Environmental Geochemistry & Petrology of the Lake Sediments in the vicinity of the Alberta Coal-Fired Power Plants

A joint study by

NRCan (ESS-GSC Calgary) &

University of Victoria

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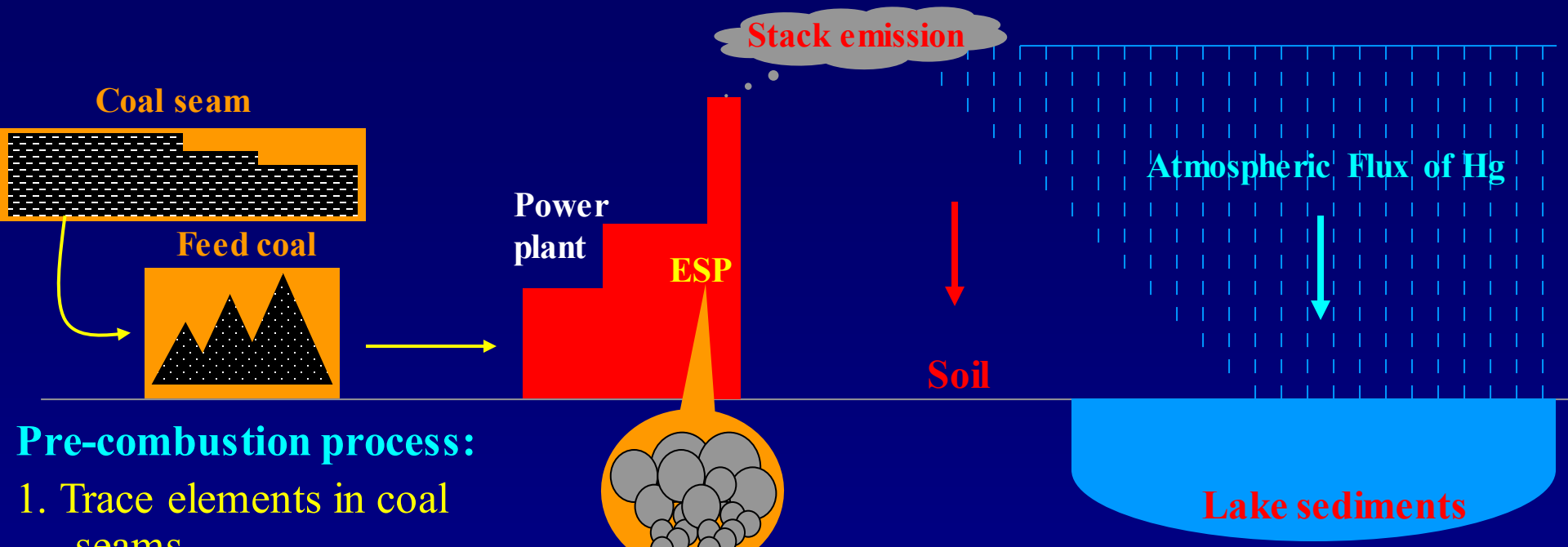


Pre-combustion process:

1. Trace elements in coal seams
2. Geochemical study of feed coal

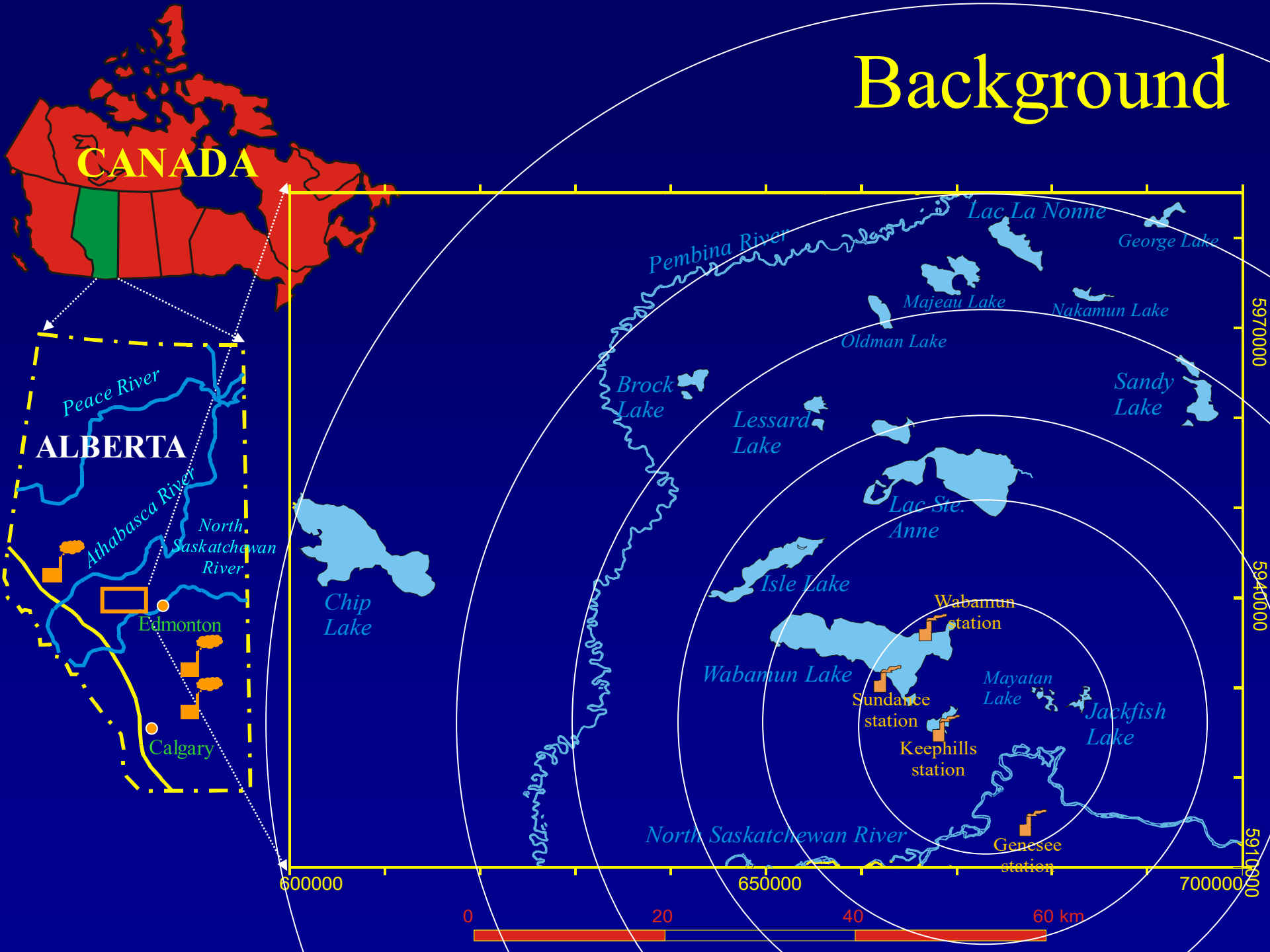
In-process studies:

1. Geochemical study of fly ash
2. Geochemical study of bottom ash
3. Stack emission study (gaseous, particles)

Environmental impact:

1. Aerial deposition of particles (moss-monitoring)
2. Mercury Wet deposition
3. Soil study
4. Lake sediments

Background

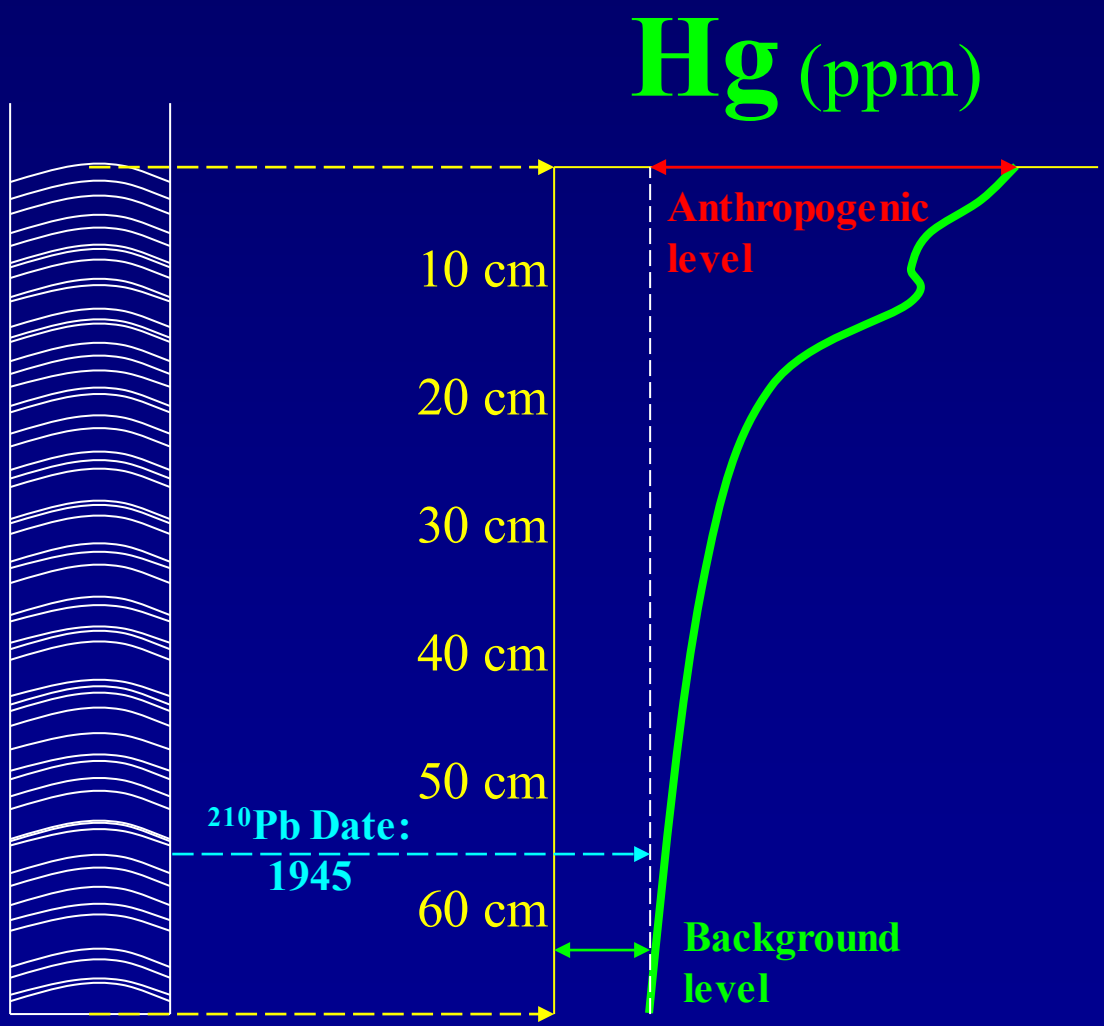

CANADA
ALBERTA
Peace River
Athabasca River
North Saskatchewan River
Edmonton
Calgary
Pembina River
Lac La Nonne
George Lake
Majeau Lake
Nakamun Lake
Oldman Lake
Brock Lake
Lessard Lake
Sandy Lake
Lac Ste. Anne
Chip Lake
Isle Lake
Wabamun station
Wabamun Lake
Mayatan Lake
Sundance station
Jackfish Lake
Keephills station
Genesee station
North Saskatchewan River
5970000
5940000
5910000
600000
650000
700000
0
20
40
60 km

