Hyperspectral analysis of an open-pit mine for qualitative and quantitative features related to seasonal changes in acid mine drainage

2014 HyspIRI Science and Applications Workshop
Wednesday, October 15

Gwen Davies
MS Hydrogeology Candidate
Graduate Program of Hydrologic Sciences
University of Nevada, Reno

Outline

- Motivation
- Background
  - AMD
  - Pyrite weathering rates
  - Study site
- Objectives of Study
  1. Mineralogy
  2. Mine Water
- Mineralogy
  - Methods
  - Preliminary data
- Water Spectra
  - Methods
  - Preliminary data

Motivation

- Some 20,000 km of river are contaminated by hardrock mining in U.S. (EPA, 1997).
- About 40 pit lakes in the state of Nevada, and increasing (Shevenell, 1999).
- Hyperspectral RS a tool for rapid assessment of acid mine drainage contamination and monitoring environmental quality/regulatory compliance.

Acid Mine Drainage (AMD)

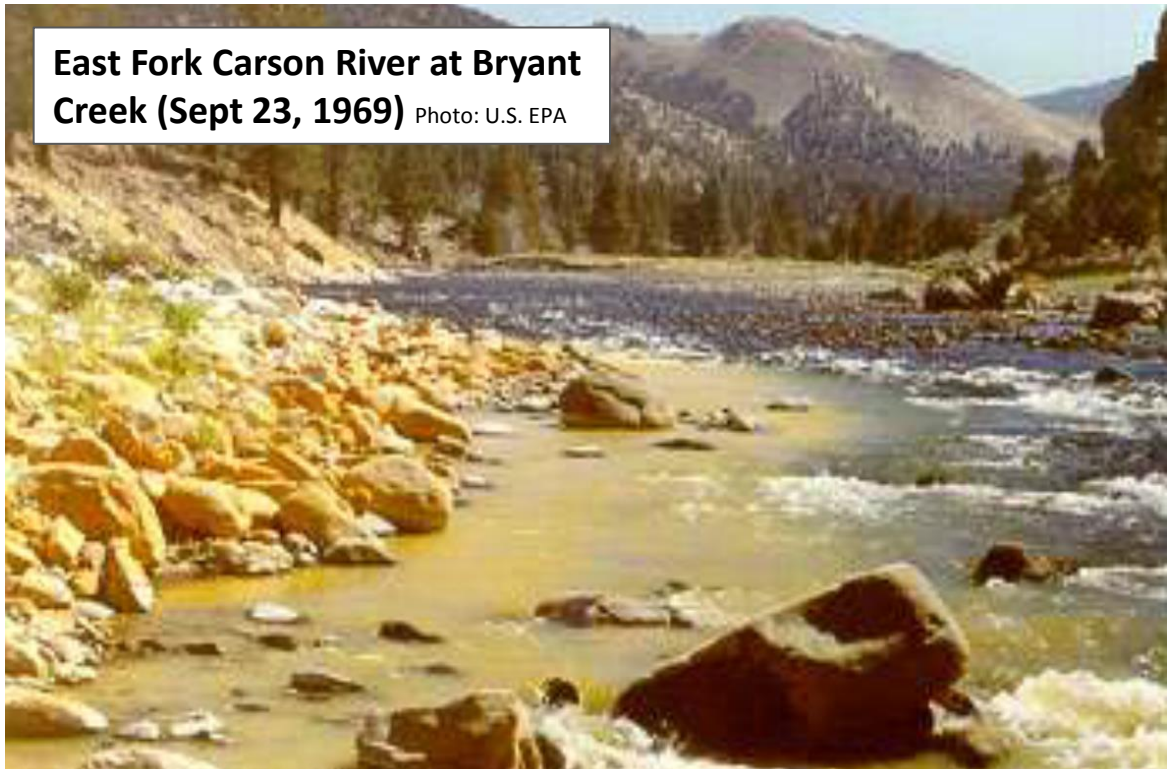
- Exposure of metal sulfides to oxygen and water produces chemical instability, resulting in acid generating reactions and the formation of insoluble Fe OH^- and soluble Fe SO_4^{2-}.

$$FeS_2\ (s) + 15/4\ O_2\ (aq) + 7/2\ H_2O\ (l) \rightarrow$$

$$Fe(OH)_3\ (s) + 2H_2SO_4\ (aq)$$

- Precipitant speciation controlled by pH, oxidation state, moisture content. Common fe-bearing minerals: copiapite, jarosite, goethite, ferrihydrite, hematite.

Leviathan Creek 3 miles down from mine site (1999) Photo: U.S. EPA



East Fork Carson River at Bryant Creek (Sept 23, 1969) Photo: U.S. EPA

Pyrite Weathering

Mechanisms:

- Atmospheric gases, meteoric water, microorganisms.

Reaction Rates Influenced by:

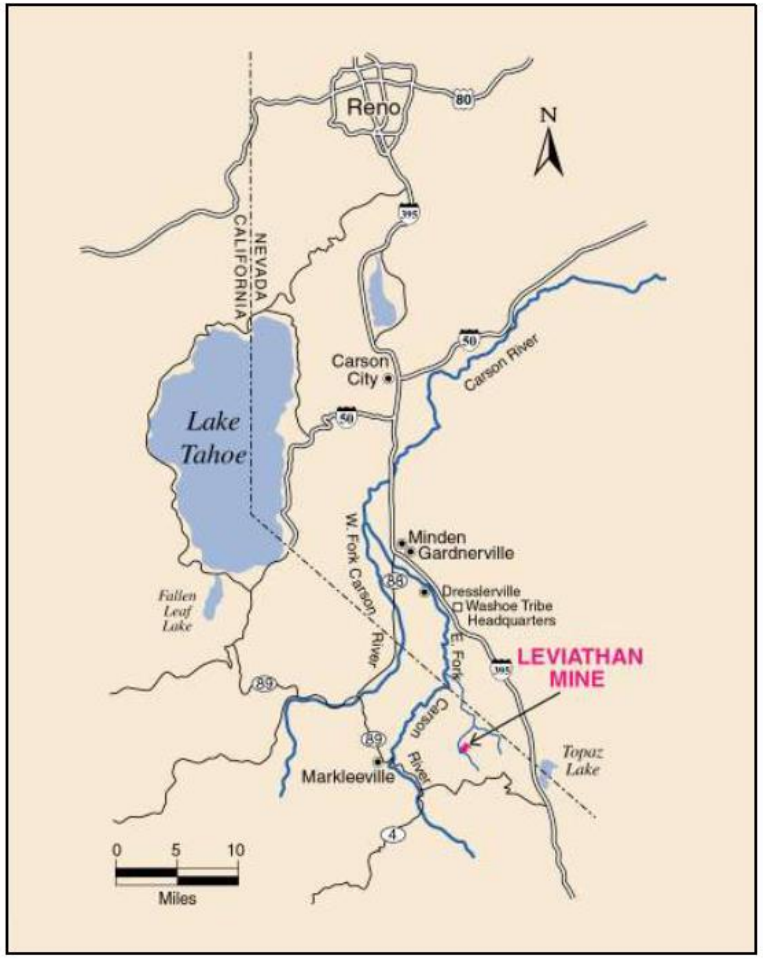
- Mineral's composition, crystal size/shape, surface area, and crystal perfection
- Volume of weathering solution
- pH and dissolved CO_2 content of weathering solution
- Temperature

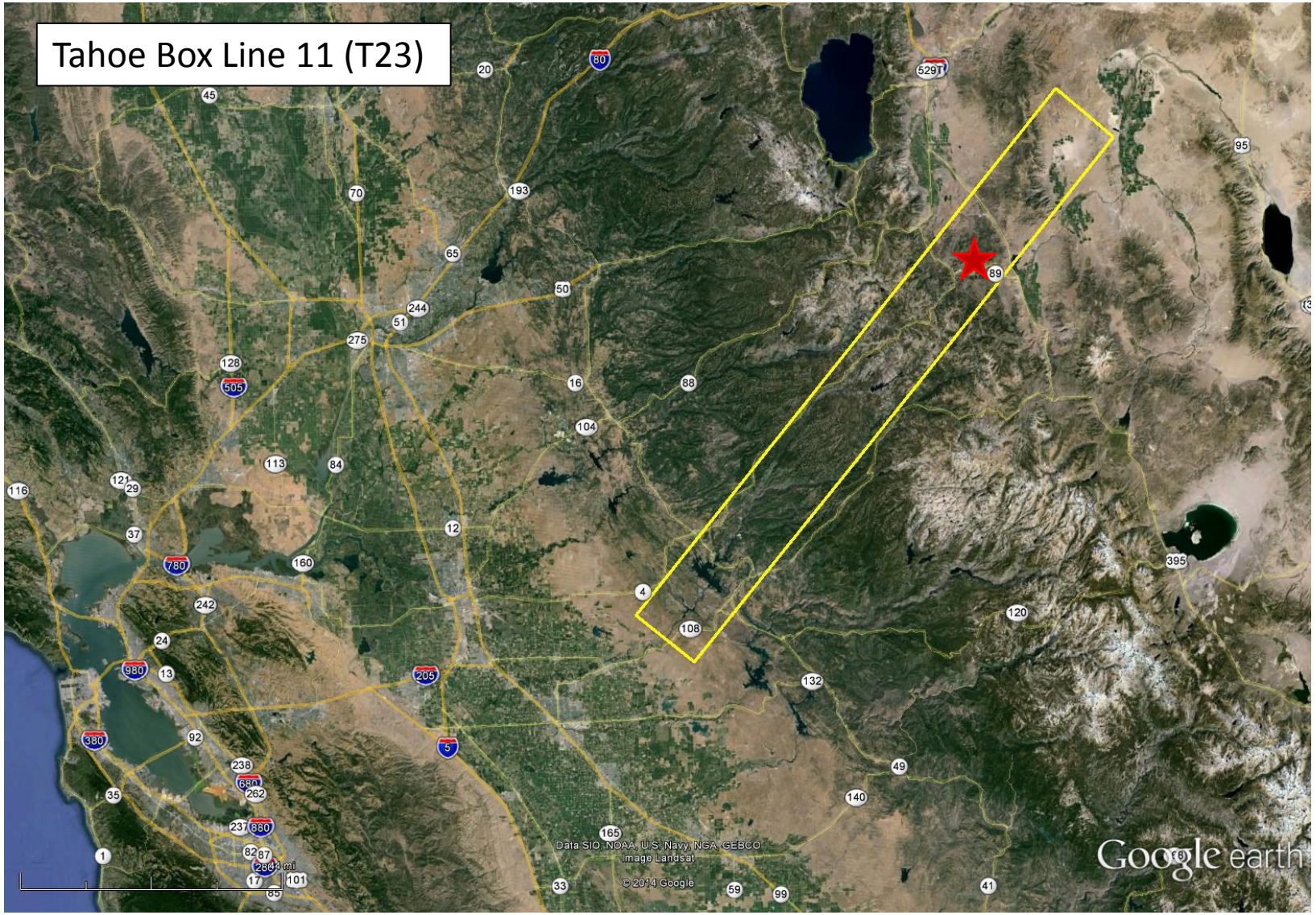
Rate of pyrite oxidation:

- Rates found at Leviathan Mine by Ball and Nordstrom (1989), 40 mmol/hr
- For reference, silicate weathering rates, 0.4-1.5 mmol/day (Colman, 1981).

