Grand Challenges and Opportunities in Soil Chemistry in the 21st Century

XXIV Brazilian Congress of Soil Science
Florianopolis, Santa Catalina, Brazil
July 28-August 2, 2013

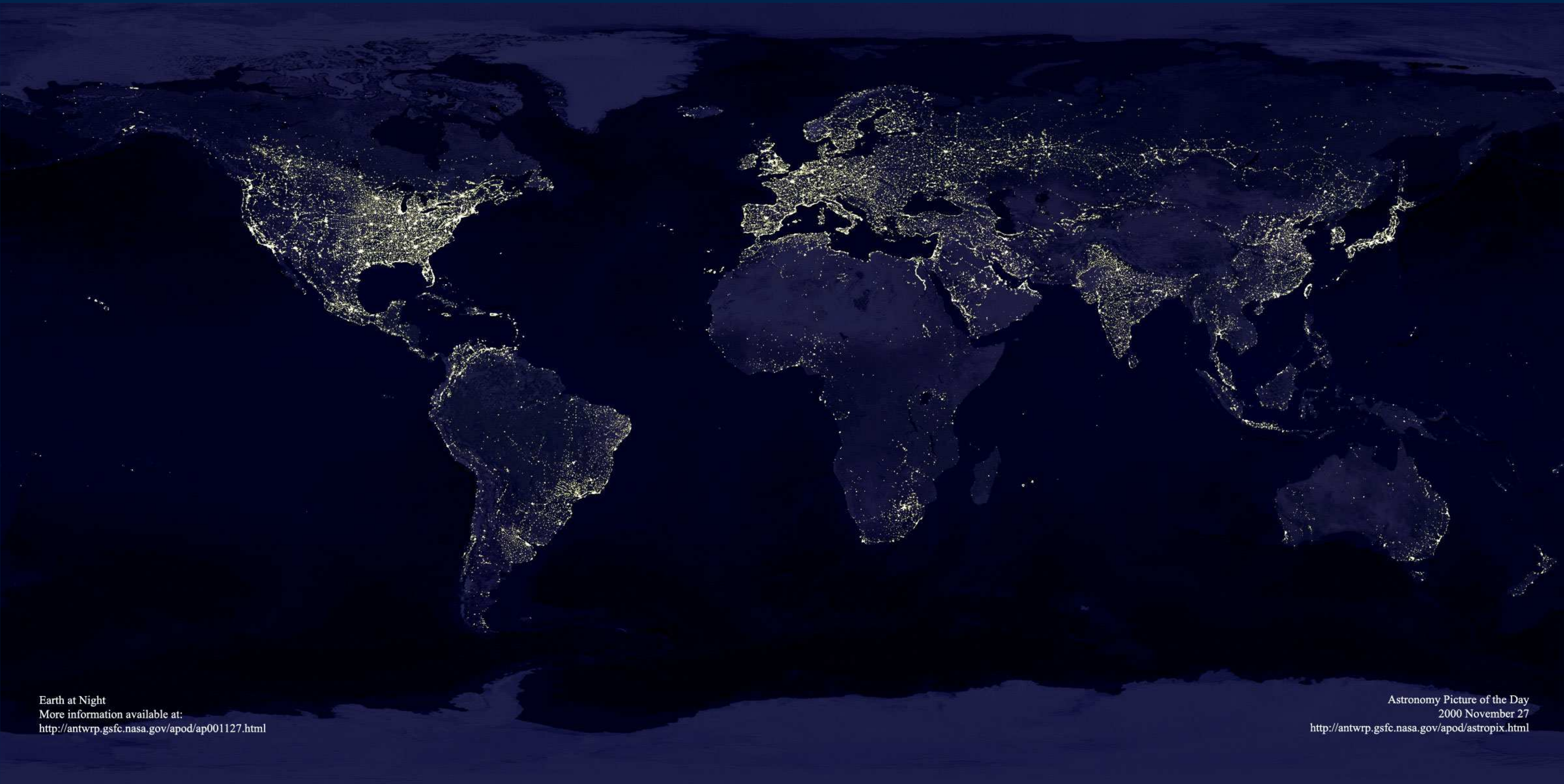
DELAWARE ENVIRONMENTAL INSTITUTE
UNIVERSITY OF DELAWARE

Donald L. Sparks
S. Hallock du Pont Chair
Director, Delaware Environmental Institute

UNIVERSITY OF DELAWARE 1743

Global Environmental Challenges

- Population Expansion and Food Production/Security
- Water Quantity and Quality
- Air Quality
- Soil Contamination
- Global Climate Change
- Energy Sustainability
- Biodiversity



C. Mayhew R. Simmon (NASA/GSFC), NOAA/ NGDC, DMSP Digital Archive

Rapid Urbanization
(Health, Water, Climate Nexus)

Rural → Urban Migration

At end of 21st century, >80% of world's population will live in cities

Increasing slums in magacities (>10 million)

- Lack of water or sanitation, health care, education
- Climate change impacts (droughts, flooding, sanitation)

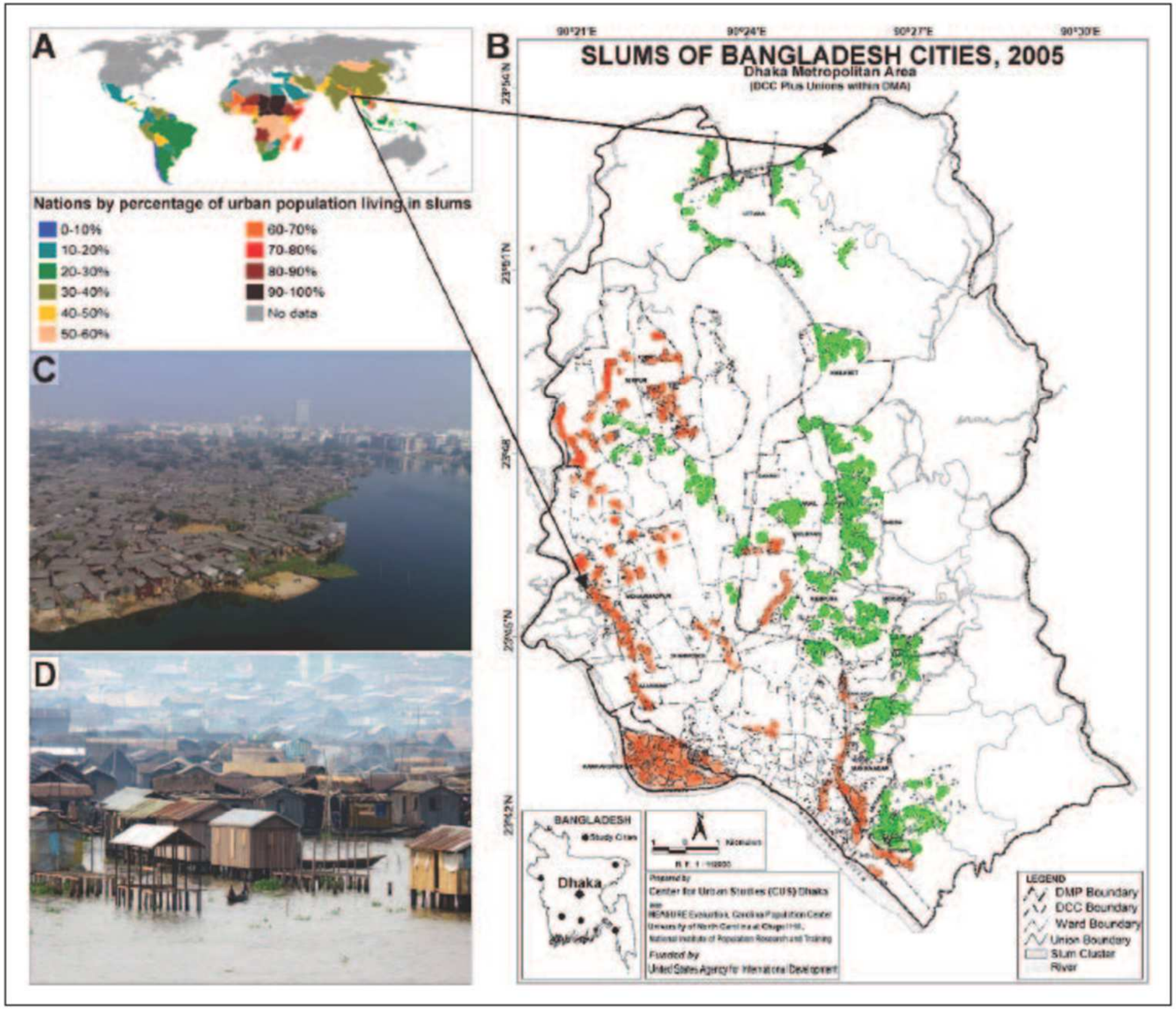
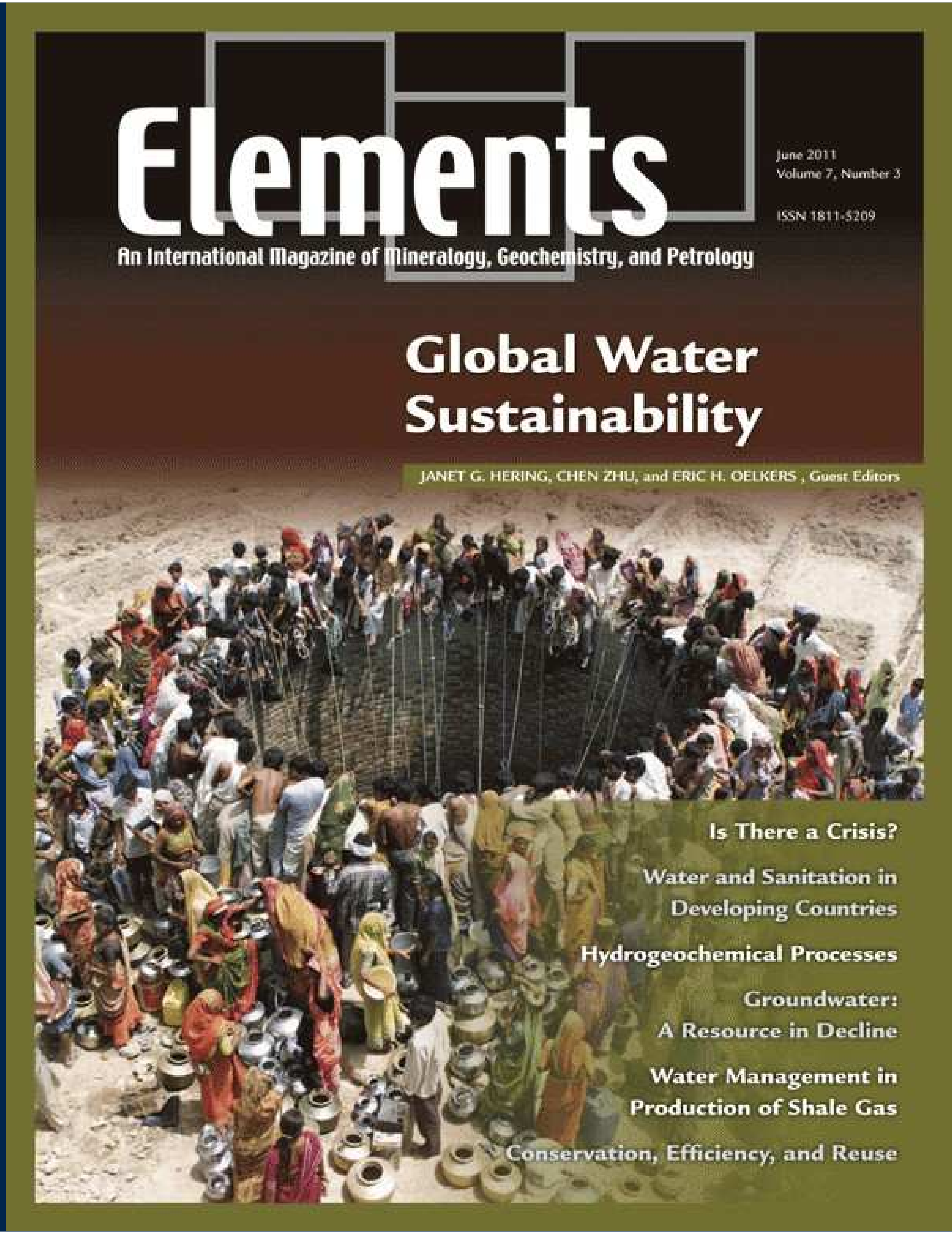


*Fig. 1. (a) Global distribution of population living in slums. Credit: UN-HABITAT, http://www.unhabitat.org. (b) Map of slums in Dhaka according to surveys conducted a decade apart: Orange represents slums identified in 1995 survey, and green represents new slums identified in 2005 [*Islam et al., *2006]. (c) Karail slum of Dhaka near a large water body (Gulshan Lake). (d) The Makoko slum of Lagos, Nigeria (photo by Rainer Wozny).*

The Earth is **shrinking**

YEAR
Hectar of surface per person

Ecological footprint = the land we need to provide daily needs and take up the waste. Now we are using 1.5 Earths per year.



Elements

An International Magazine of Mineralogy, Geochemistry, and Petrology

June 2011
Volume 7, Number 3

ISSN 1811-5209

Global Water Sustainability

JANET G. HERING, CHEN ZHU, and ERIC H. OELKERS , Guest Editors

Is There a Crisis?

Water and Sanitation in Developing Countries

Hydrogeochemical Processes

Groundwater: A Resource in Decline

Water Management in Production of Shale Gas

Conservation, Efficiency, and Reuse

Table 1 MAJOR EARTH-SURFACE WATER RESERVOIRS (AFTER GLEICK 1996)

Water reservoir	Water volume (10^3 km^3)	Percent of total water	Percent of fresh water	Mean residence time
Oceans, seas, bays	1,338,000	96.5	0	2500 years
Ice caps, glaciers	24,064	1.74	69	9700 years
Groundwater	23,400	1.69	–	1400 years
• fresh	10,530	0.76	30	–
• saline	12,870	0.93	0	–
Ground ice and permafrost	300	0.022	0.86	10,000 years
Lakes	176.4	0.013	–	17 years
• fresh	91	0.007	0.26	
• saline	85.4	0.007	0	
Atmosphere	12.9	0.001	0.04	8 days
Swamps	11.47	0.0008	0.03	5 years
Rivers	2.12	0.0002	0.002	16 days
Biological water	1.12	0.0001	0.003	4 hours

Oelkers, *Elements*, June 2011

"Because many of the threats from climate change affect the land, soil scientists will need to be at the forefront of climate change research."

Janzen et. al, CSA News, April 2011

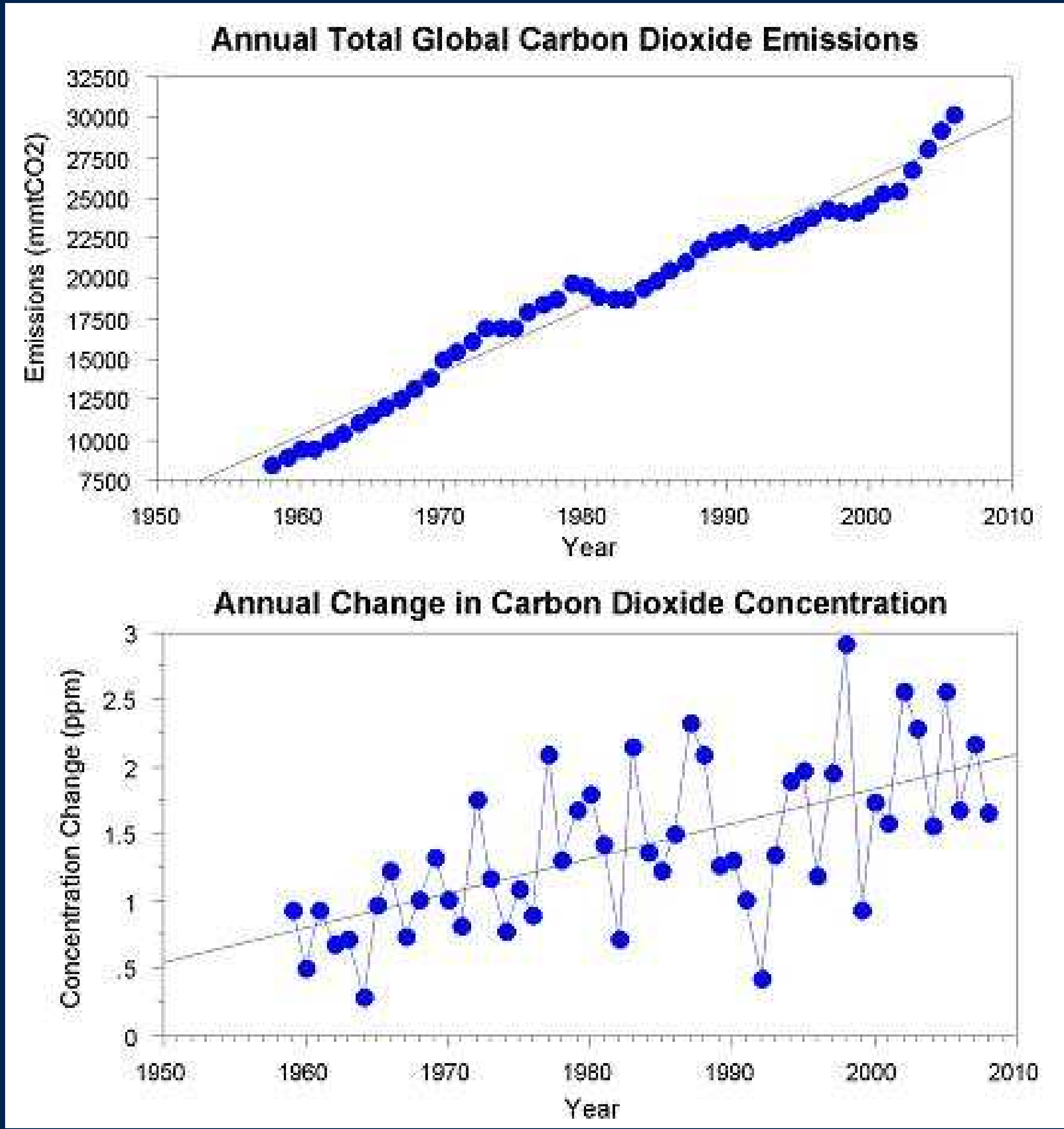
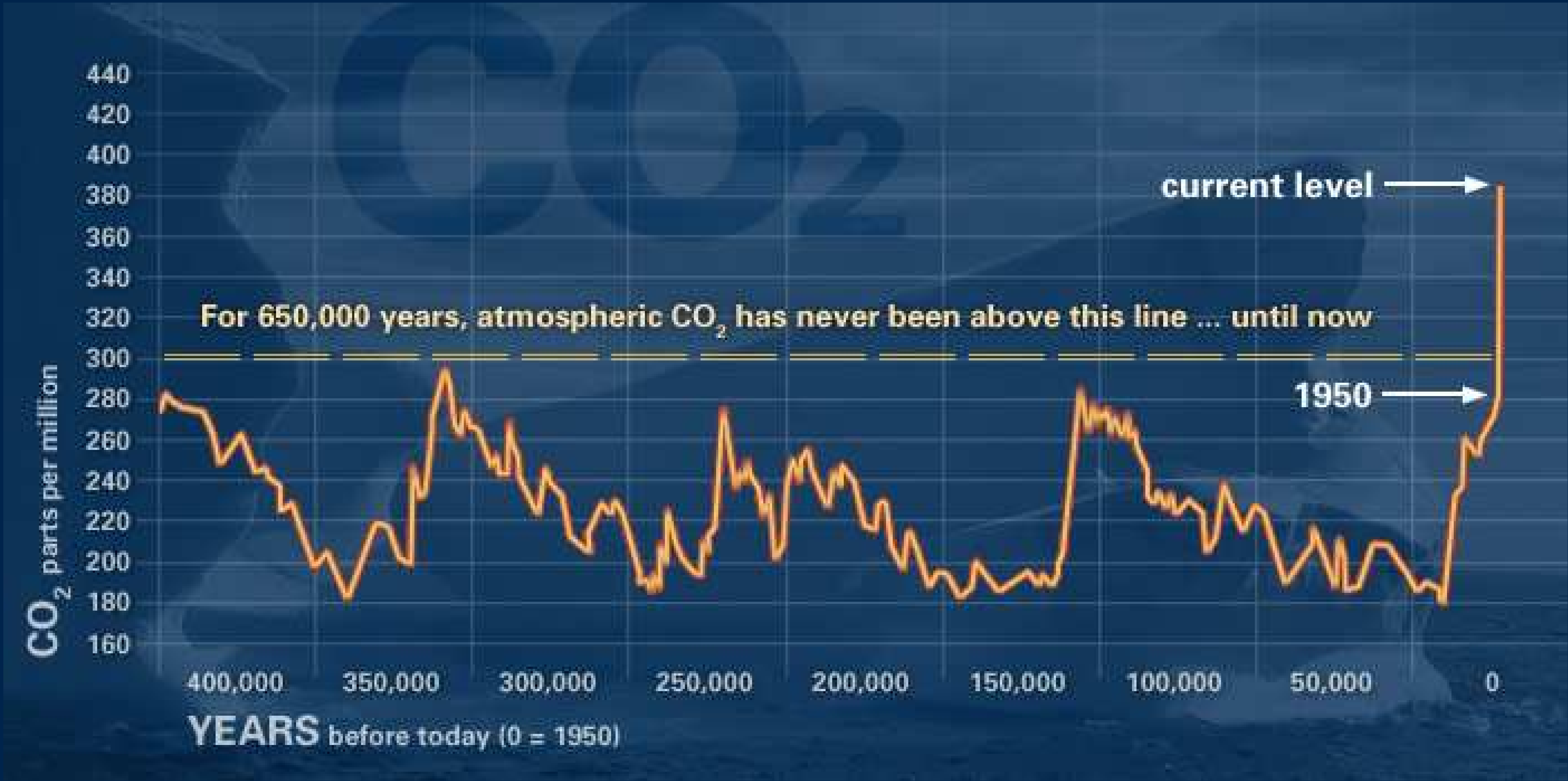


Figure 1. (top) Annual global total carbon dioxide emissions (mmt), 1958-2006; (bottom) Year-to-year change in atmospheric CO2 concentrations (ppm), 1959-2006. (Data source: Carbon Dioxide Information Analysis Center)



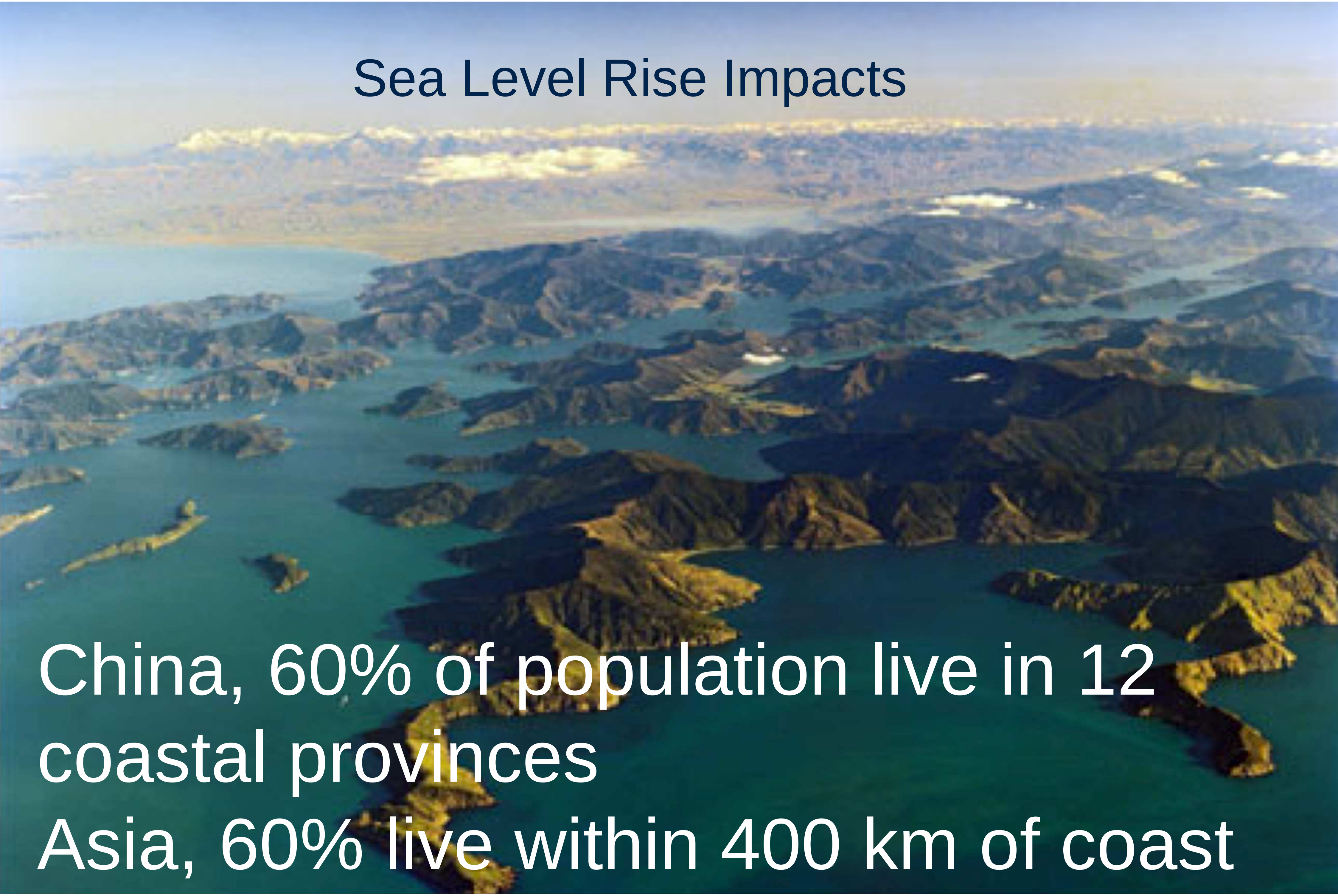
This graph, based on the comparison of atmospheric samples contained in ice cores and more recent direct measurements, provides evidence that atmospheric CO2 has increased since the Industrial Revolution. (Source: NOAA)

Table 1. Estimated mass of carbon in the world's soils.
Source: USDA.