Sediment Studies in the Wabamun Region:

- **Alberta Environment**
- **Various Environmental Consultants (e.g., Goldar Associates)**
- **University of Alberta**

Problems:

1. Majority of these lake sediment studies use simplistic liminological approach.
2. Often geochemistry of the porewater is ignored.
3. The mobility of the chemicals are often not taken into account.
4. The natural condition of the sediments are usually not preserved.
5. Inadequate sample quantity.



Impacts of coal-fired power plants on trace metals and polycyclic aromatic hydrocarbons (PAHs) in lake sediments in central Alberta, Canada

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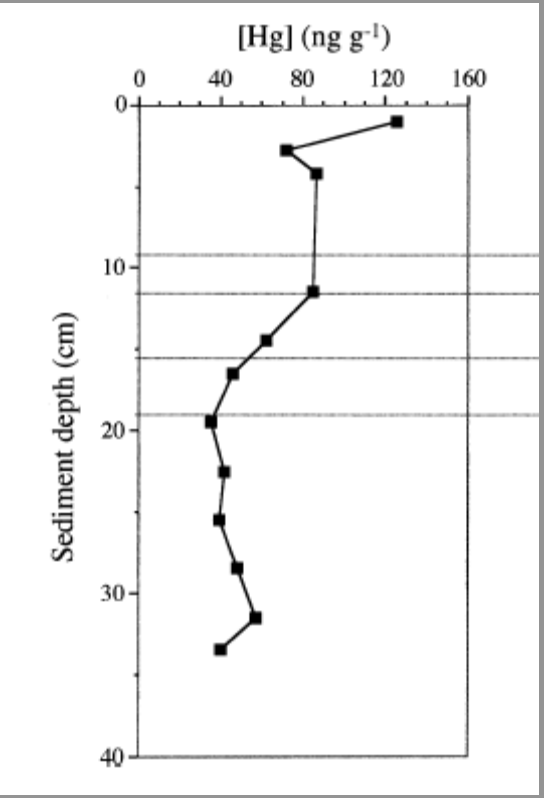
Key words: Coal combustion, Mercury, Pb^{210} dating, Polycyclic aromatic hydrocarbons, Sediment core, Trace metals

Abstract

Trace metals and polycyclic aromatic hydrocarbons (central Alberta lakes to determine the contributions loadings. In Wabamun Lake, with four power plants concentrations of mercury, copper, lead, arsenic and se enrichments were less pronounced in Lac Ste. Anne a south of Wabamun Lake, respectively. Total Hg flux to increased 6-fold since 1950, compared to 2- and 1.5- respectively, since *circa* 1900. Total PAH flux to surface Lake, 290–420 $\mu g\ m^{-2}\ yr^{-1}$ in Lac Ste. Anne, and 140– of pollution-abatement technology that compensates expansion of coal-burning industry in Alberta will res from local sources.



Introduction

Coal-fired power plants are a major source of contaminants to terrestrial and aquatic ecosystems (Nriagu and Pacyna 1988). Among the contaminants released by coal combustion are trace metals such as mercury (Hg), arsenic (As), selenium (Se), lead (Pb), and copper (Cu), and organic compounds such as polycyclic aromatic hydrocarbons (PAHs). Trace metals and PAHs are pollutants of concern in aquatic ecosystems for their persistence, toxicity, and bioavailability (van Brummelen et al. 1998; MacDonald et al. 2000). Of particular concern are bioaccumulative contaminants such as Hg contaminants (e.g., Rose et al., 2004), mercury (e.g., Hynynen et al. 2004) and other metal levels (e.g., Couillard et al. 2004; Boyle et al. 2004), few studies have reconstructed the depositional

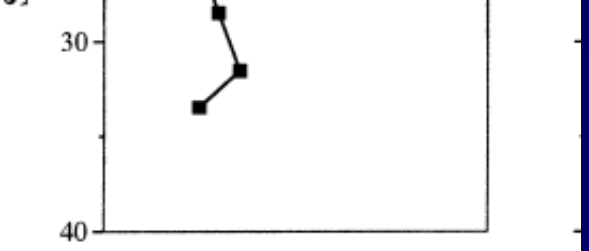


Figure 4. Total mercury concentration an

began to increase exponentially. From 1956 to 2001, the average annual increase in Hg flux to Wabamun Lake was 3.9%, compared to 1.6% over the 'pre-coal combustion' period of 1840 to 1956. In comparison, Lac Ste. Anne and Pigeon Lake exhibited average annual increases in Hg flux of 1.2% (1818 to 2001) and 0.7% (1915 to 2001), respectively. Anthropogenic Hg flux (recent – historic flux) accounted for 85% of the total flux to Wabamun Lake, and 50% of total flux to Lac Ste. Anne and Pigeon Lake (Tables 3 and 4). Thus Hg flux has increased to the greatest extent in Wabamun Lake, and decreases with increasing distance from the four power plants surrounding it.

Donahue et al., (2006) Journal of Paleolimnology 35:111 –128

Objectives:

Detailed geochemistry of the recent sediments

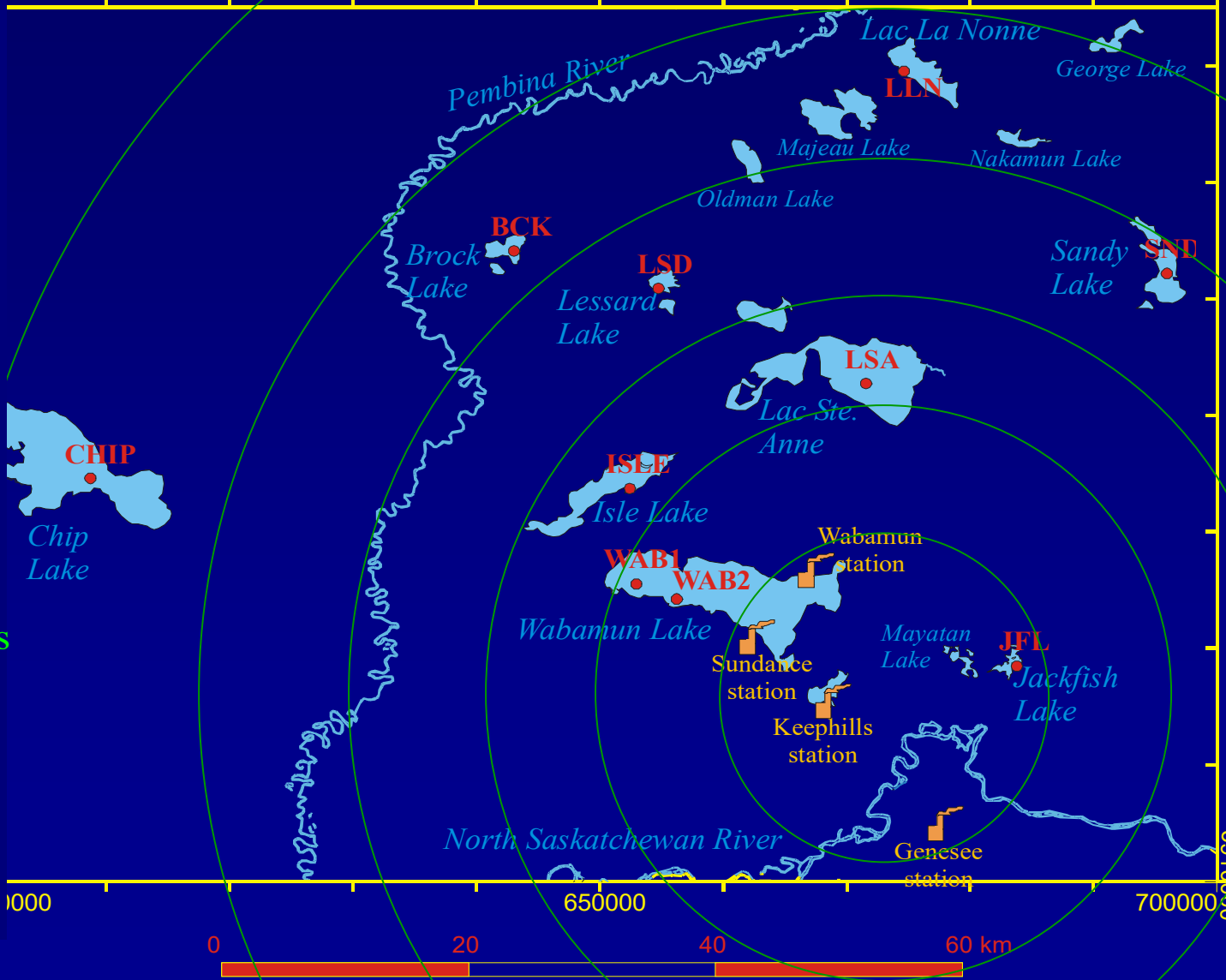
Temporal variation of elements & organic matter