Weathering rates of pyrite oxidation products varies as well.

Leviathan Superfund Site





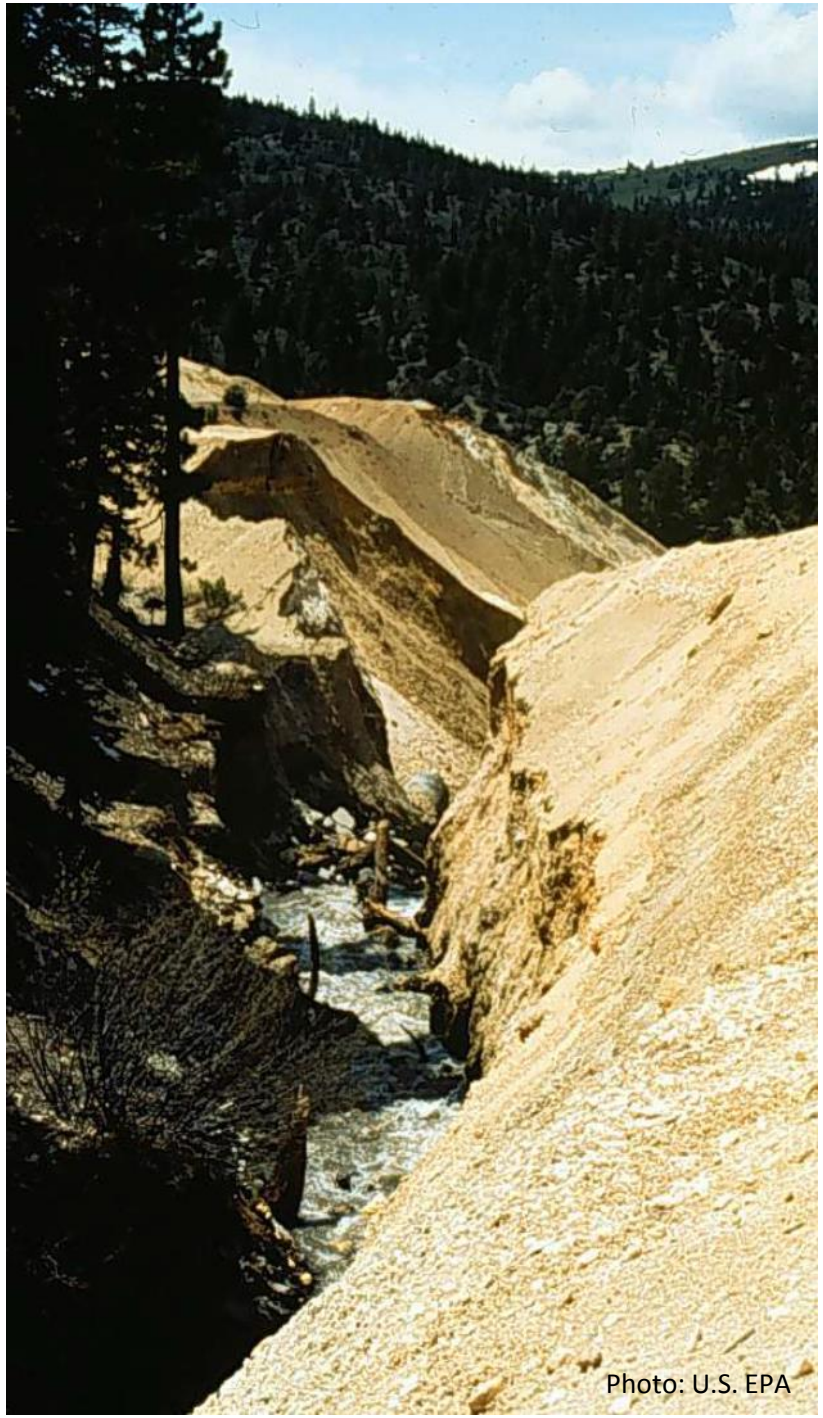


Photo: U.S. EPA

Leviathan Mine, post mining 1980

Leviathan Creek

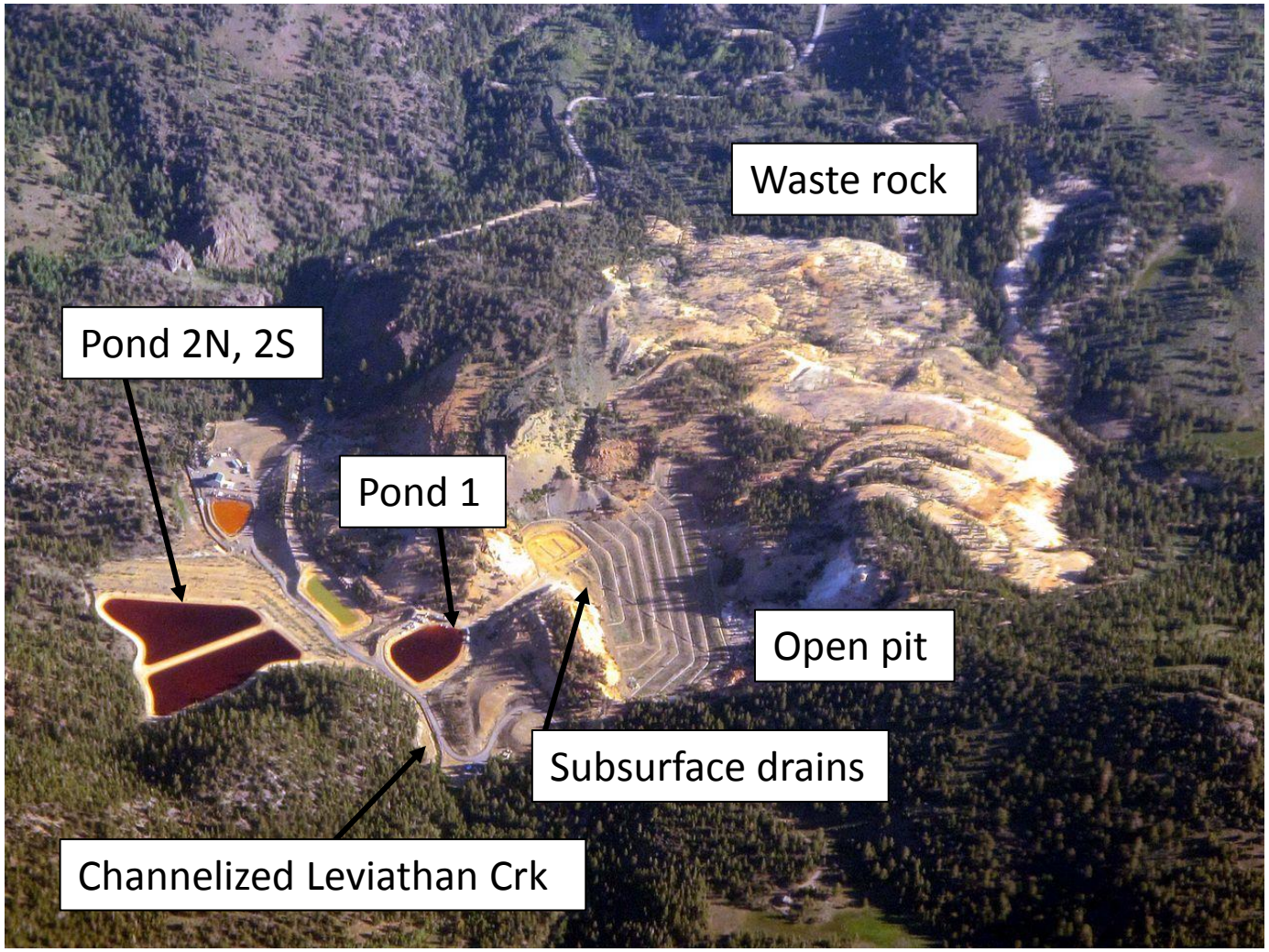
Photo: USGS Carson City, NV

N

200 m

Leviathan Superfund Site

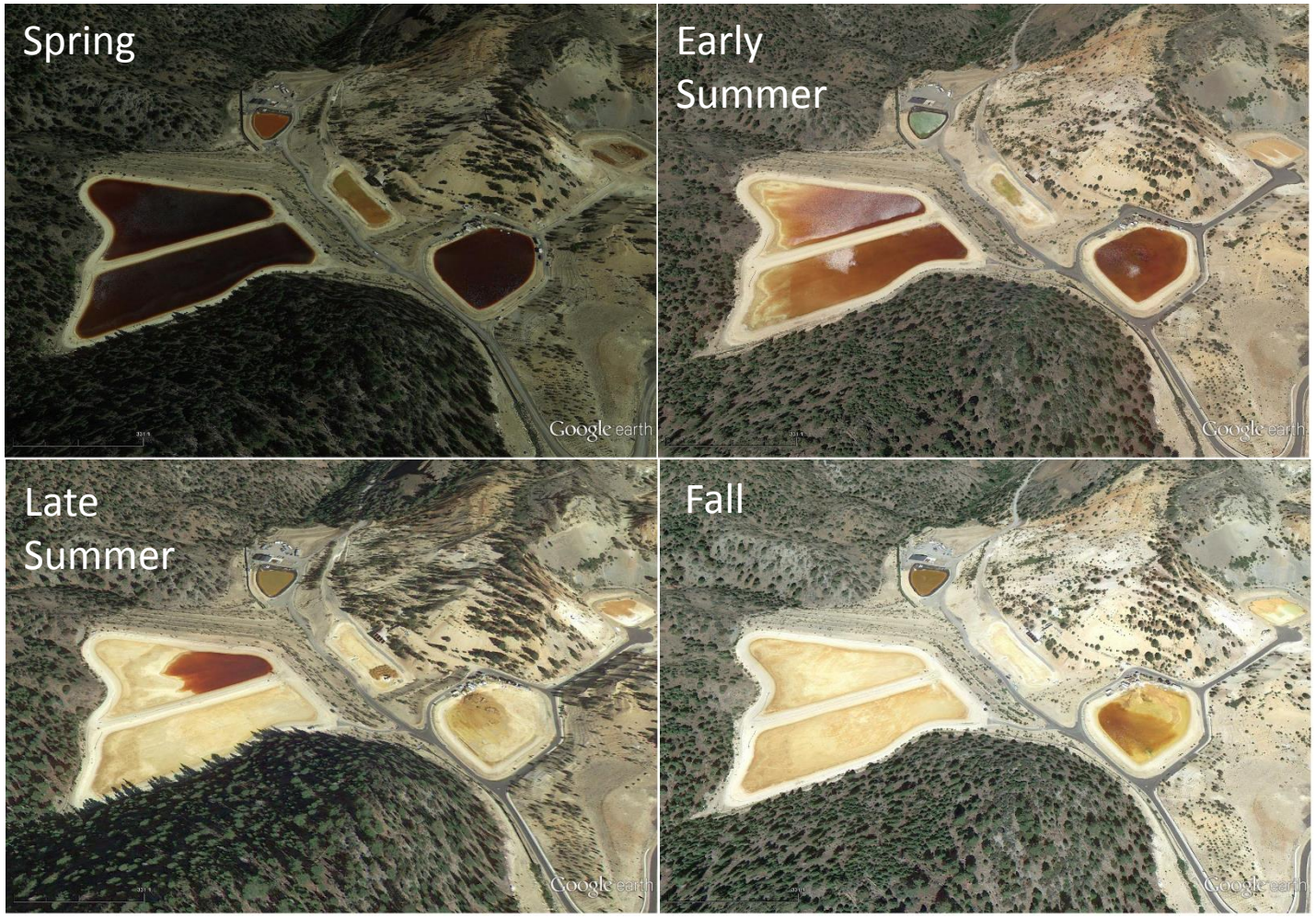
- 3 million gallons treated annually
- Pond water composition:
  - pH 2.5
  - 660 mg/L Fe
  - 2.1 mg/L As
  - 3200 mg/L SO_4
- 200 acres disturbed land, 12 acre pond surface area
- Seasonality of evaporation ponds (captured by HyspIRI flights)



Leviathan Mine 2010 aerial photo (Wikipedia.org)

Leviathan Superfund Site

- 3 million gallons treated annually
- Pond water composition:
  - pH 2.5
  - 660 mg/L Fe
  - 2.1 mg/L As
  - 3200 mg/L SO_4
- 200 acres disturbed land, 12 acre pond surface area
- Seasonality of evaporation ponds (captured by HyspIRI flights)



Google Earth Images


Pond 3 (meteoric water collection) on 04/24/2014

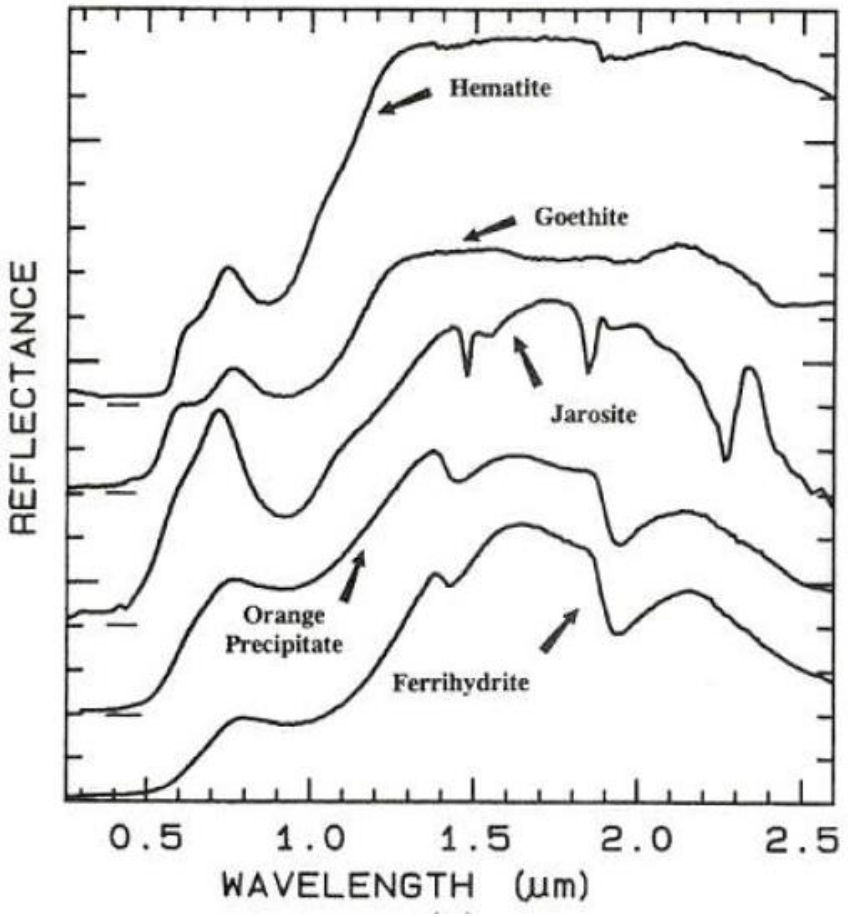
Objectives:

1.) **Mineralogy**: Identify seasonally induced changes in mineralogy on disturbed surfaces and on pond wall liners at the Leviathan Mine Superfund site.

2.) **Mine Water**: Identify spectral signatures of mine affected waters and explore the factors influencing them.

Methods:
Mineral Classification

- Identify AMD minerals:
  - Fe^{3+}-bearing oxidation products display distinctive absorption bands: narrow feature at 0.43 µm, 0.6 and wide 0.8-0.9 µm, sometimes 2.3 µm.
- Use additional hyperspectral image with 2 m pixel (SpecTIR) to aid classification
- Ground verification with ASD



Iron oxide, iron hydroxide, iron sulfate spectra. From Remote Sensing for Earth Sciences, Ch. 1 Spectroscopy of Rocks and Minerals and Principles of Spectroscopy by R.N. Clark.

