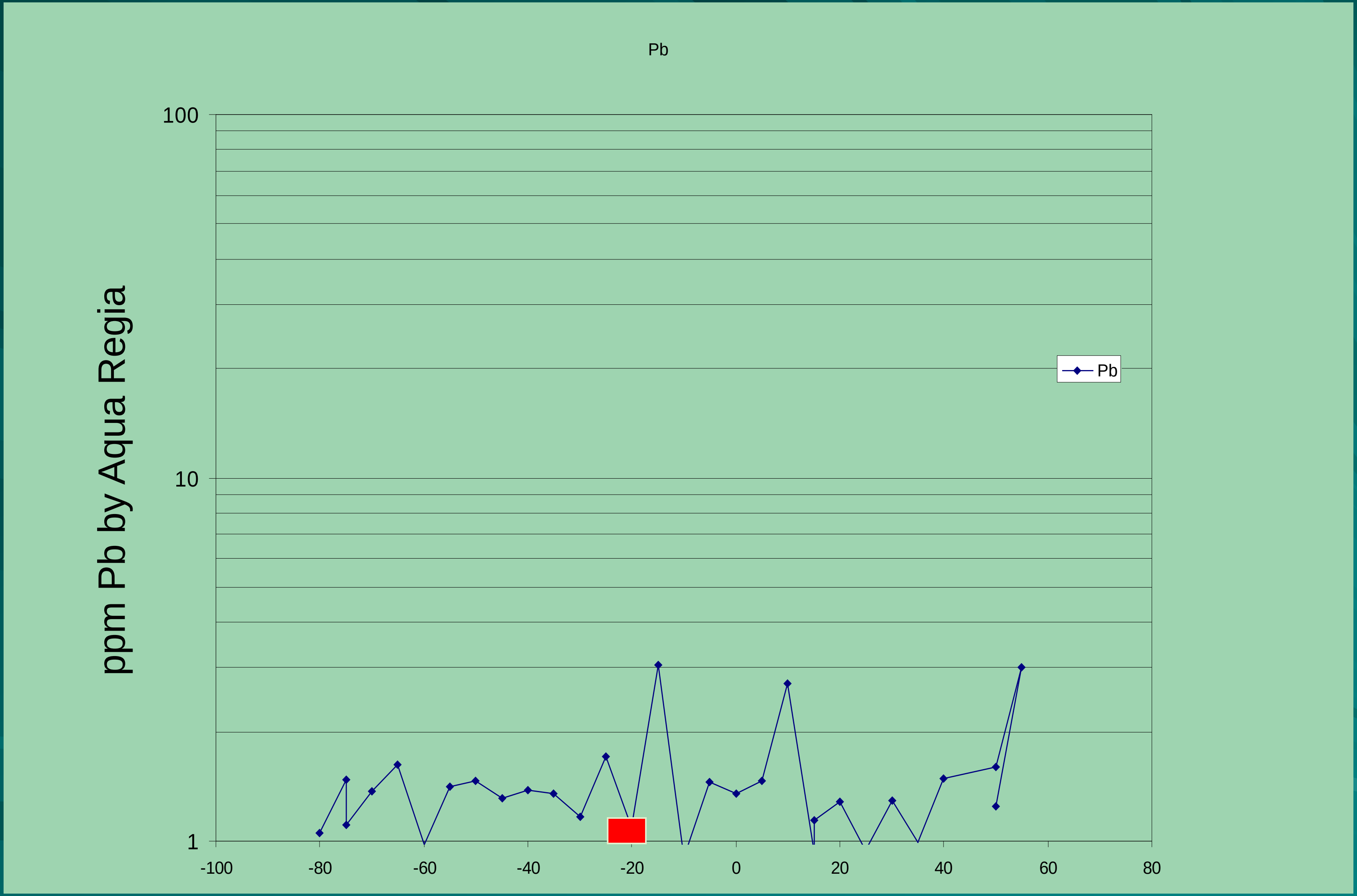
Pb at MZ - 60 cm depth



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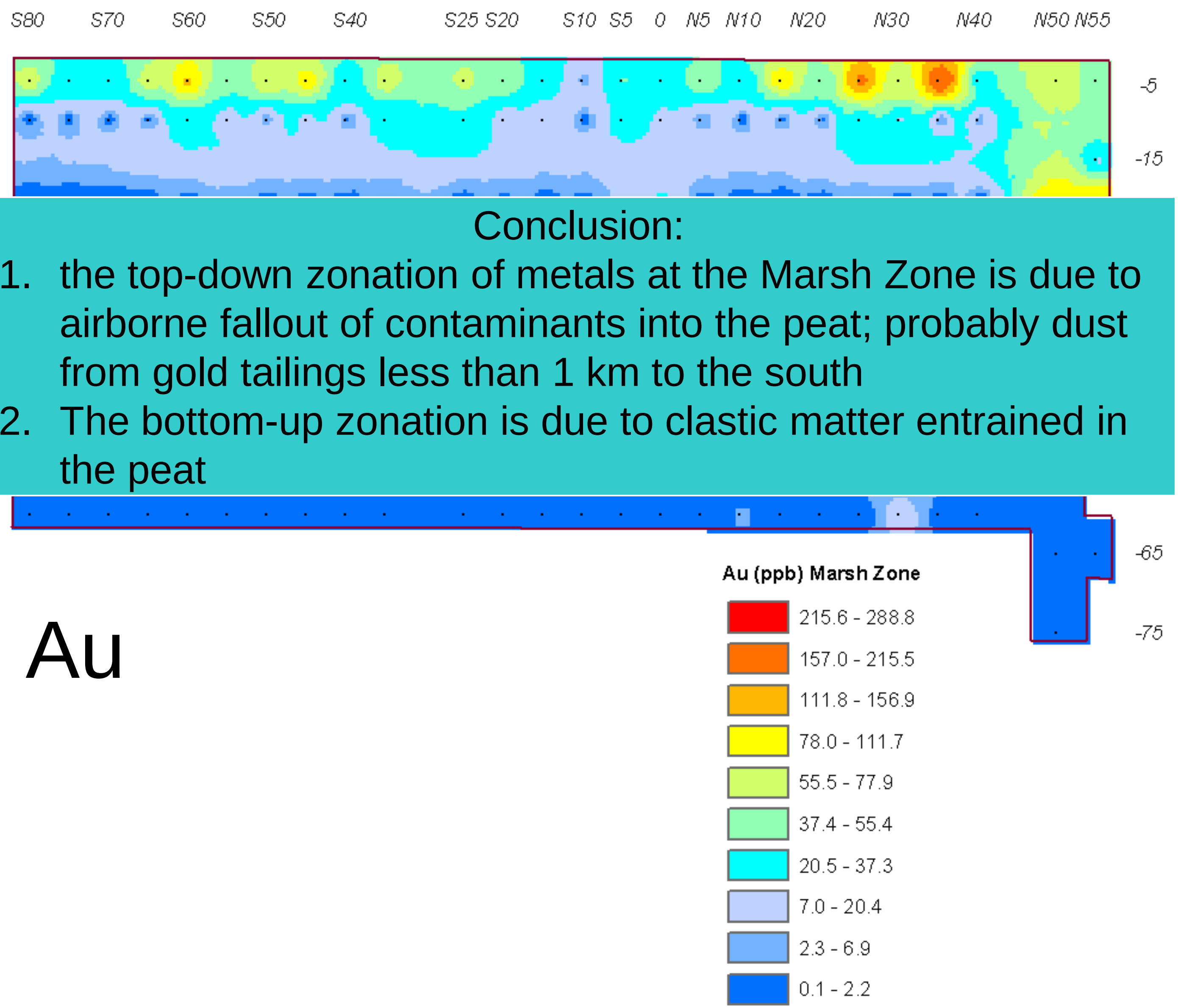
Vertical Metal Zonation in Peat



