The Science Behind the Debate: Mining in the Bad River Watershed

A Presentation at:

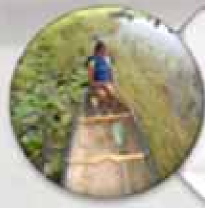
Lakes Partnership Convention

April 11th, 2013

Cyrus Hester

Bad River Band Natural Resources
Environmental Program

Outline



- A People and a Place

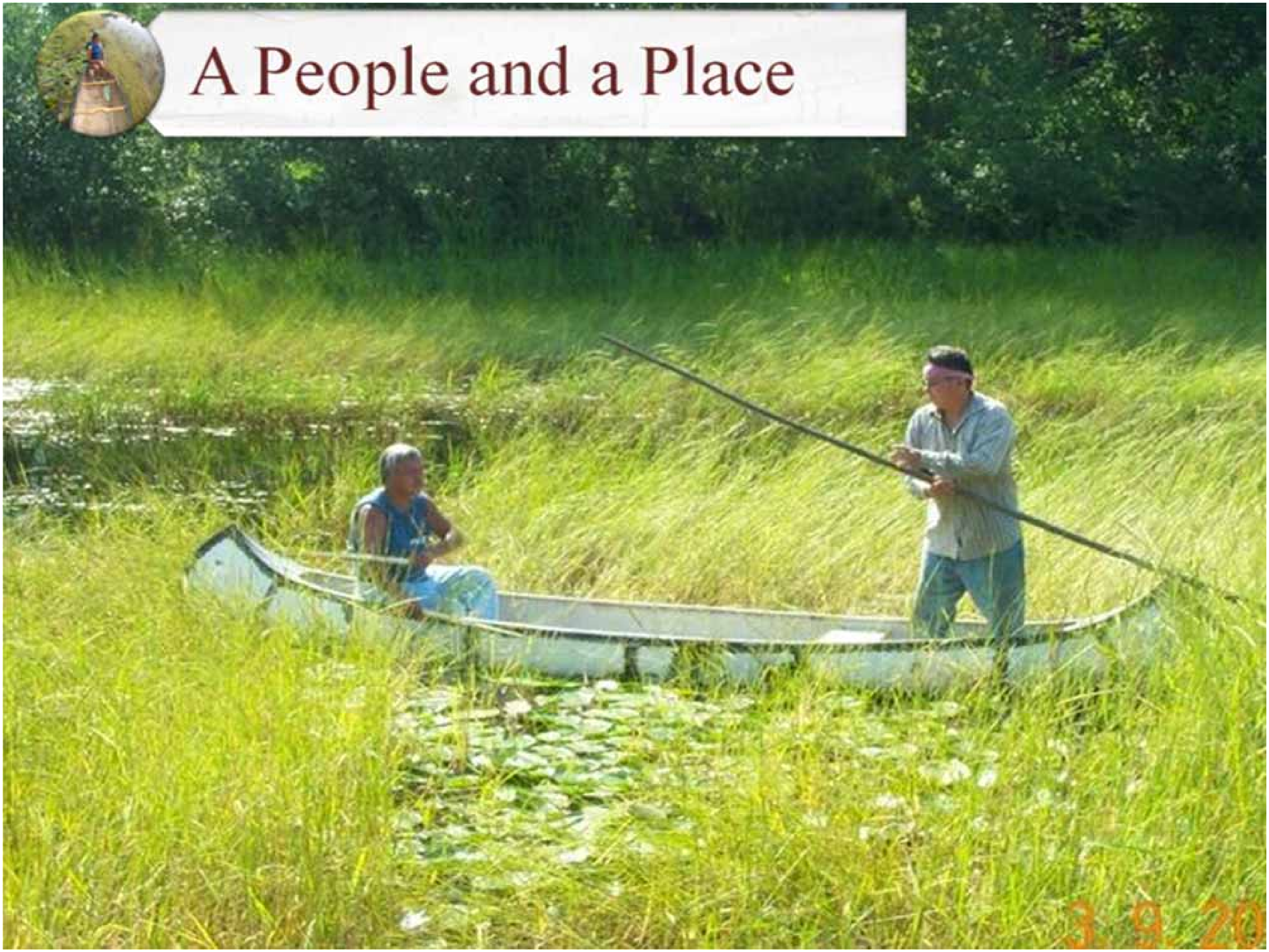
- Of the Earth

- Lands and Waters

- Down to Earth

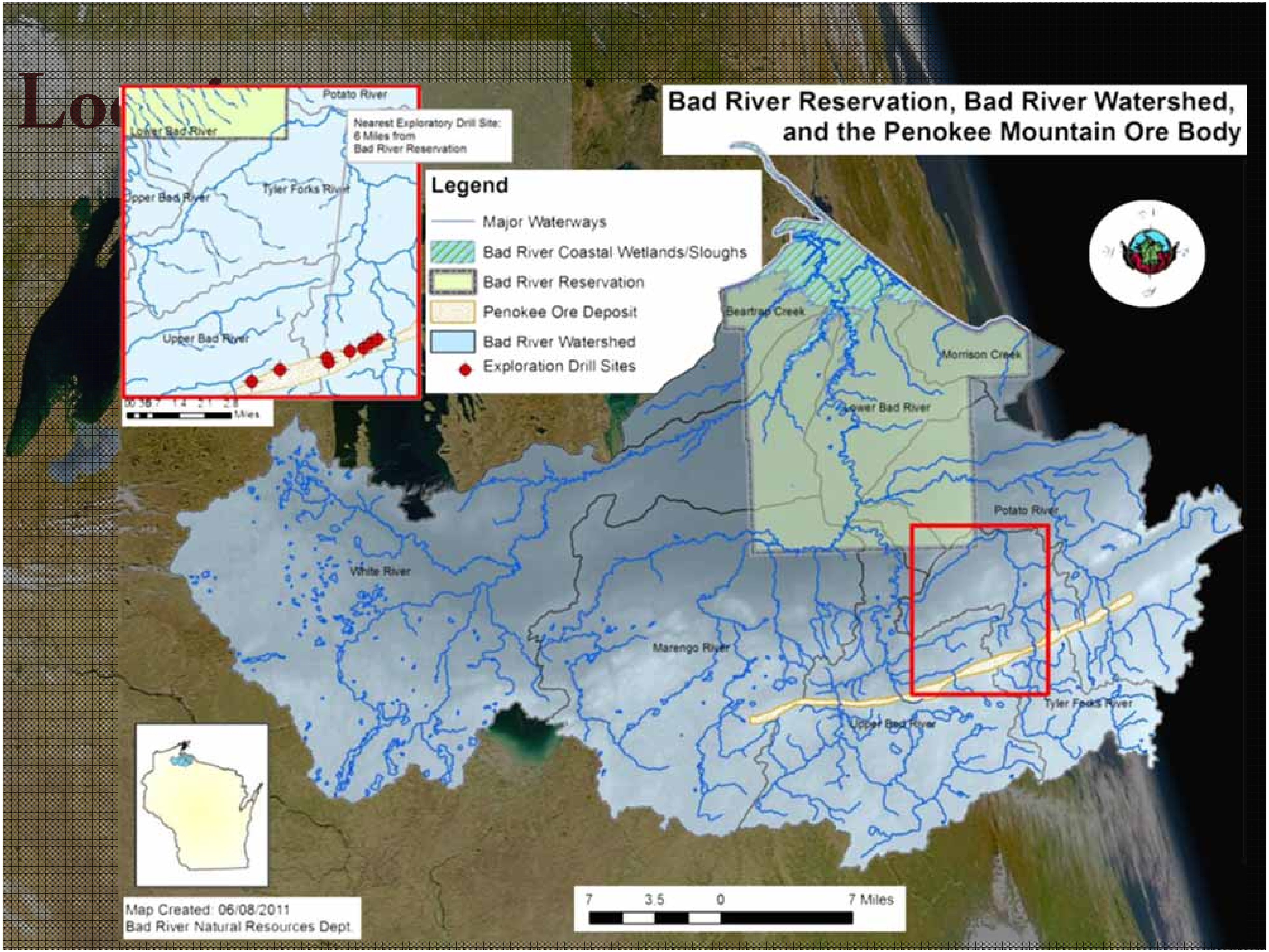
- Dollars and Sense