Study the mobility of elements in sediment profile

Geochemical interactions between sediment & porewater during early-diageneses

Geochemical affinity of trace elements & various organic/inorganic compounds

Characterization of minerals & organic matter in the sediments



Phase I
Spatial distribution
Winter (frozen water)

Fieldwork
-Coring (60-90 cm long core)
-Sub-sampling (1cm interval)

Sediments

% Water

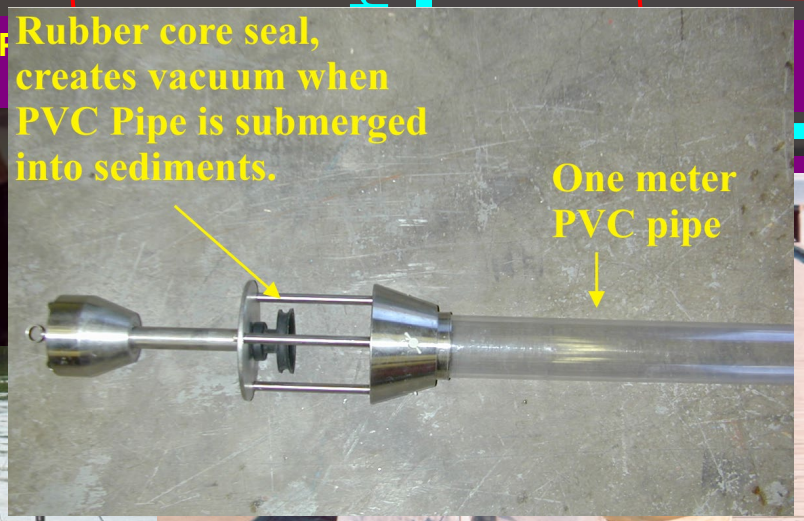
Isotope Dating
- Pb-210 dating
- Cs-137 dating

Phase II
Temporal distribution
Fall (open water)

Fieldwork
- Coring (60-90 cm long core)
- Sub-sampling (1-cm interval)

Porewater

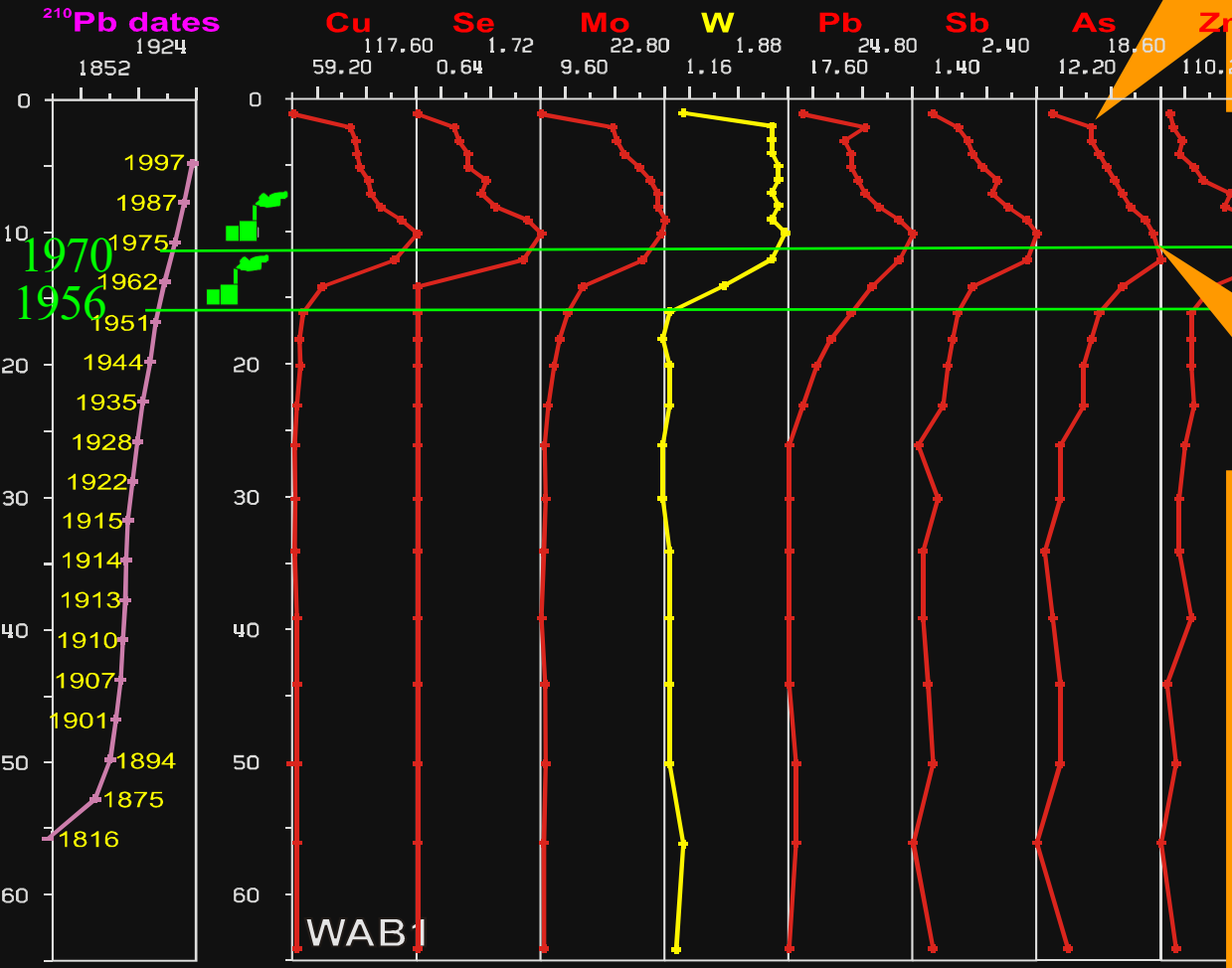
hamber

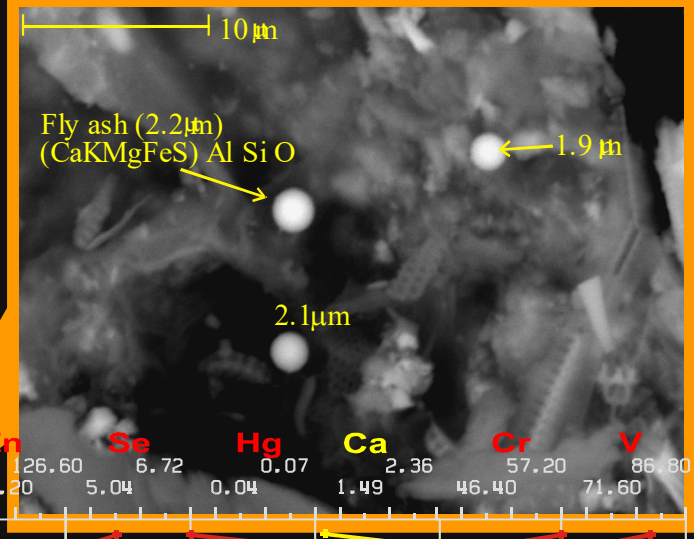


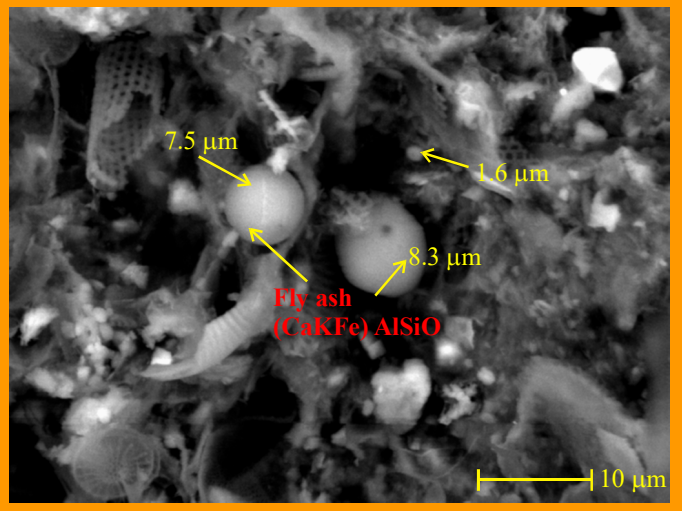
Temporal Distribution of Elements in a Sediment Profile from the Wabamun Lake