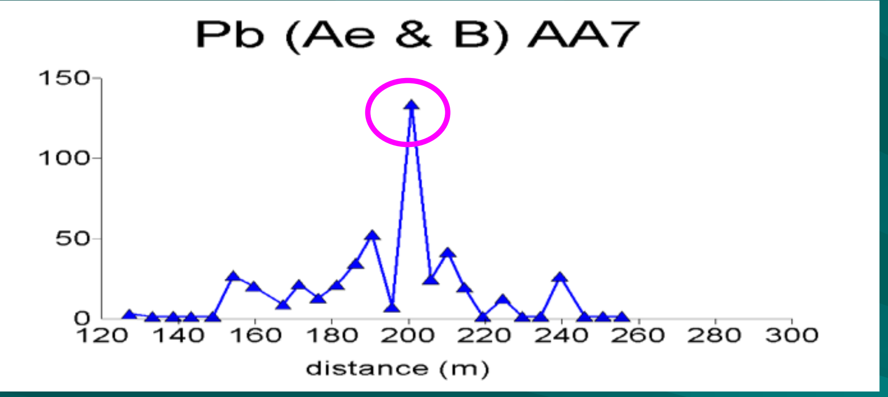
Conclusion:

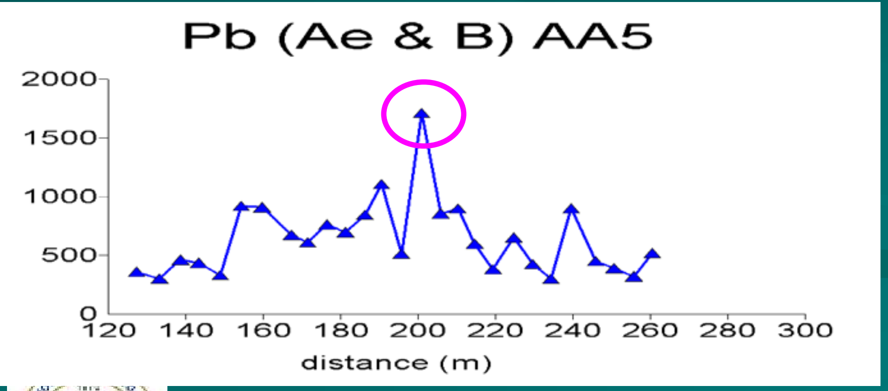
1. the top-down zonation of metals at the Marsh Zone is due to airborne fallout of contaminants into the peat; probably dust from gold tailings less than 1 km to the south
2. The bottom-up zonation is due to clastic matter entrained in the peat

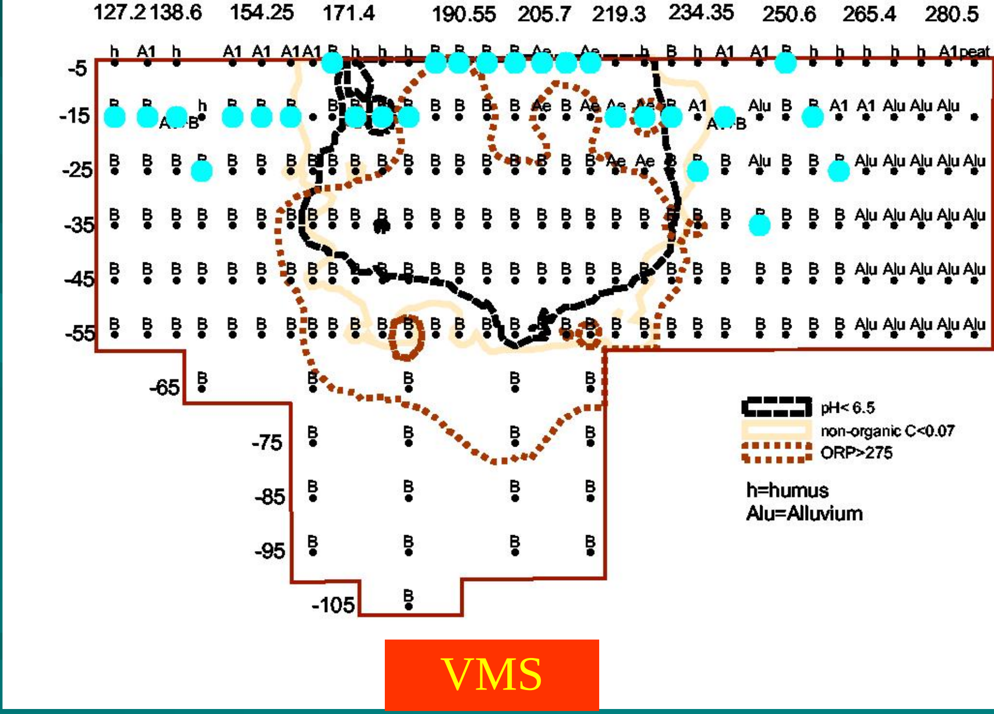
Au

Determining source of Pb anomalies using isotopes

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







30 m

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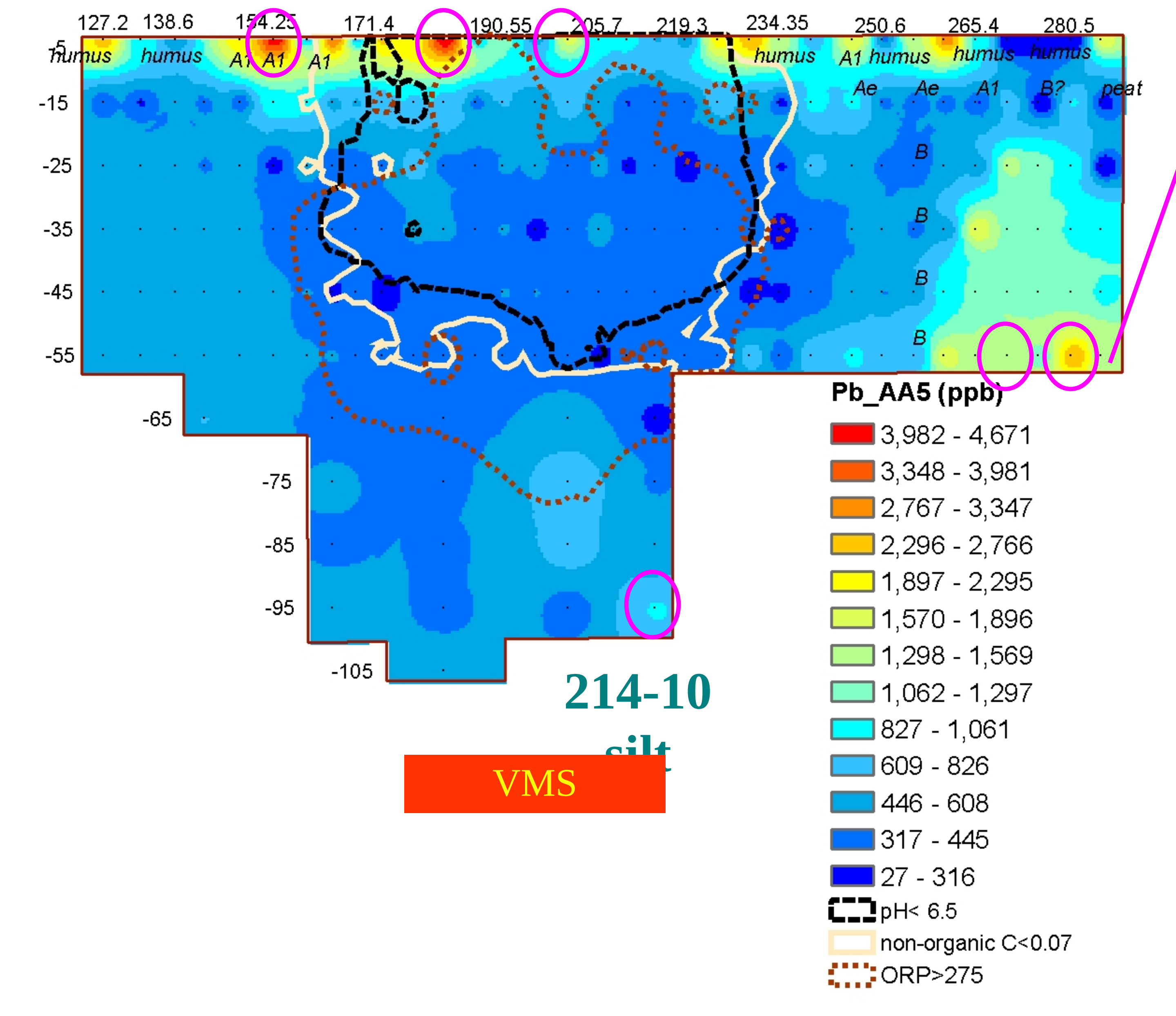
154-1 A1 181-1 H **200-1 Ae**

