

Pre- and Post-Remediation Characterization of Acid- Generating Fluvial Tailings Material

**Kathleen S. Smith, Katherine Walton-Day,
Karin Olson Hoal*, Rhonda L. Driscoll, and
Kevin Pietersen***

**9th International Conference on Acid Rock Drainage
May 20-26, 2012 Ottawa, Canada**

Overview

- Pre- and post-remediation samples of fluvial tailings material deposited from historical mining operations
 - ✓ *in situ* remediation treatment with lime, fertilizer, and compost
- Collected pre- and post-remediation samples from different depths to examine changes in mineralogy, acid-generation, and extractable nutrients
- Incomplete treatment depth at one site results in an acidic zone at the base of the fluvial tailings deposit
 - ✓ geochemical and mineralogical characterization
- Mineral Liberation Analysis (MLA) is useful in revealing mineralogical textures, relationships, and complexities

Fluvial Tailings Deposits along the Arkansas River (downstream of Leadville, Colorado, USA)



Fluvial tailings deposits

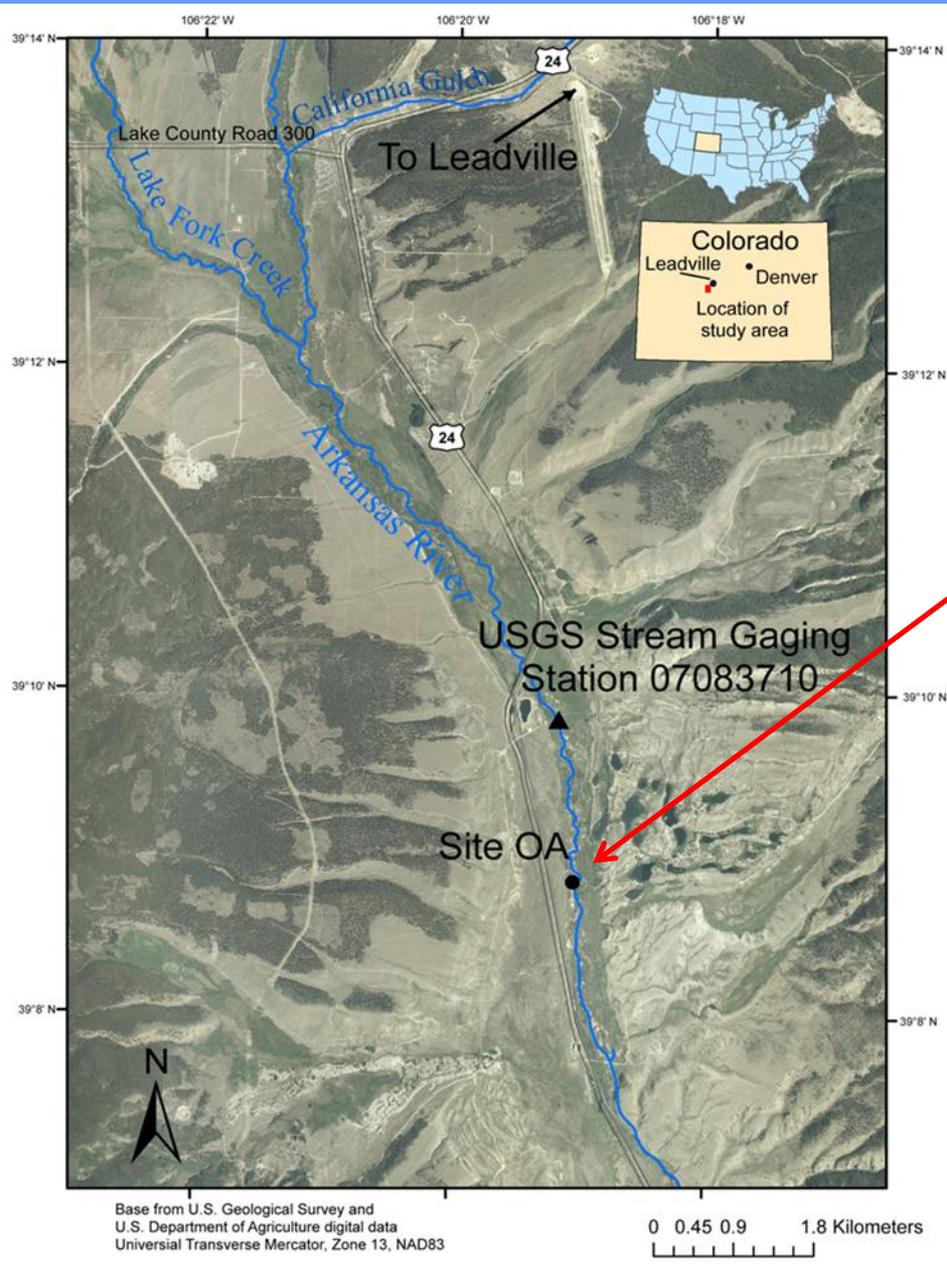


Arkansas River

Bank erosion



Study site (0.004 km²)
is adjacent to the
Arkansas River
downstream of
Leadville, Colorado



Leadville, Colorado



Elevation
about 3050 m

California Gulch Superfund Site (1983)

- 18 square-mile site
- 12 Operable Units (including the City of Leadville, a portion of Lake County, and two miles of the Arkansas River)
- Silver, gold, copper, lead, and zinc deposits in the Leadville Mining District sustained mining and smelting operations for more than 130 years



Little Johnny Mine
(Denver Public Library Collection)



Arkansas Valley
Smelting Co.
(Denver Public Library Collection)



Fluvial Tailings Deposits - Characteristics

- Fine-grained to sandy tailings and fluvial sediments deposited over sand and cobble alluvium along the banks of an 18-km reach of the Arkansas River
- Contaminants of concern include Ag, As, Ba, Be, Cd, Cr, Cu, Hg, Mn, Ni, Pb, Sb, Tl, and Zn
 - ✓ As and Pb are primary elements of concern for human health
- Monitoring* indicates that
 - ✓ Groundwater quality beneath the fluvial tailings deposits has been degraded (decreased pH and elevated metal concentrations)
 - ✓ Water quality in the Arkansas River exhibits minimal impact from the deposits

Revegetation Demonstration Project

- U.S. EPA initiated a soil amendment and revegetation demonstration project in 1998
 - ✓ Revegetation of denuded areas
 - ✓ Soil neutralization
 - ✓ Reduced soil erosion
 - ✓ Re-establishment of riparian communities
- Mixed fluvial tailings deposits with biosolids, lime, fertilizer, and compost

Deep till
rotary mixer

*Photos courtesy of
Jan Christner (URS)*



Pre- and Post-Remediation Trenches (Site OA)



Pre-remediation conditions in April 2009. Top-to-bottom approx. 1 m. (Water table just below 1 m.)



Post-remediation conditions in August 2011. Top-to-bottom approx. 60 cm.

