Remote sensing for characterizing mine waste minerology, mine drainage geochemistry, and site assessment and monitoring

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Mine and Mineral Processing Virtual Workshop

Session 1 - Site Characterization

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Problem:
The environmental effects of mining operations

- Oxidation of sulfide minerals associated with coal and ore deposits creates a variety of environmental problems:
  - Erosion
  - Corrosion
  - Sedimentation
  - Loss of biological diversity
  - Drainage waters with acid and high metal loads

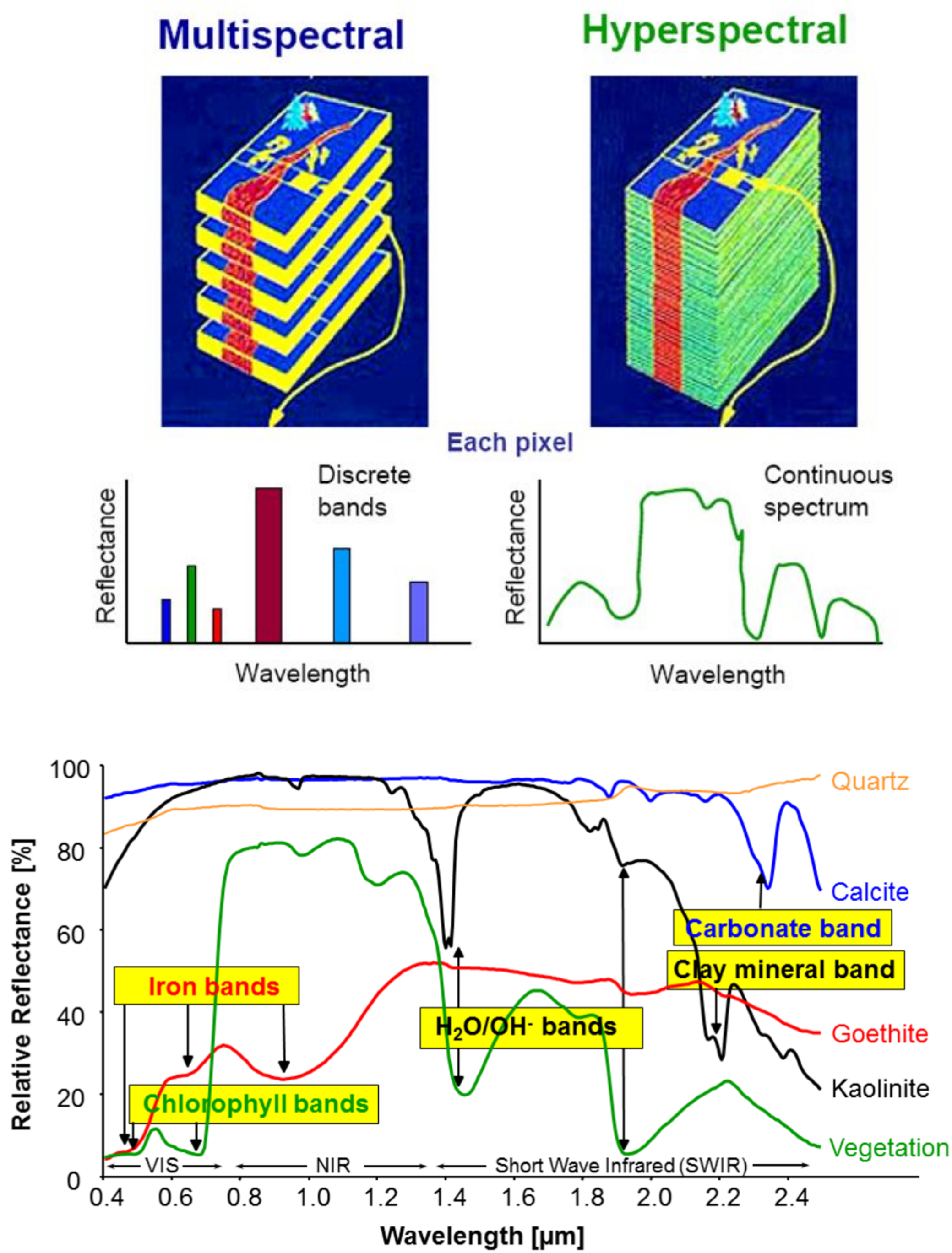
- Site assessment requires soil and water sampling that can be aided by remote sensing measurements

Remote Sensing Technologies (airborne and satellite)

- In the past, remote sensing imagery provided an overhead picture of a site. Making quantitative measurements was difficult.
- Current technologies include:
  - Imaging spectroscopy using hyperspectral sensors
    - Spectral analysis similar to lab spectroscopy
  - High resolution LiDAR and SAR (synthetic aperture radar)
    - Provides topographic information and some material characteristics
  - Multispectral imagers with bands clustered to characterize specific spectral regions
    - Example: 8-band commercial satellite imaging for vegetation characterization
  - Very high spatial and temporal resolution satellite imaging systems
    - Persistent imaging at high spatial resolution
- Combining two or more of these systems together can be used to create a nD dataset that can be analyzed using machine learning (AI)

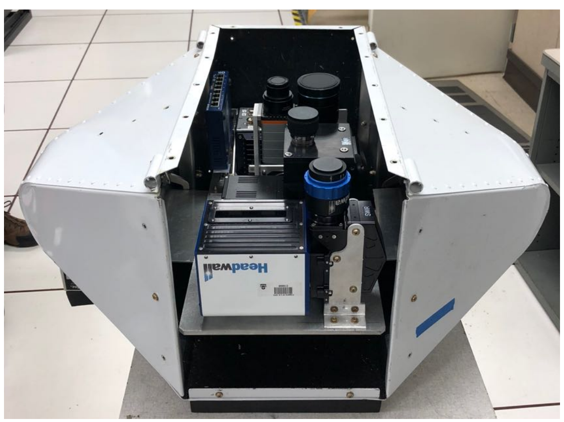
Pictures versus measurement

- The difference between multispectral and hyperspectral data.
- A multispectral imager is identical to a common camera. Discrete bands are hard to use for quantitative measurements.
- The continuous spectral measurement from a hyperspectral system is used for imaging spectroscopy. Absorption bands can be measured to identify minerals and other materials.



EPA's TEROS system
(Transportable Environmental Resource Observation Suite)

TEROS can fly on commercial Cessna aircraft
Cost to fly ~$5k/week (pilot + aircraft)



Pod upside down to show instruments

These instruments are integrated into the pod.

