



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

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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

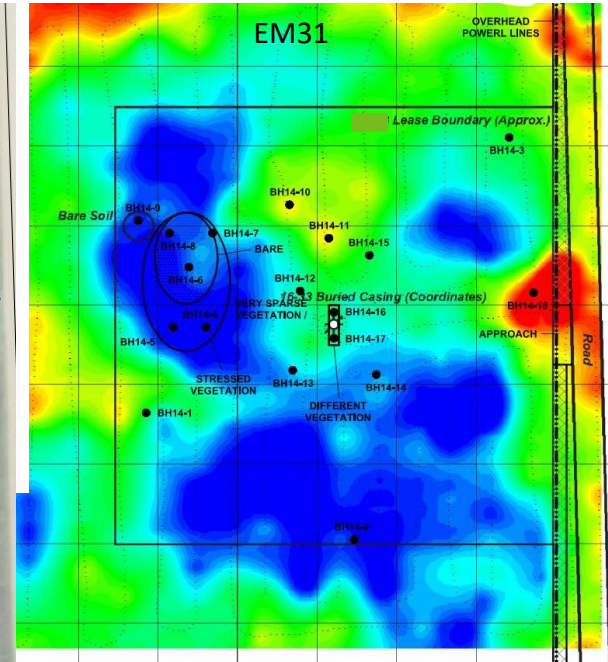
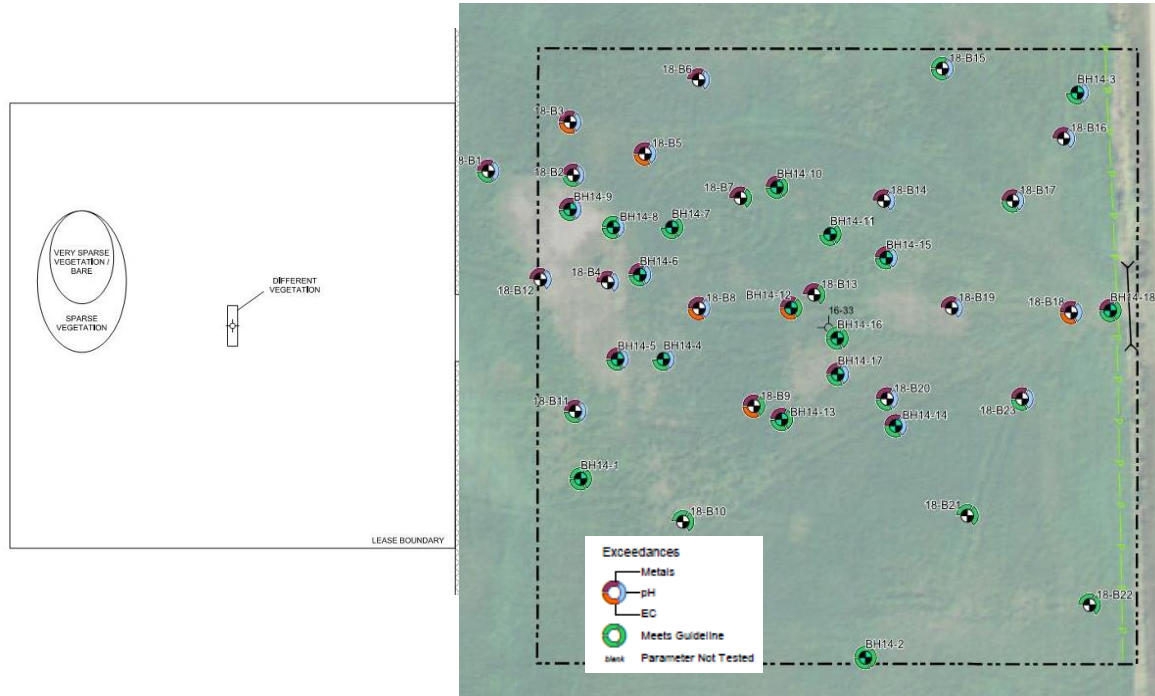
- ❑ focused on site footprint
- ❑ sampling targeted surface-spread drilling waste and bare areas west of and at well centre
- ❑ 12 elevated trace metals and acidic pH encountered in soil profile
 - ❑ potential source – drilling waste and associated cuttings
- ❑ soil parent material – combination of till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