1. Source 2. Mobility

- Possible Anthropogenic Input



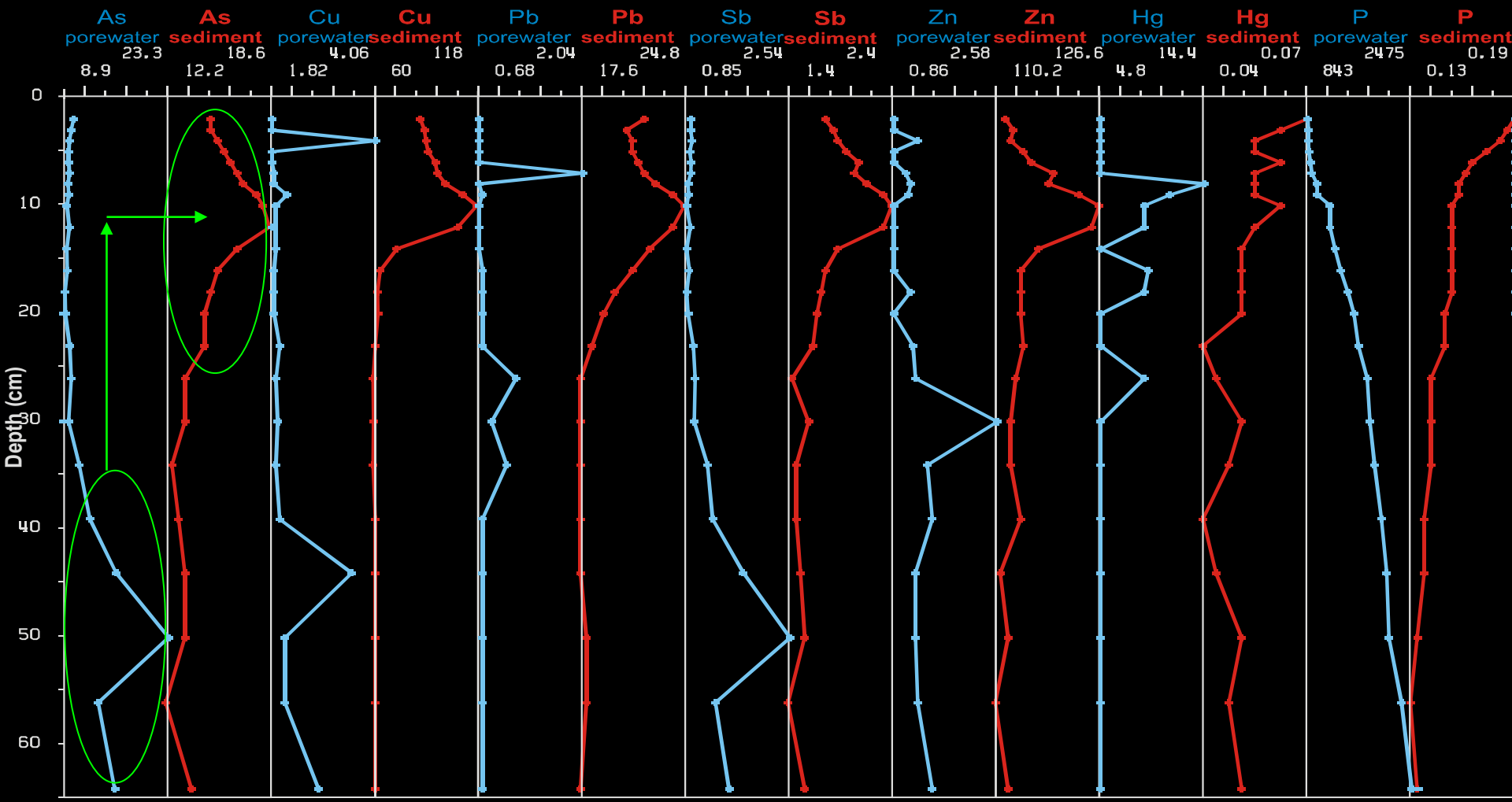




Temporal Distribution of Elements in a Sediment Profile from the Wabamun Lak

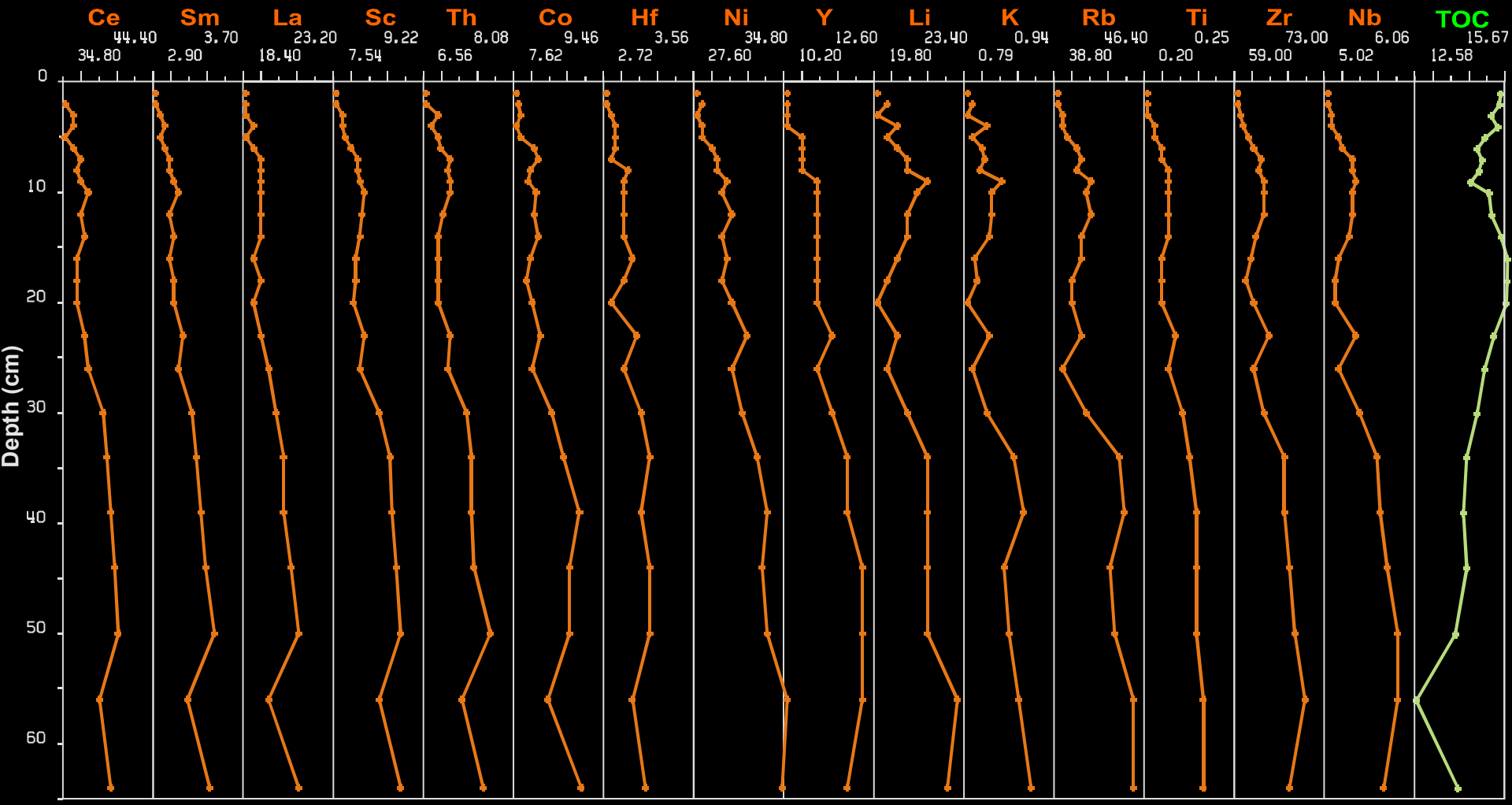
2. Mobility and Ea

While fly ash remain in the sediments, more soluble elements show mobility within the porewater column due to the post-depositional diagenesis