- VNIR & SWIR imaging spectrometers
- Hi-Res camera for "LiDAR-like" data
- Thermal camera
- GPS/INS

TEROS can fly on NASA aircraft:

- King Air B-200 aircraft for large projects.
- Cost: $2,500/hour

- NASA Cessna 206H for local projects on the east coast Cost: $400/hour
- Flown using wing strut
- or pod

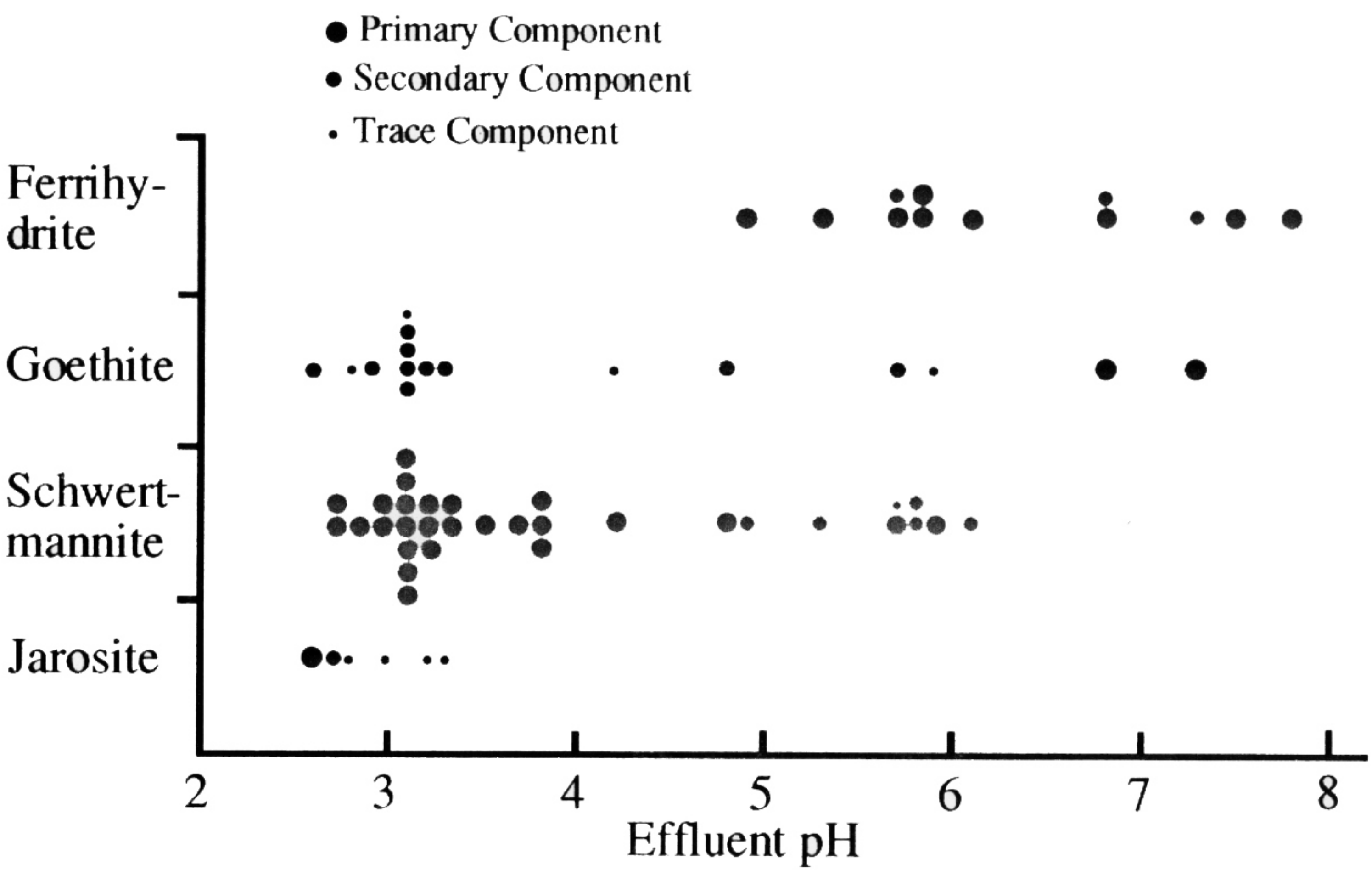
TEROS instruments in wing strut

Remote Sensing Approach for Mine Site Characterization

- Based on current and/or previous sample collections, determine the geochemical regime of the site, such as
  - Acidic, high Fe, S or arid high Fe, low S
  - Model potential minerals present (PHREEQC, WATEQ4F)
  - Use remote sensing to find these minerals
- Utilize additional remote sensing capabilities to add topographic information
  - Combine mineralogy and topography to map features such as waste piles. Integrate hydrologic models to estimate waste pile runoff, model transport of solutes downstream (USGS GSFLOW)

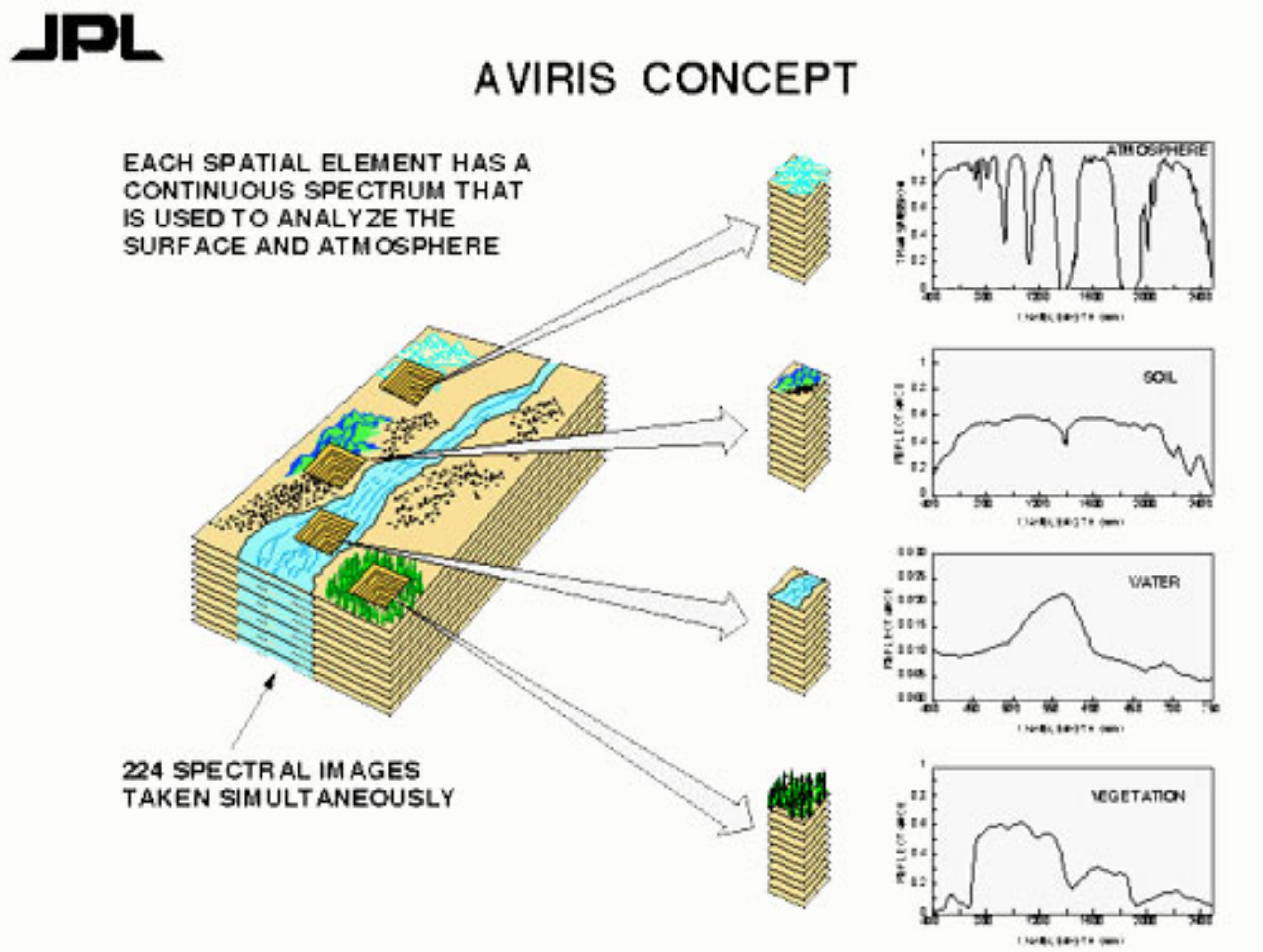
Example 1: Imaging Spectroscopy at Copper Basin, TN

