Monitoring the Behaviour of Sludge in the Vadose Zone

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Mine Location

Background

- Mined 1982-1985;
  - 250 acre site (100 ha).
- AMD since mid-80's.
- Hydrated lime treatment
  - 4 one -acre sludge ponds/yr
- Long term solution-sludge disposal into waste rock

Initial Dredging Rationale

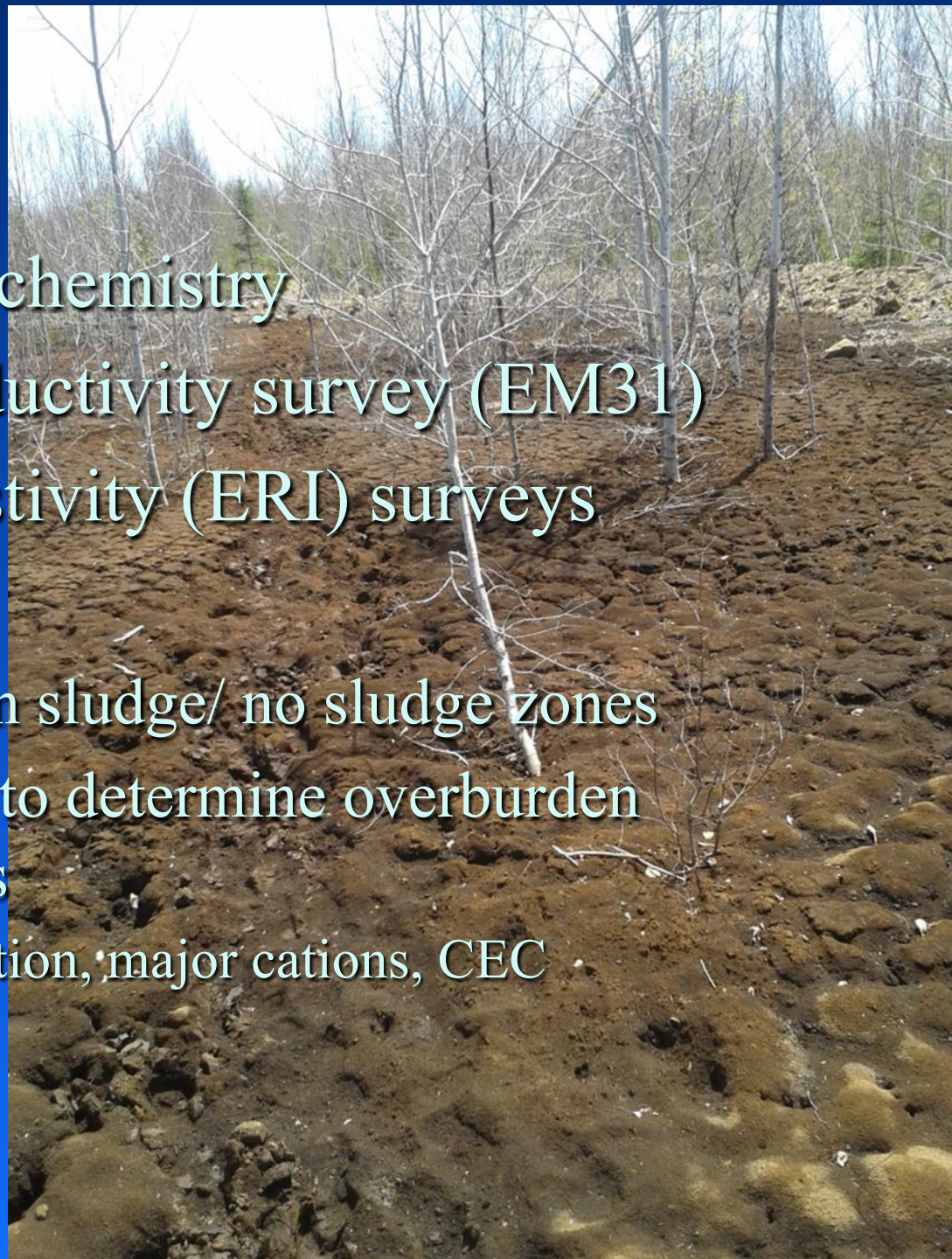
- Disposing of lime neutralization sludge into acid generating rock could provide several benefits including:
  - utilization of the excess alkalinity
  - final disposal area for sludge, still dredge cost
  - minimize land disturbance
  - decrease personal liability
  - reduce diffusion of oxygen into the waste rock.

