Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

Assessing Source of Trace Metals at a Wellsite in Alberta to Support Remediation and Reclamation Planning

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RemTech Conference 2020

Introduction

- ❑ Site Background and Assessment History
- ❑ Regional Information
- ❑ 2019 Phase 2 ESA
  - ❑ Methods
  - ❑ Results
    - ☆ Additional interpretation of data
- ❑ Conclusions and Outcomes

Site Background

- Drilled and abandoned wellsite
- Cultivated land
- 100 km NW of Edmonton, Alberta
- Phase 1 ESA (2014)
- Three Phase 2 ESAs (2014, 2018, 2019)
- Total of 71 boreholes within and outside of former lease boundary

Source: ESRI 2020

Assessment History

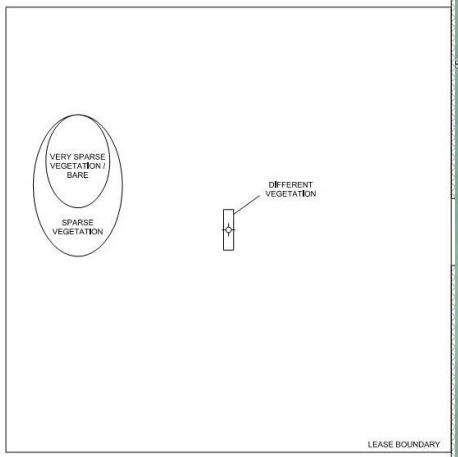
2014 and 2018 ESAs

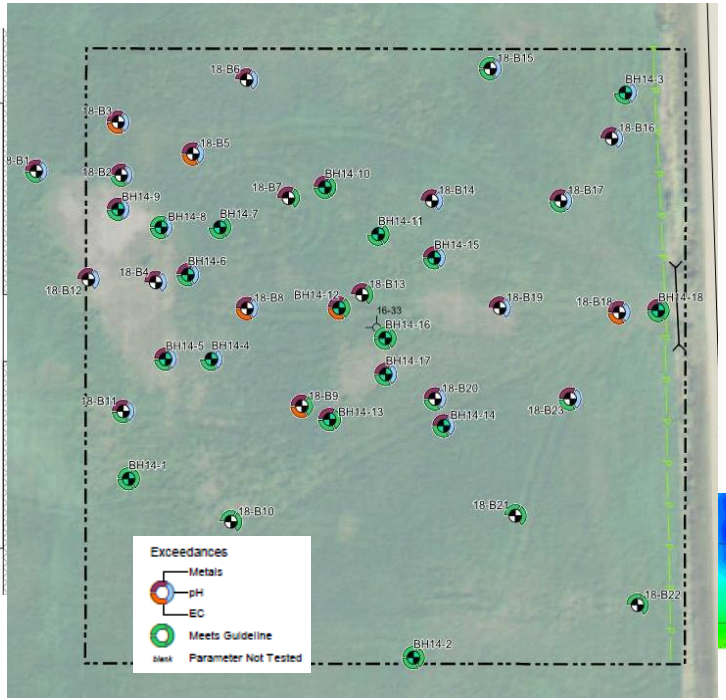
- ❑ focused on site footprint
- ❑ sampling targeted surface-spread drilling waste and bare areas west of and at well centre
- ❑ 12 elevated trace metals and acidic pH encountered in soil profile
  - ❑ potential source – drilling waste and associated cuttings
- ❑ soil parent material – combination of till and a black clay of unknown origin

2019 ESA

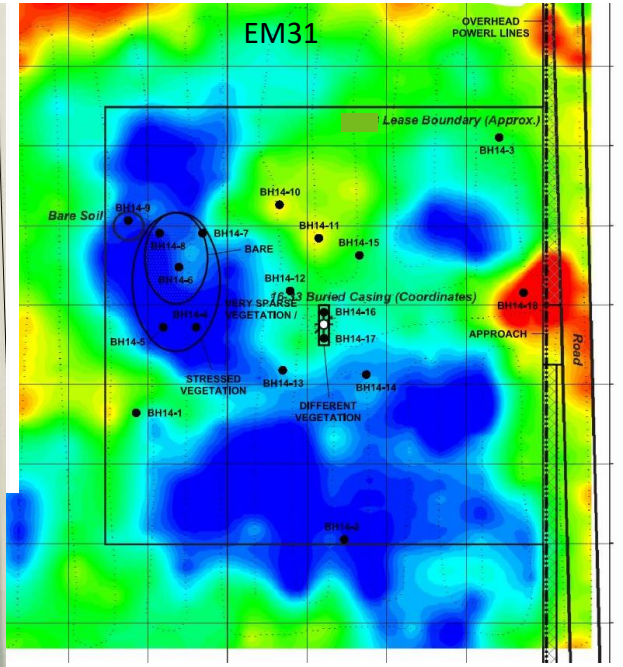
- ❑ to delineate perceived impacts – deeper soils within former lease boundary and background soils west, north and east

Assessment History





Source: Meridian 2014

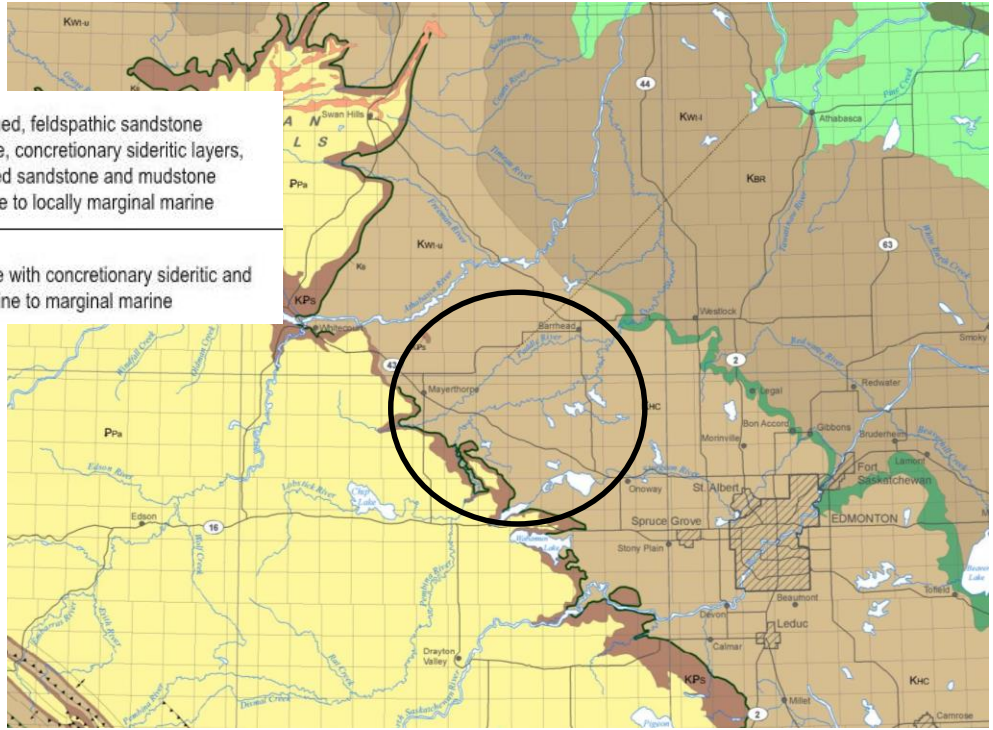


Source: Meridian 2015

Regional Information

KHC **HORSESHOE CANYON FORMATION:** pale grey, fine- to very fine grained, feldspathic sandstone interbedded with siltstone, bentonitic mudstone, carbonaceous mudstone, concretionary sideritic layers, and laterally continuous coal seams; includes white, pedogenically altered sandstone and mudstone interval at top (formerly assigned to the Whitemud Formation); nonmarine to locally marginal marine

