Characterizing Sources of ARD and Resulting Water Quality Impacts Using Hyperspectral Remote Sensing

– Examples from the Upper Arkansas River Basin, Colorado

Matthew A. Sares, Phoebe L. Hauff, Douglas C. Peters,
David W. Coulter, David A. Bird,
Frederick B. Henderson III, and Eric C. Prosh

NASA Grant #NAG13-02026

COLORADO GEOLOGICAL SURVEY

SII SPECTRAL INTERNATIONAL INC.

PETERS GEOSCIENCES

HENDCO Services

Overhill Imaging

Project Goals

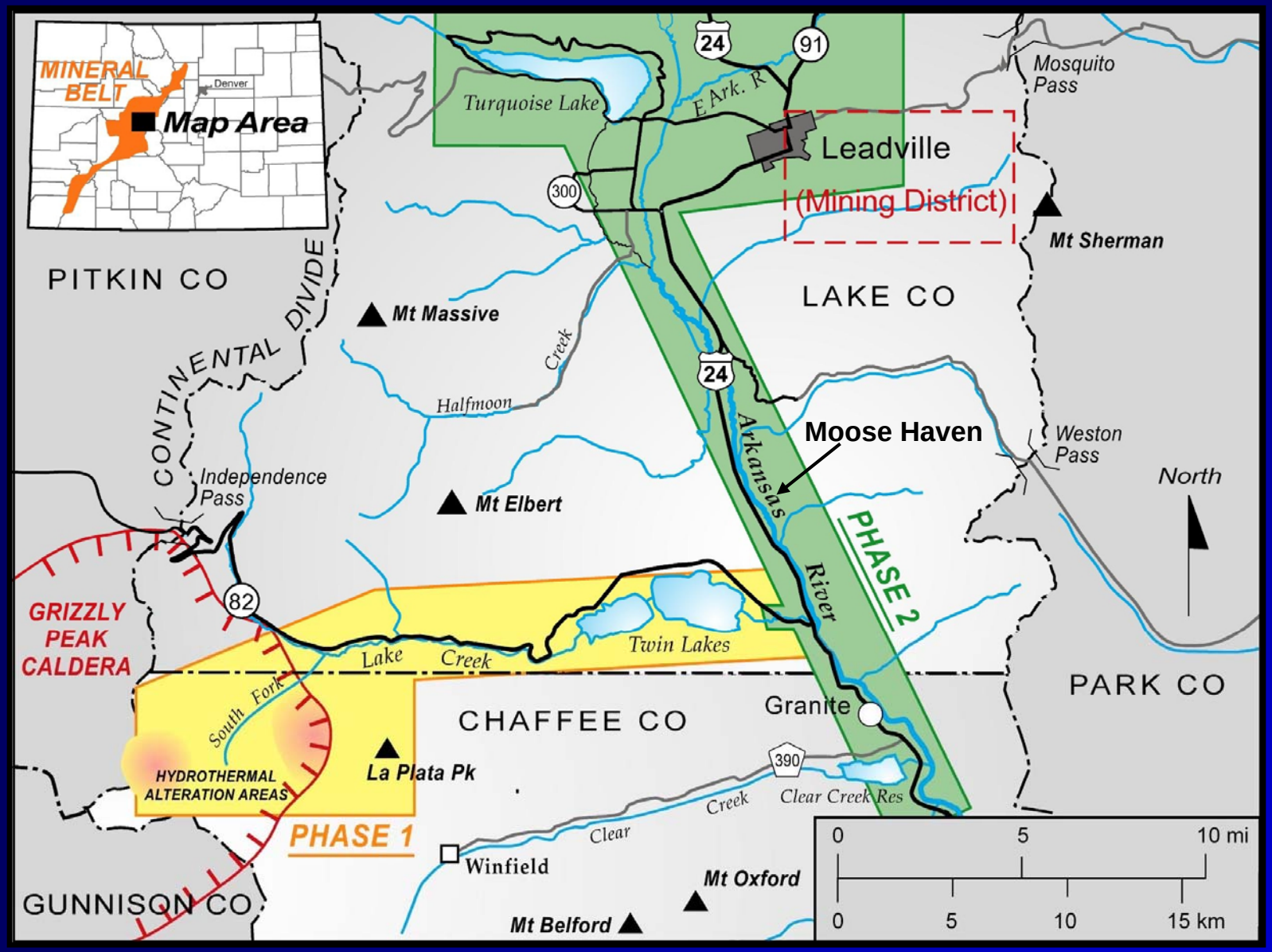
1) **Identify mineralogy and tie to stream water quality -** source area & streambed

2) **Identify controls on metal solubility and mobility, through mineral ID and geochemical modeling**

3) **Identify effective remote sensing technologies for identification of mineralogy**

4) **Assess the ability of remote sensing to identify natural and anthropogenic issues**

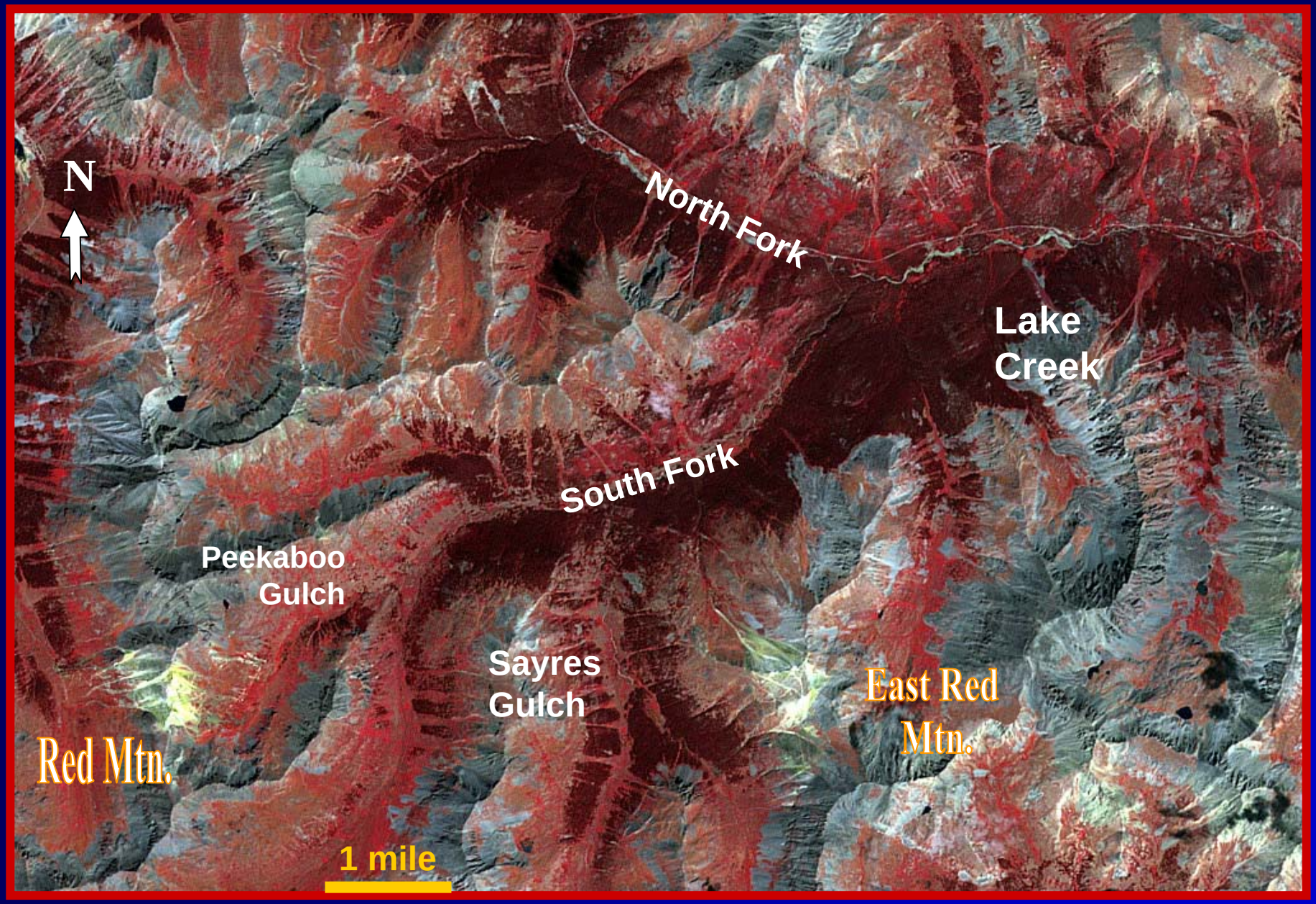
Study Area-Phases 1 & 2



Phase 1
Lake Creek Watershed

- **Natural Acid Rock Drainage**

ASTER – False Color Infrared Composite – 15m



- Satellite-based sensor

Hydrothermally Altered Areas

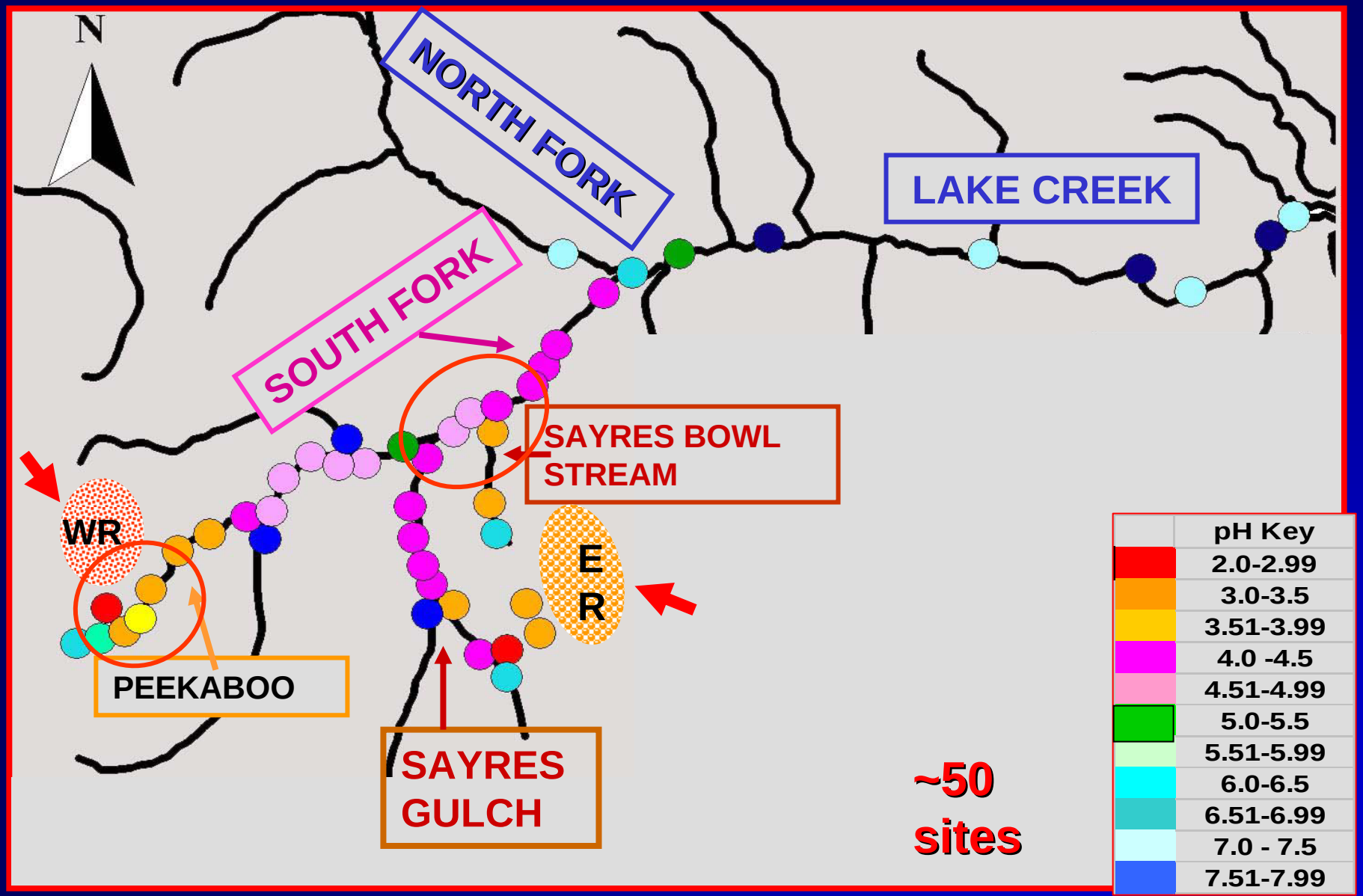
Sources of ARD

Red Mountain (West)

Red Mountain East

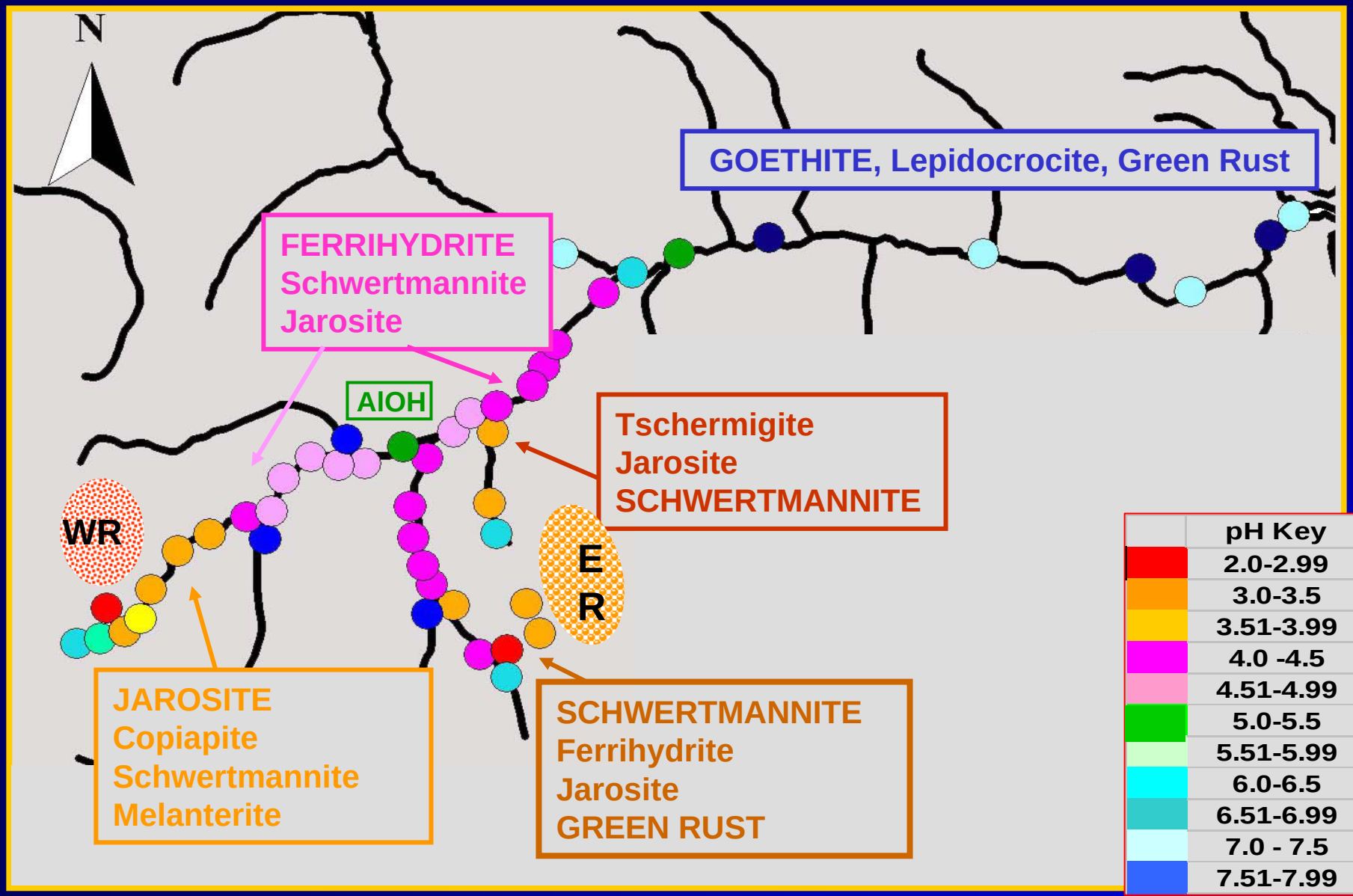
Field Sampling:

pH DISTRIBUTION LAKE CREEK WATERSHED



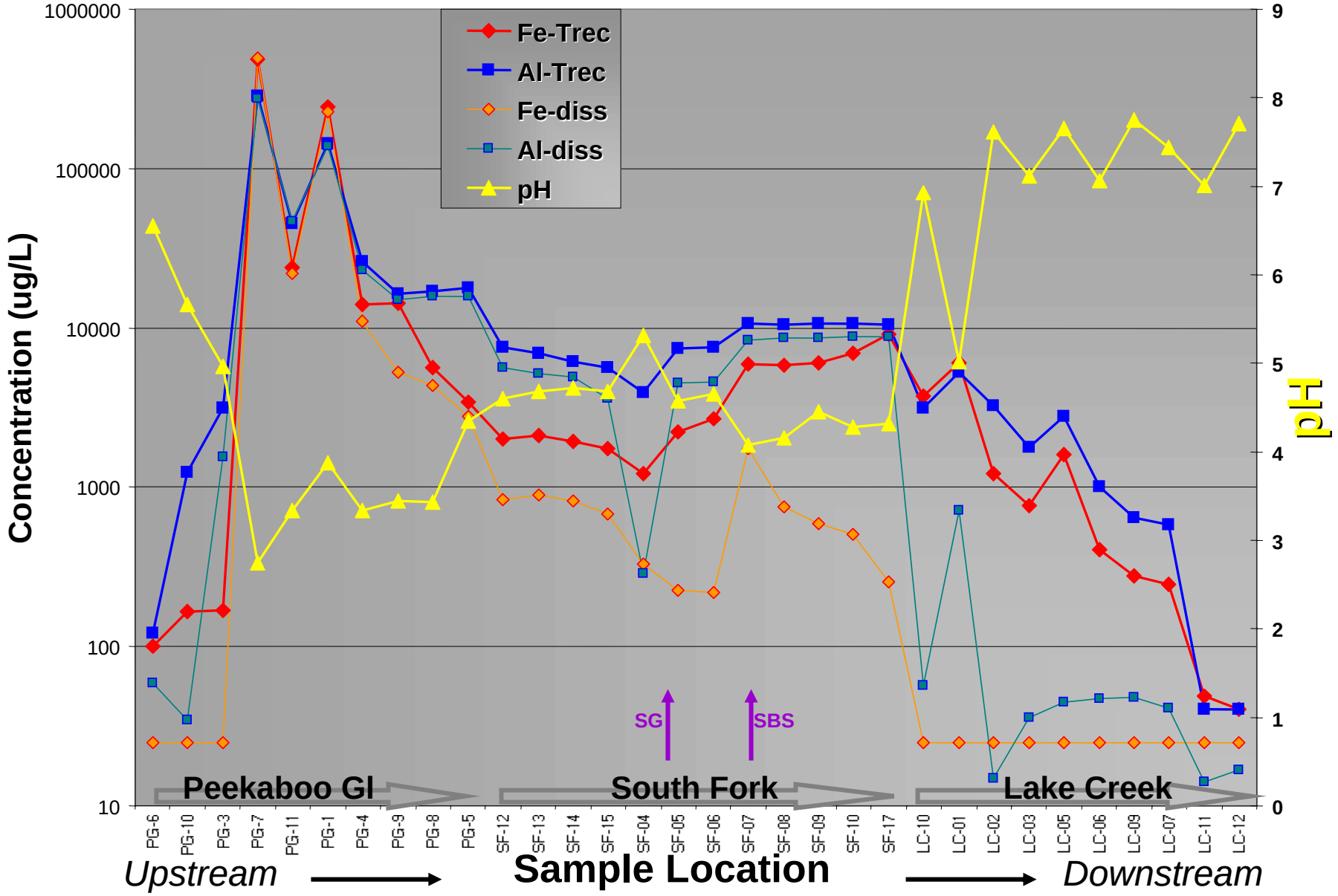
Field Sampling:

MINERAL DISTRIBUTION

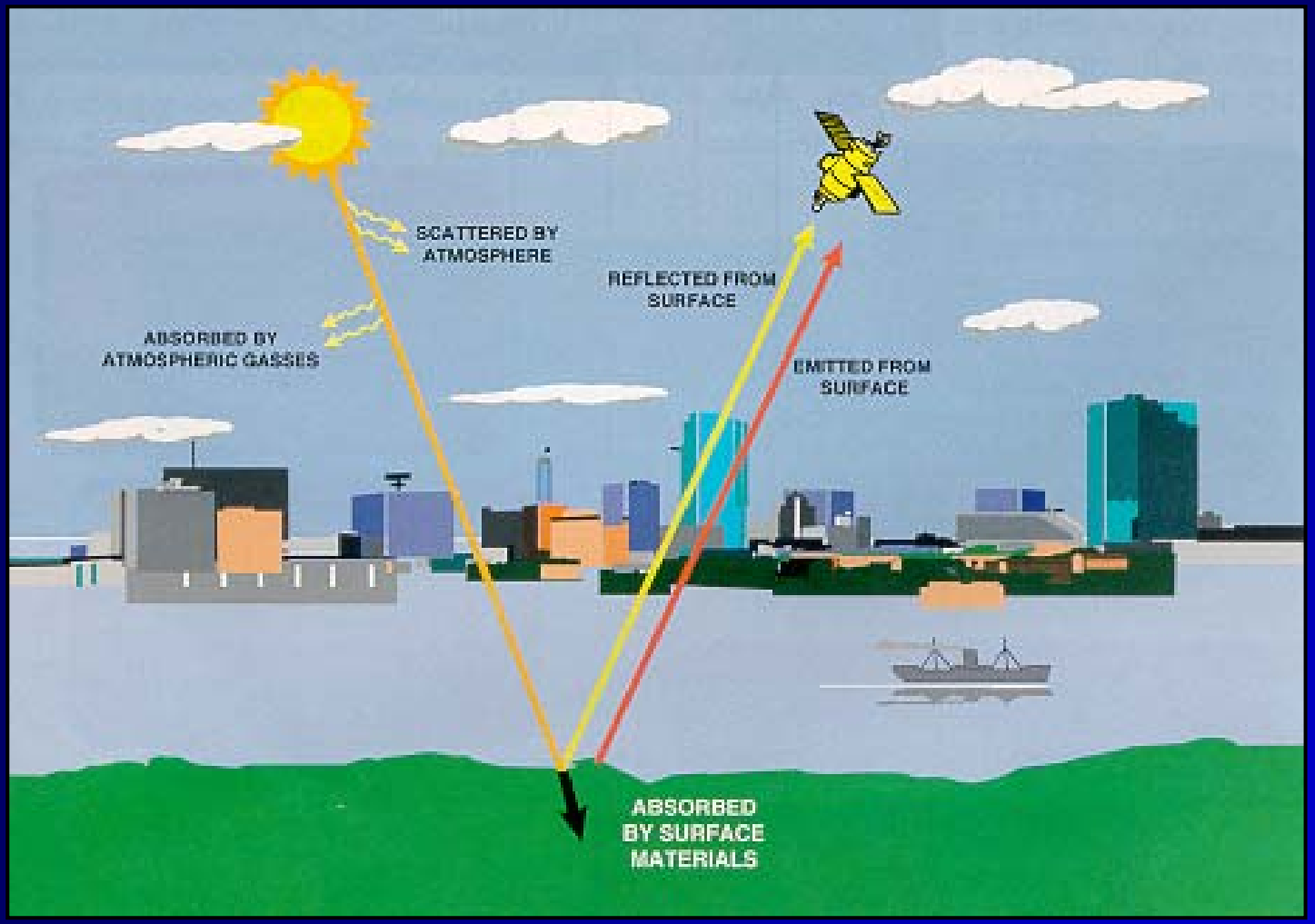


Water Quality - Peekaboo Gulch to Lake Creek

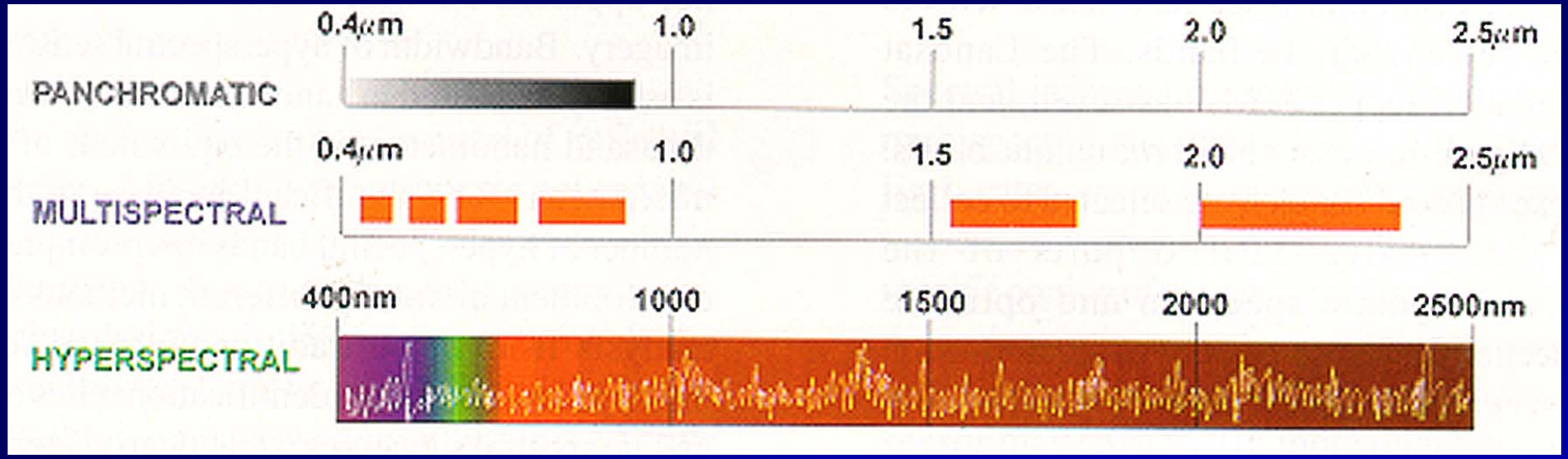
September 9-12, 2002



Sunlight Interaction with the Atmosphere and the Earth's Surface



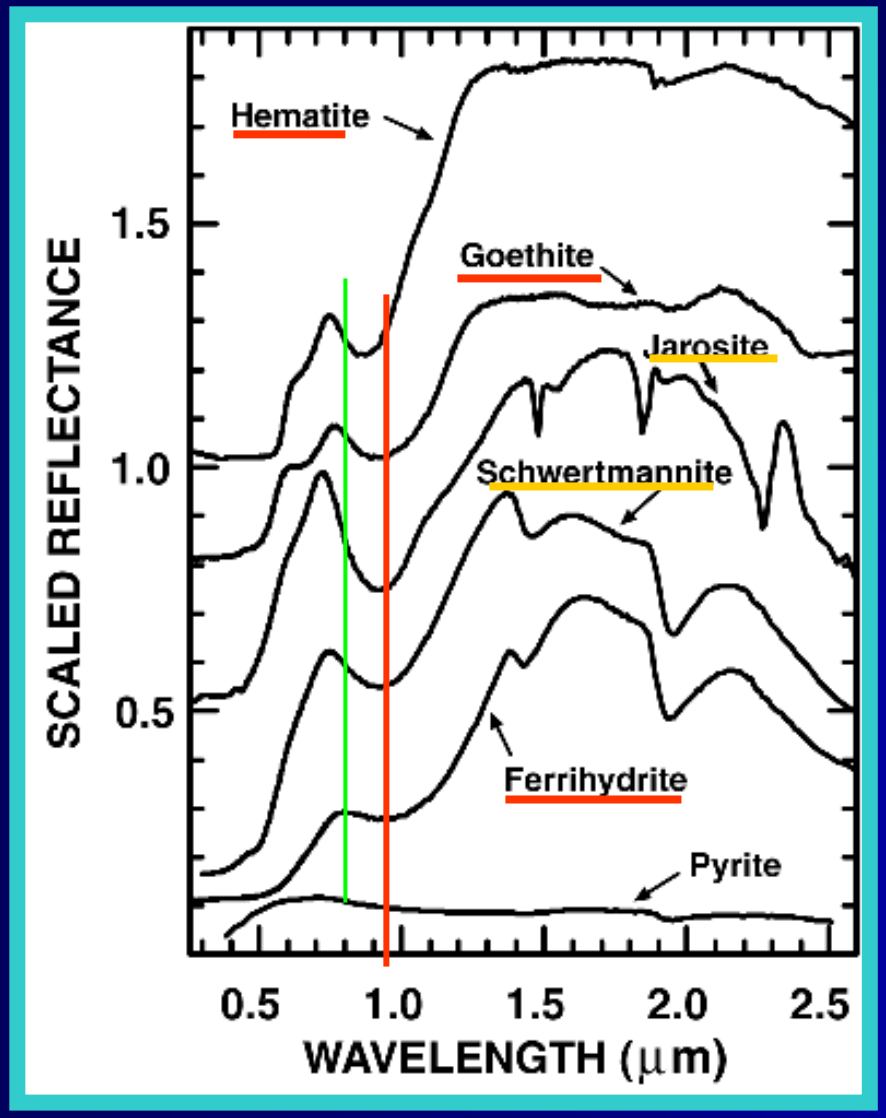
Characteristics of Hyperspectral Remote Sensing

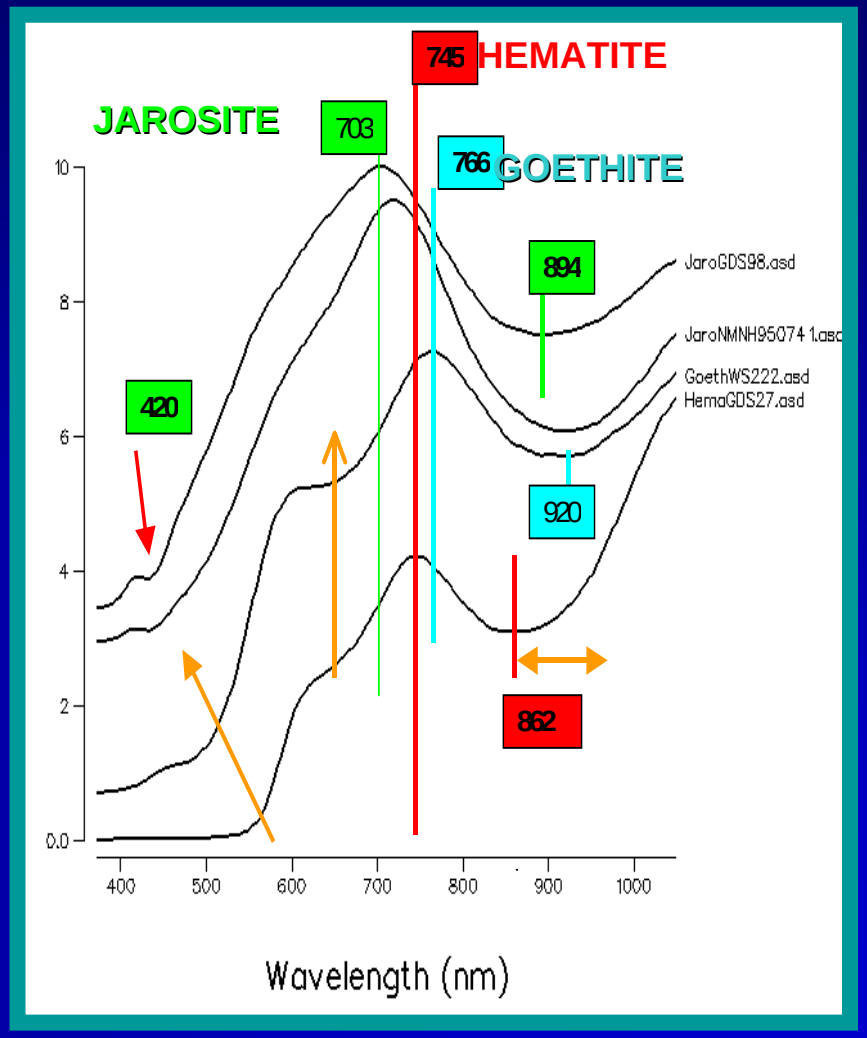


- **AVIRIS - LOW ALT (4 m)** ***-SPECTRAL & SPATIAL DETAIL***
- **SpecTIR HST-1 (1-4 m)** ***-SPECTRAL & SPATIAL DETAIL***

- **ASTER (15/30 m)** ***-MONITOR POTENTIAL***
- **SPOT 4 (20 m)** ***-SPATIAL DETAIL***
- **Hyperion (30 m)** ***-SPECTRAL DETAIL***

IRON OXIDES + SULFATES

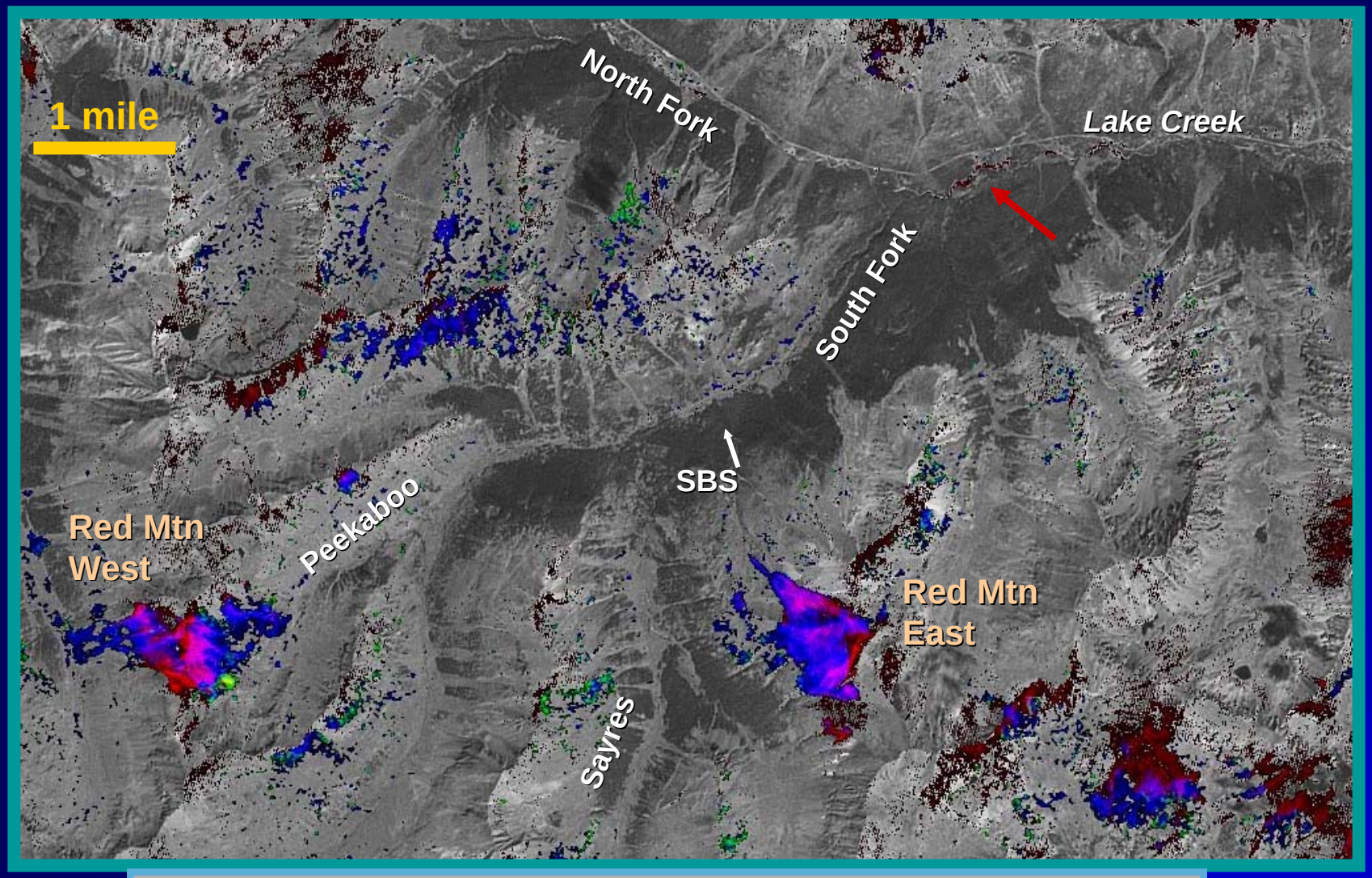




Main iron minerals observed in the Phase 1 study area (Lake Creek)

USGS References

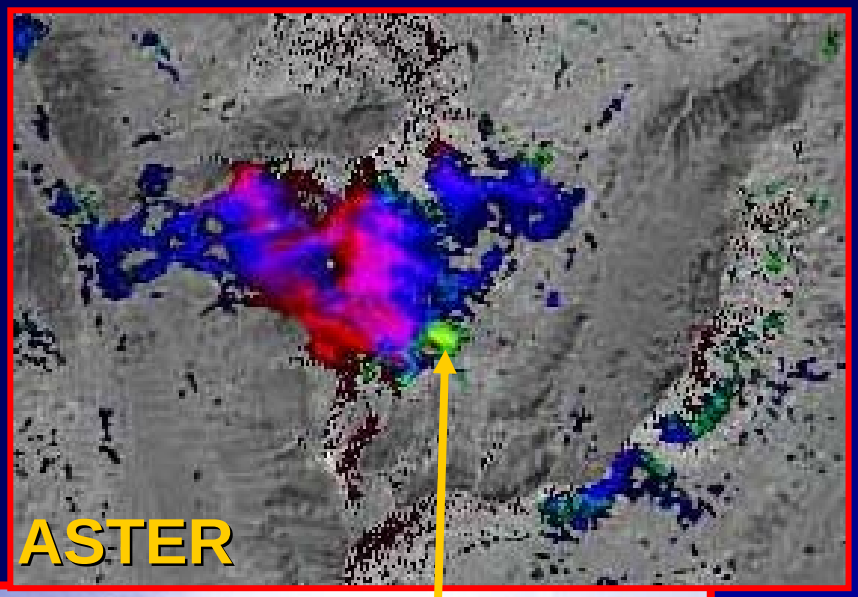
ASTER - Preliminary Mineral Classifications

