


## Lake sediment archives of trace metal deposition in the oil sands

**Colin A Cooke** Alberta Environment and Parks & University of Alberta

**Jane L Kirk**  
**Derek C G Muir** Environment and Climate Change Canada  
**Xiaowa Wang**  
**Marlene Evans**  
**Amber Gleason**  
**Jonathan Keating**



---

---

---

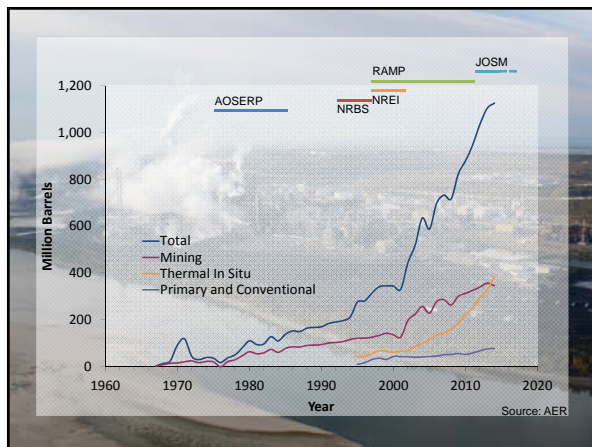
---

---

---

---

---



---

---

---

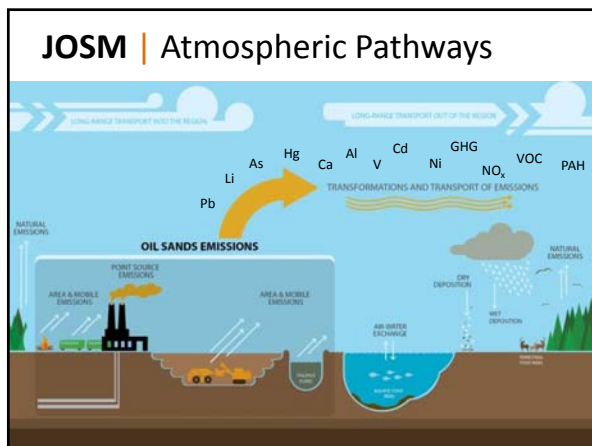
---

---

---

---

---



---

---

---

---

---

---

---

---

**Oil sands development contributes elements toxic at low concentrations to the Athabasca River and its tributaries**

Erin N. Kelly<sup>1</sup>, David W. Schindler<sup>1\*</sup>, Peter V. Hodson<sup>2</sup>, Jeffrey W. Short<sup>3</sup>, Rosanna Radmanovich<sup>1</sup>, and Charlene C. Nielsen<sup>4</sup>

<sup>1</sup>Department of Biological Sciences, University of Alberta, Edmonton, AB, Canada T6G 2E9; <sup>2</sup>Department of Biology and School of Environmental Studies, Queen's University, Kingston, ON, Canada K7L 3N6; and <sup>3</sup>Ozama, Juneau, AK 99801

Contributed by David W. Schindler, July 2, 2010 (sent for review March 2, 2010)

PNAS 2010

**ENVIRONMENTAL Science & Technology** Article  
pubs.acs.org/est  
ES&T 2014

**Sphagnum Mosses from 21 Ombrotrophic Bogs in the Athabasca Bituminous Sands Region Show No Significant Atmospheric Contamination of "Heavy Metals"**

William Shoty<sup>1,\*</sup>, Rene Belland<sup>1</sup>, John Duke<sup>2</sup>, Heike Kemper<sup>3</sup>, Michael Krachler<sup>1</sup>, Tommy Noernberg<sup>4</sup>, Rick Pelletier<sup>1</sup>, Melanie A. Vile<sup>2</sup>, Kelman Wieder<sup>5</sup>, Claudio Zaccone<sup>1,6</sup>, and Shuangquan Zhang<sup>1,4</sup>

---

---

---

---

---

---

---

---

---

---

---

---




---

---

---

---

---

---

---

---

---

---

---

---

**Study Sites**

- Lakes (and watersheds) span a range of environmental gradients
- >15 years of lake water monitoring data
- Grouped according to distance from AR6
  - near-field (<20 km)
  - mid-field (20–50 km)
  - far-field (>50 km)