Unoxidised clay in alluvial area, 270 and 280-6



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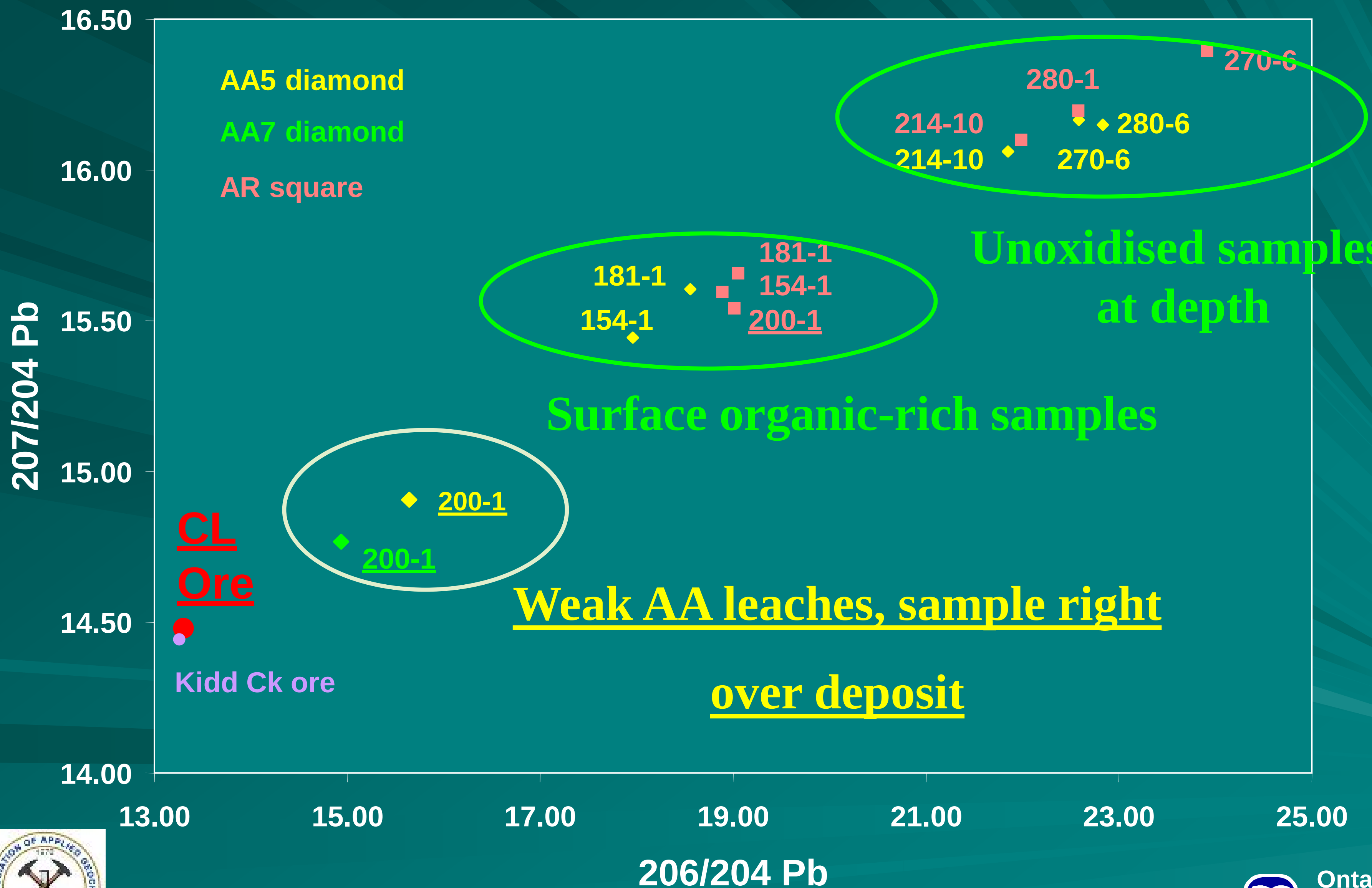
Pb isotopes, Line 6



ublished GSC/OGS data

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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.)

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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