Distribution of mine drainage precipitates with pH

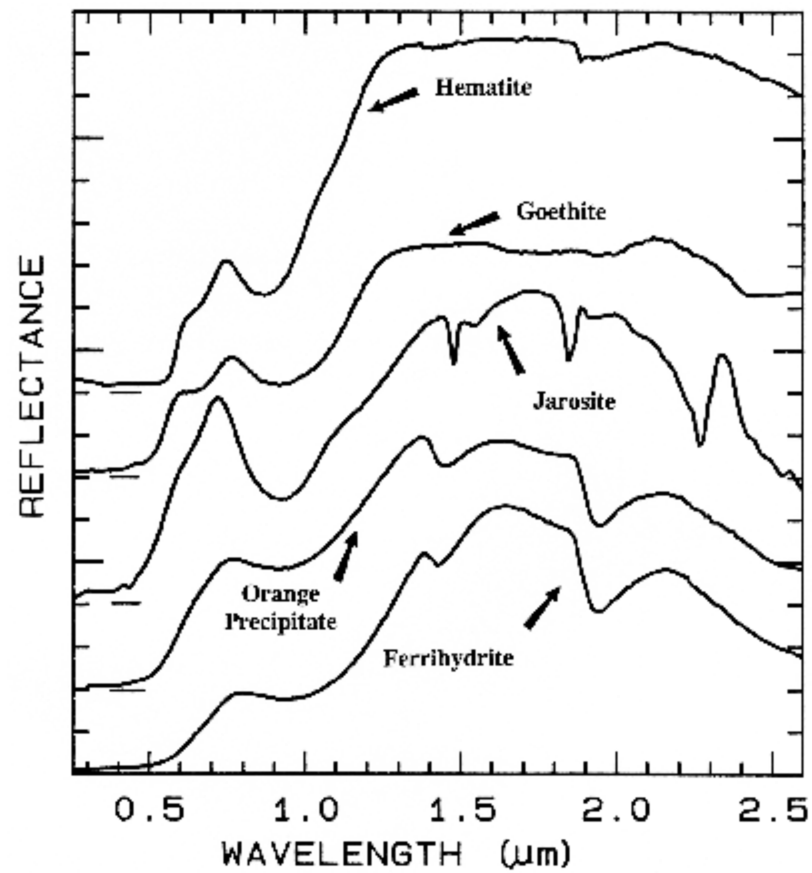


Imaging Spectroscopy

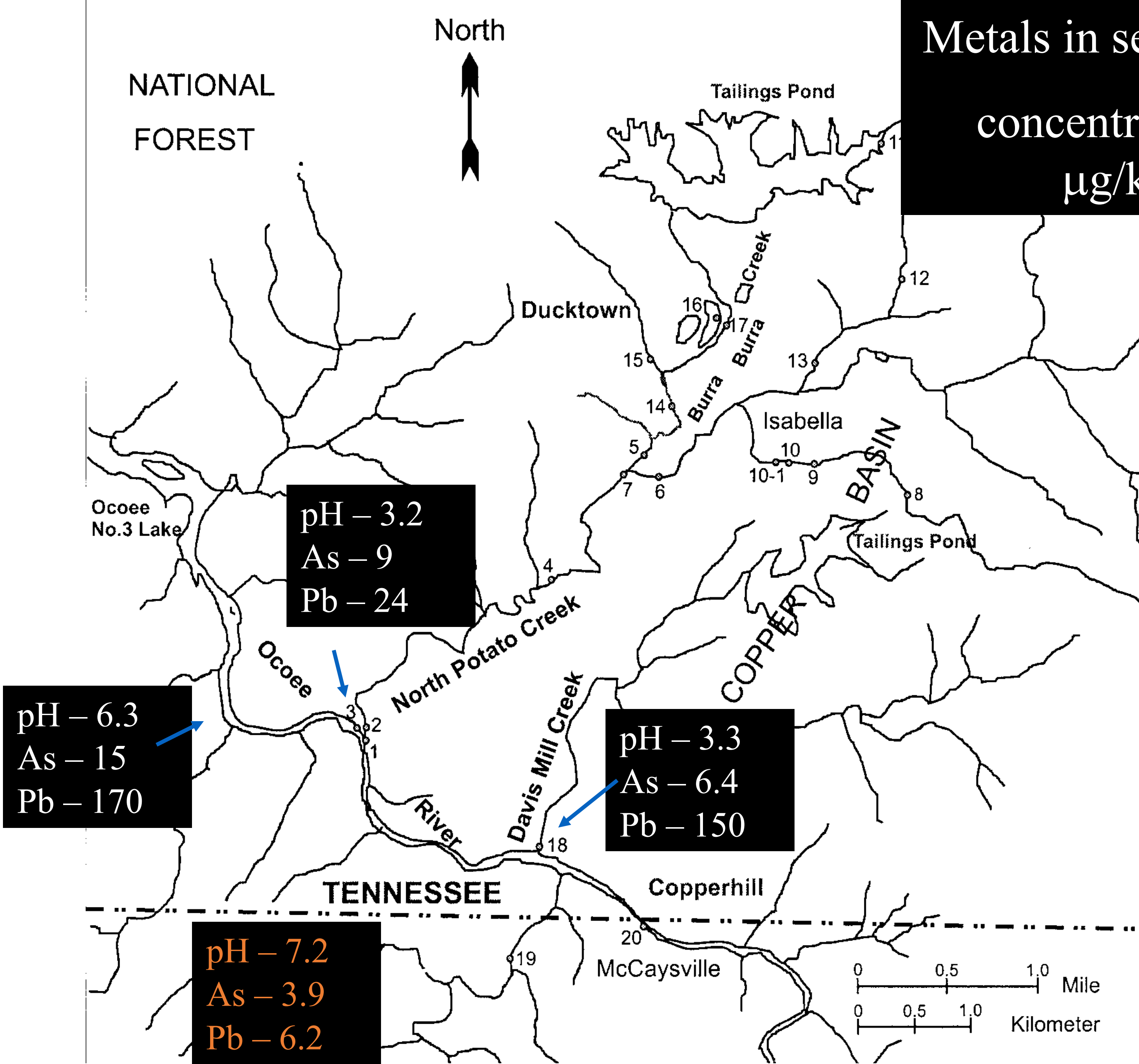
- These spectra are used to derive information based on the signature of the interaction of matter and energy expressed in the spectrum.