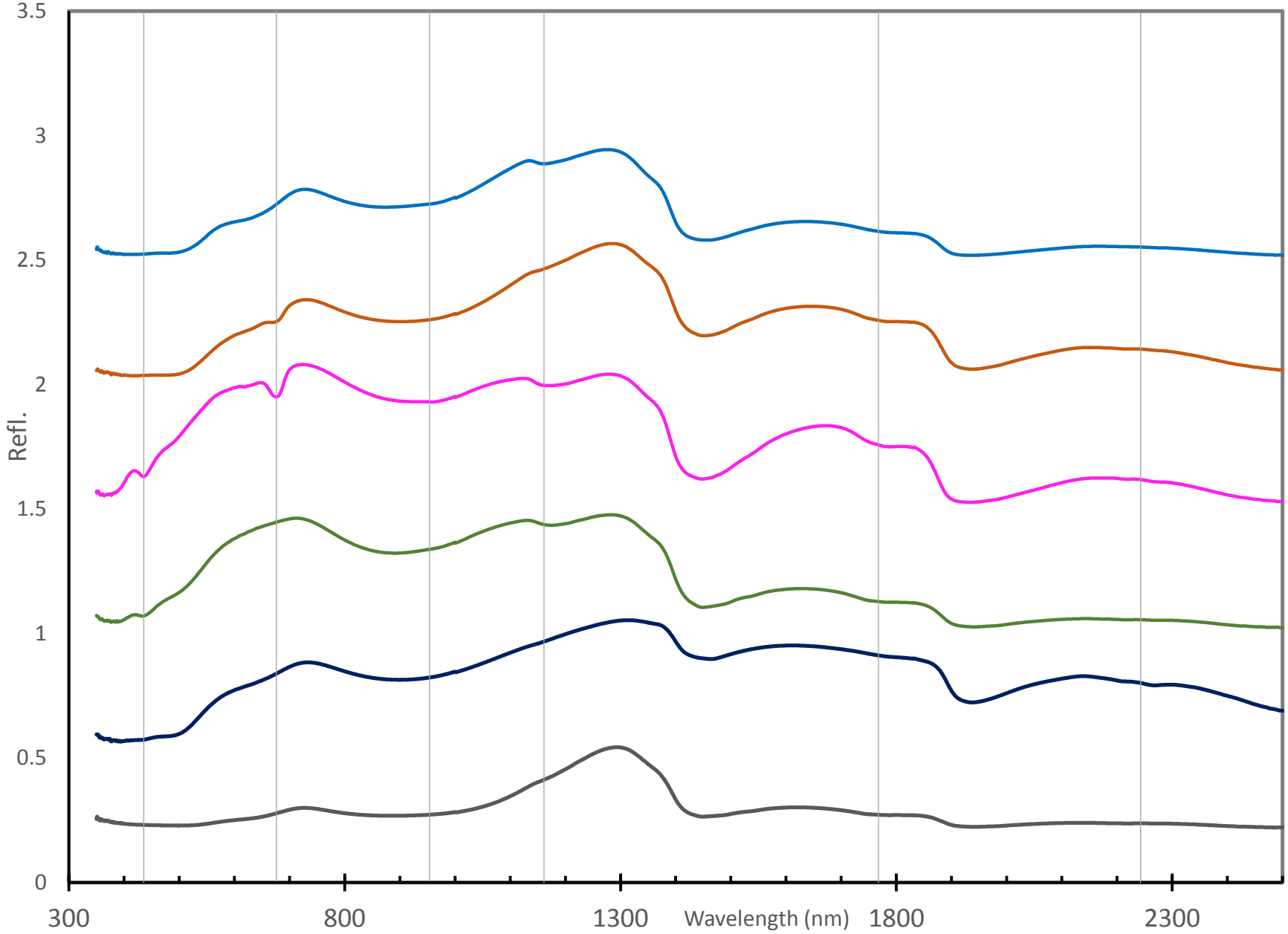

Pond 1 on 10/09/14

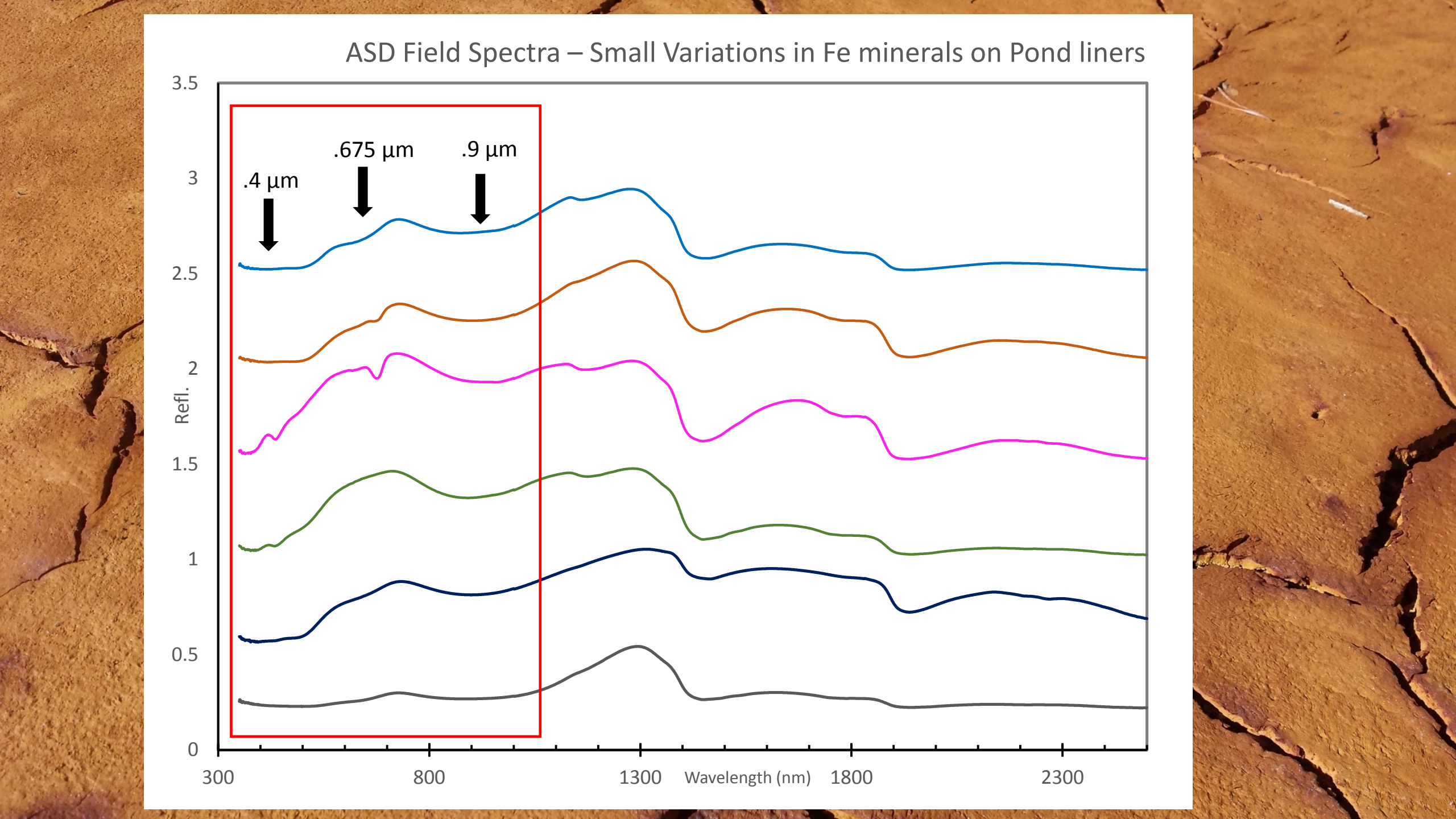

Pond 1 on 10/09/14

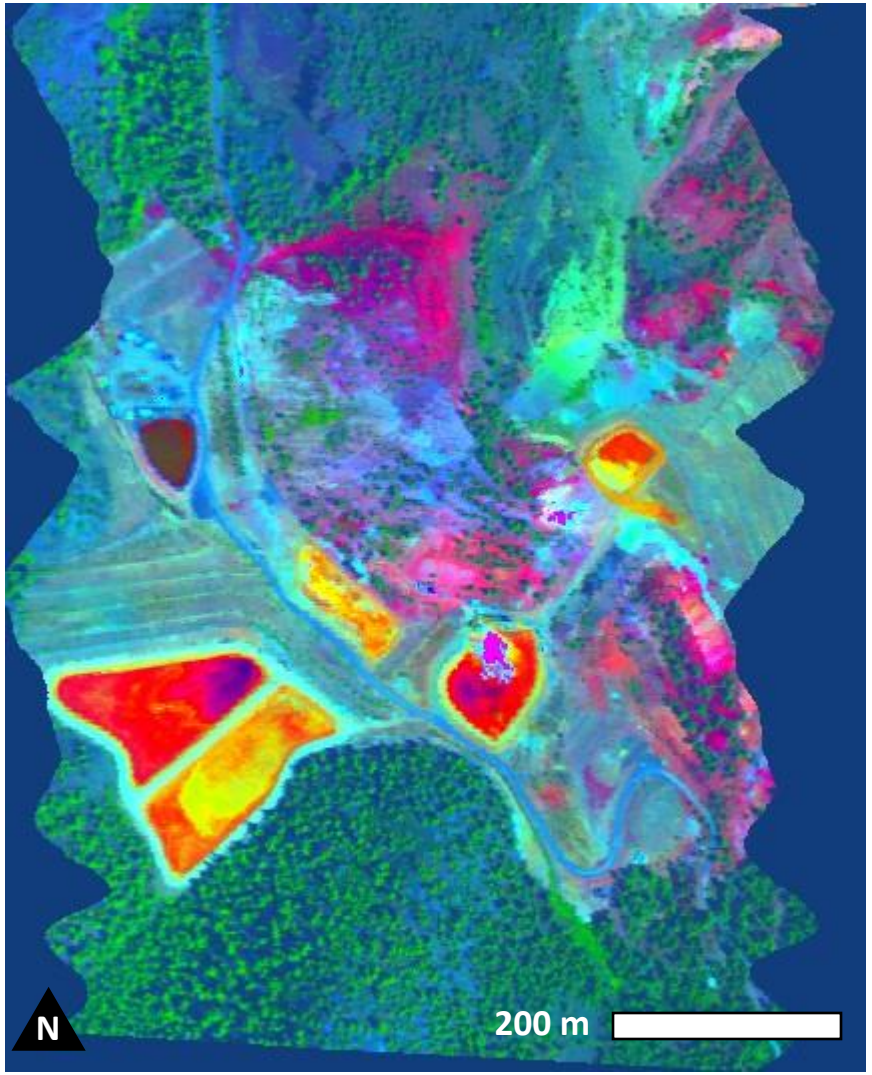

Pond 2S on 08/08/14


Clarifier (sludge storage)
on 10/31/13

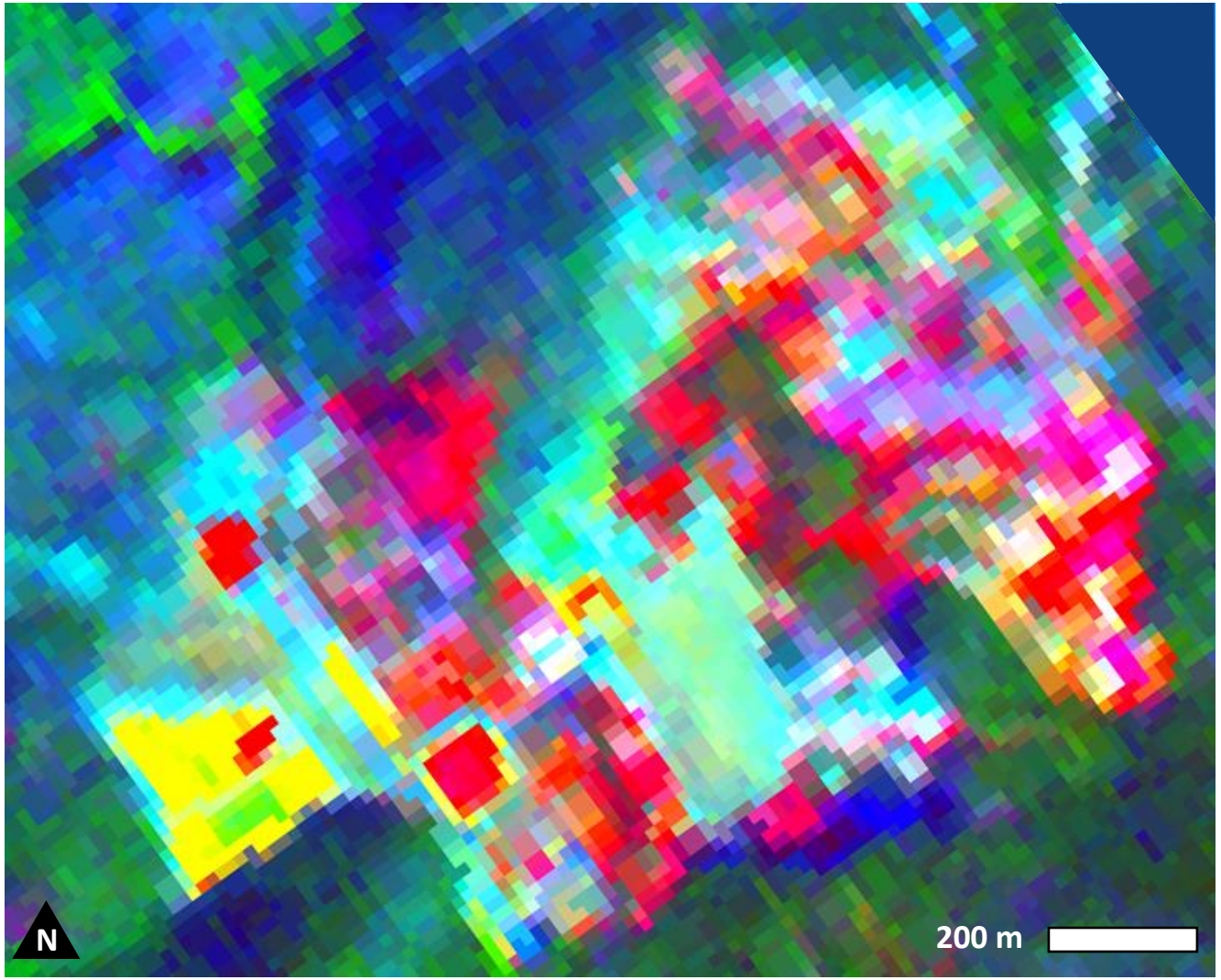
ASD Field Spectra – Small Variations in Fe minerals on Pond liners




ASD Field Spectra – Small Variations in Fe minerals on Pond liners
.4 µm
.675 µm
.9 µm
Refl.
3.5
3
2.5
2
1.5
1
0.5
0
300
800
1300
Wavelength (nm)
1800
2300