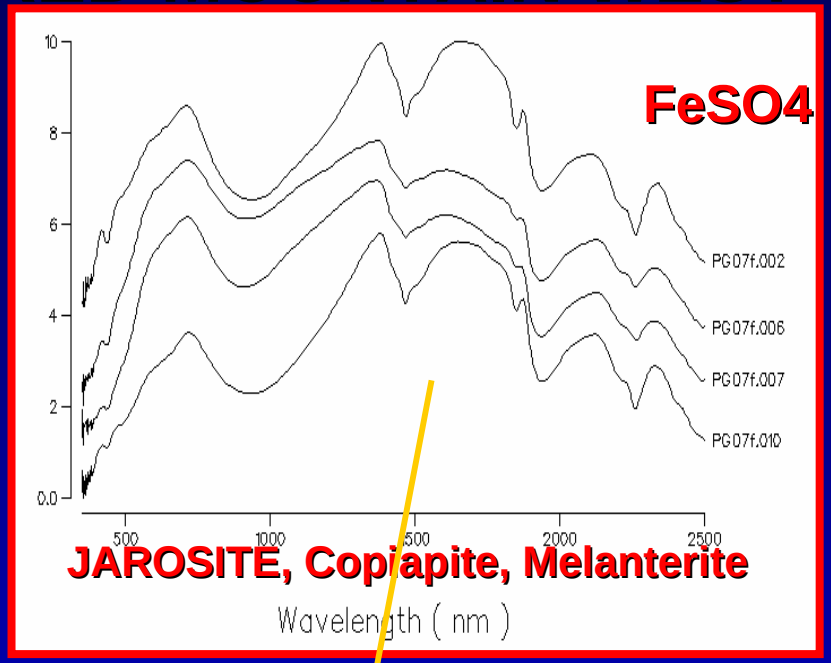


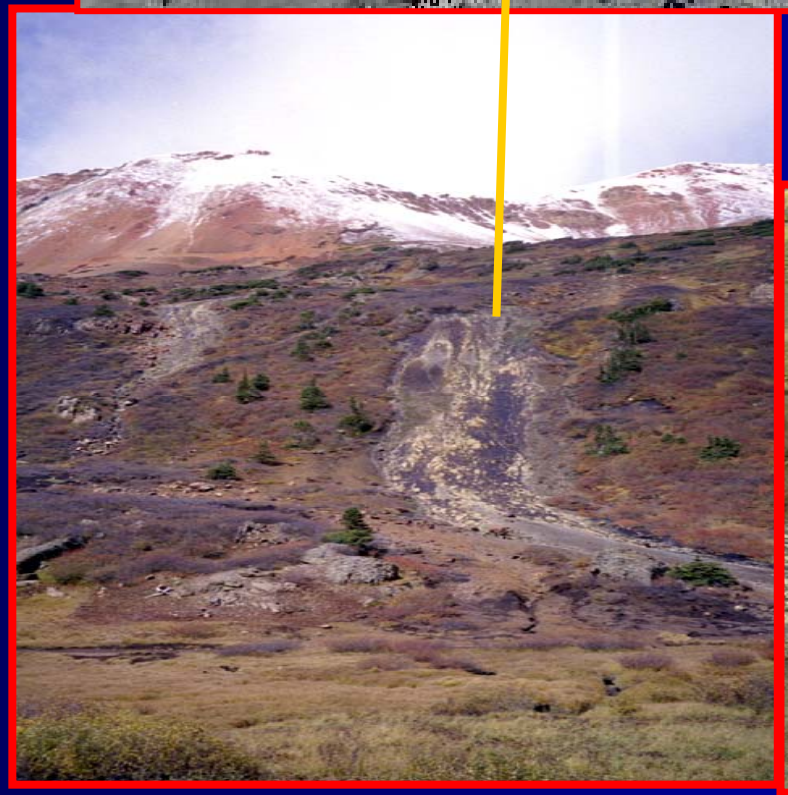
Reds = iron oxides; Blue = Illite; Green = Jarosite