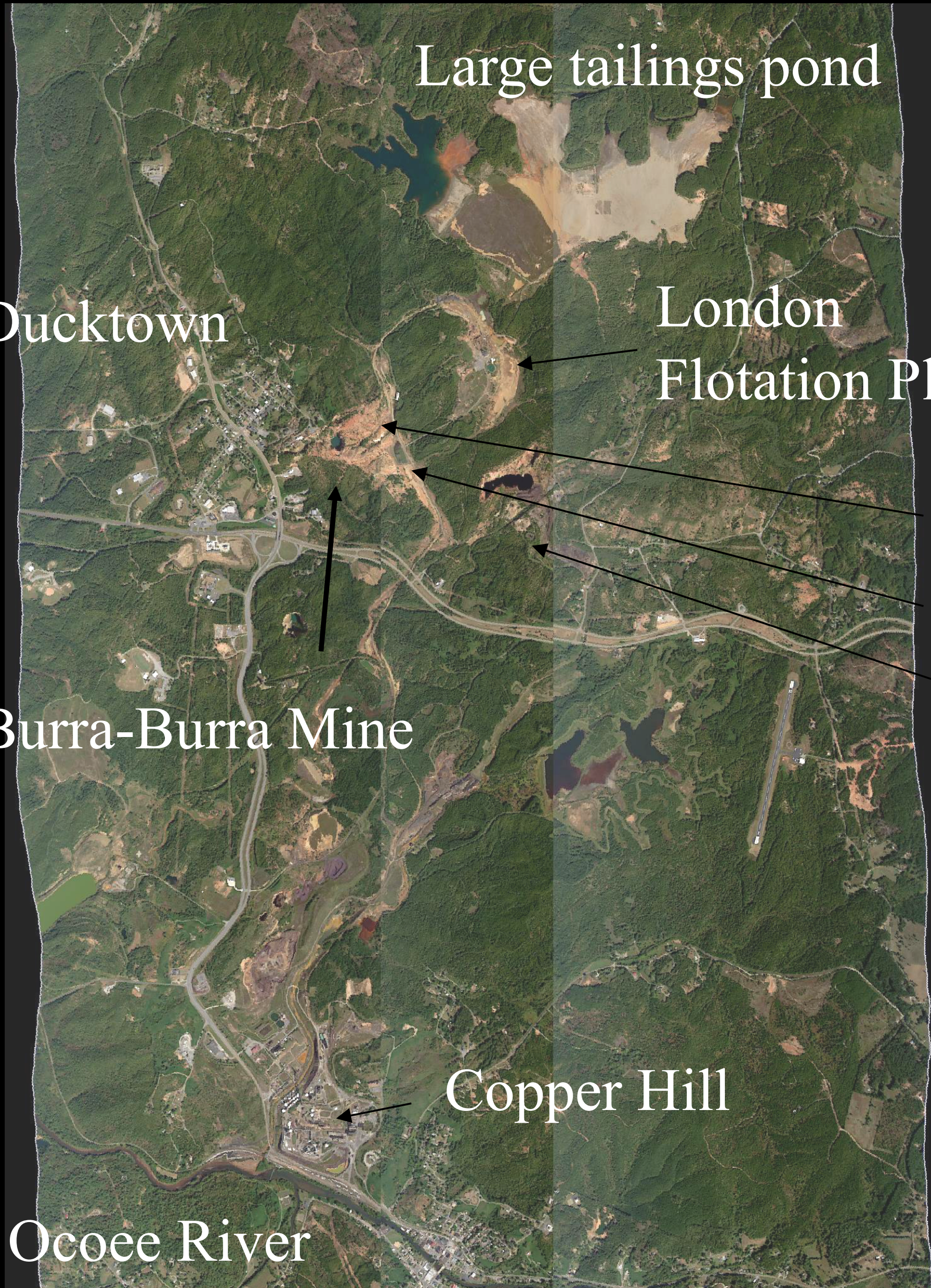
Spectral differences between mine precipitates (poorly organized minerals) and minerals



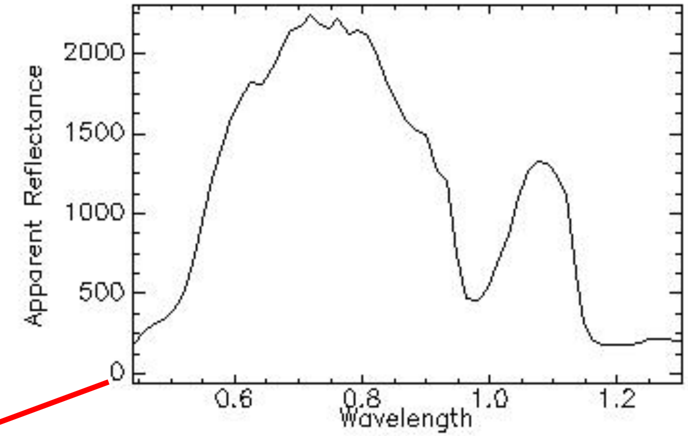
Metals in sediments concentrations in µg/kg (ppm)



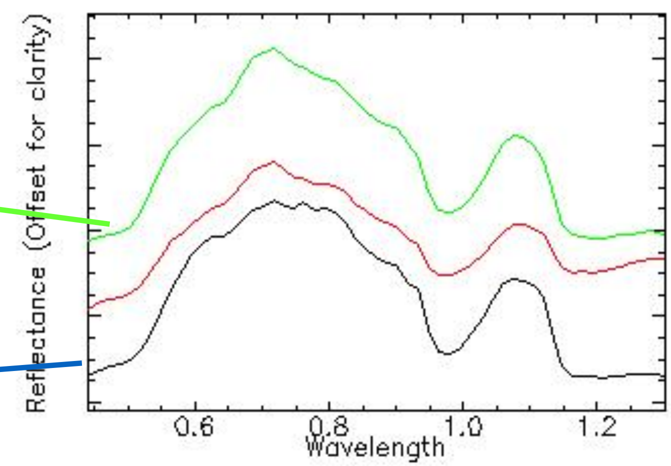
Davis Mill Creek


Large tailings pond
Ducktown
London
Flotation Plant
McPherson Mine
Eureka Mine
Isabella Mine
Burra-Burra Mine
Copper Hill
Ocoee River