KBp **BEARPAW FORMATION:** dominantly dark grey to brown-grey mudstone with concretionary sideritic and bentonite concretionary layers; concretions locally yield ammonites; marine to marginal marine



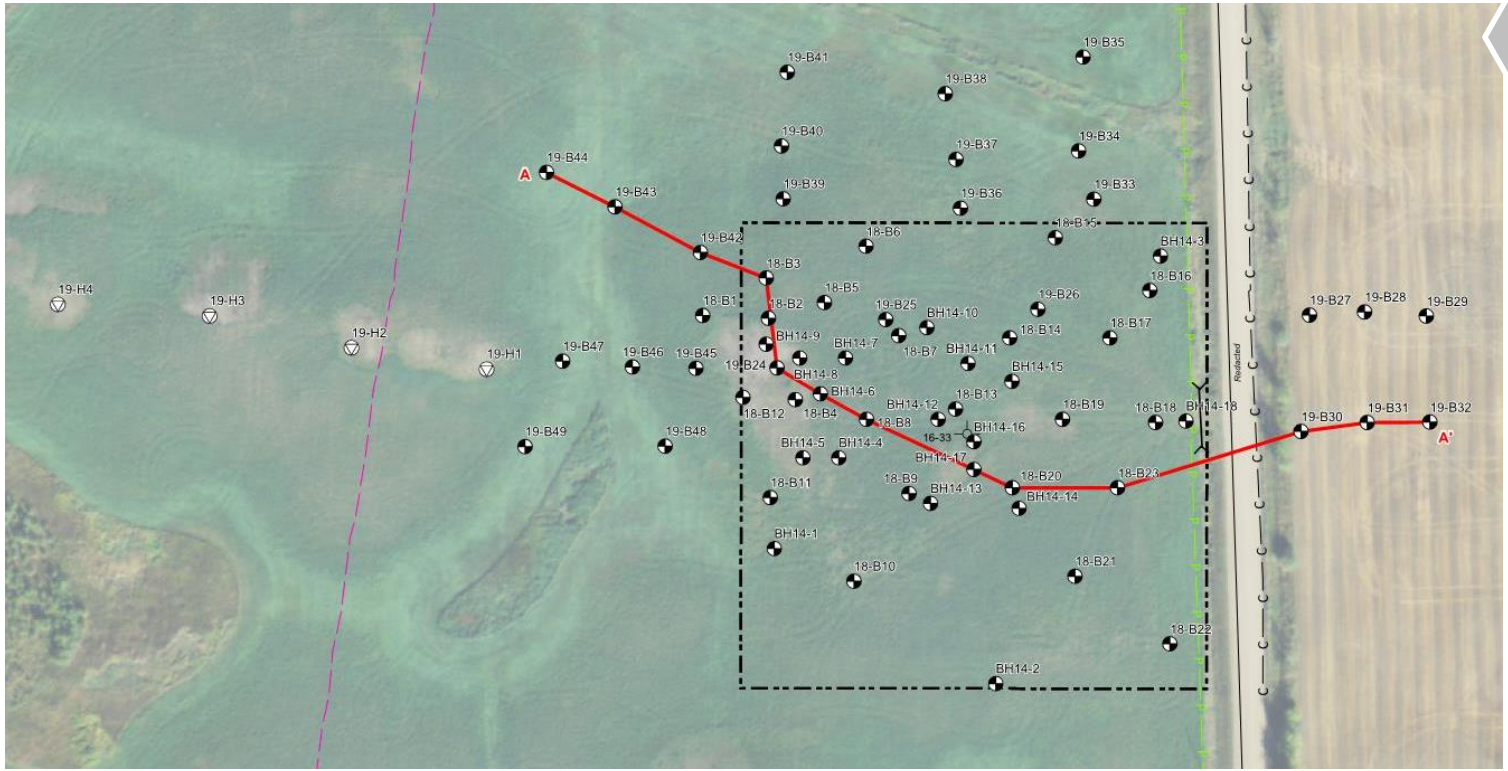
Source: Prior et al. 2013

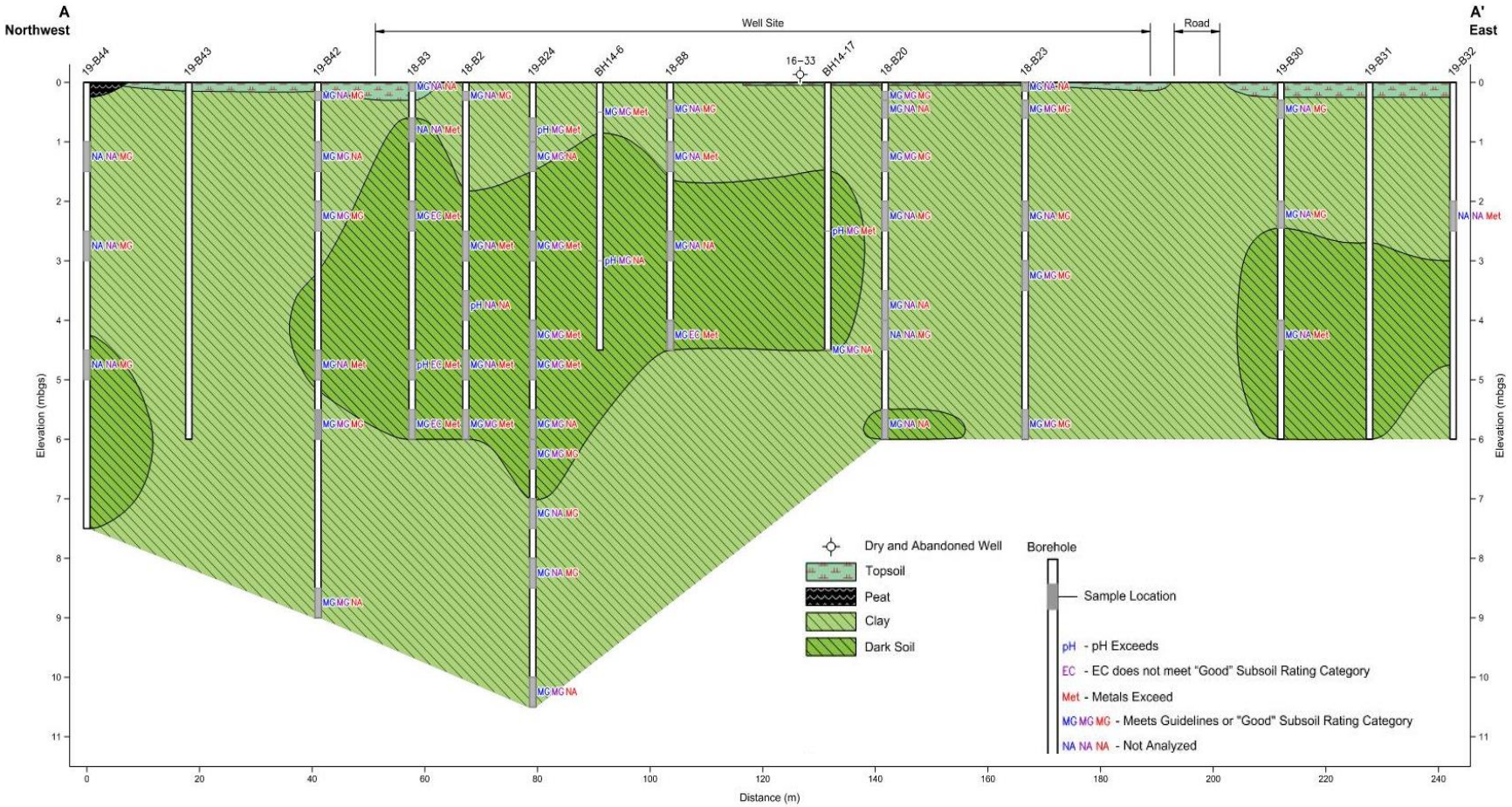
2019 ESA Methods

- December 2019 – drilled 26 boreholes by solid stem auger
  - Original objective to delineate metals and pH
    - Deeper soils within former lease boundary
    - Background soils to west, north and east