- Satellite-based sensor

RED MOUNTAIN WEST







pH = 2-3

Airborne Hyperspectral

AVIRIS

JPL/NASA Sensor

4 m Spatial

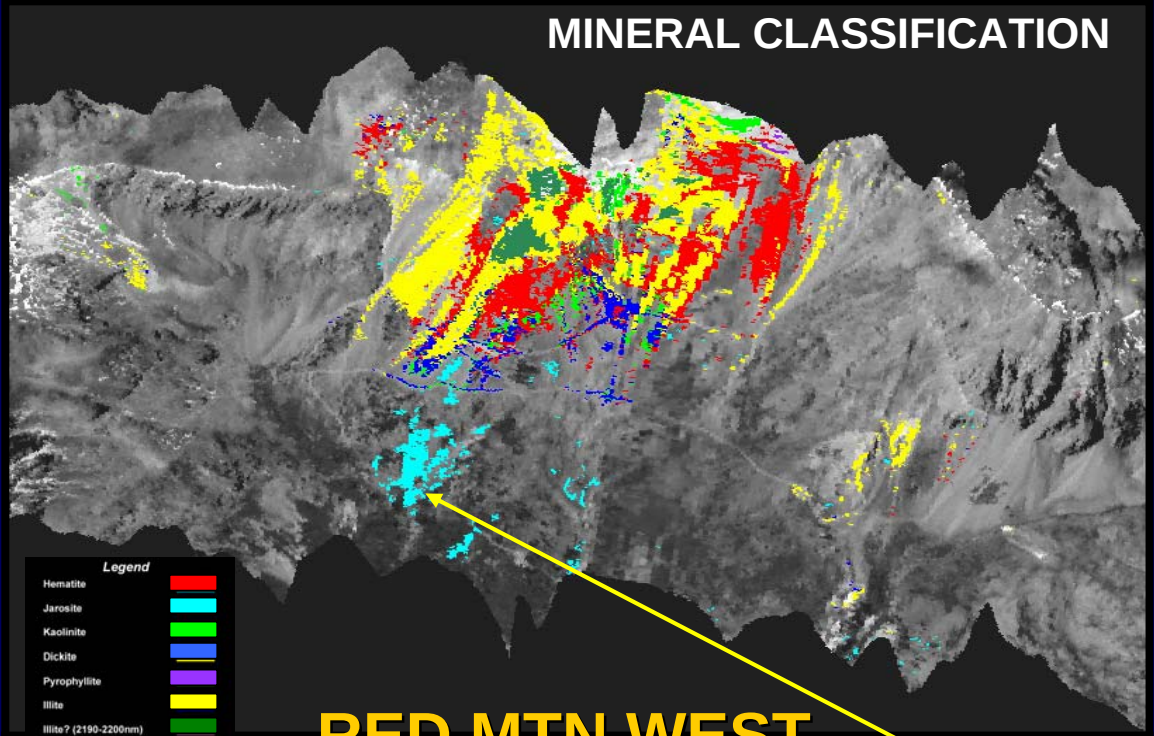
12-15 nm Spectral

Used to identify individual mineral species

Great S:N

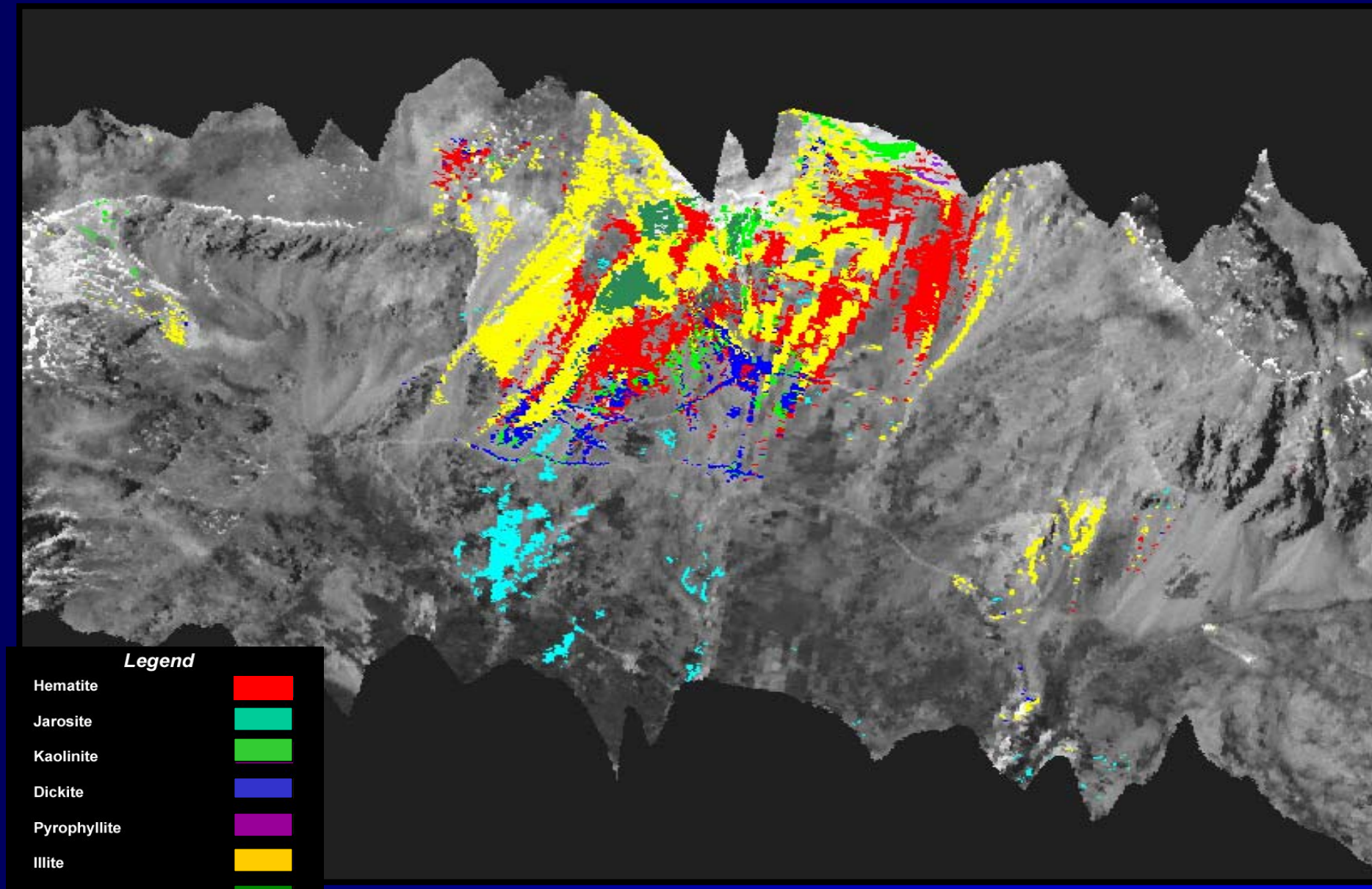
Low Altitude AVIRIS

Red Mountain West



RED MTN WEST

Low Altitude AVIRIS Red Mountain West

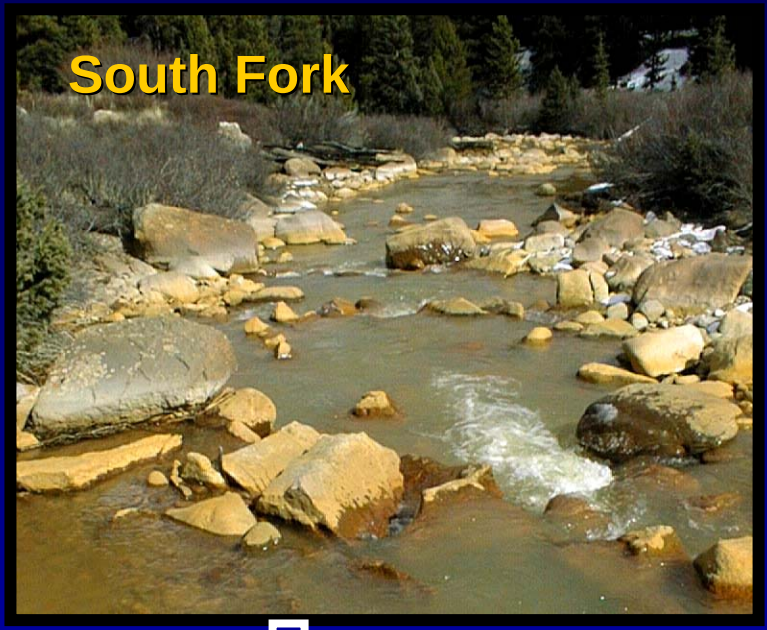


PYRITE SOURCE

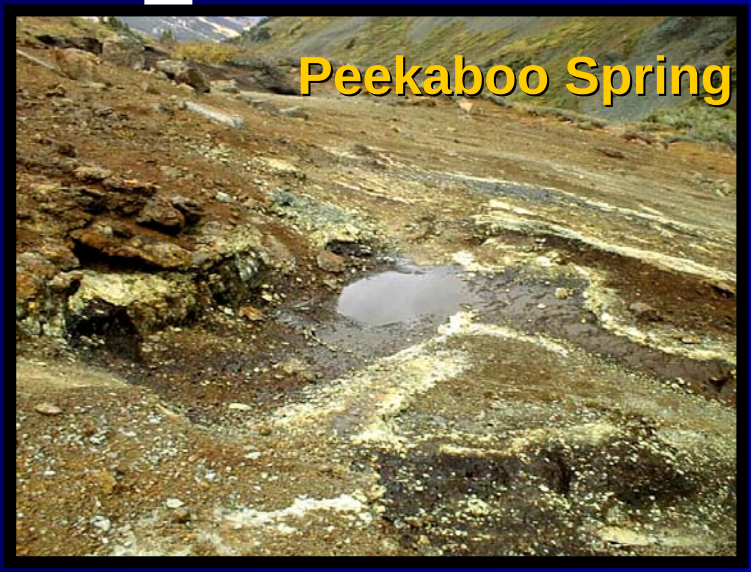
SPRING

JAROSITE

pH = 2.3-2.8



pH = 3-6 **SCHWERTMANNITE**



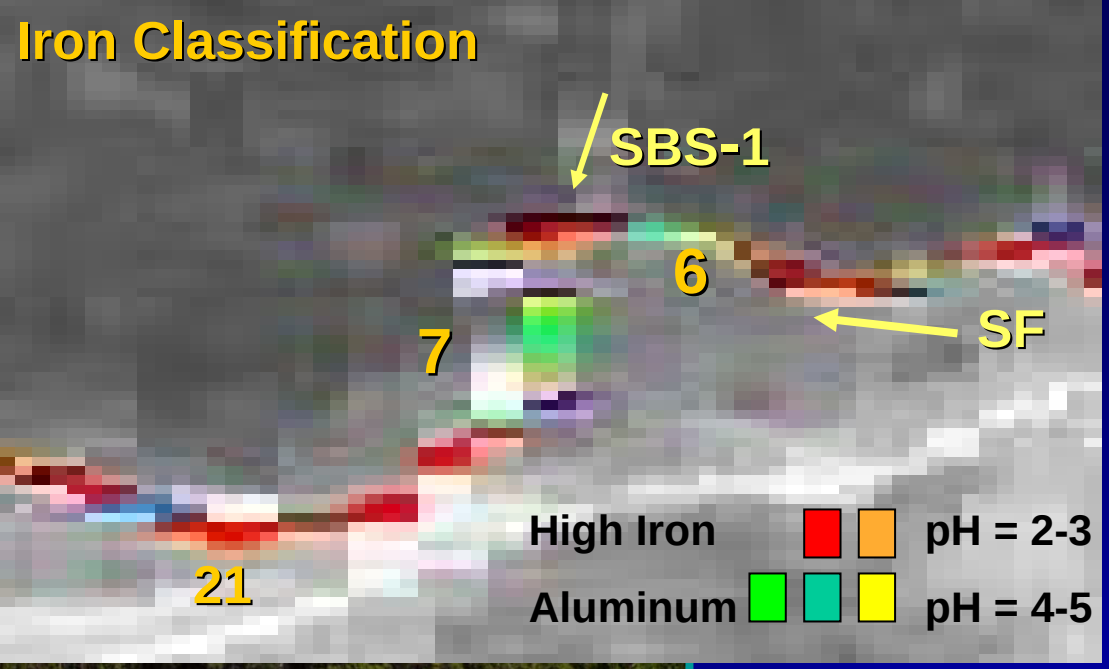
FERRIHYDRITE

pH = 4.5->

GOETHITE

pH = 7+

IRON MINERALS in NATURAL ACID DRAINAGE


Iron Classification
SBS-1
6
7
SF
21
High Iron
pH = 2-3
Aluminum
pH = 4-5

SF-6

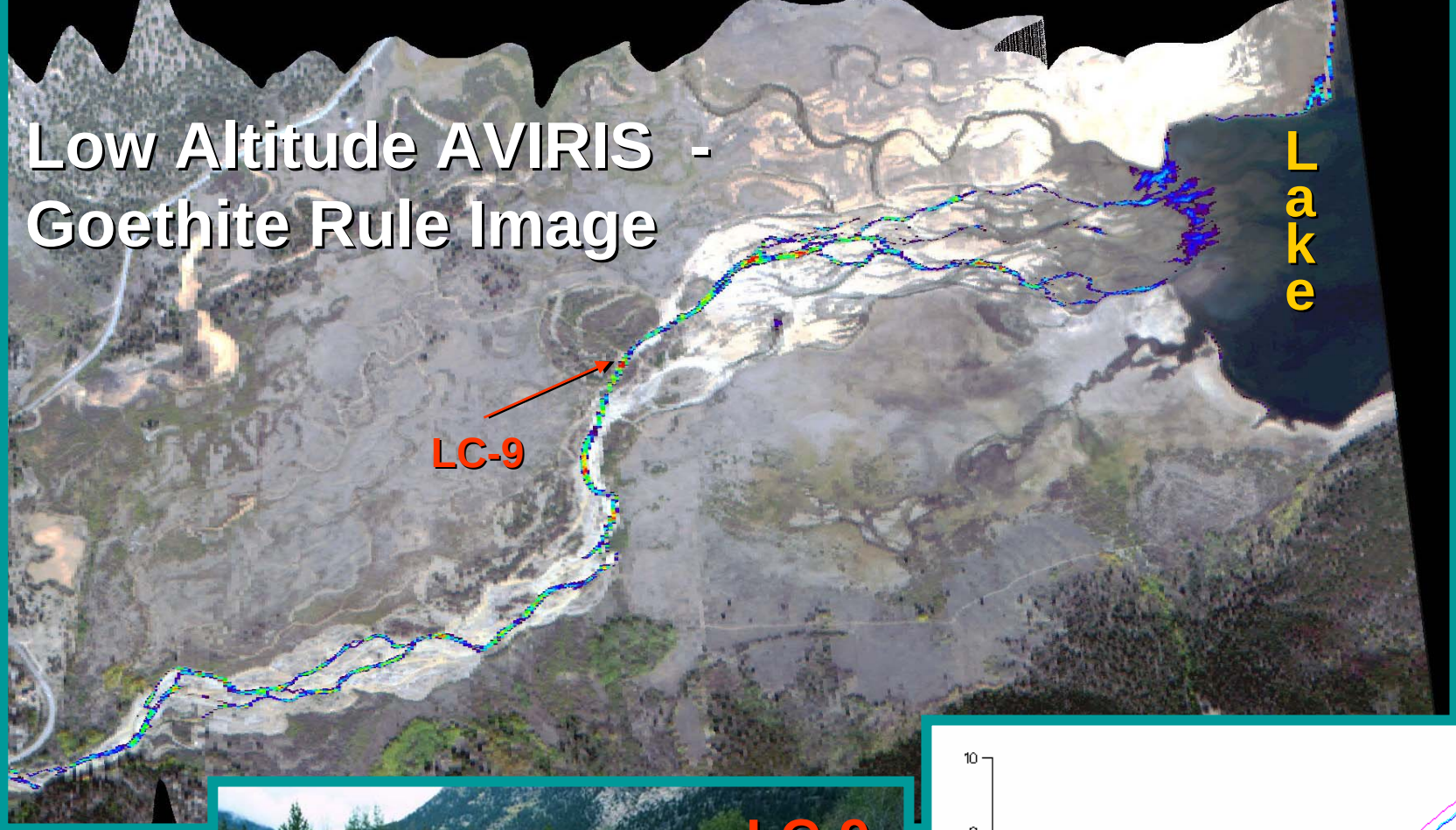
SF-21

SF-7

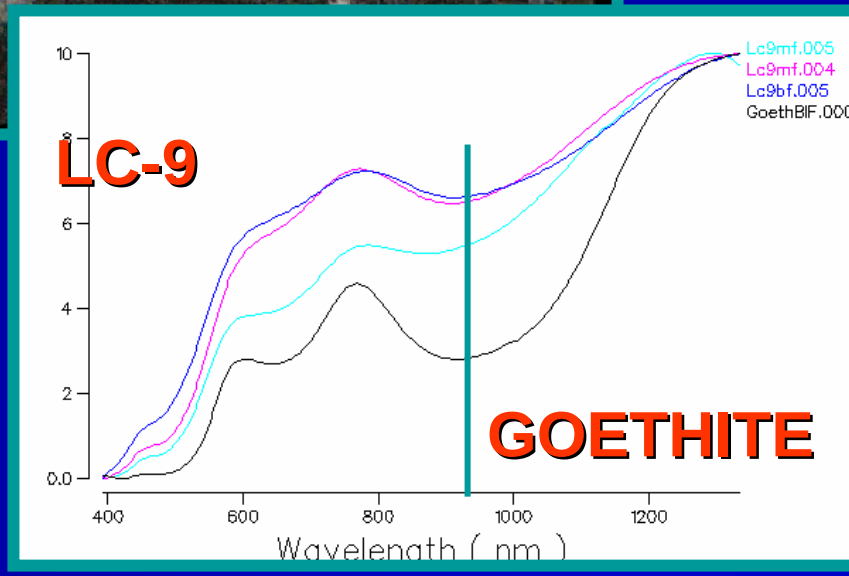
SBS-SF Confluence
pH
~5.0
SBS-1
pH
~3.0

4-m AVIRIS

Low Altitude AVIRIS - Goethite Rule Image



LAKE CREEK



RED

YELLOW

GREEN

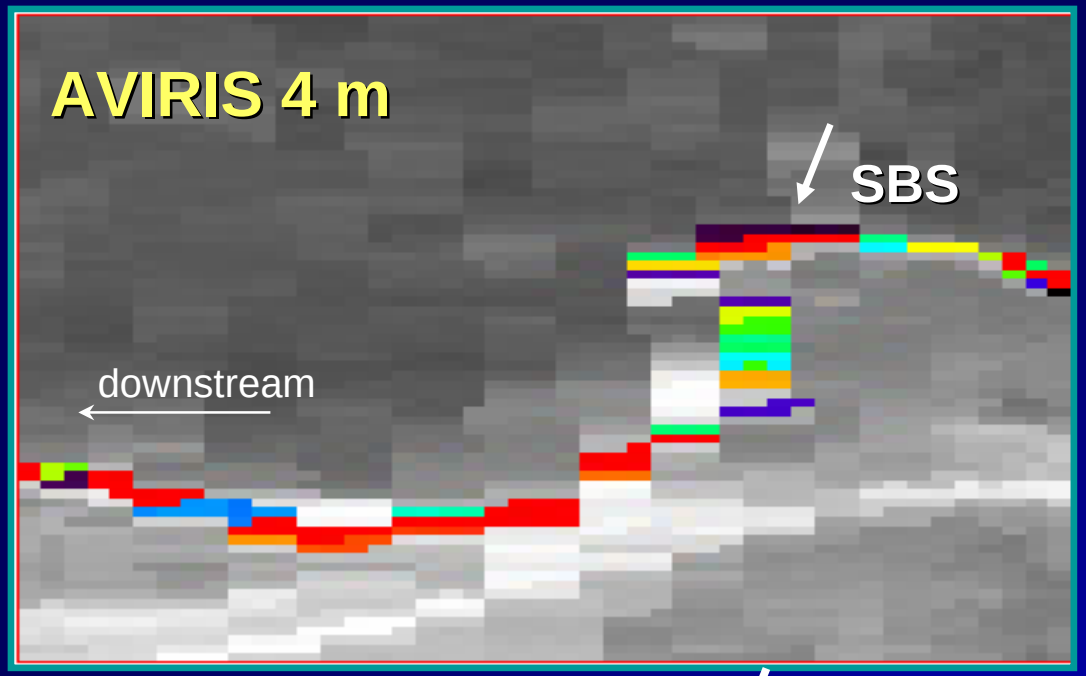
BLUE

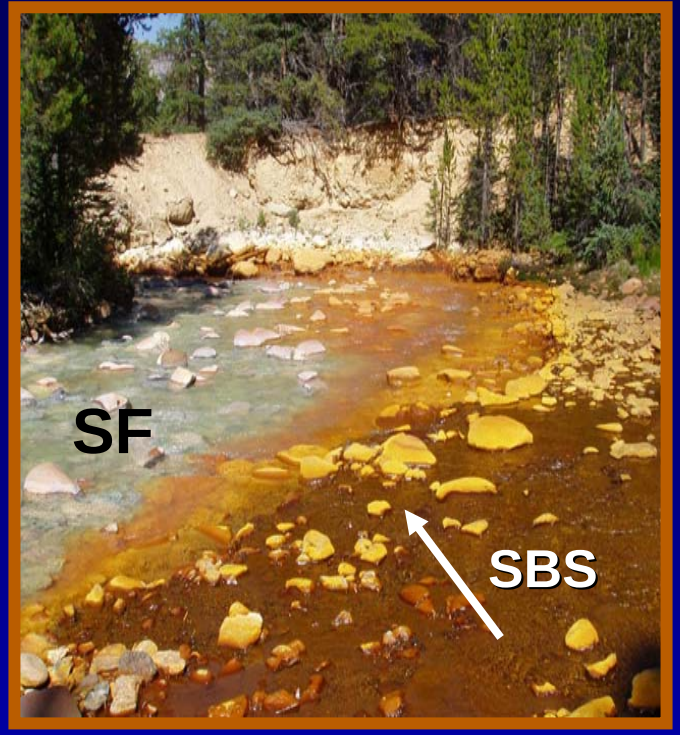
Airborne Hyperspectral

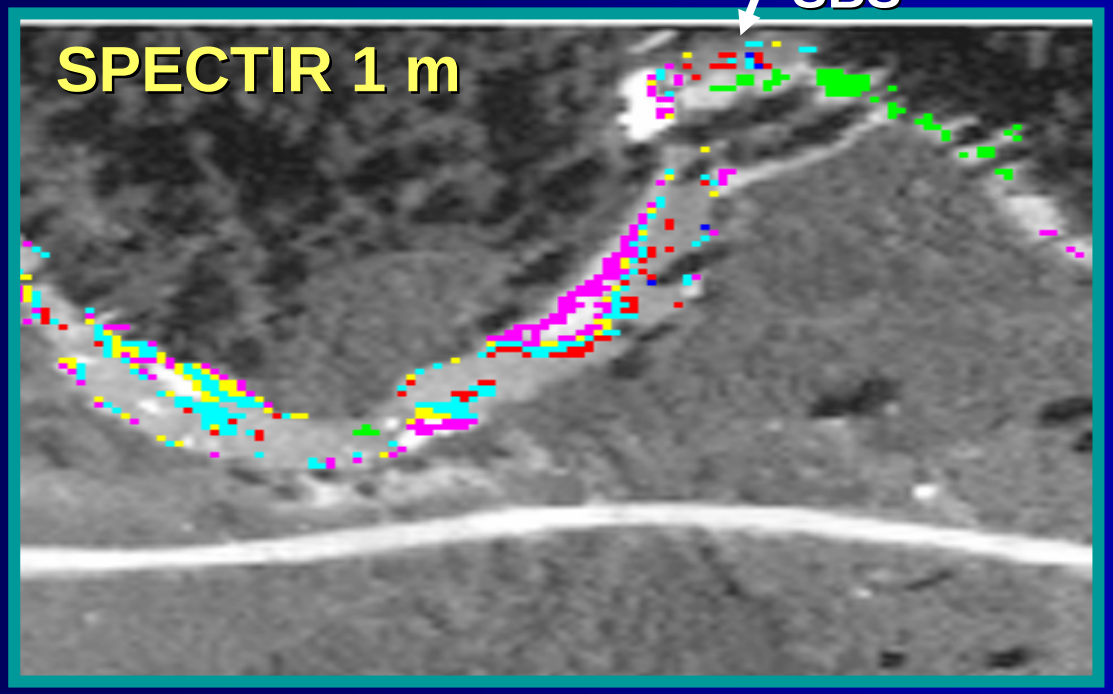
SpecTIR

0.5 - 2.5 m spatial resolution

10 nm spectral resolution

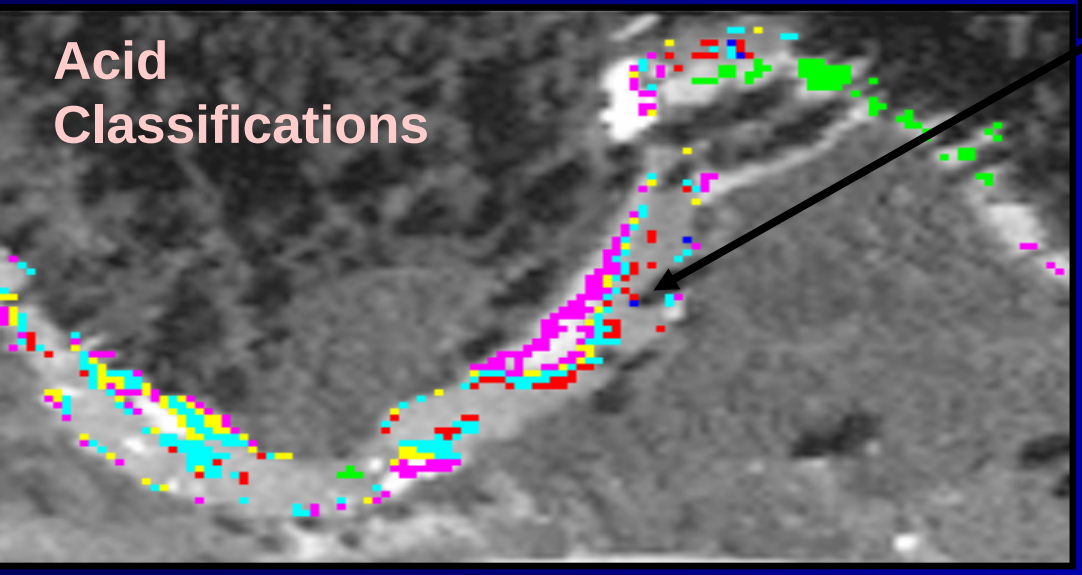






Comparison of AVIRIS and SpecTIR for SBS/SF Confluence Area

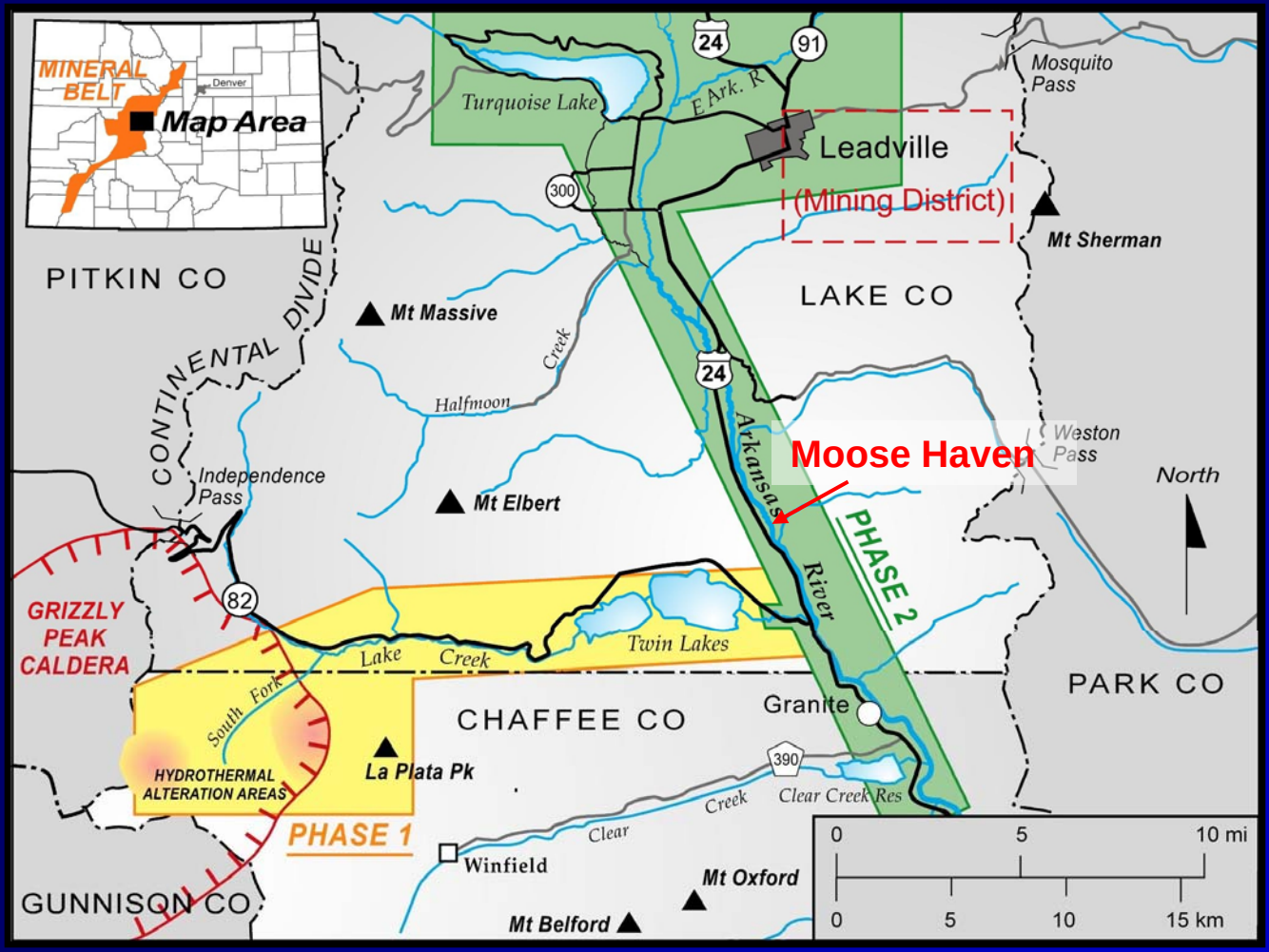
SpecTIR Mineral Classification



Jarosite	🔴	pH = 2
Ferri + Schwert	🟡	pH = 3
Schwertmannite	🔵	pH = 3-4
Ferrihydrite	🩷	pH = 4-5
Aluminum	🟢	pH = 5.0

Overhill Imaging

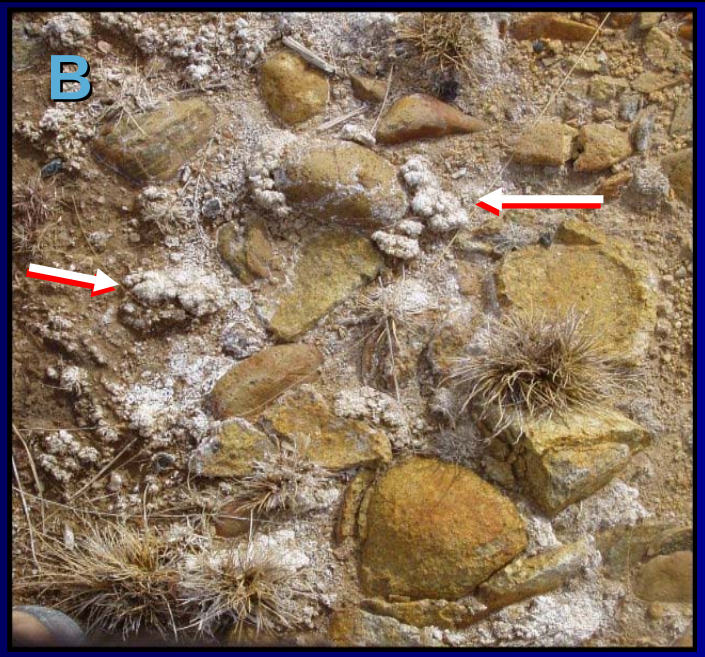
Phase 2
Arkansas River Mainstem



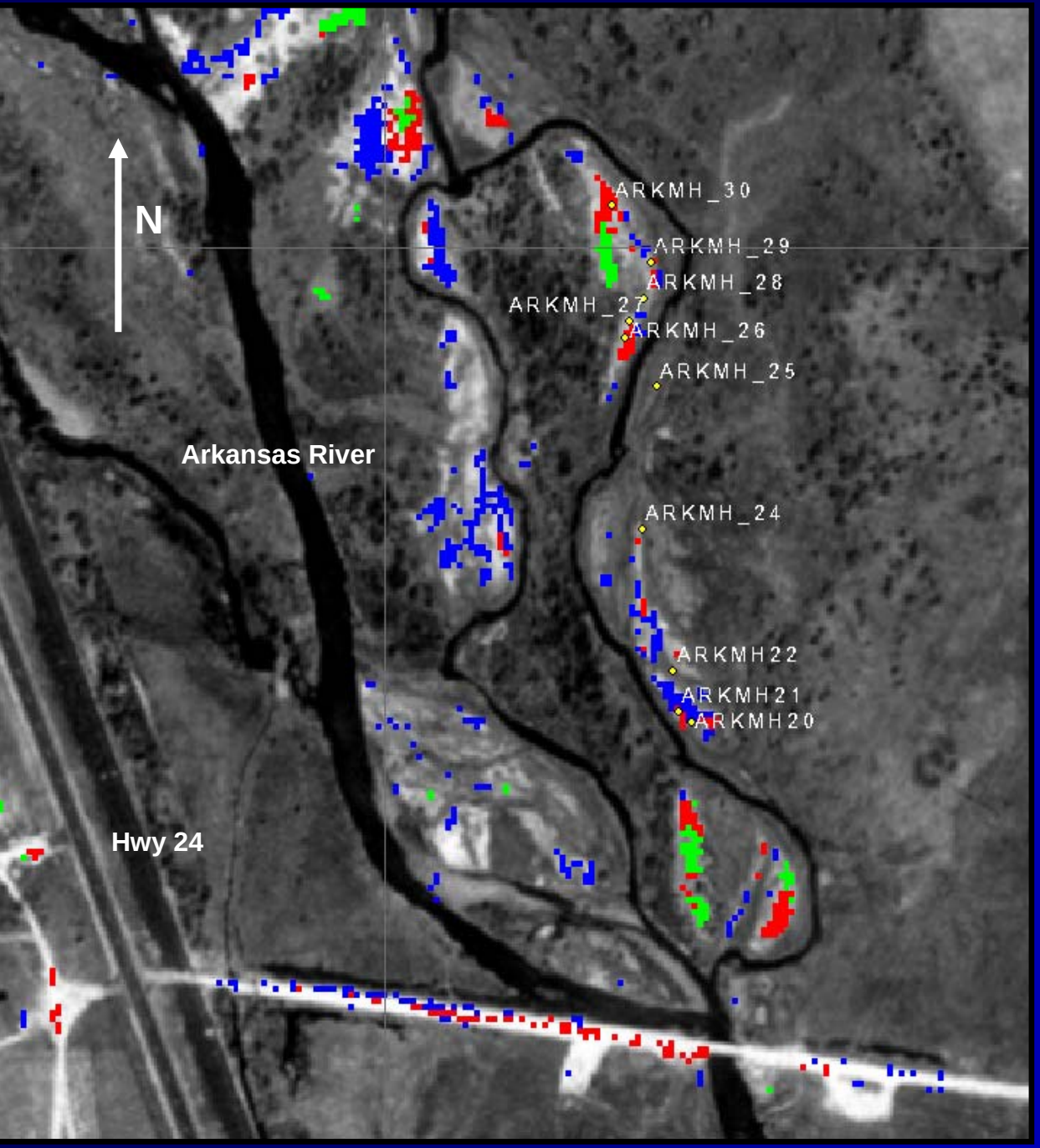
Mining Impacts

Tailings along the Arkansas River

- transported downstream from Leadville



Tailings at Moose Haven



- Tailings-iron minerals
- Tailings
- River clays

Summary

- ***Hyperspectral remote sensing is useful in characterizing ARD environments – therefore, it is useful in making remedial decisions and in post-remedial monitoring***