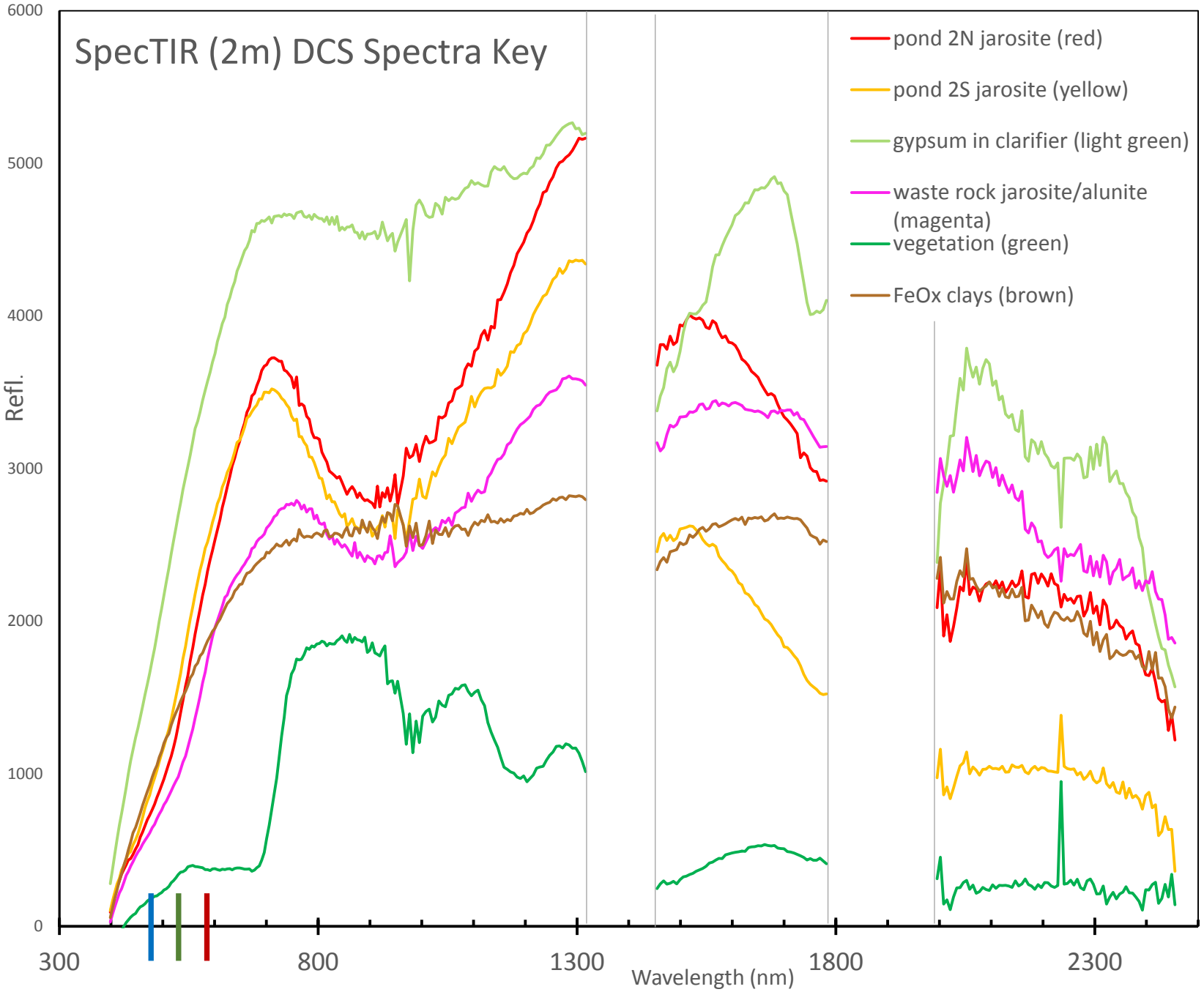


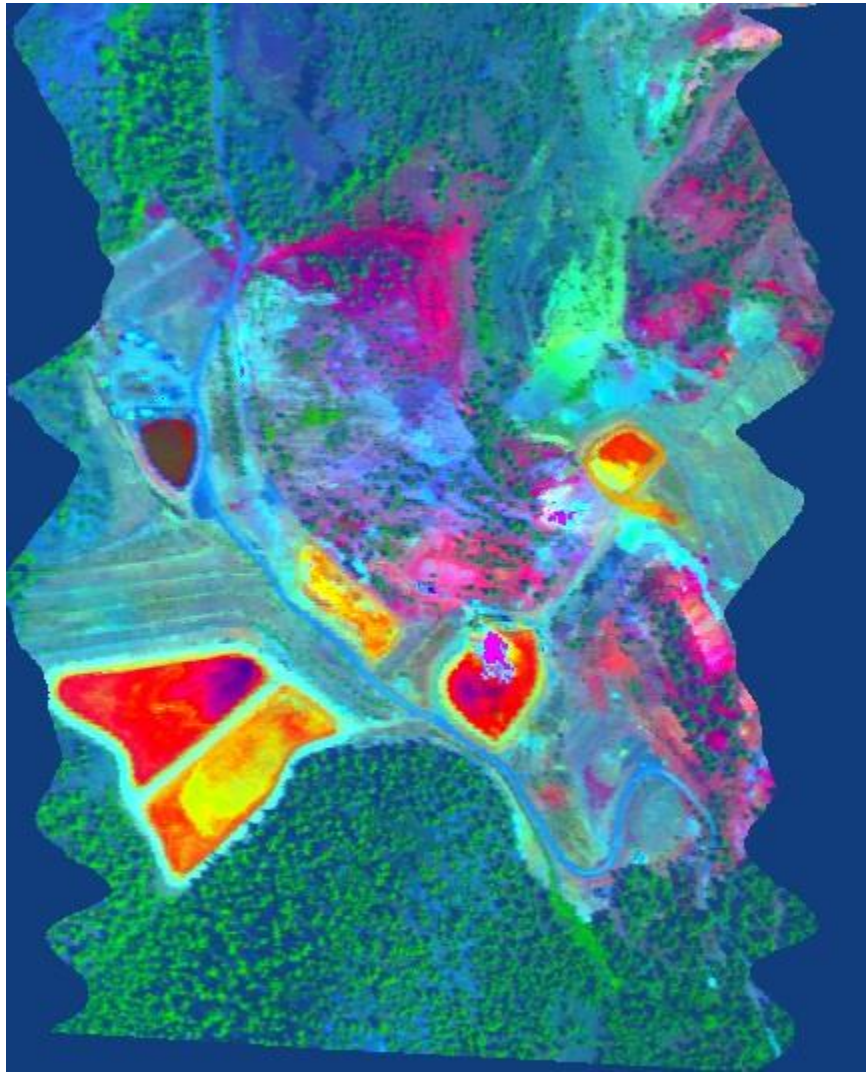
SpecTIR 2 meter pixel (08/17/07)
DCS: R: 590 nm
G: 529 nm
B: 483 nm