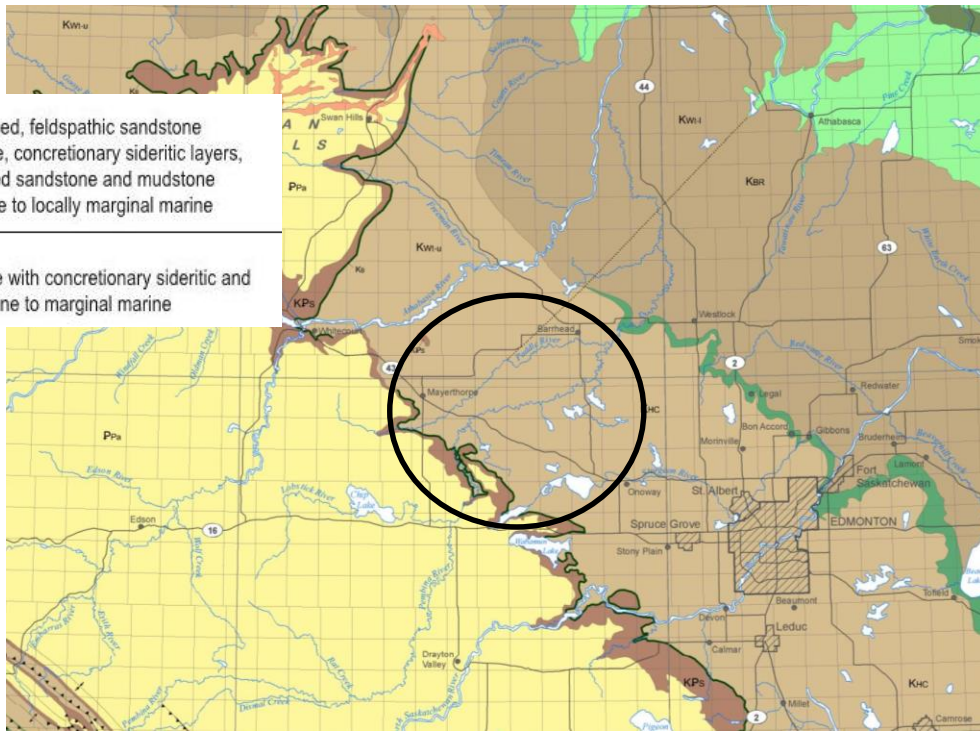


KHC

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



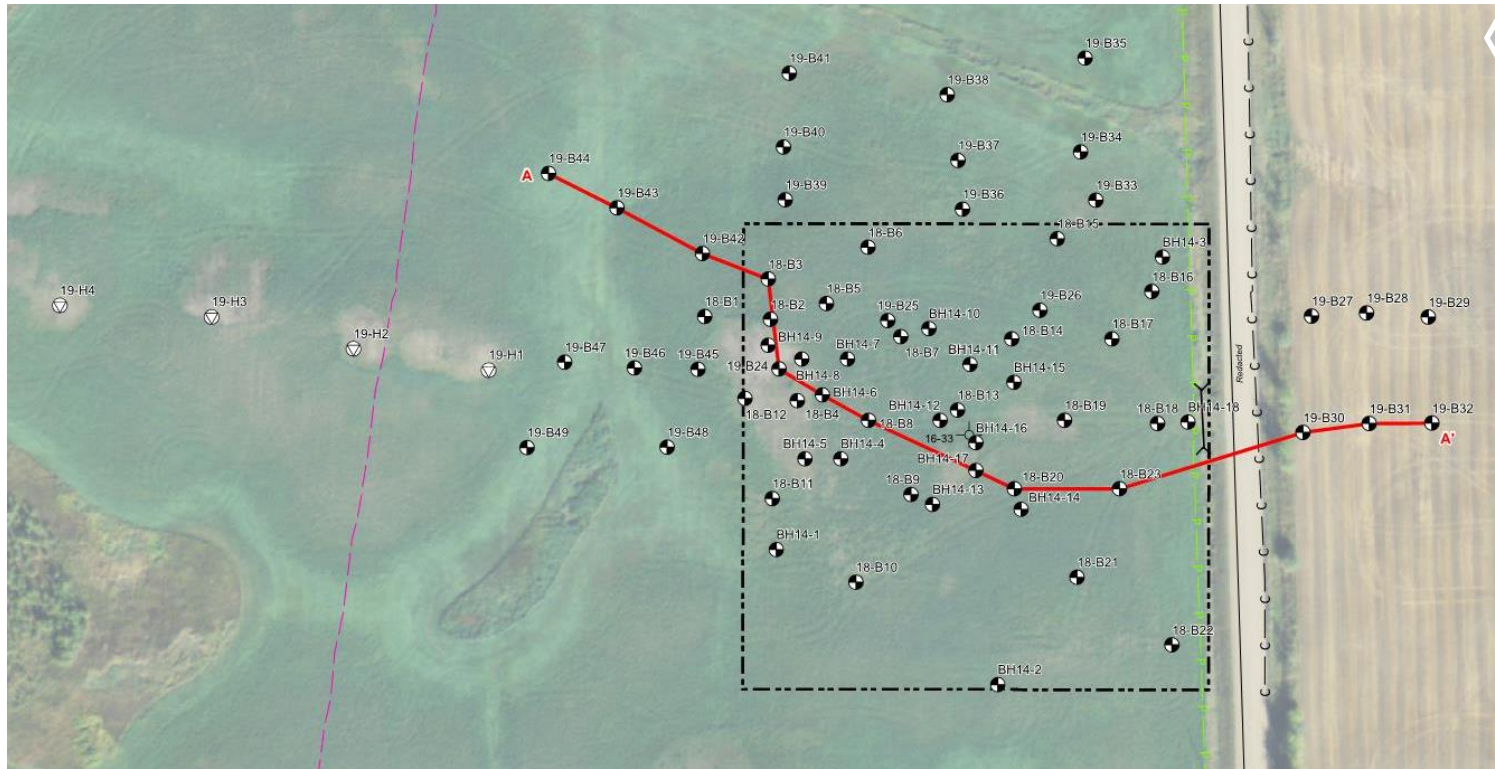
2019 ESA Methods

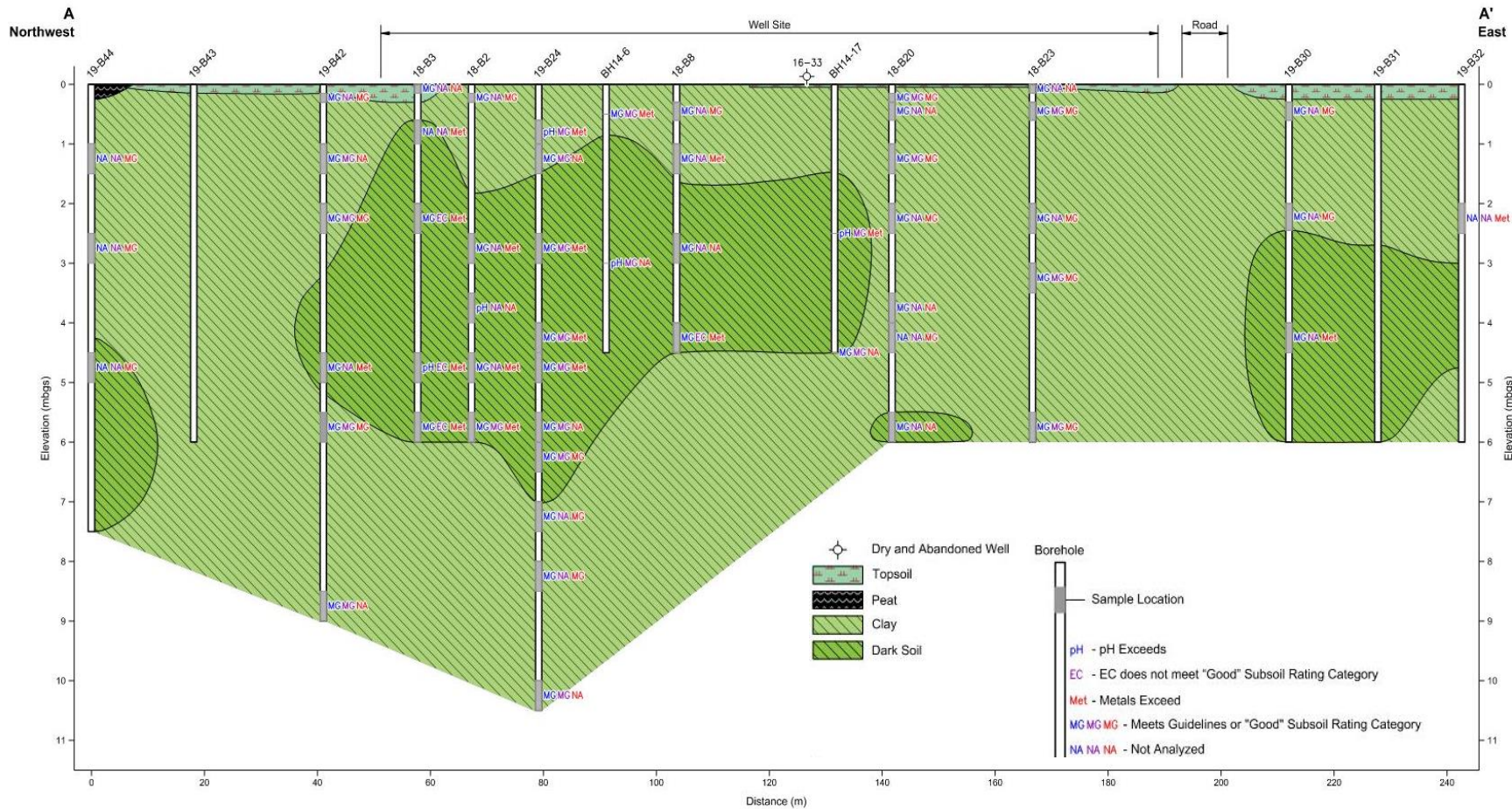
- ❑ December 2019 – drilled 26 boreholes by solid stem auger
 - ❑ Original objective to delineate metals and pH
 - ❑ Deeper soils within former lease boundary
 - ❑ Background soils to west, north and east
 - ❑ Maximum depth – 10.5 m below ground surface
 - ❑ 4 hand auger holes in bare areas west of site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