- ***Source areas for ARD can be characterized and "hot spots" identified with hyperspectral remote sensing***

- ***Hyperspectral remote sensing can identify mineral precipitates on exposed stream beds***

Summary

- ***Qualitative stream pH can be identified spatially within ARD affected stream reaches***

- ***1m hyperspectral remote sensing can identify temporal changes in pH from high- to low-flow.***

- ***Tailings deposited in river sediments can be identified and characterized spatially and compositionally***

Questions?

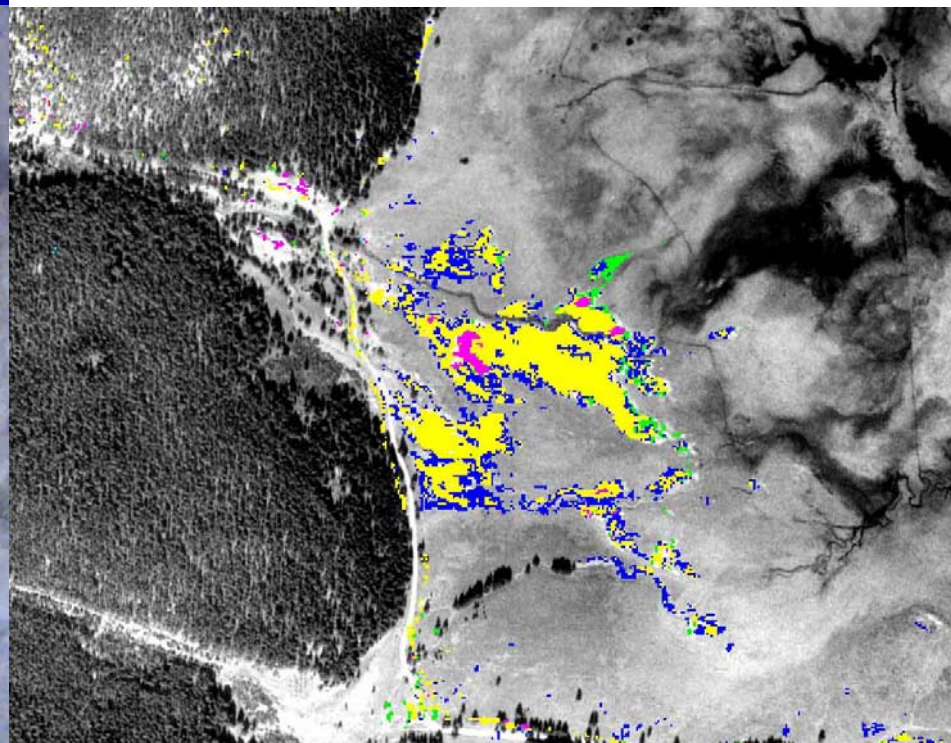
SpecTIR 2.5-m Data

Comparison of True Color and Mineral Classification Images

Closeup of Lower St. Kevin Gulch and Tailings Deposits

Legend

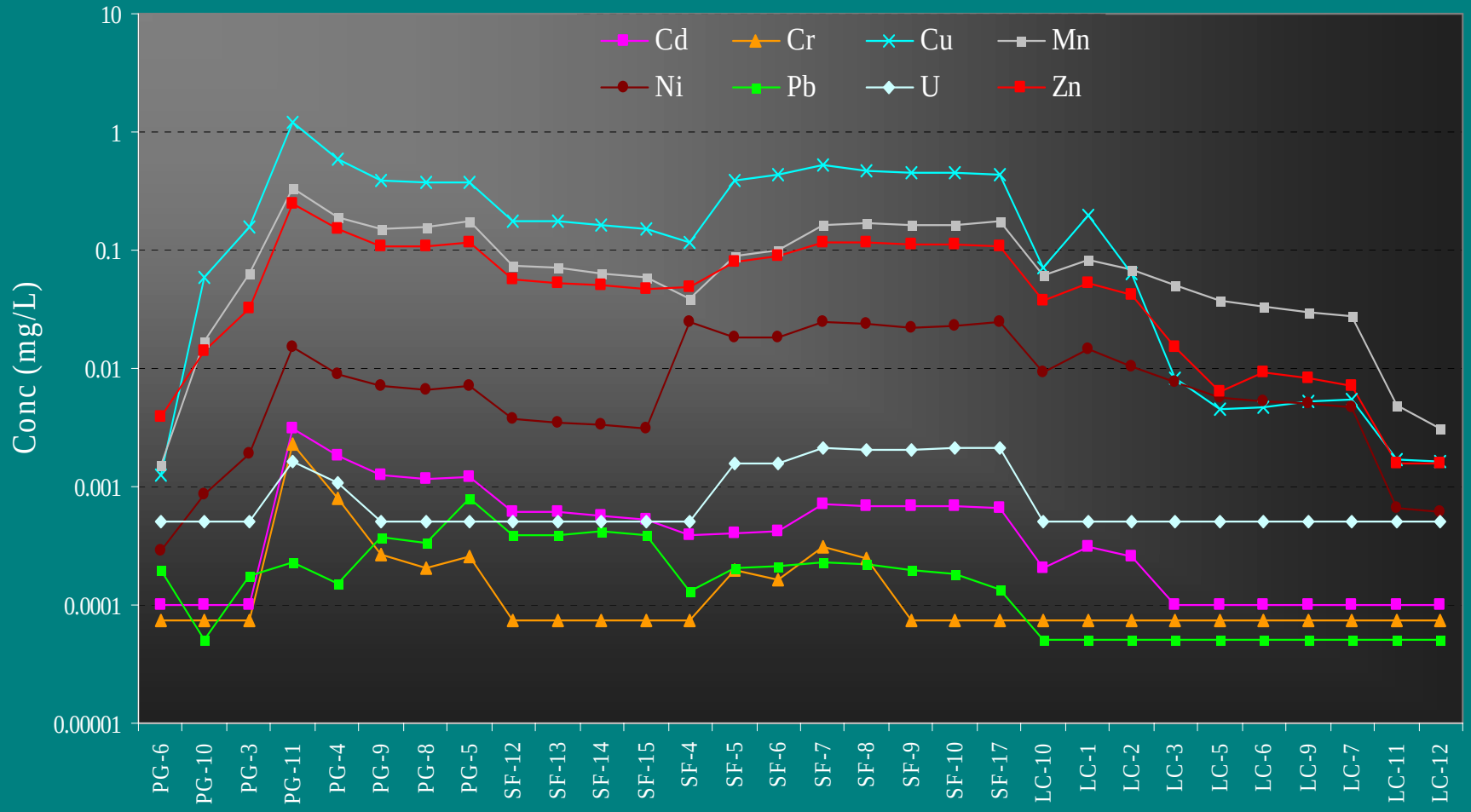
- Tails - Weak Illite Moderate Carbonate
- Tails - Weak Illite Weak Carbonate
- Tails - Moderate Illite Moderate Carbonate
- Tails - Strong Illite Moderate Carbonate
- Dumps - Strong Illite Moderate Carbonate
- Dumps - Strong Illite



Concentration vs. Loading

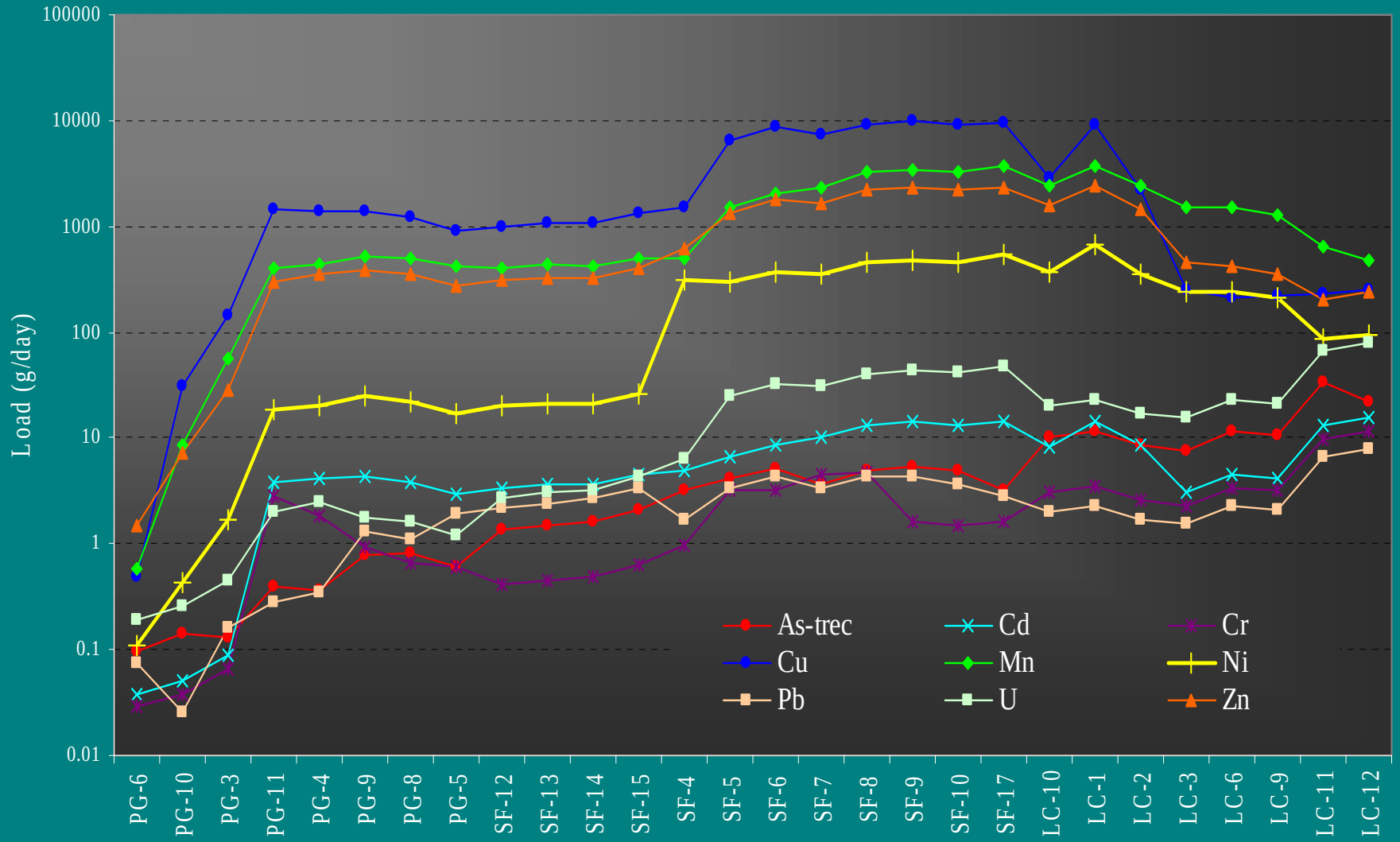
- Decrease in concentration = actual removal or simply dilution?
- Loadings = the rest of the story
- Loading data incorporates streamflows

Trace Element Concentrations - Low Flow



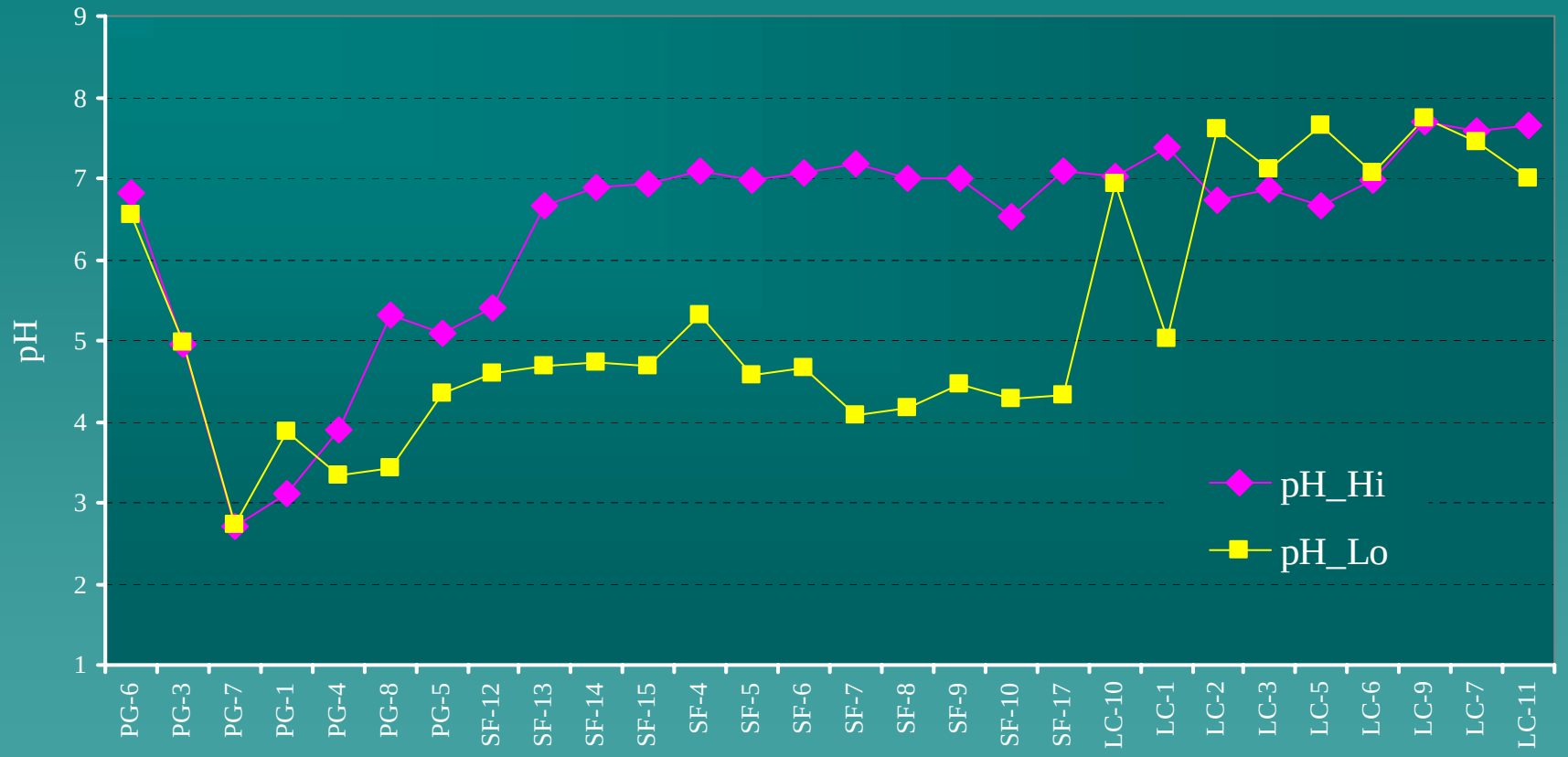
Peekaboo Gulch → South Fork Lake Creek → Lake Creek