Note:

Vegetation

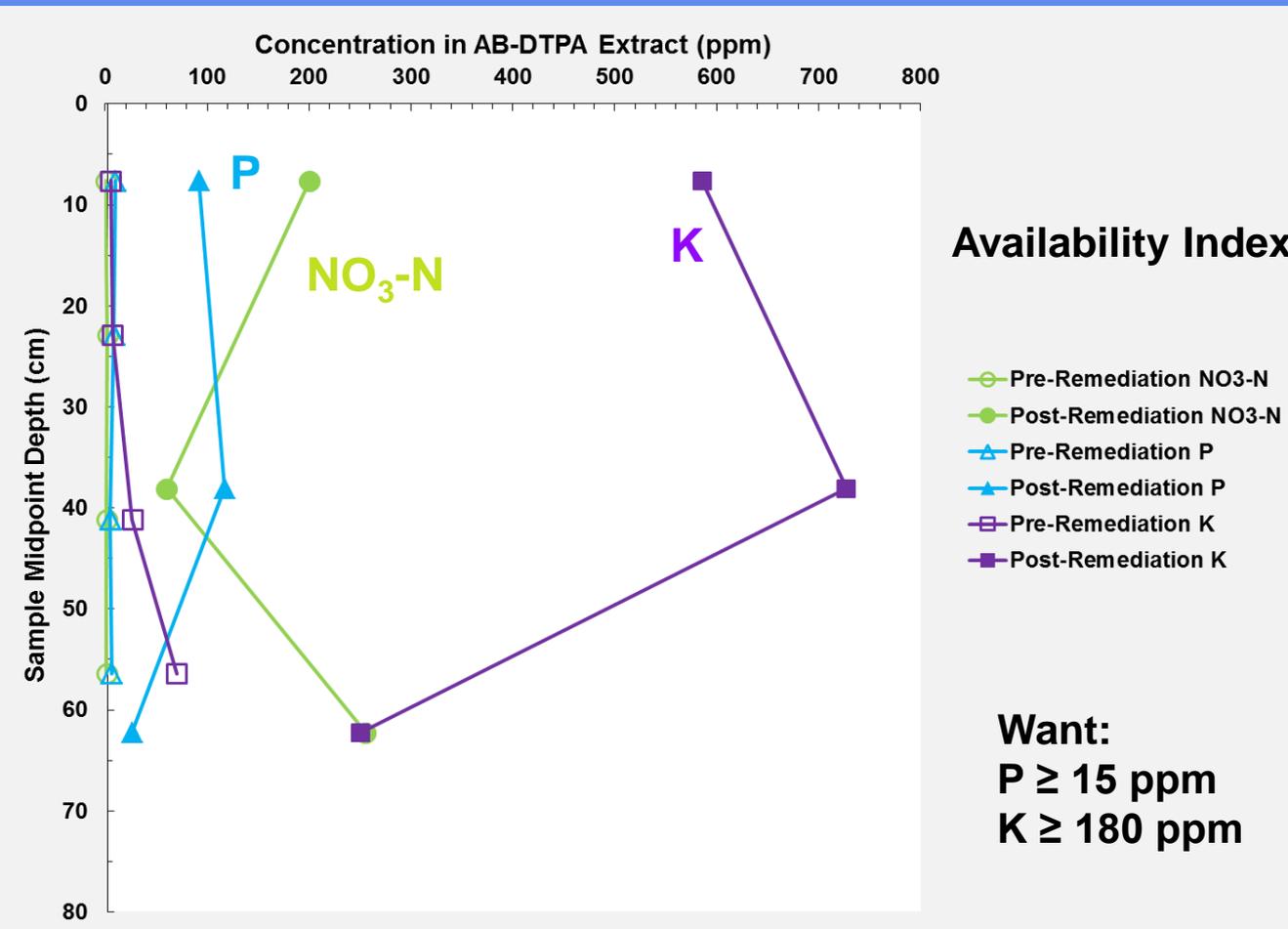
Homogeneous nature of deposit post-remediation

Tailings material near bottom

Remediation and amendment addition completed in June 2009

Extractable Nutrients

(pre-remediation April 2009; post-remediation October 2009)



Amendments:

- (1) lime (sugar beet processing residual) applied at a rate of 182 dry tons calcium carbonate equivalence per 1000 tons soil
- (2) fertilizer (0-45-0 NPK) applied at a rate of 153 lb per 1000 tons soil
- (3) Cow manure compost (1.5% organic carbon) applied to top 30 cm

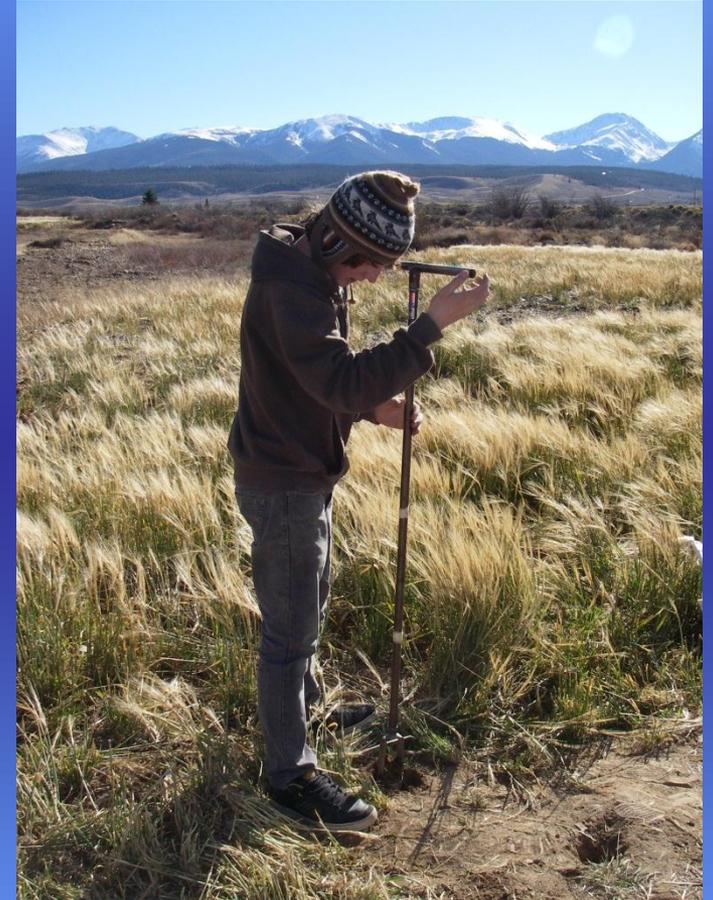
Want:
P ≥ 15 ppm
K ≥ 180 ppm

Post-remediation samples have good availability of extractable nutrients for plant growth