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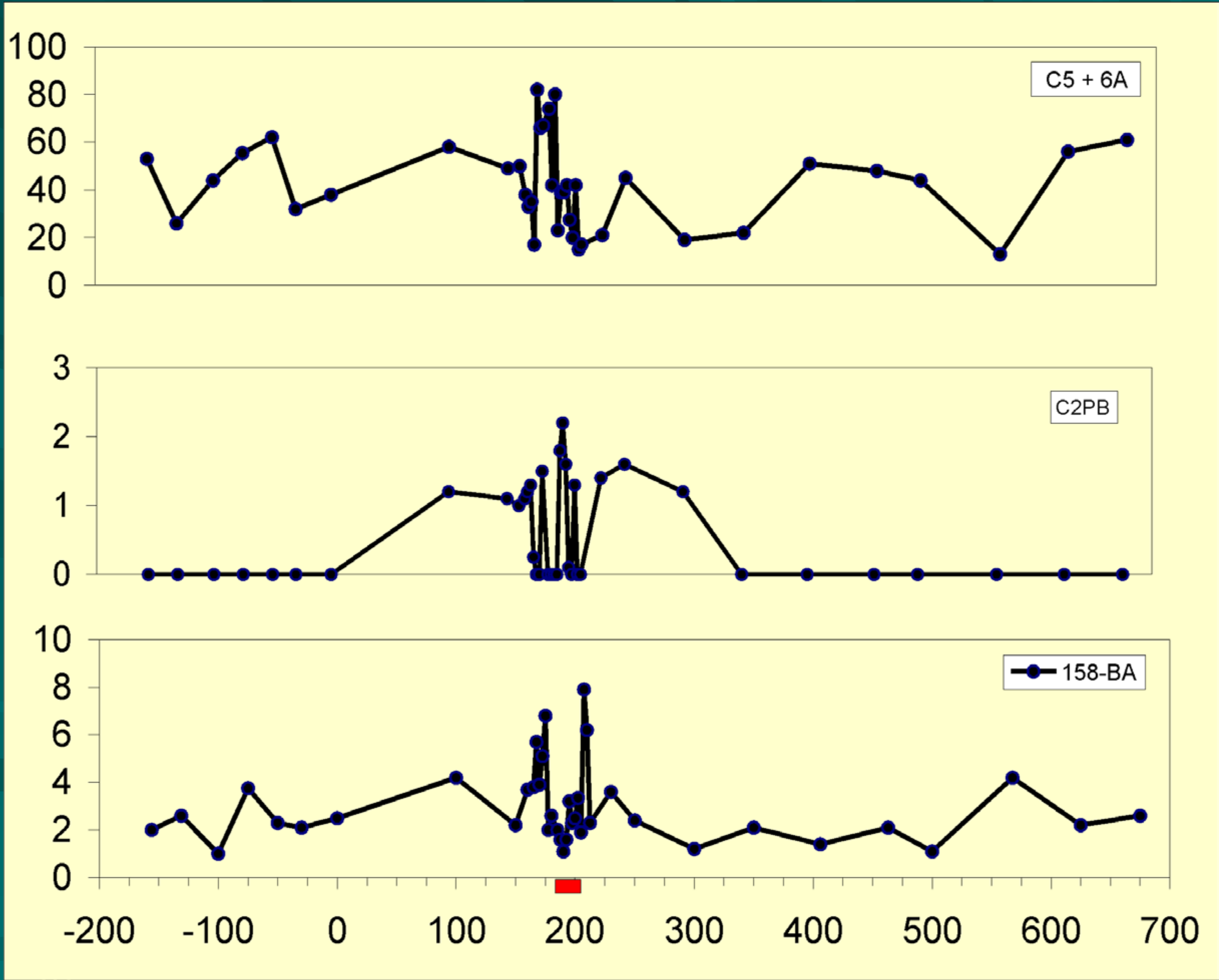
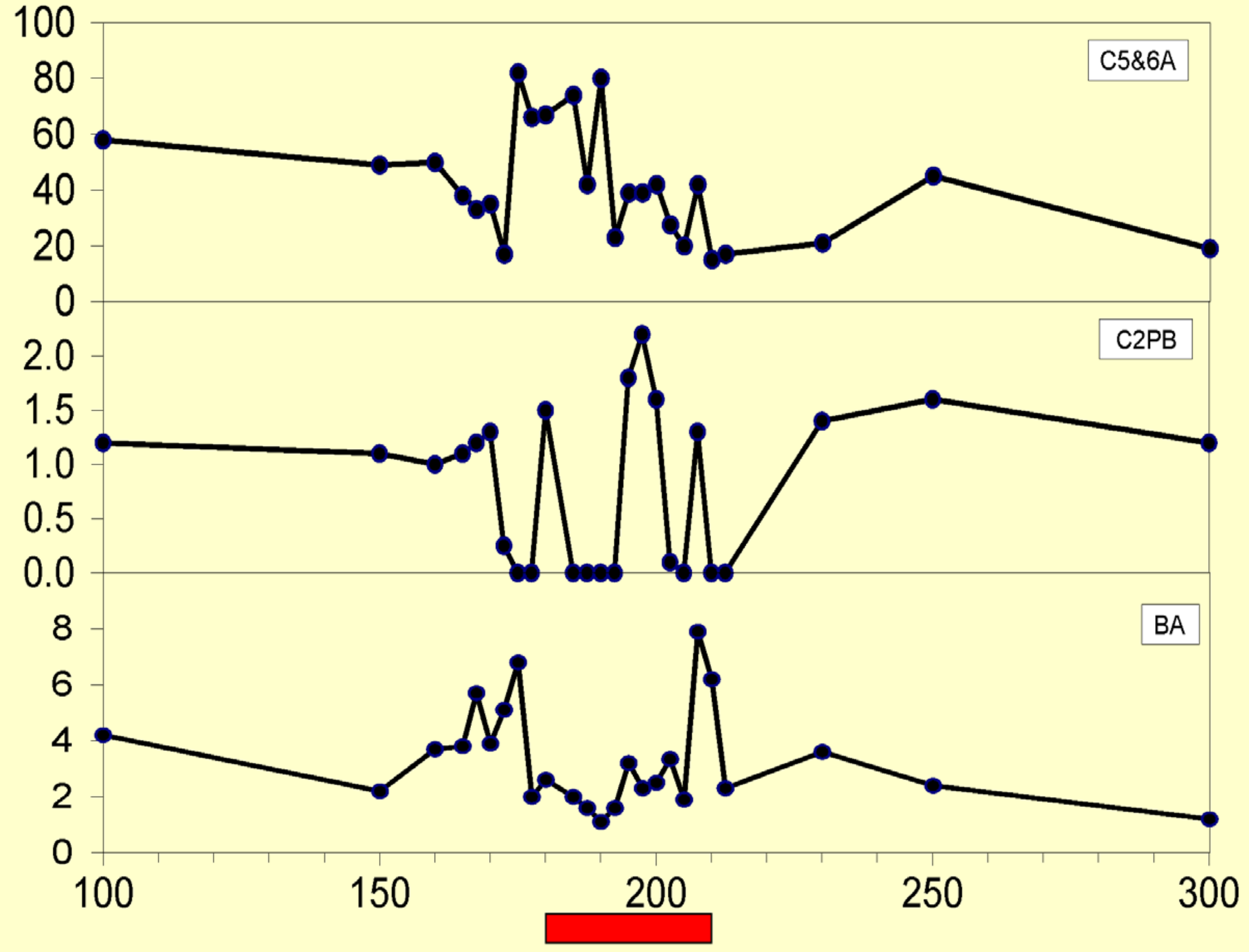
Soil Gas Hydrocarbons