Soil orders	Area	Organic C
	10^3 km^2	Gt
Alfisols	13,159	90.8
Andisols	975	29.8
Aridisols	15,464	54.1
Entisols	23,432	232.0
Gelisols	11,869	237.5
Histosols	1,526	312.1
Inceptisols	19,854	323.6
Mollisols	9,161	120.0
Oxisols	9,811	99.1
Spodosols	4,596	67.1
Ultisols	10,550	98.1
Vertisols	3,160	18.3
Other soils	7,110	17.1
TOTALS	130,667	1,699.6

Sea Level Rise Impacts

	Coastal Population, %
Australia	>85
USA	53
Brazil	>50
Globally	44



Sea Level Rise Impacts

China, 60% of population live in 12 coastal provinces

Asia, 60% live within 400 km of coast

Storm Barrels Through Region, Leaving Destructive Path, NY Times, Oct 29, 2012

Storm Barrels Through Region, Leaving Destructive Path, NY Times, Oct 29, 2012

Storm Barrels Through Region, Leaving Destructive Path, NY Times, Oct 29, 2012

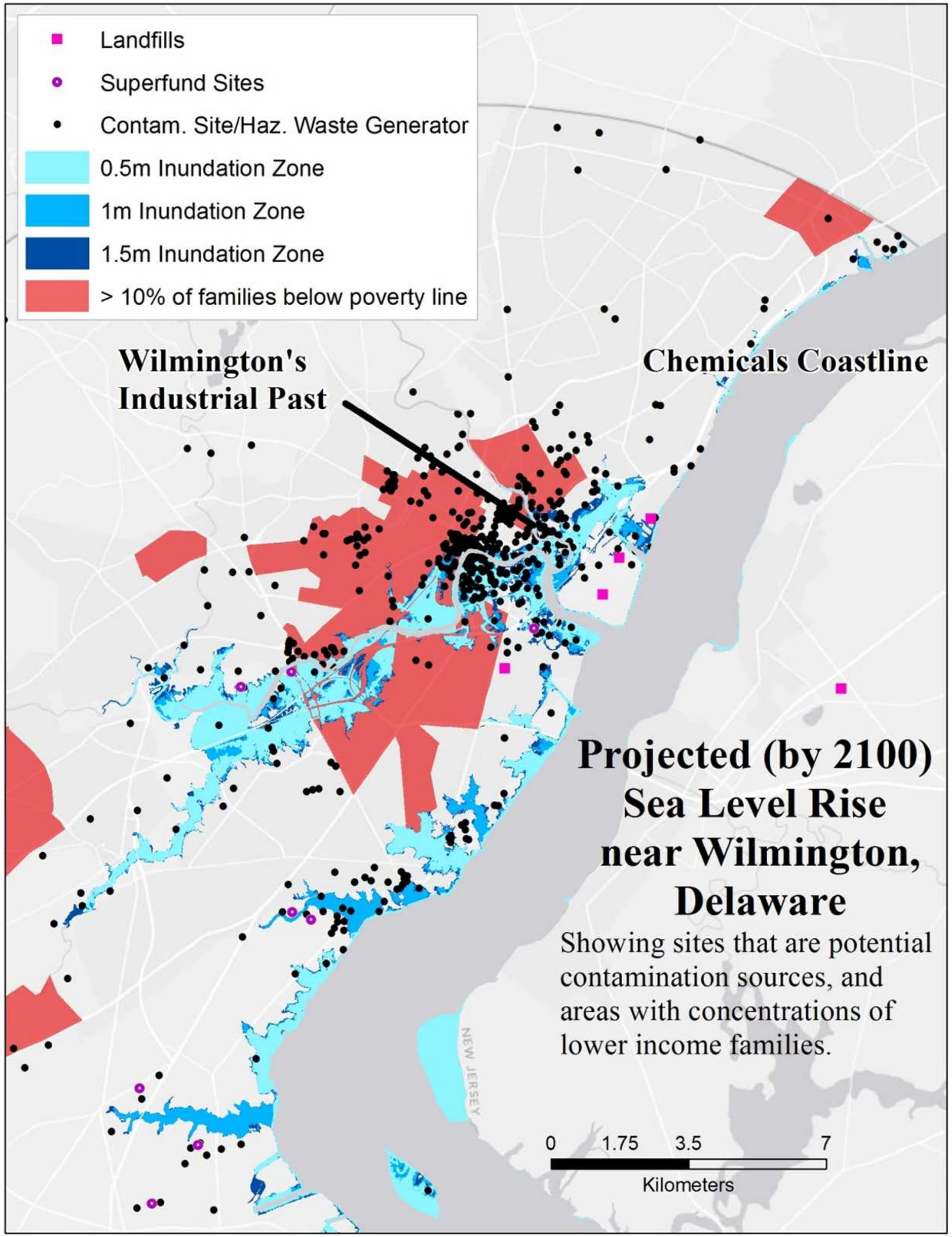
SPECIAL REPORT **CLIMATE CHANGE ON THE COAST** **PART 2 OF 3**

Mark Wells stands on the 6-foot-high berm he built to try and keep brine water from inundating crops on his farm near Milford. Wells has doubts that his son will be able to take over the farm before sea-level rise ruins the land. SUCHAT PEDERSON/THE NEWS JOURNAL

FIGHTING TIDES

WHICH PROPERTIES TO PROTECT?

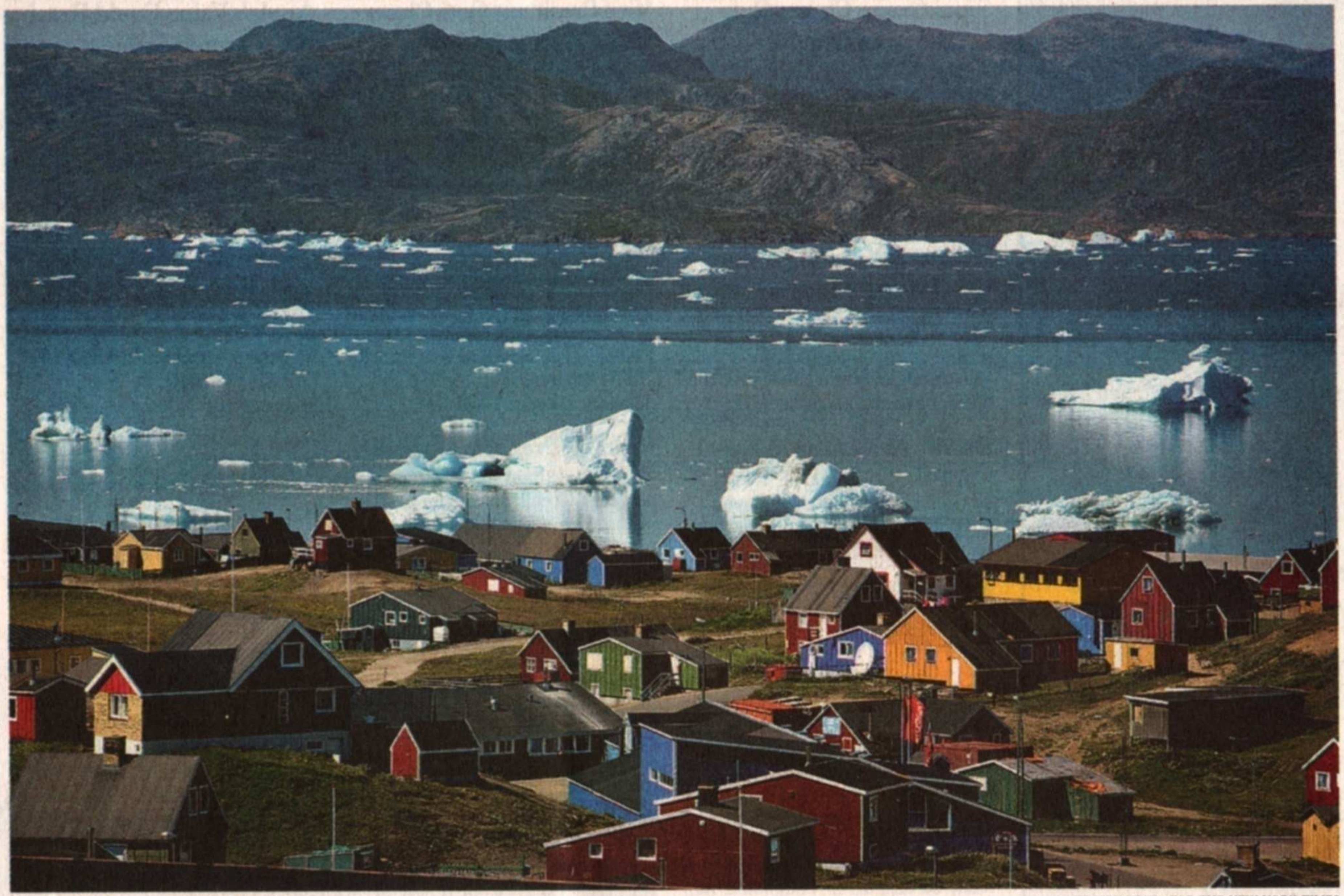
Mark Wells' farm field shows damage from salt water among his crops in Sussex County.


Landfills
Superfund Sites
Contam. Site/Haz. Waste Generator
0.5m Inundation Zone
1m Inundation Zone
1.5m Inundation Zone
> 10% of families below poverty line
Wilmington's Industrial Past
Chemicals Coastline
Projected (by 2100) Sea Level Rise near Wilmington, Delaware
Showing sites that are potential contamination sources, and areas with concentrations of lower income families.
NEW JERSEY
0 1.75 3.5 7
Kilometers

Climate Change and National Security/ Military Response

- Humanitarian Relief and Conflict (food shortages, water crises, pollution, flooding)
- Sea Level Rise Impacts on Military Bases
- Arctic Melting (opening of shipping channels; undersea resources, e.g., oil, gas, rare minerals

What are the new relationships among resources, diplomacy, crises and conflict?



ANDREW TESTA FOR THE NEW YORK TIMES

Greenland Weighs Peril and Potential of Climate Change

In one Greenland town, climate change is threatening a fishing culture but also hinting at new opportunities in mining. Page A4.

New York Times, September 24, 2012

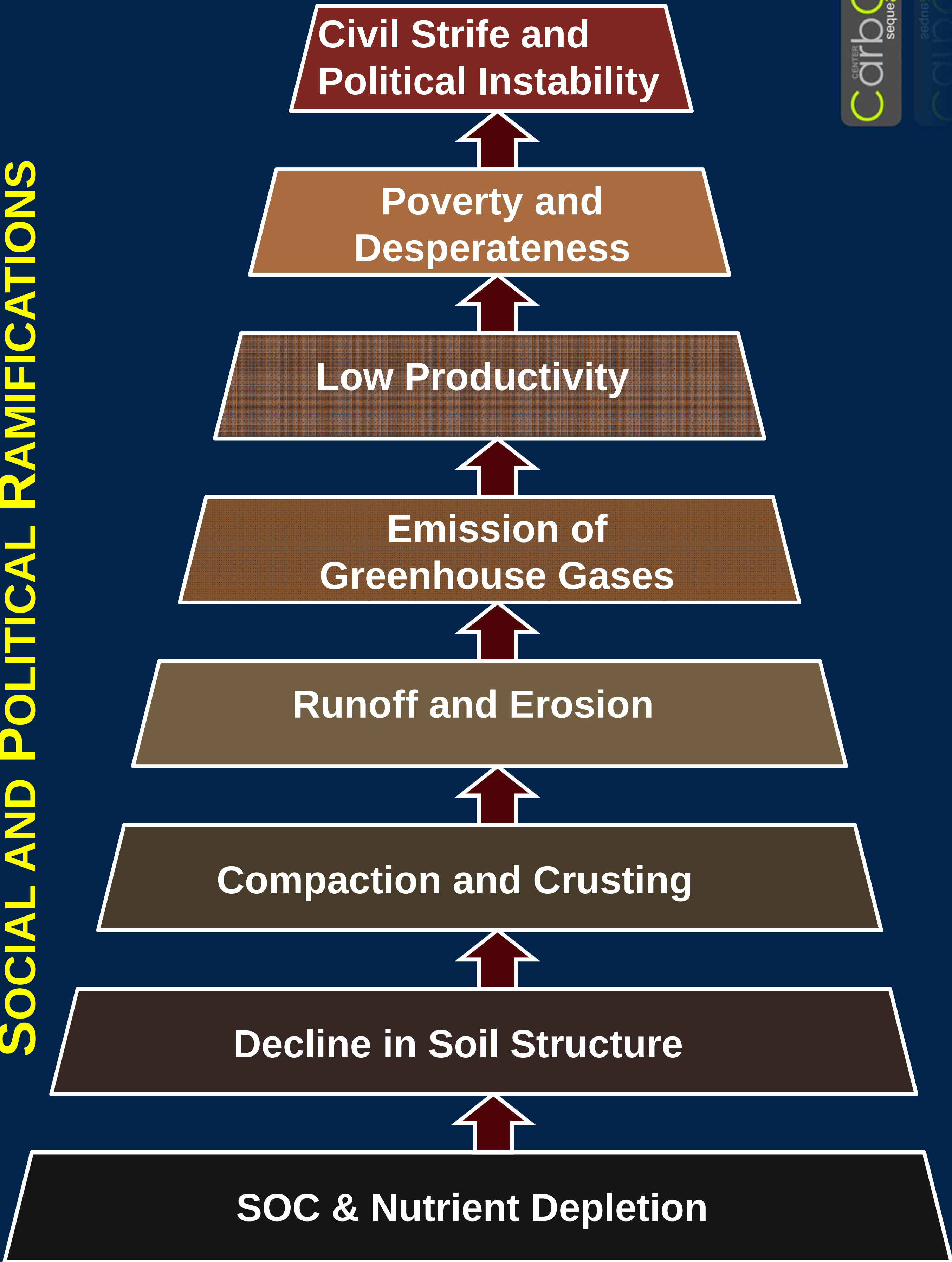
Global Food System Threats

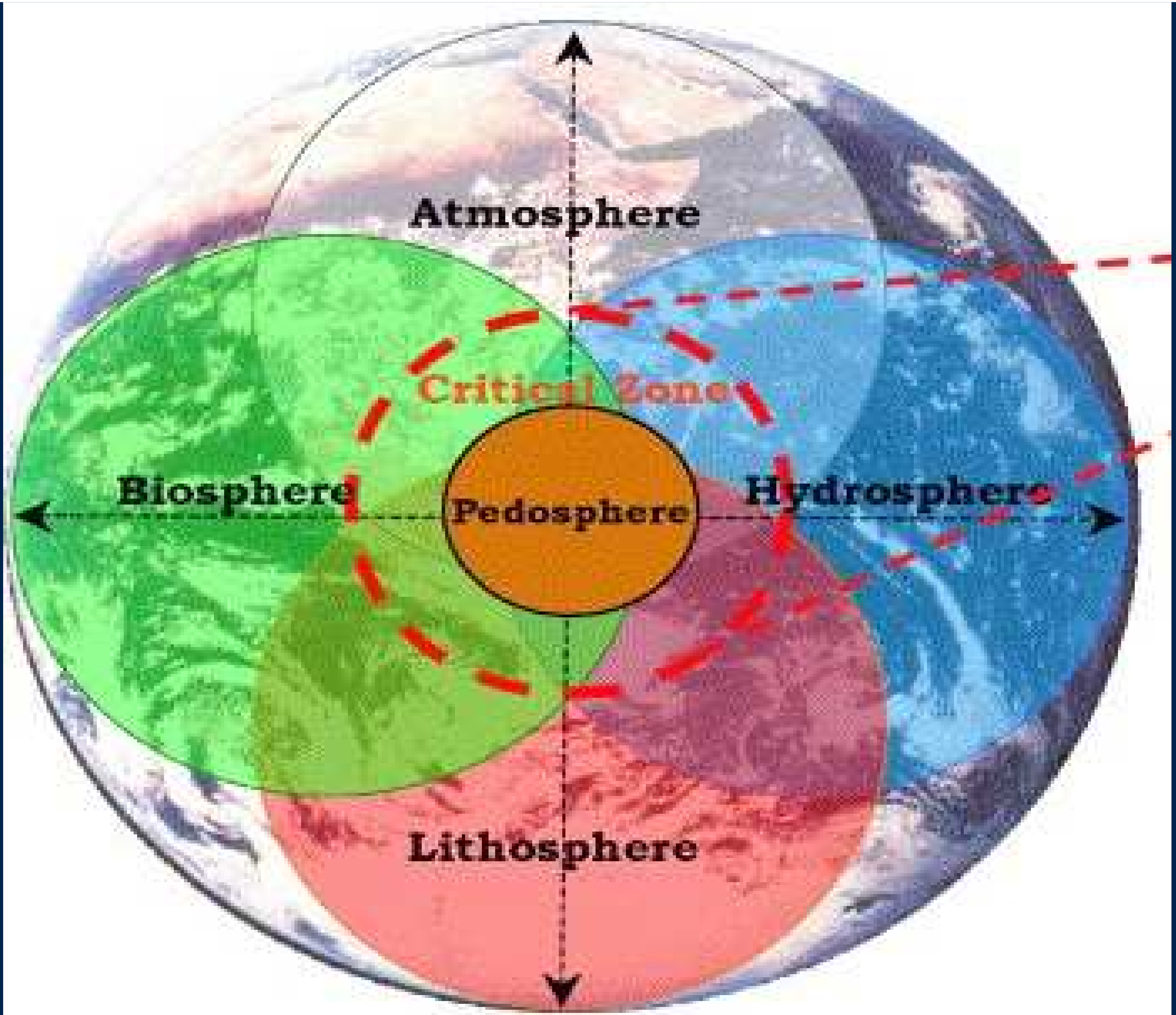
- Climate Change
- Soil and Ecological Degradation
- Population Growth
- Rising Energy Prices
- Increasing Demand for Meat and Dairy Products
- Urban Expansion
- Increasing Competition for Land from Biofuels, Industry and Urbanization
- Conflicts over Water

Food Security

- 925 million hungry people
  (2010, Food and Agr. Org. of U.N.)
- Food prices could more than double by 2030; climate change responsible for 50% of rise

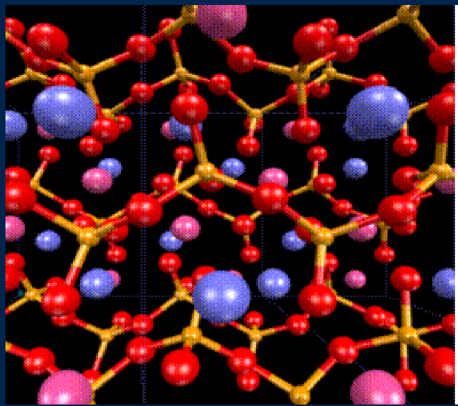
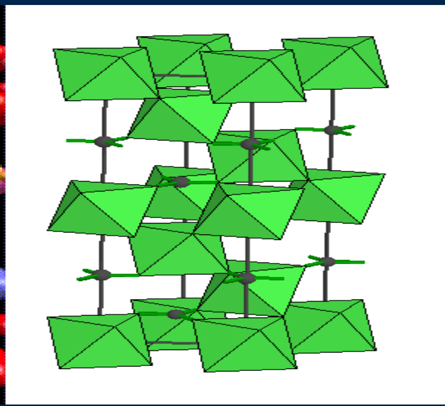
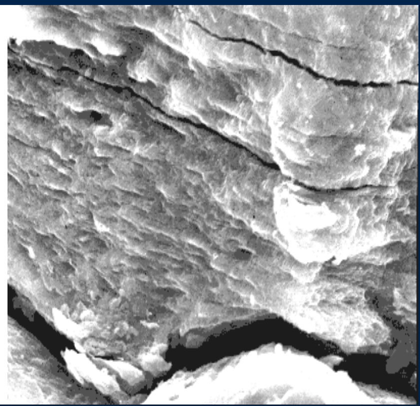
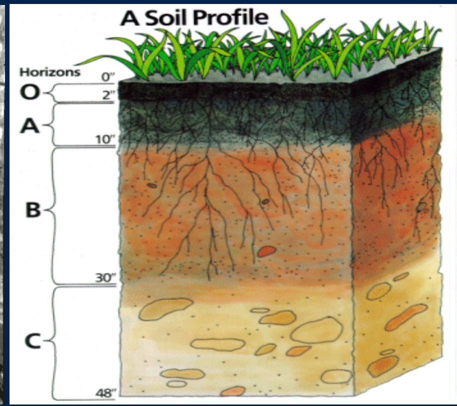
Soil Degradation and Its Environmental, Economic, Social and Political Ramifications




Atmosphere
Critical Zone
Biosphere
Pedosphere
Hydrosphere
Lithosphere


Science
11 June 2004
Vol. 304 No. 5677
SOILS
The Final Frontier
AAAS

A Range of Scales

Atomic	Molecular	Microscopic	Macroscopic	Field
				

Atomic

- XRF
- XPS
- XAS

Requires synchrotron radiation.

Molecular

- XRD
- TGA
- FTIR
- DRS

Microscopic

- Enhanced Visual Analysis:
  1. SEM
  2. TEM
  3. AFM

Macroscopic

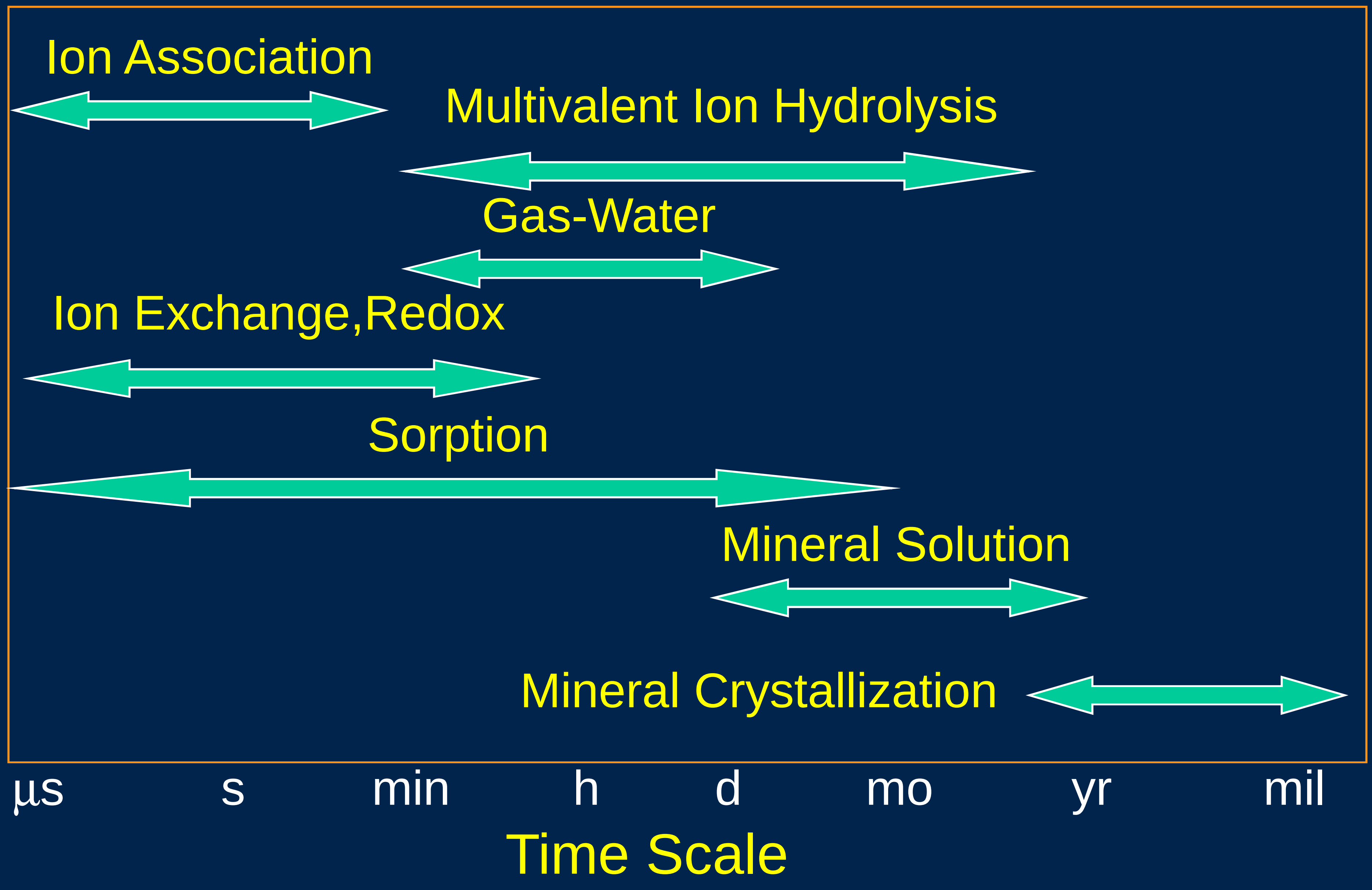
- Field Plots
- Equilibrium Studies
- Kinetic Studies
- Extractions

Field

- Visual/ Intuitive Insight
- Field Plots

Adaptation of Bertsch and Hunter, 1996.

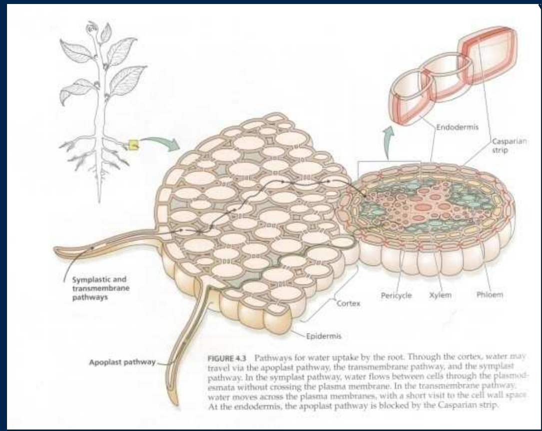
Time Scales of Reactions in Natural Environments



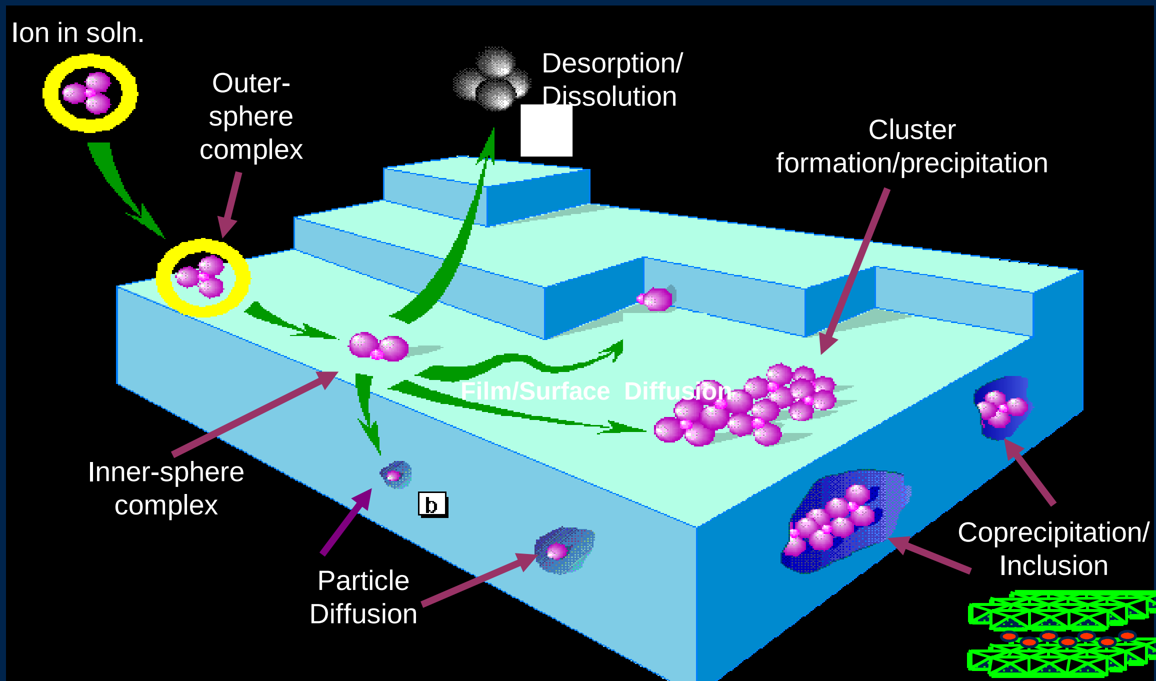
Amacher. 1991. SSSA Spec. Pub. 27: 19-60.

It's About Interfaces!