Revegetation

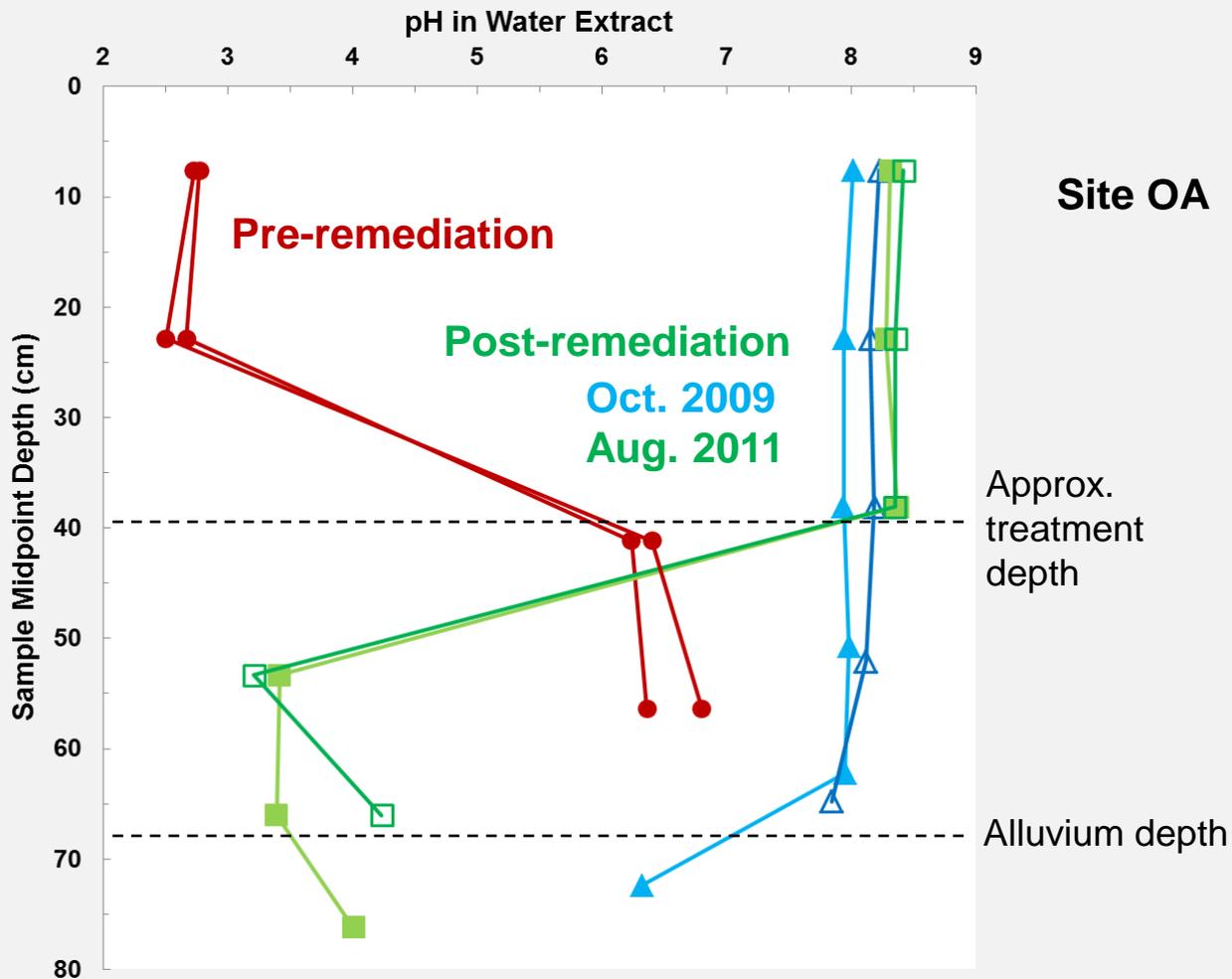


Pre-remediation



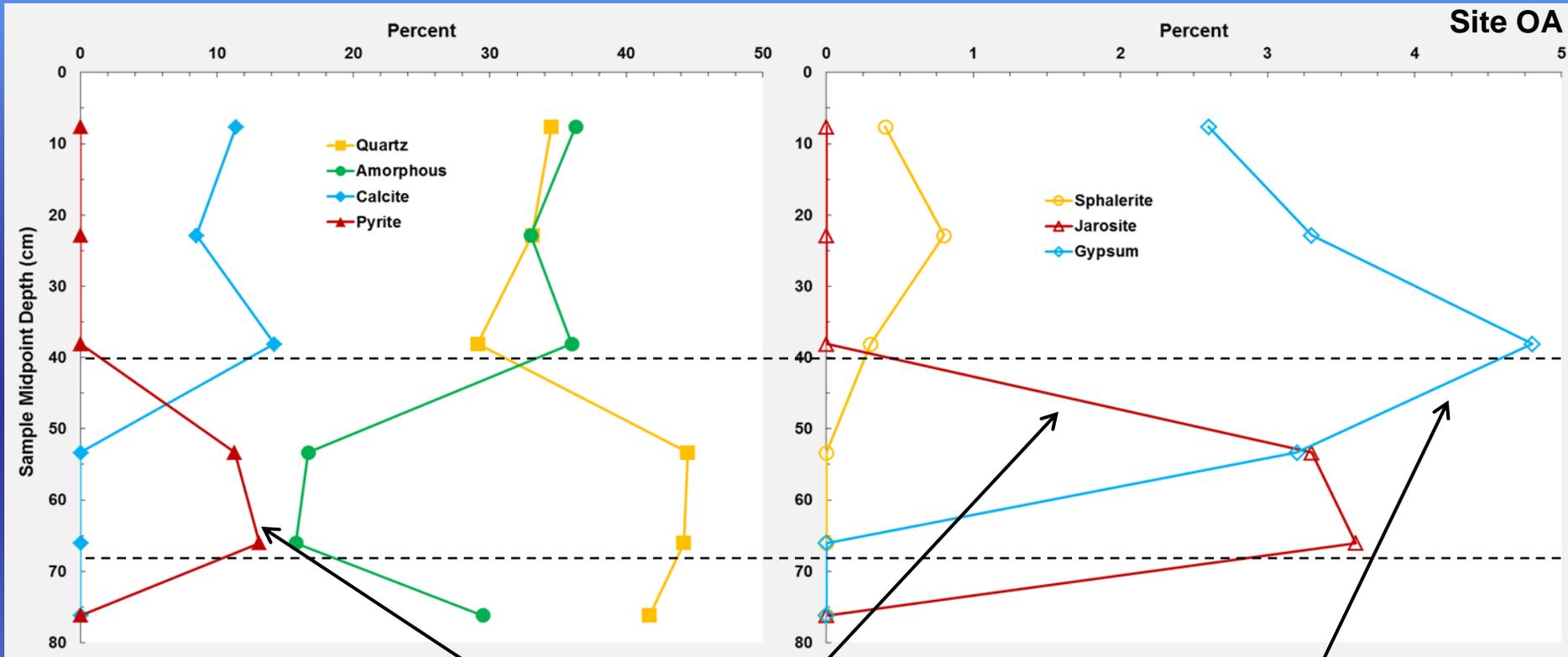
Post-remediation

pH in Water Extracts



Note acidic pH values in Aug. 2011 post-remediation samples below about 40-cm depth

Post-Remediation Mineralogy (semi-quantitative XRD; August 2011)



Note presence of pyrite and jarosite below 40-cm depth

Note decrease in gypsum and calcite below 40-cm depth

Acid generation due to pyrite oxidation at depths below the treatment depth (40 cm)

Formation of Secondary Minerals



The presence of jarosite is indicative of acid-sulfate weathering with pH values ranging from 1 to 3.