Cross Lake
Line 6

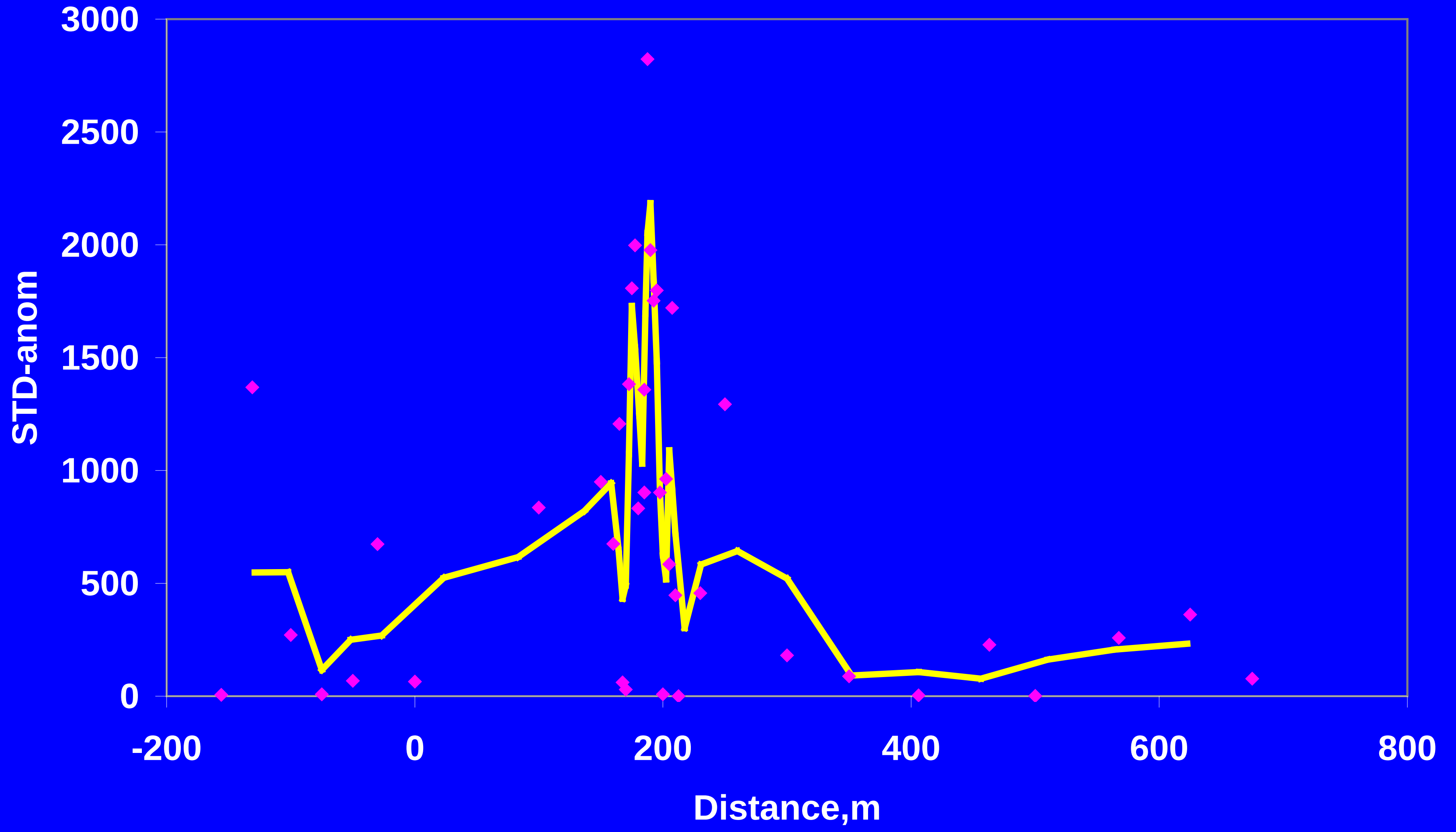


Soil Gas Hydrocarbons

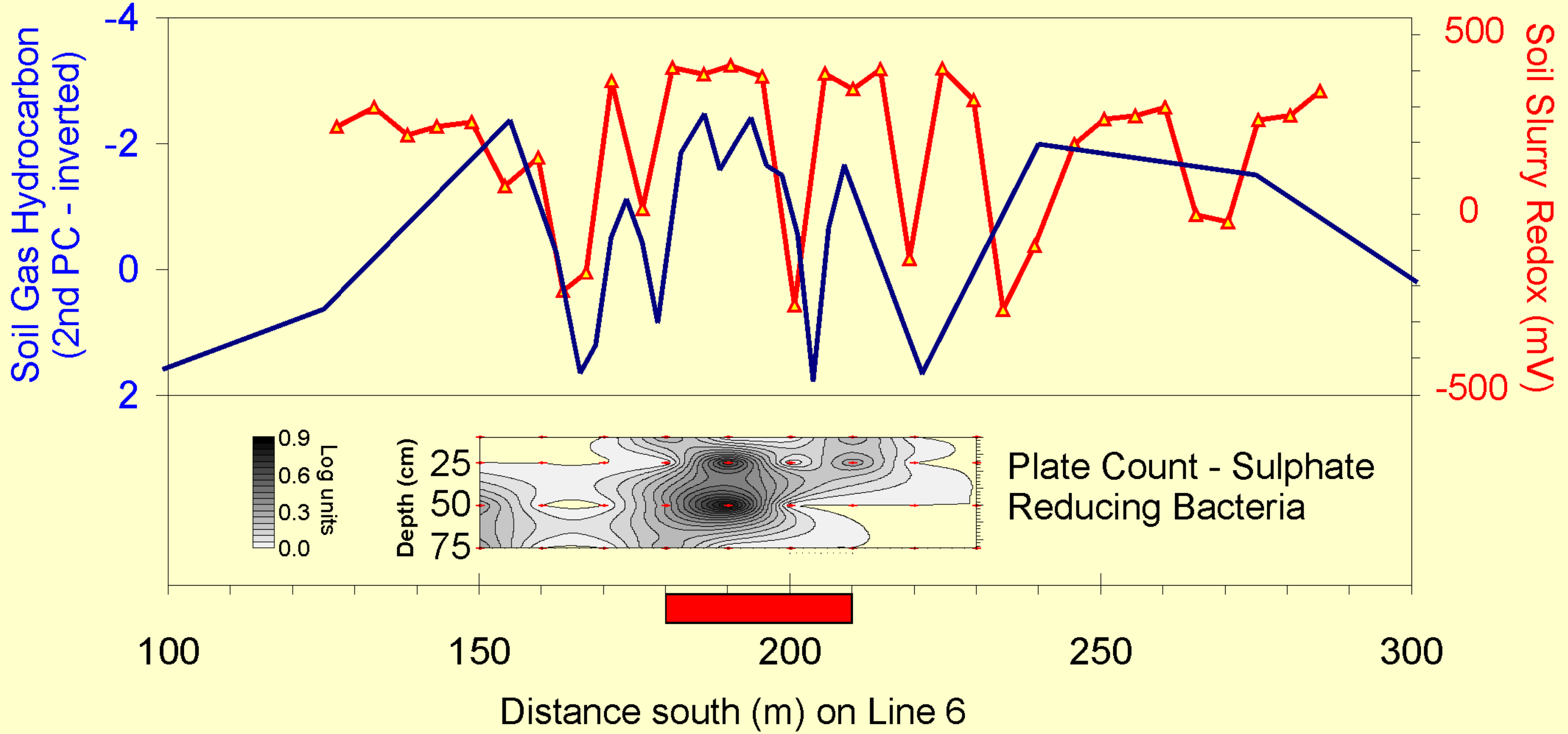
Cross Lake
Line 6
(expanded)



SDP, Line 6, anom



SGH & Redox



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The source of hydrocarbons

- Hydrocarbon anomalies correlate with:
  - Mineralization (spatially)
  - Reduced chimneys (spatially)
  - Redox variation
  - pH anomalies in soil
  - O_2 depletions / CO_2 enrichments in soil gas
  - Organic carbon depletions
  - Metal enrichments
  - Increased bacterial populations

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The source of hydrocarbons

- 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 <u>an excellent proxy for redox</u>

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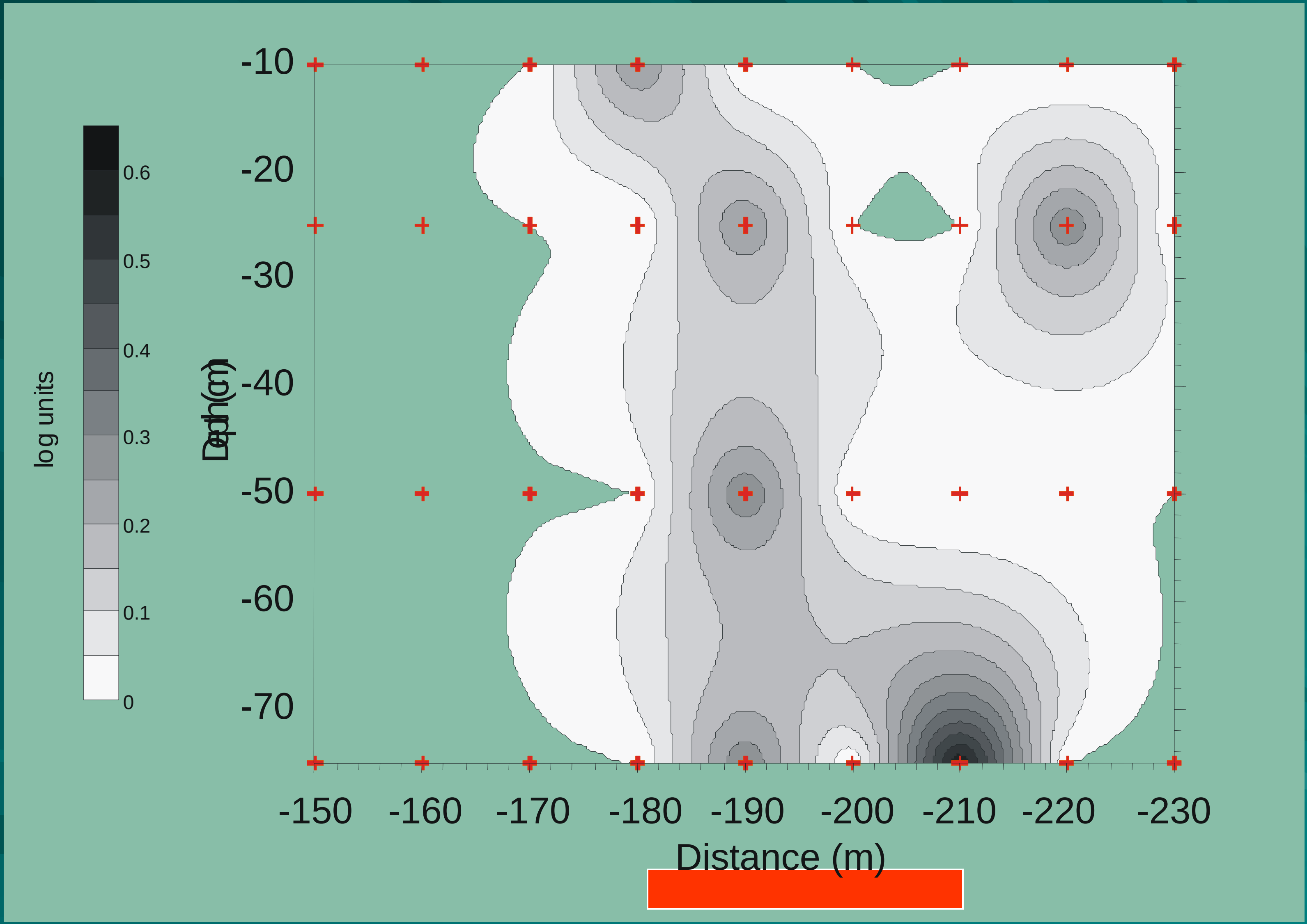
SRBs - Cross Lake - 14 m from line