  - Maximum depth – 10.5 m below ground surface
  - 4 hand auger holes in bare areas west of site
- Compared to Alberta Tier 1 guidelines for fine-grained agricultural land use
- Additional interpretation of data needed for this site

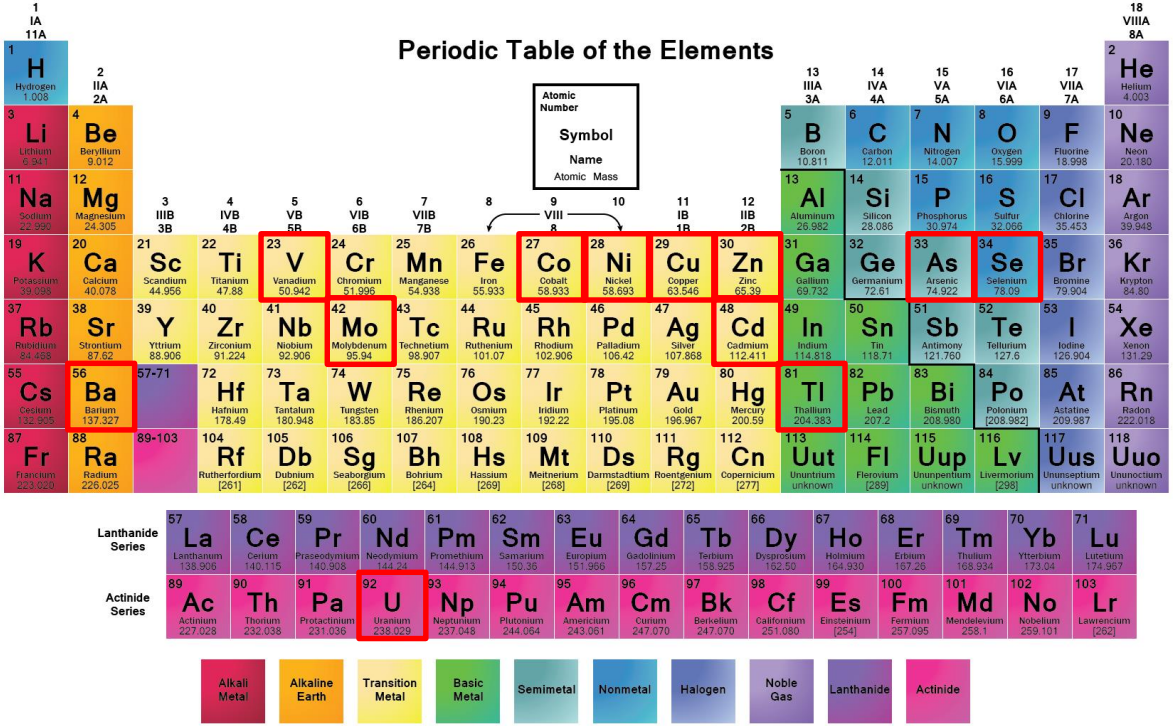

Local Area Background Metal Guideline Development
Detailed Review of Regional and Site-specific Geology
Contour Mapping
Geostatistical Profiling
Quantitative Evaluation of Materials by Scanning Electron Microscopy (QEMSCAN)
Acid Base Accounting
Phase 2 ESA Results