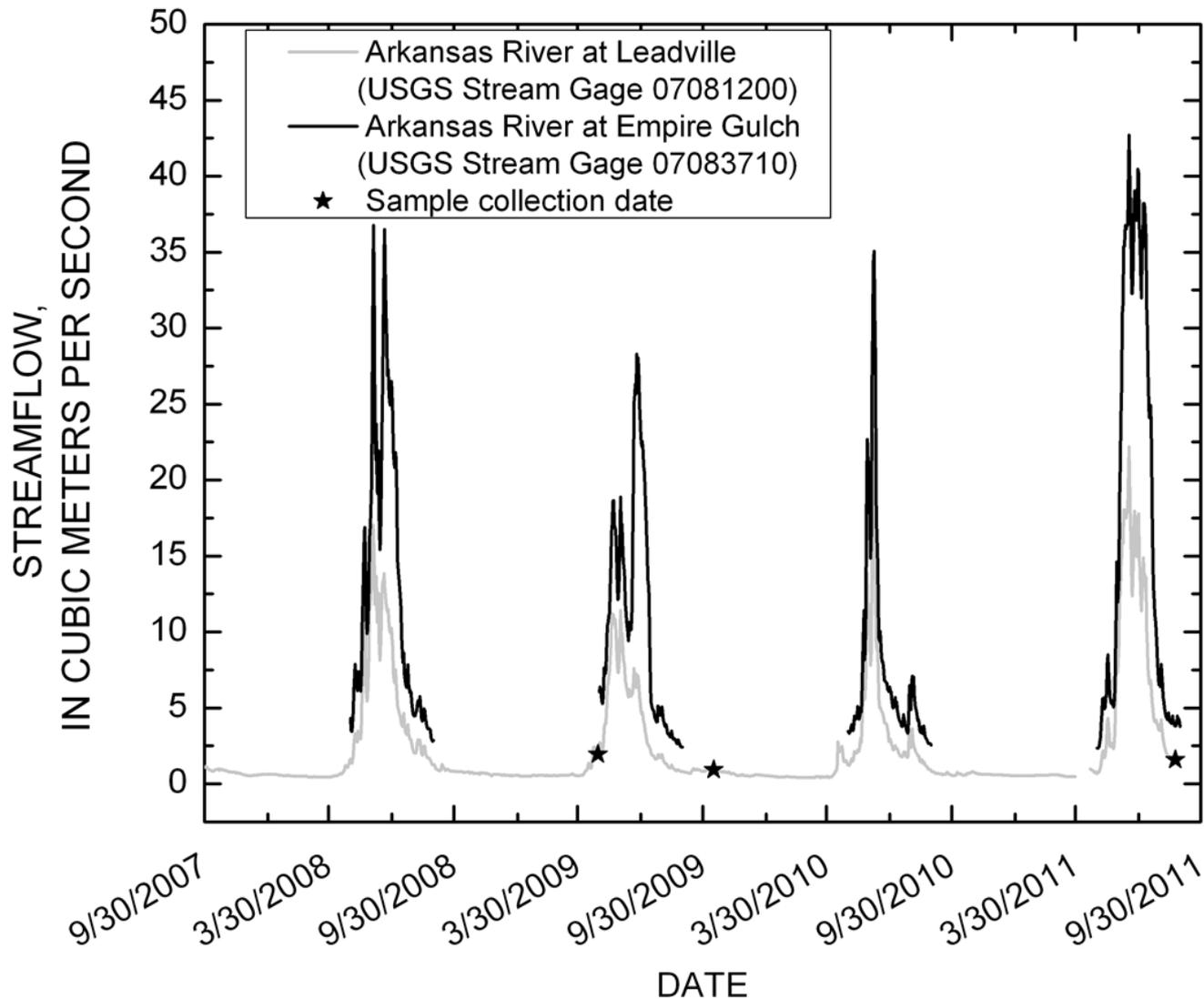


Gypsum precipitation is not directly dependent on pH conditions, but does require a source of Ca^{2+} and SO_4^{2-} . The steady decrease in gypsum below 40 cm reflects the decreasing source of Ca^{2+} from the lime amendment.

Role of the Fluctuating Water Table

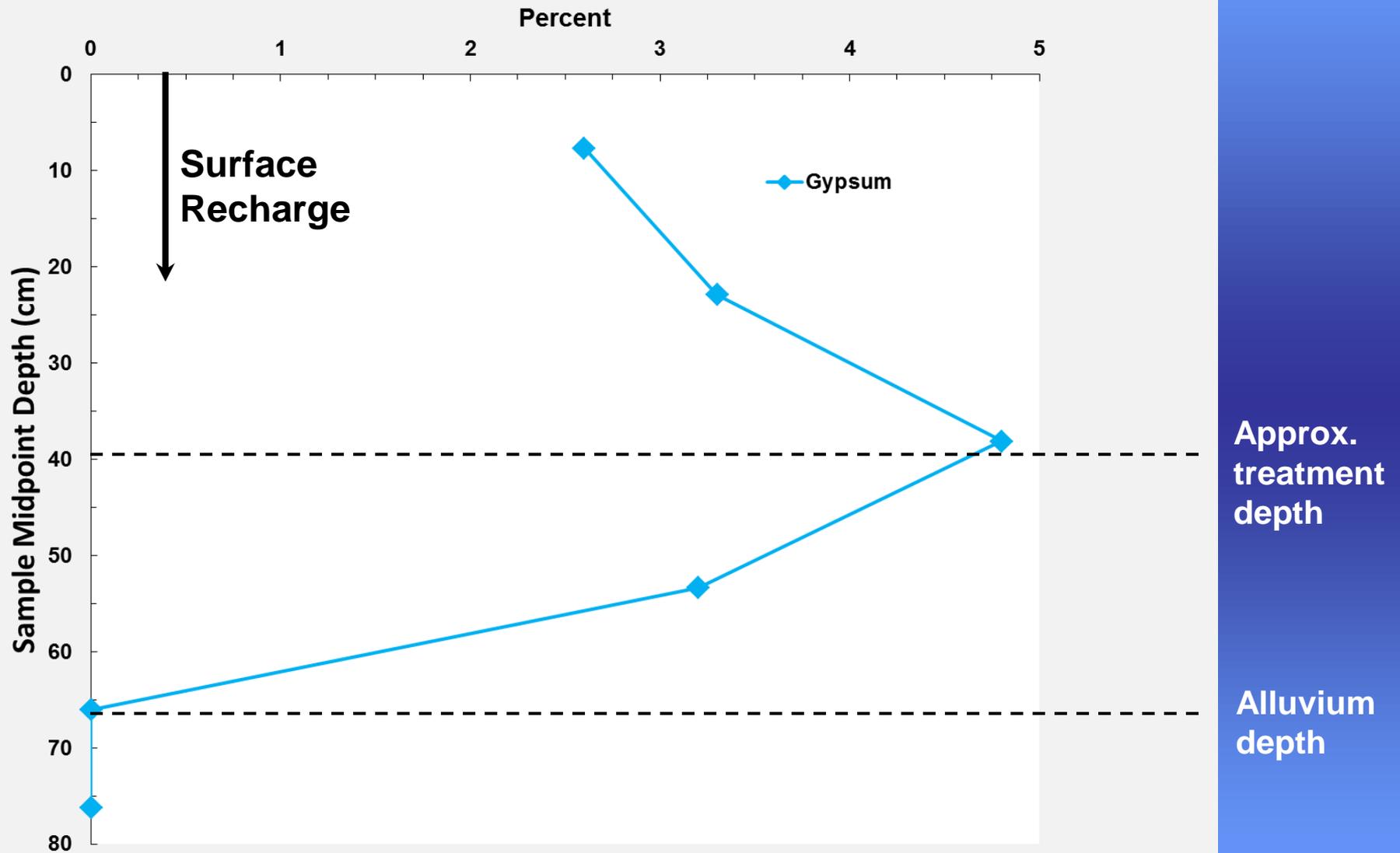
- A possible mechanism to provide oxygen and water to the zone of pyrite oxidation is the fluctuating water table beneath the fluvial tailings deposit
- Seasonal maximum height of the water table relates to streamflow
 - ✓ Higher in years of greater runoff
 - ✓ 2011 runoff was significantly above average
- Provides fuel for pyrite oxidation

Streamflow Data for the Arkansas River



2011
runoff is
above
average

Post-Remediation Gypsum Profile (August 2011)