Temporal Distribution of Elements in a Sediment Profile from the Wabamun Lake

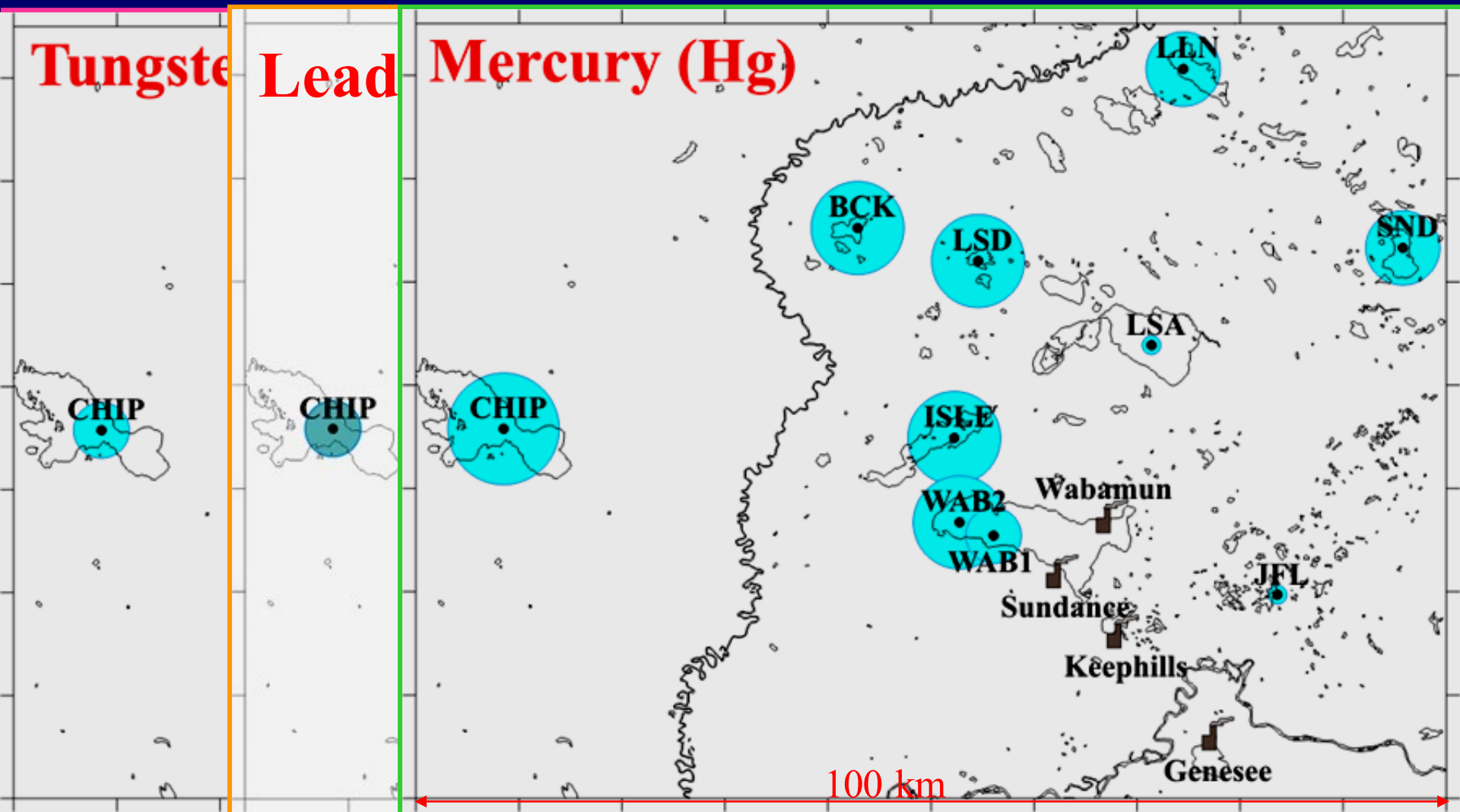
3. Dilution

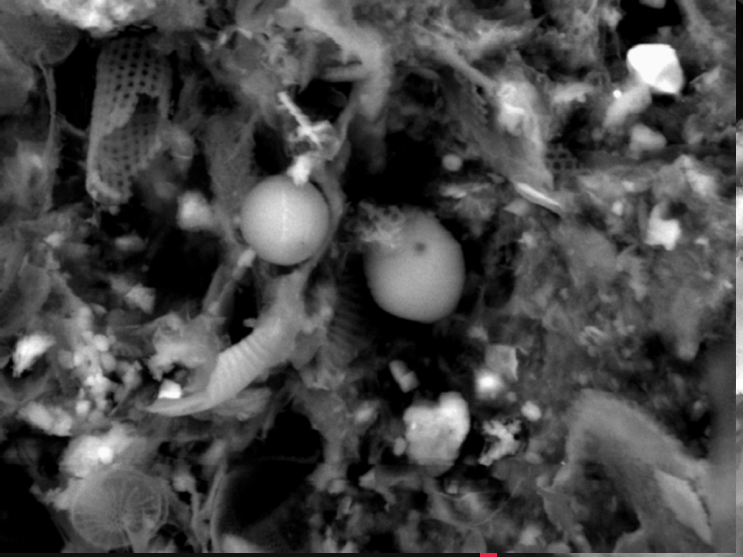


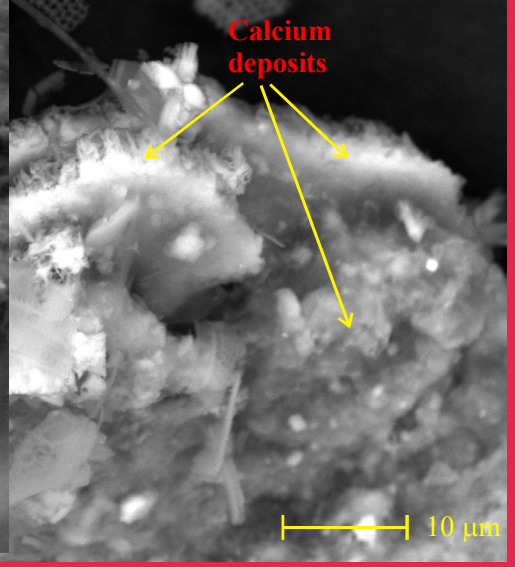
Spatial Distributions of Elements

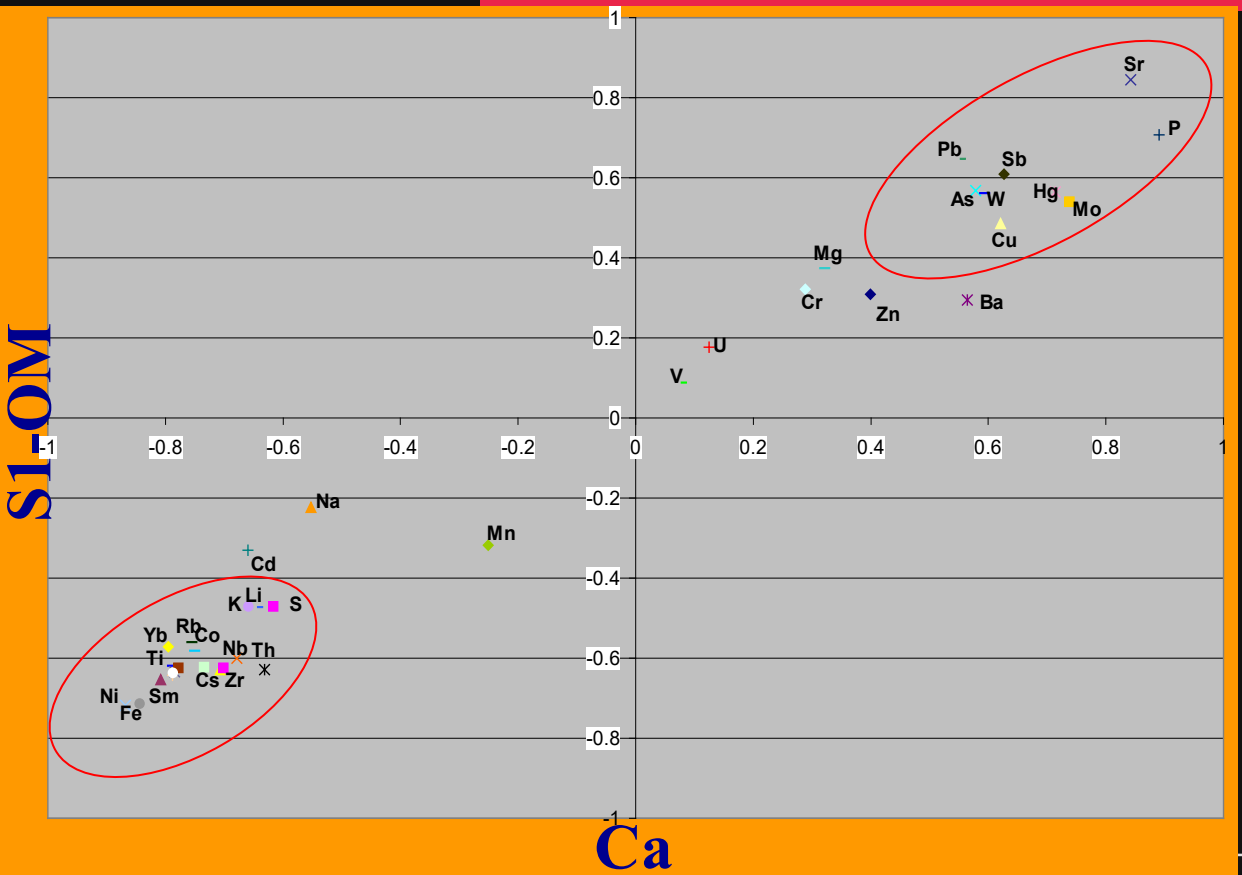
in

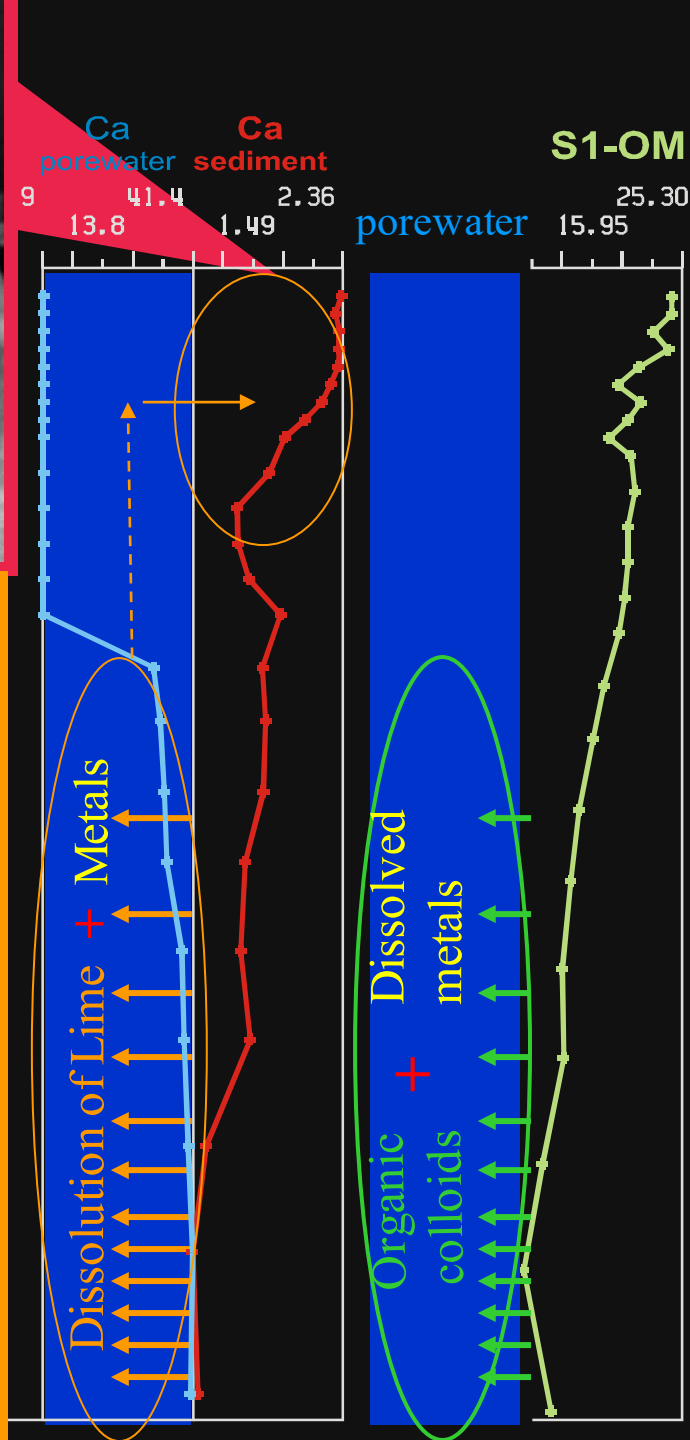
post-industrial sediments

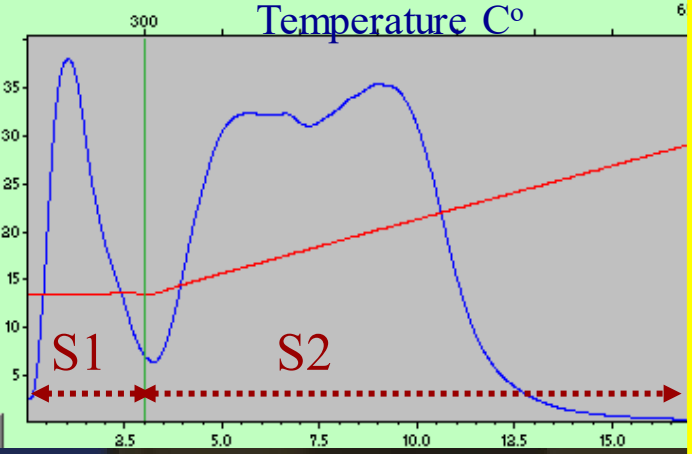





Calcium
deposits
10 µm


S1-OM
Ca
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
Sr
P
Pb
Sb
As
W
Hg
Mo
Cu
Mg
Cr
Zn
Ba
U
V
Na
Mn
Cd
K
Li
S
Yb
Rb
Co
Ti
Nb
Th
Cs
Zr
Ni
Sm
Fe