---

---

---

---

---

---

---

---

---

---

---

---

## Analyses | Dating & Geochemistry

- 3 sediment cores collected per lake ("A, B, C")
- Cores extruded at 0.5-cm intervals from 0-20 cm depth; 1-cm intervals below
- $^{210}\text{Pb}$  &  $^{137}\text{Cs}$  dating to relate depth to time
- $n=46$  elements by ICPMS
- PAHs, Hg, Chl-a, %C, %N,  $\delta^{13}\text{C}$ ,  $\delta^{15}\text{N}$ , diatoms, black carbon




---

---

---

---

---

---

---

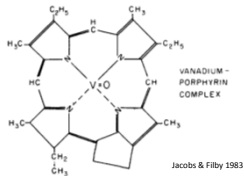
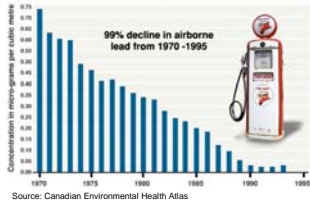
---

---

---

## 3 key elements

Canadian trends in means concentration of lead in air



Source: Canadian Environmental Health Atlas

**ENVIRONMENTAL Science & Technology**

Atmospheric Deposition of Mercury and Methylmercury to Landscapes and Waterbodies of the Athabasca Oil Sands Region

Jane L. Kirk,<sup>1</sup> Derek C. G. Muir,<sup>2</sup> Amber Gleason,<sup>1</sup> Xiaowu Wang,<sup>3</sup> Greg Lawson,<sup>3</sup> Richard A. Frank,<sup>1</sup> Igor Lehenbert,<sup>1</sup> and Fred Wrona<sup>3</sup>

---

---

---

---

---

---

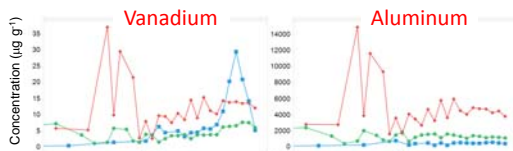
---

---

---

---

## Concentration and flux



- Clear relationship between V and Al in far-field sites
- Temporal and spatial variability in both concentration and flux among and within near-, mid-, and far-field sites
- Clear increase in near-field sites independent of Al

---

---

---

---

---

---

---

---

---

---

### Enrichment factors & flux ratios

- $EF = (TE/Al)_i / (TE/Al)_{pre-1900}$ 
  - A standard way to normalize for the erosional input of inorganic (mineral) matter
- Flux ratio =  $(TE_{flux})_i / Avg(TE_{flux})_{pre-1900}$ 
  - Provides a measure of flux increase relative to each site-specific background

---

---

---

---

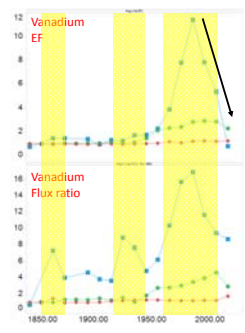
---

---

---

---

### Enrichment factors & flux ratios



- EF and flux ratio do not always agree... integrate different processes
- Early increase in near-field V flux ratios likely due to lithogenic input
- Clear post-1960 increase in near-field sites
- Post-1980s decrease to near-field sites

---

---

---

---

---

---

---

---



---

---

---

---

---

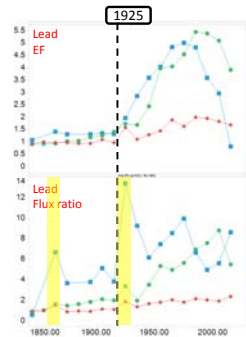
---

---

---

### Enrichment factors & flux ratios

- Similar late 19<sup>th</sup> century and early 20<sup>th</sup> century increases in flux
- Early increase in EF in near- and mid-field sites, ~5-fold in both
- Regional enhancement above global Pb pollution