Comparing remote sensing imagery to field spectra

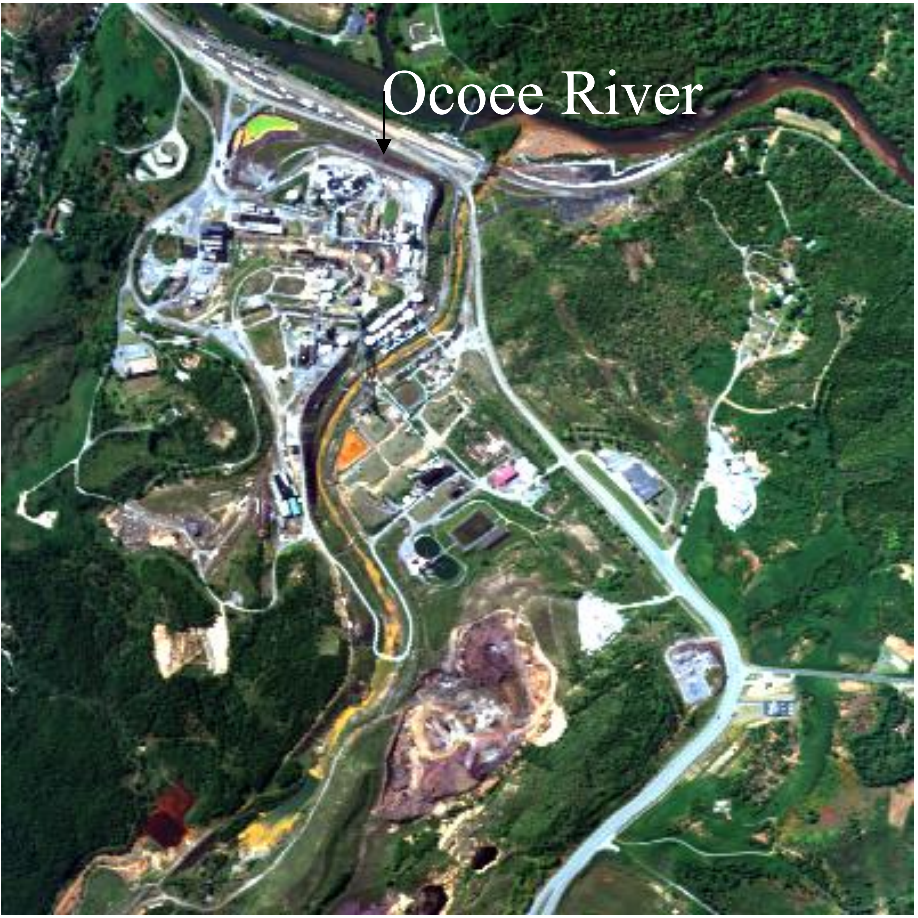


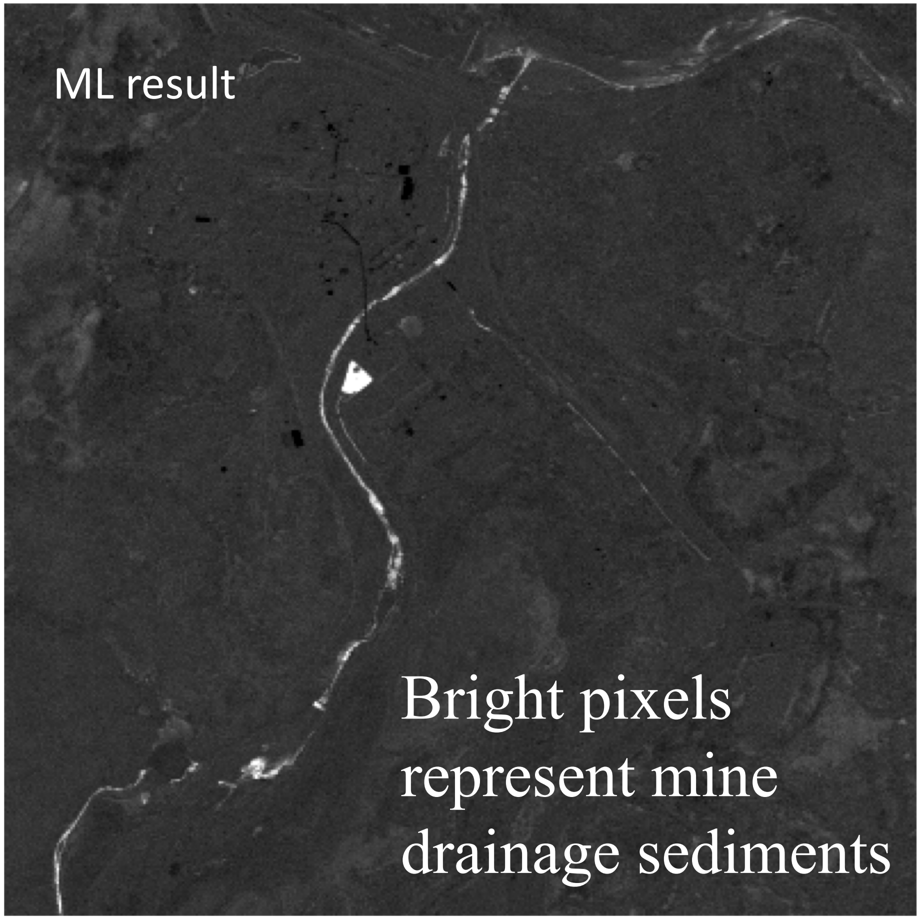
Field reference spectra



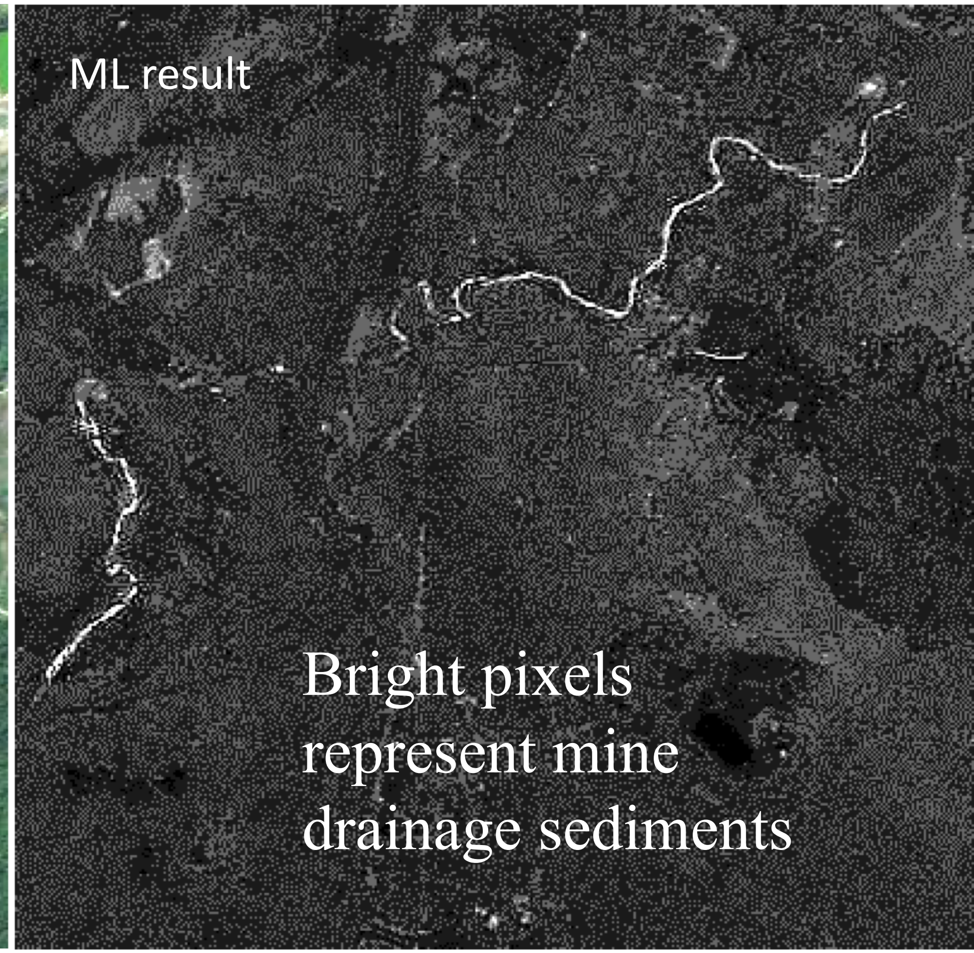
Airborne acquired spectra

Results: Machine learning methods use the laboratory to train the algorithm to find matching materials in the airborne data





ML identifies pixels in image that match the reference material in the spectral database