Objectives

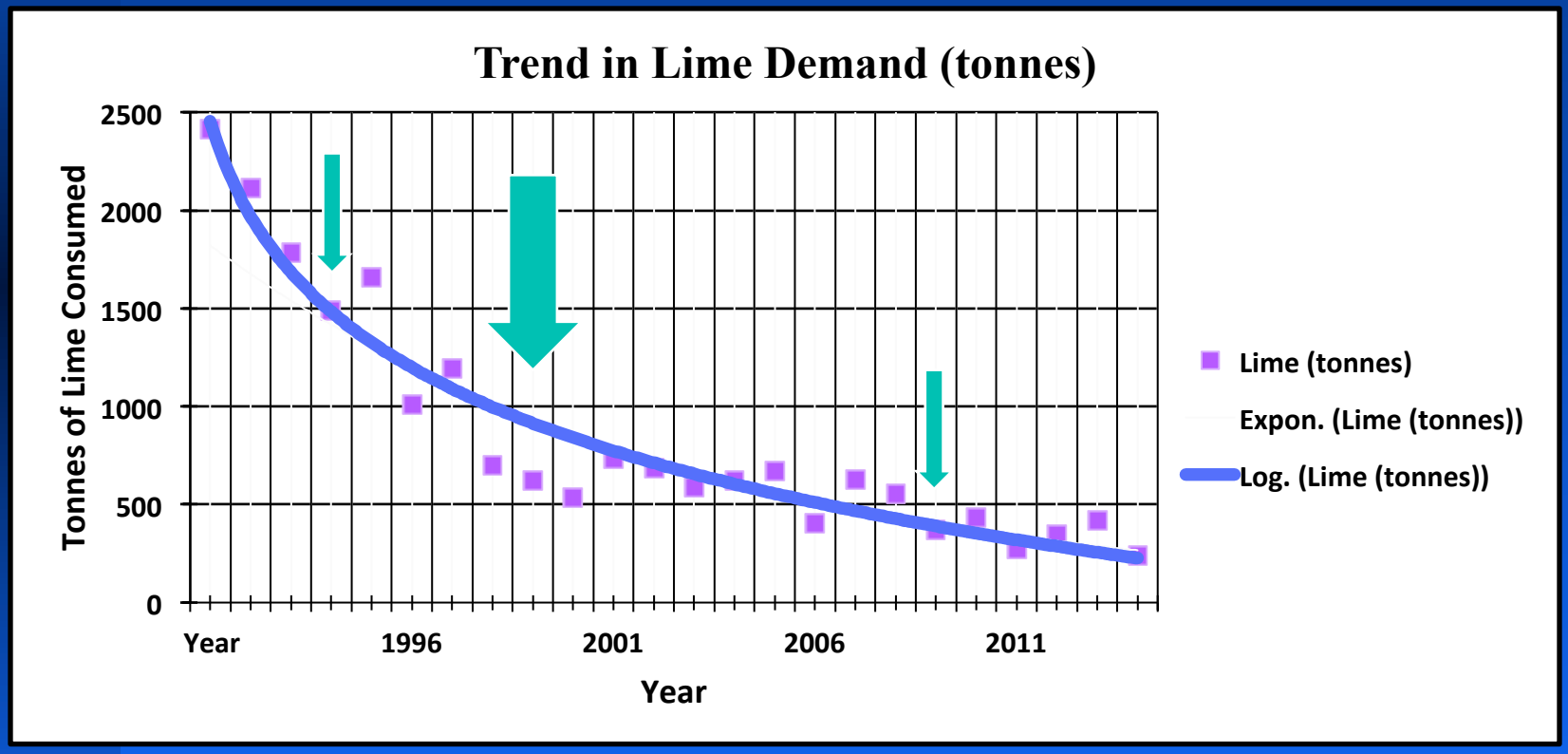
- We are noticing a decrease in mine water acidity.
- Why are some previously highly conductive zones becoming less conductive over time?
- Does the sludge dry out and become less conductive over time?
- If so, is the benefit of depositing sludge in the vadose zone temporary, or is it long term.

Methodology

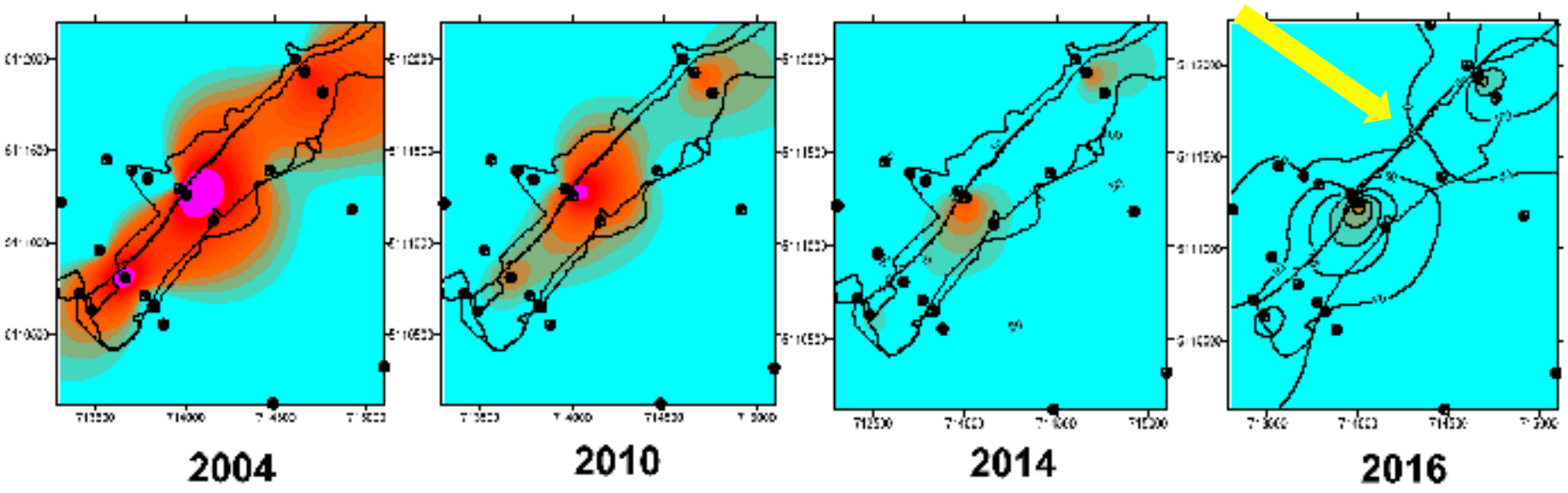
- Ground water chemistry
- Apparent conductivity survey (EM31)
- Electrical resistivity (ERI) surveys
- Test pits
  - Comparison in sludge/ no sludge zones
  - Soil analysis to determine overburden characteristics
    - pH, size fraction, major cations, CEC