---

---

---

---

---

---

---

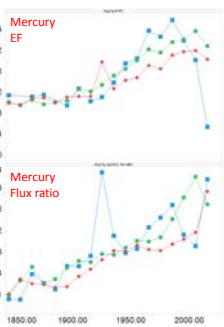
---

---

---

### Enrichment factors & flux ratios

- Secular 20<sup>th</sup> century 2- to 3-fold increase among sites
- No evidence for oil sands impact
- Similar to lake sediment cores from across North America (Drevnick et al. in press)




---

---

---

---

---

---

---

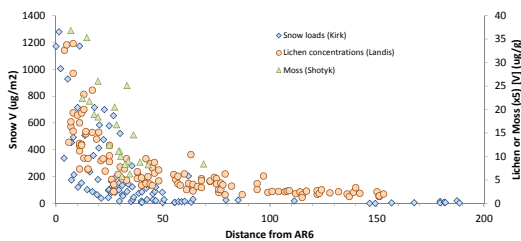
---

---

---

### Integrating archives

- Increase in vanadium enrichment evident closer to open-pit mines regardless of media



Landis et al. 2012; Kirk et al. 2014; Shotyky et al. 2014

---

---

---

---

---

---

---

---

---

---

**Conclusions | 1**

- Clear spatial pattern of “heavy metal” contamination in the Athabasca oil sands region



---

---

---

---

---

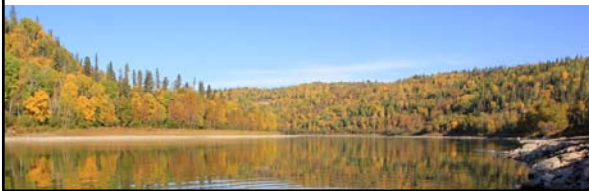
---

---

---

**Conclusions | 2**

- Regional impact extends beyond those elements that are enriched in bitumen (i.e., V)
- A change in emission sources through time from stacks to fugative dust