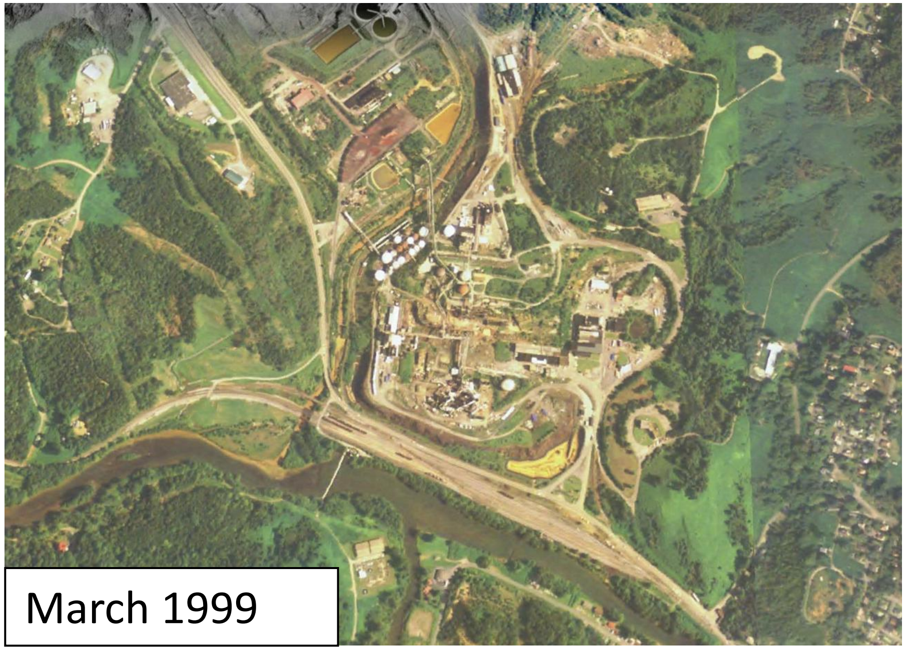


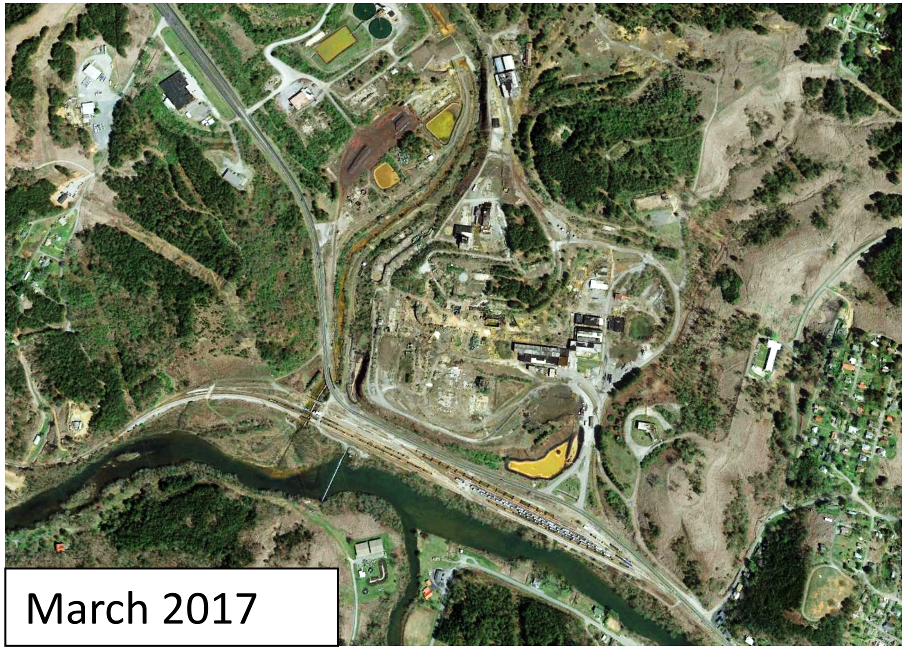
Results

- Mine drainage sediments Davis Mill Creek and lower North Potato Creek are comprised of schwertmannite with trace (tr) to small amounts of goethite
  - These minerals form in acid sulfate systems
- The sediments in upper North Potato Creek are composed of ferrihydrite and schwertmannite (tr)
  - This mineral forms in near neutral systems
- The pH of these stream reaches can be estimated:
  - Davis Mill Creek - pH 3-4 with moderate to high dissolved sulfate loads
  - North Potato Creek – pH 5-6 with low to moderate dissolved sulfate

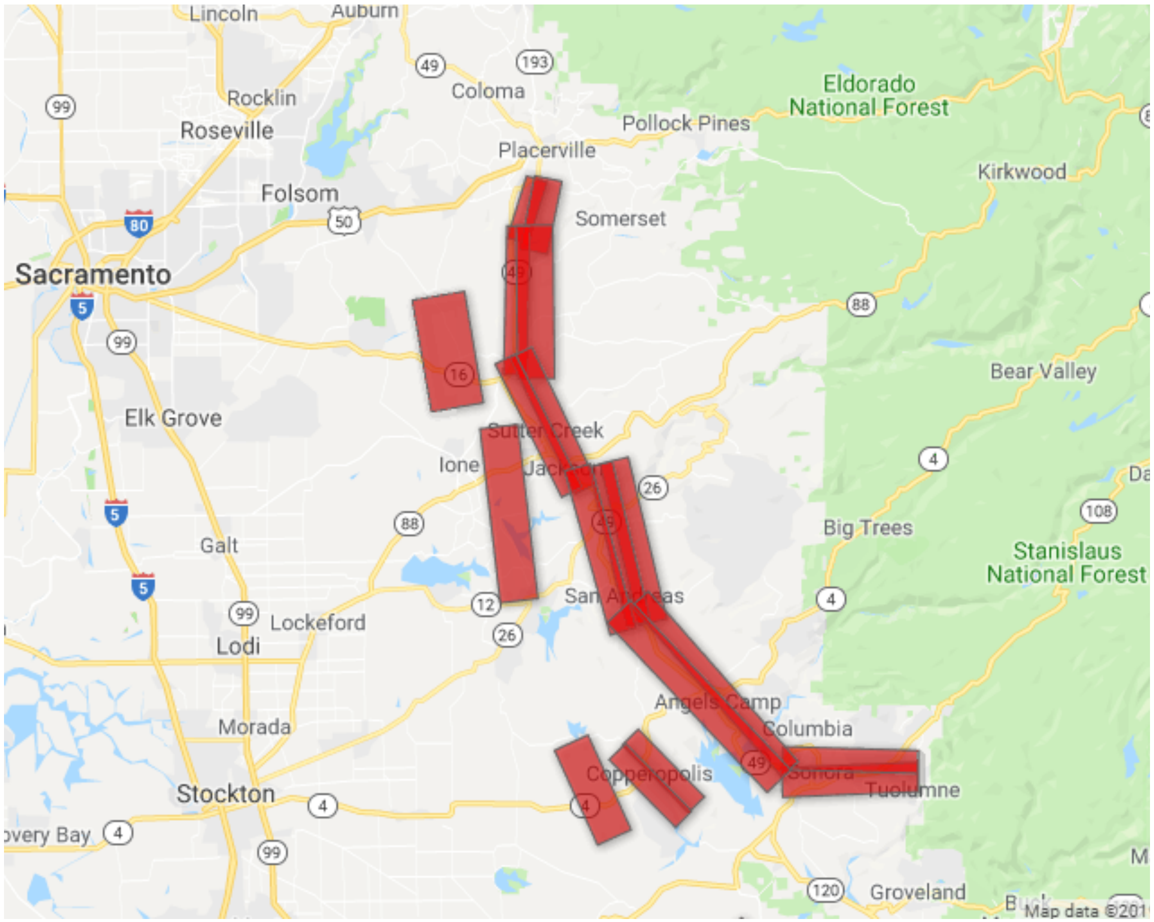
Upcoming manuscript: remote sensing retrospective analysis of Ducktown, TN