Slide courtesy of Gordon Southam

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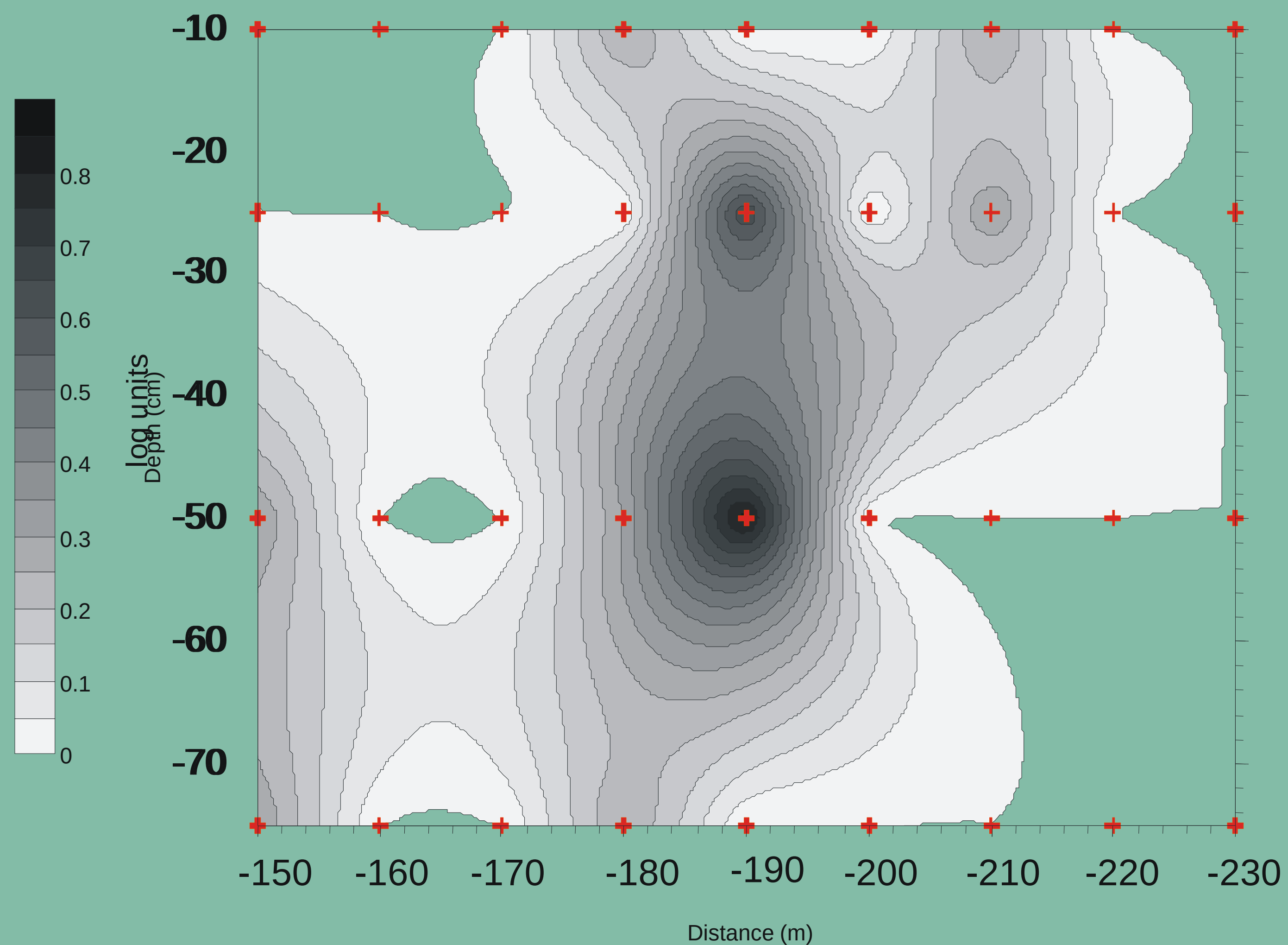
SRBs - Cross Lake - 12 m from line



Slide courtesy of Gordon Southam

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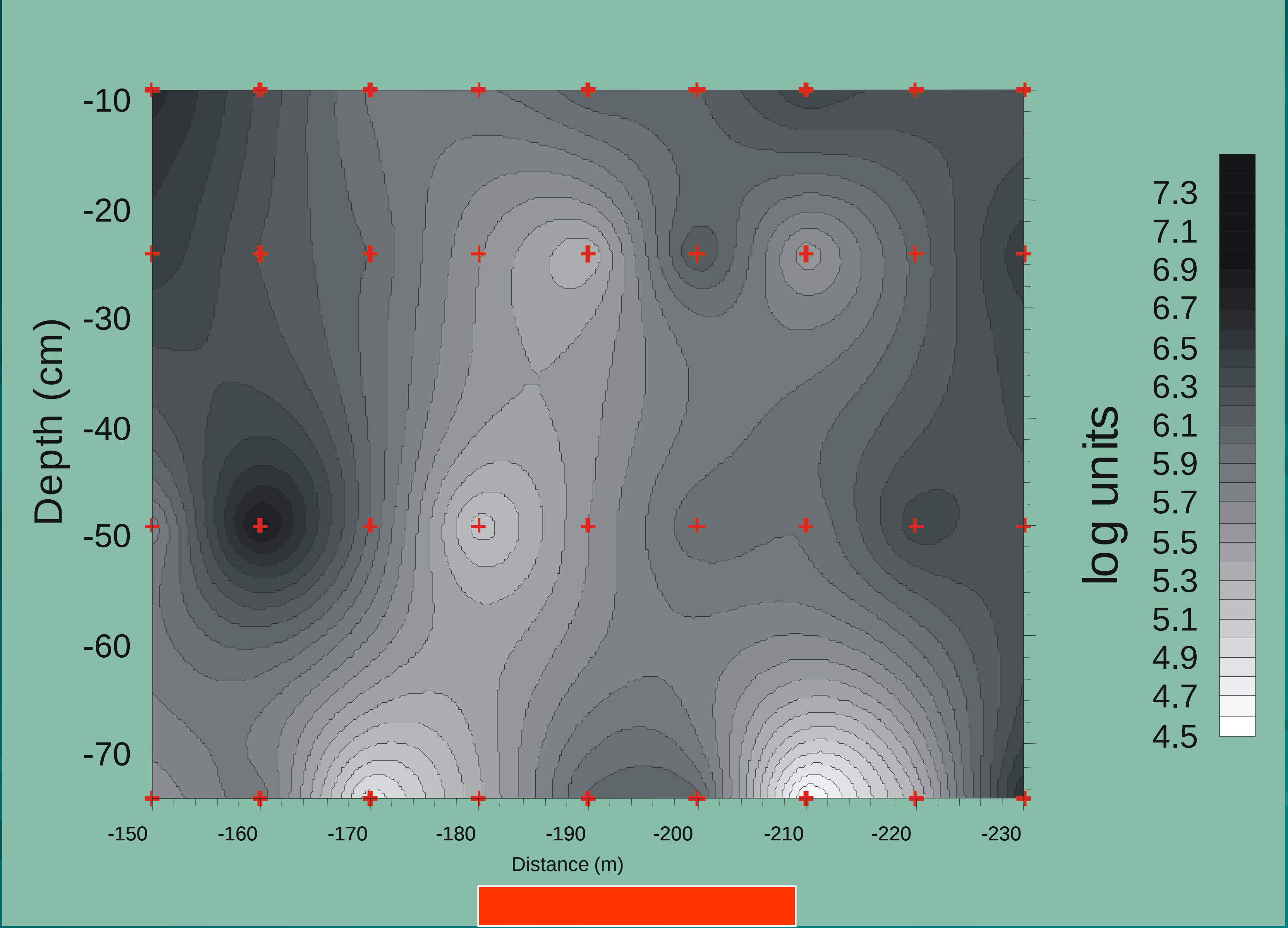
Aerobic Heterotrophs - Cross Lake - 12 m from line