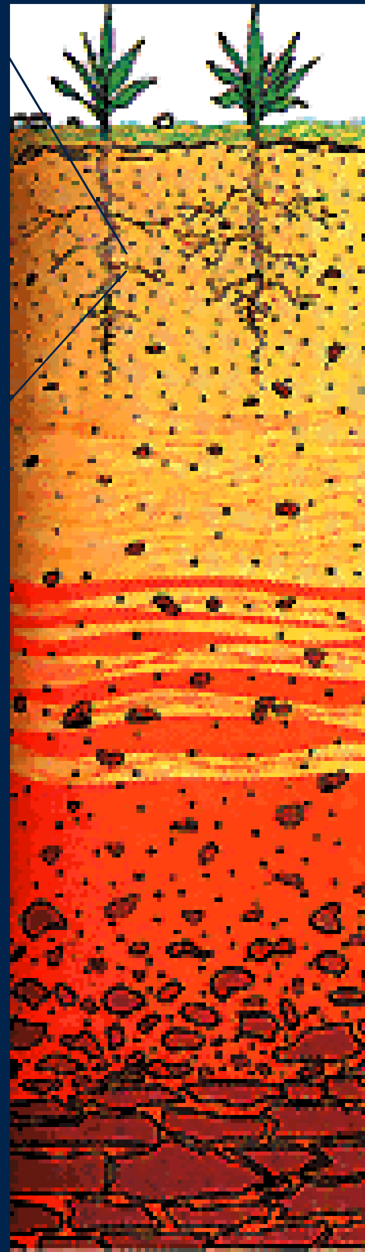
The microbe-mineral interface



The root-soil interface



The water-rock-mineral interface



The Critical Zone

Molecular Environmental Science

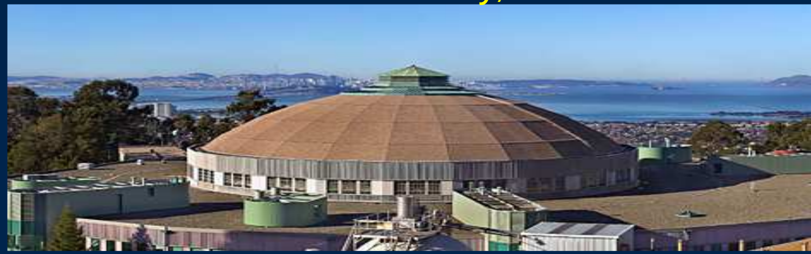
Study of the chemical and physical forms and distribution of contaminants in soils, sediments, waste materials, natural waters, and the atmosphere at the molecular level.

Synchrotrons of the World – The Generations

Spring-8 Garden City, Japan

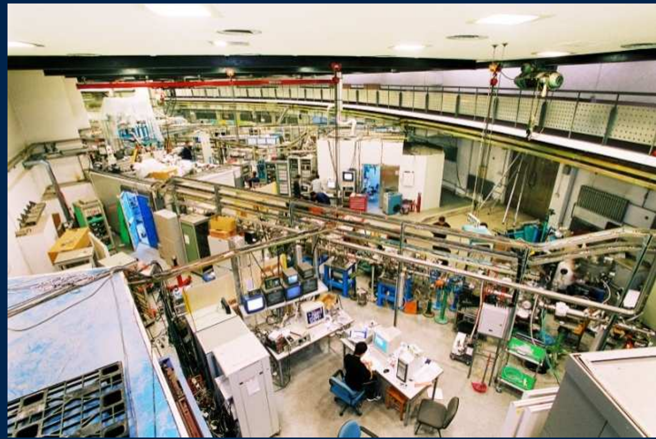
NSLS -BNL Upton, NY USA

LBNL-ALS Berkeley, CA USA



Shanghai Synchrotron Radiation Facility (SSRF)

Beijing Synchrotron Radiation Facility (BSRF)



ESRF Grenoble, France

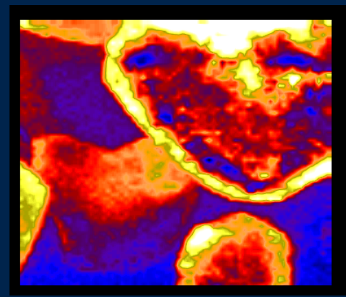
SSRL Stanford, CA USA

ANL-APS Chicago, Ill. USA

Principal Synchrotron Techniques Used in Environmental Science

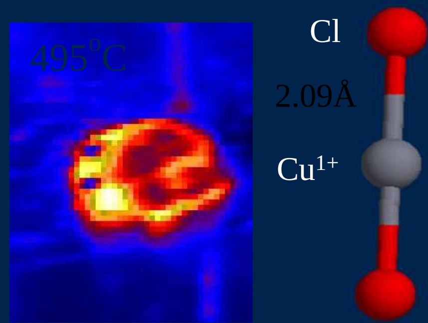
- X-ray Fluorescence (XRF): chemical composition (quantification, mapping)

Arsenic on Bangladesh Biotite



- X-ray Absorption Fine Structure (XAFS) Spectroscopy: chemical speciation (oxidation state, coordination, nearest neighbors)

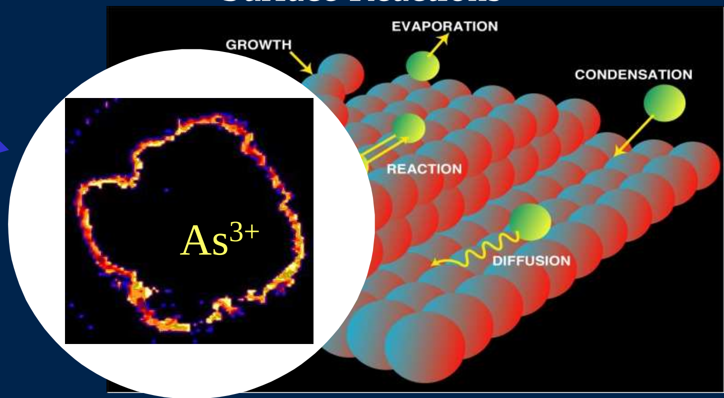
Copper Speciation in Fluid Inclusions



- Surface Scattering and Diffraction: surface structure, sorption processes

- Microtomography: 3D imaging of internal microstructure (porosity, fluid flow, composition)

Surface Reactions



Arsenic in Cattail Root Plaque

Courtesy of S. Sutton, GSECARS, U of Chicago

Anatomy of a µXAS Experiment

(1.) Sample Prep.

(2.) µSXRF mapping

(3.) Region of interest

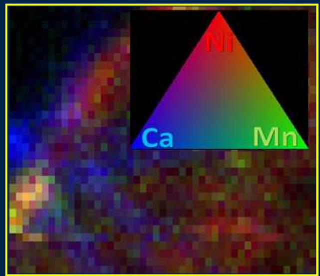
(4.) Obtain µXRD

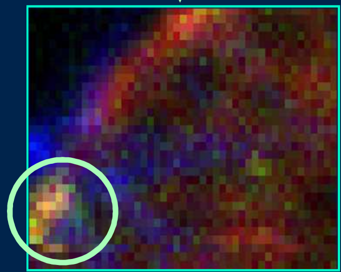
(5.) Obtain µXAFS spectra

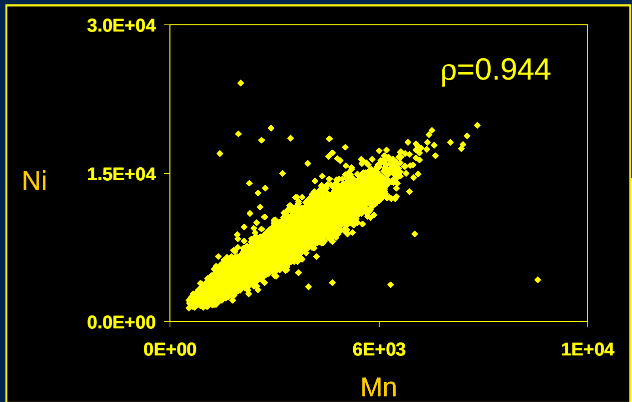
(6.) Data Fitting

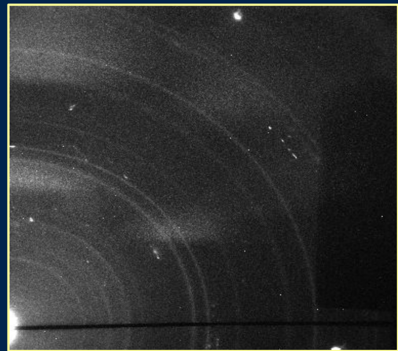
- or -

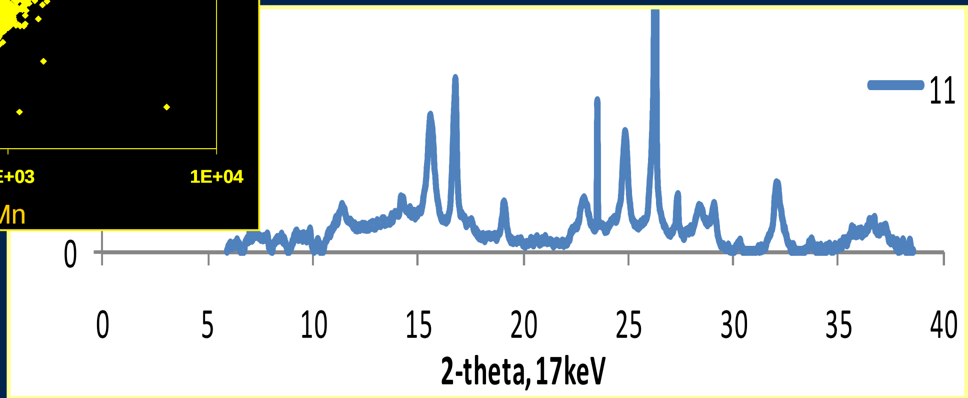
- or -

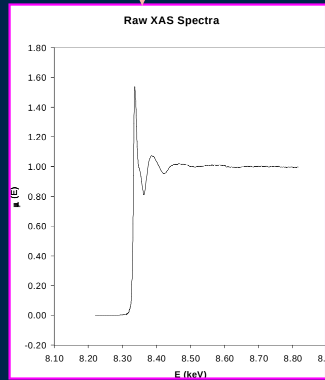


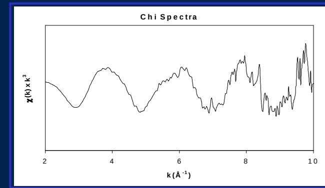


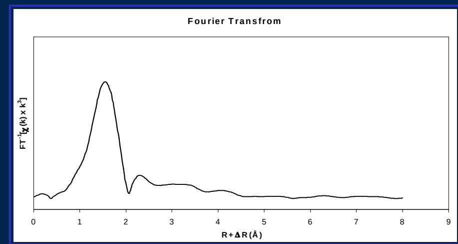












Soil	Atoms	N	R (A)	σ^2	C_3
SS11	O	6.18	2.06	0.005	0.0002
	Ni	9.72	3.04	0.009	0.0002
HSTONE	O	6.00	2.05	0.004	0.0000
	Ni	5.93	3.11	0.010	0.0000
HRUSKA	O	5.33	2.06	0.004	0.0002
	Ni	9.98	3.05	0.015	-0.0010

Slide adapted from D. McNear

Soil and Environmental Science Research Thrusts and Frontiers

- Metal(loid) Speciation and Reactivity in Heterogeneous Systems
- Nutrient Cycling/Sequestration
- Particulate Transport and Reactivity
- Microbe/Metal/Carbon Interactions at Critical Zone Interfaces
- Plant/Soil Interfacial Processes
- Climate Change and Carbon Cycling

Speciation of Heterogeneous Systems


A site contaminated by heavy metals
(Pb, Cd, Cu, Zn)

Arsenic, a public health crisis

2010 ASA-CSSA-SSSA
International Annual Meetings
Oct. 31-Nov. 3 • Long Beach, CA

Citations: WHO, 2000; Booth 2008; Zhao 2010

Maatheide Area, Belgium

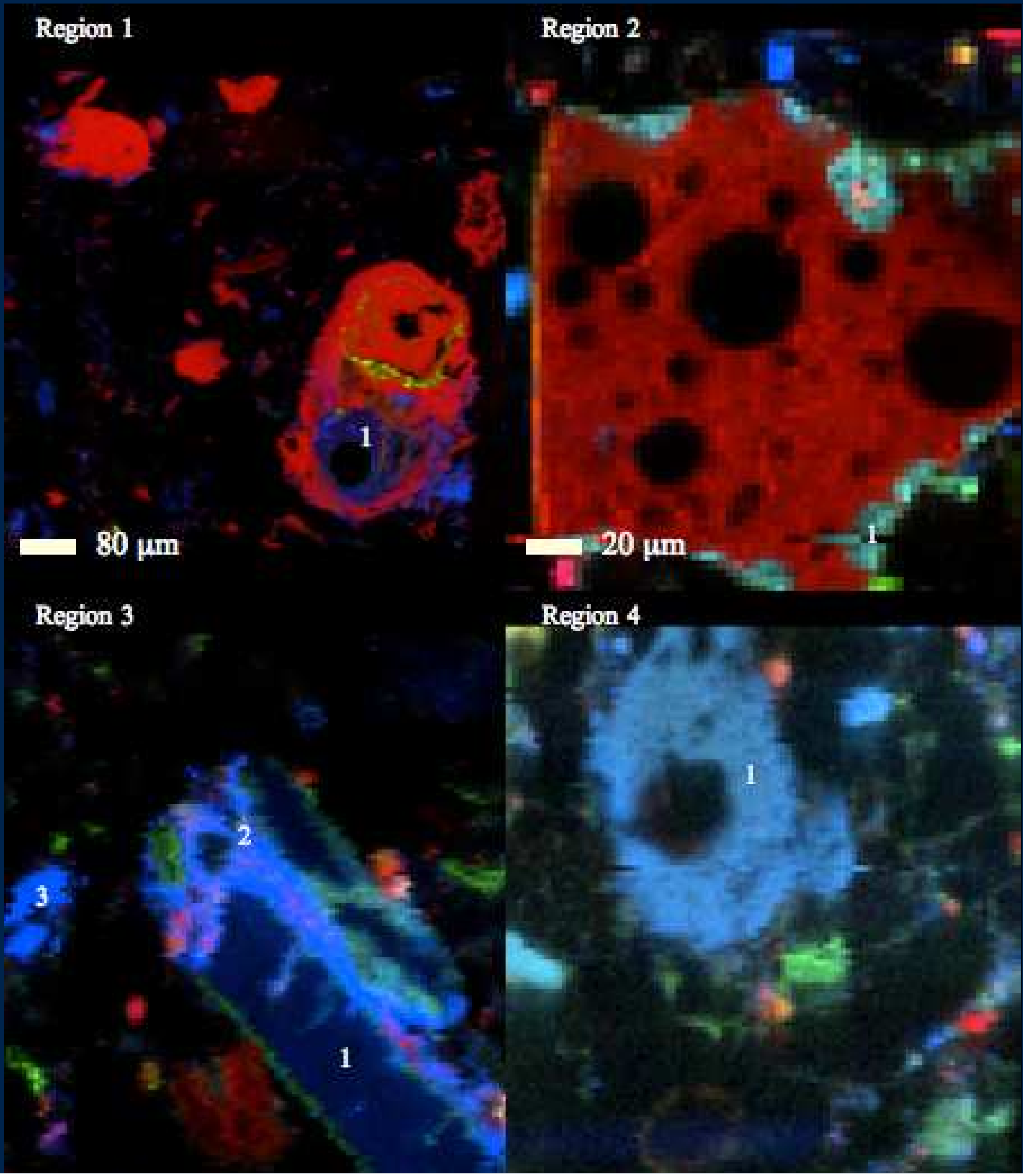
1990

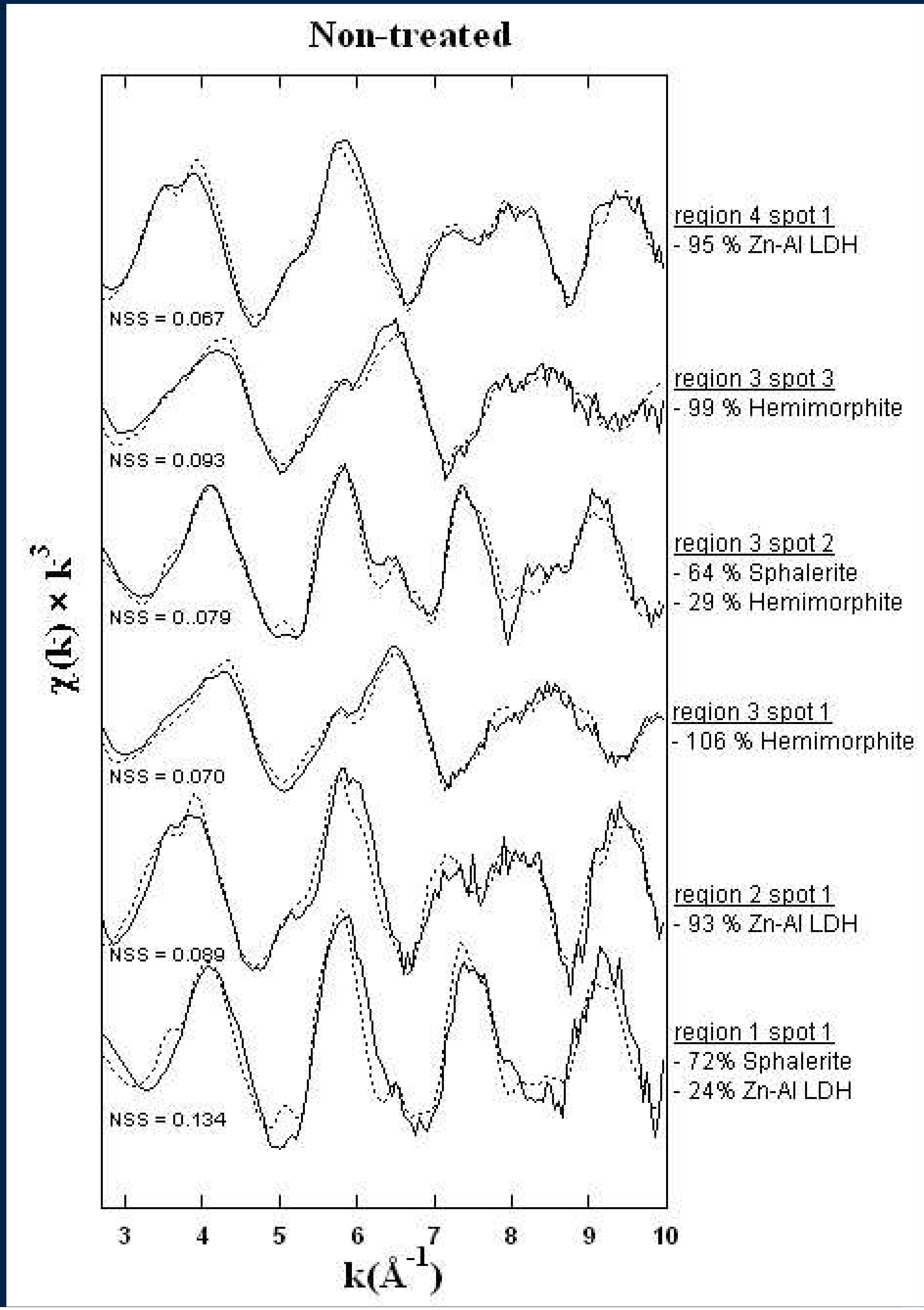
2002

• 135 Ha of bare land due to elevated Zn, Pb, and Cd concentrations from the Zn smelting facility in Maatheide, Belgium.

• Cleanup strategy: *In situ* immobilization of contaminants, by addition of beringite and compost combined with metal tolerant plants.

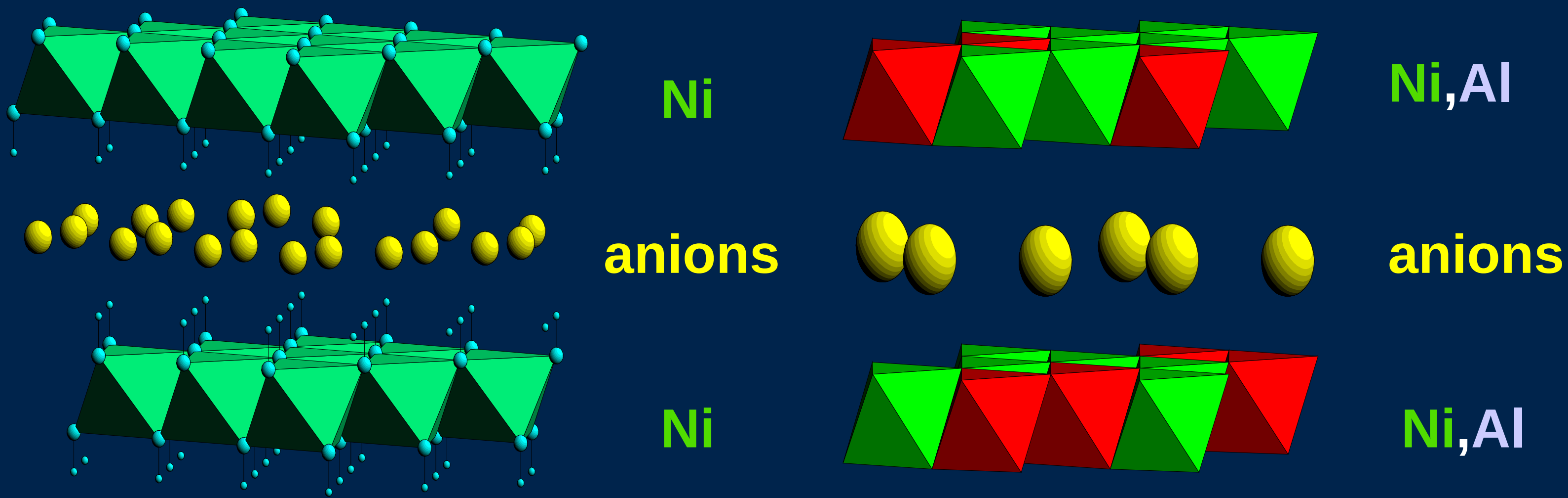
μ- focused SXRF and EXAFS (non-treated soil)





Candidate Phases for Ni Precipitates:

Hydroxides



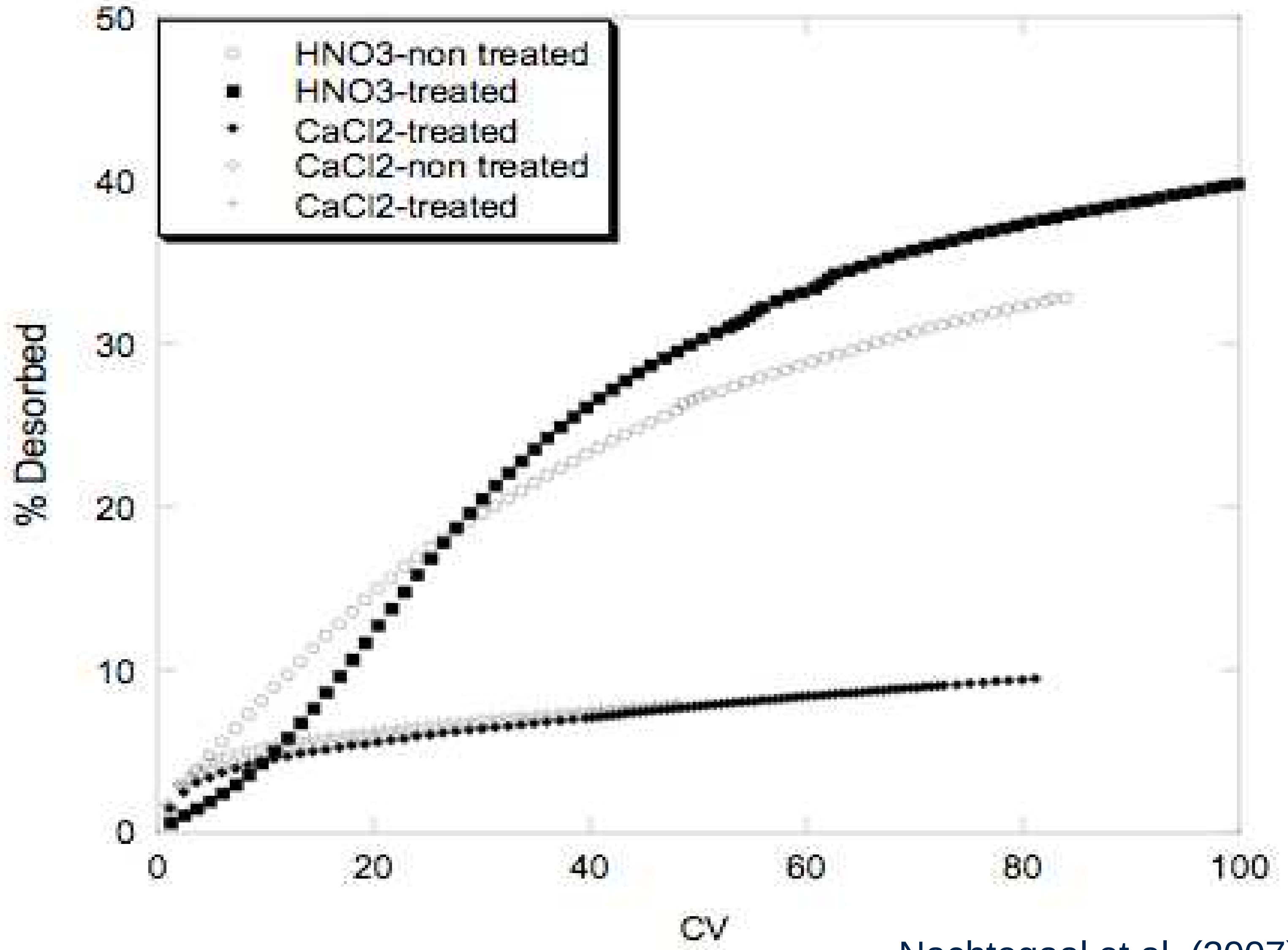
$Ni(OH)_{2-x}A^{-}_{x}$

α- Ni hydroxide

$Ni_{1-x}Al_{x}(OH)_{2}A^{-}_{x}$

LDH (hydrotalcite)

Percentage Zn desorbed from the non-treated and treated zinc smelter soils



Nachtegaal et al. (2007)

BIOMET data

	pH 6		pH 7.5	
	Bioavailable Ni (mg/kg)	% of Total	Bioavailable Ni (mg/kg)	% of Total
Matapeake	1640	90	2447	27
Berryland	2606	70	3492	27
Fort Ellis	3027	74	3020	25