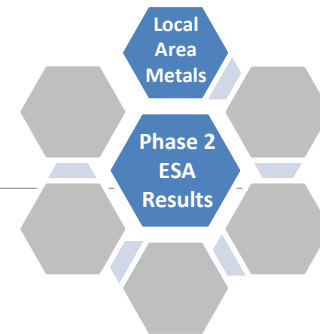


2019 ESA Results





Background Metals



Periodic Table of the Elements

1 IA 11A												18 VIIIA 8A					
1 H Hydrogen 1.008											2 He Helium 4.003						
3 Li Lithium 6.941	4 Be Beryllium 9.012											10 Ne Neon 20.180					
11 Na Sodium 22.990	12 Mg Magnesium 24.305	3 IIB 3B	4 IVB 4B	5 VB 5B	6 VIB 6B	7 VIIB 7B	8 VIII 8	9 VIII 9	10 VIII 10	11 IB 11	12 IIB 12	17 VIIA 7A	18 Ar Argon 39.948				
19 K Potassium 39.098	20 Ca Calcium 40.078	21 Sc Scandium 44.956	22 Ti Titanium 47.88	23 V Vanadium 50.942	24 Cr Chromium 51.996	25 Mn Manganese 54.938	26 Fe Iron 55.933	27 Co Cobalt 58.933	28 Ni Nickel 58.693	29 Cu Copper 63.546	30 Zn Zinc 65.39	33 As Arsenic 74.922	34 Se Selenium 78.03	35 Br Bromine 79.904	36 Kr Krypton 84.96		
37 Rb Rubidium 84.466	38 Sr Strontium 87.62	39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molybdenum 95.94	43 Tc Technetium 98.907	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.906	46 Pd Palladium 106.42	47 Ag Silver 107.868	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.71	51 Sb Antimony 121.760	52 Te Tellurium 127.6	53 I Iodine 126.904	54 Xe Xenon 131.29
55 Cs Cesium 132.905	56 Ba Barium 137.327	57-71 Lanthanide Series	72 Hf Hafnium 178.49	73 Ta Tantalum 180.948	74 W Tungsten 183.85	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.22	78 Pt Platinum 195.08	79 Au Gold 196.967	80 Hg Mercury 200.59	81 Tl Thallium 204.383	82 Pb Lead 207.2	83 Bi Bismuth 208.980	84 Po Polonium [208.982]	85 At Astatine 208.987	86 Rn Radon 222.018
87 Fr Francium 223.020	88 Ra Radium 226.025	89-103 Actinide Series	104 Rf Rutherfordium [261]	105 Db Dubnium [262]	106 Sg Seaborgium [266]	107 Bh Bohrium [264]	108 Hs Hassium [269]	109 Mt Meitnerium [268]	110 Ds Darmstadtium [269]	111 Rg Roentgenium [272]	112 Cn Copernicium [277]	113 Uut Ununtrium unknown	114 Fl Flerovium [289]	115 Uup Ununpentium unknown	116 Lv Livermorium [293]	117 Uus Ununseptium unknown	118 Uuo Ununoctium unknown
57 La Lanthanum 138.906	58 Ce Cerium 140.115	59 Pr Praseodymium 140.908	60 Nd Neodymium 144.24	61 Pm Promethium 144.913	62 Sm Samarium 150.36	63 Eu Europium 151.966	64 Gd Gadolinium 157.25	65 Tb Terbium 158.925	66 Dy Dysprosium 162.50	67 Ho Holmium 164.930	68 Er Erbium 167.26	69 Tm Thulium 168.934	70 Yb Ytterbium 173.04	71 Lu Lutetium 174.967			
89 Ac Actinium 227.028	90 Th Thorium 232.038	91 Pa Protactinium 231.036	92 U Uranium 238.029	93 Np Neptunium 237.048	94 Pu Plutonium 244.064	95 Am Americium 243.061	96 Cm Curium 247.070	97 Bk Berkelium 247.070	98 Cf Californium 251.080	99 Es Einsteinium [254]	100 Fm Fermium 257.095	101 Md Mendelevium 258.1	102 No Nobelium 259.101	103 Lr Lawrencium [262]			