Mineral Liberation Analysis (MLA)



from JKTech Pty Ltd 2008

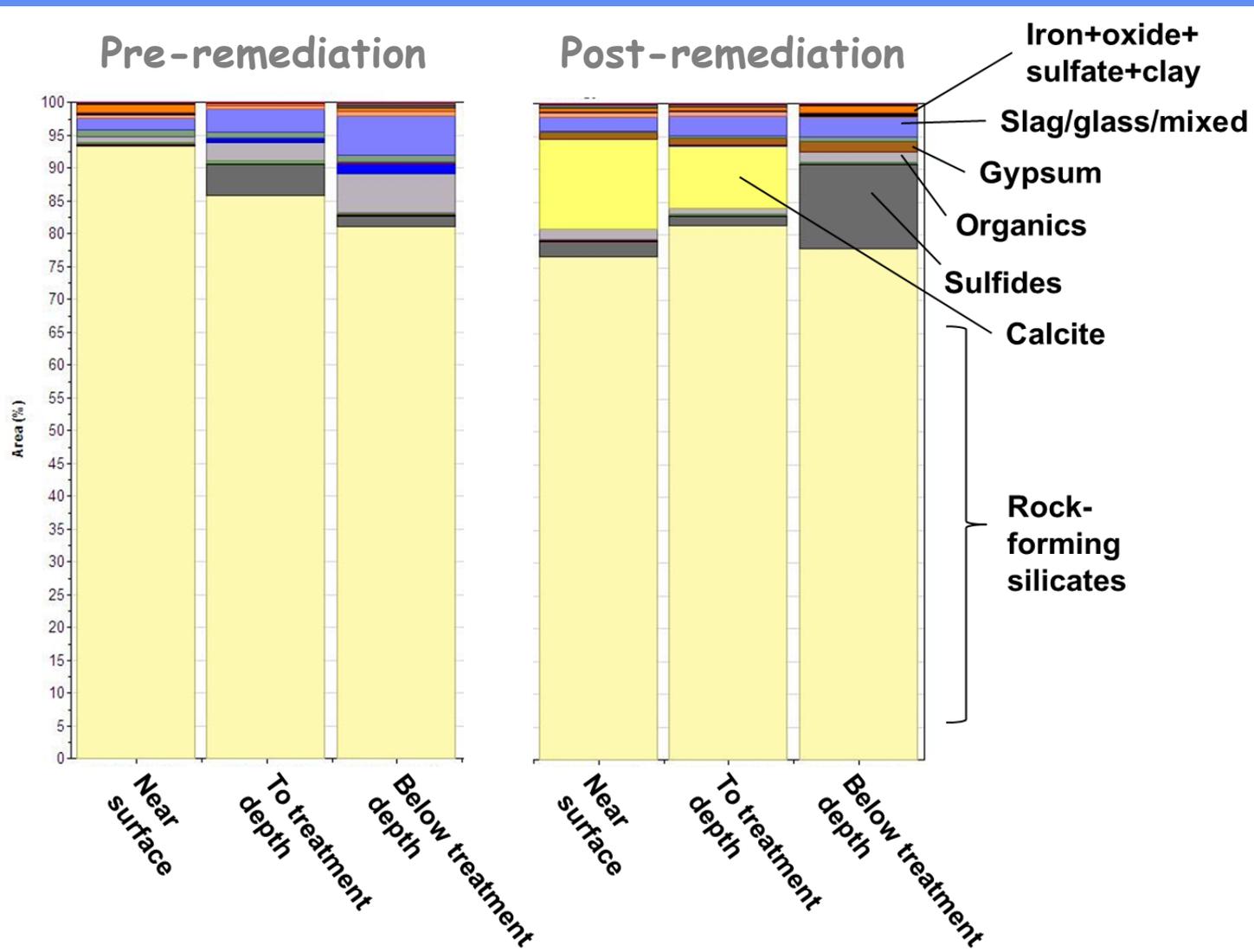
- Automated scanning electron microscope (SEM) / energy dispersive spectrometer (EDS) technique
- Rapid acquisition and quantification of mineralogical information
 - ✓ Image analysis
 - ✓ X-ray element/mineral identification
 - ✓ Textural information

Mineral Liberation Analysis (MLA)

Mineralogical Results

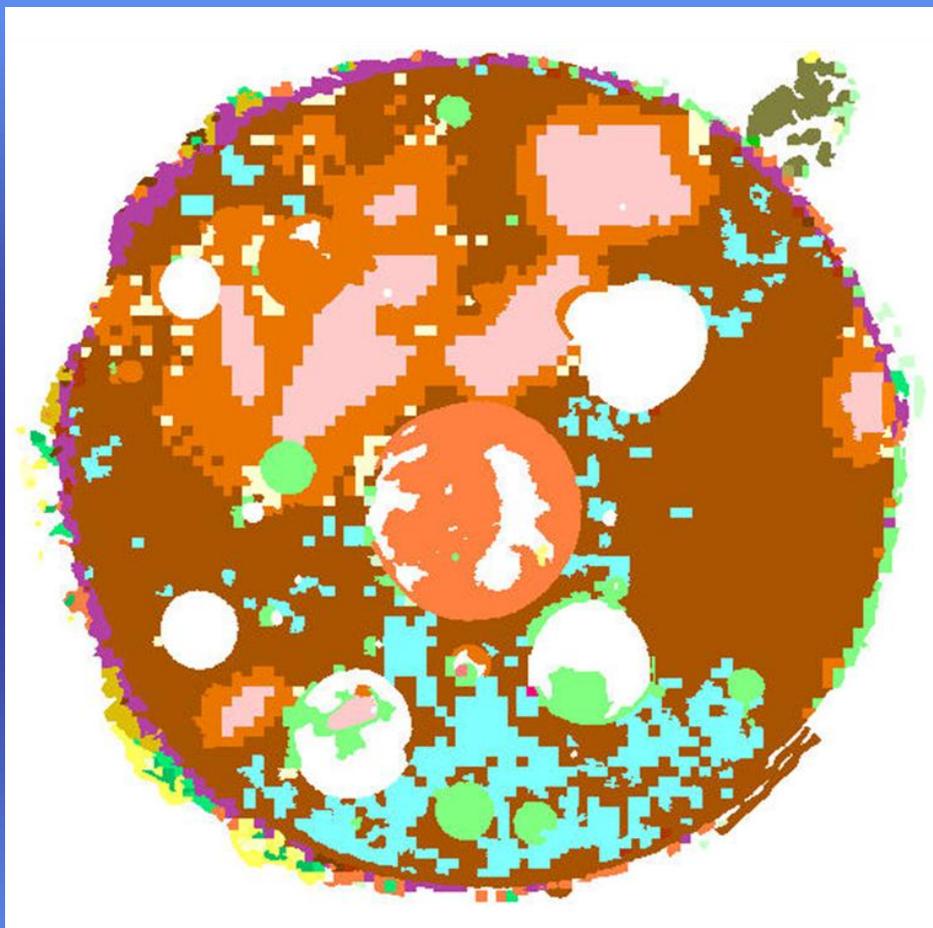
- Mineralogical differences between pre- and post-remediation samples largely is reflected in changes in carbonate and sulfate abundances
 - ✓ Presence of gypsum in post-remediation samples
- Complexity of grain coatings and cementation
- Role of organic phases (detritus and cellulose remnants of plants and roots)
 - ✓ Residence phase for Cd, Pb, and Zn

Mineral Liberation Analysis (MLA) Simplified Modal Mineralogy



Mineral Liberation Analysis (MLA)