A People and a Place

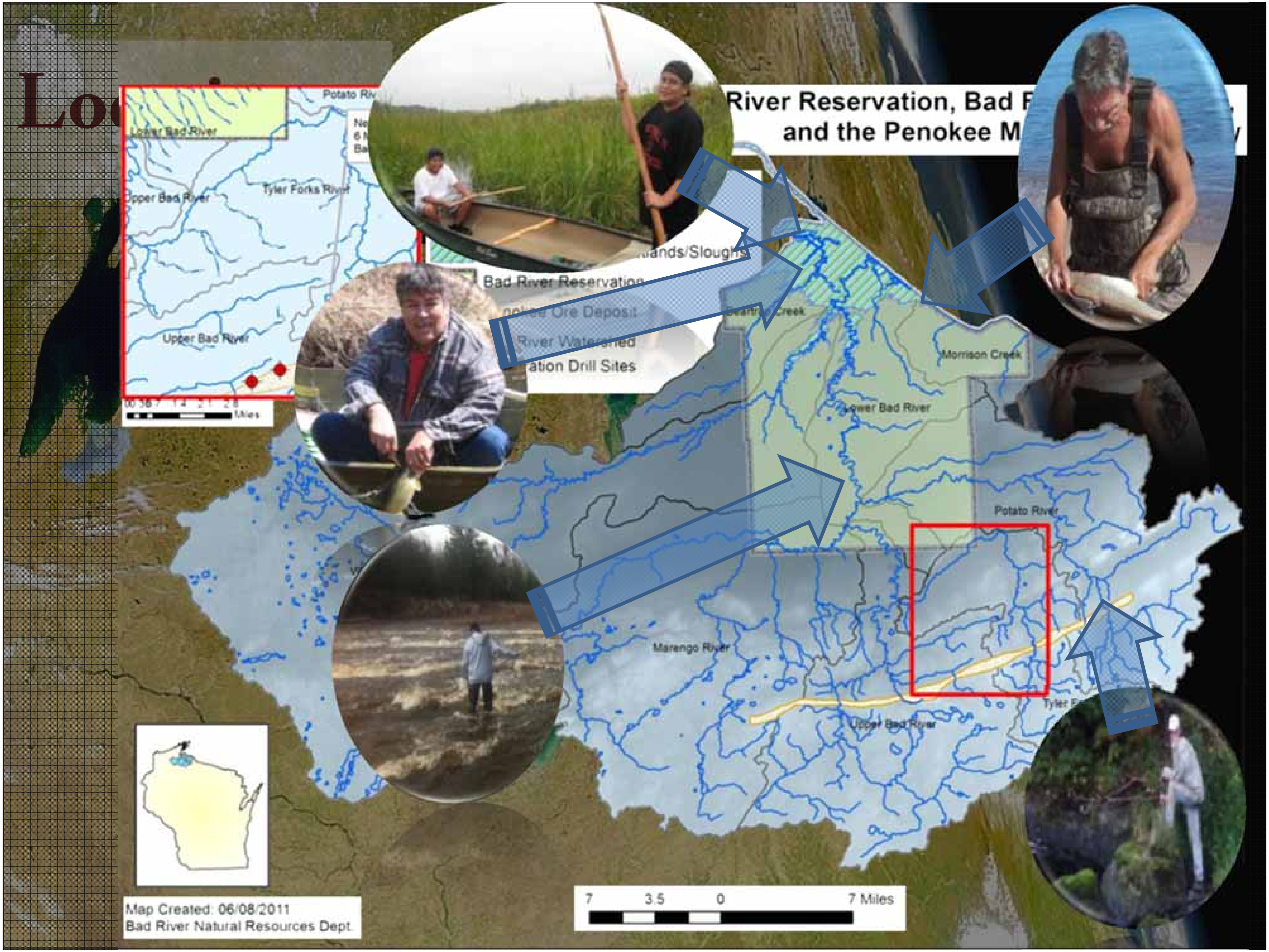


Location

Stock Photo Credit: NASA



Bad River Reservation, Bad River Watershed, and the Penokee Mountain Ore Body
Legend
Major Waterways
Bad River Coastal Wetlands/Sloughs
Bad River Reservation
Penokee Ore Deposit
Bad River Watershed
Exploration Drill Sites
Nearest Exploratory Drill Site: 6 Miles from Bad River Reservation
Potato River
Lower Bad River
Upper Bad River
Tyler Forks River
Beartrap Creek
Morrison Creek
White River
Marengo River
7 3.5 0 7 Miles
Miles
Map Created: 06/08/2011
Bad River Natural Resources Dept.



Potato River
Lower Bad River
Upper Bad River
Tyler Forks River
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Miles
and the Penokee M
Bad River Reservation
Beartrap Creek
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7 3.5 0 7 Miles


Photo Credit: M. Wiggins Jr.