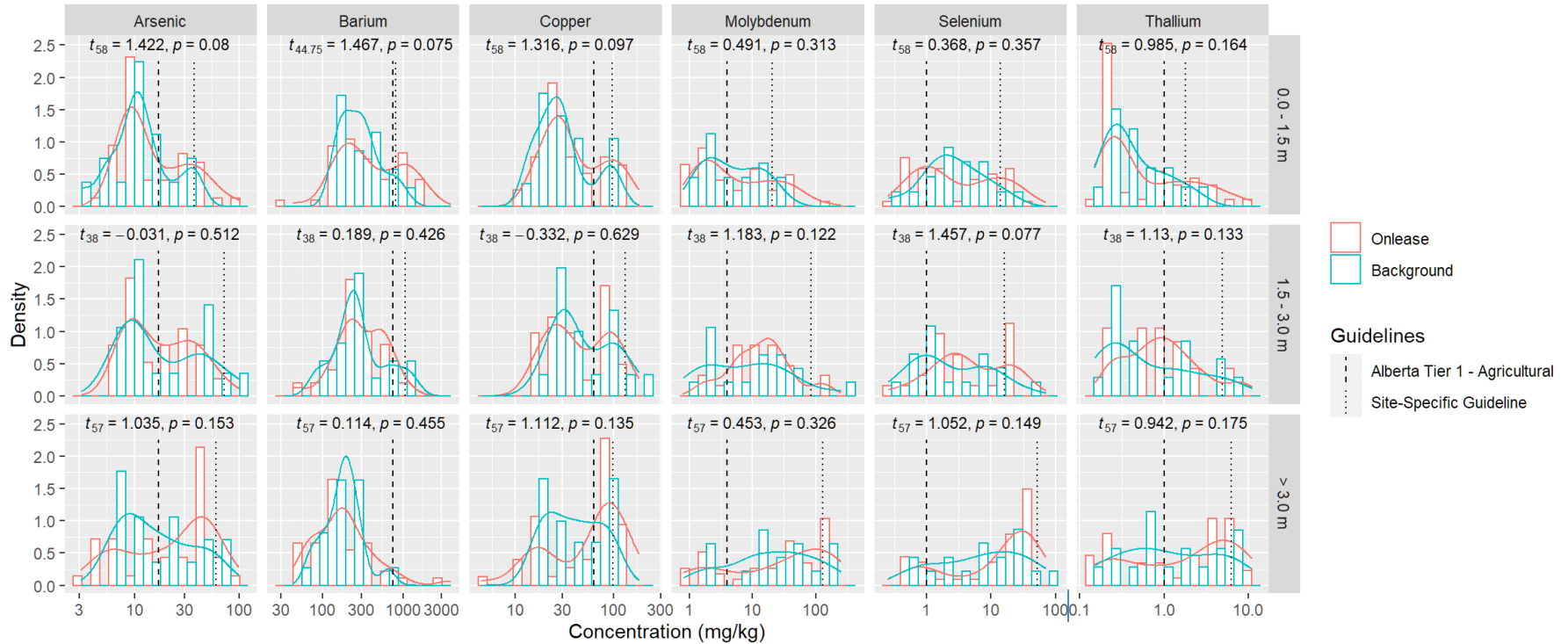
Atomic Number	Symbol	Name	Atomic Mass
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Alkali Metal	Alkaline Earth	Transition Metal	Basic Metal	Semimetal	Nonmetal	Halogen	Noble Gas	Lanthanide	Actinide
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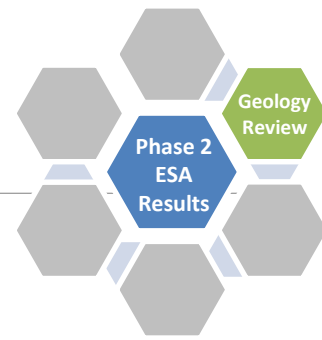
Source: Helmenstine 2013



Background Metals



Detailed Geology Review



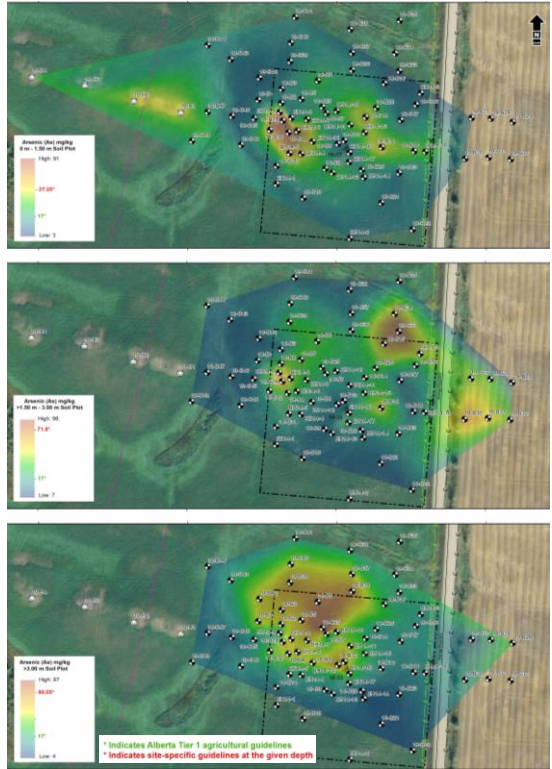
- ❑ Thickness of Horseshoe Canyon Formation (HCF) beneath former lease ~ 300 m
- ❑ Surficial geology is melt-out till associated with the Quaternary Laurentide Ice Sheet – thickness < 25 m
- ❑ Shallow boreholes encountered sediments at some locations that were consistent with glacial till
- ❑ HCF and 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



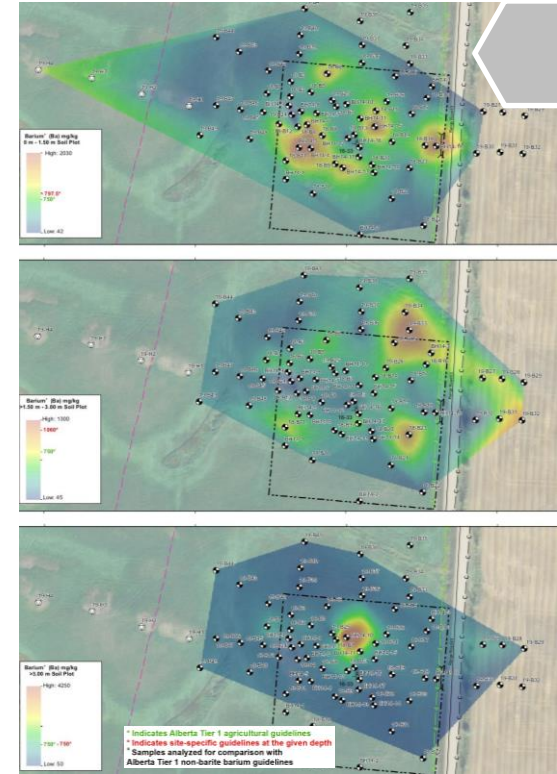
Contour Mapping



Arsenic

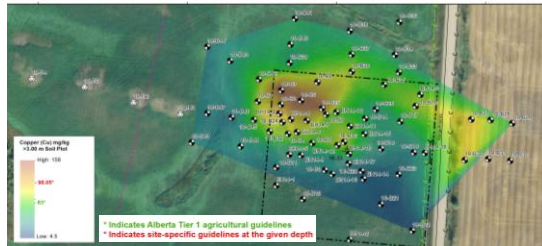
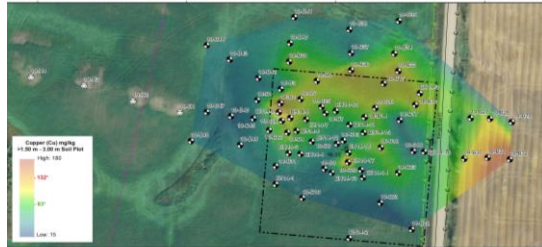
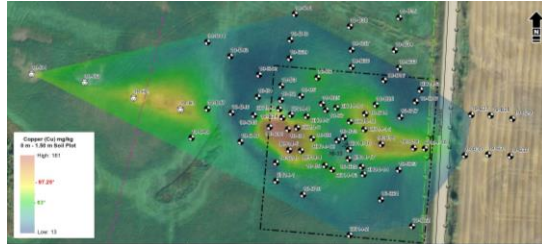