Decreasing Lime Demand for Mine Water Treatment

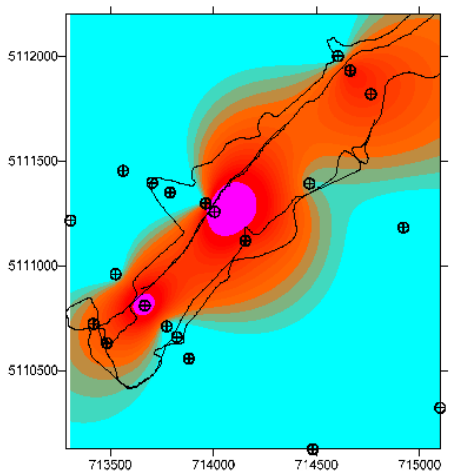


Decreasing Acidity in Mine Water from Monitoring Wells

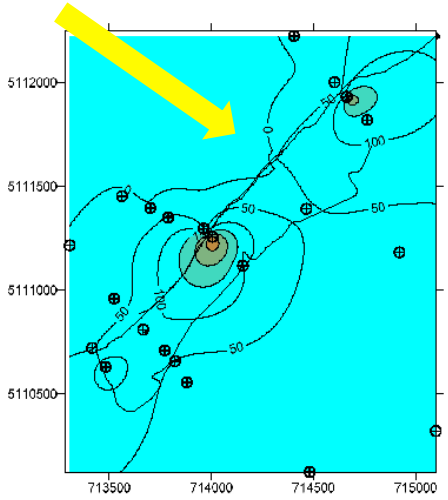


Acidity Scale (mg/l)
Pink >1000
Orange 200-1000
Gray 150-200
Green <150

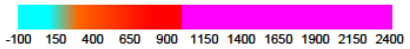
Decreasing Acidity in Mine Water from Monitoring Wells



2004



2016



Colour Scale
(non-linear)

Acidity in Groundwater (mg/L as CaCO3)

Acidity Scale (mg/l)
Pink >1000
Orange 200-1000
Gray 150-200
Green <150

Geophysical Investigations

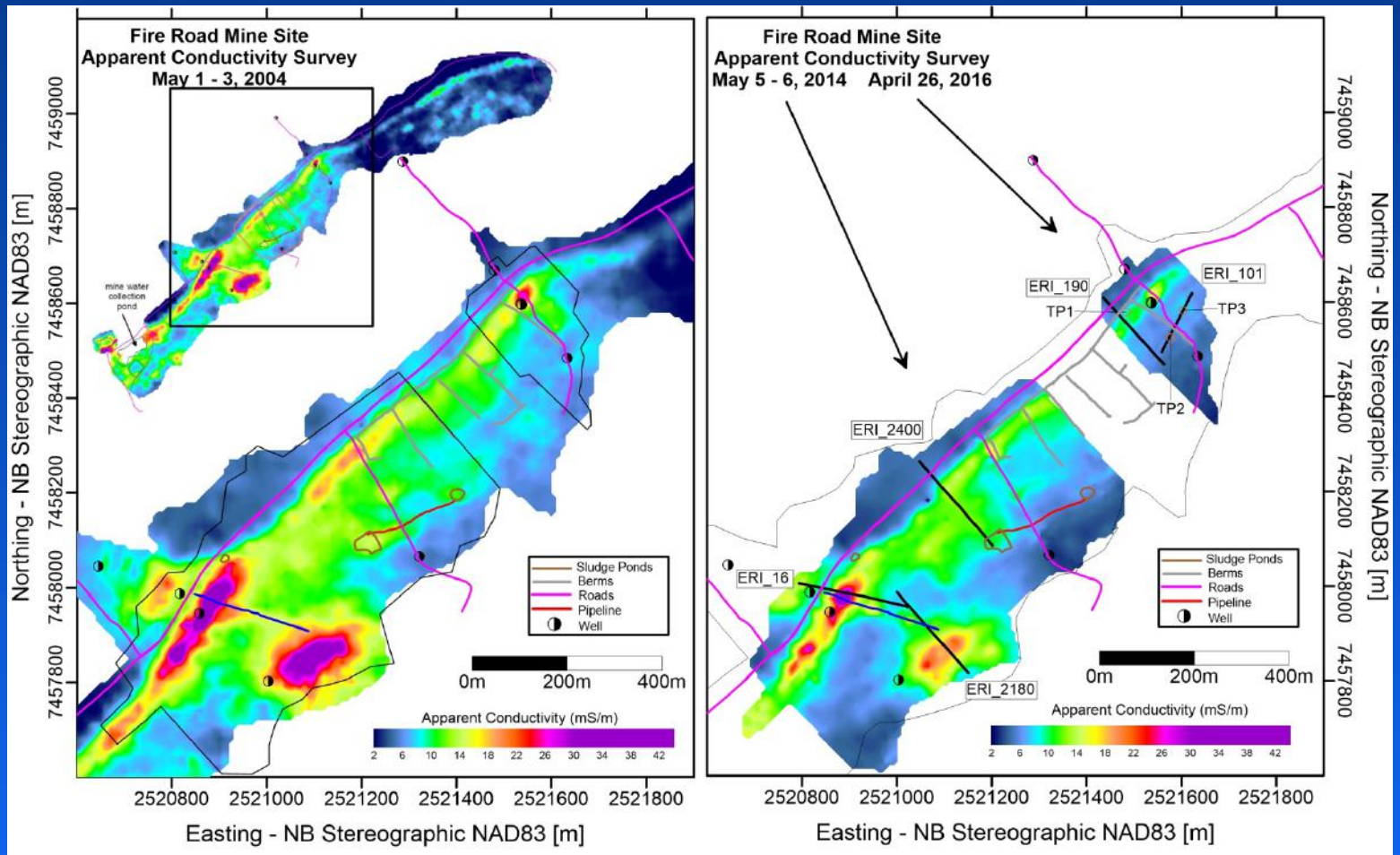
- University of New Brunswick Earth Sciences Department Field Camps, senior projects, graduate students research at the site since 2000
- Electrical resistivity imaging (ERI) and electromagnetic apparent conductivity (EM31):
  - map lateral and vertical variations in AMD and sludge concentration within the mine site
  - Conductivity is proportional to ion concentration, ion valence, and ion mobility.
  - AMD, sludge and clays have high electrical conductivity compared to natural ground waters