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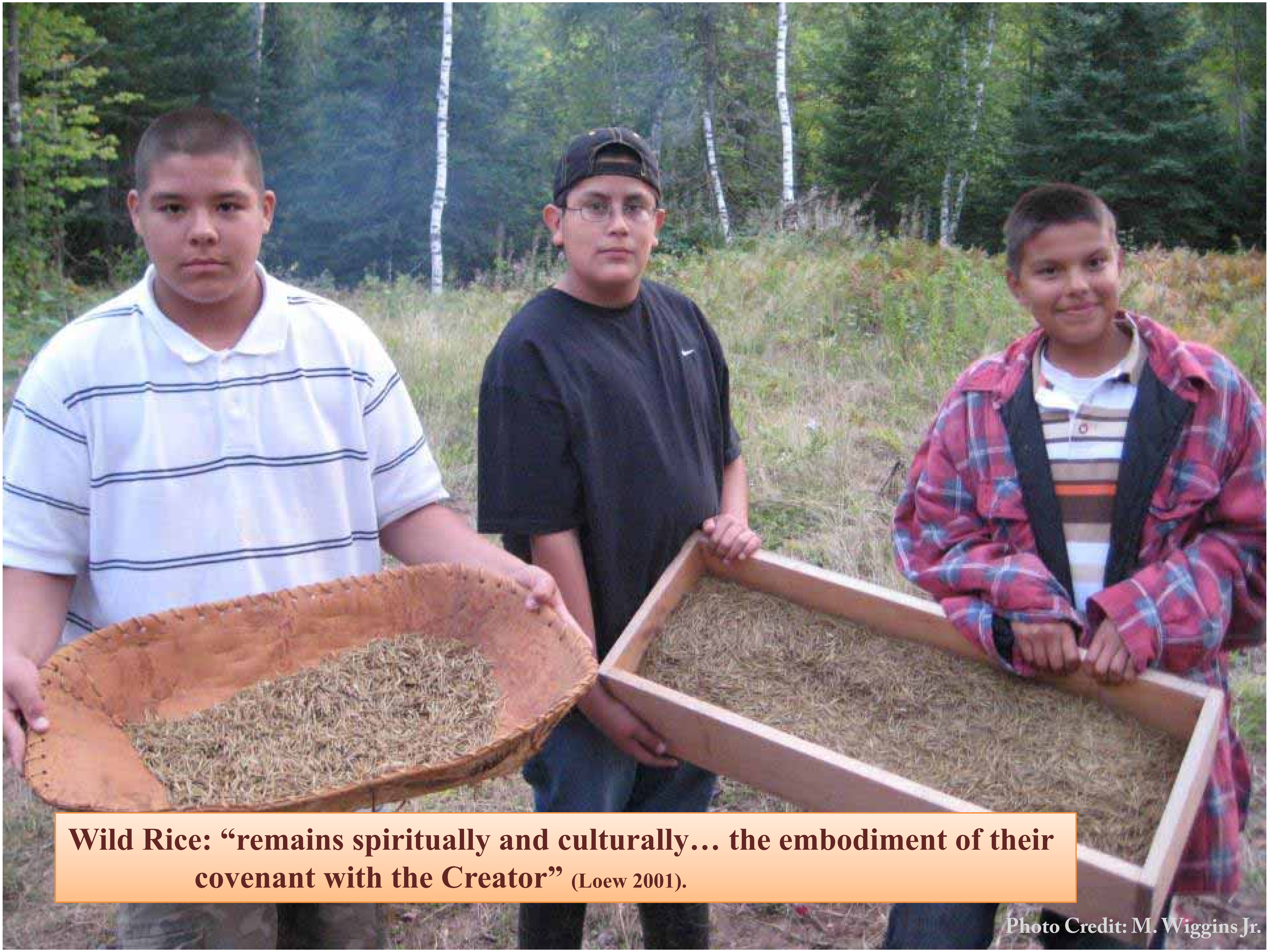

Wild Rice: “remains spiritually and culturally… the embodiment of their covenant with the Creator” (Loew 2001).

Photo Credit: M. Wiggins Jr.