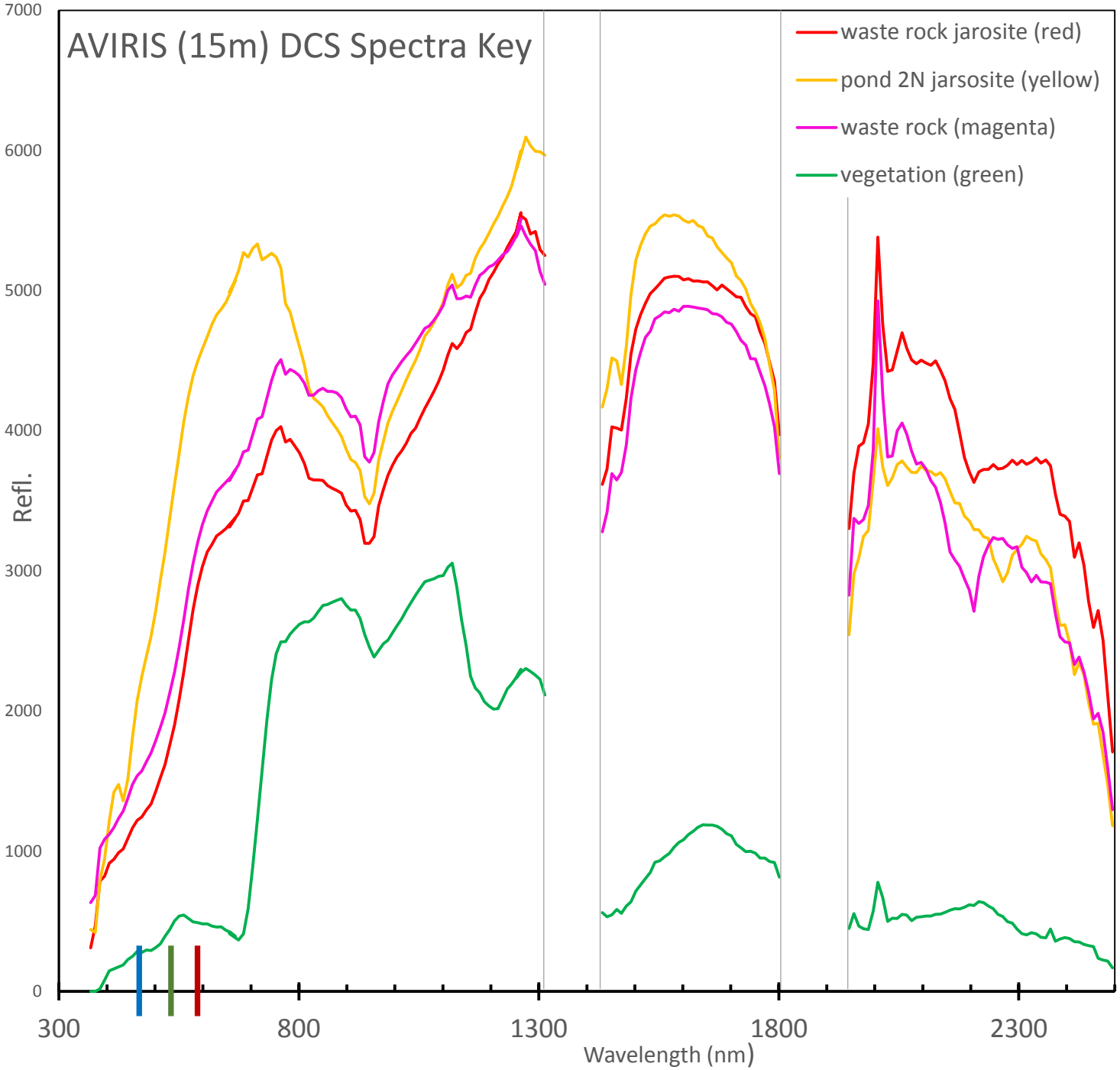


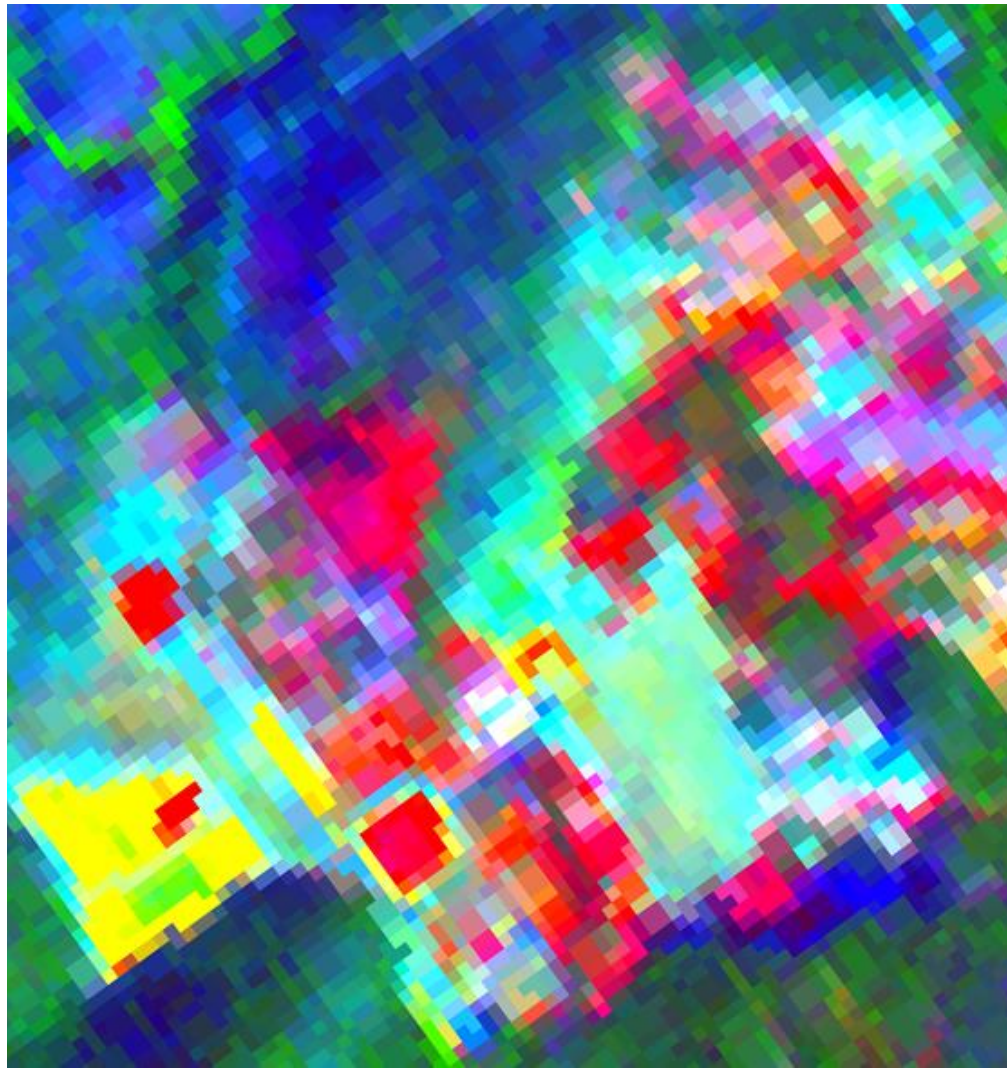
AVIRIS 14.5 meter pixel (09/19/13)
DCS: R: band 24 (589 nm)
G: band 18 (530 nm)
B: band 13 (482 nm)

Red, **magenta**, **yellow**, **orange** → concentrated areas of AMD minerals

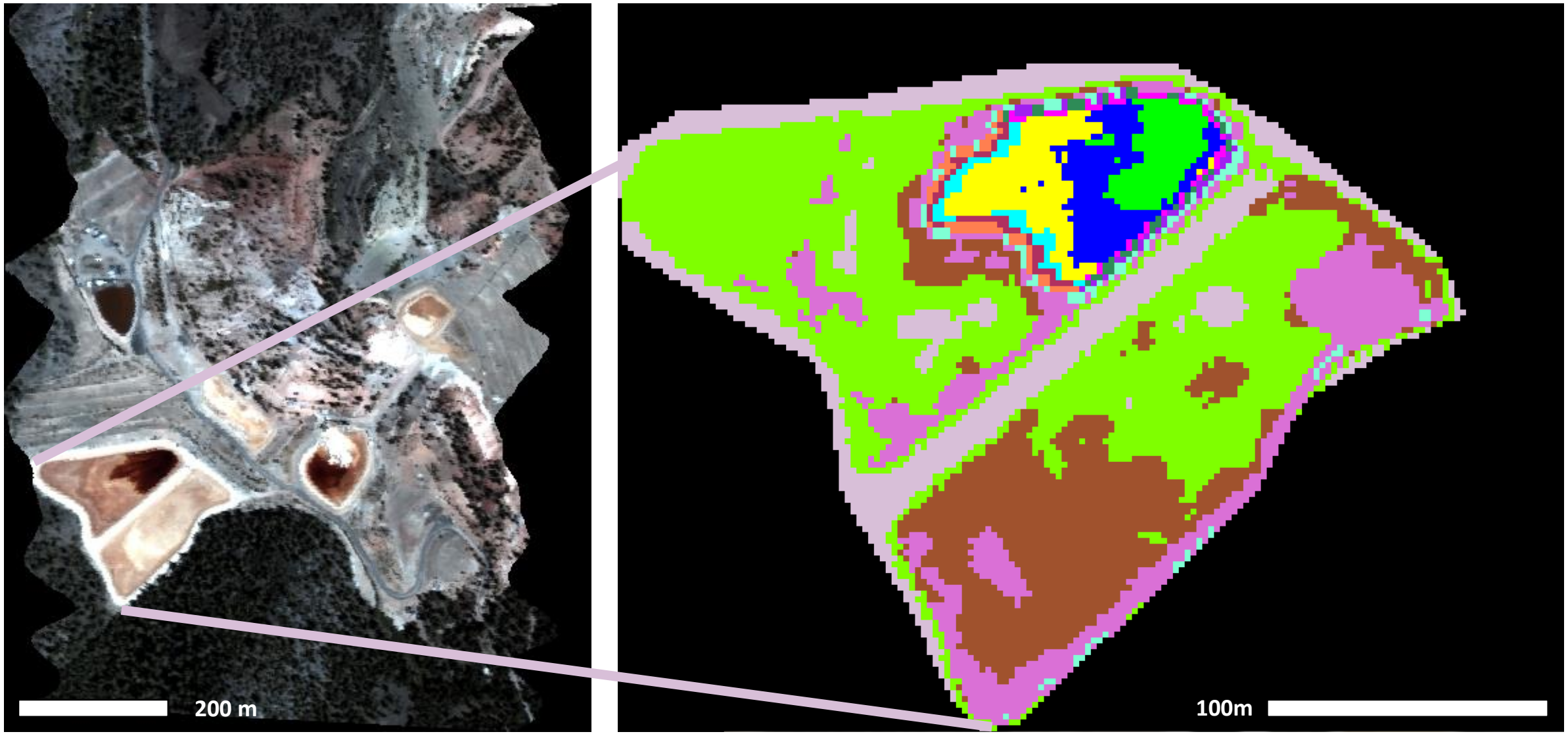

SpecTIR (2m) DCS Spectra Key
pond 2N jarosite (red)
pond 2S jarosite (yellow)
gypsum in clarifier (light green)
waste rock jarosite/alunite (magenta)
vegetation (green)
FeOx clays (brown)
Refl.
6000
5000
4000
3000
2000
1000
0
300
800
1300
1800
2300
Wavelength (nm)




AVIRIS (15m) DCS Spectra Key
waste rock jarosite (red)
pond 2N jarsosite (yellow)
waste rock (magenta)
vegetation (green)
Refl.
7000
6000
5000
4000
3000
2000
1000
0
300
800
1300
1800
2300
Wavelength (nm)



K-mean on SpecTIR image: 15 classifications



Illustrates subtle differences in Jarosite spectra in dried out ponds.
Differences not distinguishable in AVIRIS (15m) image. HyspIRI (30m)?

Mineralogy Summary:

- Mixtures of iron hydroxides/sulfates commonly associated with AMD are present at Leviathan and can be seen spectrally in airborne data and on the ground.
- Patterns of AMD minerals definitely apparent in ground data and SpecTIR. Pattern identification in HyspIRI data will be more challenging.