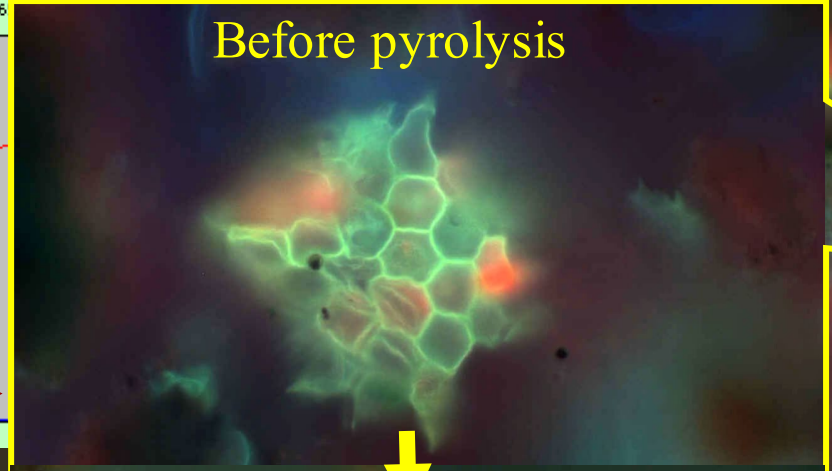

Ca
porewater
Ca
sediment
9
41.4
2.36
13.8
1.49
porewater
S1-OM
25.30
15.95
Dissolution of Lime + Metals
Dissolved
metals
+
Organic
colloids

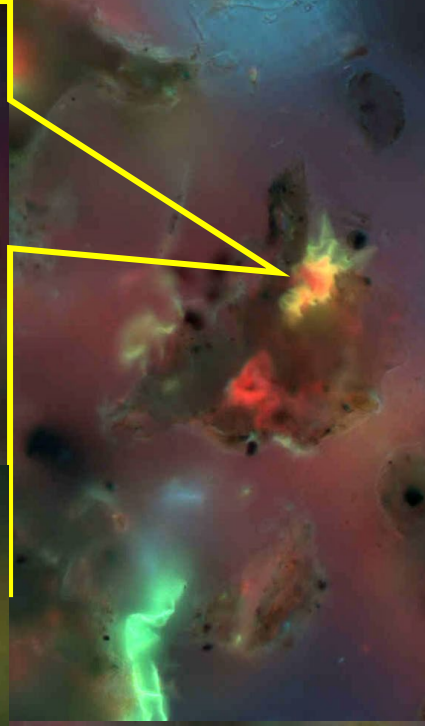


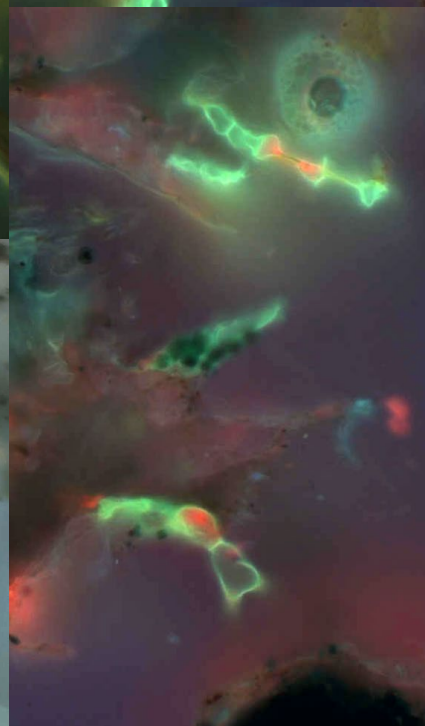
- **S1**: Very Labile, free hydrocarbon; Pyrolysis up to 300°C