Loadings of Trace Elements - Lake Creek Low Flow



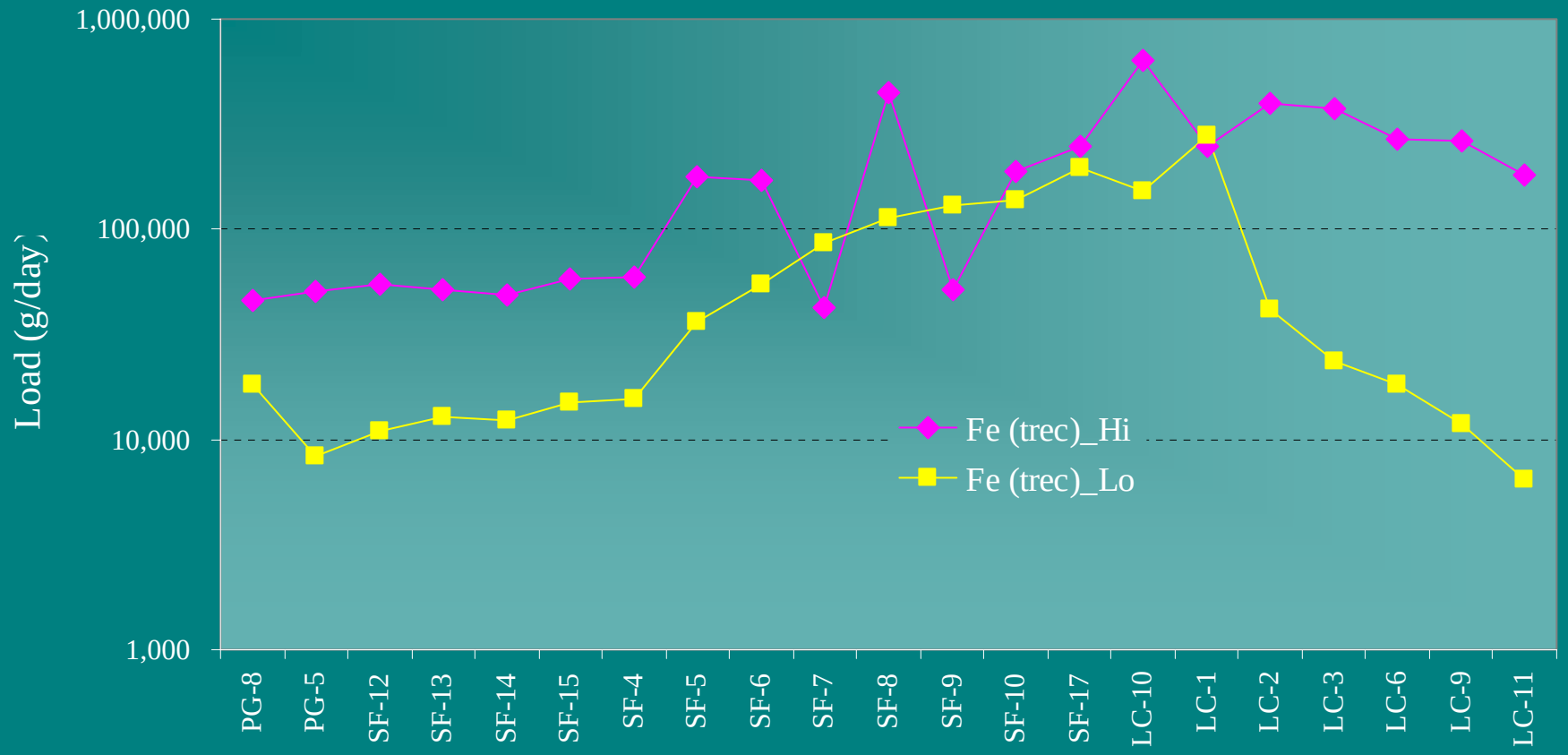
Peekaboo Gulch → South Fork Lake Creek → Lake Creek

pH - Lake Creek



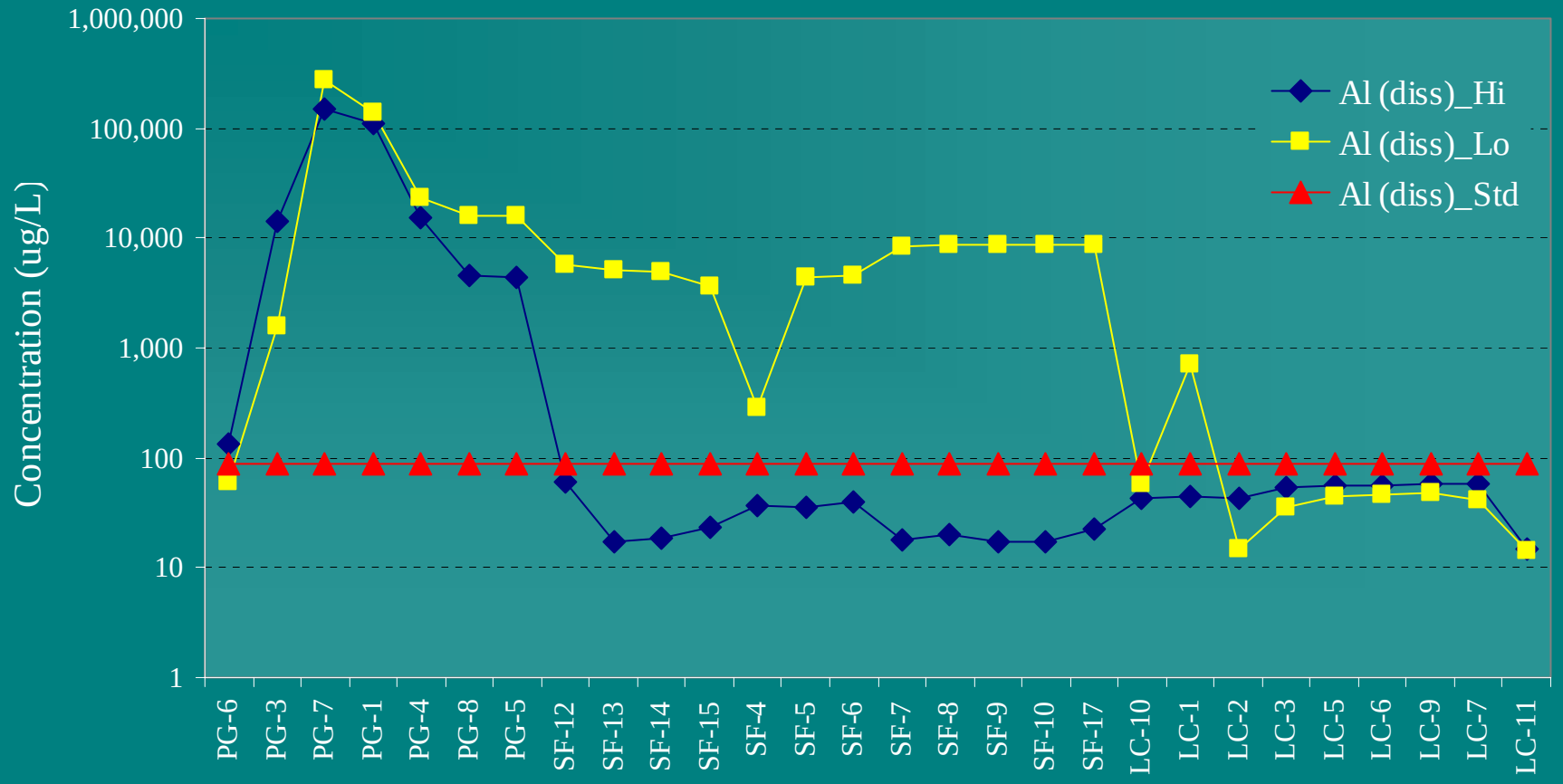
Peekaboo Gulch → South Fork Lake Creek → Lake Creek

Iron (total recoverable) loadings at high and low flow



Peekaboo Gulch → South Fork Lake Creek → Lake Creek

Dissolved aluminum concentrations vs aquatic life standard



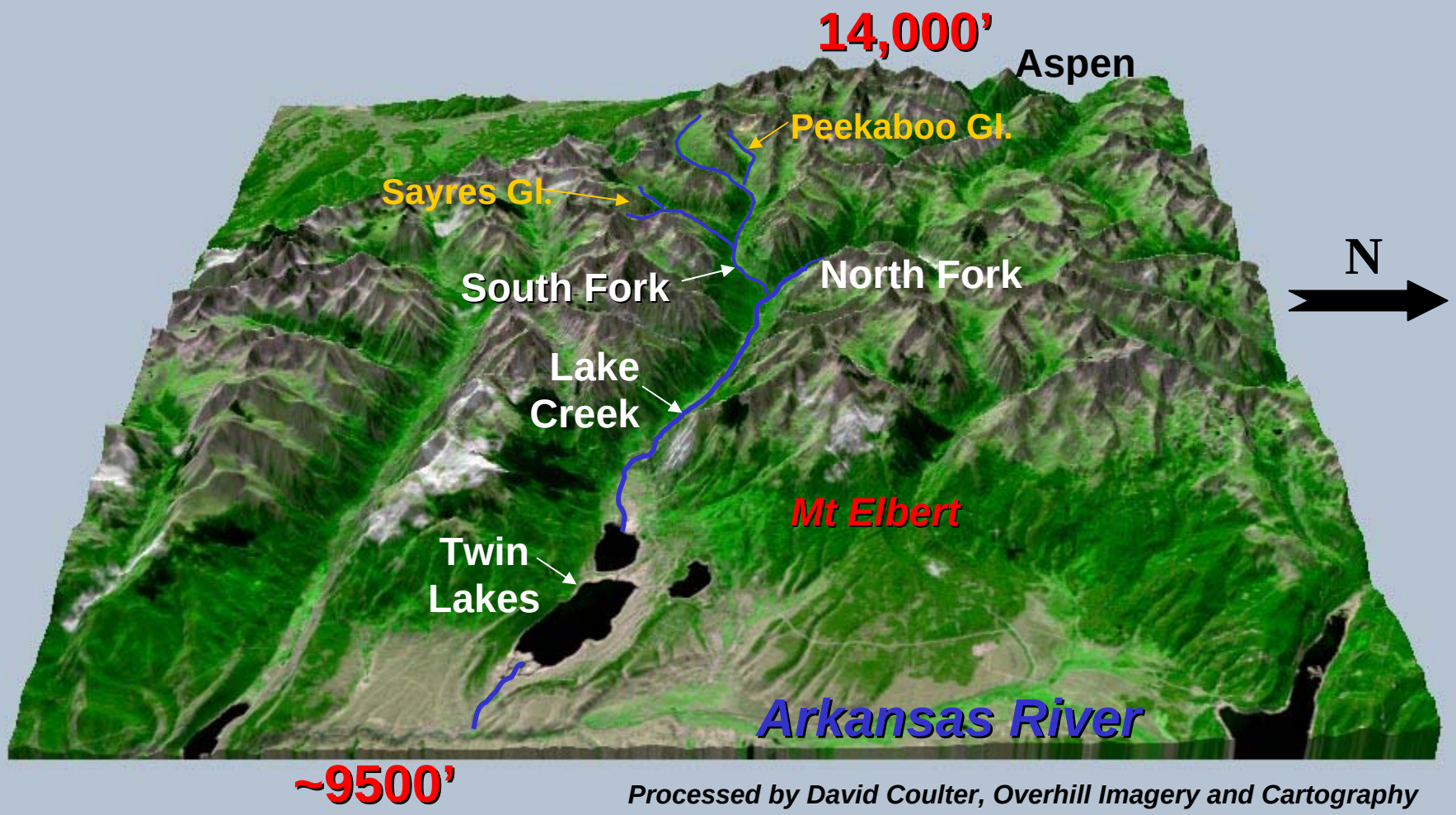
Summary

- Spring runoff streamflows 10X baseflow.
- High flow dilutes dissolved solids and significantly effects pH and metals concentrations
- pH diluted to neutral range (>6) much earlier at high flow (10 km)
- pH-dependent constituents are attenuated higher in watershed at high flow

Summary

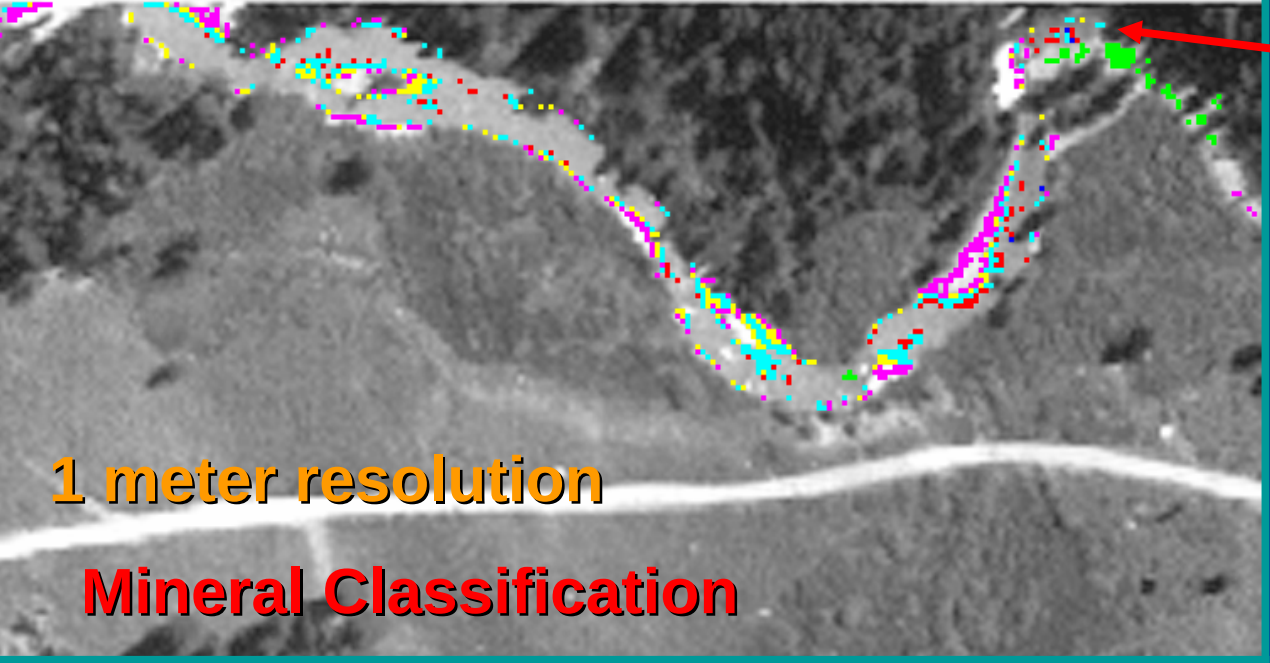
- Minerals (Al and Fe) precipitate higher in watershed and over a wider range, at high flow
- Sorption follows Al and Fe precipitates
- Exceedances of standards more likely during low flow
- Twice annual monitoring crucial to track metals behavior

3D Perspective of Lake Creek (Phase I) Study Area, Looking West



Processed by David Coulter, Overhill Imagery and Cartography

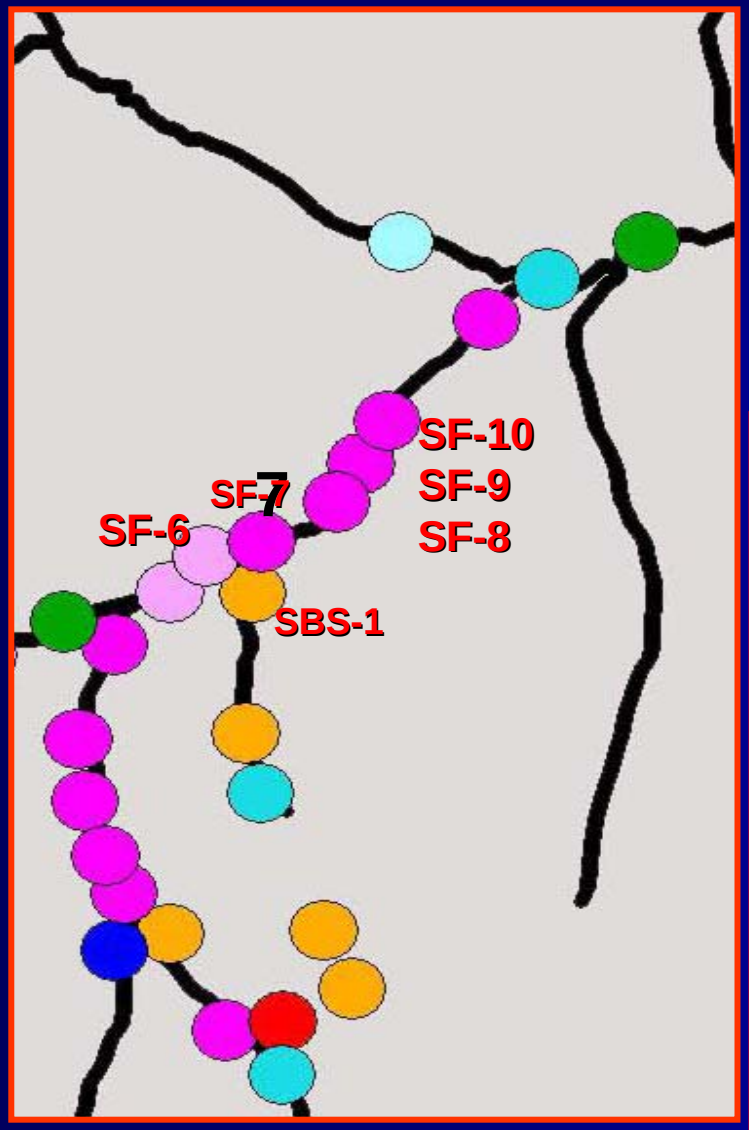
ASTER Image Acquired September 2, 2002

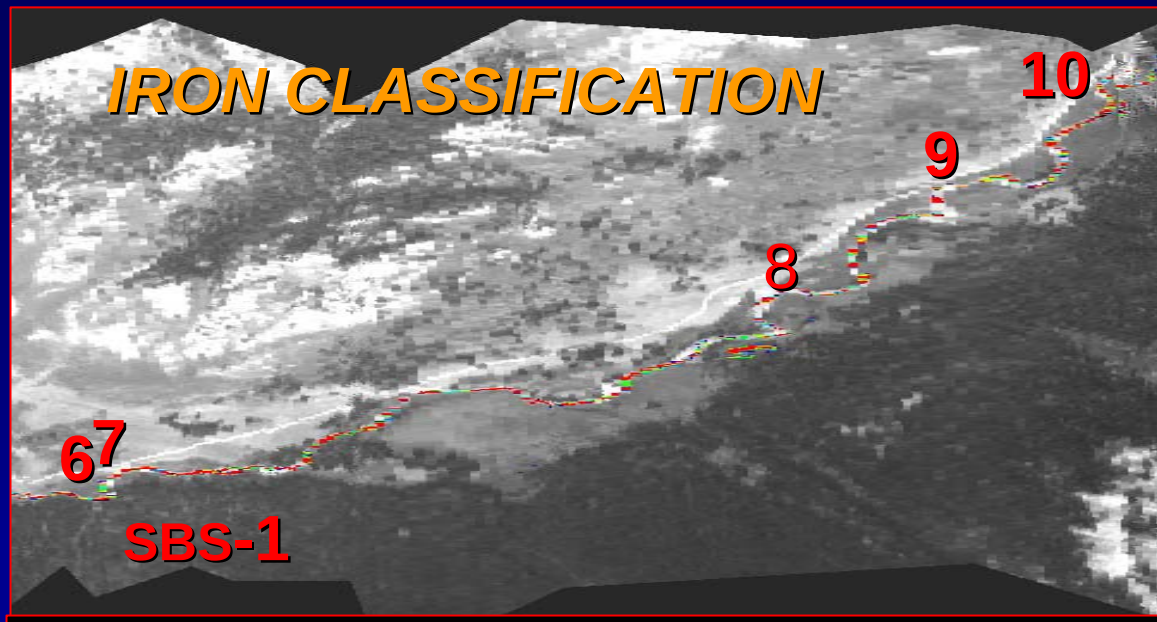


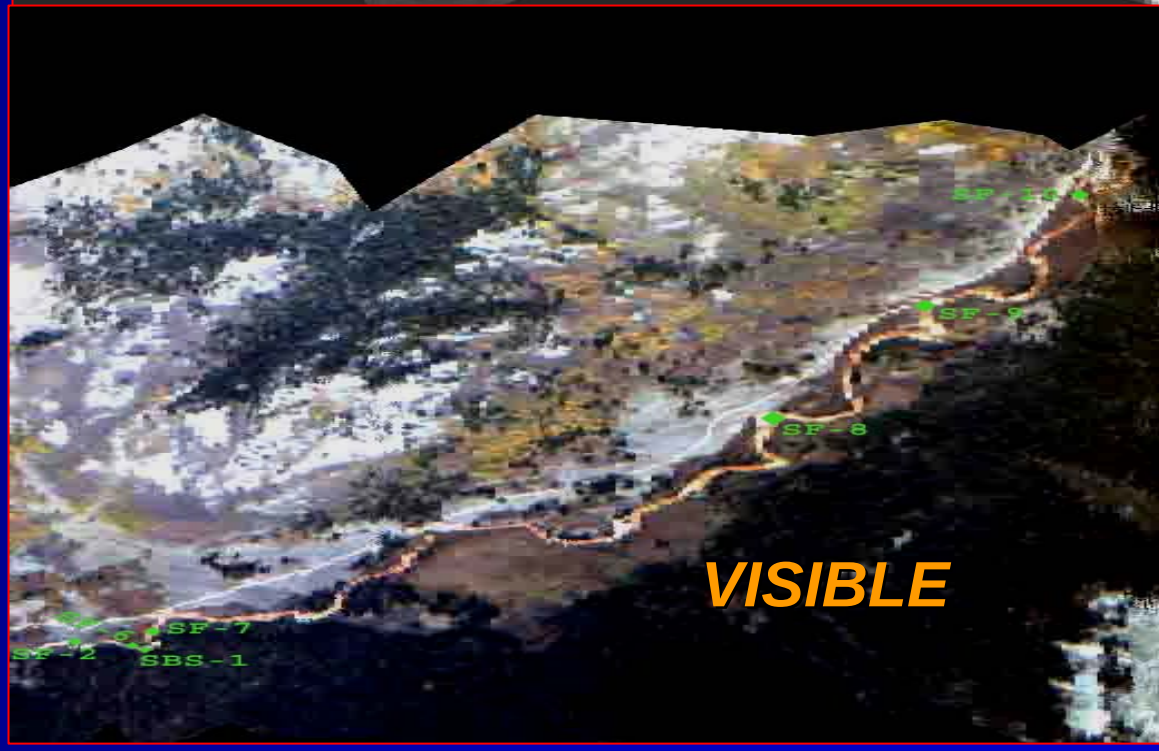
Legend

SBS-HST-2	Jarosite	
SBS-HST-5	aluminum	
SBS-HST-8	Sch/ferrihydrite	
SBS-HST-9	schwertmannite	
SBS-HST-3	Ferri>schwert	