BIOMET data

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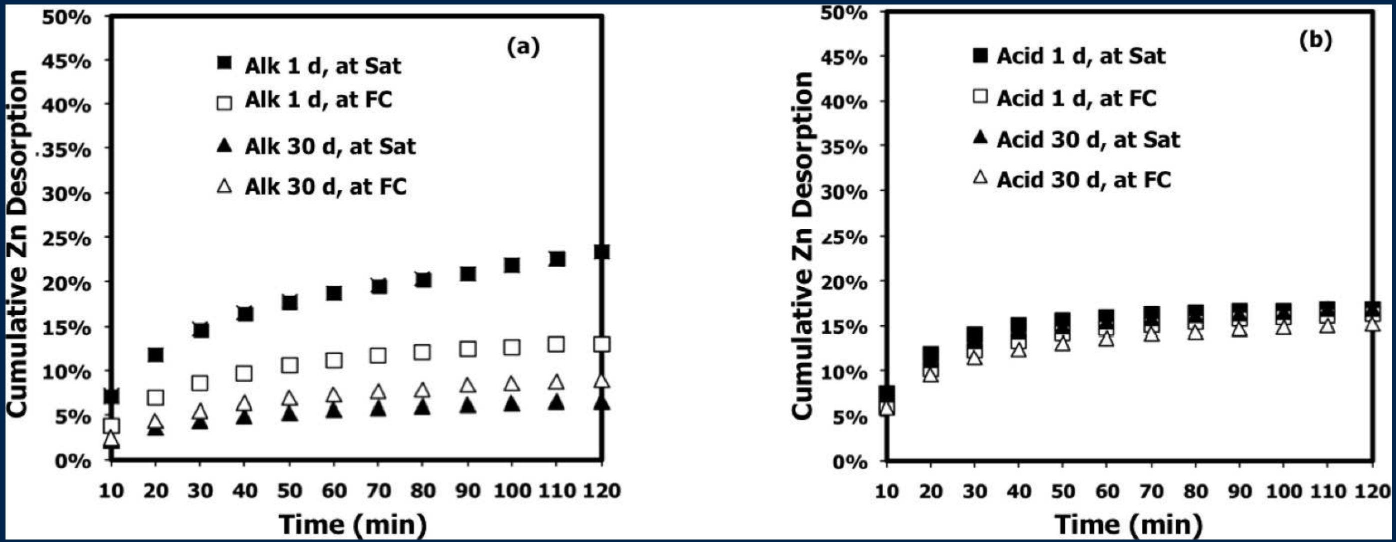
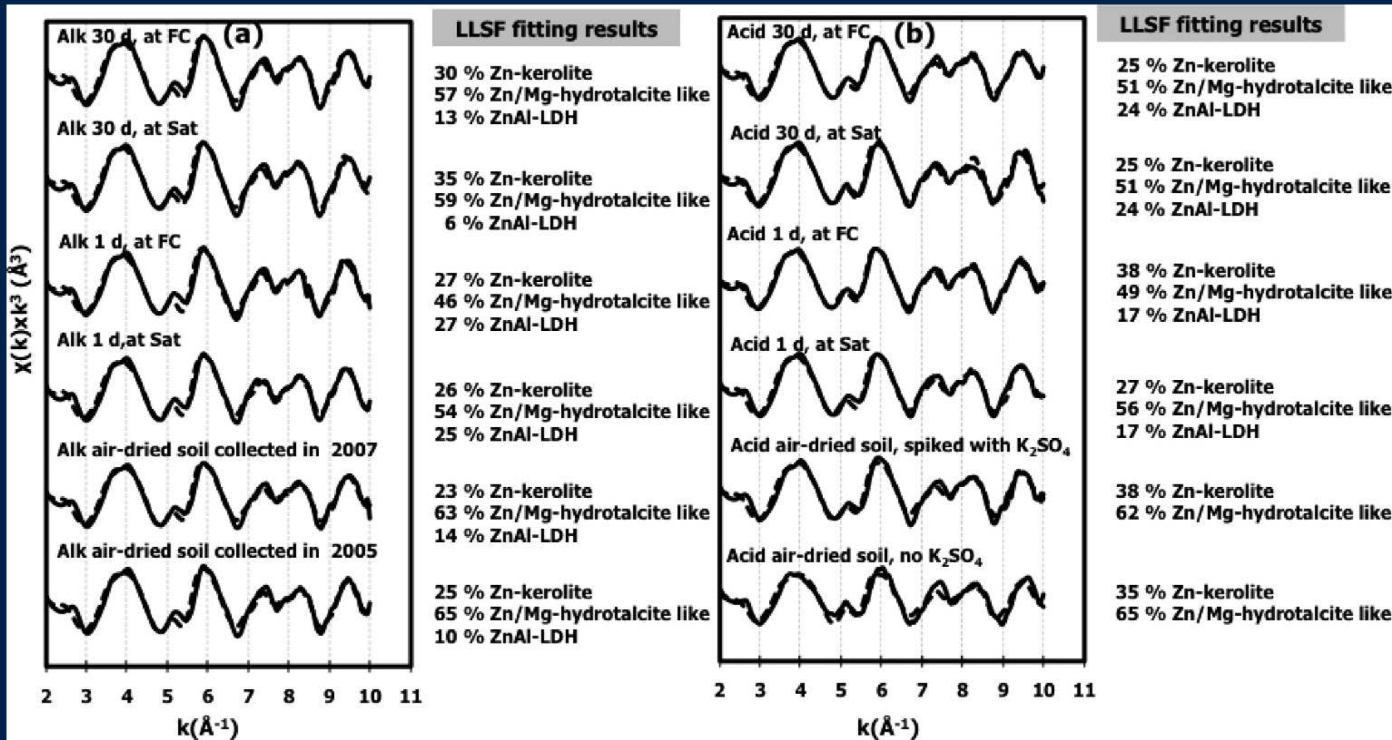


Cumulative Zn desorption (in %) by DTPA-TEA-Ca from (a) the alkaline soil (Alk) and (b) the acidified soil (Acid), after 1 and 30 days (d) of flooding, and draining to saturation (Sat) or field capacity (FC).

Published in: Saengdao Khaokaew; Gautier Landrot; Rufus L. Chaney; Kaumudi Pandya; Donald L. Sparks; *Environ. Sci. Technol.* **2012,** 46, 3957-3963.
DOI: 10.1021/es204007t

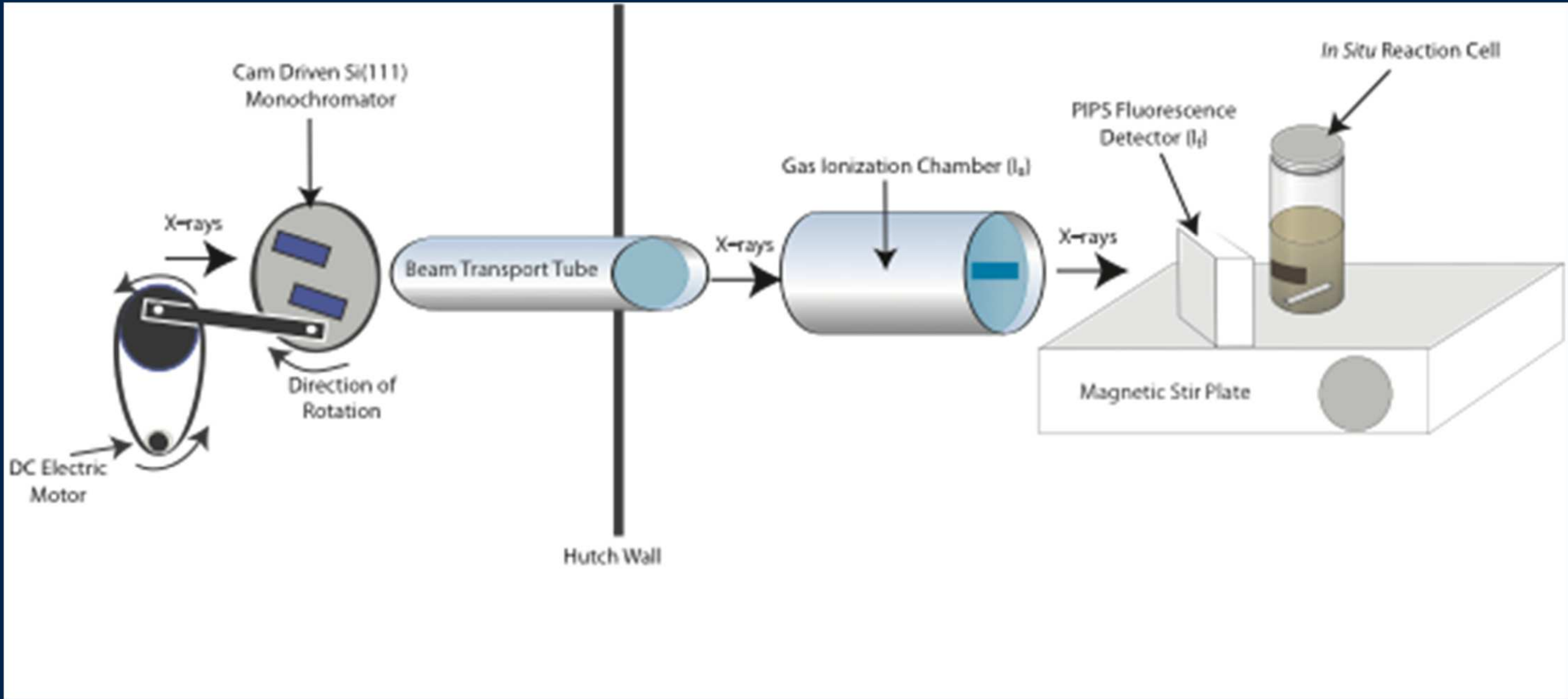


Linear least-squares fitting results for bulk-XAFS spectra of the (a) alkaline soil (Alk) and (b) the acidified (Acid) soil, air-dried or flooded for different periods (d = days), and drained to saturation (Sat) or field capacity (FC). Solid lines represent the *k*3-weighted χ-spectra and the dotted line represents the best fits obtained using linear least-squares fitting.

Published in: Saengdao Khaokaew; Gautier Landrot; Rufus L. Chaney; Kaumudi Pandya; Donald L. Sparks; *Environ. Sci. Technol.* **2012,** 46, 3957-3963.
DOI: 10.1021/es204007t

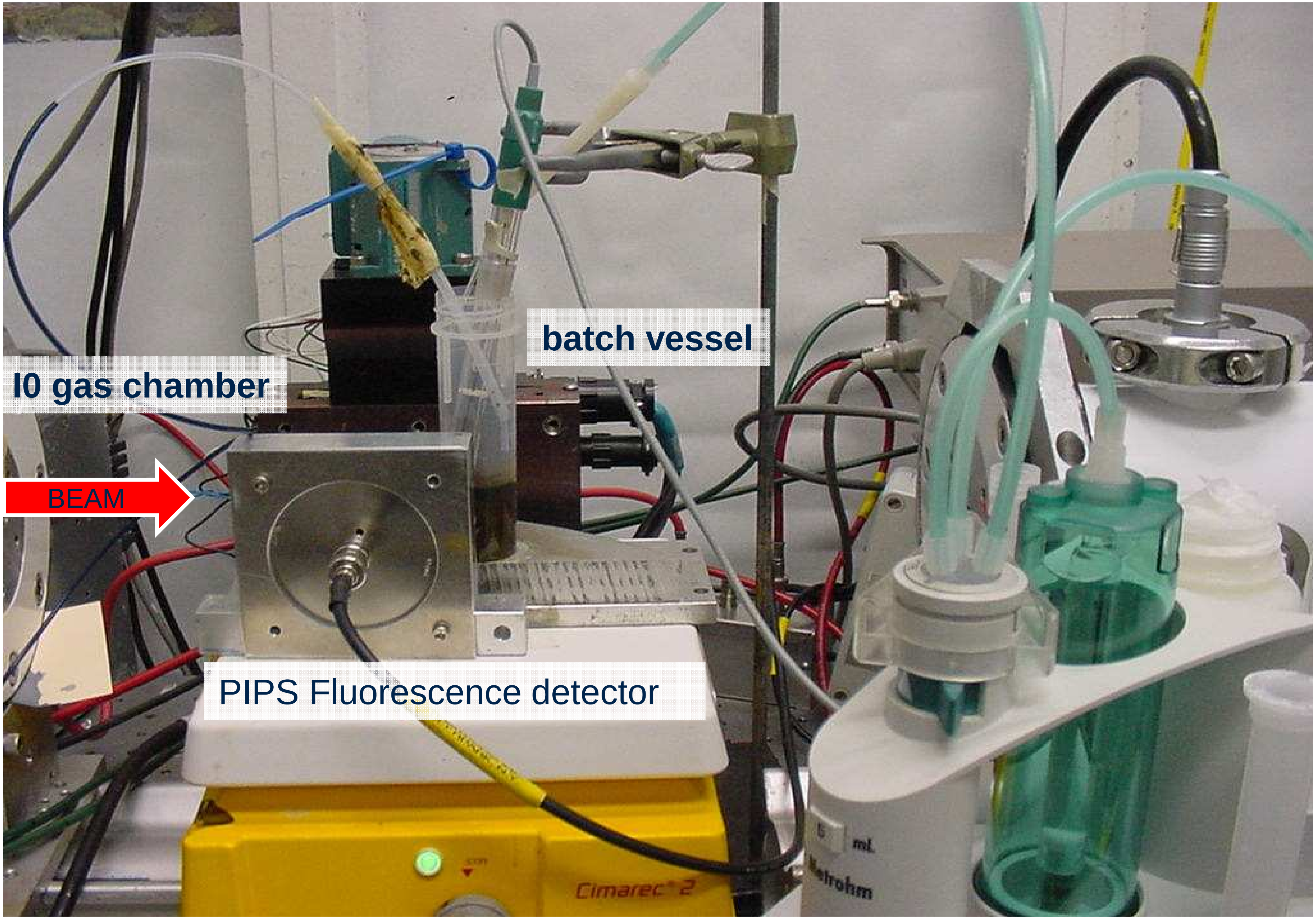
Real-time Kinetics at the Molecular Scale

Experimental Setup Used to Collect Quick-scanning X-ray Absorption Spectroscopic (Q-XAS) Data



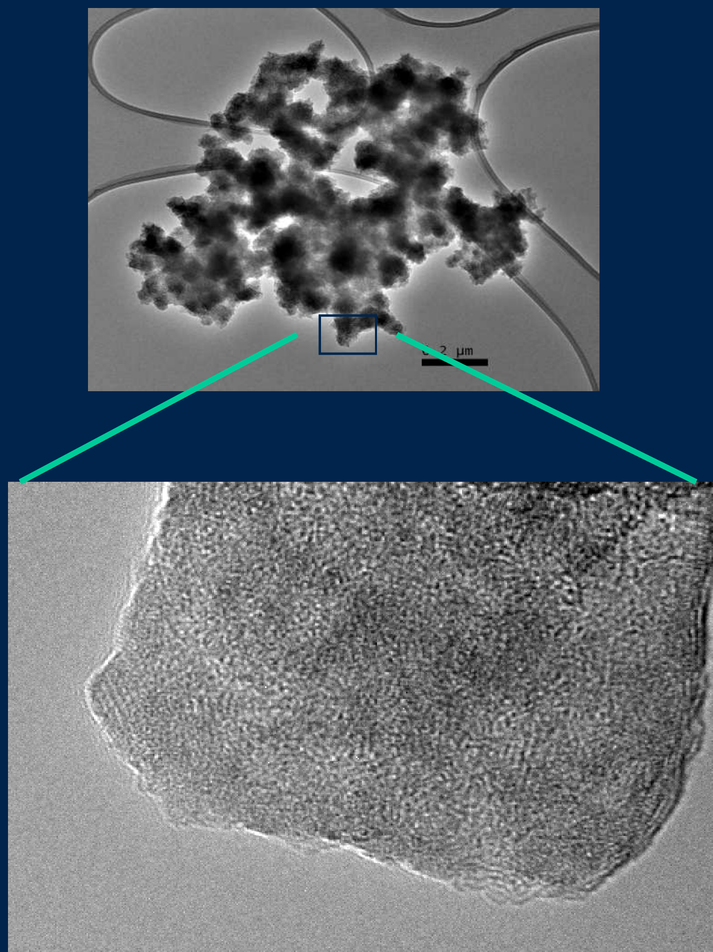
Ginder-Vogel et al. 2009. PNAS 106:16124 –16128.

Real-time, *in-situ* Kinetics Batch Experiments



As(III) Oxidation by Hydrous Manganese Oxide (HMO)

HMO



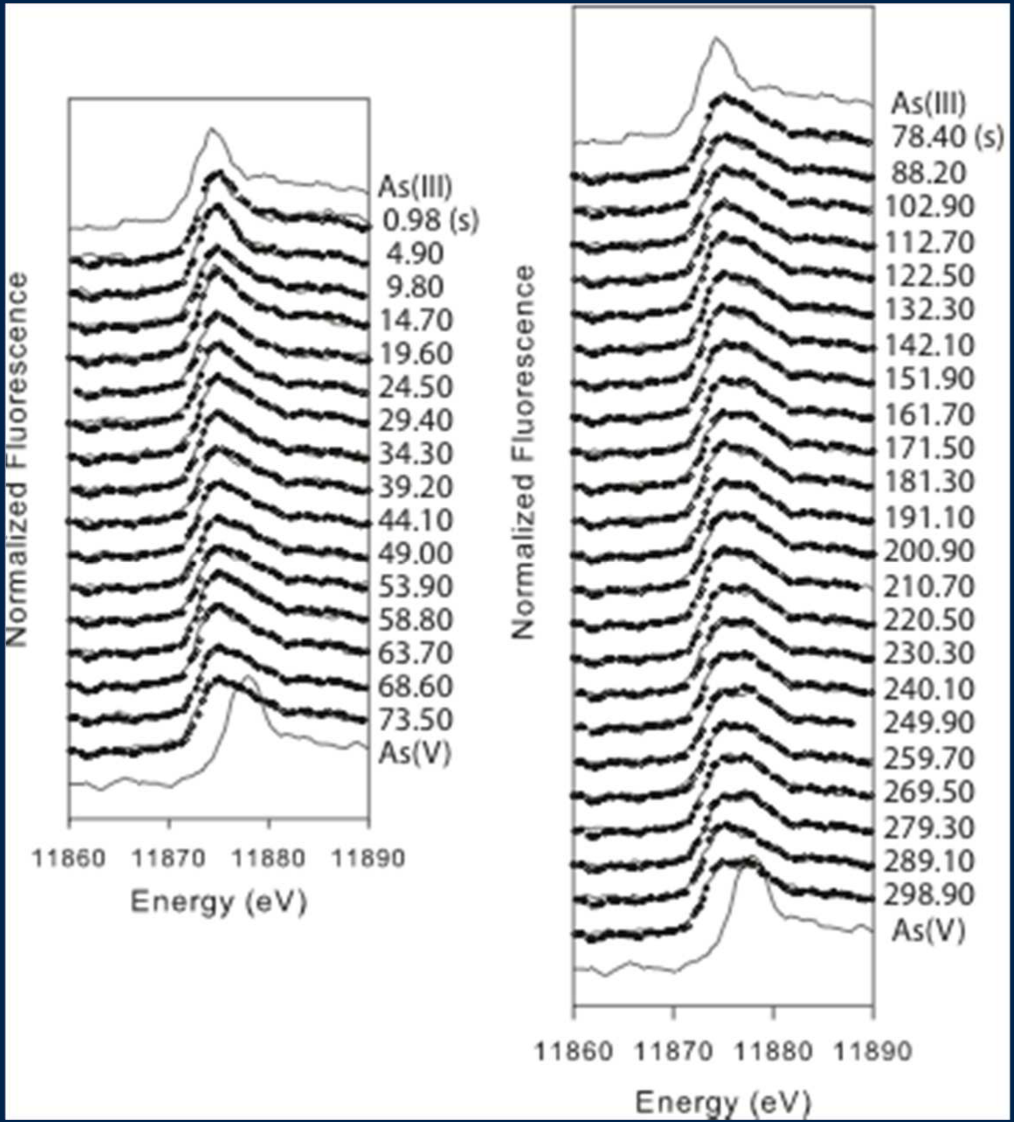
Q-XAS Batch Reactor

- Continuous data collection (2,000 points s^{-1})
- Collection of XANES spectrum in 980 ms
- 5 mM As(III), 1 g L^{-1} HMO, pH 7.0 , 5 mM NaCl

Experimental Goal

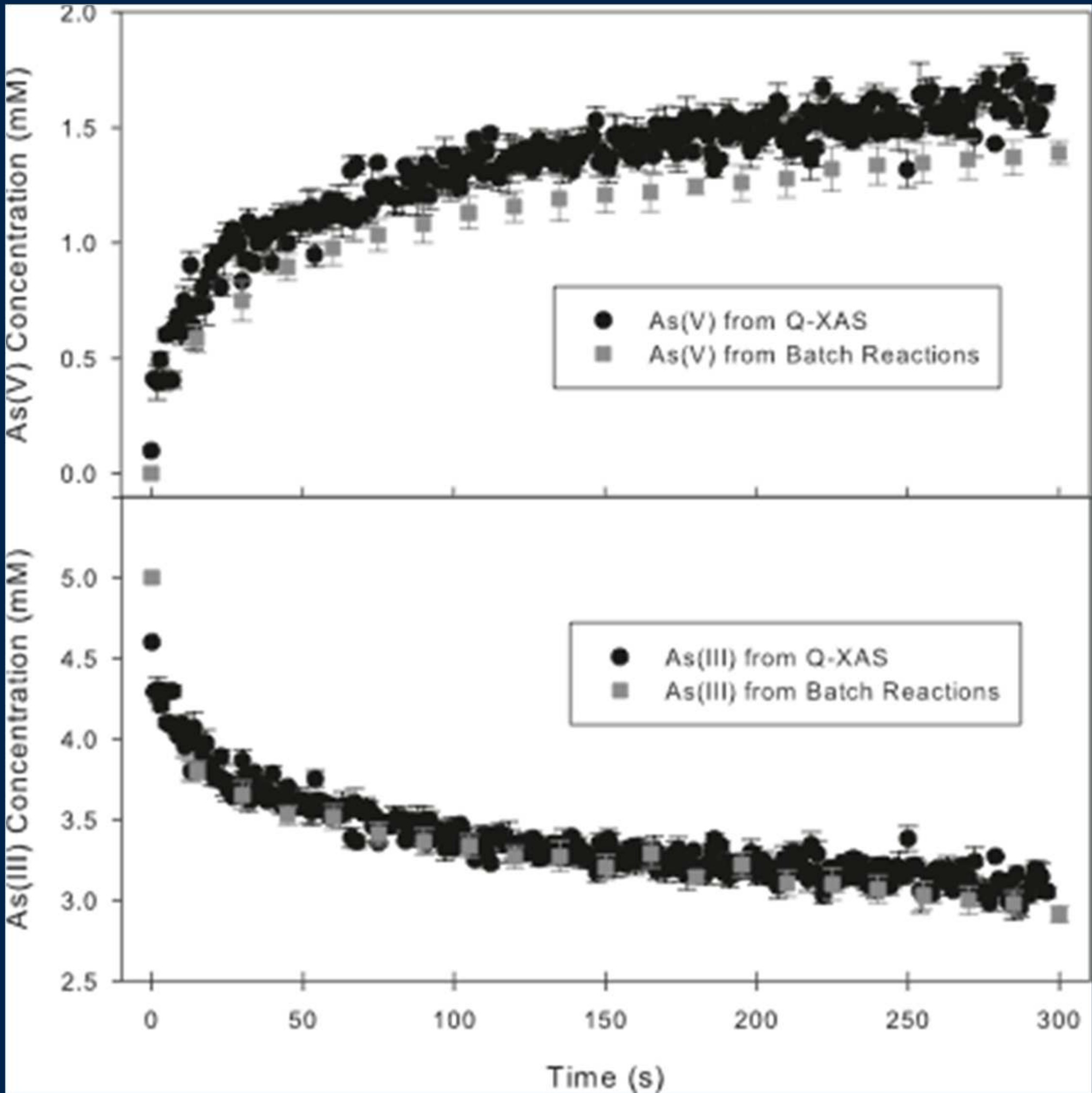
- *Characterize initial (<30 s) reaction rates*

Data (solid) and Linear Combination Fits (dots) of Individual As K-edge XANES Spectra Used to Determine As(III) and As(V) Concentrations

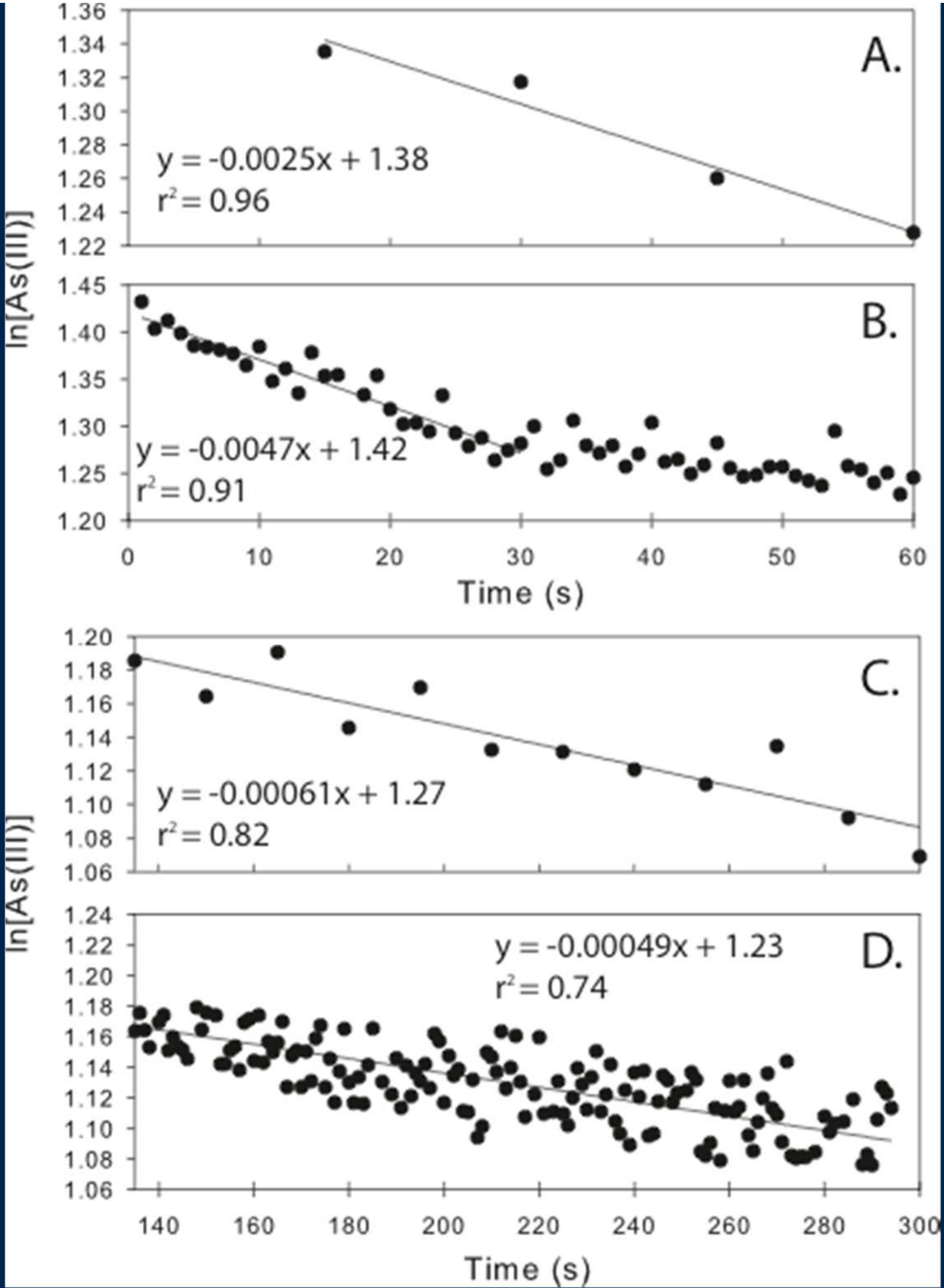


Ginder-Vogel et al. 2009. PNAS 106:16124 –16128.