Example of Fresh Sludge Deposition

- 26,000 m^3 sludge, late fall 2014

2016 UNB Earth Sciences Field Camp

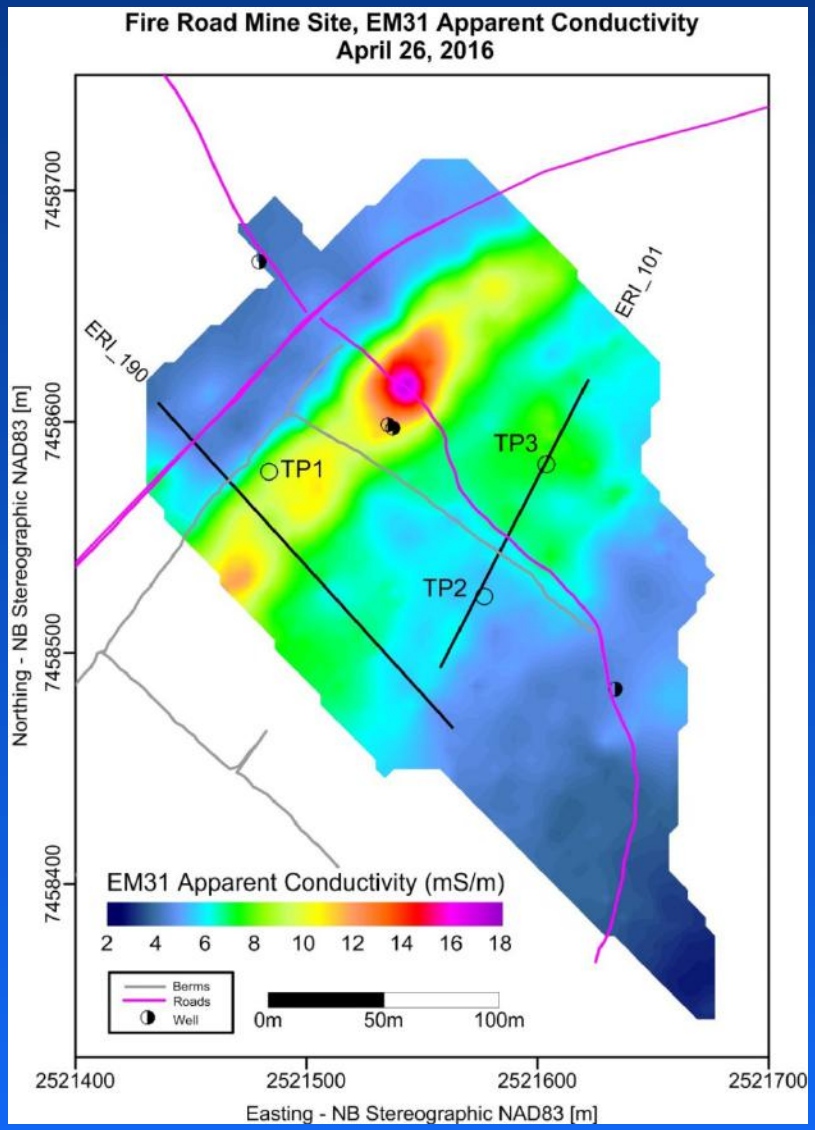
Comparisons Over Time
EM31 Apparent Conductivity



Maps showing variations in shallow apparent conductivity at the Fire Road Mine site measured using an EM31ground conductivity meter. Inset shows the whole mine site. Areas re-surveyed during ESCI 3713 field schools in 2014 and 2016 is shown at an enlarged scale. (a) Data collected in early May and late June, 2004. (b) Data collected May 5 - 6, 2014 and Apr. 26, 2016. Electrical resistivity imaging (ERI) lines are plotted in black.

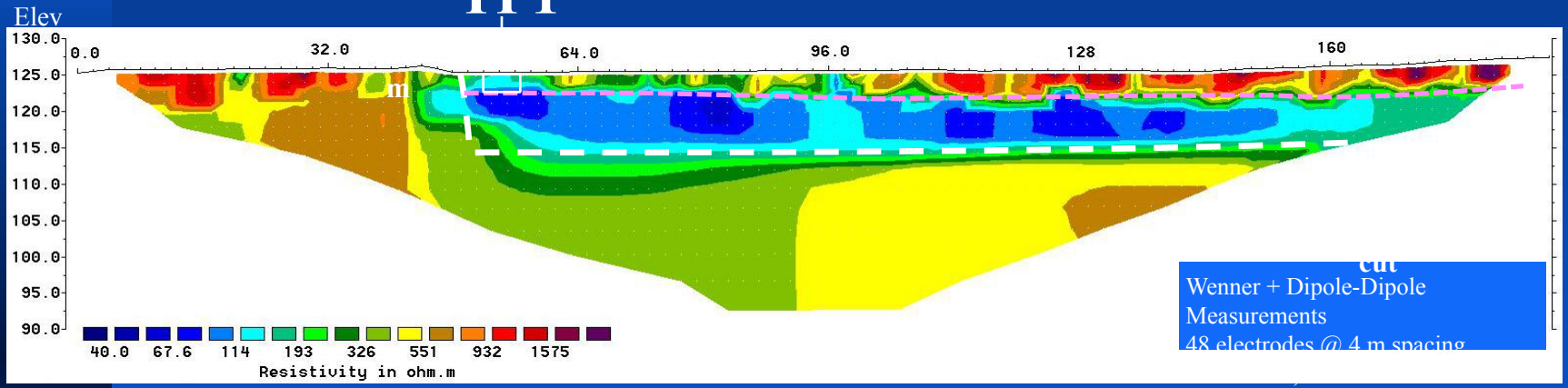
EM31 Apparent Conductivity in 2016

(with reduced range colour scale & showing TP locations)