- **S2**: Higher molecular, long chain hydrocarbon; Pyrolysis up to 650°C

- **TOC**: Sum of pyrolysable OM and residual carbon

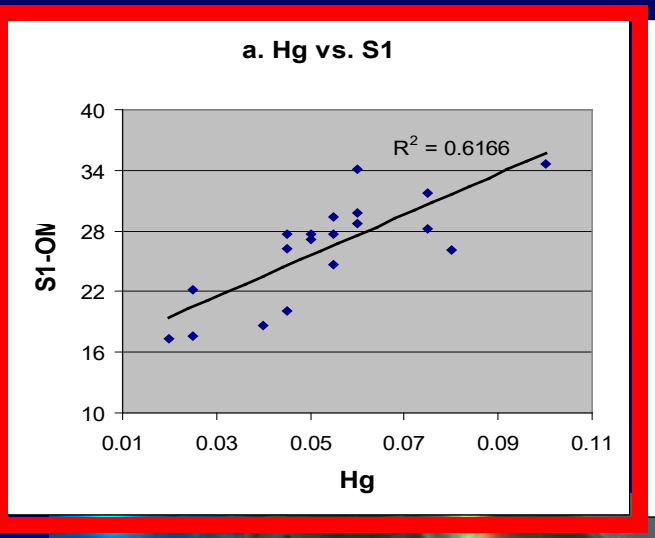


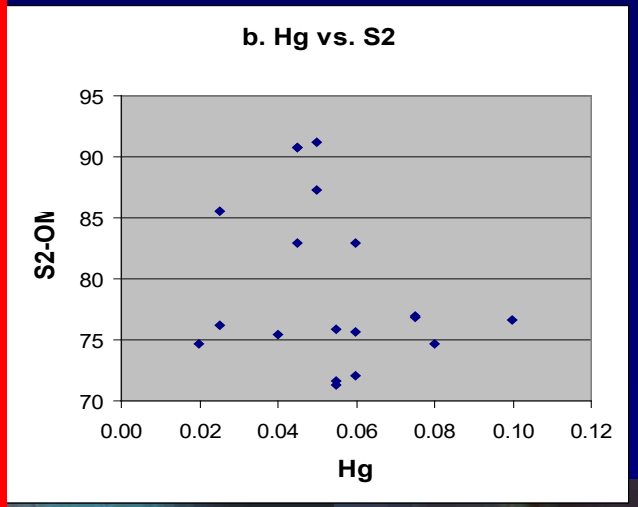


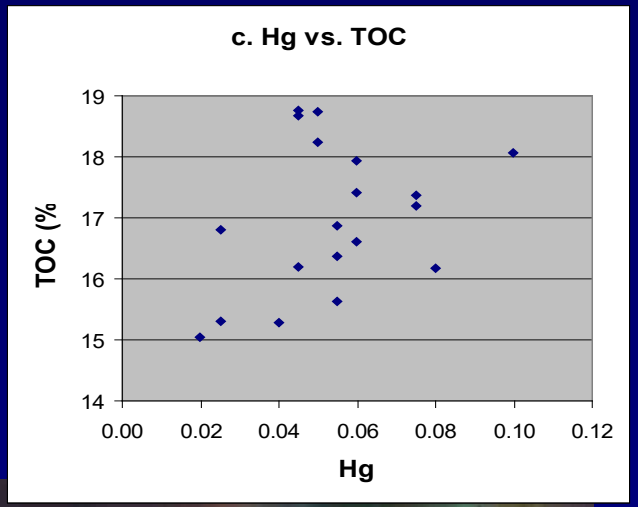


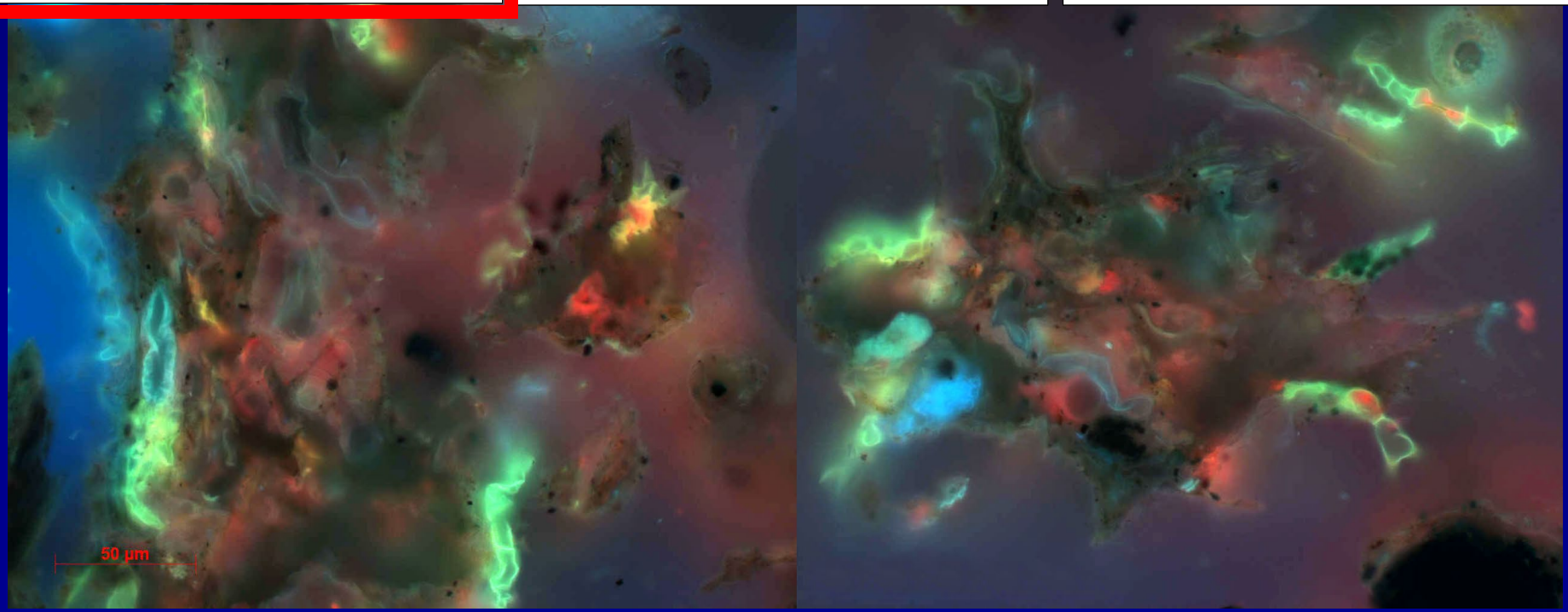
Relationship between Hg and OM Type

Wabamun Lake





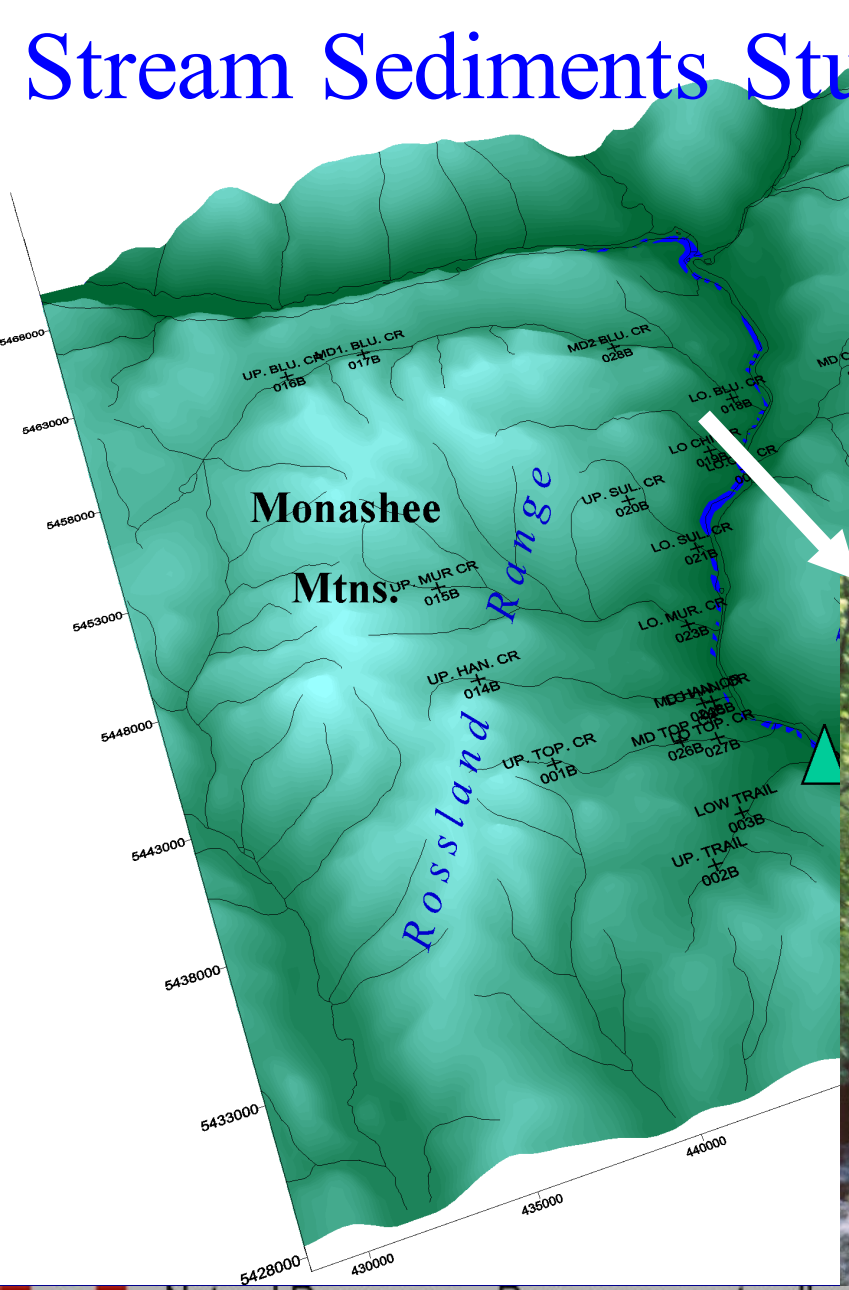


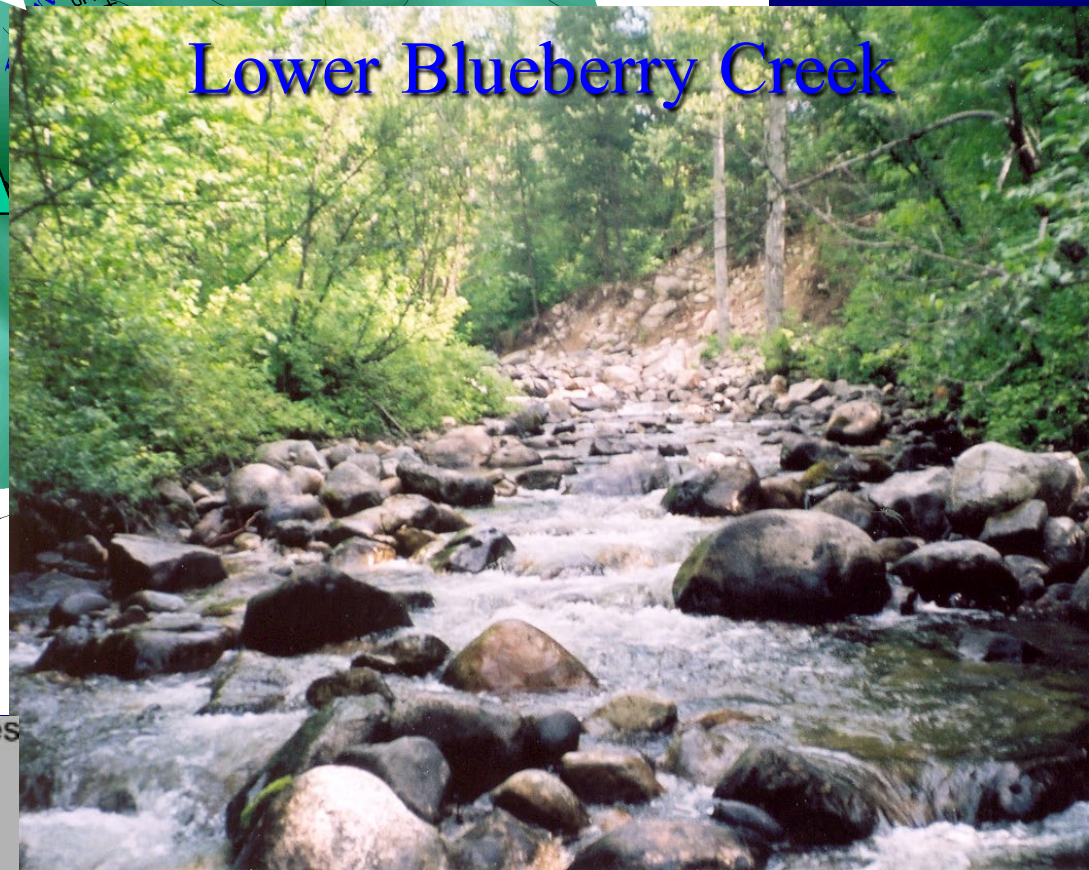


The important achievements of this study:

1. It provides a comprehensive data base on the ^{210}Pb flux & sediment age for reconstruction of the environmental history in the Wabamun area.
2. Determining the vertical distribution of elements while the anoxic condition of the sediments were preserved.
3. The spatial distribution of elements (the geographic extent of impact by the power plants on the lakes).
4. Provide compelling evidence on mobility of the elements throughout the sediment column. The results of this study modifies the way sediment profiles were interpreted in this area.
5. The overall geochemistry of the elements in the sediments and their elemental affinities.
6. The detailed SEM study, showing the variations of flyash particles and reconstructing the emission history of the power plants in the Wabamun region.
7. The rare earth elements study provides evidences confirming some of the geochemical processes described in the sediment columns.
8. The relationship between the trace elements in the sediments and type of organic matter.

Stream Sediments Study Area, Trail, B.C.





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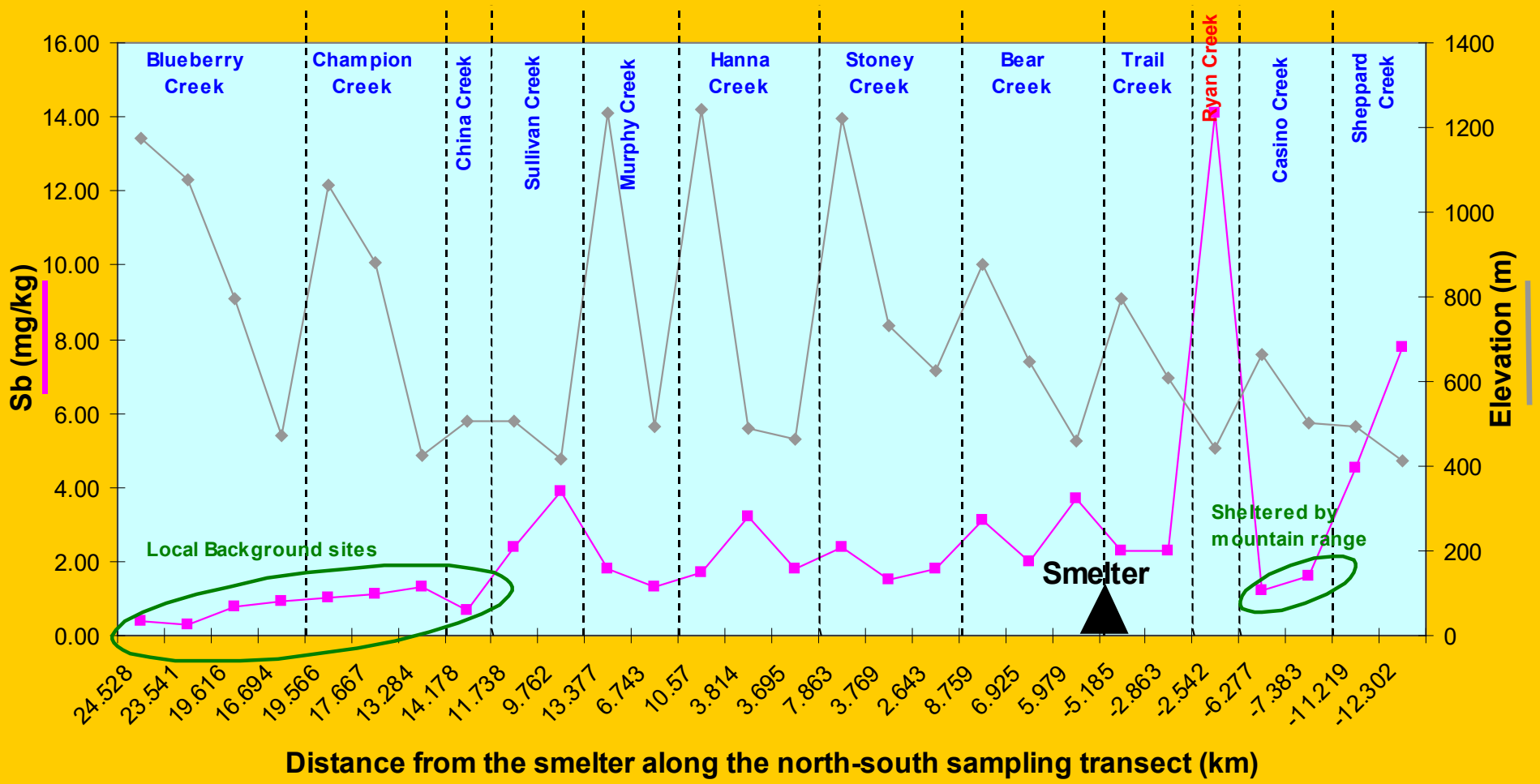
Concentration of Metals in the Stream Sediments, Trail, B.C. (Upstream of Teck-Cominco Smelter)