As(V) and As(III) Concentrations Determined from Traditional Batch and Q-XAS Methods

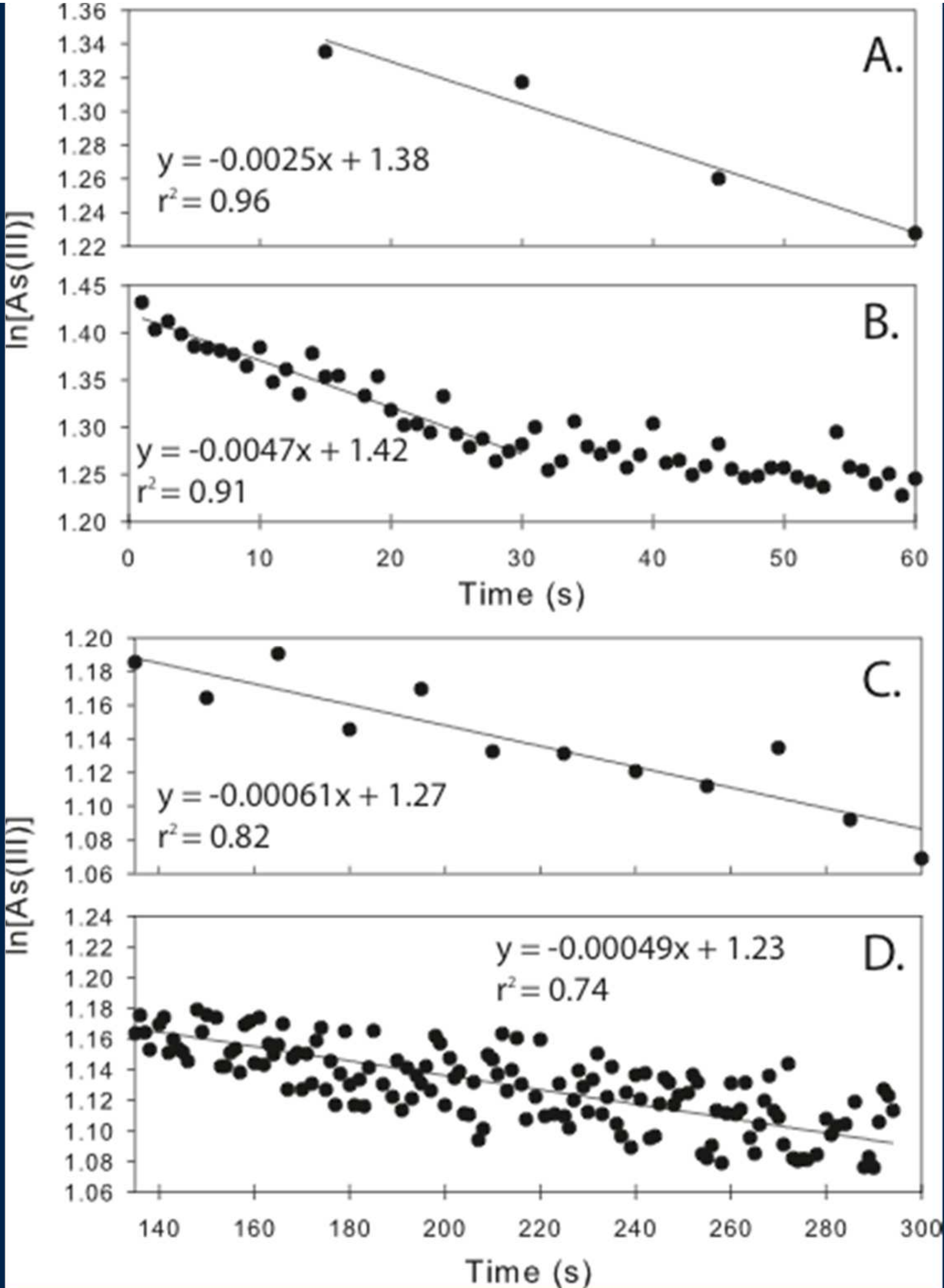


Ginder-Vogel et al. 2009. PNAS 106:16124 –16128.



First-order As (III) Depletion Rate Plots Determined from As(III) Concentrations Using Batch (A and C) and Q-XAS (B and D) Methods.

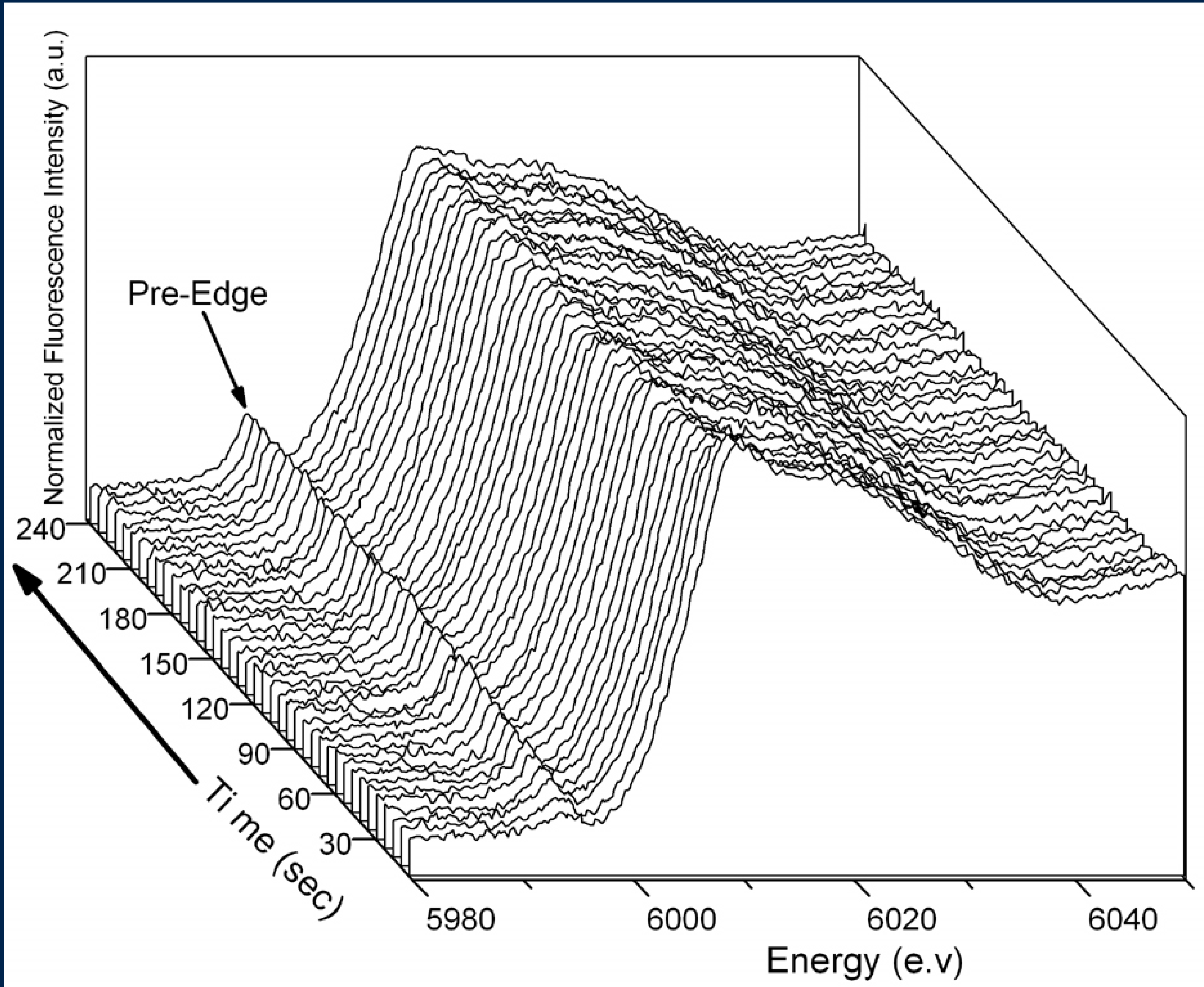
Ginder-Vogel et al. 2009. PNAS 106:16124 –16128.



First-order As (III) Depletion Rate Plots Determined from As(III) Concentrations Using Batch (A and C) and Q-XAS (B and D) Methods.

Ginder-Vogel et al. 2009. PNAS 106:16124 –16128.

Cr(III) Oxidation Kinetics using a Q-XAS Technique



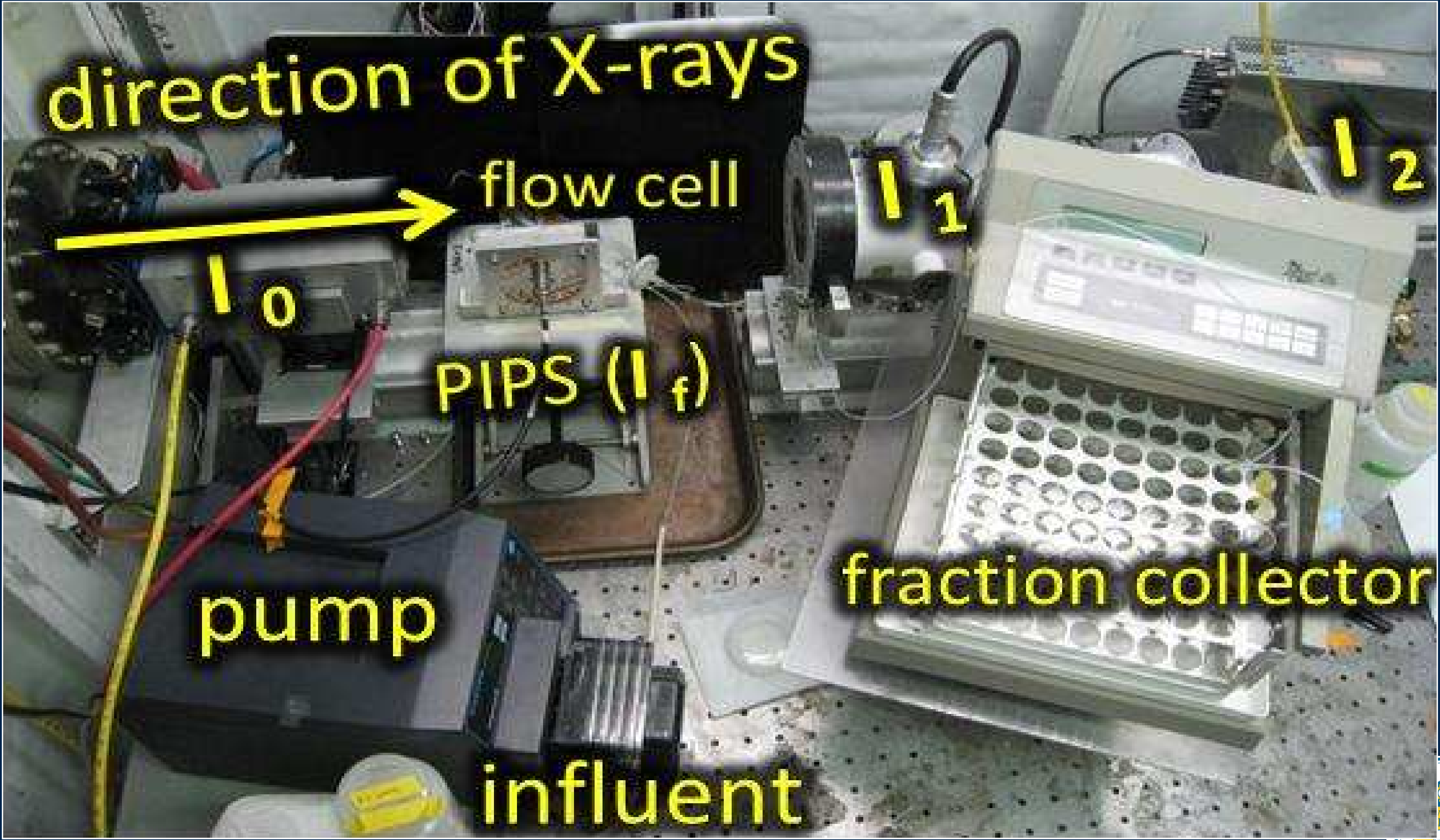
Landrot et al. 2010. Environ. Sci. Technol. 44: 143–149.

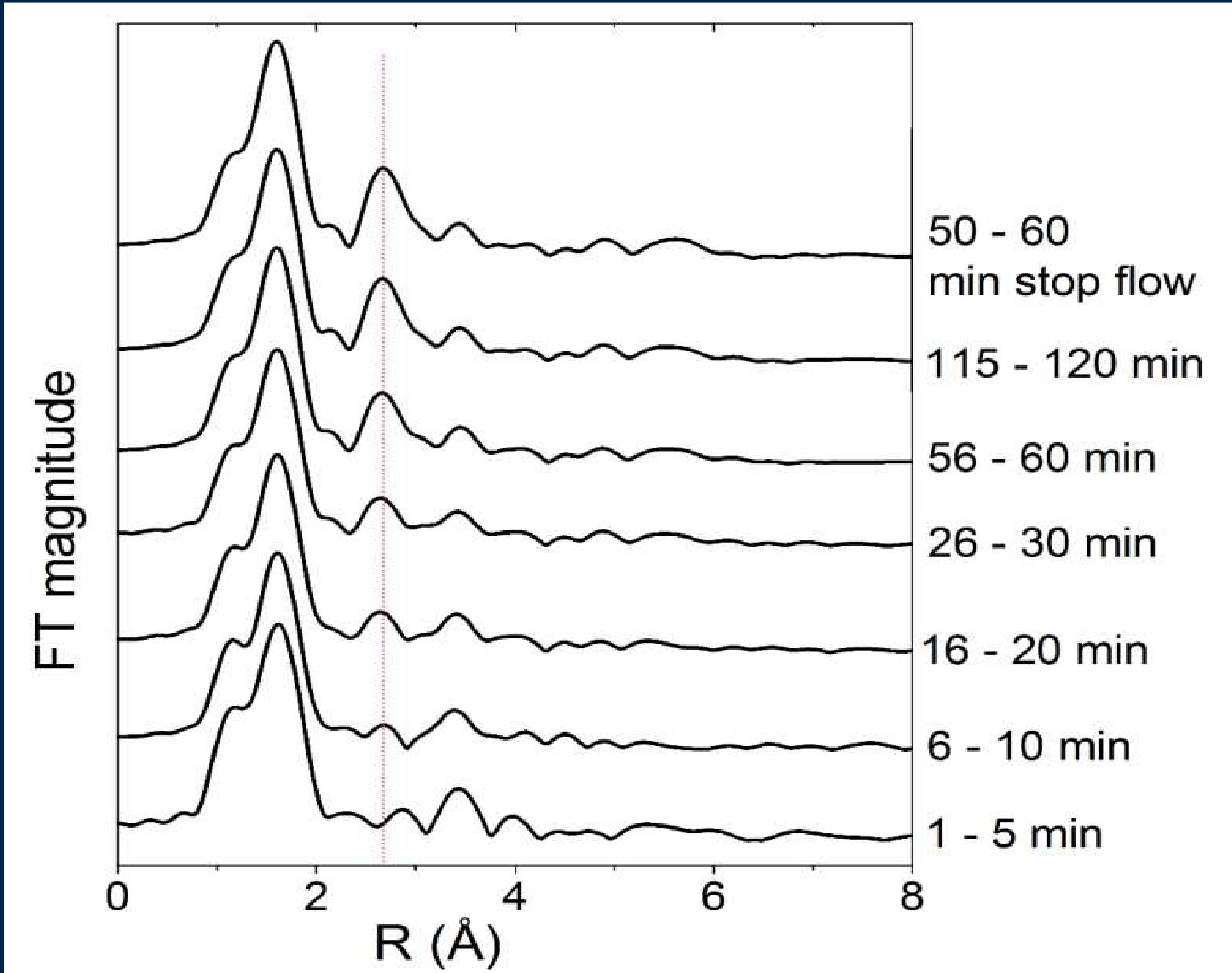
Initial Conditions and Rate Parameters

[Cr(III)] (mM)	[HMO] (g/L)	k (sec^{-1}) *pH=2.5*	*pH=3*	*pH=3.5*
100	**20**	0.204/0.228	0.277/0.202	0.295/0.364
80	**20**	0.202/0.220	0.270/0.198	0.353/0.308
60	**20**	0.197/0.215	0.303/0.208	0.302/0.357
40	**20**	0.208/0.235	0.266/0.199	0.296/0.363
100	**20**	0.204/0.228	0.277/0.202	0.295/0.364
100	**15**	0.206/0.207	0.293/0.219	0.291/0.328
100	**10**	0.169/0.171	0.287/0.244	0.280/0.311
100	**5**	0.157/0.203	0.257/0.316	0.283/0.346

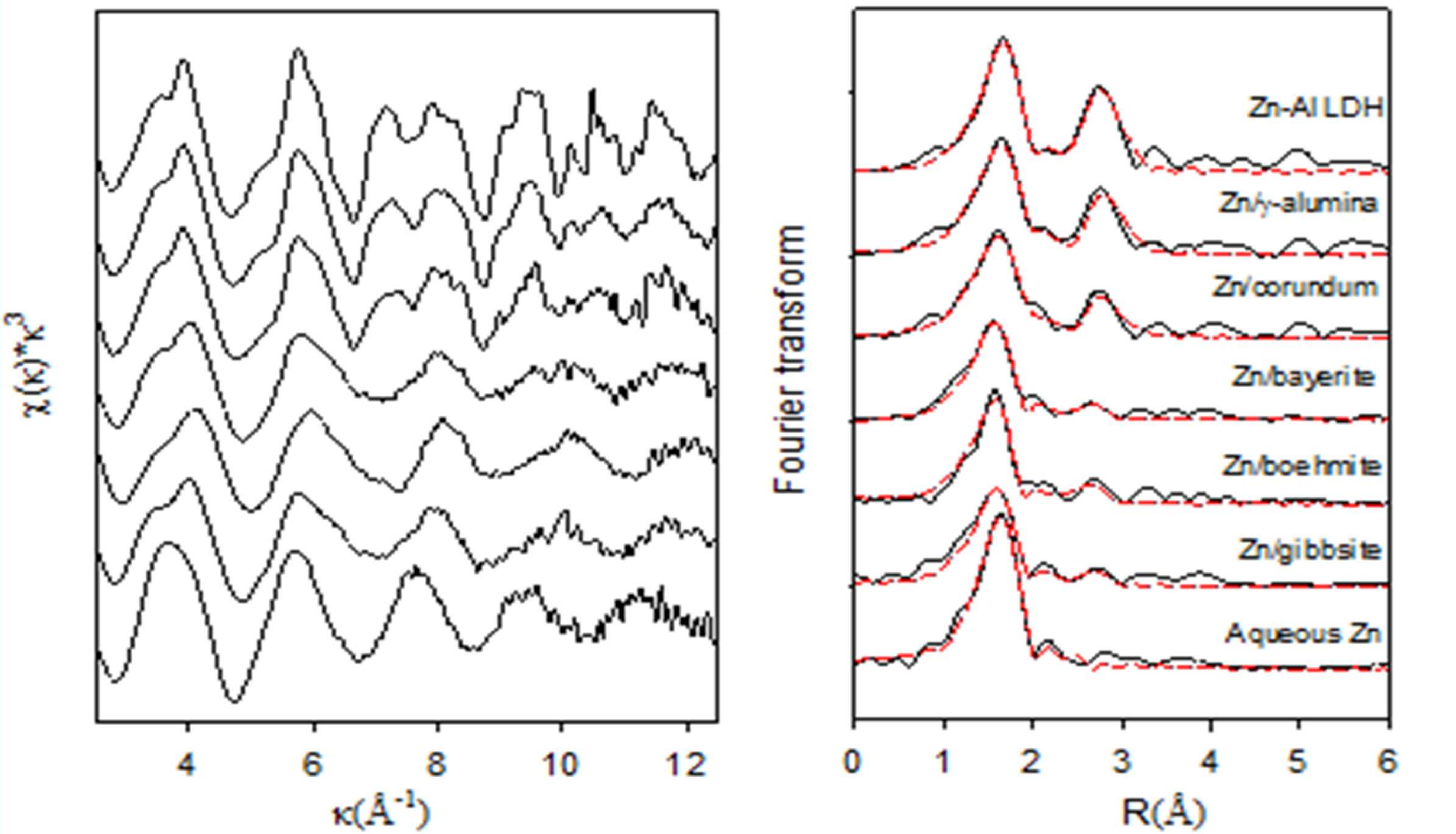
k (averaged) in sec^{-1} *pH=2.5*	*pH=3*	*pH=3.5*
0.192/0.211	0.279/0.227	0.300/0.340
0.201	**0.242**	**0.322**

Landrot et al. 2010. Environ. Sci. Technol. 44: 143–149.


direction of X-rays
flow cell
I 0
I 1
I 2
PIPS (I f)
fraction collector
pump
influent



FT magnitude
R (Å)
0
2
4
6
8
50 - 60
min stop flow
115 - 120 min
56 - 60 min
26 - 30 min
16 - 20 min
6 - 10 min
1 - 5 min



χ(k)*k³
κ(Å⁻¹)
4
6
8
10
12
Fourier transform
R(Å)
0
1
2
3
4
5
6
Zn-Al LDH
Zn/γ-alumina
Zn/corundum
Zn/bayerite
Zn/boehmite
Zn/gibbsite
Aqueous Zn

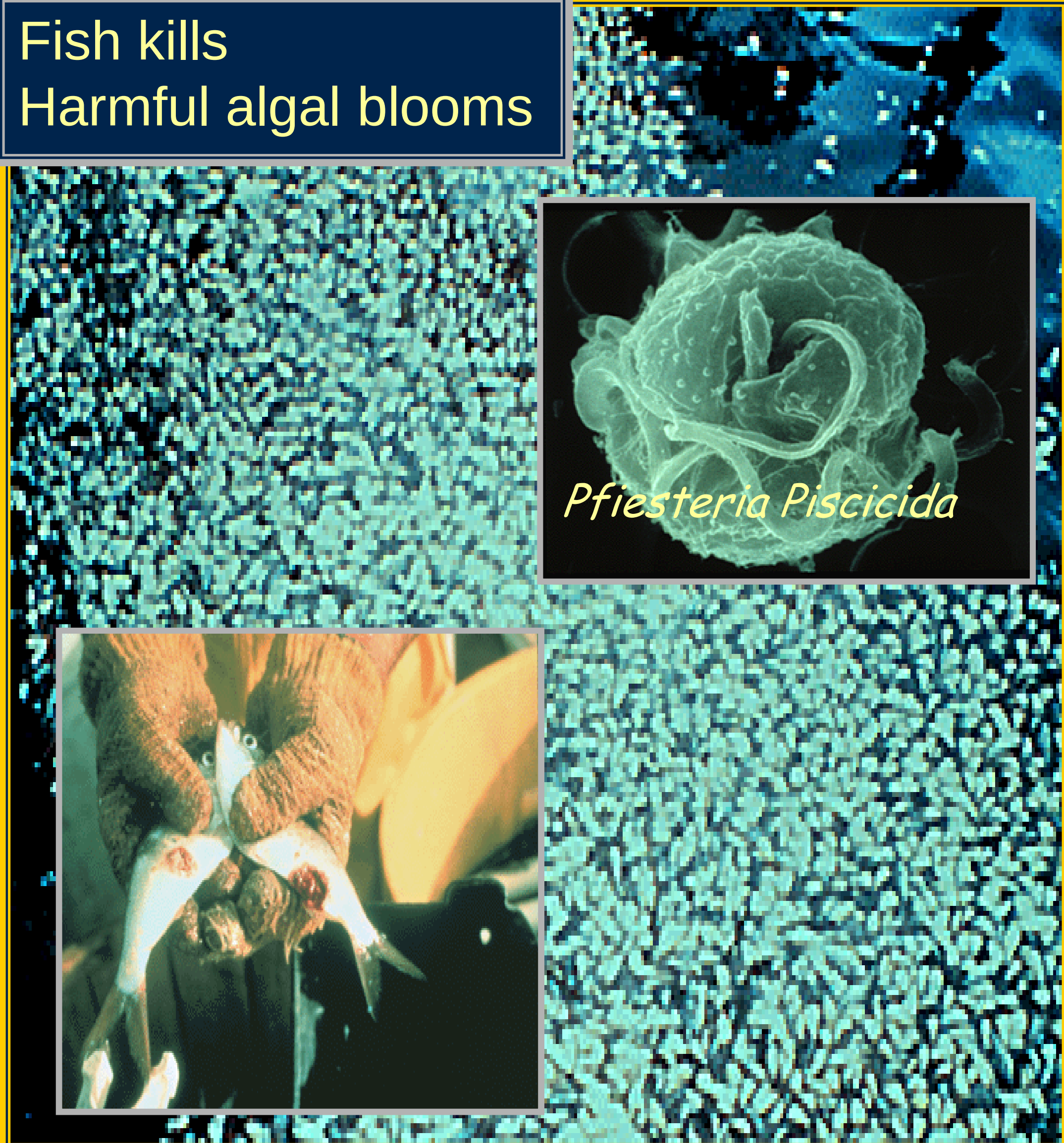
Chemistry of Low Atomic Number Elements

Al, B, C, Cl, Mg, N, Na, P and S

Nutrient Management:
Human and Ecosystem Health

Nuisance seaweed blooms in Delaware’s Inland Bays

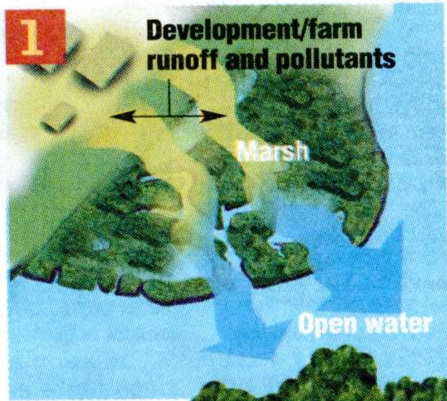
Fish kills
Harmful algal blooms

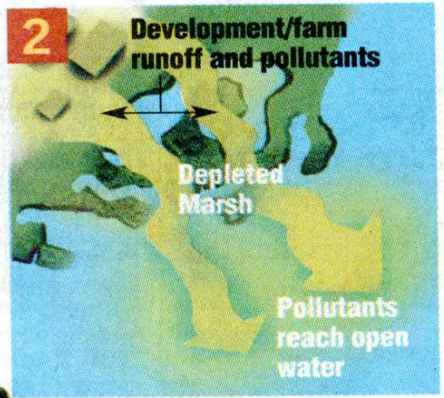


The problems when marshland is gone

1: Brackish and saltwater tidal marshes along the Delaware Estuary absorb excess water during floodings, reducing upland damage. Wetlands fiilter out pollutants before they reach the Delaware River and Bay.

2: When marshes recede, soils, sediment and pollutants aren't filtered and end up in Delaware's waterways. Nutrients from farm runoff and motor oil, road salt, and antifreeze from suburban development pass into clean water.





A functioning marsh

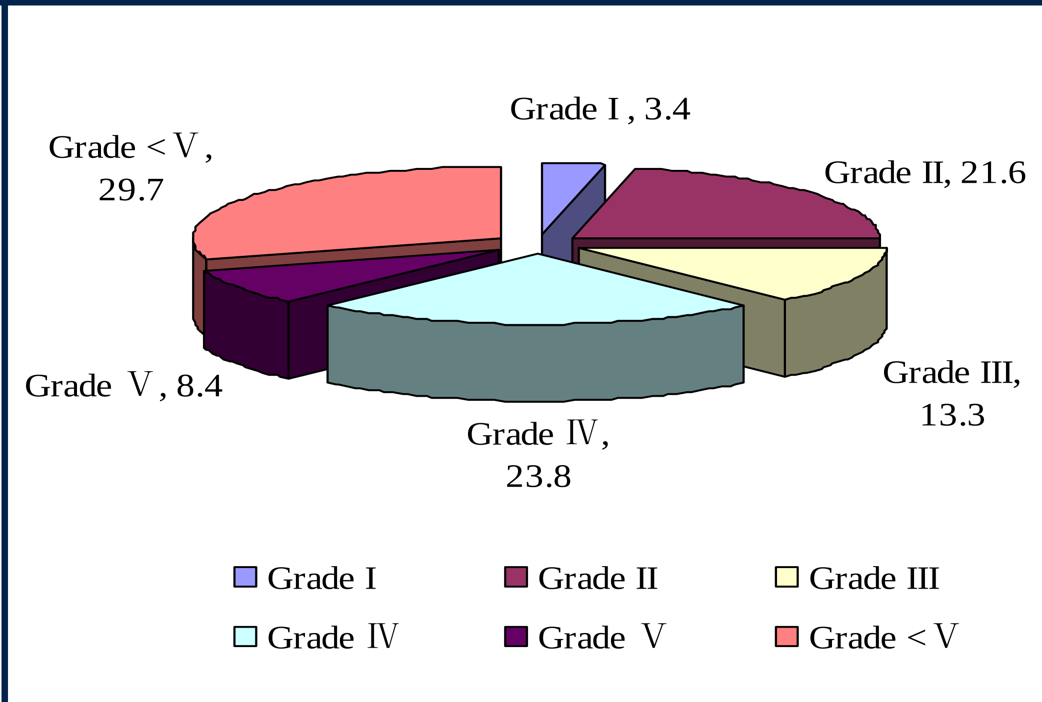
Beyond filtering out pollutants, wetlands are important for other reasons. At high tide in tidal marshes, water covers low-lying areas, drawing ospreys and other birds that feed on fish in the shallow water. High ground remains dry, attracting wildlife such as foxes, turtles and frogs.