2019 ESA Results



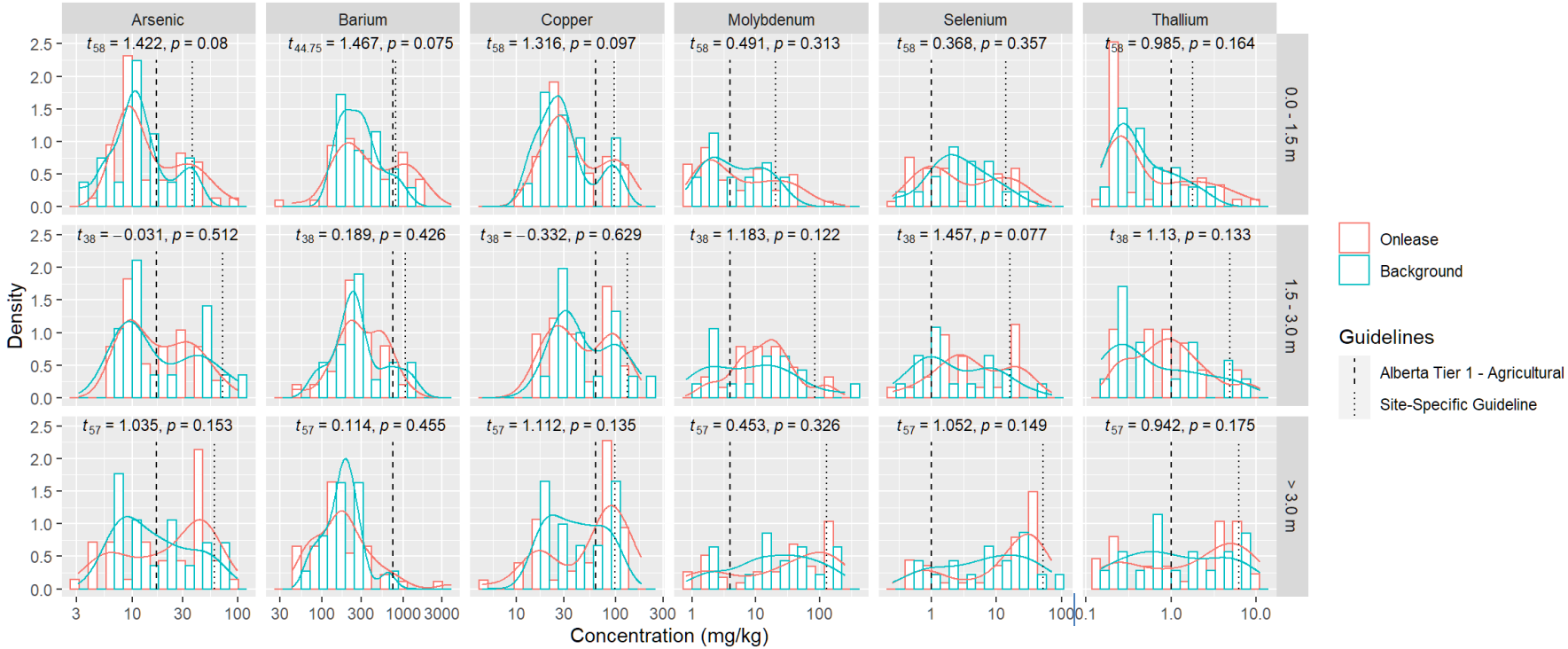

A
Northwest
A'
East
Well Site
Road
19-B44
19-B43
19-B42
18-B3
18-B2
19-B24
BH14-6
18-B8
16-33
BH14-17
18-B20
18-B23
19-B30
19-B31
19-B32
Elevation (mbgs)
Distance (m)
Dry and Abandoned Well
Topsoil
Peat
Clay
Dark Soil
Borehole
Sample Location
pH - pH Exceeds
EC - EC does not meet "Good" Subsoil Rating Category
Met - Metals Exceed
MG MG MG - Meets Guidelines or "Good" Subsoil Rating Category
NA NA NA - Not Analyzed

Background Metals

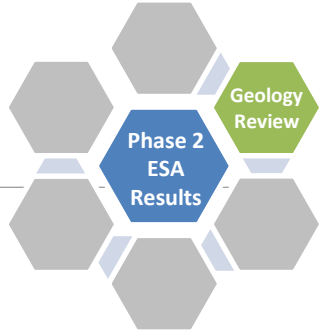


Source: Helmenstine 2013

Background Metals



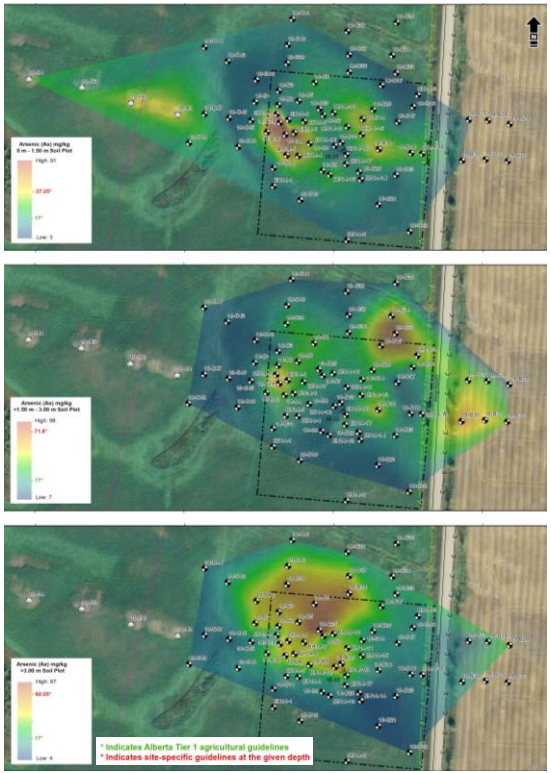
Detailed Geology Review



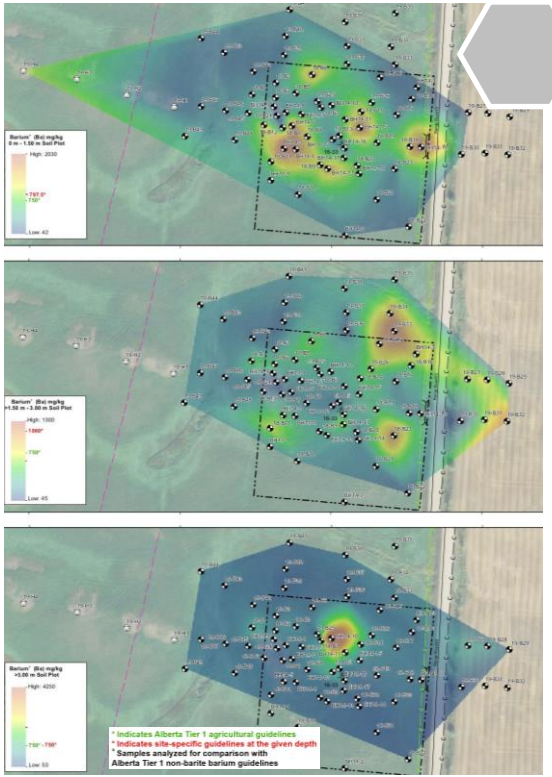
- Thickness of Horseshoe Canyon Formation (HCF) beneath former lease ~ 300 m
- Surficial geology is melt-out till associated with the Quaternary Laurentide Ice Sheet – thickness < 25 m
- Shallow boreholes encountered sediments at some locations that were consistent with glacial till
- HCF and Bearpaw Formation (BPF) contain abundant coal and marine shales
  - Known to contain iron sulphide minerals (e.g., pyrite)
- Likely that sediments between HCF and BPF subcrop edge were locally eroded and entrained within ice sheet, then redeposited within the glacial till
- Naturally occurring, acid-sulphate soils with elevated arsenic known to occur in isolated areas of Alberta (Dudas 1987) not previously documented at this location