Further work…

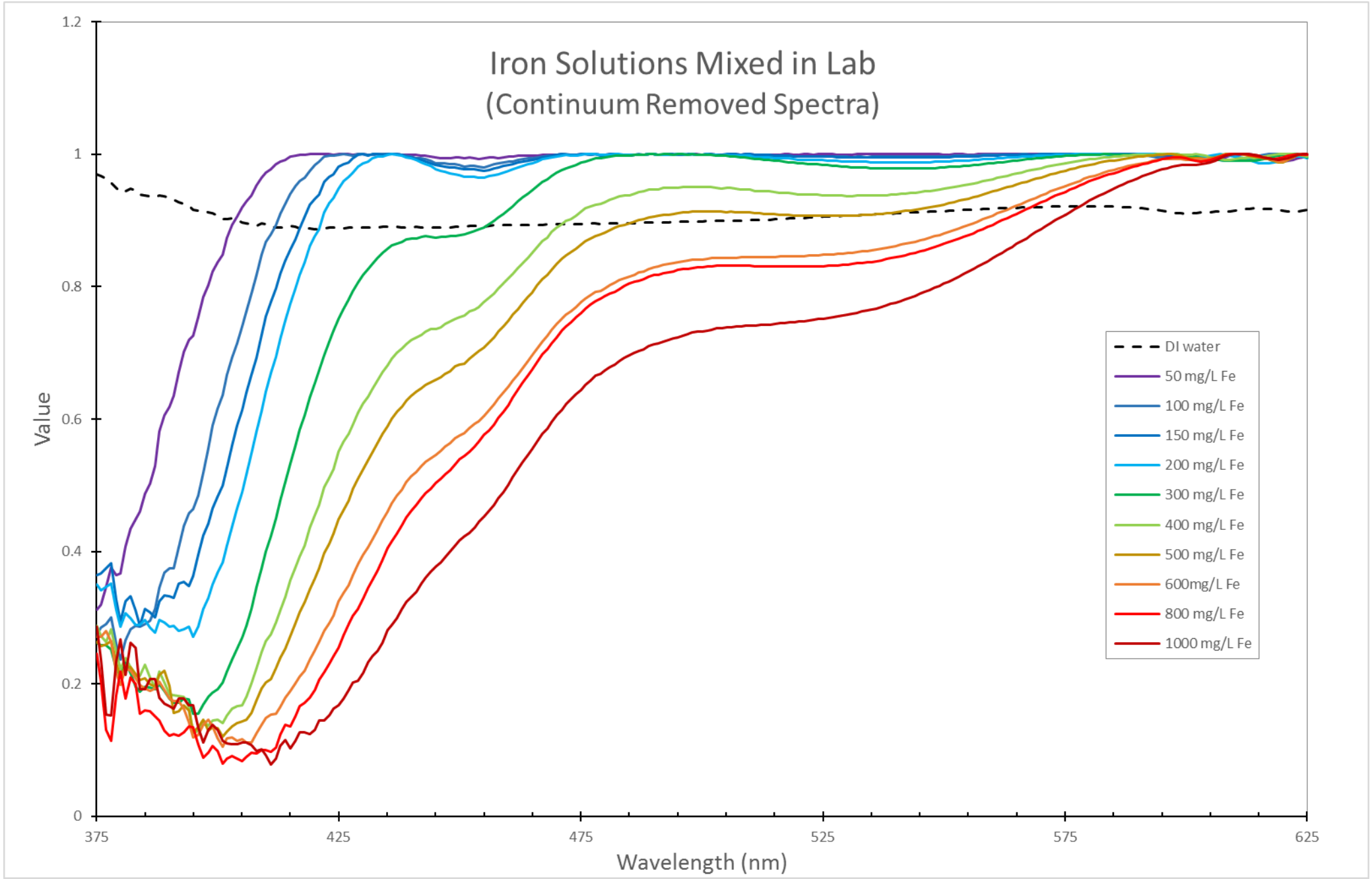
- Employ spectral unmixing.
- Identify seasonal changes in iron minerals by comparing AVIRIS scenes (2013-2014).
- Make conclusions about weathering rates/patterns.

Methods: Water Spectra

Pond 2N on 04/24/2014

Methods: Characterize Water Spectra

- Test idea that soluble iron is causing unique spectral characteristics/color.
- Compare the spectral signature of mine affected waters vs. natural waters.
- Correlate mine water spectra to solutions of known iron concentrations for qualitative association.


Iron Solutions Mixed in Lab
(Continuum Removed Spectra)
Value
Wavelength (nm)
1.2
1
0.8
0.6
0.4
0.2
0
375
425
475
525
575
625
DI water
50 mg/L Fe
100 mg/L Fe
150 mg/L Fe
200 mg/L Fe
300 mg/L Fe
400 mg/L Fe
500 mg/L Fe
600mg/L Fe
800 mg/L Fe
1000 mg/L Fe

Iron Solutions Mixed in Lab
(Continuum Removed Spectra)