AVIRIS

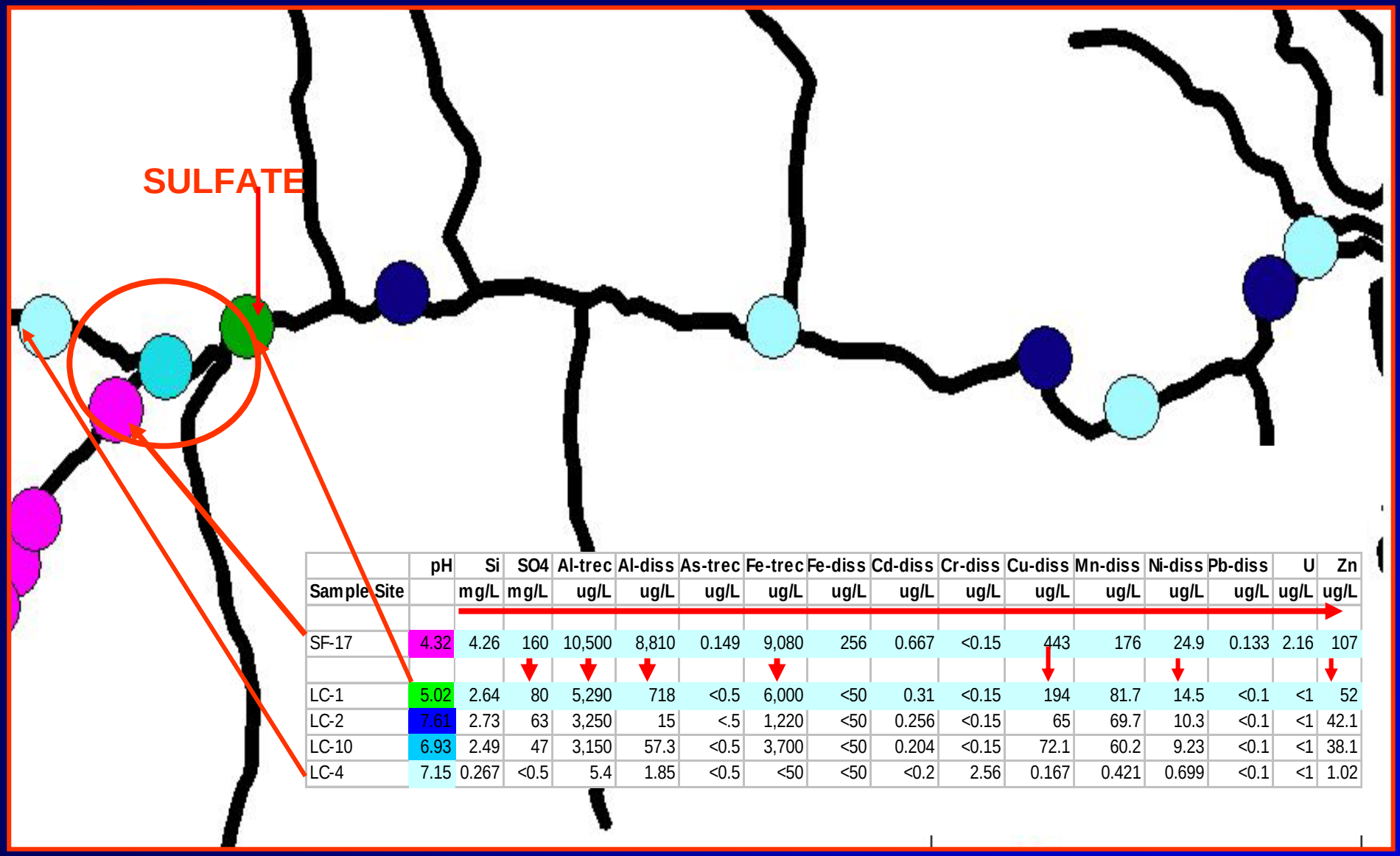

SF-10
SF-9
SF-8
SF-7
SF-6
SBS-1


IRON CLASSIFICATION
10
9
8
7
6
SBS-1


SF-10
SF-9
SF-8
VISIBLE
SF-7
SF-2
SBS-1

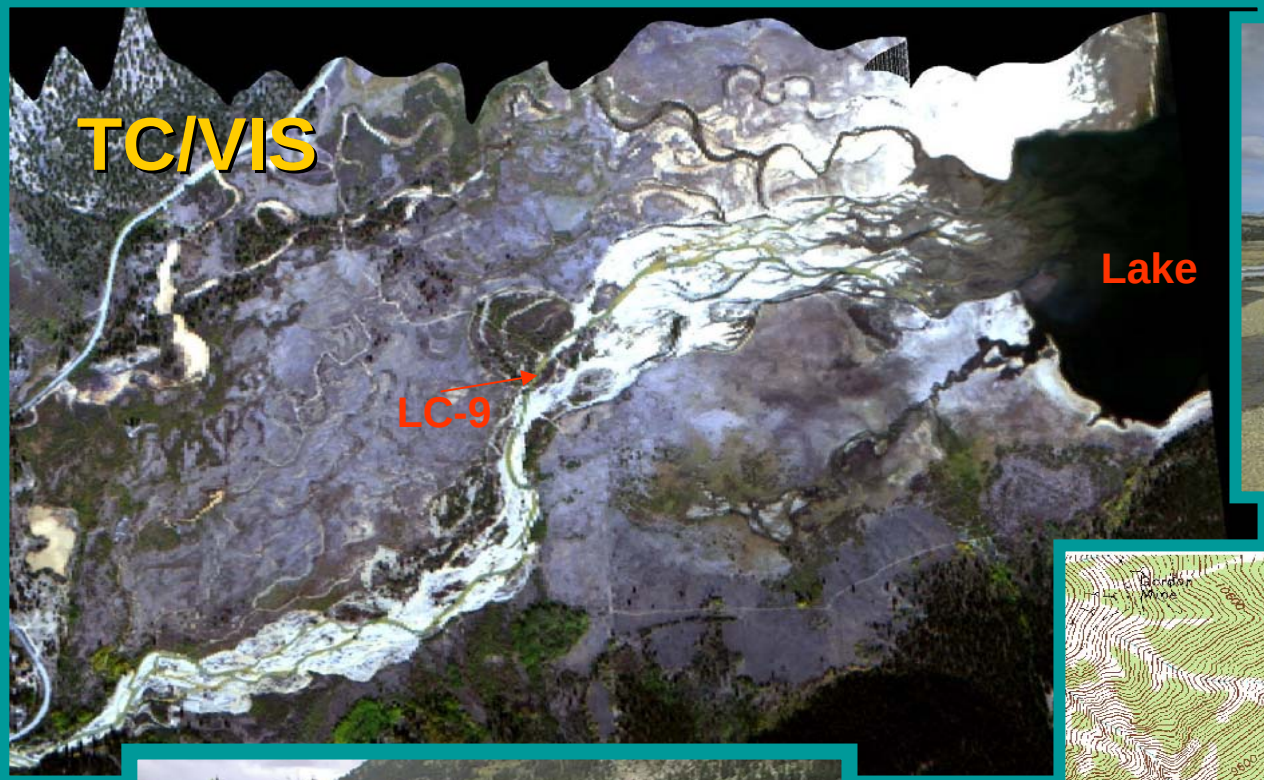
NORTH FORK - SOUTH FORK

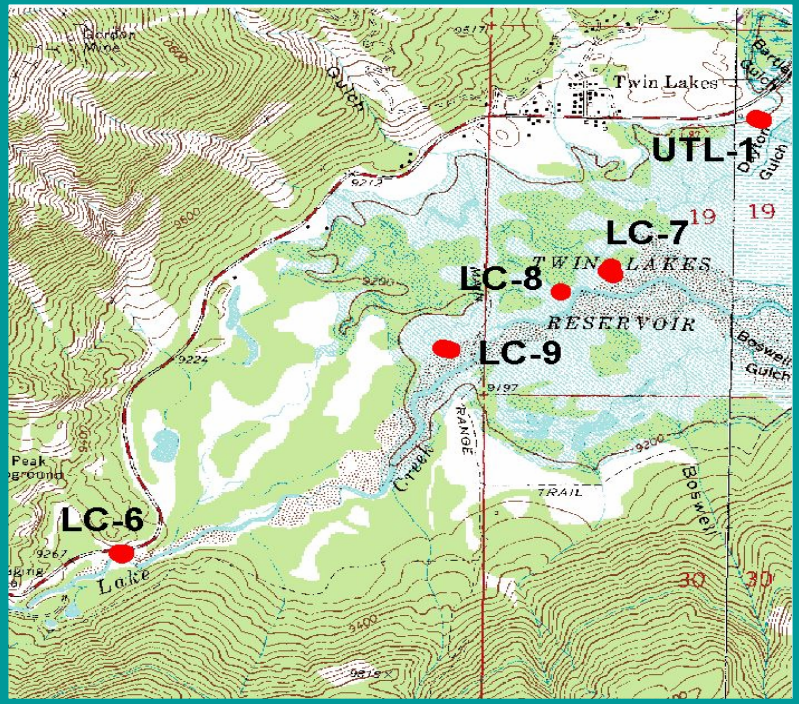
Goethite, Green Rust Lepidocrosite



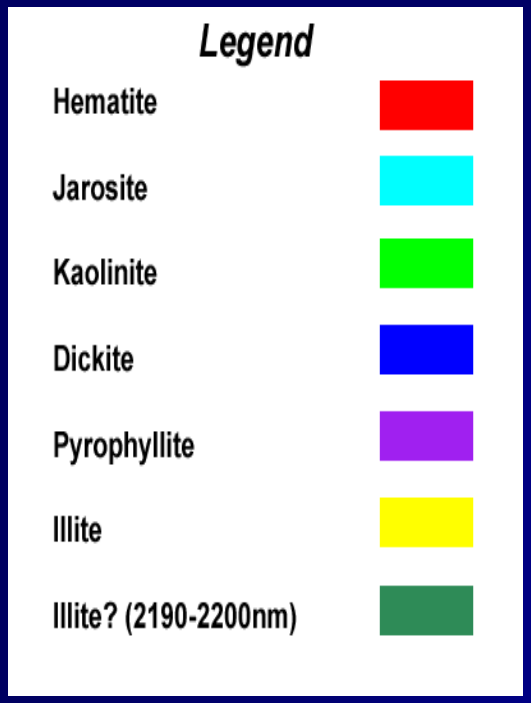
Sample Site	pH	Si mg/L	SO4 mg/L	Al-trec ug/L	Al-diss ug/L	As-trec ug/L	Fe-trec ug/L	Fe-diss ug/L	Cd-diss ug/L	Cr-diss ug/L	Cu-diss ug/L	Mn-diss ug/L	Ni-diss ug/L	Pb-diss ug/L	U ug/L	Zn ug/L
SF-17	4.32	4.26	160	10,500	8,810	0.149	9,080	256	0.667	<0.15	443	176	24.9	0.133	2.16	107
LC-1	5.02	2.64	80	5,290	718	<0.5	6,000	<50	0.31	<0.15	194	81.7	14.5	<0.1	<1	52
LC-2	7.61	2.73	63	3,250	15	<.5	1,220	<50	0.256	<0.15	65	69.7	10.3	<0.1	<1	42.1
LC-10	6.93	2.49	47	3,150	57.3	<0.5	3,700	<50	0.204	<0.15	72.1	60.2	9.23	<0.1	<1	38.1
LC-4	7.15	0.267	<0.5	5.4	1.85	<0.5	<50	<50	<0.2	2.56	0.167	0.421	0.699	<0.1	<1	1.02

LOW ALTITUDE AVIRIS – 4 m – LOWER LAKE CREEK

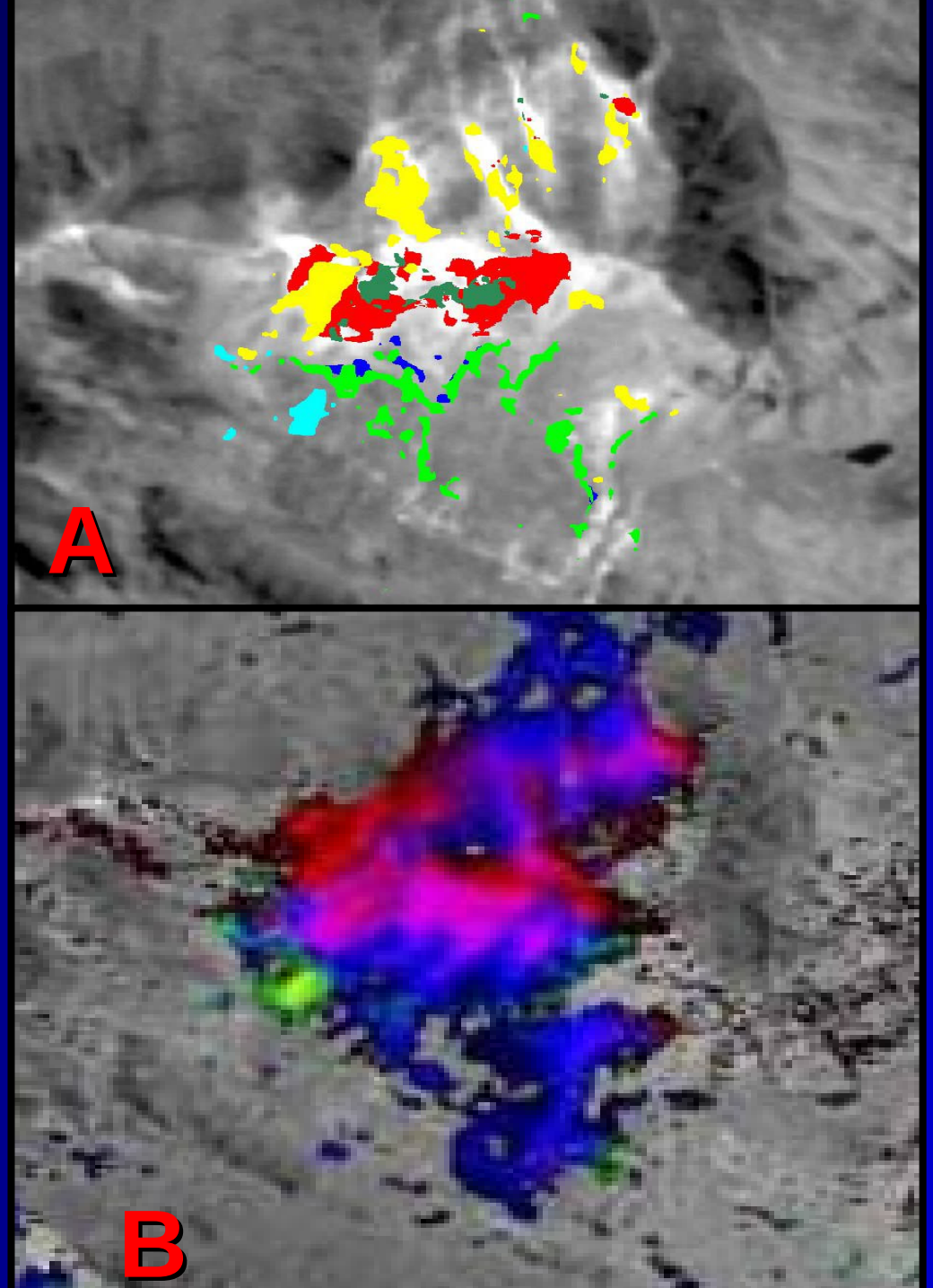




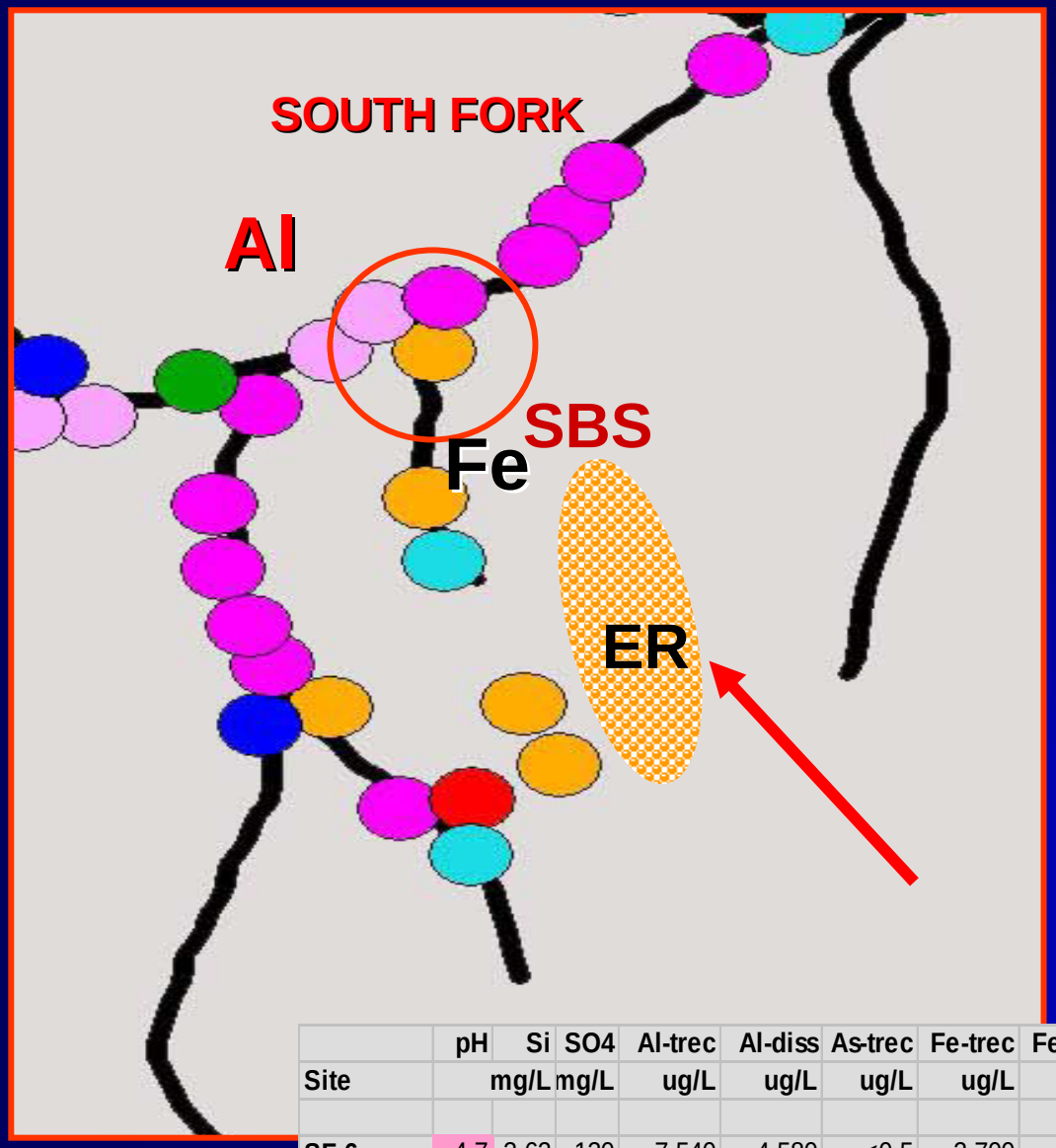
ASTER - SWIR - 30 M



Shows effects of using different processing parameters and better ground information