Barium

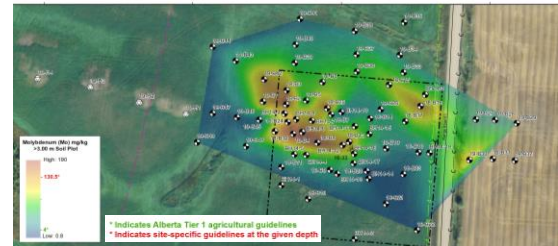
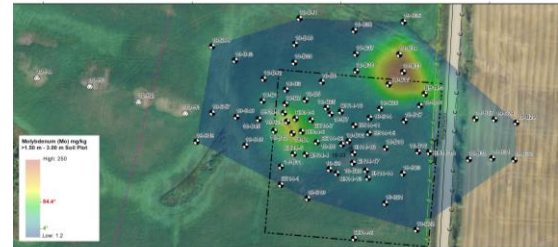
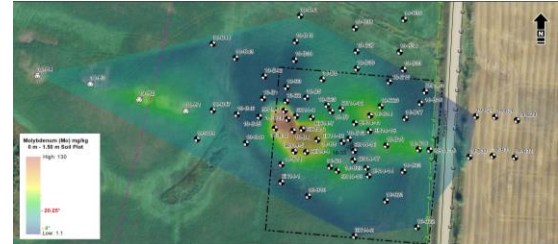


Contour Mapping

Copper

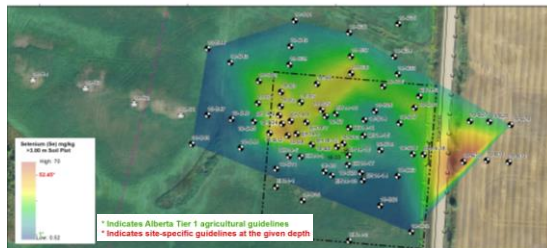
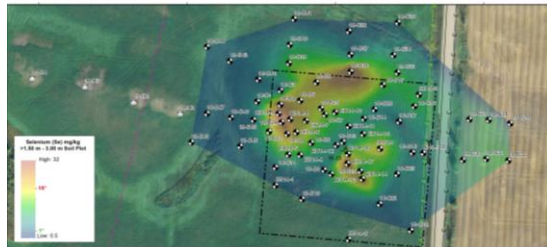
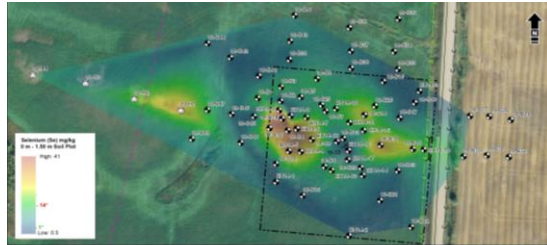


Molybdenum

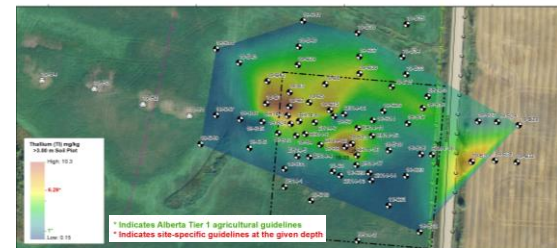
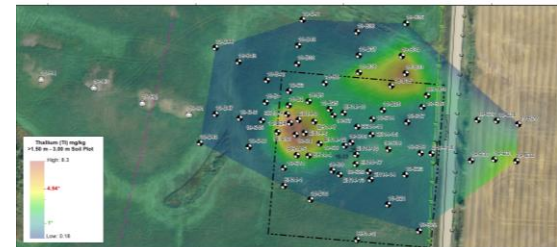
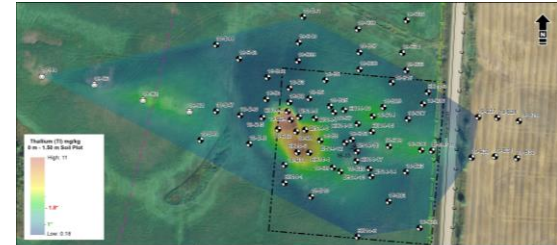


Contour Mapping

Selenium

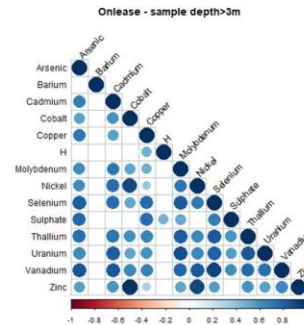
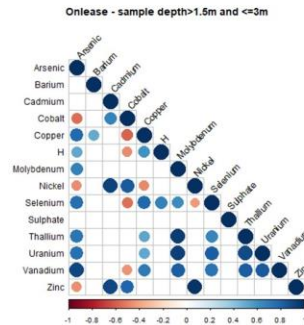
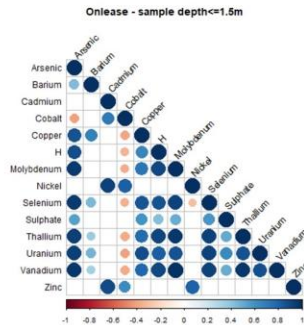
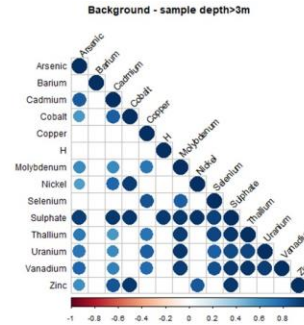
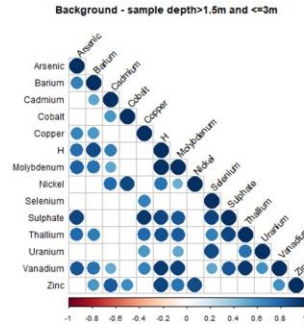
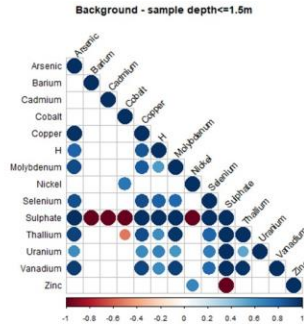
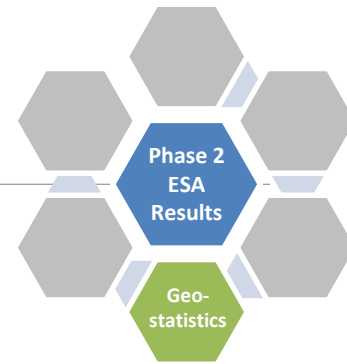