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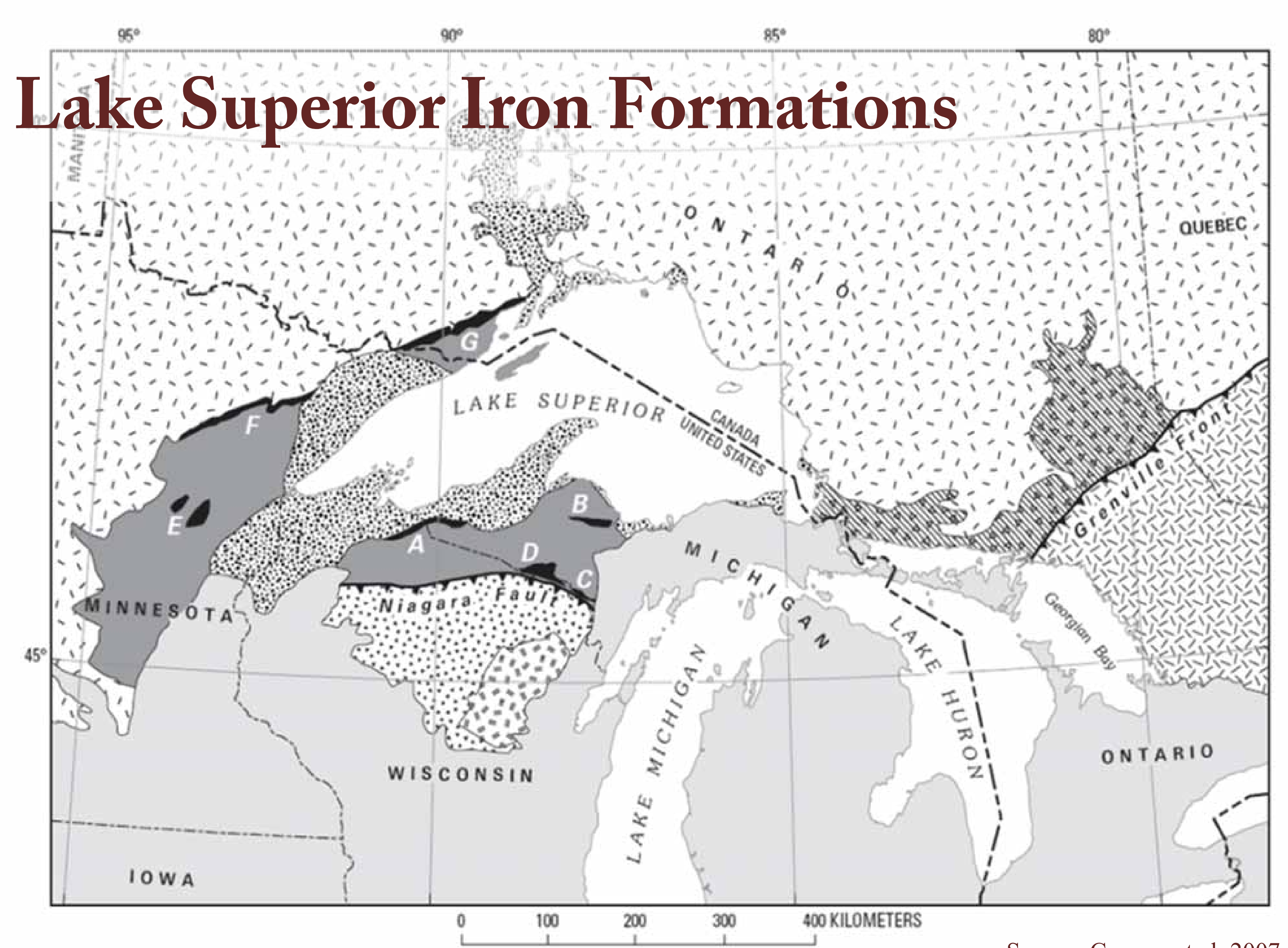
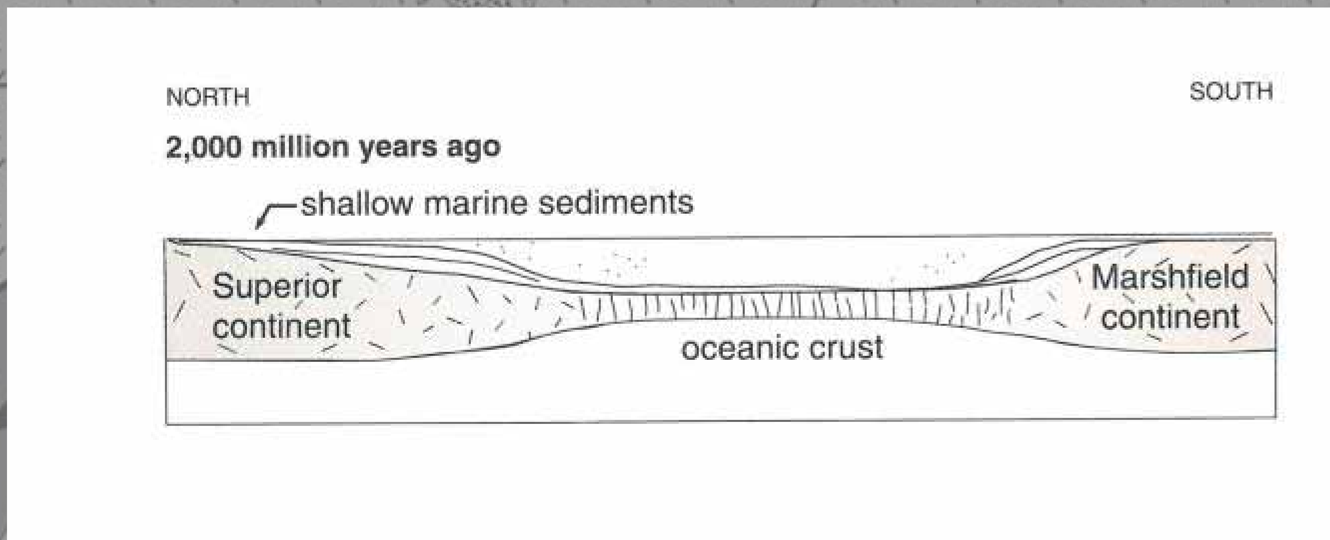
Of the Earth