SOUTH FORK : SBS



Tschermigite

JAROSITE

Schwertmannite

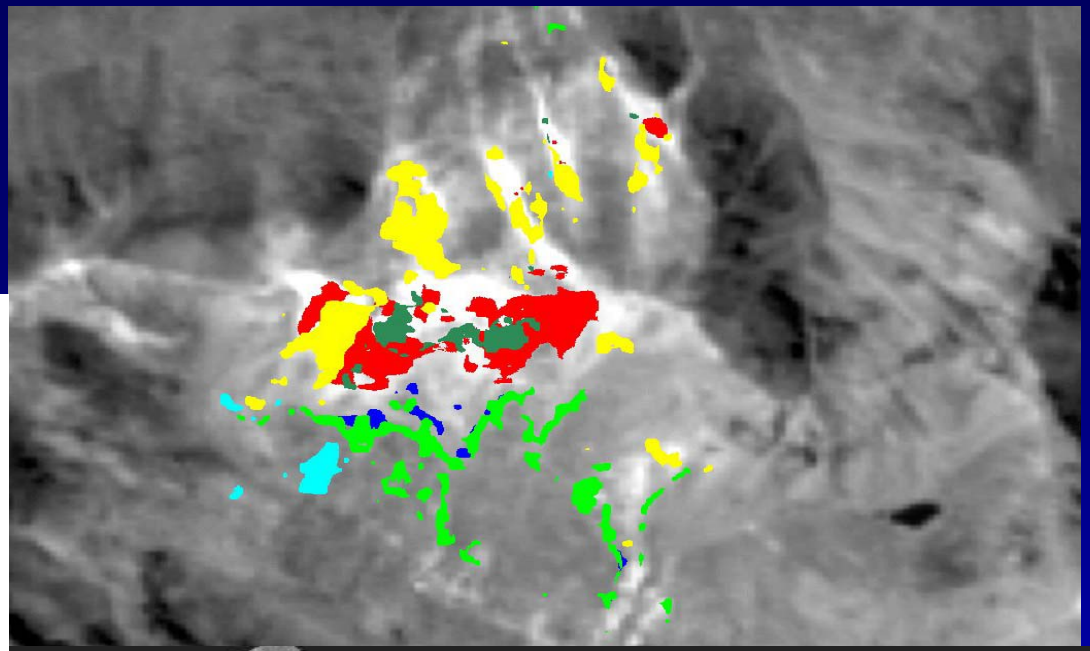
Ferrihydrite

AlOH

Site	pH	Si mg/L	SO4 mg/L	Al-trec ug/L	Al-diss ug/L	As-trec ug/L	Fe-trec ug/L	Fe-diss ug/L	Ag-diss ug/L	Cd-diss ug/L	Cr-diss ug/L	Cu-diss ug/L	Mn-diss ug/L	Ni-diss ug/L	Pb-diss ug/L	U ug/L	Zn ug/L
SF-6	4.7	3.62	130	7,540	4,580	<0.5	2,700	217	<0.1	0.425	0.161	430	100	18.3	0.21	1.6	89
SBS-1	3.2	16.6	1700	125,000	112,000	0.584	114,000	119,000	0.526	7.92	18.4	3,270	1990	183	0.433	12	839
SF-7	4.1	4.04	170	10,700	8,320	<0.5	5,960	1,760	<0.1	0.703	0.312	520	164	24.3	0.23	2.1	117

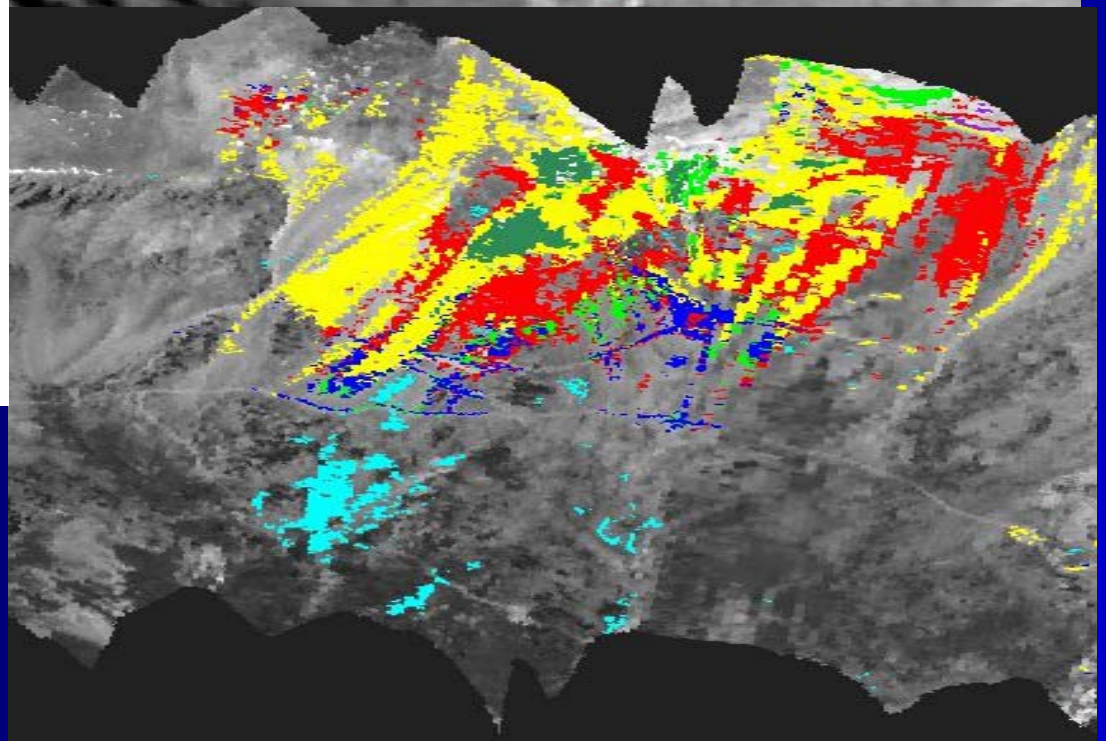
Legend

- Hematite
- Jarosite
- Kaolinite
- Dickite
- Pyrophyllite
- Illite
- Illite? (2190-2200nm)



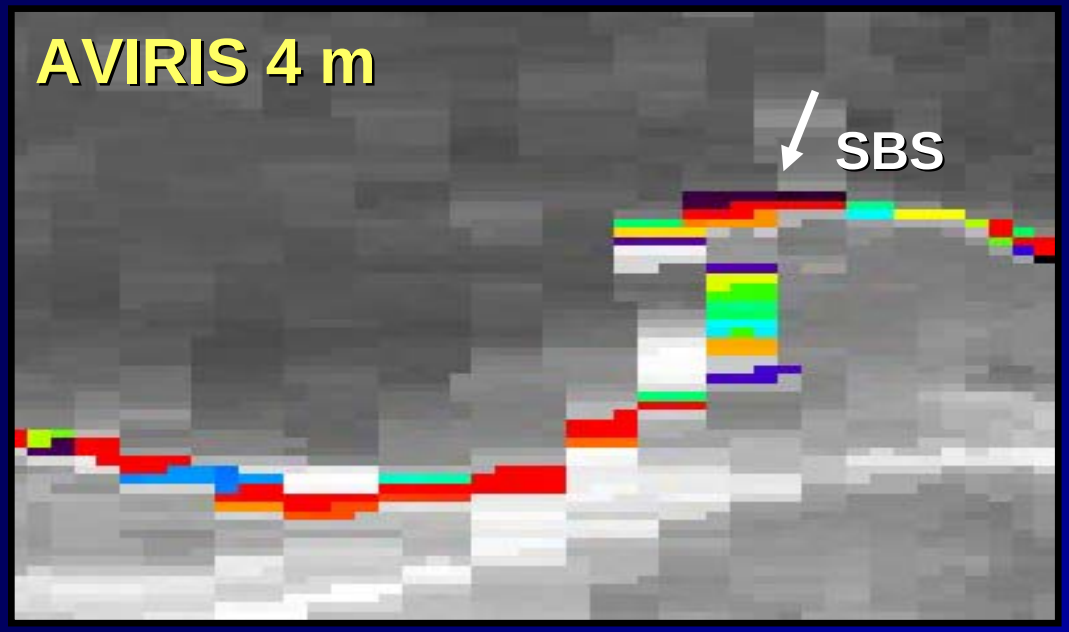
ASTER

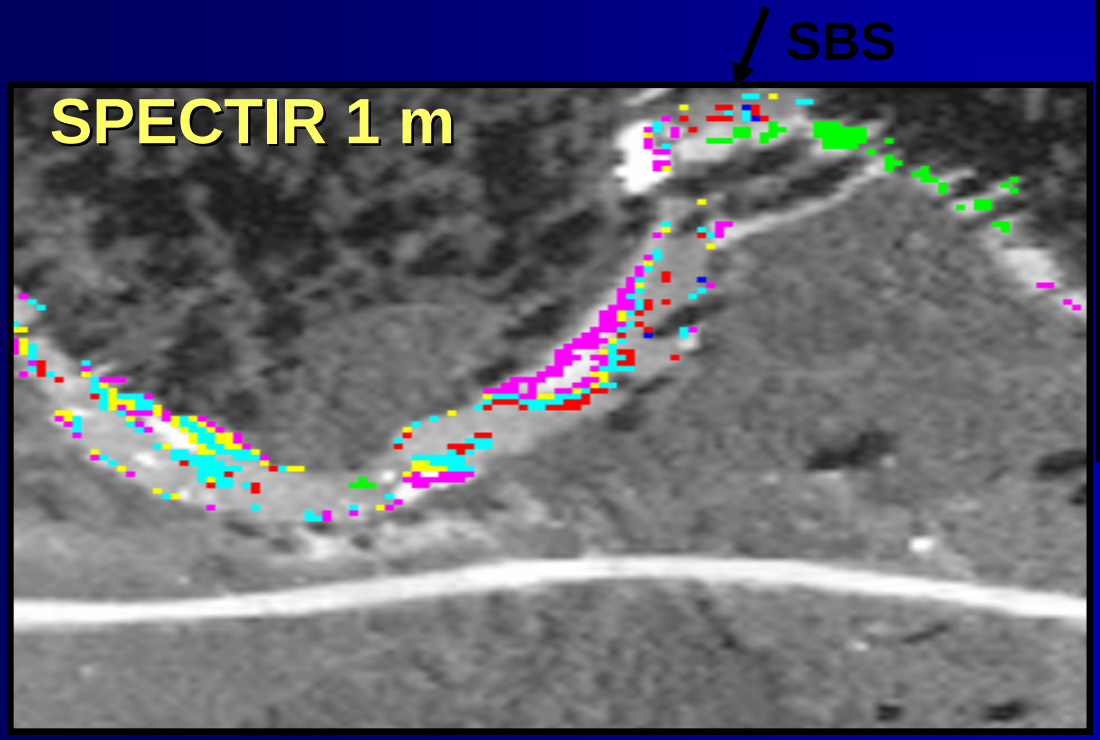
30M

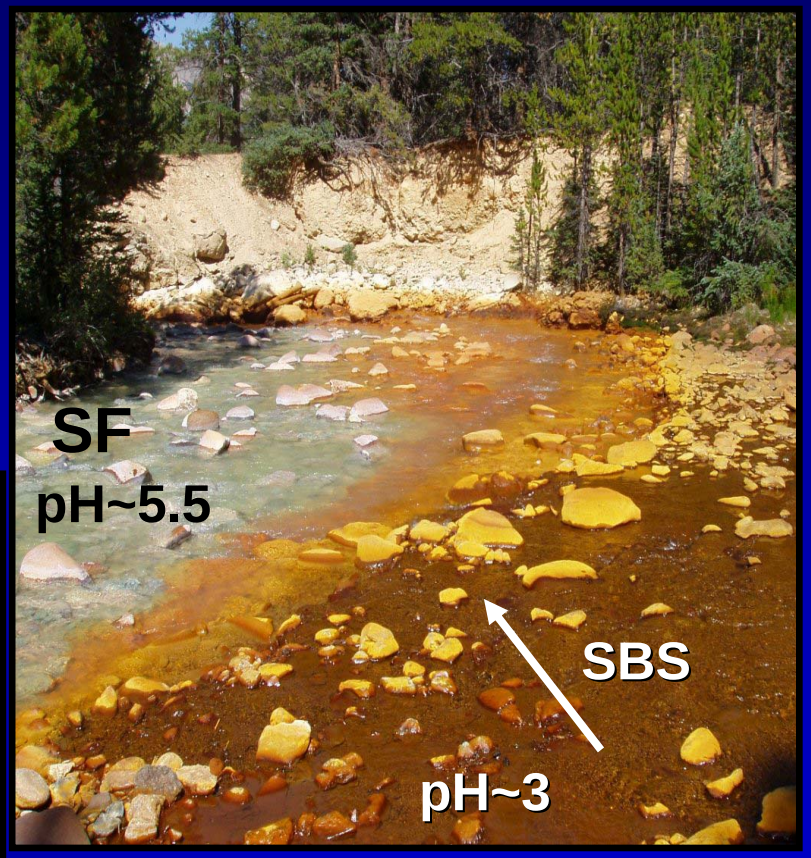


AVIRIS

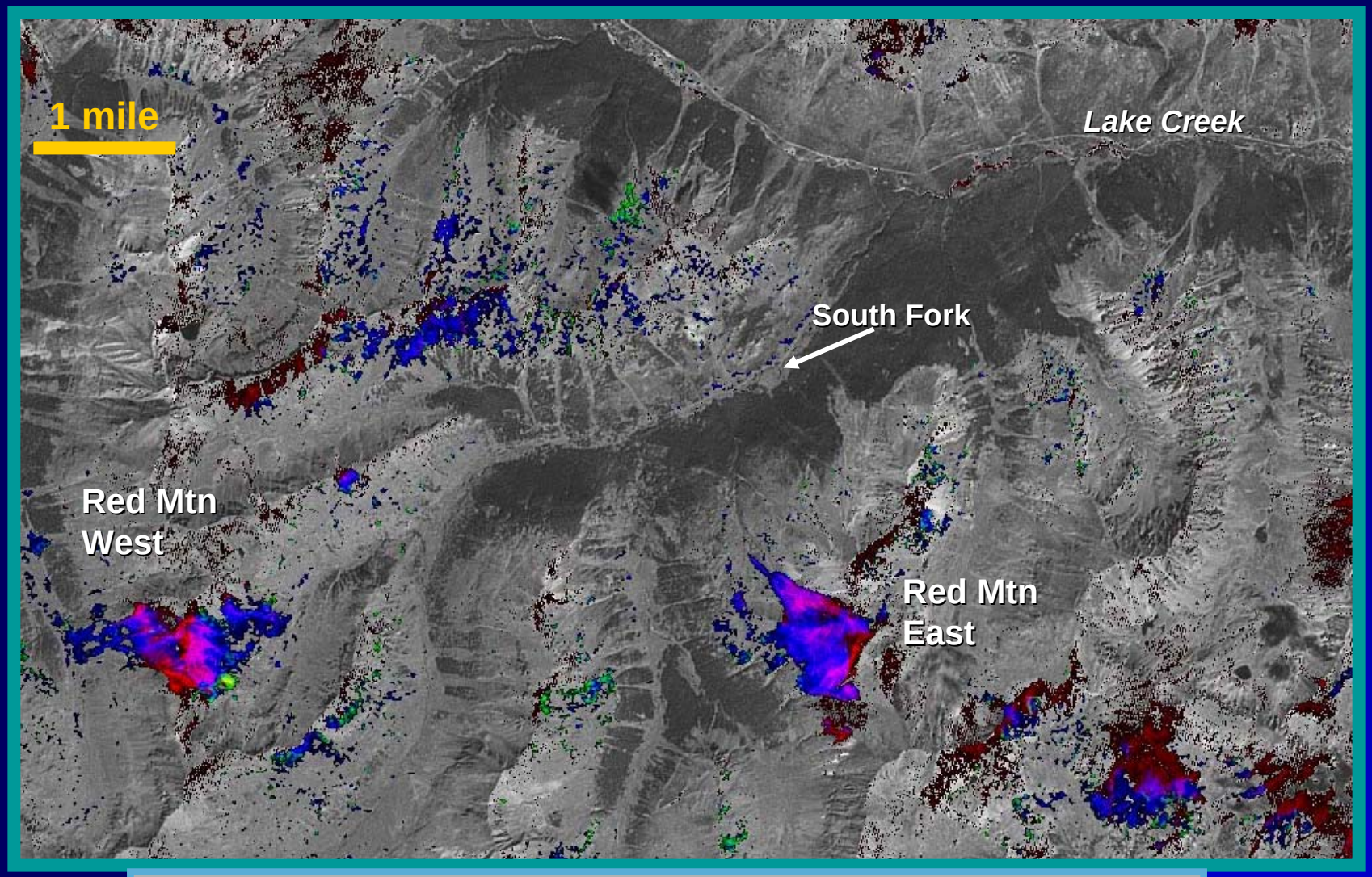
4M


AVIRIS 4 m
SBS


SBS
SPECTIR 1 m


SF
pH~5.5
SBS
pH~3

ASTER - Preliminary Mineral Classifications



Reds = iron oxides; Blue = Illite; Green = Jarosite

- Satellite-based sensor