Nature thrives

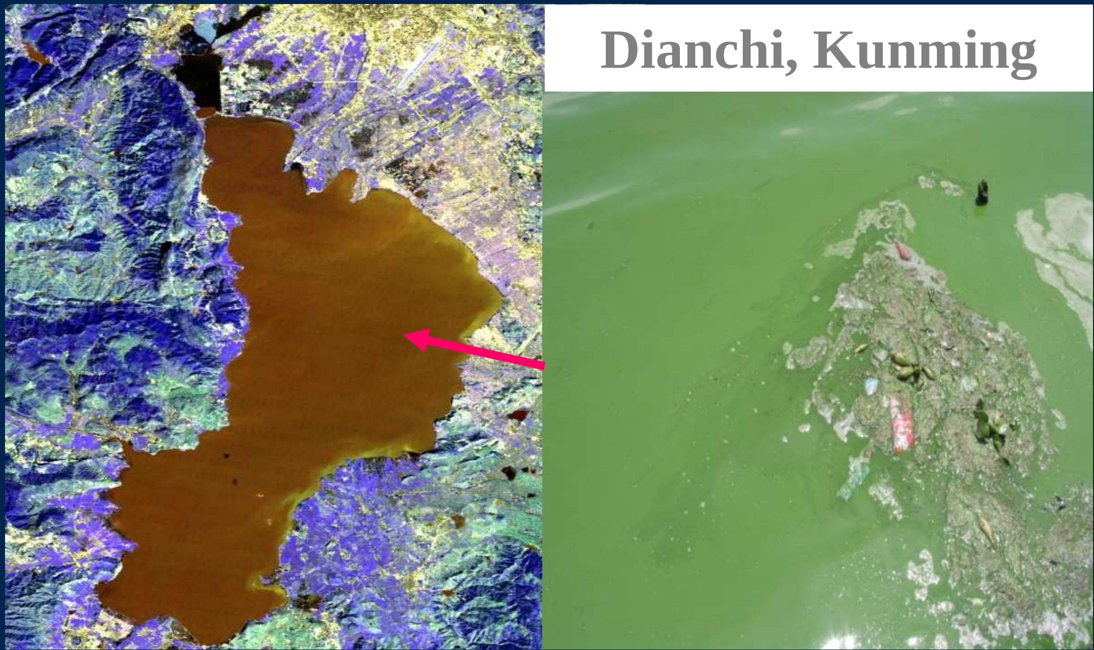
In a thriving marsh, plants and animals make their home. Commercial and game fish breed and raise their young in coastal marshes and estuaries. Inland wetlands are the only places many animals and plants can live. More than 143 species of birds have been documented living in marshy areas, making Delaware a prime bird-watching site. Here are some types of wildlife that are common to Delaware's wetlands.

The News Journal/**DAN GARROW**

Water Pollution in China

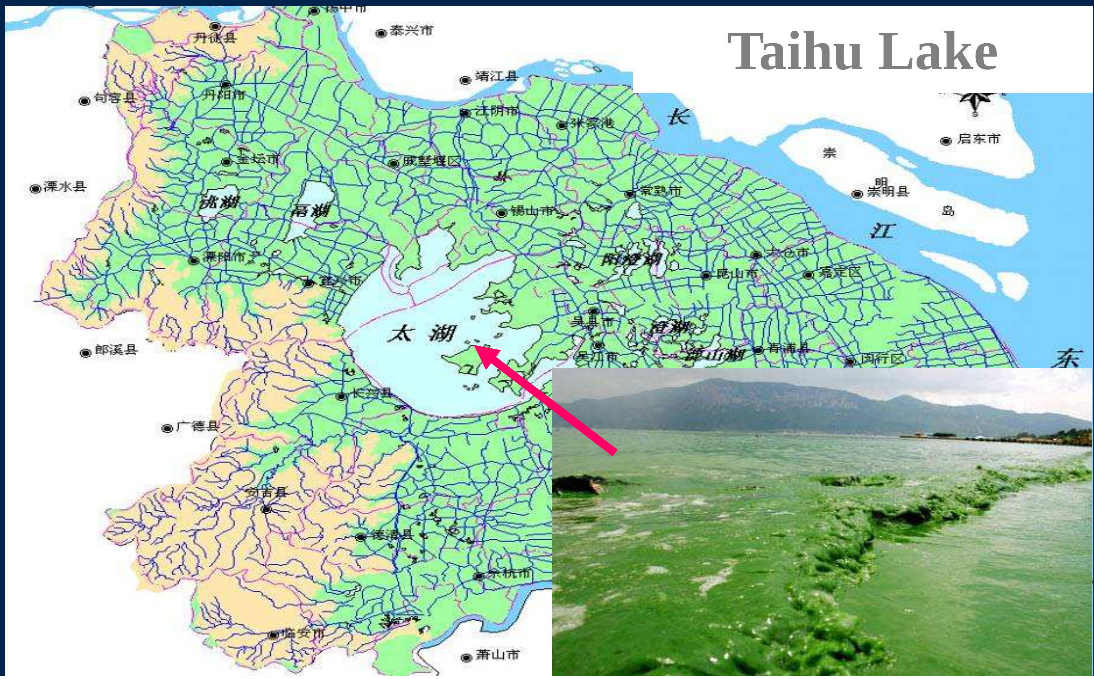


Eutrophication of lakes



Dianchi, Kunming

Xuanwu Lake, Nanjing



Taihu Lake

Hongfeng Lake, Guiyang

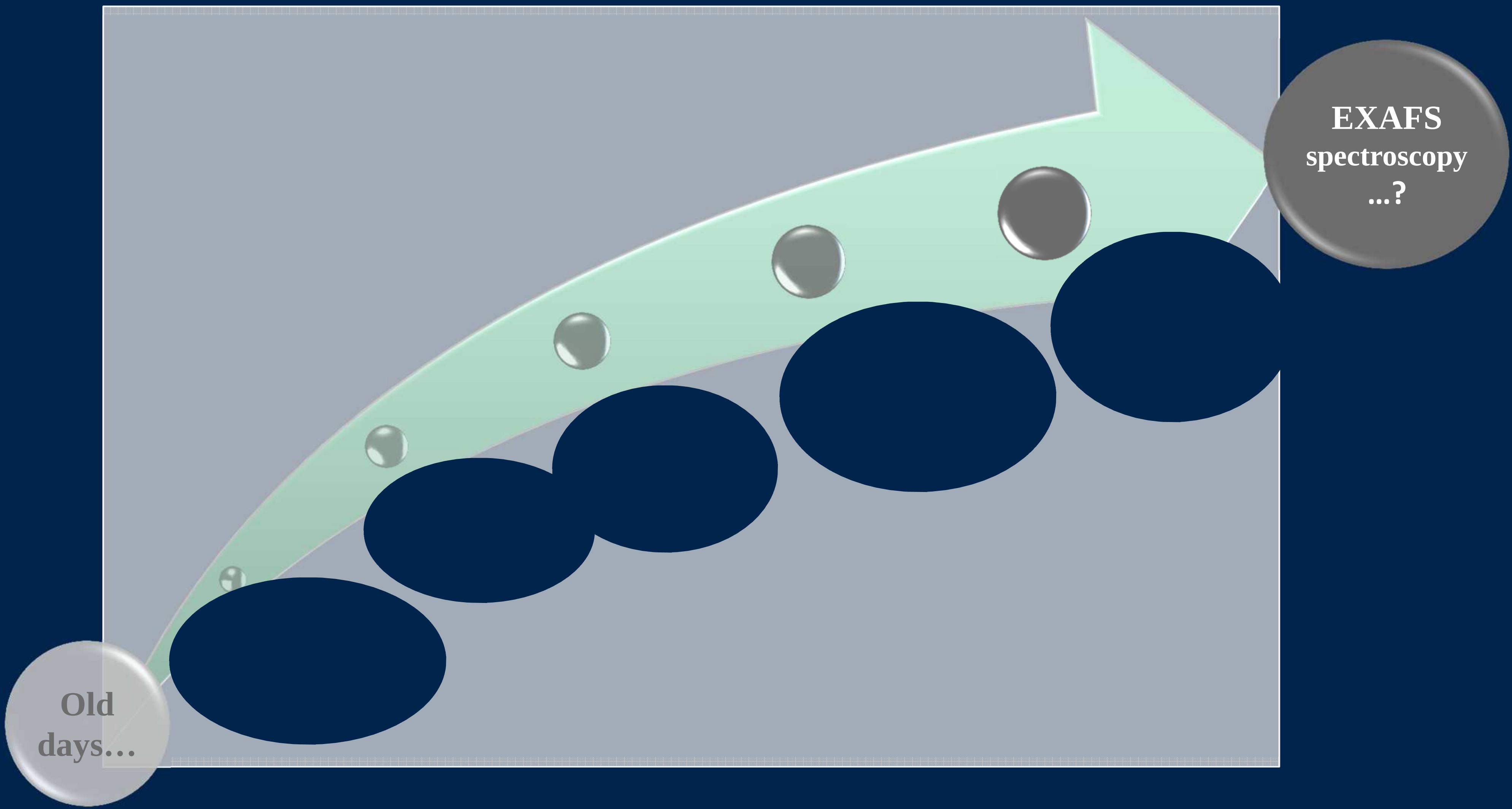
Eutrophication of city rivers

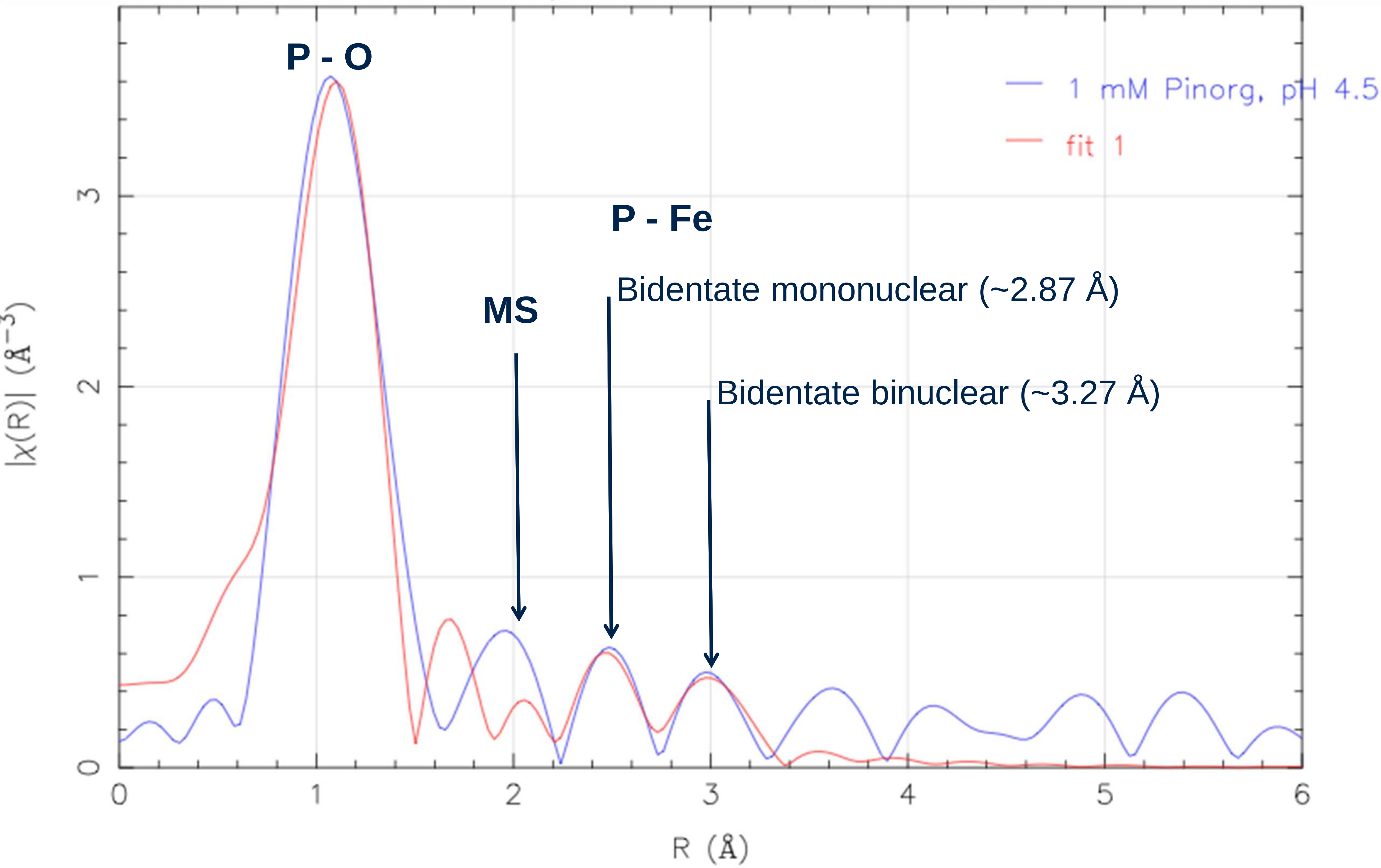
Fertilizer Overuse and Misuse

Sources of N and P Pollution

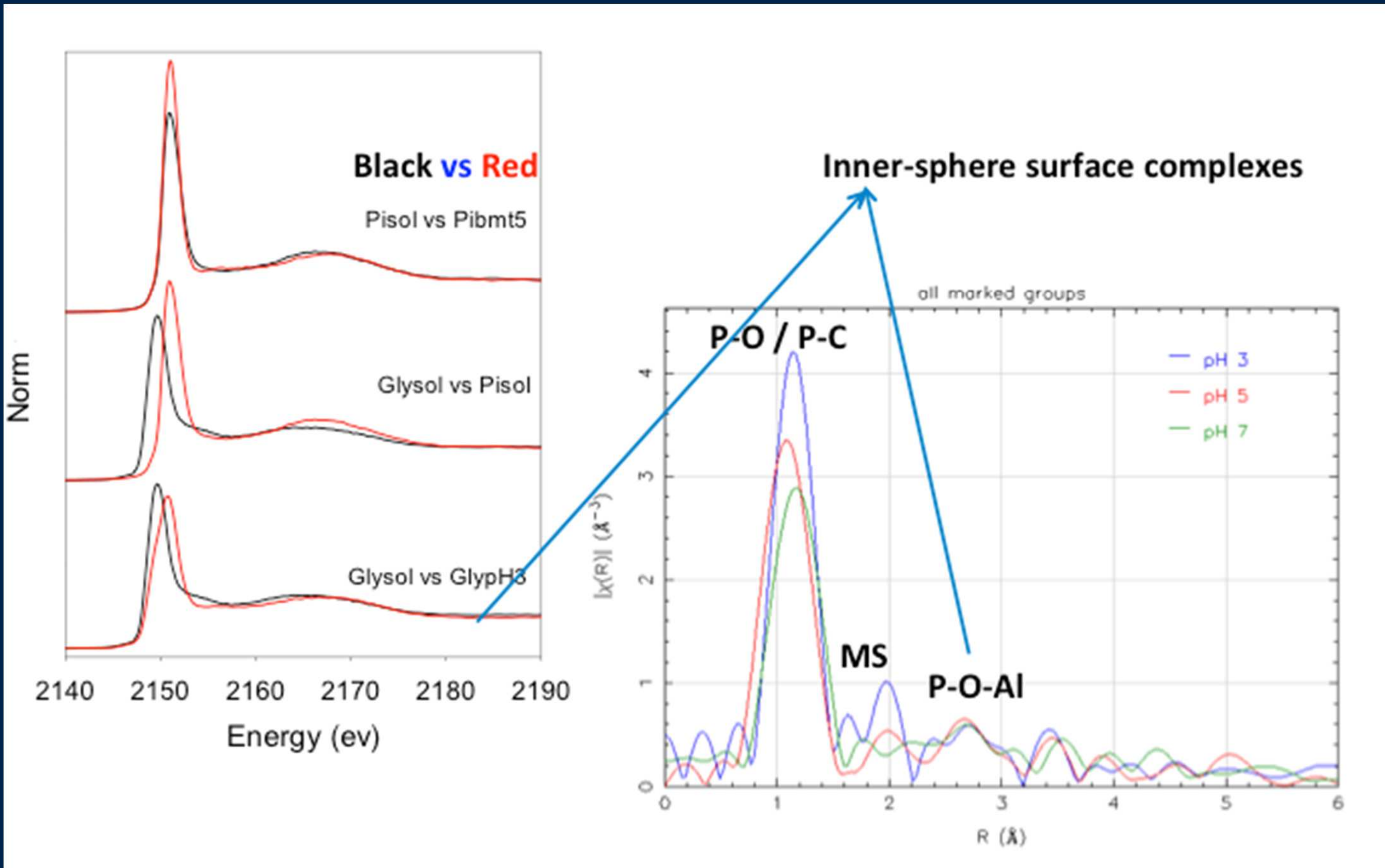
In the latest pollution resource survey of China, it is reported that agricultural pollution accounts for 50-60% of N and P pollution to water bodies.

Milestones in the study of P sorption mechanisms

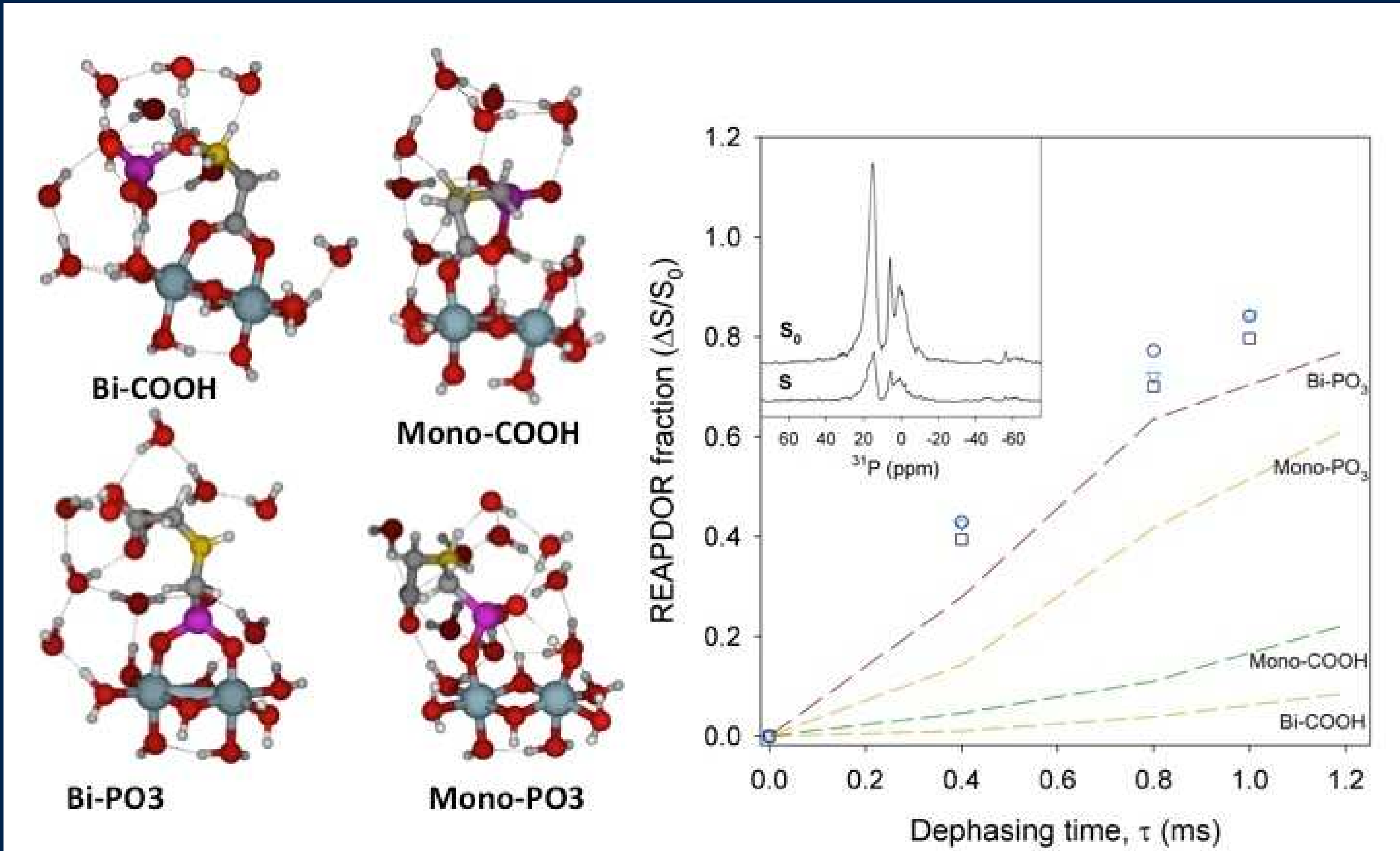



P - O
1 mM Pinorg, pH 4.5
fit 1
P - Fe
Bidentate mononuclear (~2.87 Å)
MS
Bidentate binuclear (~3.27 Å)
|χ(R)| (Å^-3)
R (Å)
0
1
2
3
4
5
6

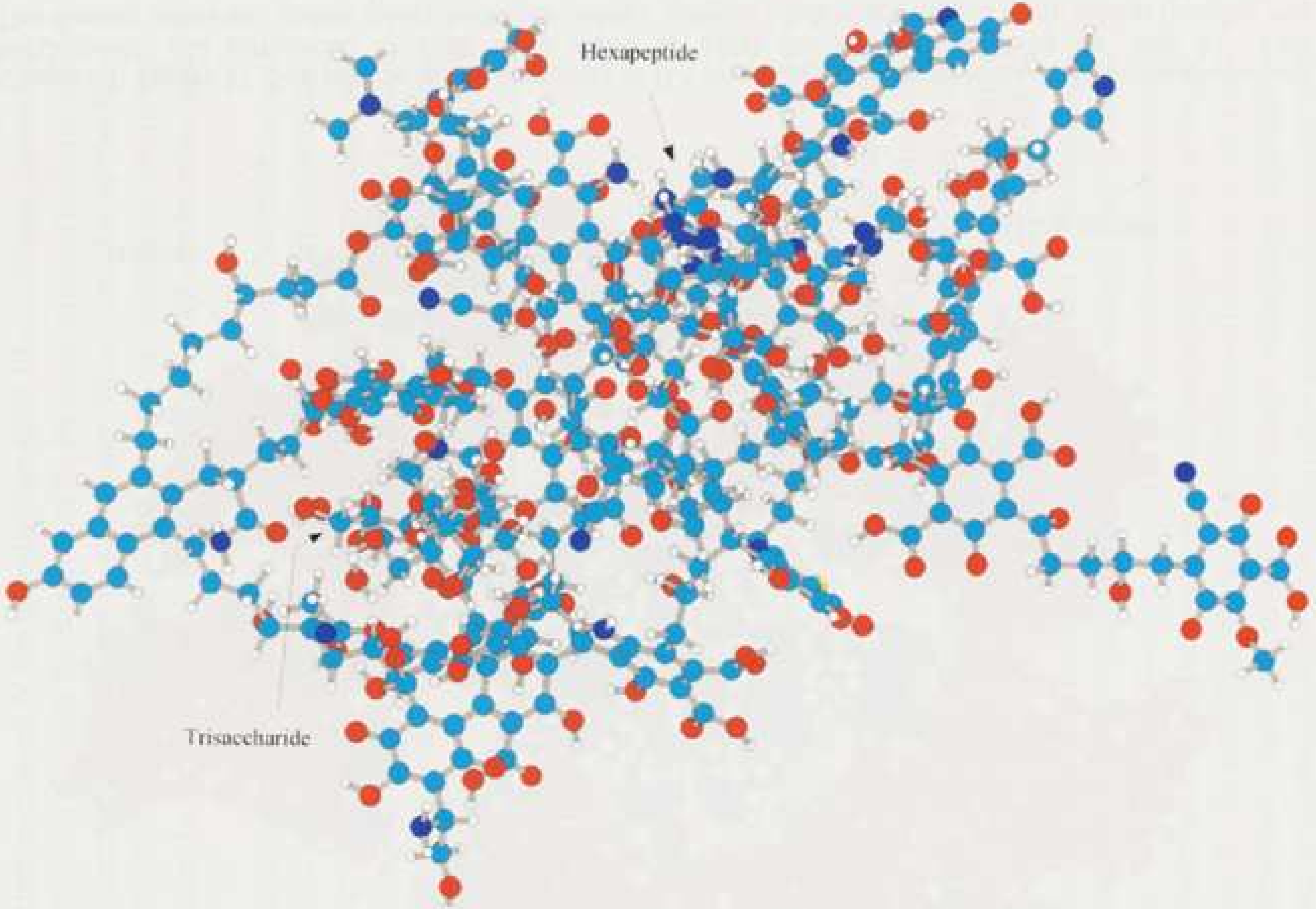
P XANES and EXAFS analysis



NMR and DFT

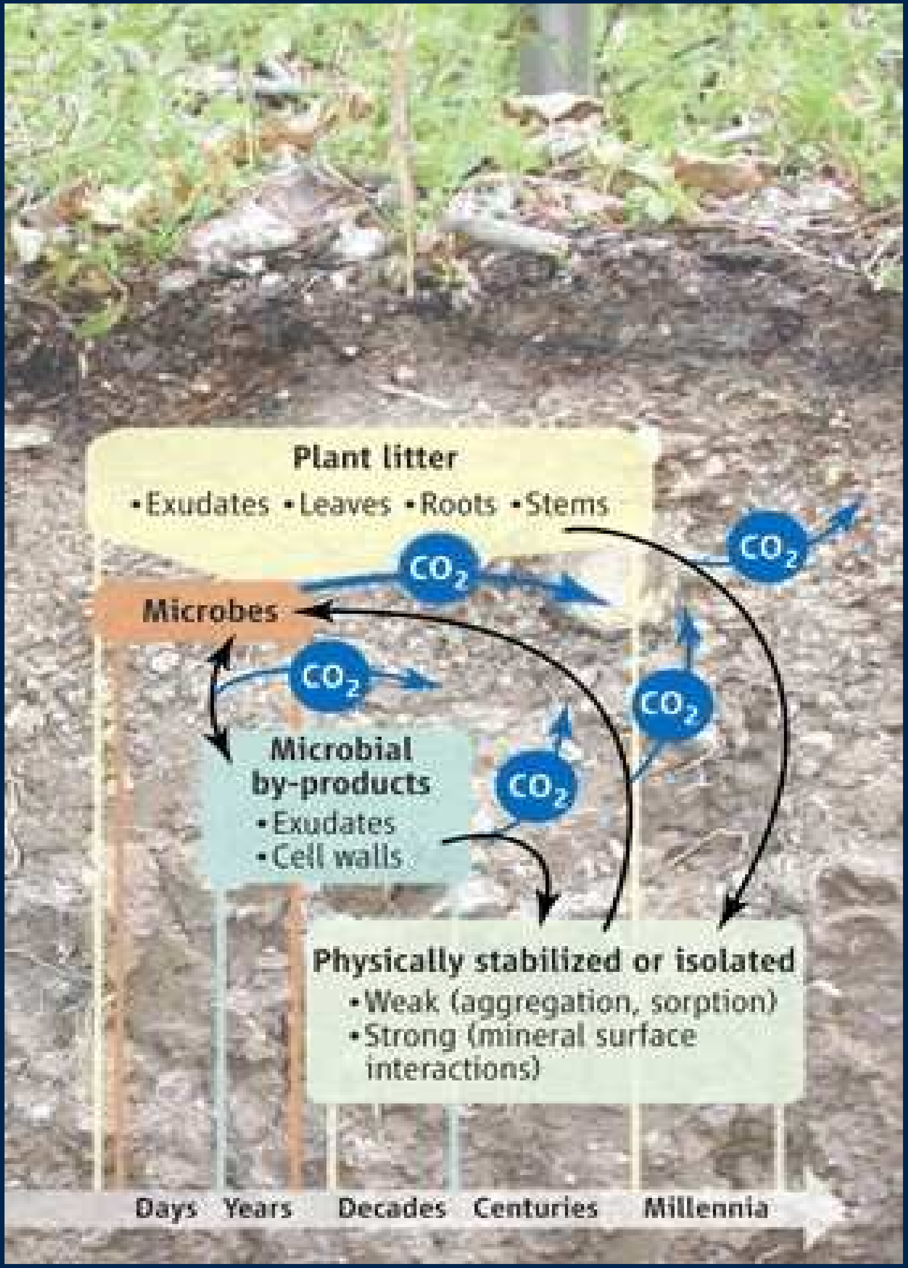


Bi-COOH
Mono-COOH
Bi-PO3
Mono-PO3
REAPDOR fraction ($\Delta S/S_0$)
Dephasing time, τ (ms)
S_0
S
^{31}P (ppm)
Bi-PO$_3$
Mono-PO$_3$
Mono-COOH
Bi-COOH



Chapter 1, Figure 16 Three-dimensional SOM(HA + carbohydrates + proteins + water) model structure. Element colors are: carbon (light blue); hydrogen (white), oxygen (red); nitrogen (deep blue); and sulfur (dark yellow) [from Schulten and Schnitzer (1997) with permission of the publisher].