Contour Mapping

Arsenic

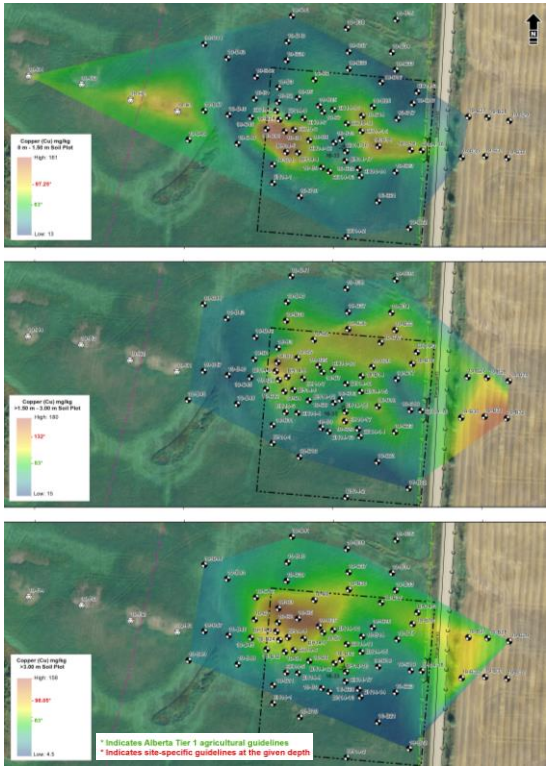


Barium

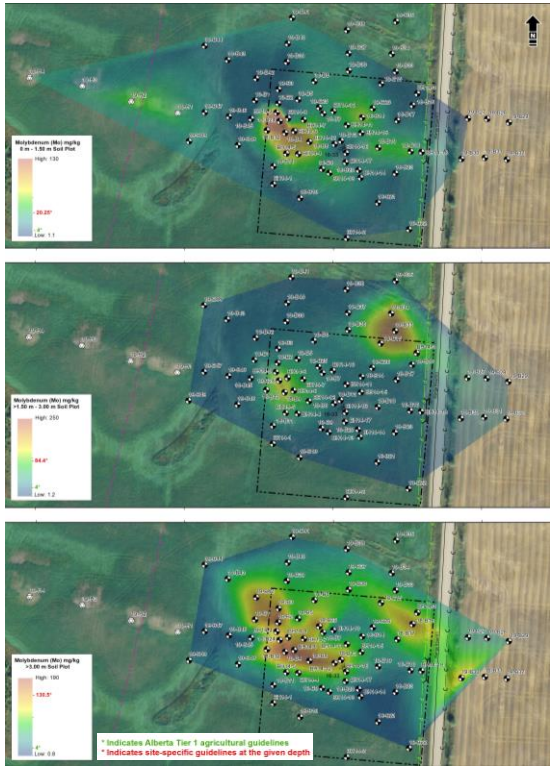


Contour Mapping

Copper

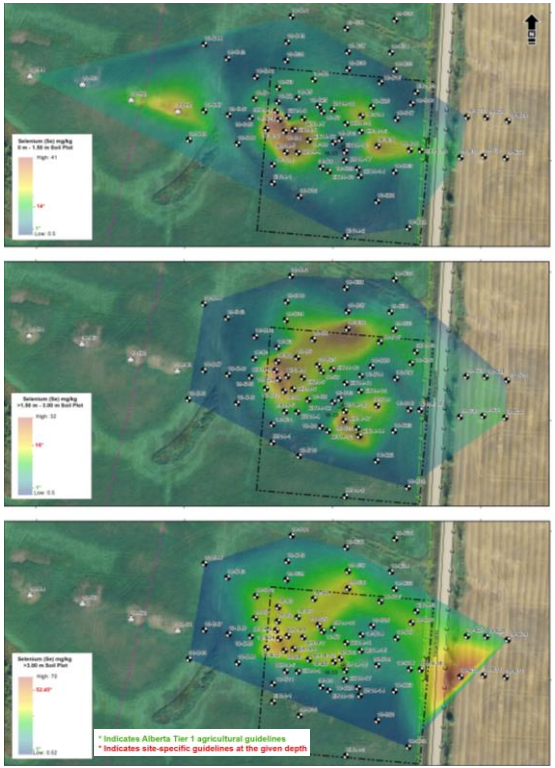


Molybdenum

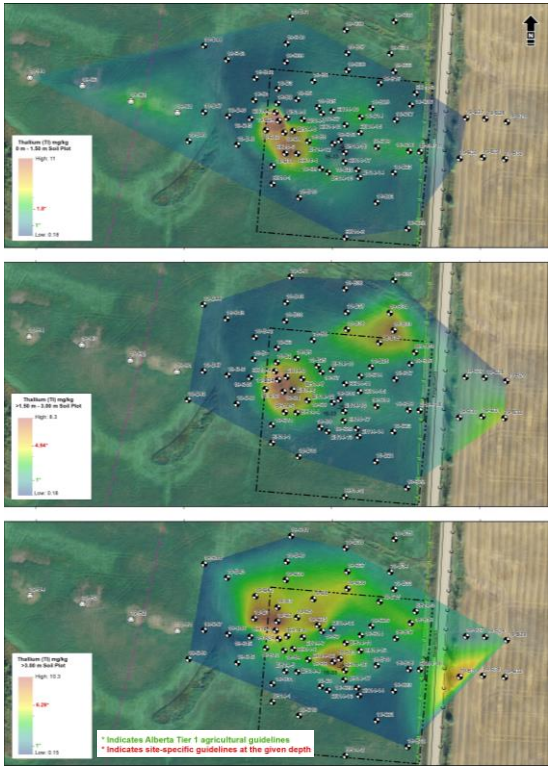


Contour Mapping

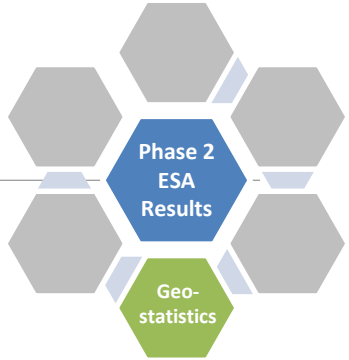
Selenium



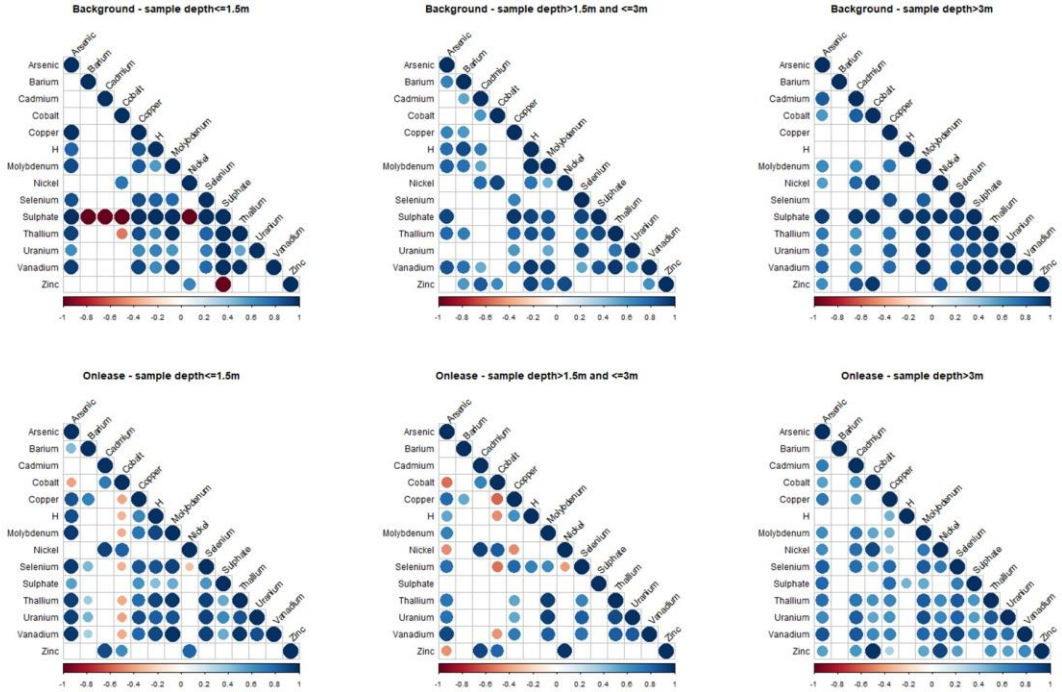
Thallium



Geostatistical Profiling

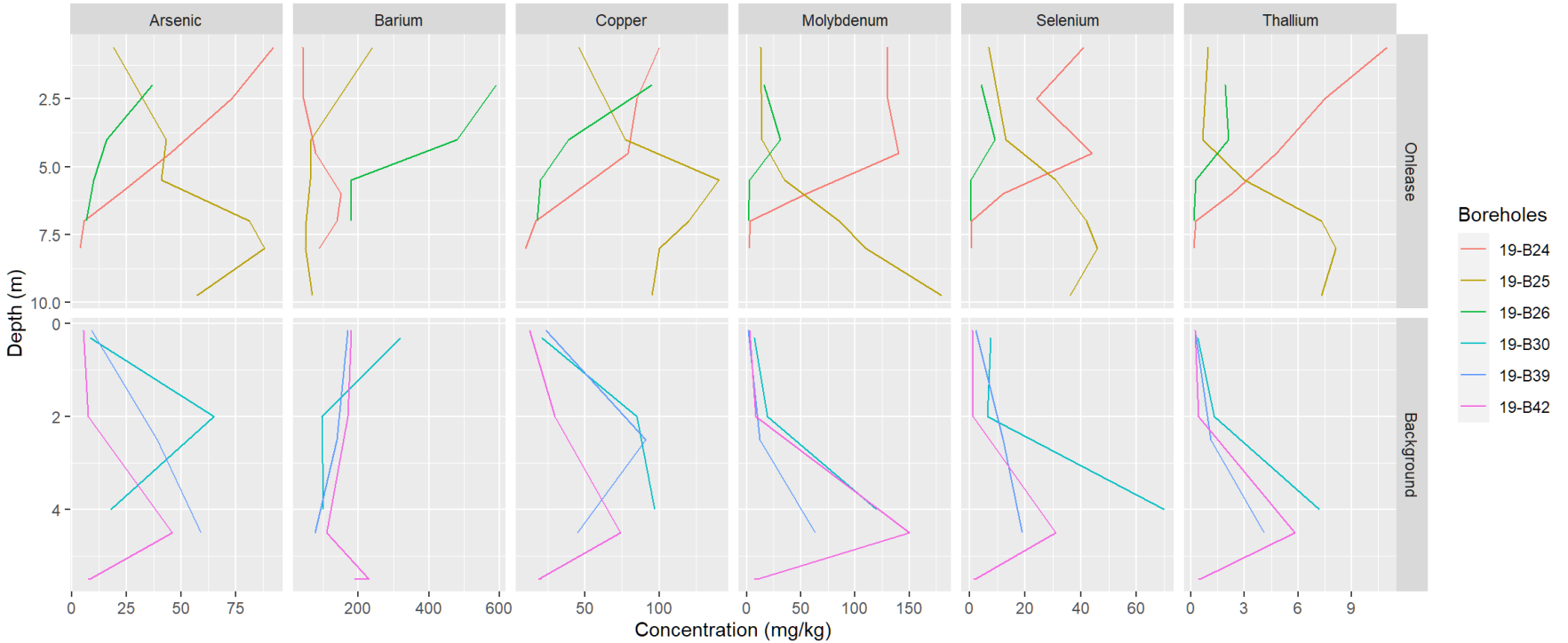


Correlation matrix for Trace Metals, Hydrogen and Sulphate specified by depths and location groups



Positive correlations are displayed in blue and negative correlations in red color. Color intensity and the size of the circle are proportional to the correlation coefficients. In the bottom of the graph, the legend color shows the correlation coefficients and the corresponding colors. We are only showing significant correlation coefficients, where p.value<=0.05.