- Comparing 1999 and 2018 imagery to detect changes in facility mine drainage treatment, landuse changes





Example 2: Mother Load California historic mine site project

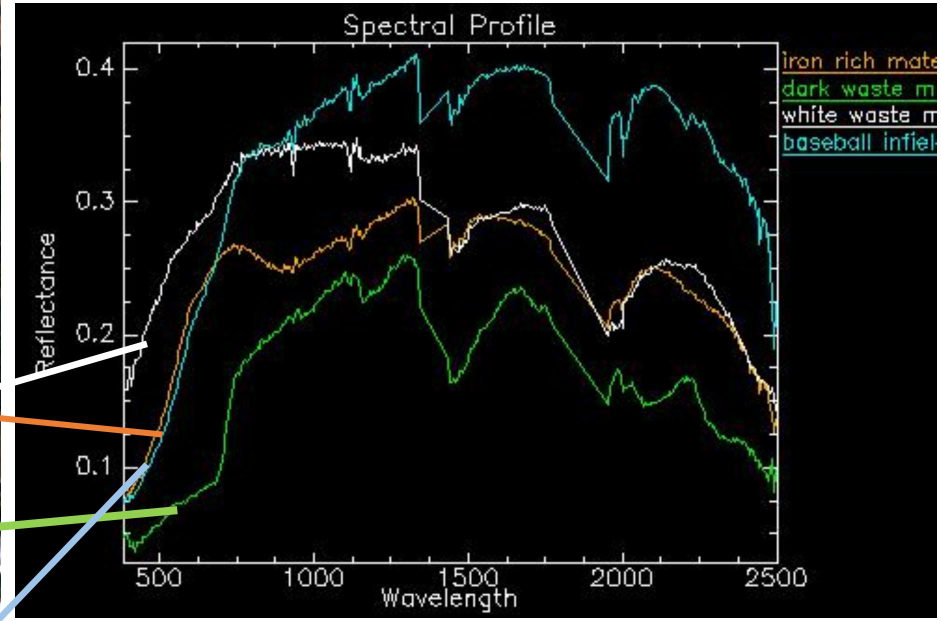


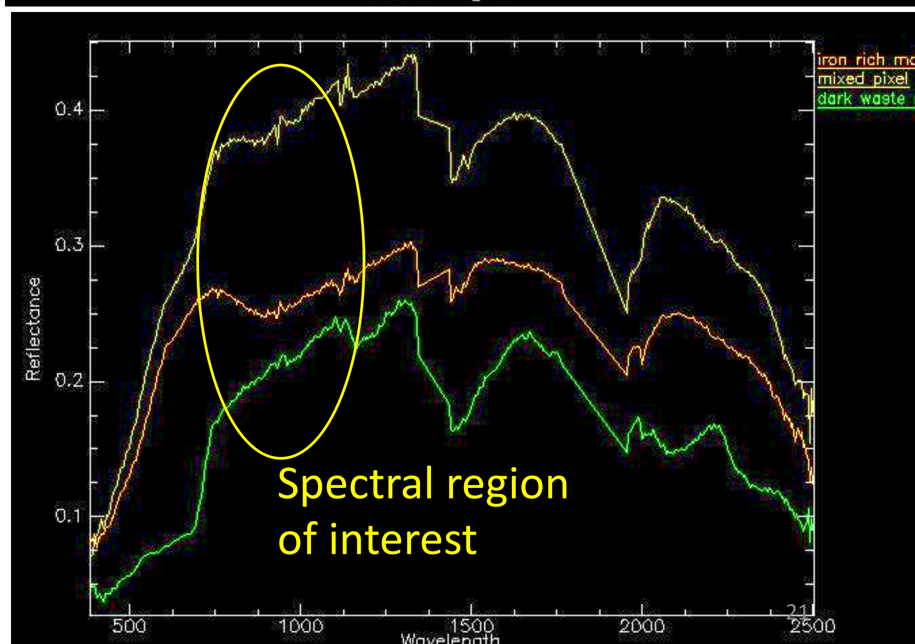
July 2019: Collected Hyperspectral imagery from NASA JPL AVIRIS-NG and ASO (LiDAR)

- Data analysis beginning

Objectives and Methods

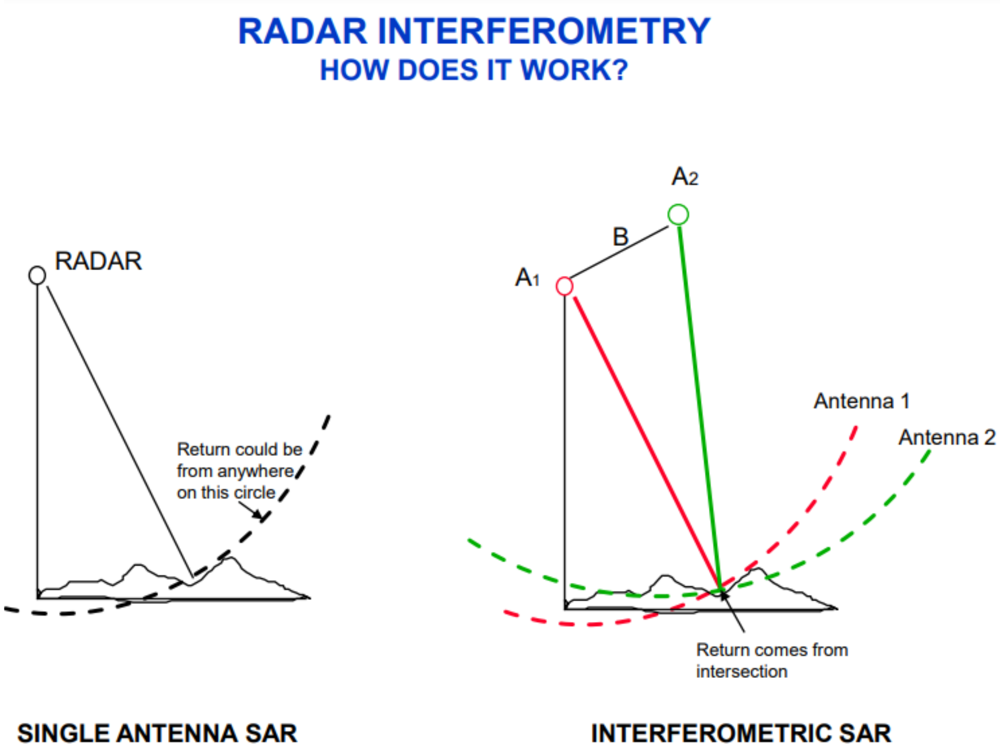
- Detect and map arsenic rich mine wastes over the Gold Belt and Copper Belt regions
- Combine high spatial resolution hyperspectral imagery with LiDAR to identify mine waste piles
- Field sampling using portable XRF and spectrometer for identify hotspots for image machine learning and validate results
- Use the mineralogy of the waste piles and the topographic models derived from LiDAR to predict off-site transport of arsenic
- Detect off-site arsenic contamination. For example from potential transport of mine material for residential fill