There is not a regularly repeating structural unit or set of units that is characteristic of HS. Consequently, no two molecules of HS are alike.



Organo-Mineral Interactions

➢ One of the major mechanisms for C stabilization

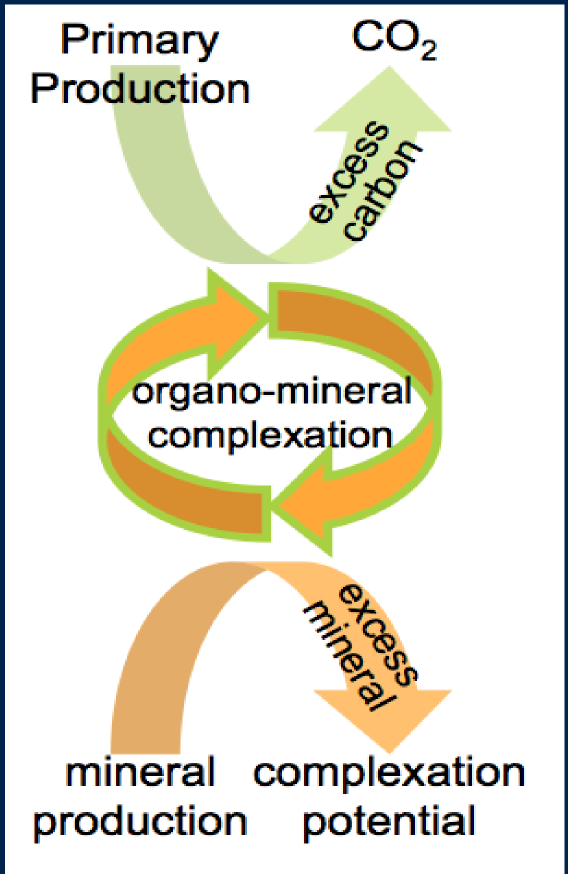
➢ Controlled by the chemistry of organic matter and mineralogy (Fe&Al oxides, aluminosilicates)

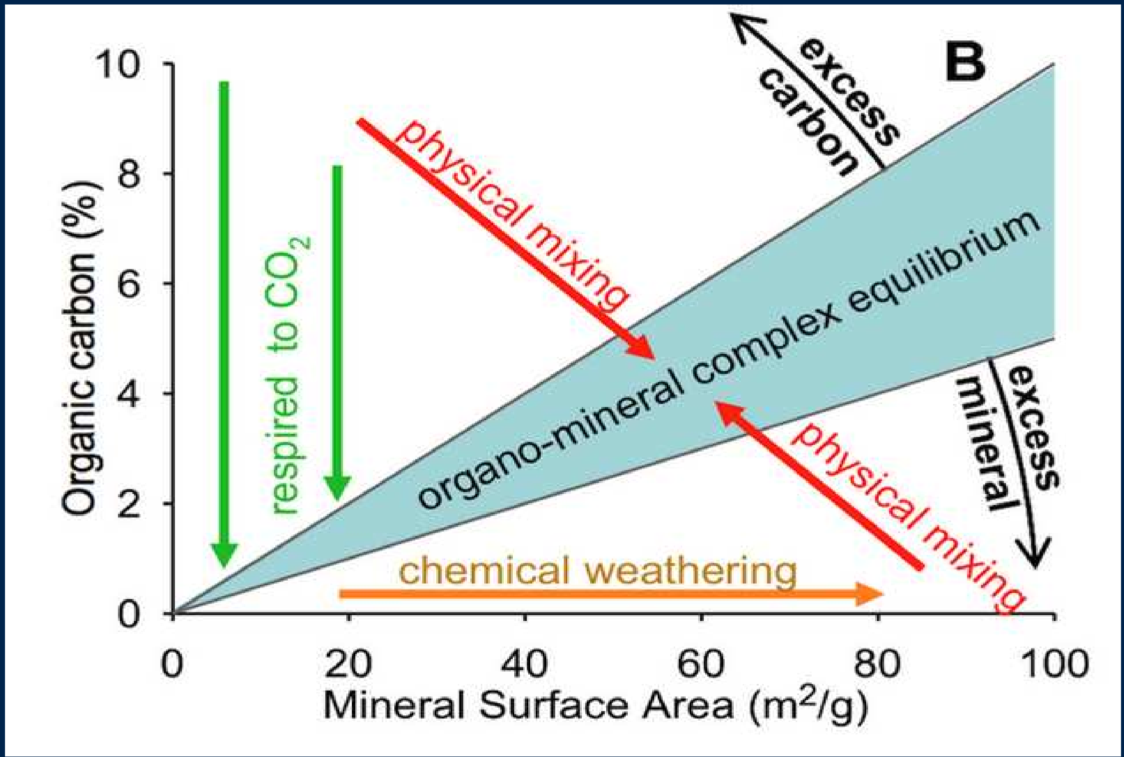
➢ Impacted by the coupled geomorphological, hydrological and microbial processes

Trumbore et al., 2008, *Science*

Christina River Basin Critical Zone Observatory

Overall Hypothesis: Organo-mineral complexation, a key process for stabilizing carbon, is limited by the supply of the mineral surfaces and the mixing of minerals with organic matter in natural ecosystems

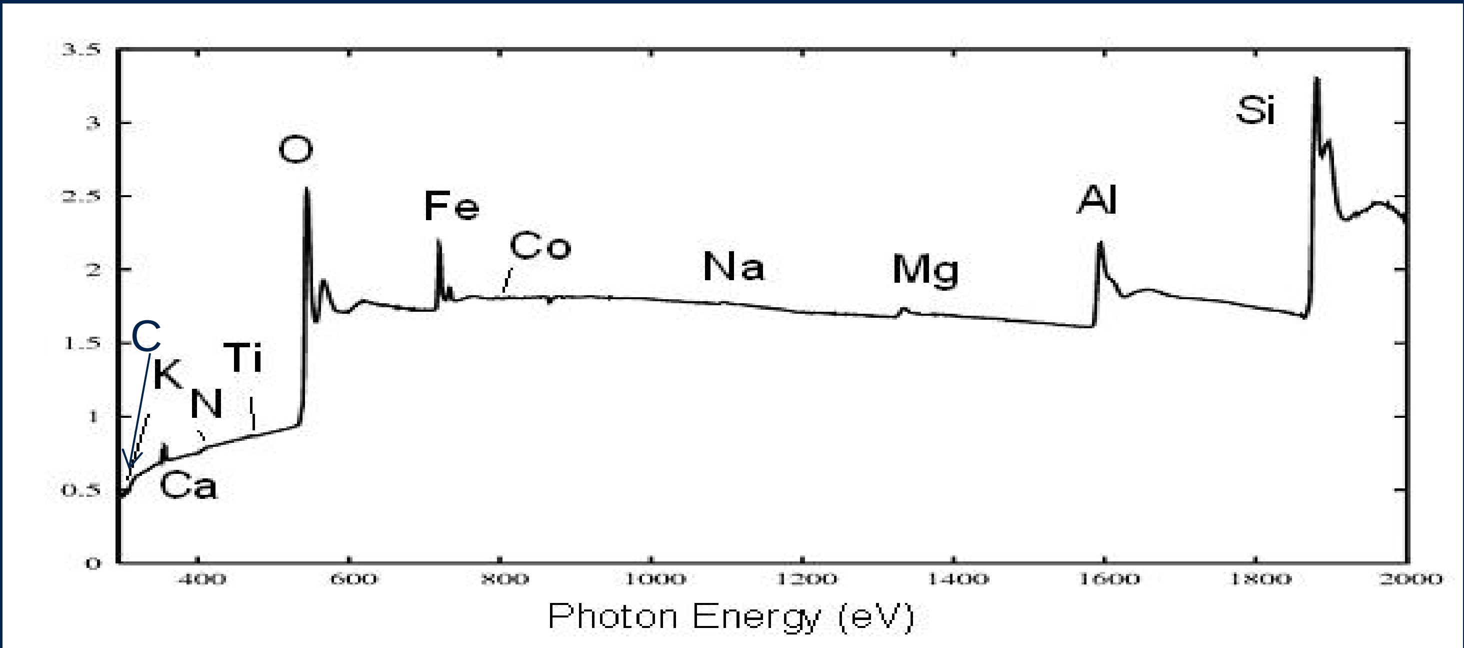


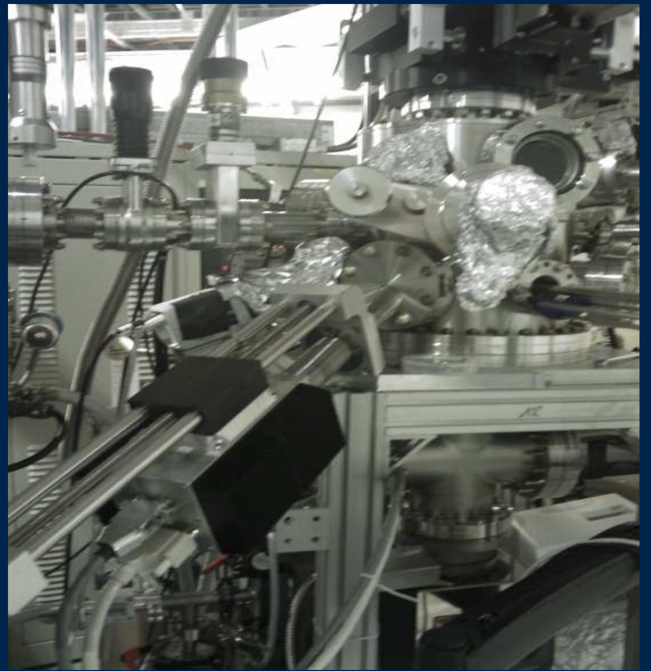


Adapted from www.udel.edu/czo/research.html

Advanced Characterization Techniques

Near-edge X-ray Absorption Fine Structure (NEXAFS)



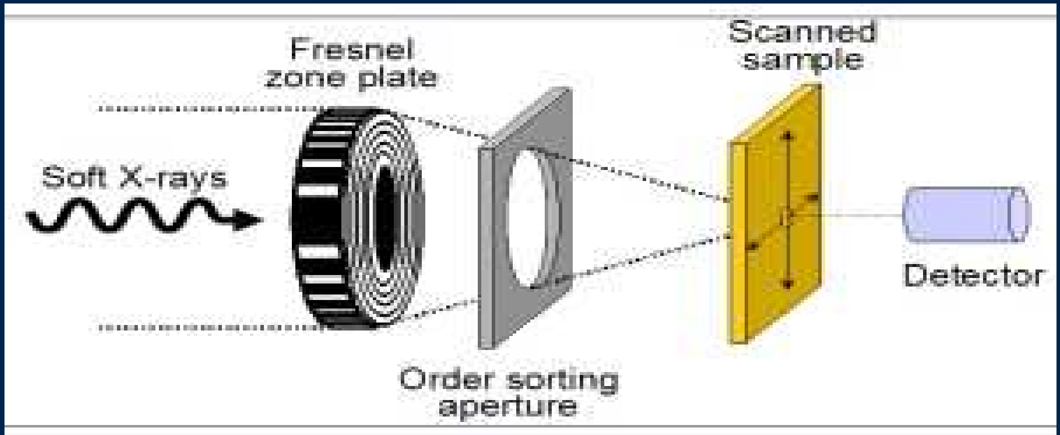


SGM beamline, CLS

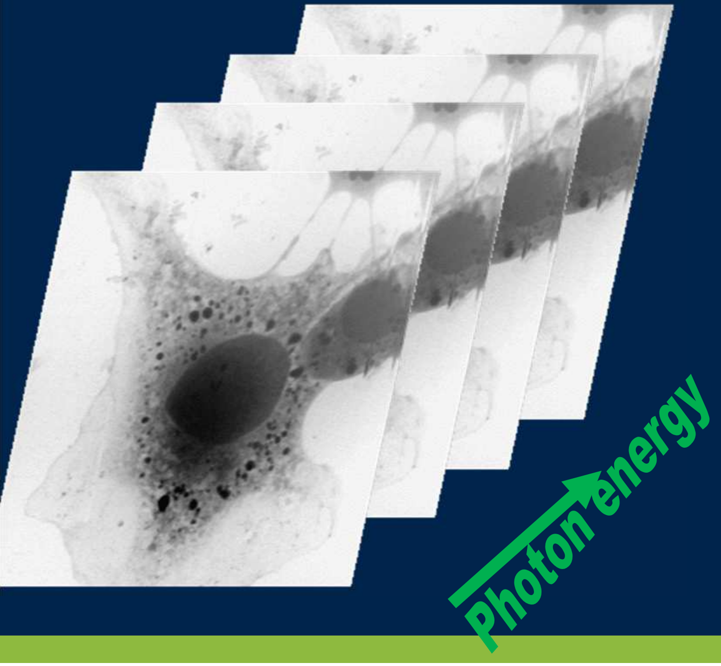
- Characterize C and N functional groups of soil organic matter without any pretreatment.
- Spot Size: 1000*100 MICRONS

Advanced Characterization Techniques

Scanning Transmission X-ray Microscopy (STXM) –NEXAFS



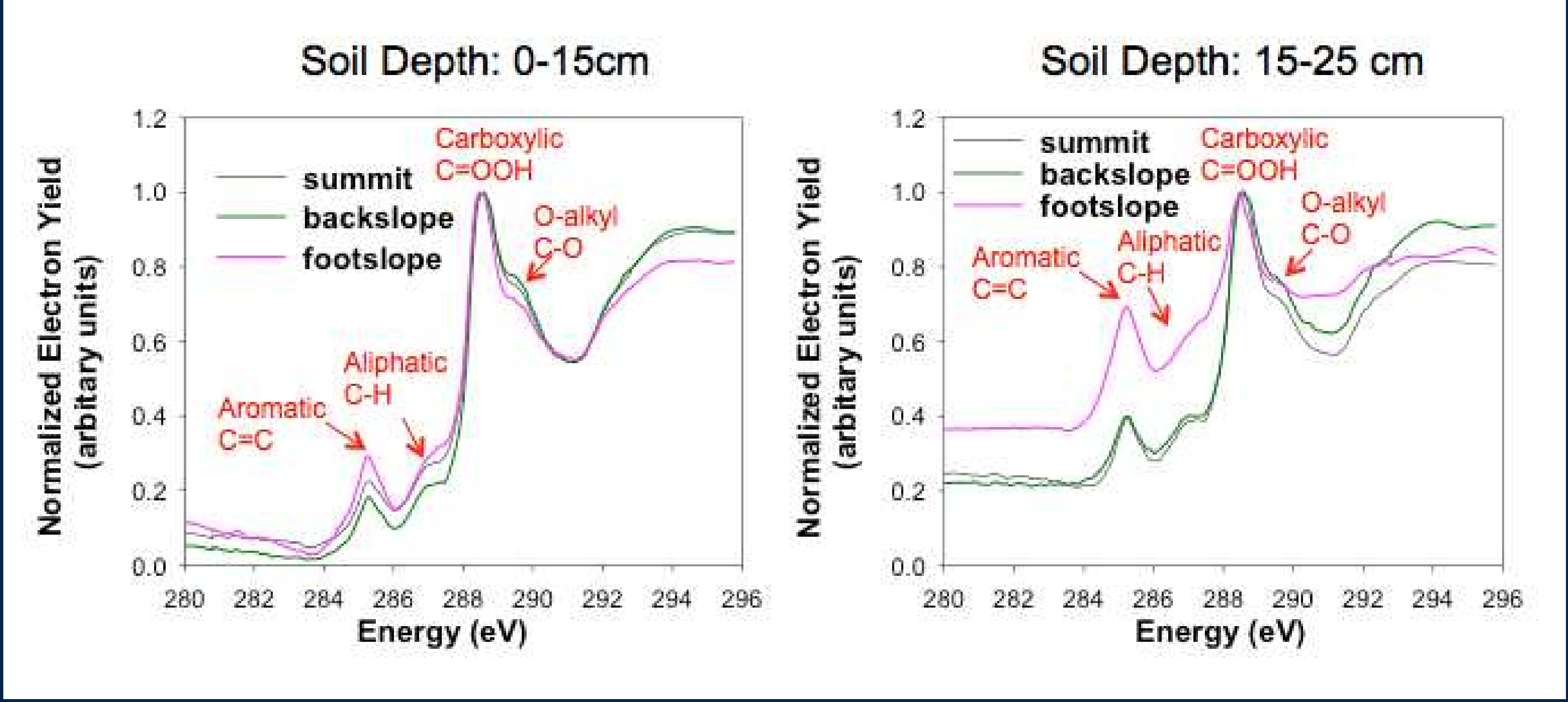
SM beamline, CLS



Acquire sequence of images over NEXAFS spectral region at 30-40nm resolution

- Map distribution of C and C forms and the major elements (K, Ca, Fe, Al, Si) in soils at nanometer scale.
- Assess the interactive mechanisms of C with specific soil minerals.

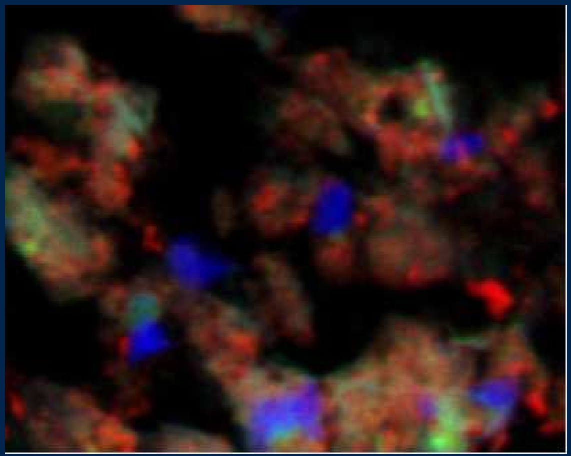
Soil Carbon Speciation by NEXAFS



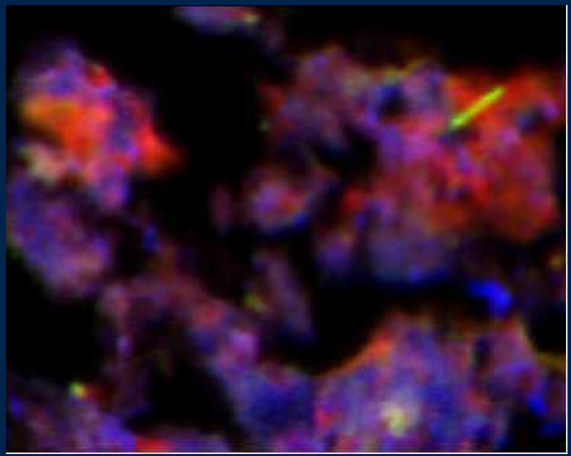
Footslope soil: enriched in aromatic C=C
depleted in aliphatic C-H

Color-coded Composite Maps of C, Ca, Fe, Al and Si from Pasture Soil Clay Fractions

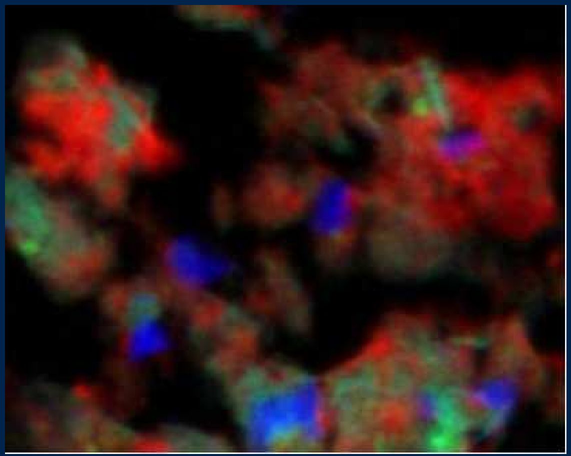
Fe Al Si



C Ca Fe

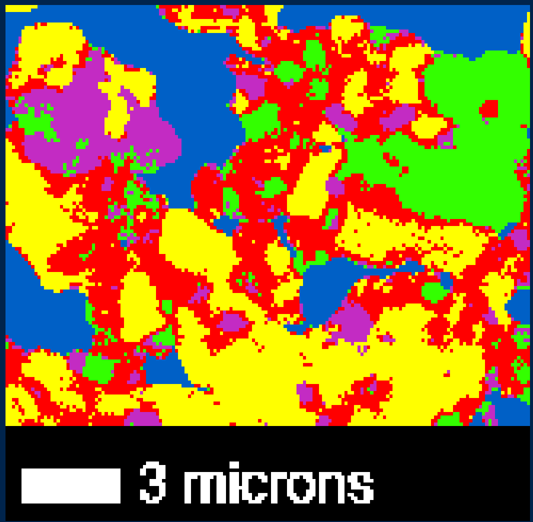


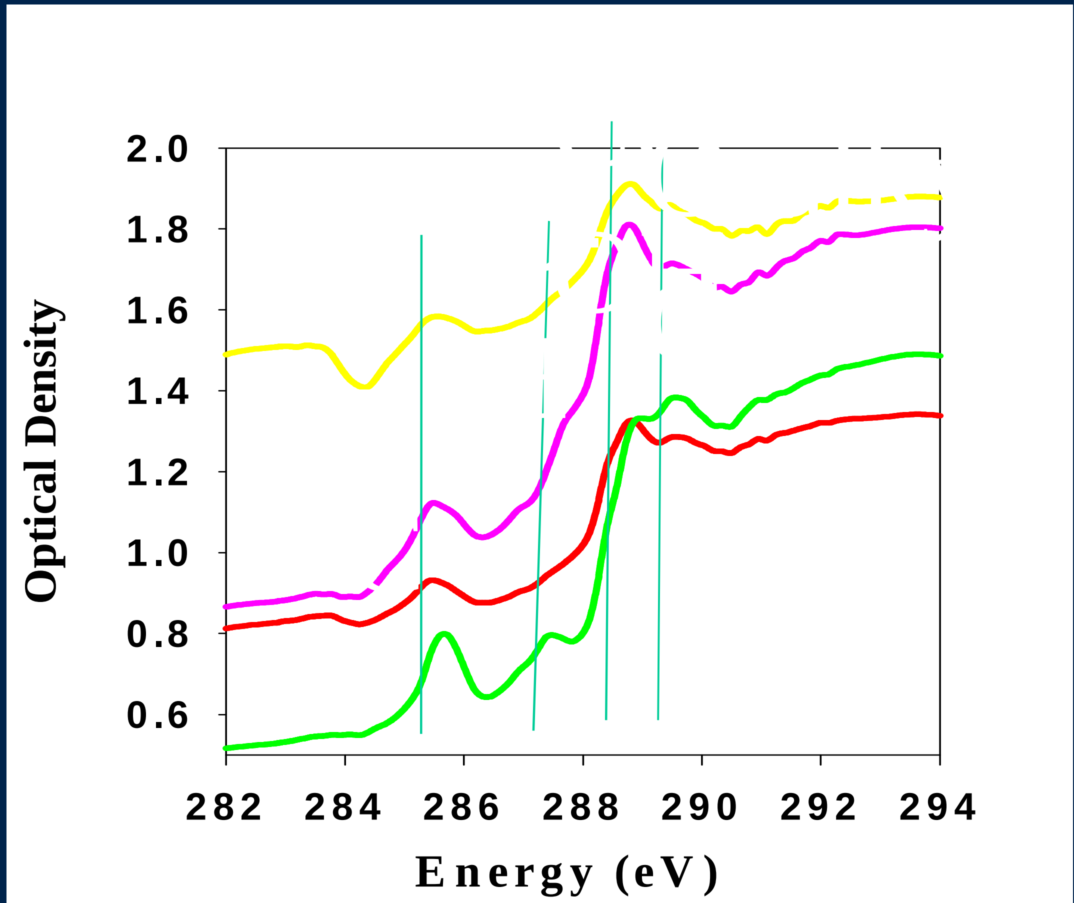
C Al Si



Fe is intimately associated with Al and Si .
Discrete quartz particles.
C is closely associated with clay particles, as particulate organic matter has been excluded from the clay fractions.
The discrete SiO_2 particles contain little or no C