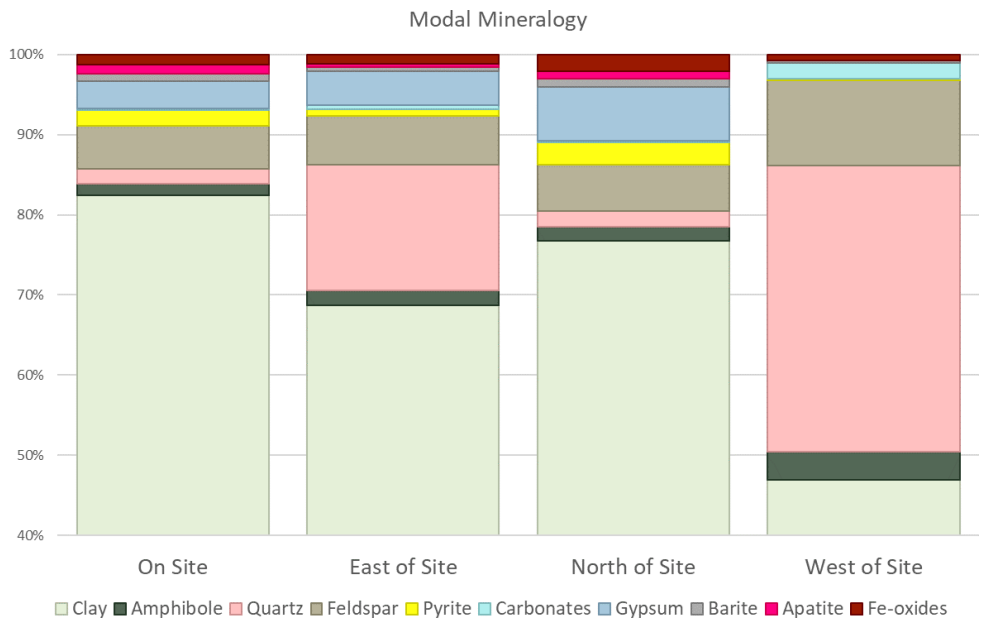
Vertical Profiles

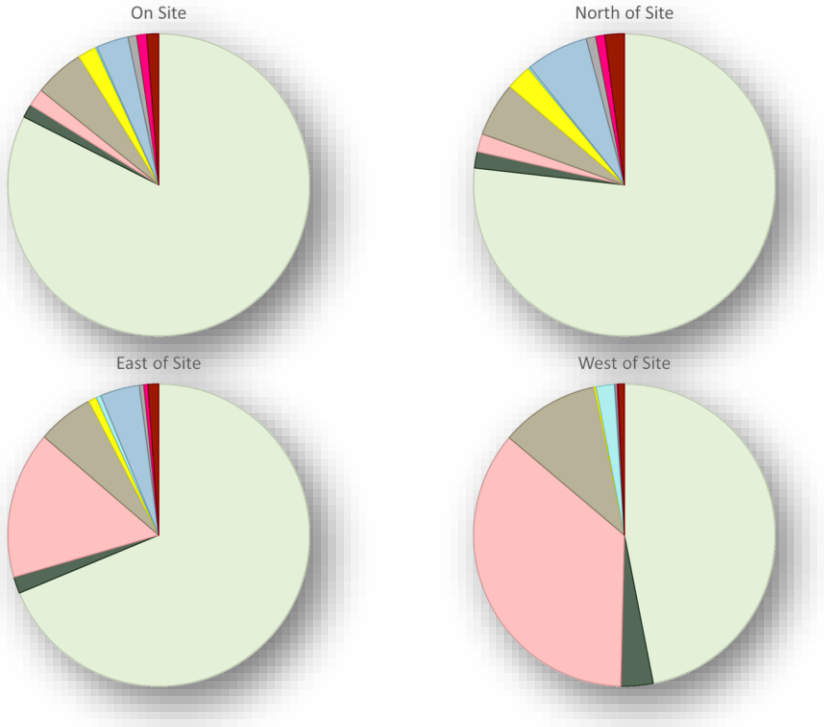


QEMSCAN

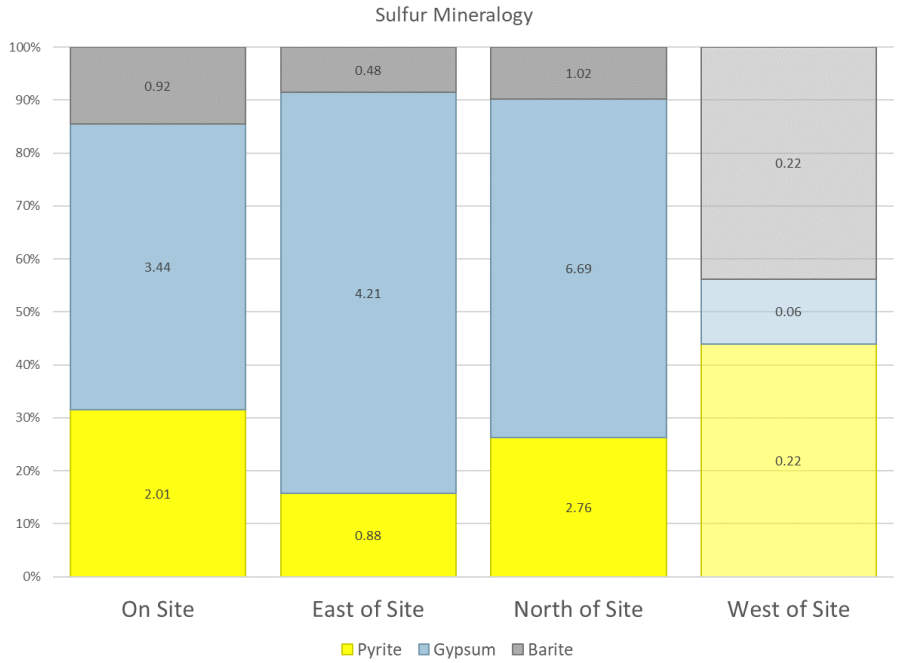
- **Q**uantitative **E**valuation of **M**ineralogy by **SCAN**ning electron microscopy
- Identifies mineral grains by combining SEM imaging and qualitative mineral chemical composition (EDX)
- Characterizes and counts mineral grains
  - Size, shape, mineral adjacencies
- Typical protocol – 100,000 grains and 1-5 million X-ray analyses
  - Detection limit on mineral grains is 1-10ppm