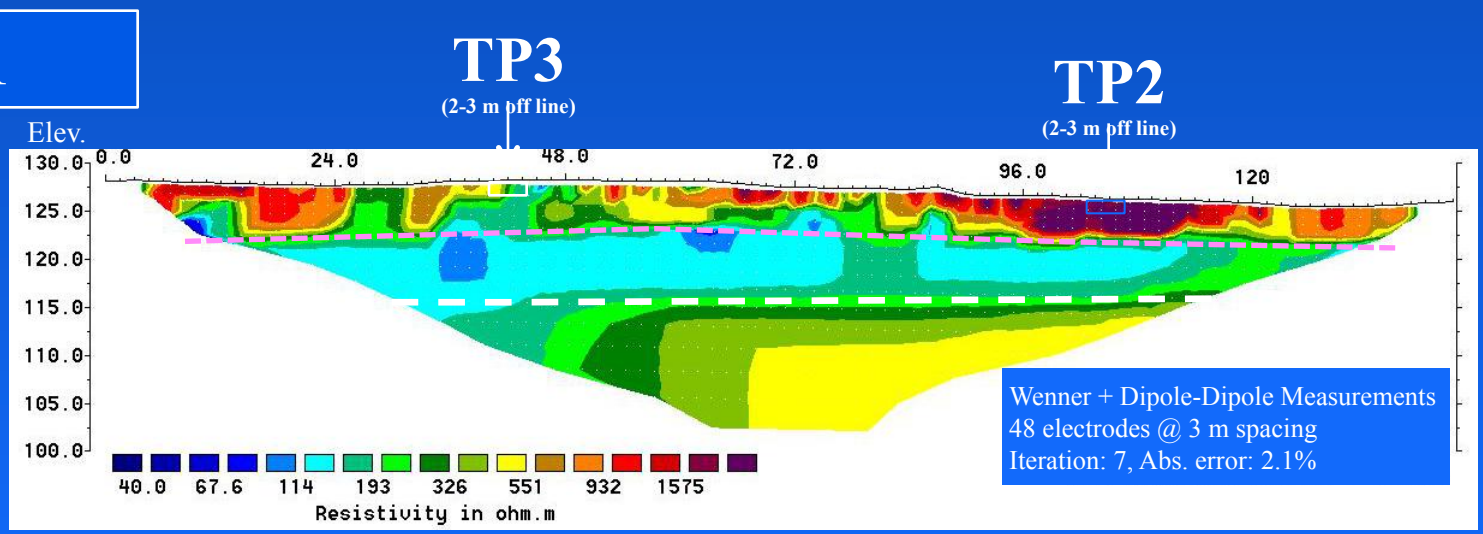


Electrical Resistivity Imaging (ERI) Sections – Fire Road, 2016

L 190



L 101



Test Pit 1

-high conductivity zone at ERI 109

- Test Pit 1, 2.5m deep
- Located along highly conductive high wall anomaly
- Fine-grained material filling the voids between waste rock blocks which felt silt size
- Color was dark brown, changing to a gray-brown hue below ~ 2.3 m depth
- Seemed to get moister with depth.

Test Pit 2

-in highly resistive area along L 101

- Test Pit 2, 1.3m deep
- Highly resistive area
- No evidence of former sludge deposition
- Blocky material, sandy fines
- Measured in-situ pH, moisture content, resistivity every 30cm
- More void space than fines below 30-50 cm