Slide courtesy of Gordon Southam

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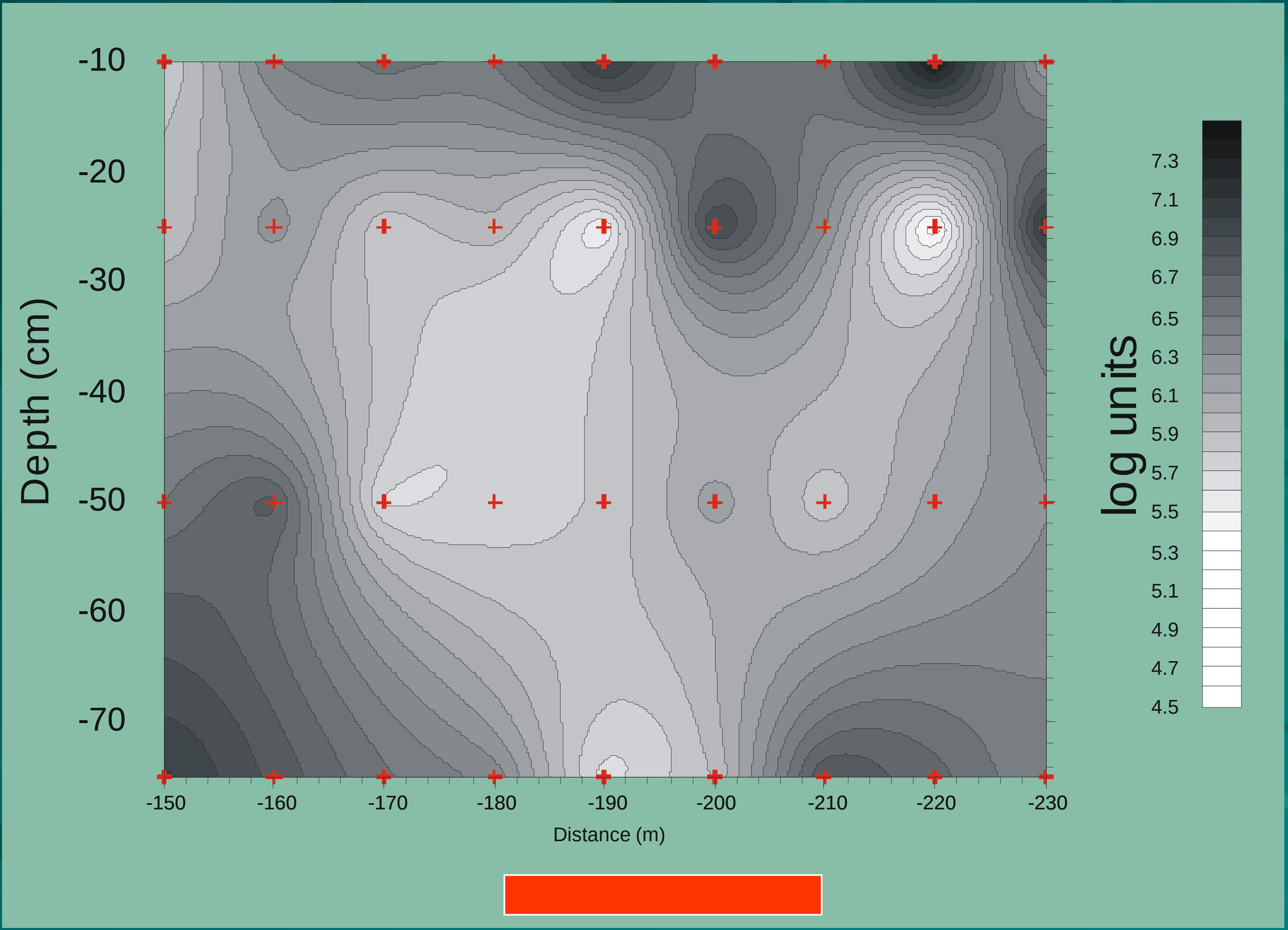
Aerobic Heterotrophs - Cross Lake - 12 m from line



Slide courtesy of Gordon Southam

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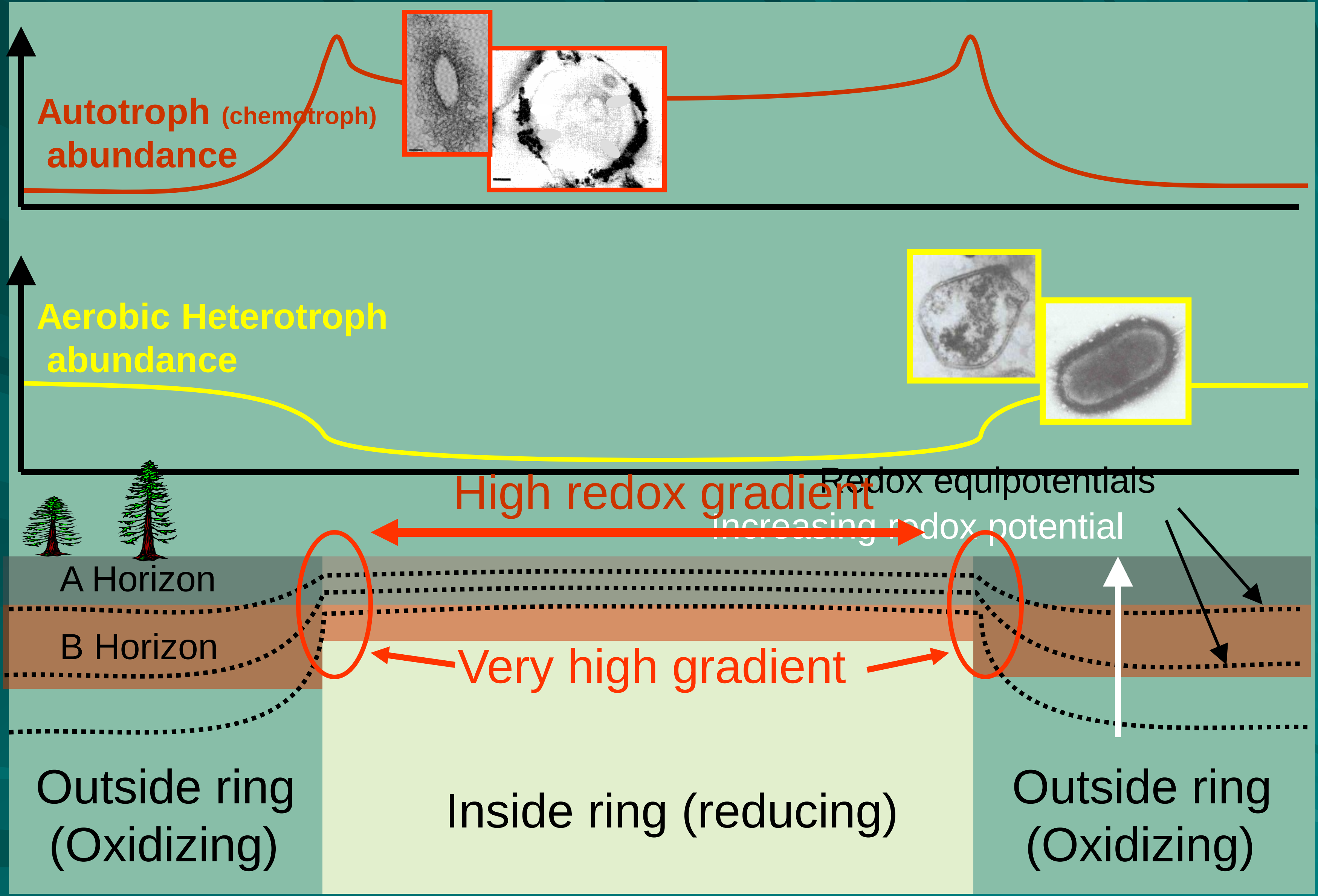