Thallium



Geostatistical Profiling

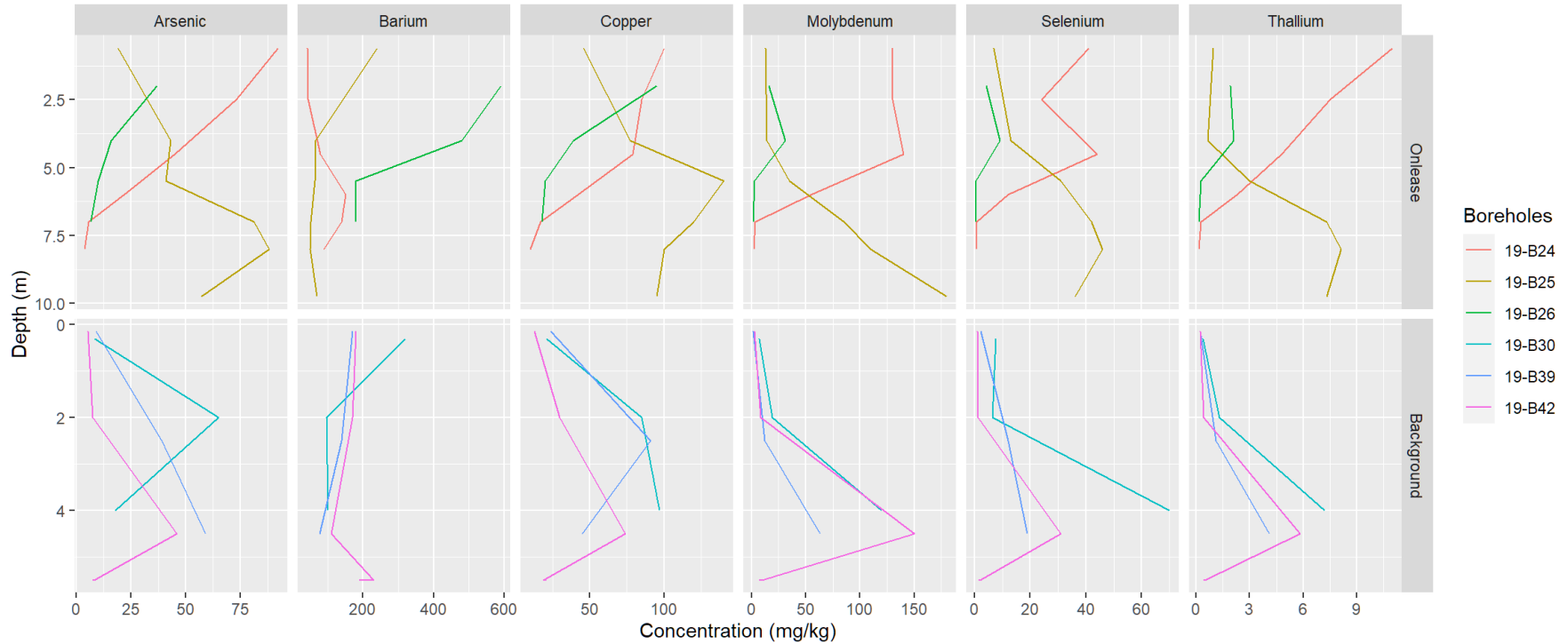
Correlation matrix for Trace Metals, Hydrogen and Sulphate specified by depths and location groups



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 $p.value \leq 0.05$.



Vertical Profiles

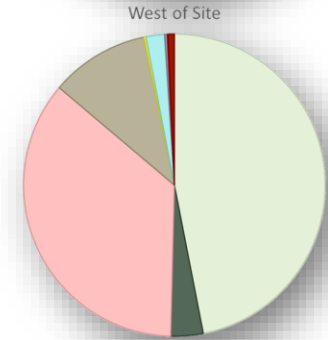
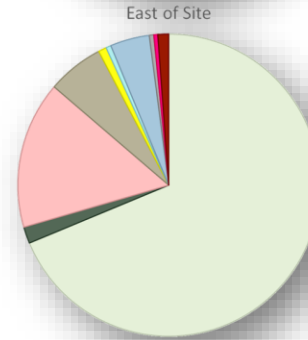
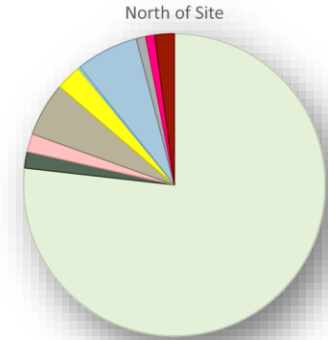
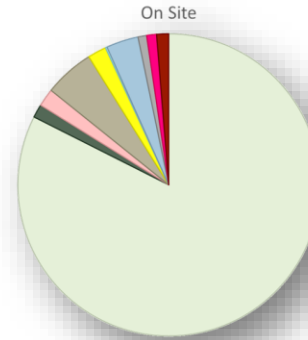
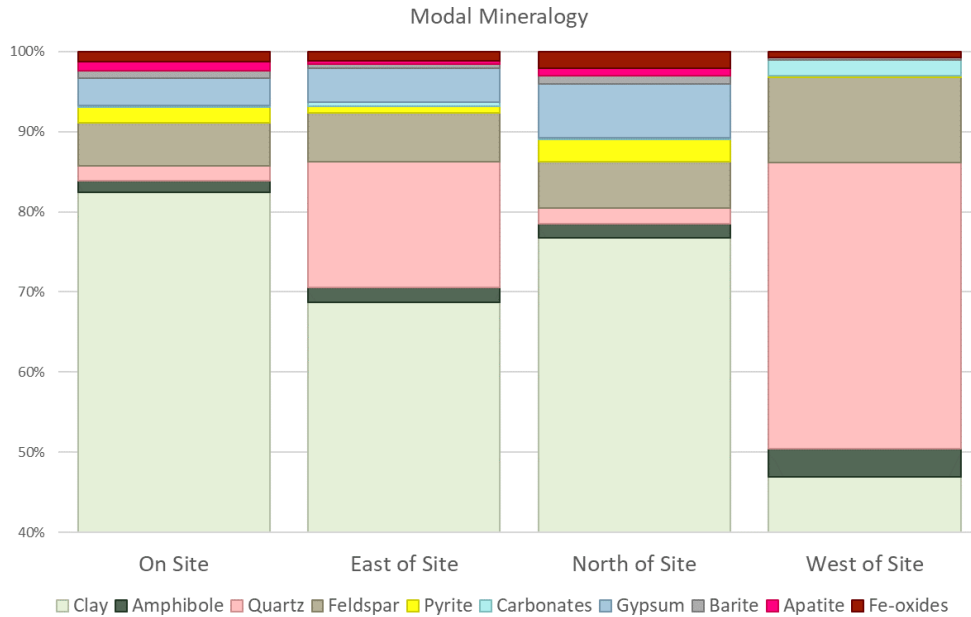