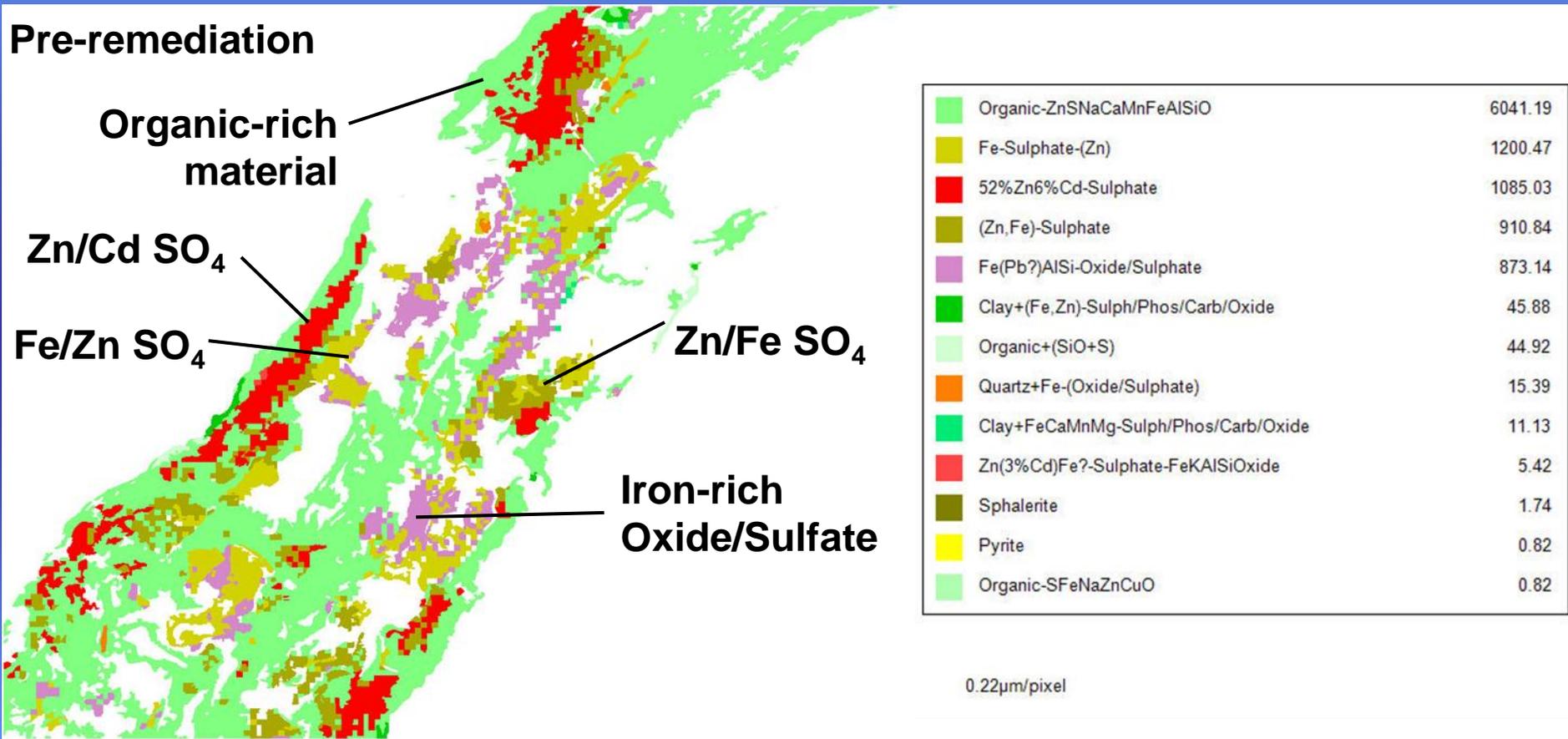
Glass or Slag Bead



FeTiCaNa-AlSilicate (+glass)	4337.70
NaFe-AlSilicate (+glass)	1414.15
Quartz	770.92
Kaolinite+Fe-Oxide	669.42
(K,Na)-AlSi-FeCaMnZn-Oxide/Sulphate	535.79
Organic-ZnSNaCaMnFeAlSiO	369.00
KAlSi-MgFeCaPbZn-OSP	288.46
Kaolinite	182.42
Albite	146.89
Gypsum	79.42
Calcite+Mg-AlSilicate+ Sulphate	56.24
Goethite+NaKCa-AlSilicates	53.19
Clay+FeCaMnMg-Sulph/Phos/Carb/Oxide	34.41
K ₂ Fe ₉ -AlSi-Oxide/Silicate	27.68
Organic+(SiO+S)	20.33
Clay+CaFeZn-Phos/Carb/Oxide	16.02
Calcite	13.31
Quartz+Fe-(Oxide/Sulphate)	12.58
Ca(Fe)-AlSilicate	11.28
Organic-SFeNaZnCuO	10.16
K[Fe, Mg]-AlSilicate	10.07
Na[Fe, Mg]-AlSilicate	5.47
Gypsum+Quartz	1.98
Quartz+K-Feldspar	1.89
Clay+(Fe, Zn)-Sulph/Phos/Carb/Oxide	1.84
Unknown	1.45