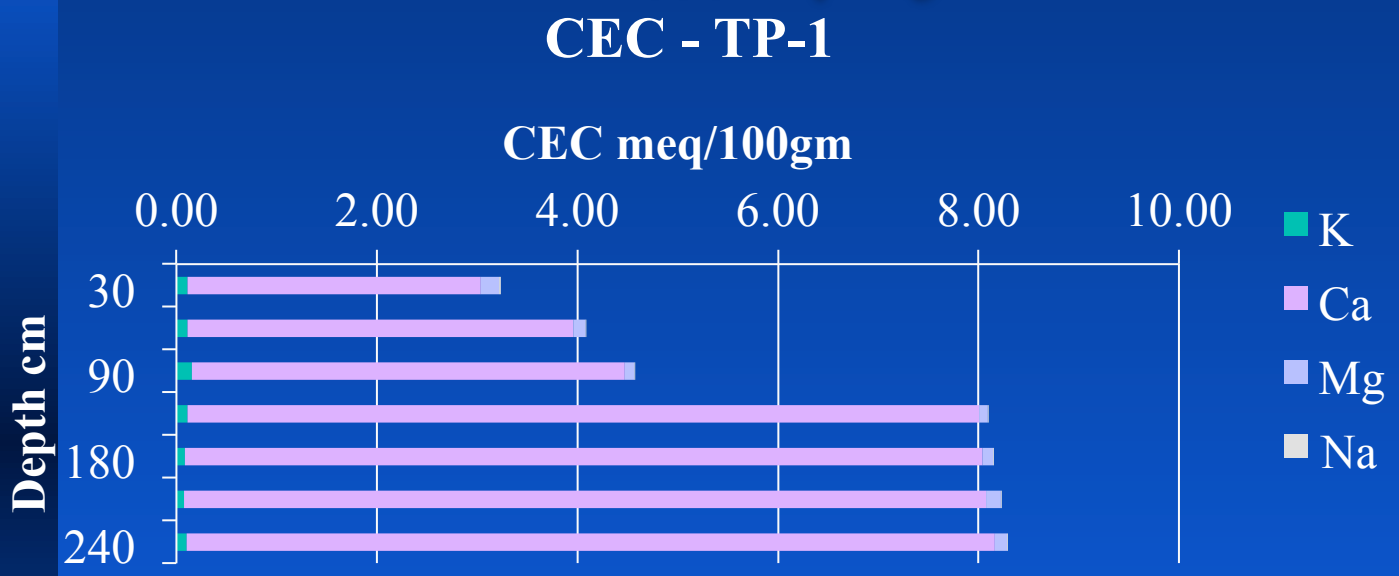
Test Pit 3

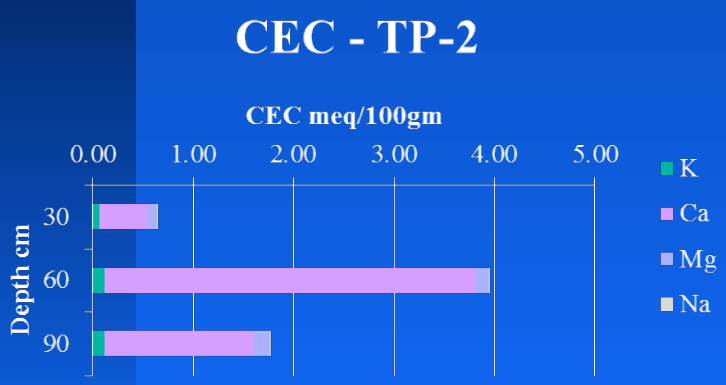
- in moderately conductive area along L101

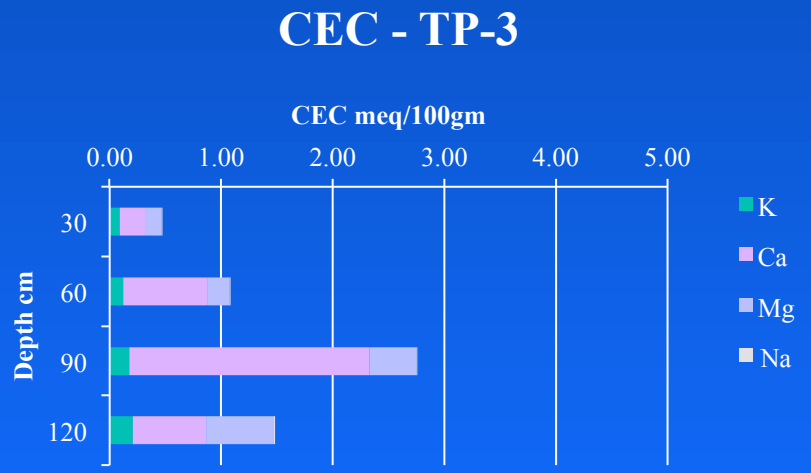
- 1.3 m deep
- Moderately conductive area, previously(?) received sludge
- Large rocks similar to pit 2
- But more fine grained material filling space between blocky material
- Texture of fines intermediate between silty TP1 and sandier TP2