Lake Superior Iron Formations



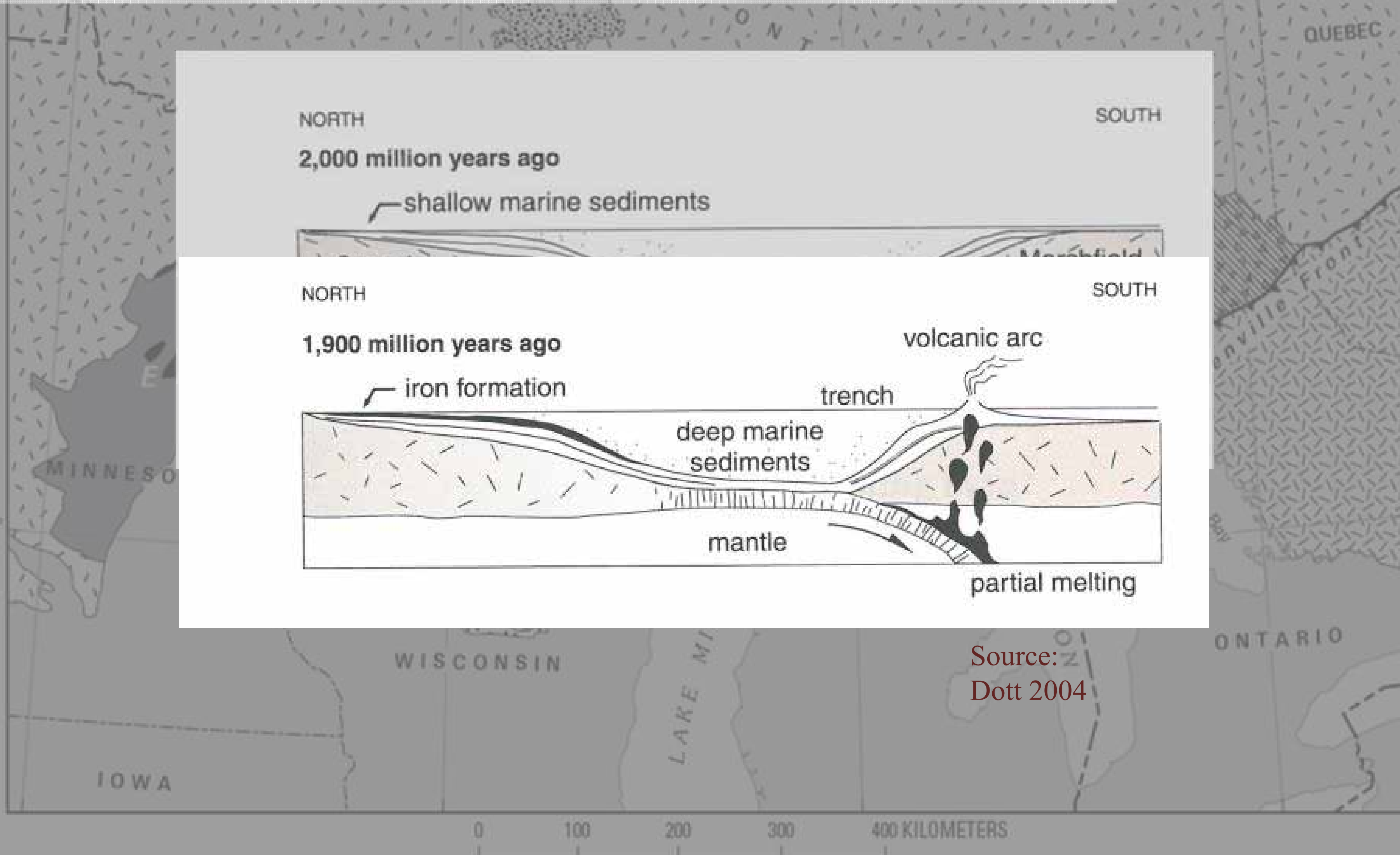
Source: Cannon et al. 2007

Lake Superior Iron Formations