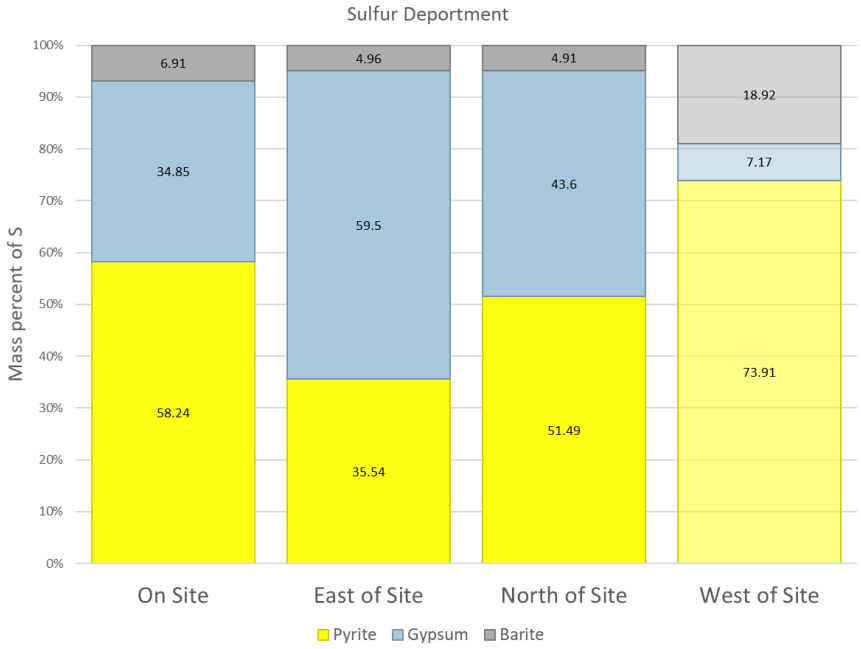
Modal Mineralogy



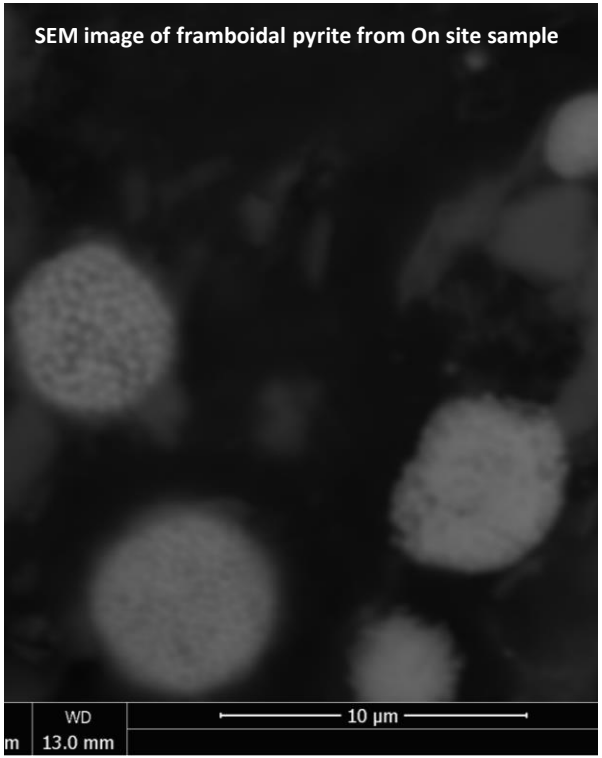


Sulfur Mineralogy and Deportment



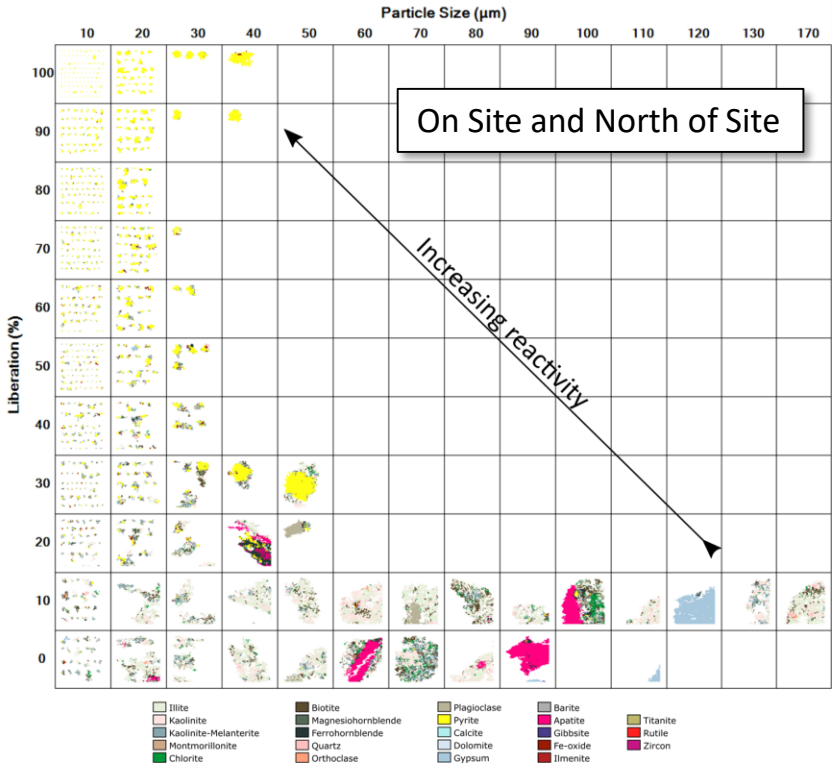


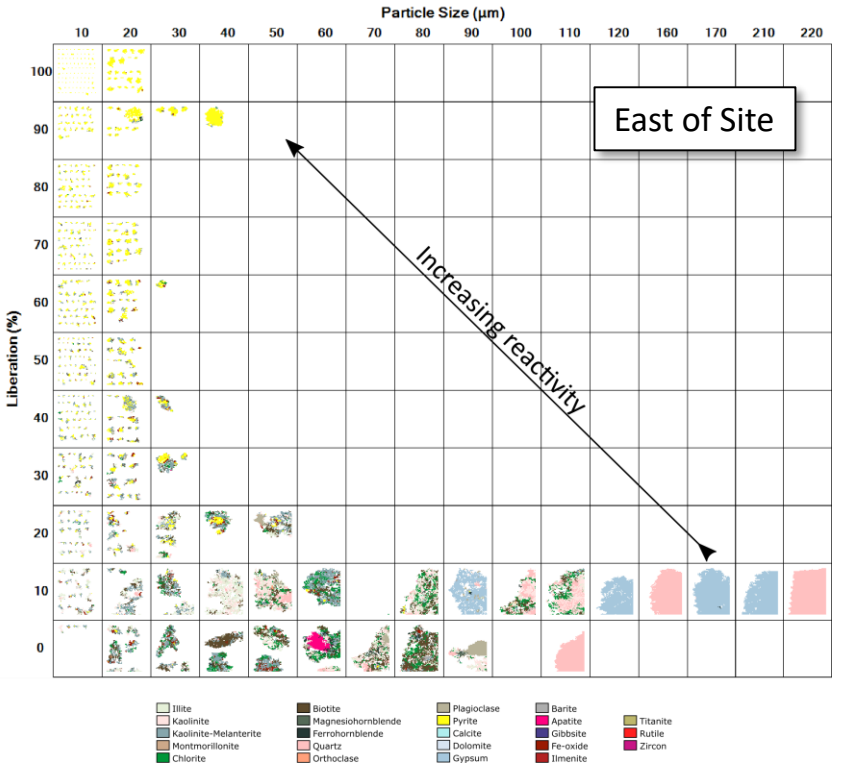
Pyrite Reactivity



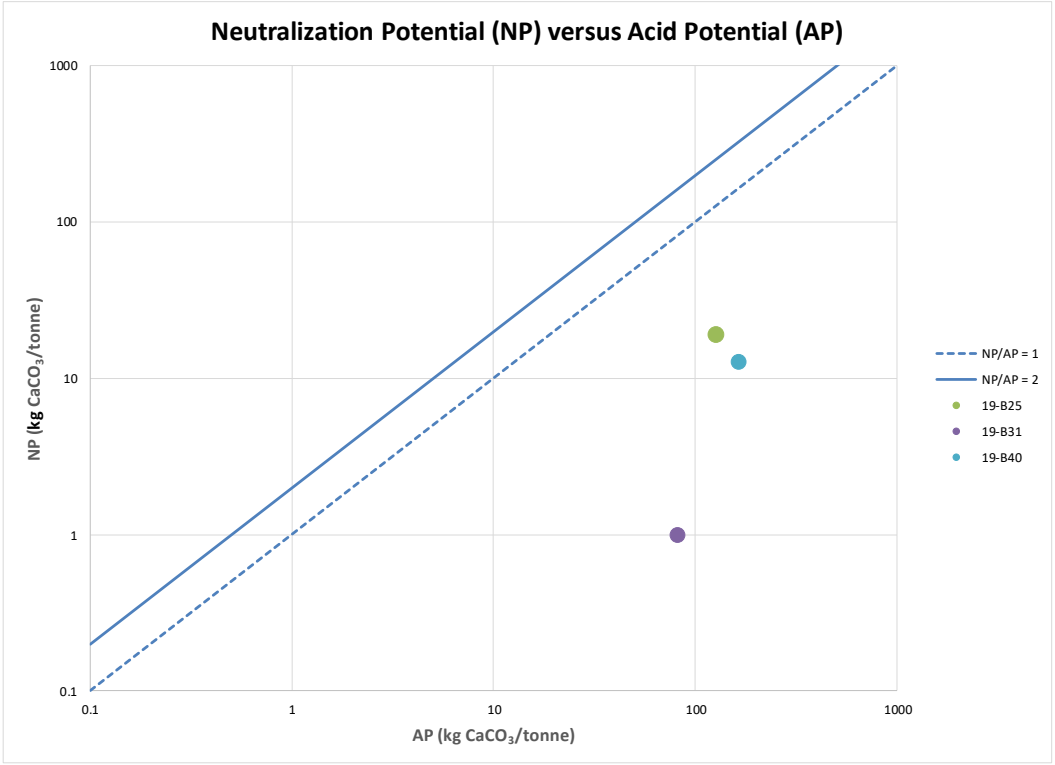
- Well known and established:
  - Oxidation of pyrite generates acid conditions
  - Finer grain sizes are more reactive
- Perhaps not always considered:
  - Pyrite locked inside non-reactive minerals can be excluded from acid-generation potential
- Combining pyrite grain size and liberation (degree of locking) gives more robust reactivity prediction

Pyrite Reactivity Matrices





Acid Base Accounting



Conclusions

- ☆ Found evidence that elevated soil metals on and off-site were attributable to naturally occurring shallow pyritic shale

Outcomes

- anticipated effort to achieve site closure substantially reduced
- remediation and reclamation will be best implemented with objective to achieve equivalent land capability rather than focussing on reaching generic guidelines

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