---

---

---

---

---

---

---

---



**Questions?**

---

---

---

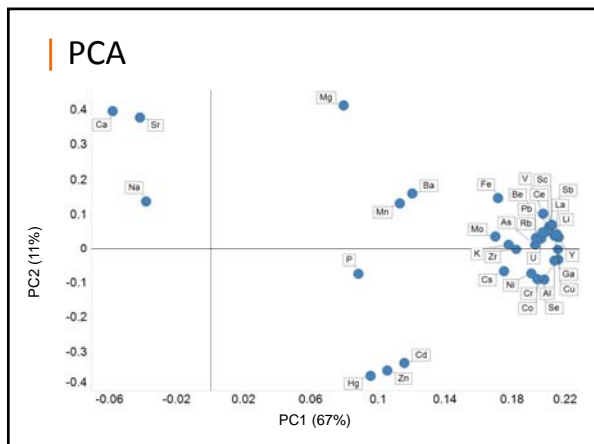
---

---

---

---

---




---

---

---

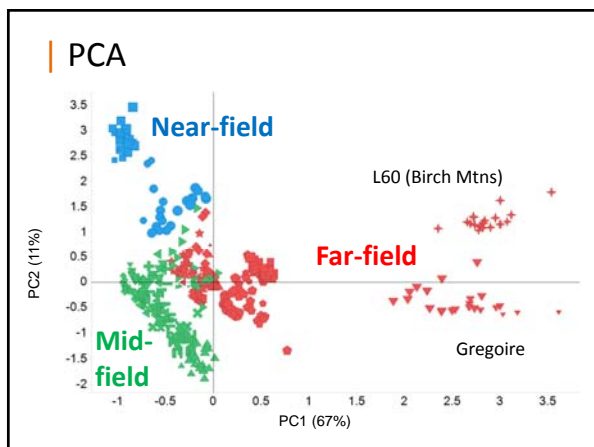
---

---

---

---

---




---

---

---

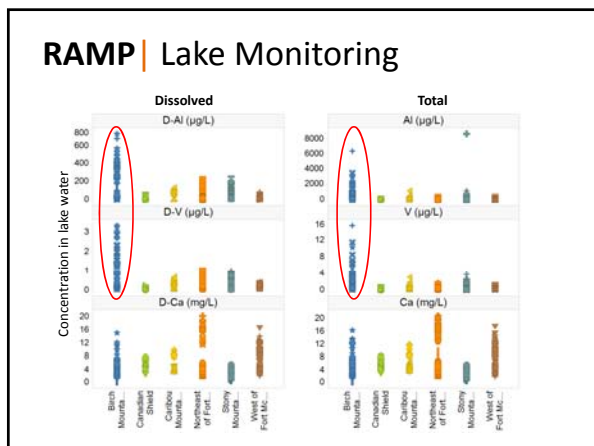
---

---

---

---

---




---

---

---

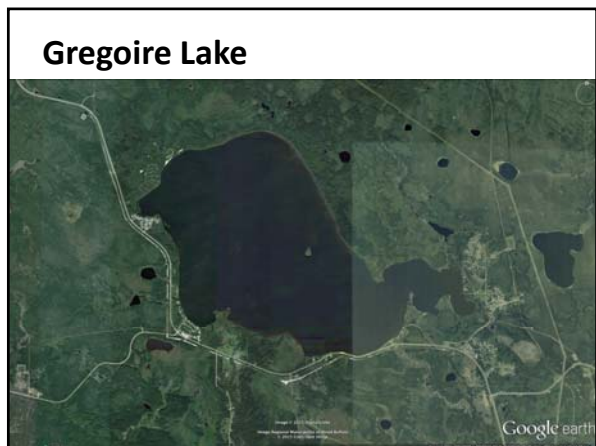
---

---

---

---

---



---

---

---

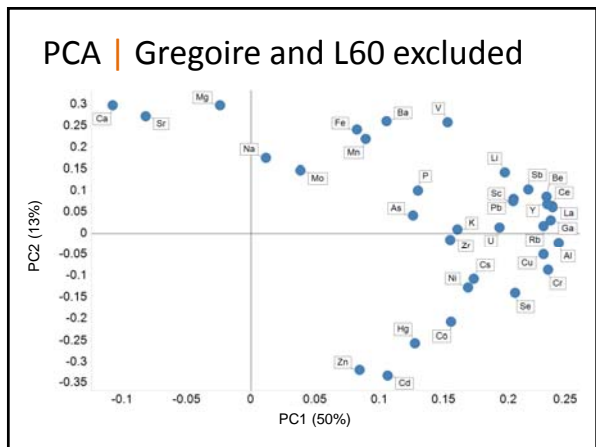
---

---

---

---

---



---

---

---

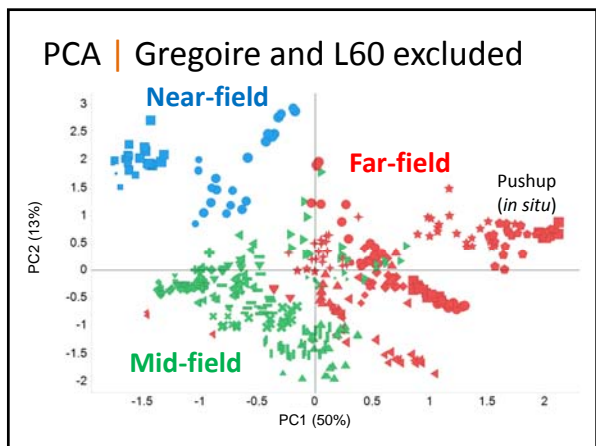
---

---

---

---

---



---

---

---

---

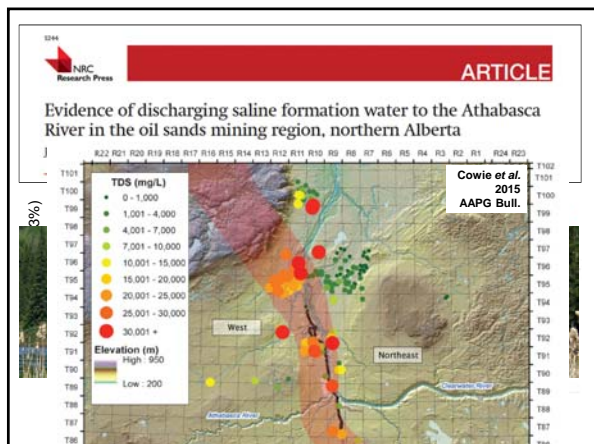
---

---

---

---





---

---

---

---

---

---

---

---