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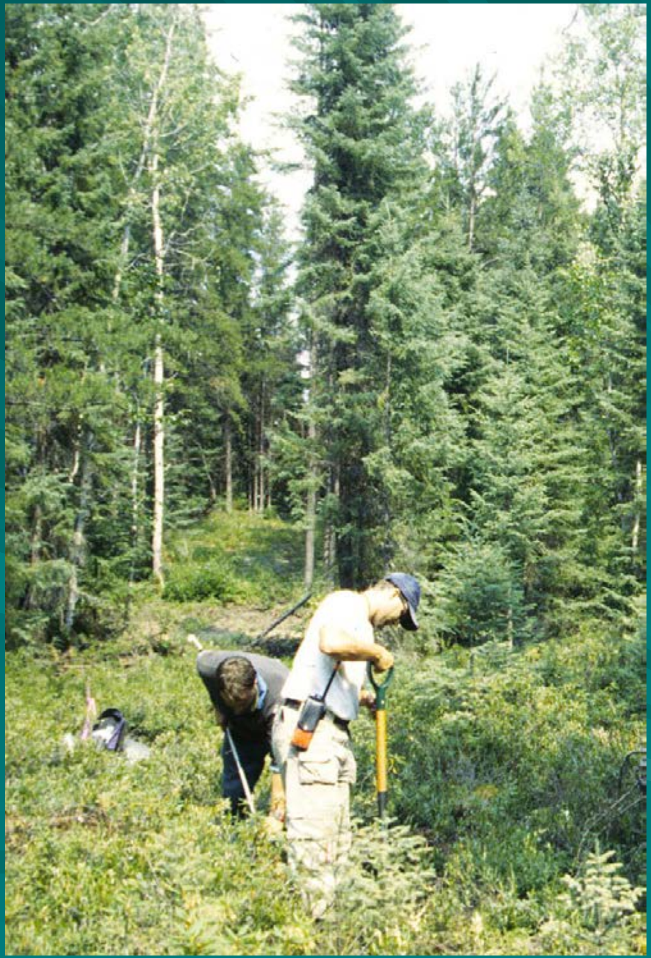
Optimizing an Exploration Strategy for the Abitibi



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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)

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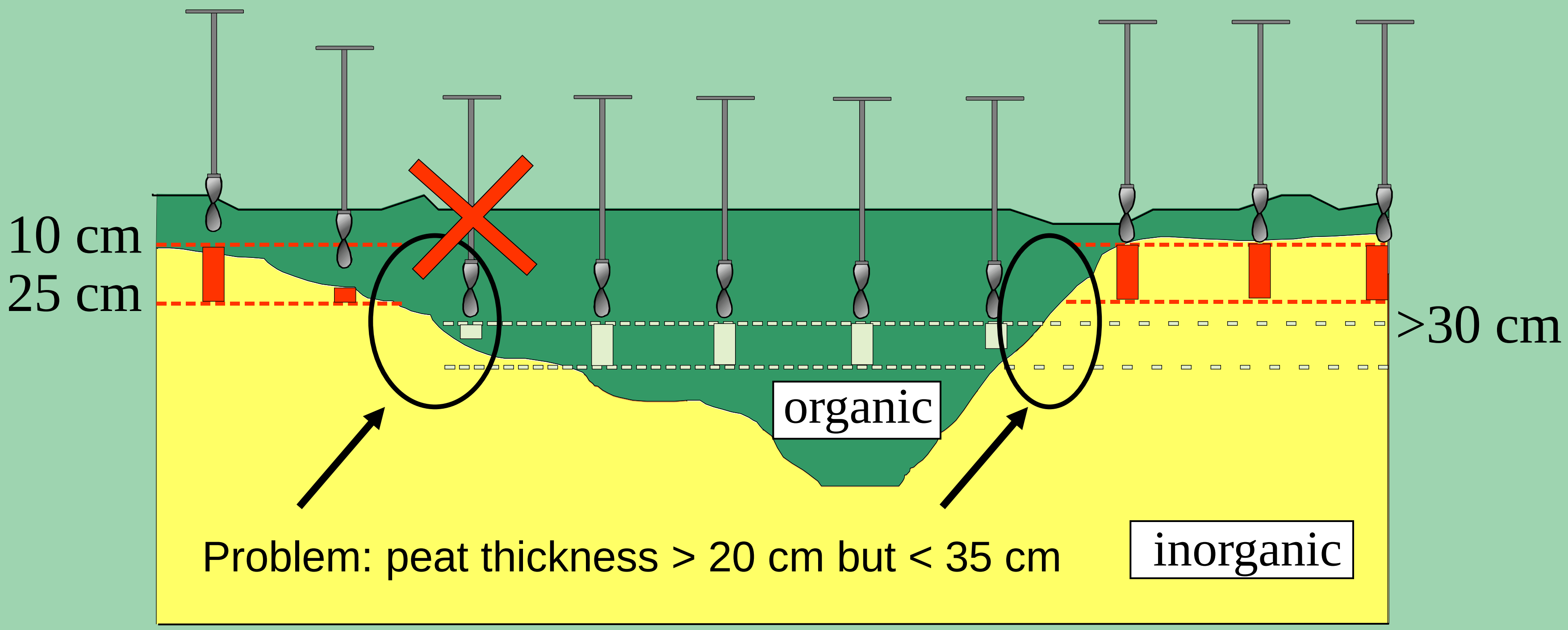
Selective Leach Sampling in Variable Terrain



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 <u>2 different media</u> from sampling right through to data interpretation

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Sampling in Oxidized Sand and Clay

- Sample inorganic media if available between

- Clay, sand … e differentiat…
- <u>Moisture</u> is … e positives

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Peat Sampling Protocol

- S… sten…
  a… oun…
- “… s de… ing
  c… d pe…
  s…
- S… if pe… in
- C… y sc… ves
  … ssible …
- (always record depth of clastics if within 1 auger length)

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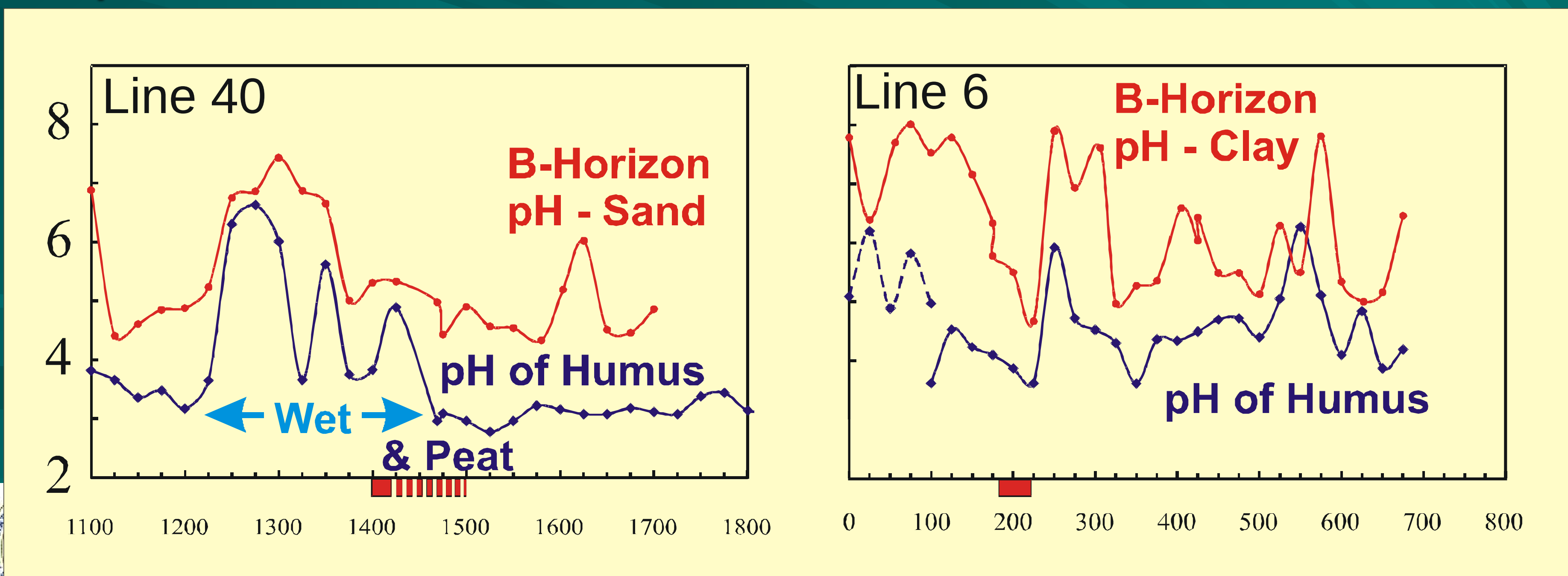
pH Measurement

- 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



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
- CO_2 / O_2 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

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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