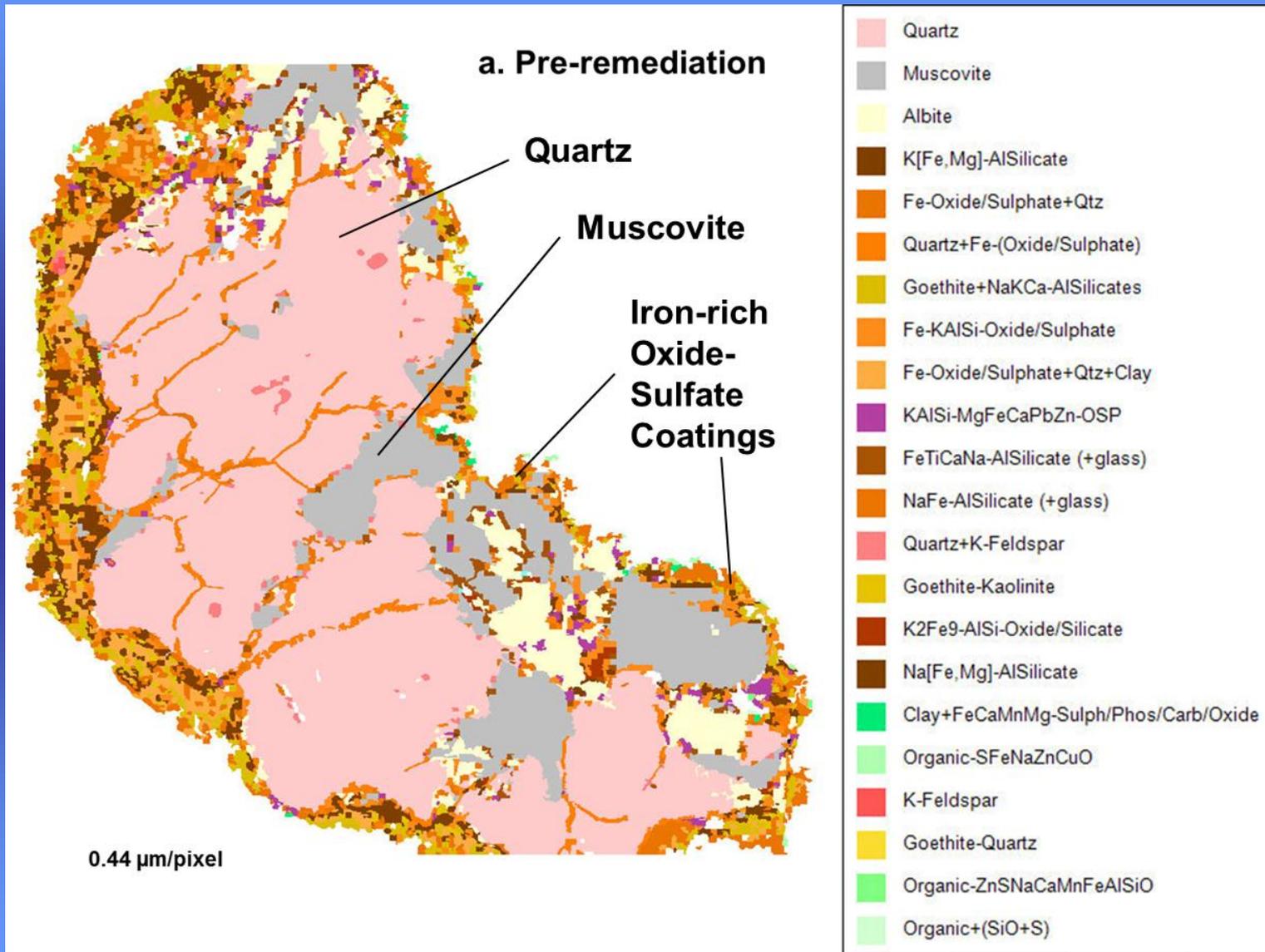
0.22µm/pixel

Mineral Liberation Analysis (MLA) Mineralized Organic Particle

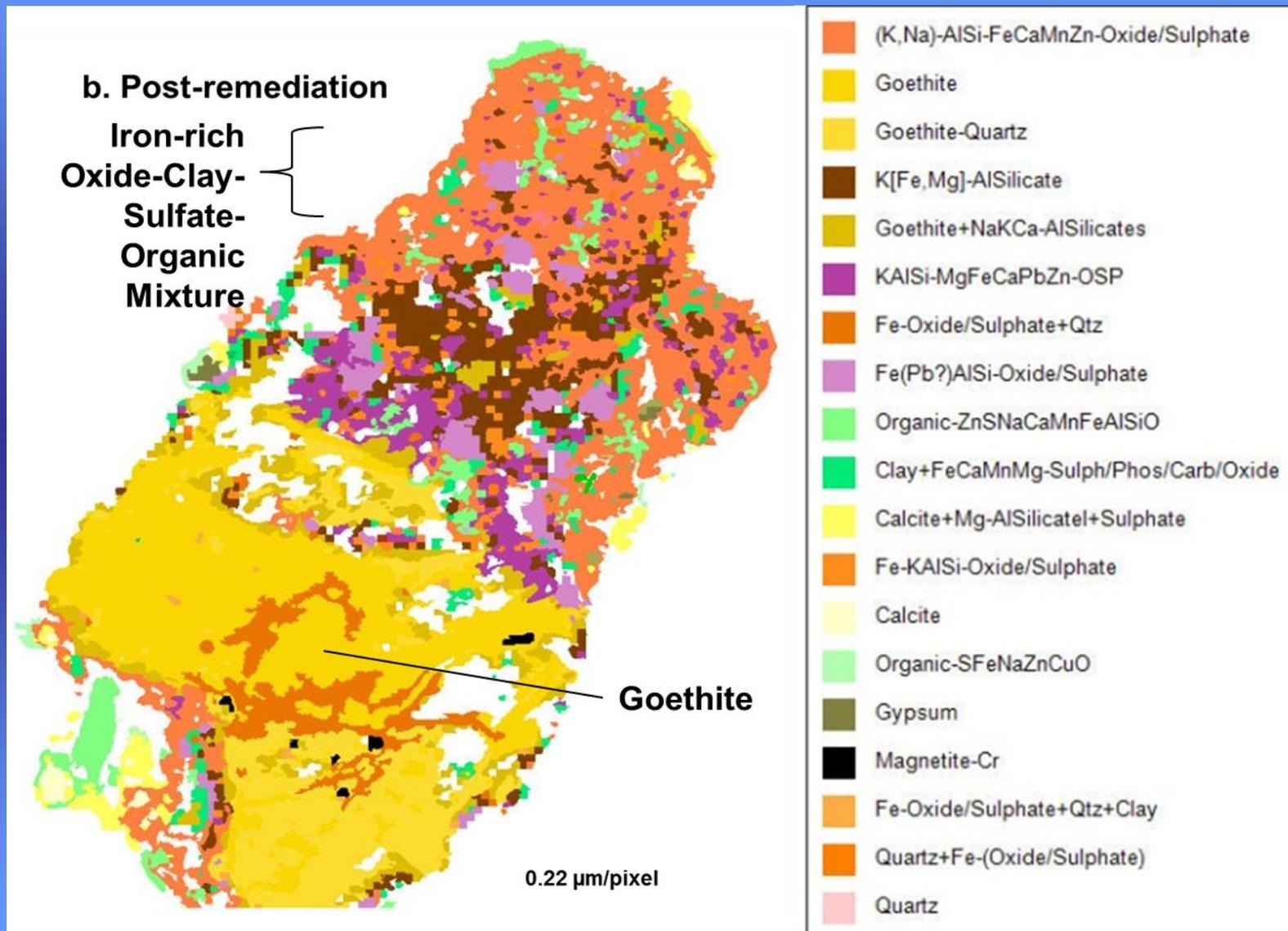


Mineral Liberation Analysis (MLA)