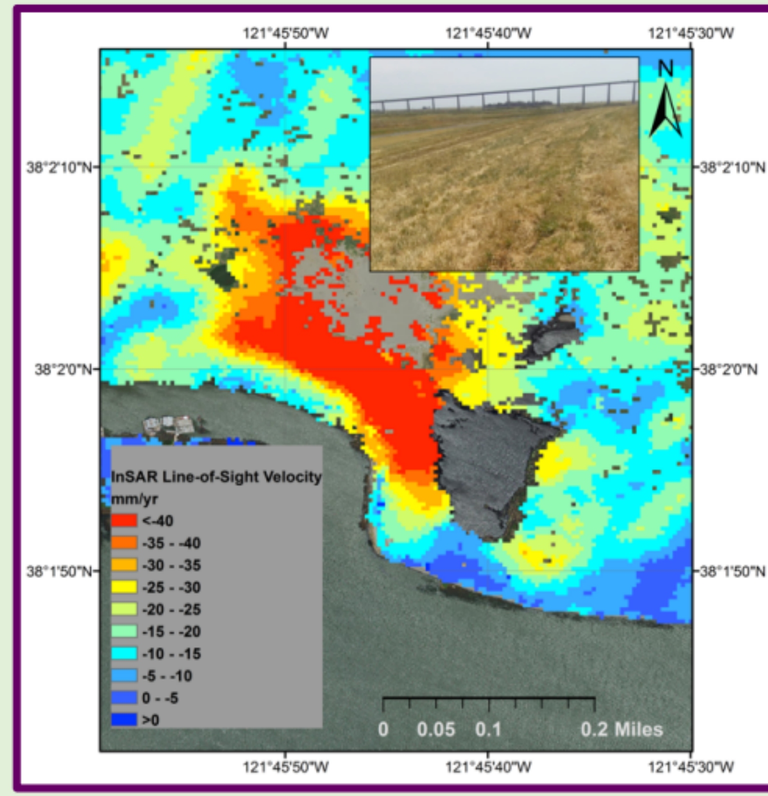


NASA AVIRIS-NG image of
Argonaut Mine
With retrieved specta

SAR Interferometry: detecting fine changes in land surface elevation



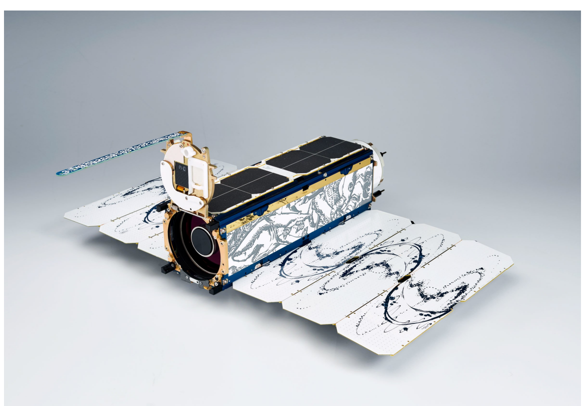
Images and information courtesy of NASA JPL and CalTech



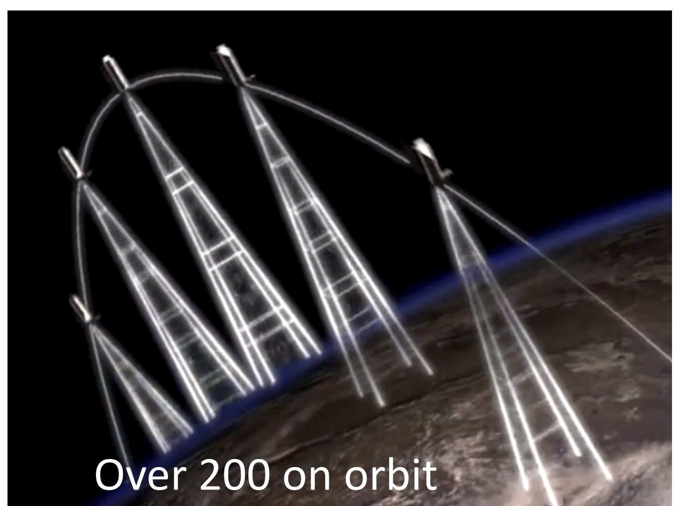
Map showing rate of ground movement along one of the levees that prevents flooding of an island in the Sacramento-San Joaquin Delta [Deverel 2016]. The inset photo shows a view looking east towards the area of most rapid movement (red/orange color). The signal, clearly visible to the radar, is not obvious to an observer on the ground.

Persistent imaging from space

- Constellations of small imaging satellites collecting daily imagery. Persistent imaging can be used to detect anomalies related to mine infrastructure issues:
  - Retention dam slumping and indications of failure
  - Waste pond breaches
  - Undocumented infrastructure changes
  - The classic waste burial and cover



Dove nano-satellite.



Over 200 on orbit

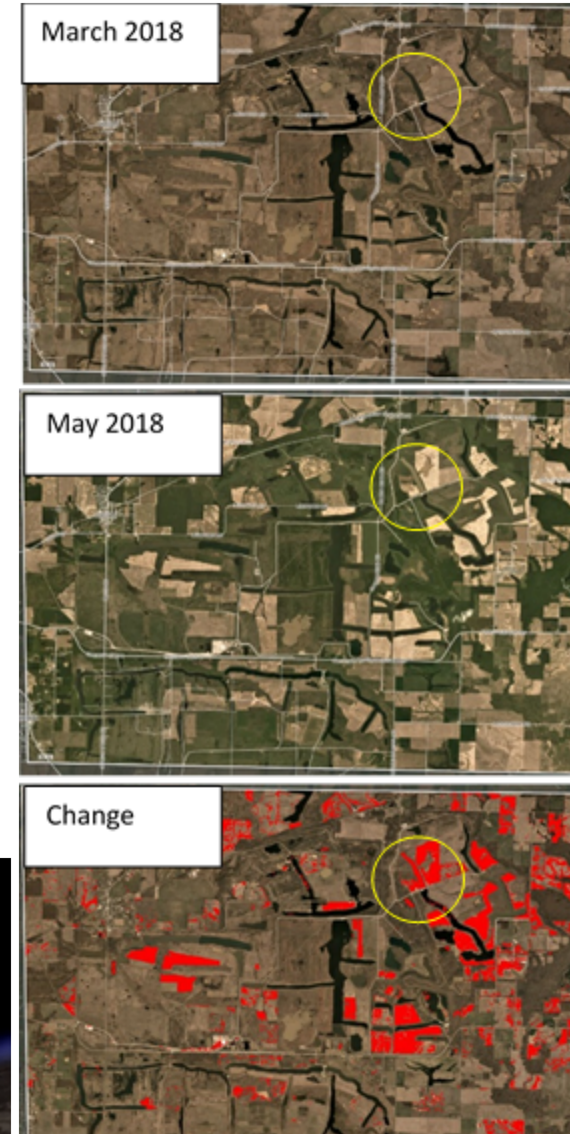


Figure 1: Example of change detection product. Planet Lab imagery for an example waste basin for March and May 2018. Change image highlights in red the land cover differences between the two dates. Most changes are due to agricultural operations. Area outlined in yellow shows possible water quality changes at former extraction basin.

Persistent imaging from space

Images courtesy of Planet Labs (planet.com)

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