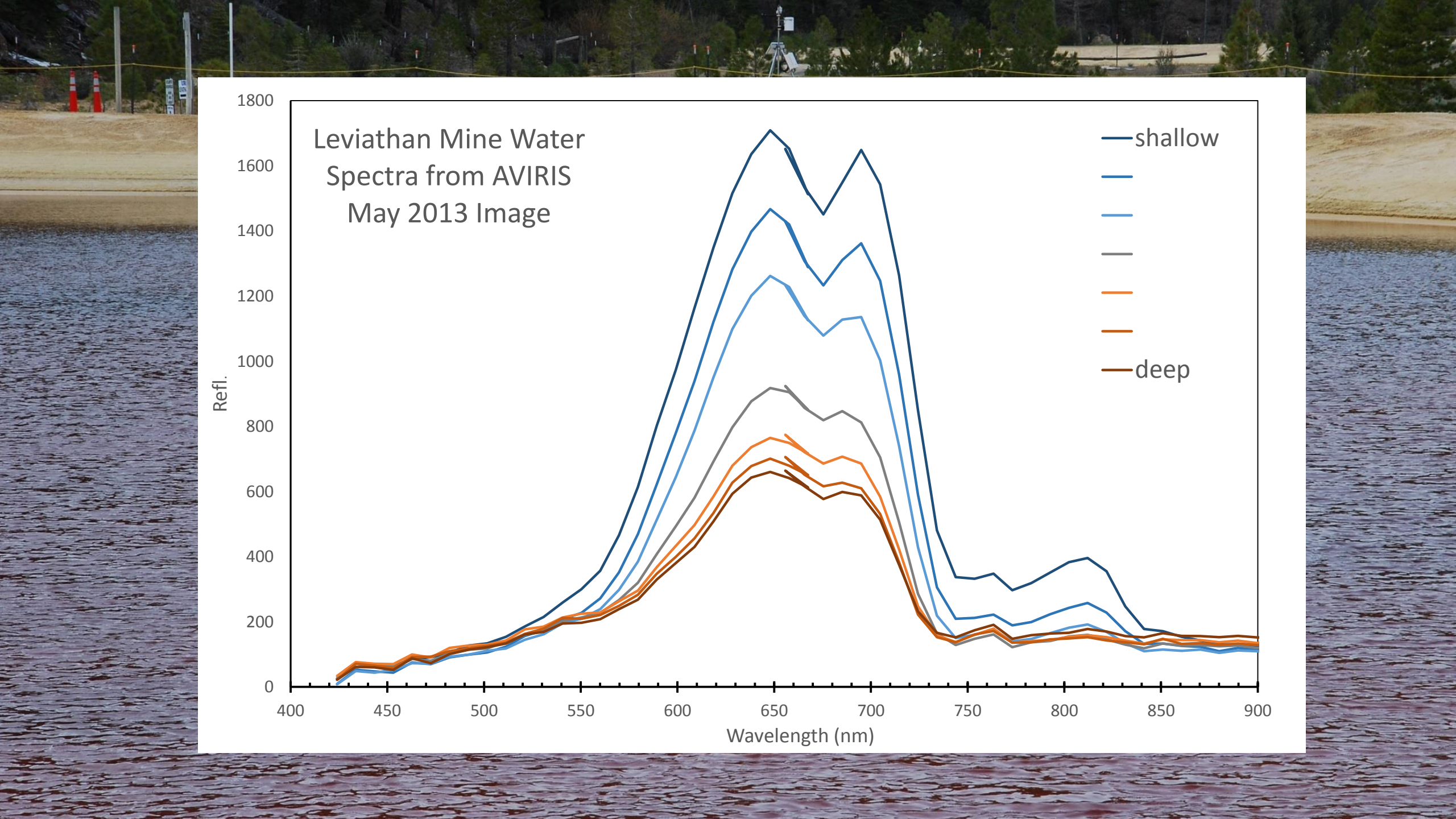
Value

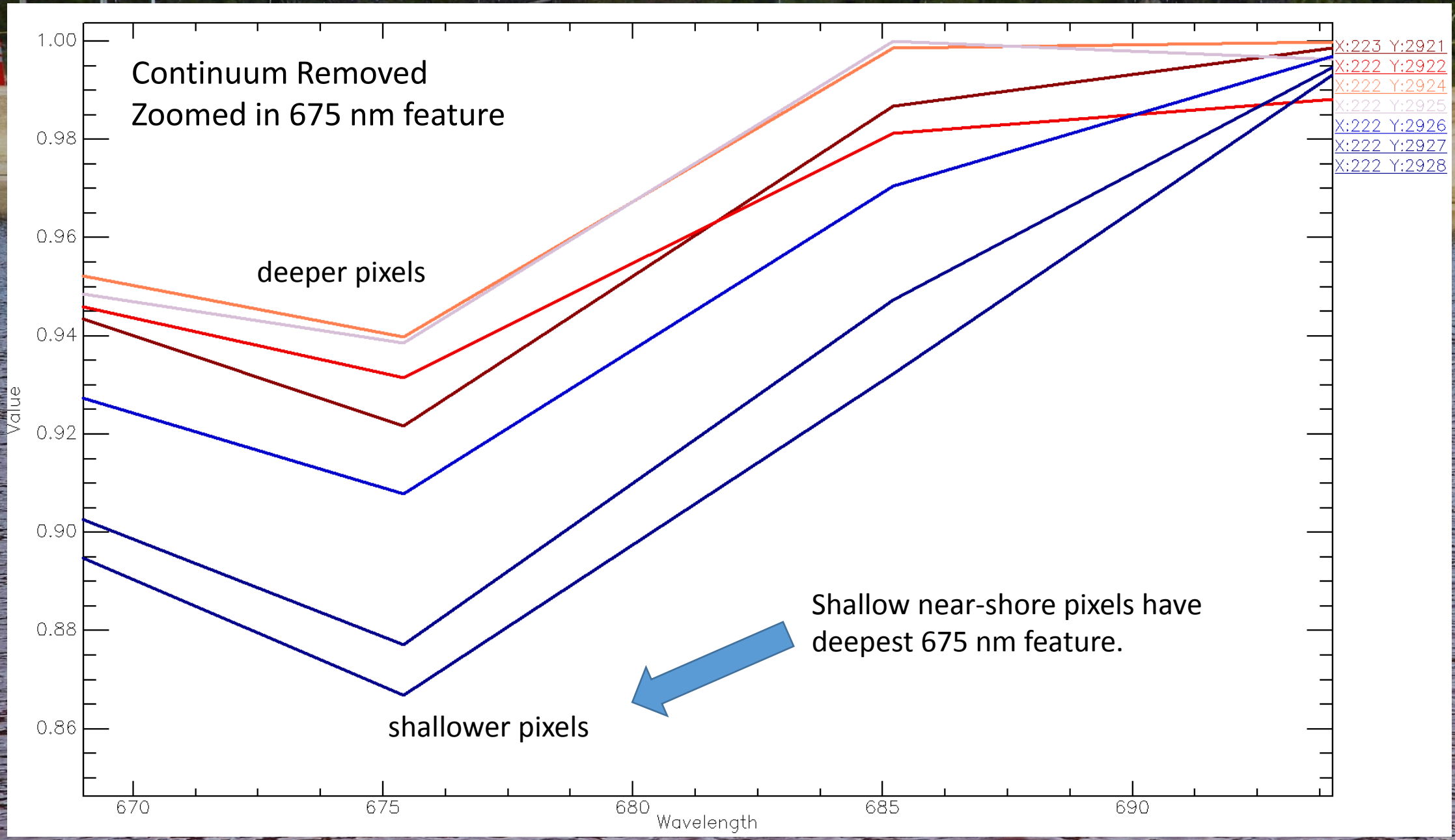
1.2
1
0.8
0.6
0.4
0.2
0

375
425
475
525
575
625

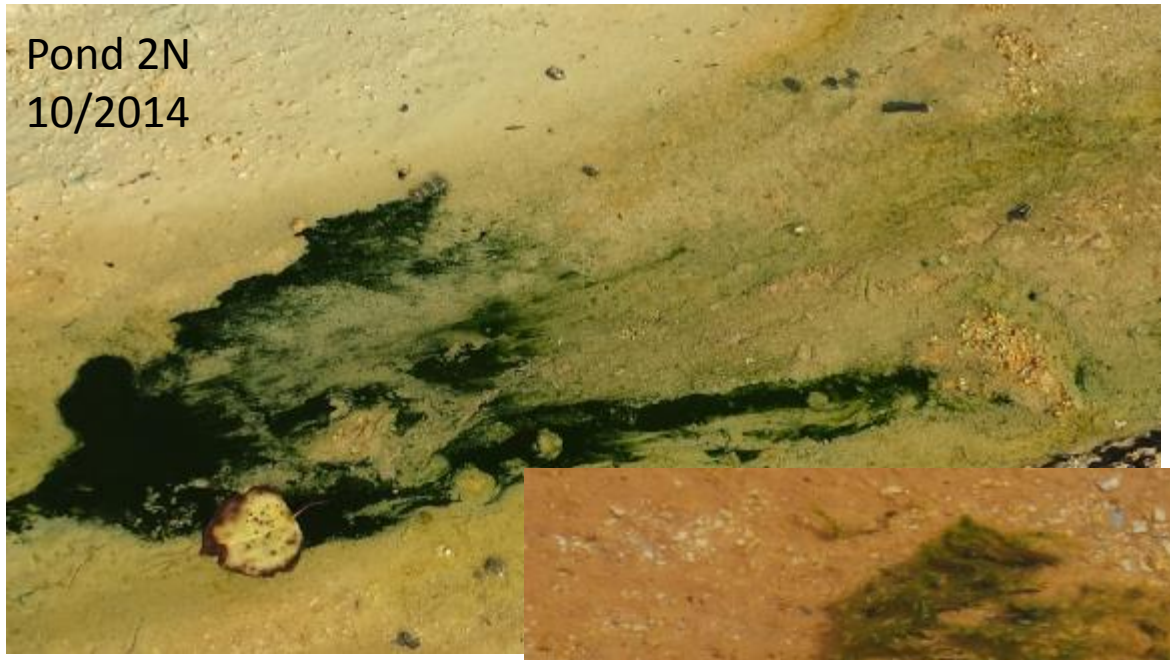
Wavelength (nm)

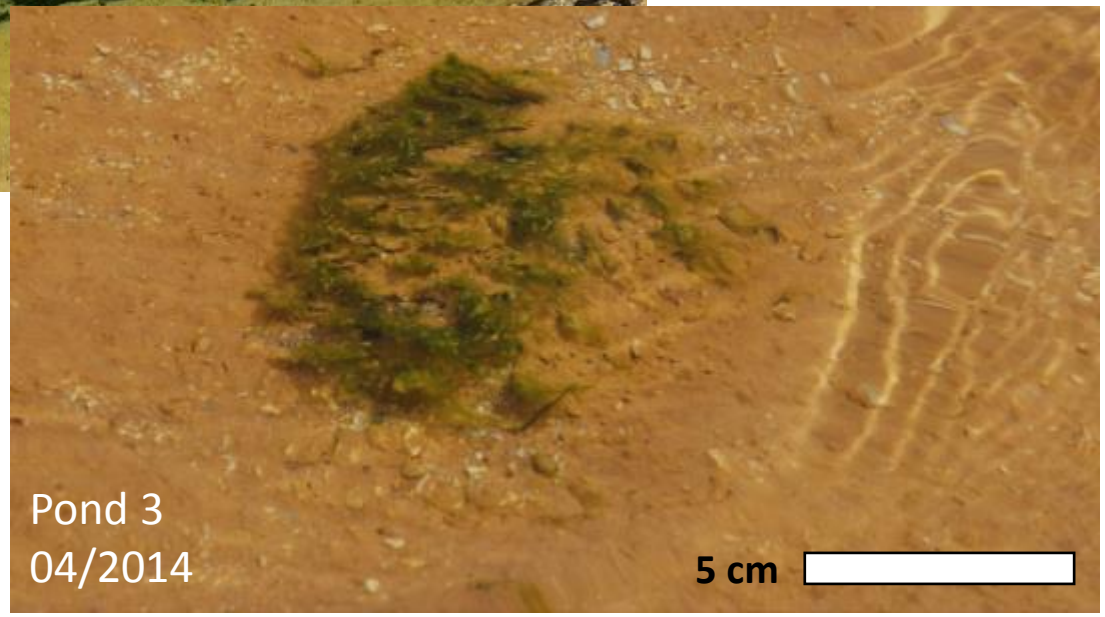
- DI water
- 50 mg/L Fe
- 100 mg/L Fe
- 150 mg/L Fe
- 200 mg/L Fe
- 300 mg/L Fe
- 400 mg/L Fe
- 500 mg/L Fe
- 600mg/L Fe
- 800 mg/L Fe
- 1000 mg/L Fe

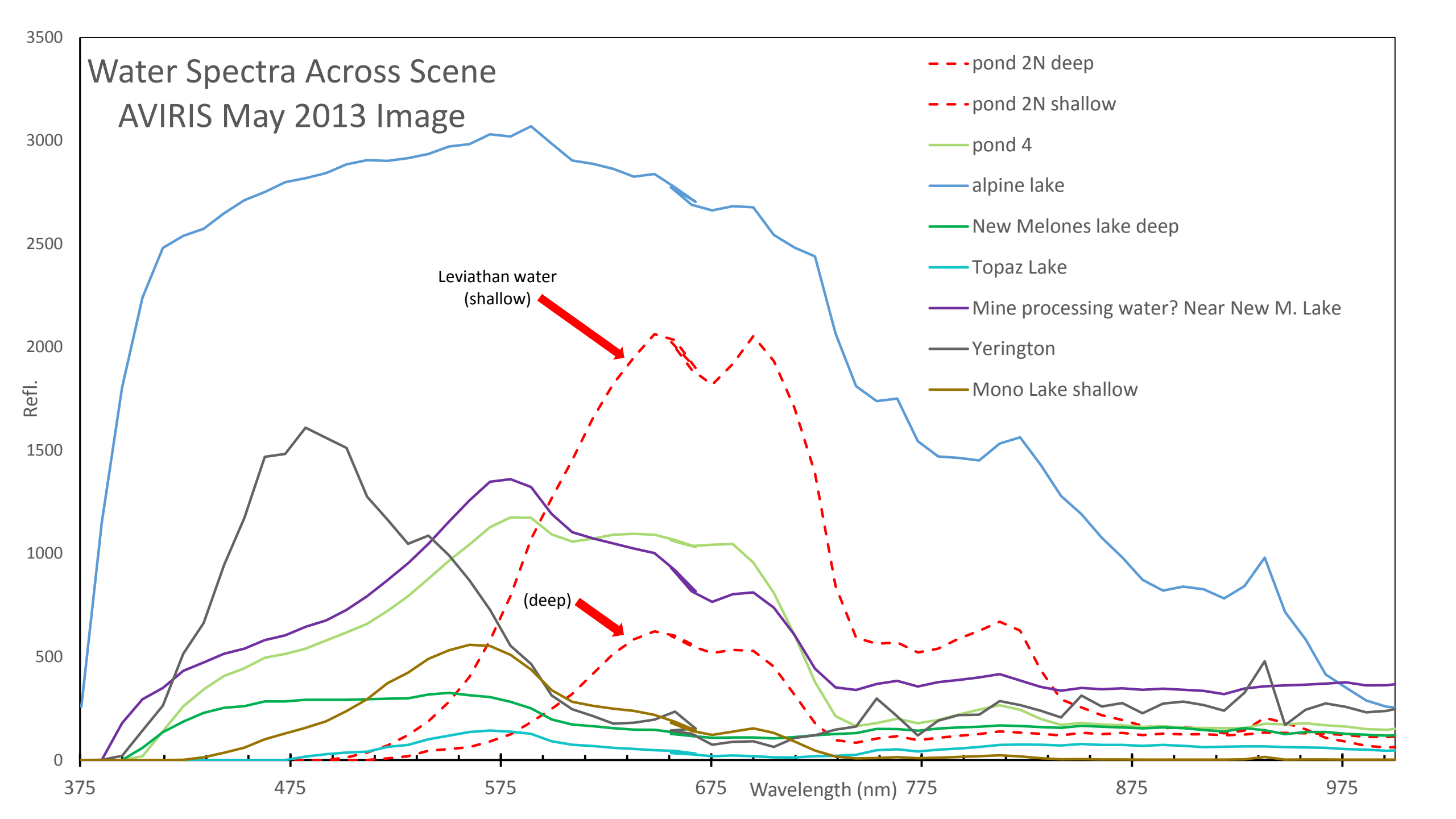

Leviathan Mine Water
Spectra from AVIRIS
May 2013 Image
shallow
deep
Refl.
Wavelength (nm)
0
200
400
600
800
1000
1200
1400
1600
1800
400
450
500
550
600
650
700
750
800
850
900


Continuum Removed
Zoomed in 675 nm feature
deeper pixels
shallower pixels
Shallow near-shore pixels have deepest 675 nm feature.
Value
Wavelength
1.00
0.98
0.96
0.94
0.92
0.90
0.88
0.86
670
675
680
685
690
X:223 Y:2921
X:222 Y:2922
X:222 Y:2924
X:222 Y:2925
X:222 Y:2926
X:222 Y:2927
X:222 Y:2928

Algae in mine water






Water Spectra Across Scene
AVIRIS May 2013 Image
pond 2N deep
pond 2N shallow
pond 4
alpine lake
New Melones lake deep
Topaz Lake
Mine processing water? Near New M. Lake
Yerington
Mono Lake shallow
Leviathan water
(shallow)
(deep)
Refl.
Wavelength (nm)
3500
3000
2500
2000
1500
1000
500
0
375
475
575
675
775
875
975

Water Summary:

- Identified that Leviathan waters exhibit unique spectral curves, different from most natural waters.
- Spectral signature is depth dependent.

Further work…

- Link airborne water spectra to laboratory solutions for qualitative comparison.

Questions