Pre-Remediation Cement

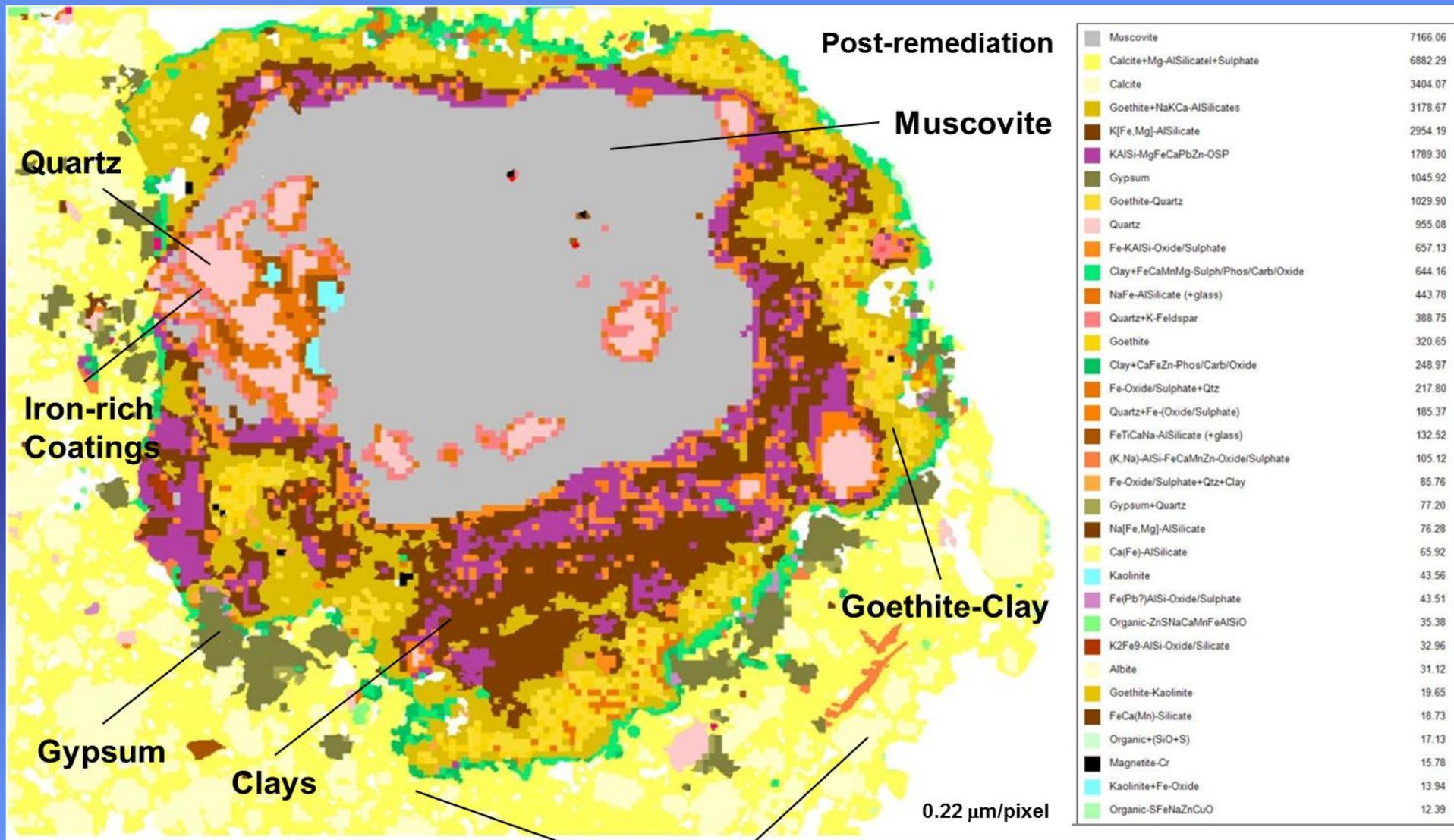


Mineral Liberation Analysis (MLA) Post-Remediation

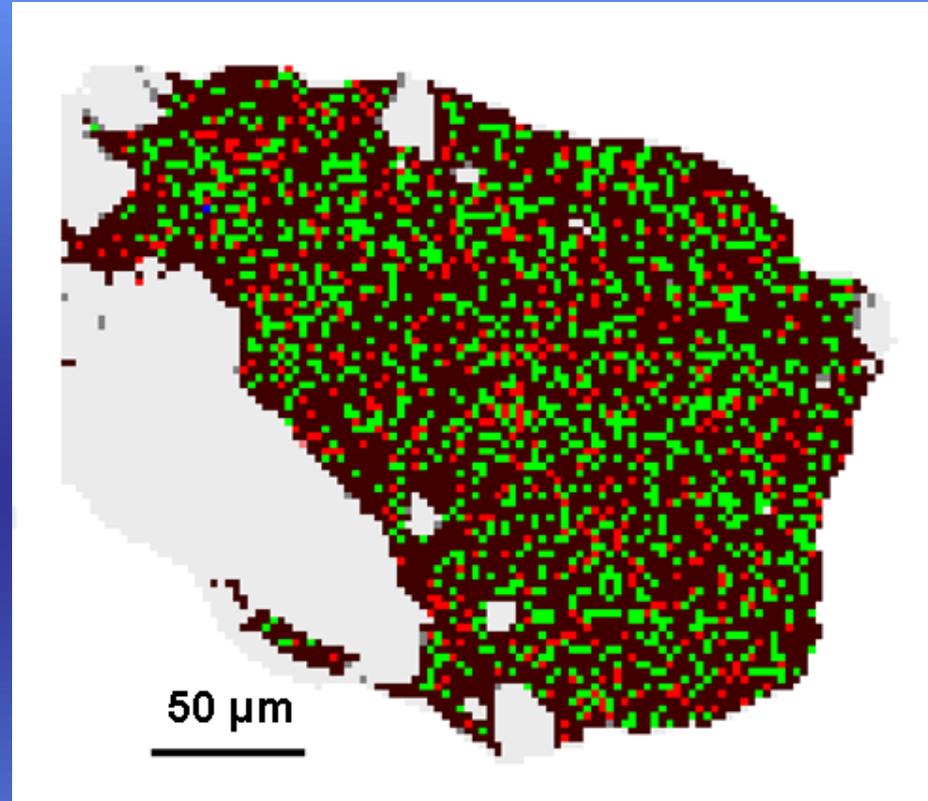
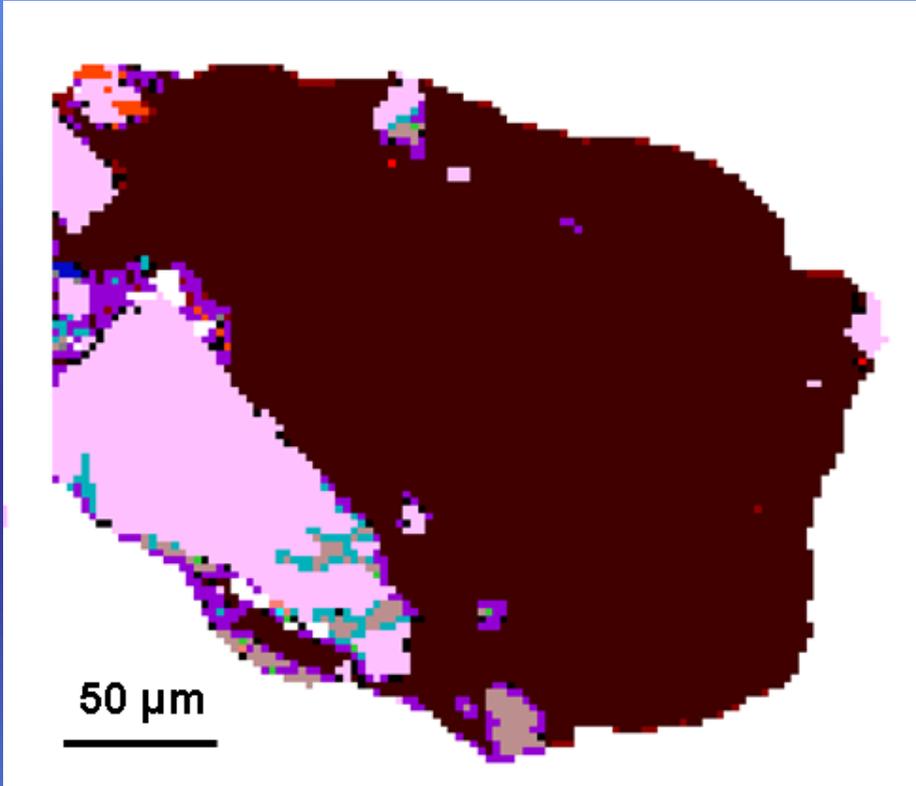


Mineral Liberation Analysis (MLA)

Post-Remediation



QEMSCAN Results



Jarosite (maroon) containing arsenic (red) and lead (green)

Summary

- Incomplete treatment to full depth at one site
 - ✓ Zone of pyrite oxidation below about 40-cm depth
 - Acidic zone at base of fluvial tailings deposit
 - Formation of jarosite
 - ✓ Not necessarily indicative of the situation throughout treatment area (need more post-remediation monitoring)
- Zone of pyrite oxidation may be enhanced by fluctuating groundwater levels beneath the deposit
- Mineral Liberation Analysis (MLA) is useful in revealing mineralogical textures, relationships, and complexities

Acknowledgements

U.S. Geological Survey:
Toxic Substances Hydrology Program
And Mineral Resources Program

Field Assistants:
Matthew Day, Anna Day, and Shera Bove

Assistance and Photos:
Mike Holmes (U.S. EPA)
Jan Christner (URS Operating Services, Inc.)

Any use of trade, product, or firm names in this presentation is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Thank you