QEMSCAN

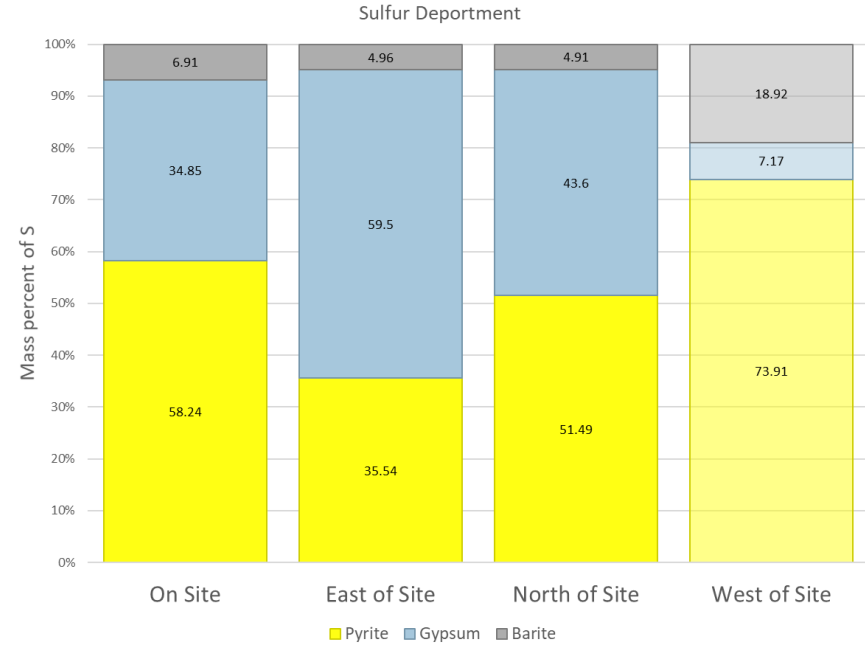
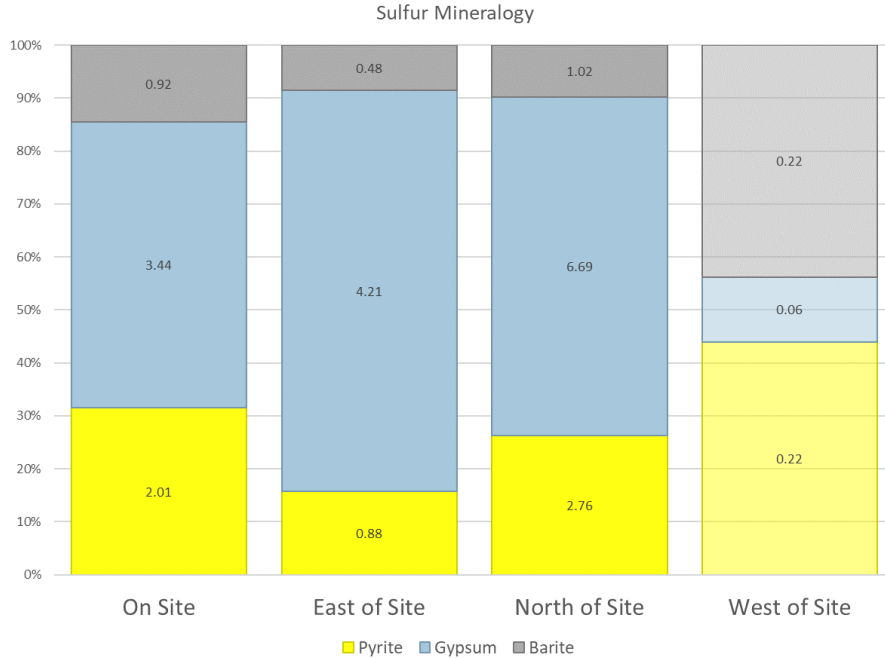
- ❑ Quantitative **E**valuation of **M**ineralogy by **S**CANning electron microscopy
- ❑ Identifies mineral grains by combining SEM imaging and qualitative mineral chemical composition (EDX)
- ❑ Characterizes and counts mineral grains
 - ❑ Size, shape, mineral adjacencies
- ❑ Typical protocol – 100,000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