Comparisons of Cation Exchange Capacity

CEC meq/100g

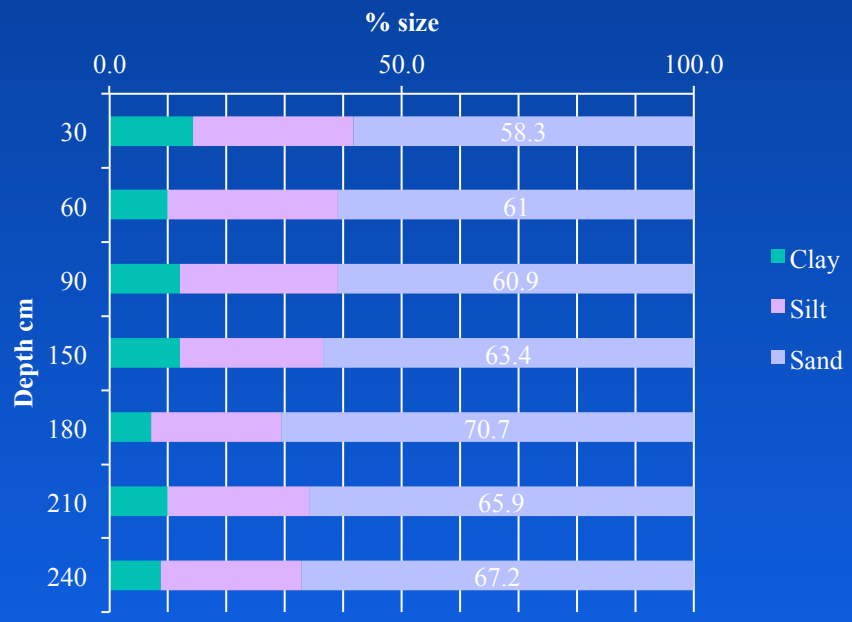




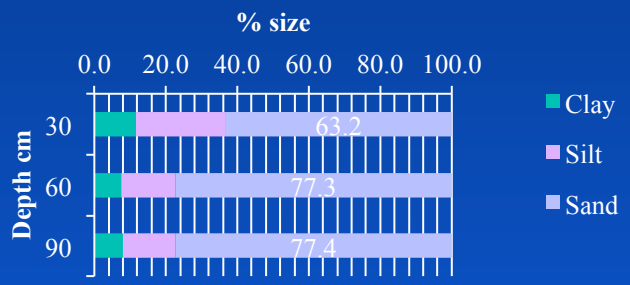


Test Pit Size Fraction Comparison

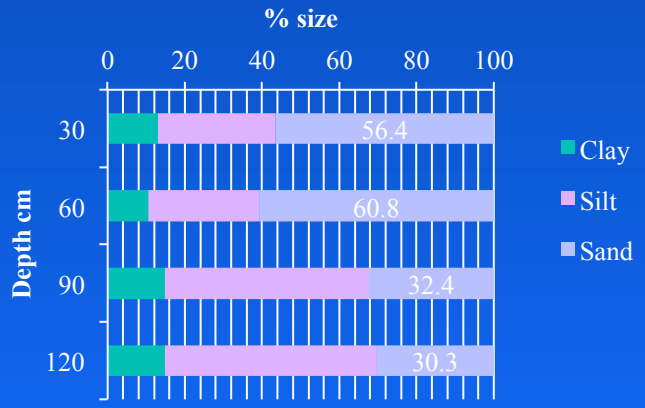
Size Fraction TP-1



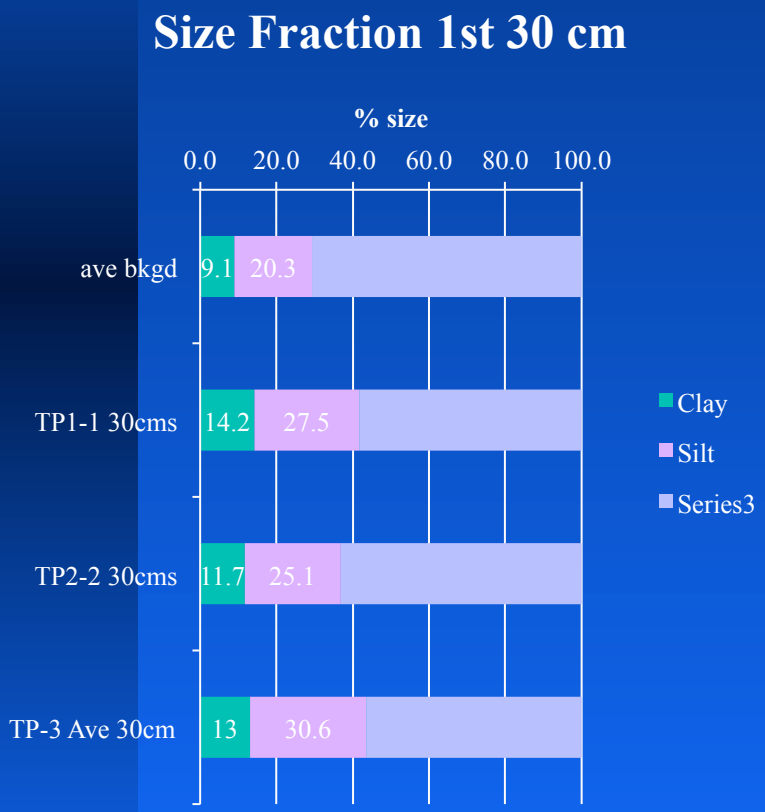
Size Fraction TP-2

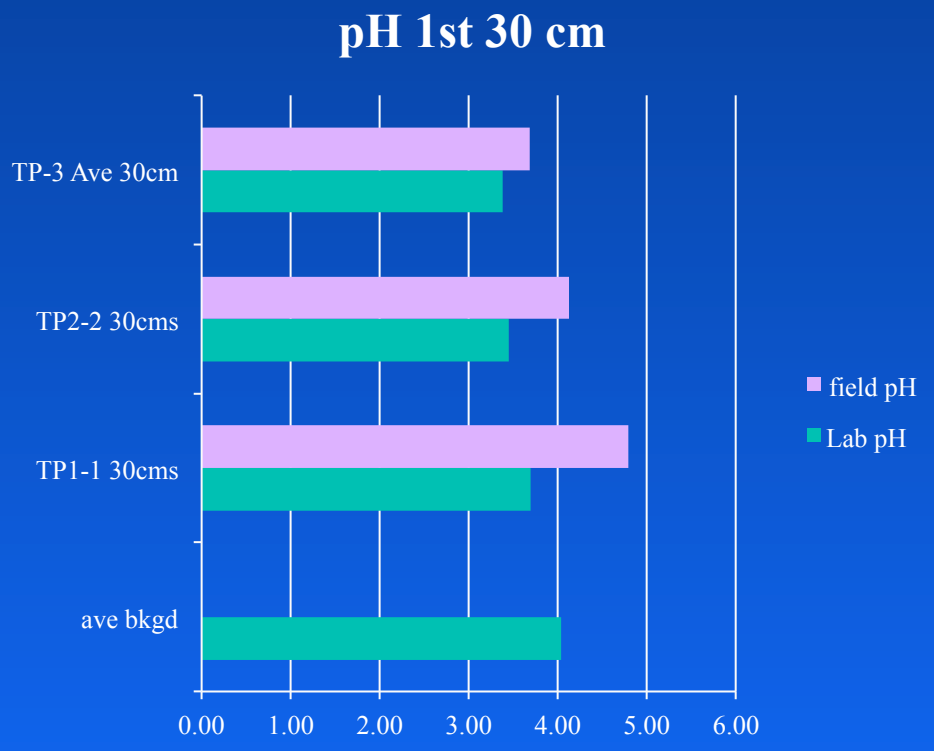


Size Fraction TP-3



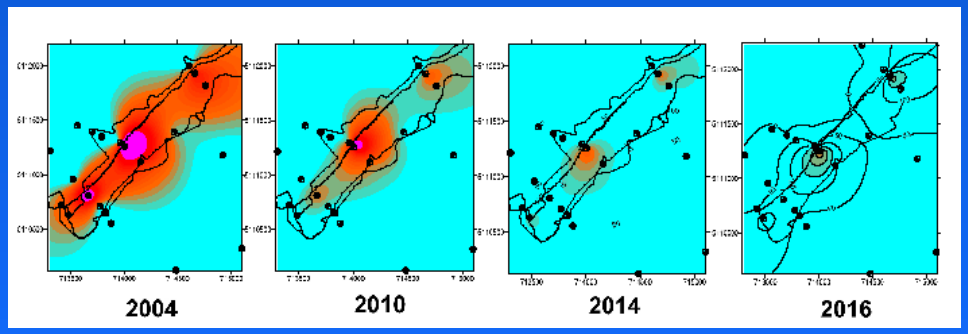
Comparison of Upper 30cm of Fines





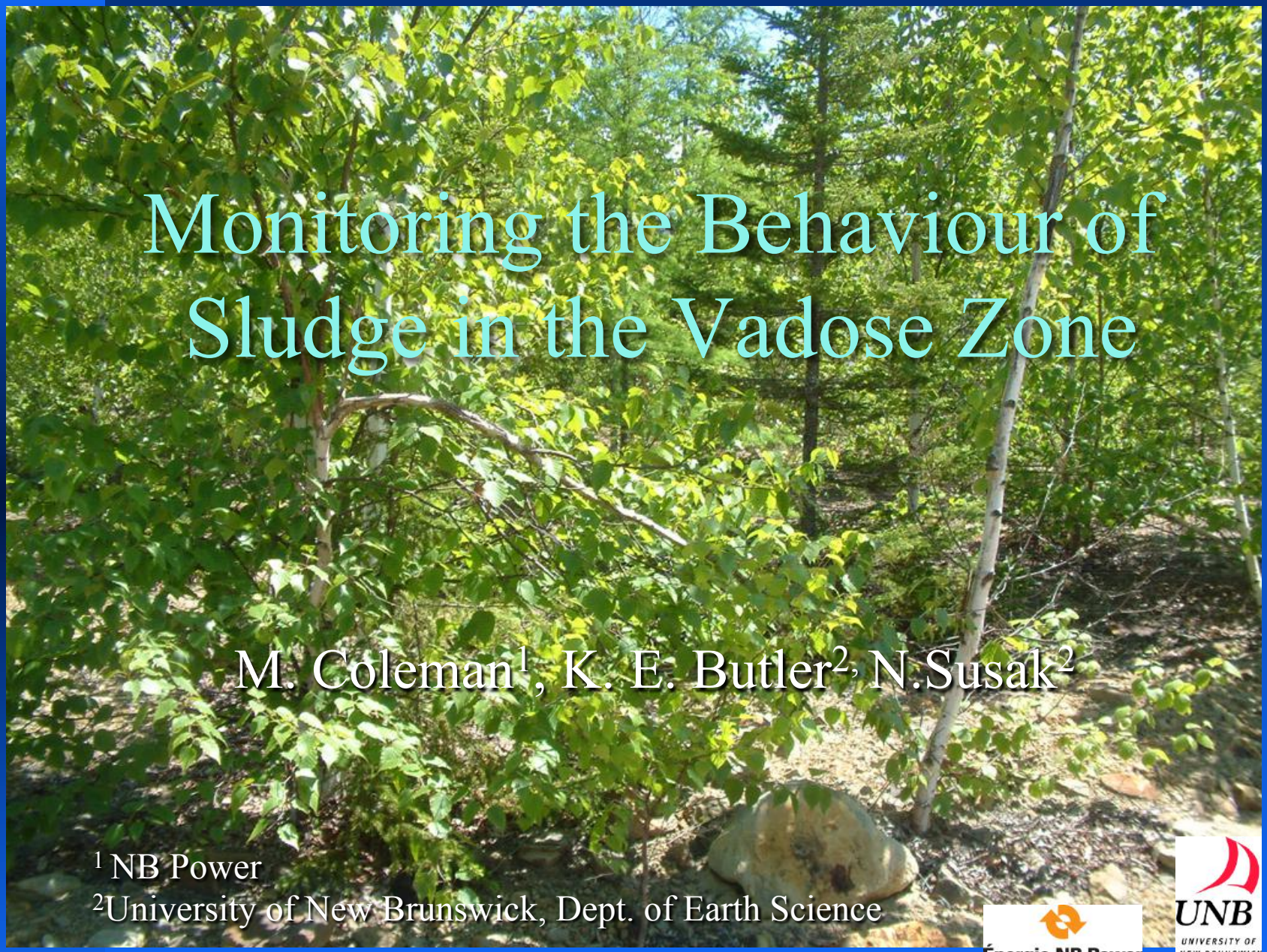
Discussion

- While we may have finally obtained evidence supporting our suspicion that vadose zone sludge can be detected by resistivity/conductivity surveys, it's another matter to prove that the presence of sludge in the vadose zone is actually helpful for remediation of the site.
- Need to prove that oxygen diffusion into the subsurface has been reduced, but since the sludge is not being applied as a complete cap, the reduction would only be local.
- Interesting to not see pH improvement reflected in test pit sediment pH data so can only speculate what the data is telling us.



Conclusions and Further Questions

- Higher conductivity was identified across areas with sludge deposition using both EM31 and ERI surveys
  - Multi-year studies indicate that as the sludge dewaters, the conductivity decreases.
    - Sludge can remain moist at depth for over a decade.
- Vadose Zone Test pits
  - Sludge does penetrate to at least 2.5 meters below the surface
    - Suggests sludge was indeed at least partially filling the void space in the vadose zone
    - Is there a benefit to locally reducing oxygen diffusion?
    - Why is soil still acidic?



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