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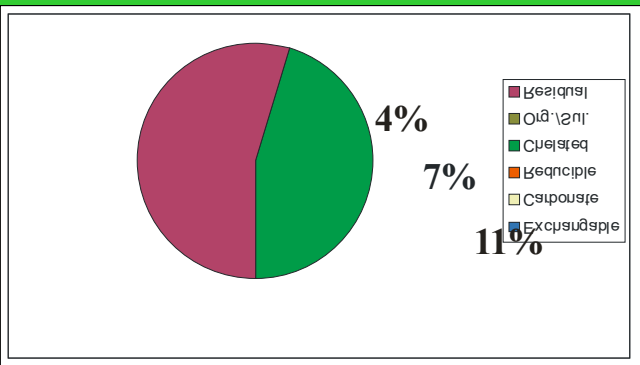
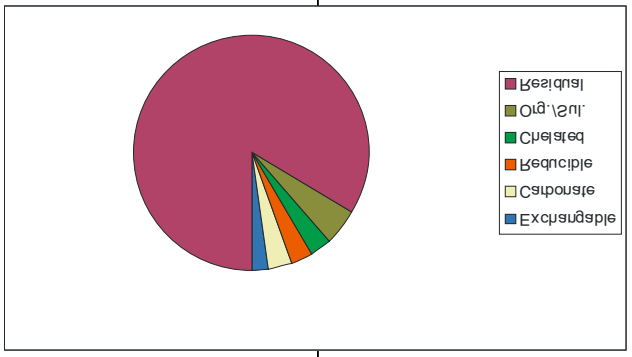
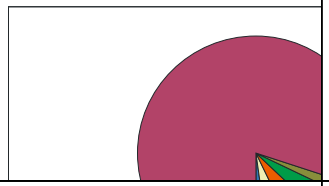
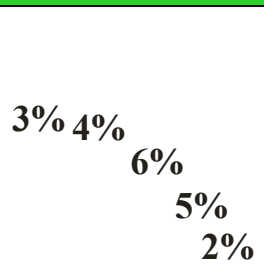
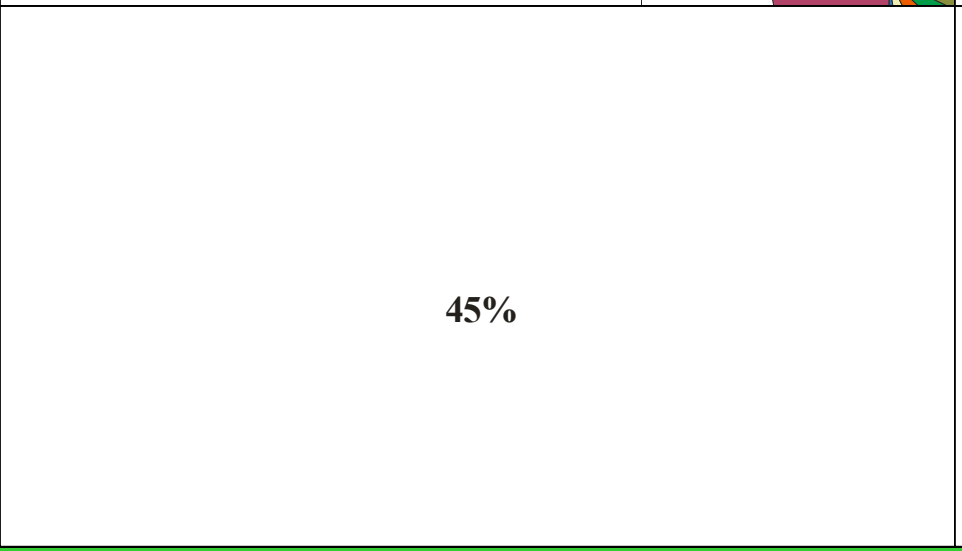
Geochemistry of the Stream Sediments
Sequential Extraction Experiment

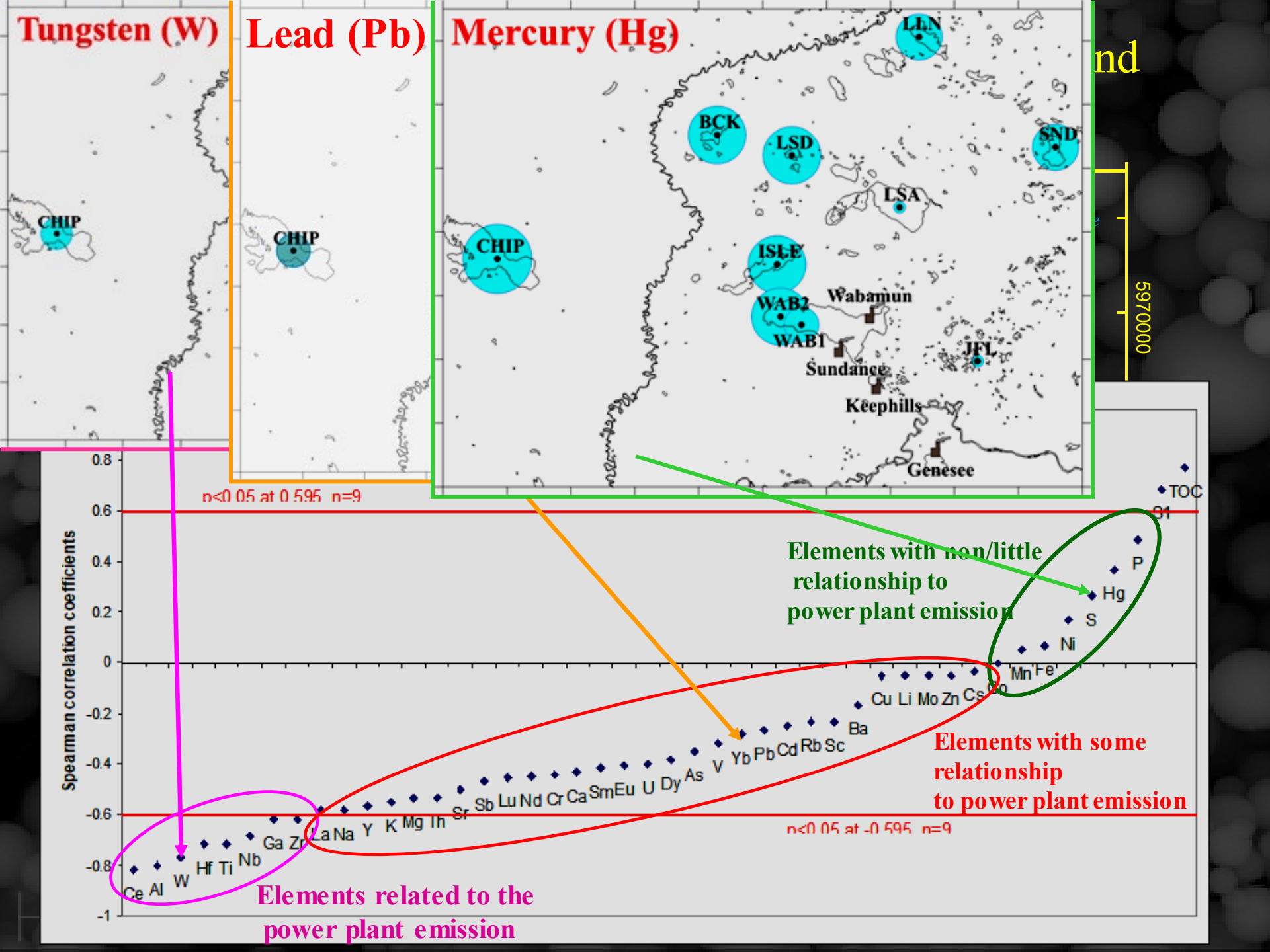











Tungsten (W)
Lead (Pb)
Mercury (Hg)
CHIP
CHIP
CHIP
BCK
LSD
LLN
SND
LSA
ISLE
WAB2
WAB1
Wabamun
Sundance
Keephills
JFL
Genesee
5970000
nd
p<0.05 at 0.595 n=9
Spearman correlation coefficients
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
Ce Al W Hf Ti Nb Ga Zr La Na Y K Mg Th Sr Sb Lu Nd Cr Ca Sm Eu U Dy As V Yb Pb Cd Rb Sc Ba Cu Li Mo Zn Cs Co Mn Fe Ni S Hg P TOC
p<0.05 at -0.595 n=9
Elements with non/little relationship to power plant emission
Elements with some relationship to power plant emission
Elements related to the power plant emission