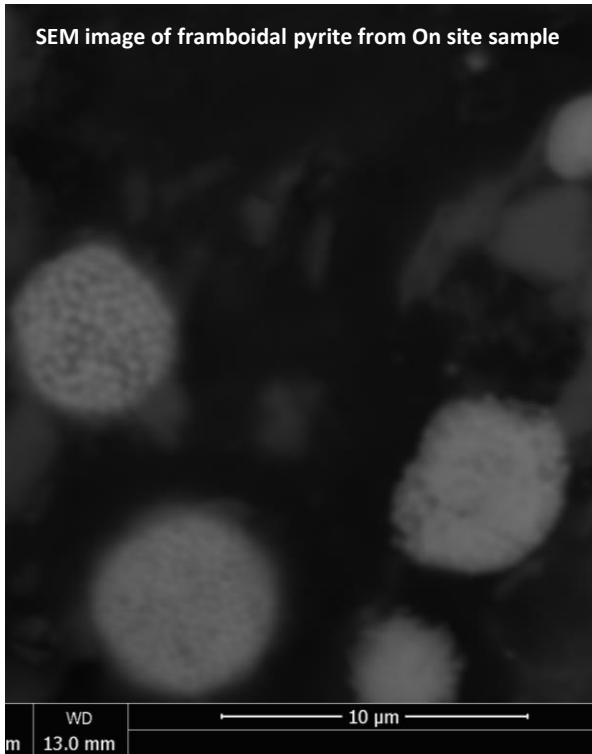
Modal Mineralogy



Sulfur Mineralogy and Department



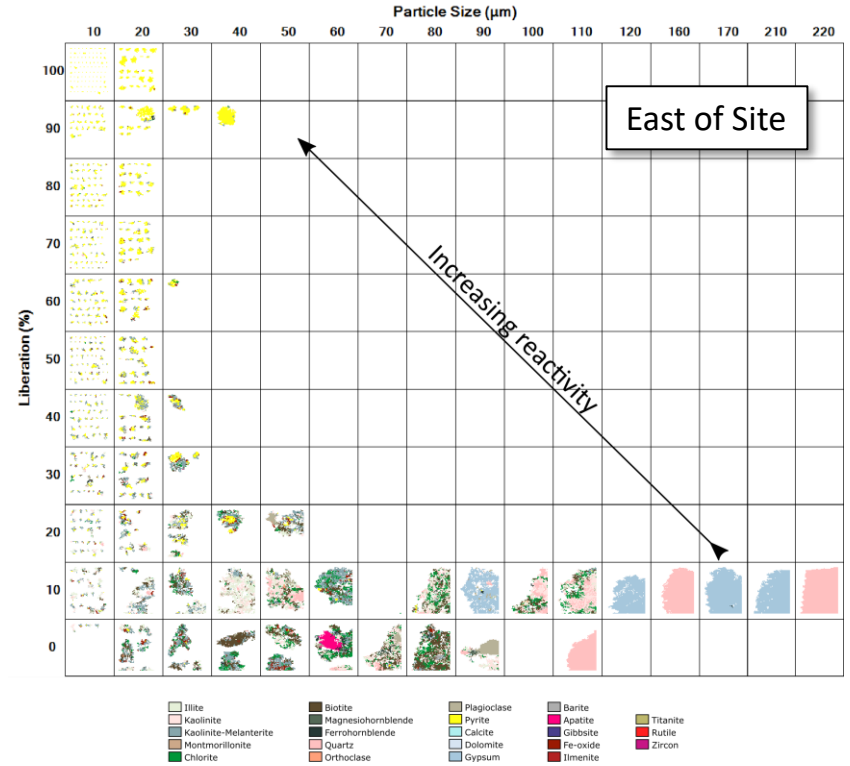
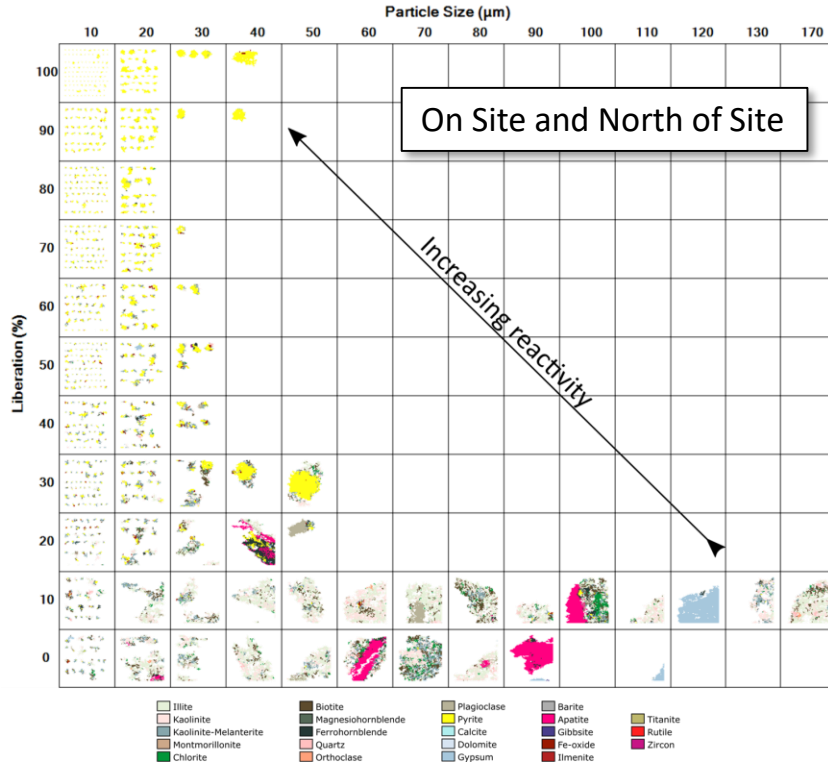
Pyrite Reactivity



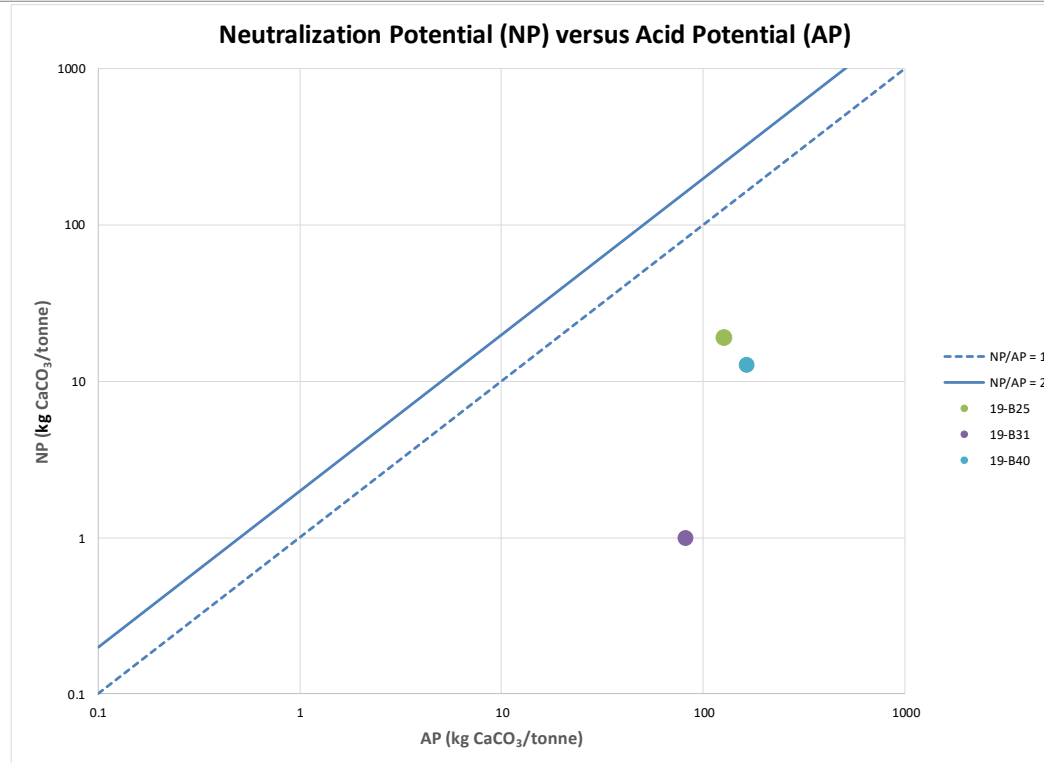
- ❑ Well known and established:
 - ❑ Oxidation of pyrite generates acid conditions
 - ❑ Finer grain sizes are more reactive
- ❑ Perhaps not always considered:
 - ❑ Pyrite locked inside non-reactive minerals can be excluded from acid-generation potential
- ❑ Combining pyrite grain size and liberation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