Distribution of C Functional Groups

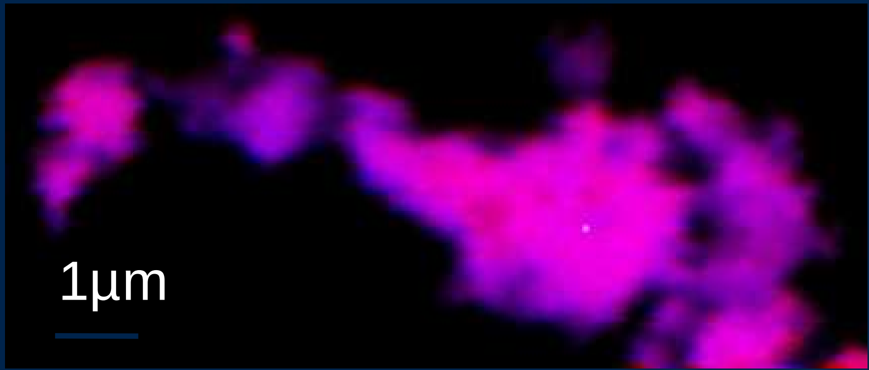


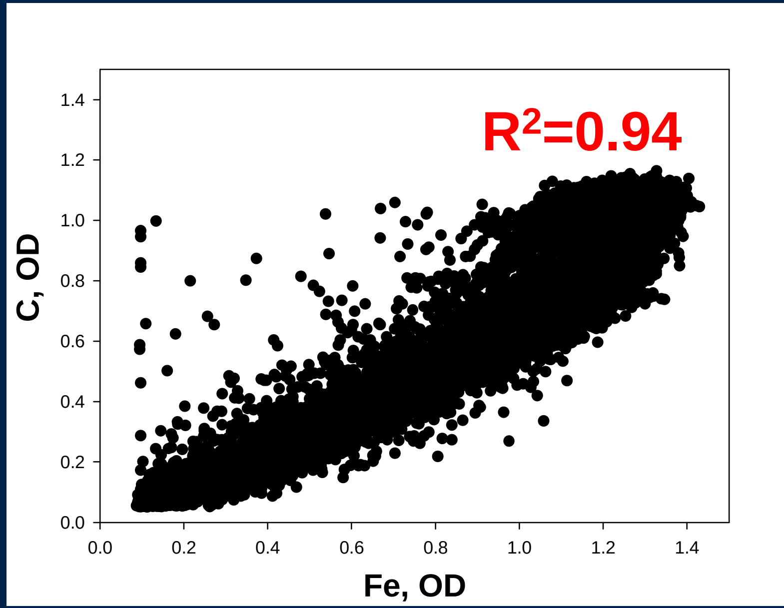


The majority of OM forms associated with soil organo-mineral assemblage are aromatic C=C, carboxylic-C and polysaccharides

C Distribution on Ferrihydrite via Adsorption

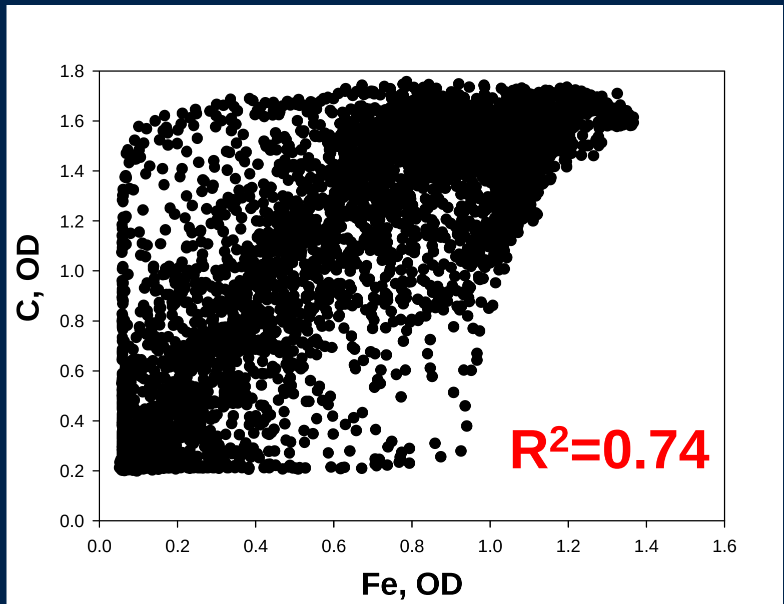
0.52 mg C m^{-2} SA



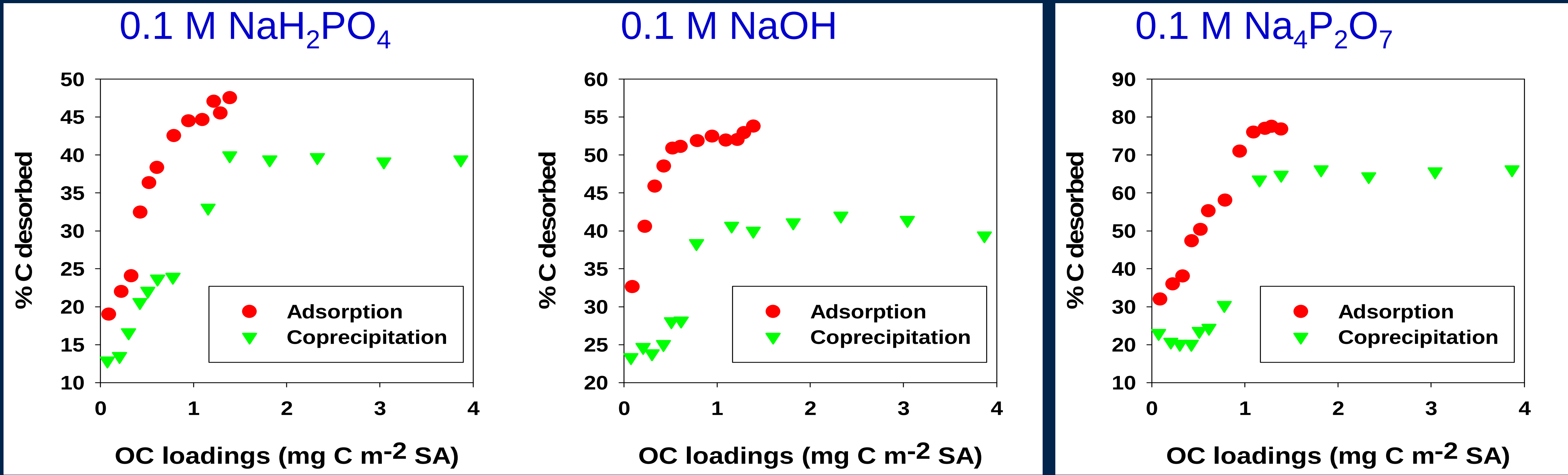


1.30 mg C m^{-2} SA

C, Fe



Desorption of Adsorbed and Coprecipitated C on Ferrihydrite



Desorption efficiency: 0.1M $Na_4P_2O_7$ > 0.1M NaOH > 0.1M NaH_2PO_4

The proportion of C being desorbed is larger for adsorbed C than coprecipitated C, indicating coprecipitation leads to greater C stability than adsorption.

The proportion of C being desorbed increases with C loading and reaches a maximum at 1 mg C m^{-2} SA.

Particulate Transport and Reactivity

Soil and Land Use/Degradation

- Soil erosion via water and wind on cropland in USA - >1.7 billion tons/yr (2007)
- Salinization
- Human Impacts (Anthropocene)
- Land Degradation – urbanization, sealing, compaction
  - 33-50% of ice-free earth's surface transformed by human action

"The reaction of land to occupancy determines the nature and duration of civilization." (Aldo Leopold, 1933)

Source: NASA http://www.nasa.gov/multimedia/imagegallery/image_feature_989.html

Source: http://www.sciencemediacentre.co.nz/2009/09/23/risk-of-respiratory-illness-as-blanket-of-dust-descends

Beijing Takes Steps to Fight Pollution as Problem Worsens

Feng Li/Getty Images

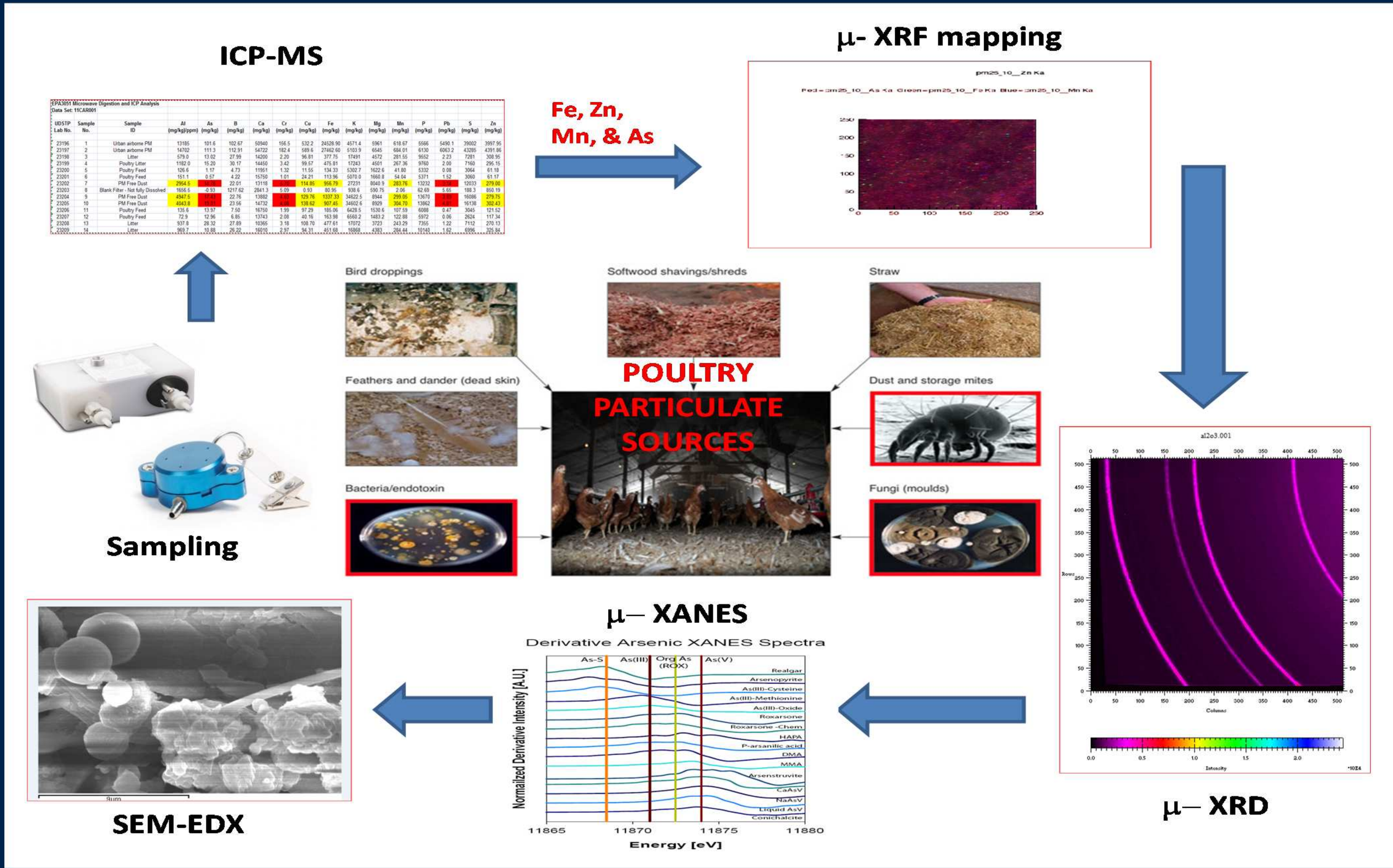
A flag-raising ceremony in Tiananmen Square obscured by thick smog.

Burning of e-wastes

Poultry Dust

- What's the problem?
  - Extensive research shows that particulate matter has had consequences on both respiratory and cardiovascular systems
    - Asthma
    - Chronic Bronchitis
    - Cardiovascular Disease
  - Fine and ultrafine PM
    - Lung deposition
  - Toxicity
    - Arsenic

Schematic of Methodology



Micro X-ray Fluorescence (XRF) Map of Poultry Particulate Matter

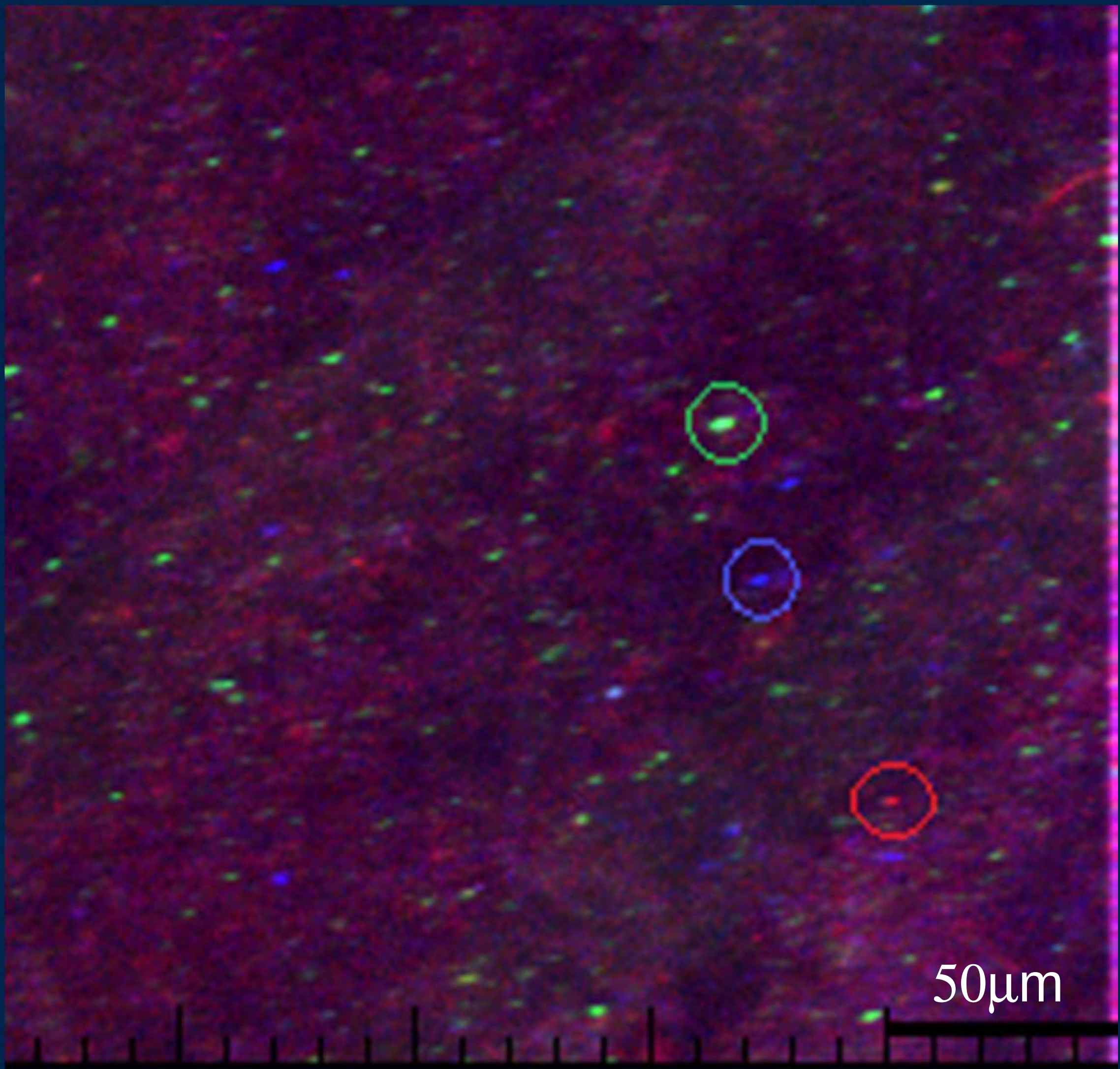
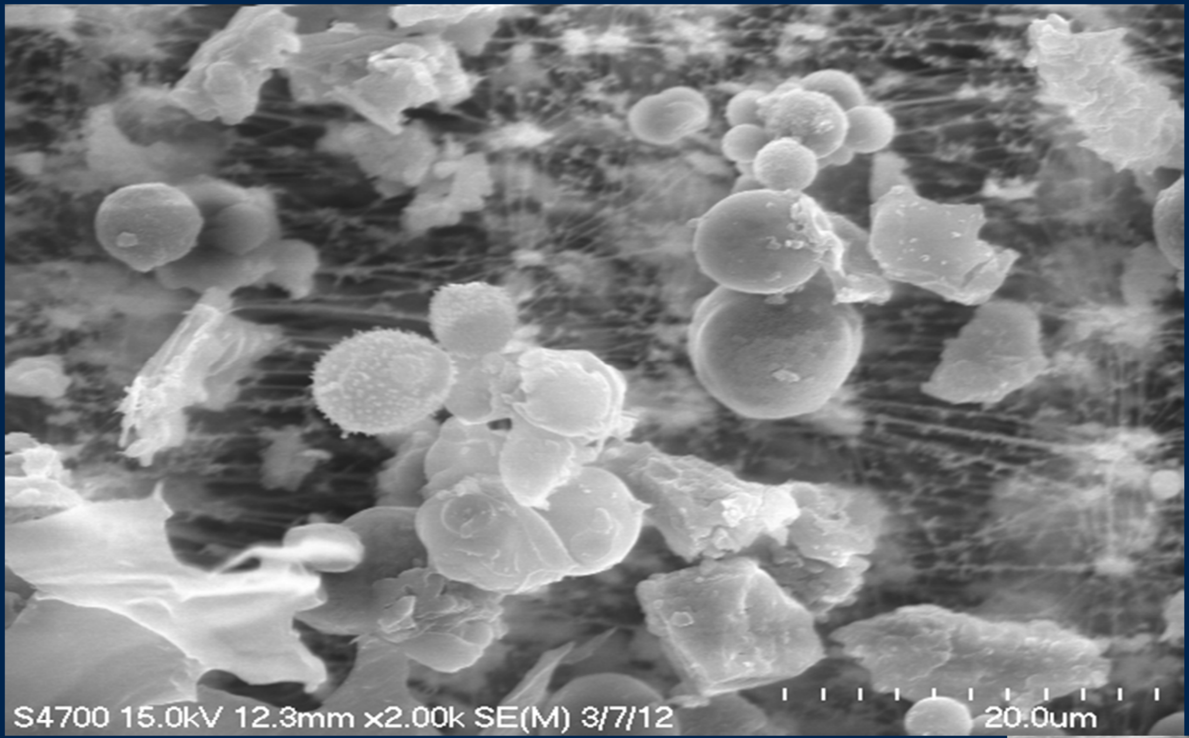
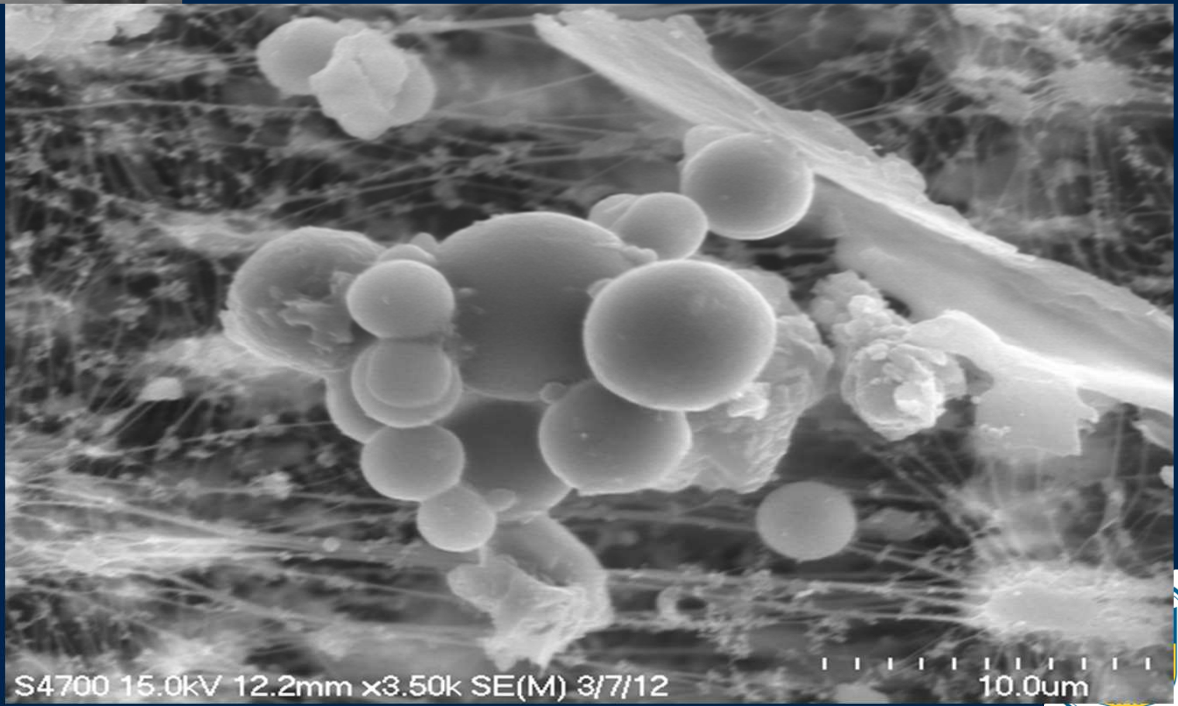


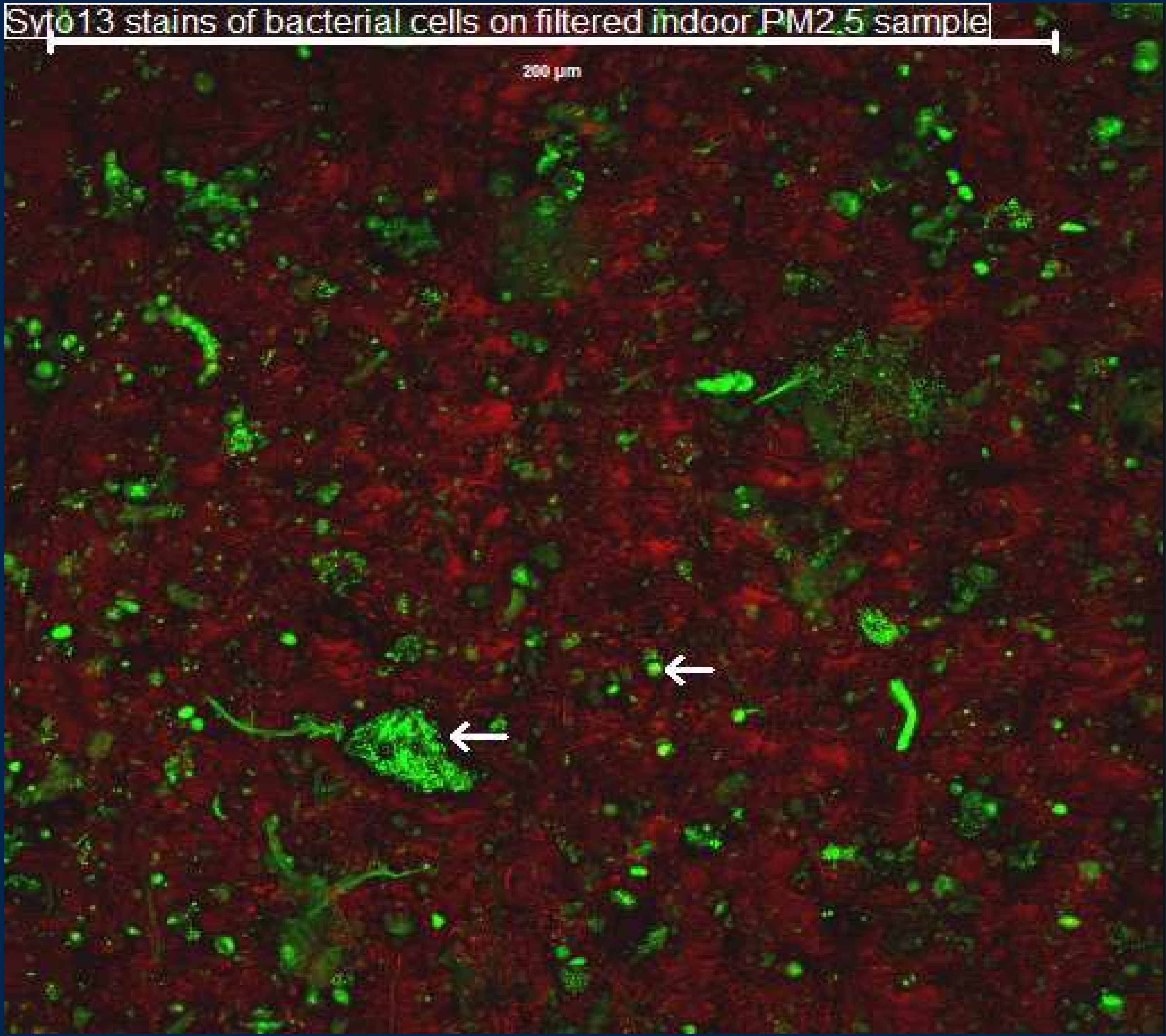
Figure 3: 2.5mm x 2.5mm X-ray fluorescence (XRF) map of filtered PM10 sample (10um-2.5um particles). Colored circles indicate the location of high intensity areas or “hotspots” corresponding to either As (red), Fe (green), or Mn (blue).

Scanning Electron Microscopy

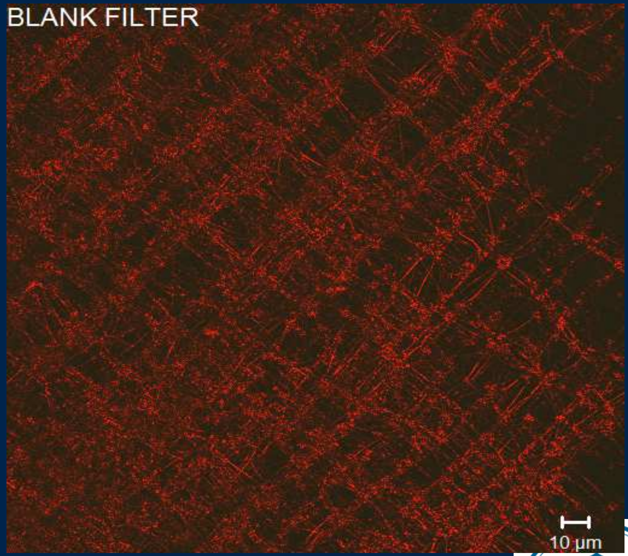


Fig’s 1 and 2 show SEM images from a single indoor PM_{10} sample. Particles are primarily found to be spherical and platy in shape. Fig 2 (right) shows a closer look at particles aggregated together.





Confocal Microscopy Image of Indoor $PM_{2.5}$



Interfaces Between Disciplines is "Where the Action Is" in Research

Team members interface skills and contributions

Secret File Points To Institutional Cover-up At Penn State

The Most Expensive 4-Year Public Colleges

WHOA! Average Price Of 4-Year University Up 15 Percent

Donald L. Sparks

S. Hallock du Pont Chair in the Department of Plant and Soil Sciences and director of the Delaware Environmental Institute

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Tipping Point

Posted: 06/13/2012 11:05 am

React > Amazing | Inspiring | Funny | Scary | Hot | Crazy | Important | Weird

Follow > Climate Change , Rio+20 2012 , Rio+20 Earth Summit , Earth's Surface , Population Growth , Rio 20 Summit 2012 , Rio+20 , College News

A group of 22 scientists sounded an alarming call to action last week.

Their paper in the June 7 issue of *Nature*, a highly regarded, peer-reviewed journal, carries the benign-sounding title, "Approaching a State Shift in Earth's Biosphere." But their conclusions are nothing short of a disaster warning.

This group of biologists, ecologists, geologists, paleontologists and complex-system theoreticians from


A&F
A&F

External Collaborators

Paul Northrup, NSLS, Brookhaven National Lab
Syed Khalid, NSLS, Brookhaven National Laboratory
Ryan Tappero, NSLS, Brookhaven National Laboratory

James Dynes, Canadian Light Source
Jian Wang, Canadian Light Source
Chithra Karunakaran, Canadian Light Source
Tom Regier, Canadian Light Source

Ken Livi, The Johns Hopkins University
Ana Rule, The Johns Hopkins University

Jim Kubicki, The Pennsylvania State University
Rufus Chaney, USDA, Beltsville
Anthony Aufdenkampe, Stroud Water Research Center
Peter Leinweber, Rostock University

Funding Sources

BROOKHAVEN NATIONAL LABORATORY

National Synchrotron Light Source

National Science Foundation

SSRL Stanford Synchrotron Radiation Lightsource

UNIDEL Foundation

Delaware EPSCoR