Source:
Dott 2004

Lake Superior Iron Formations



Source:
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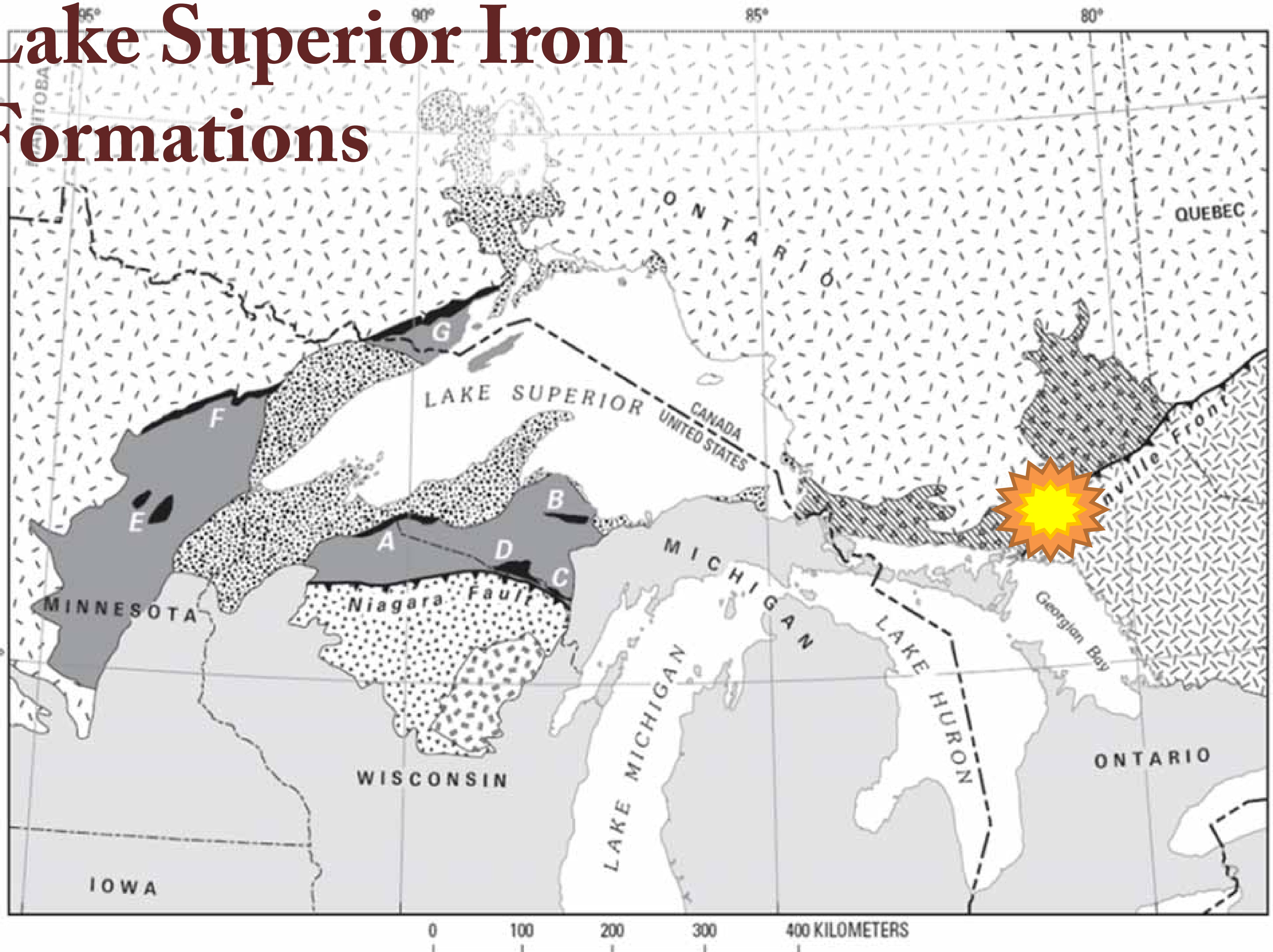
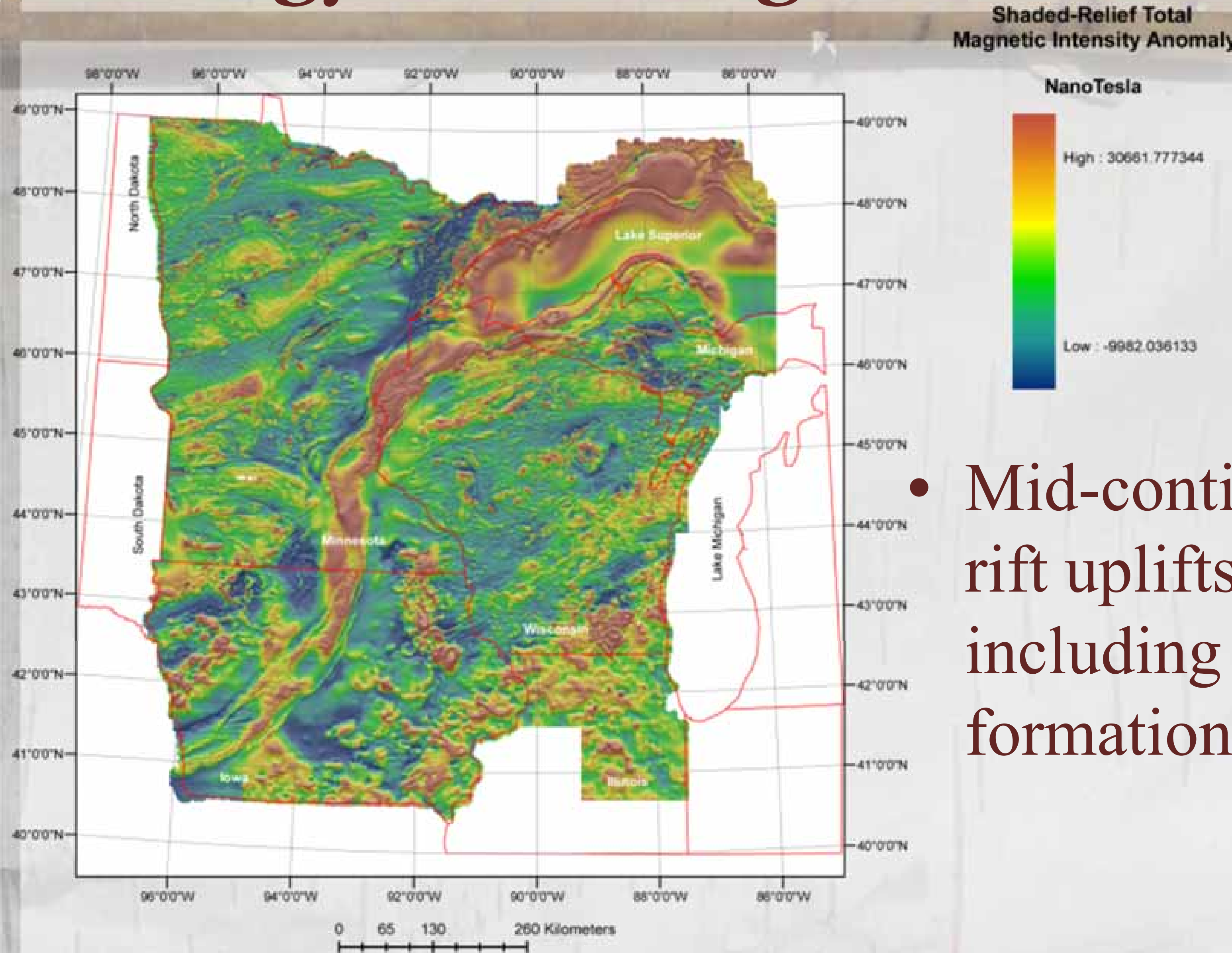
Lake Superior Iron Formations



Source: Cannon et al. 2007

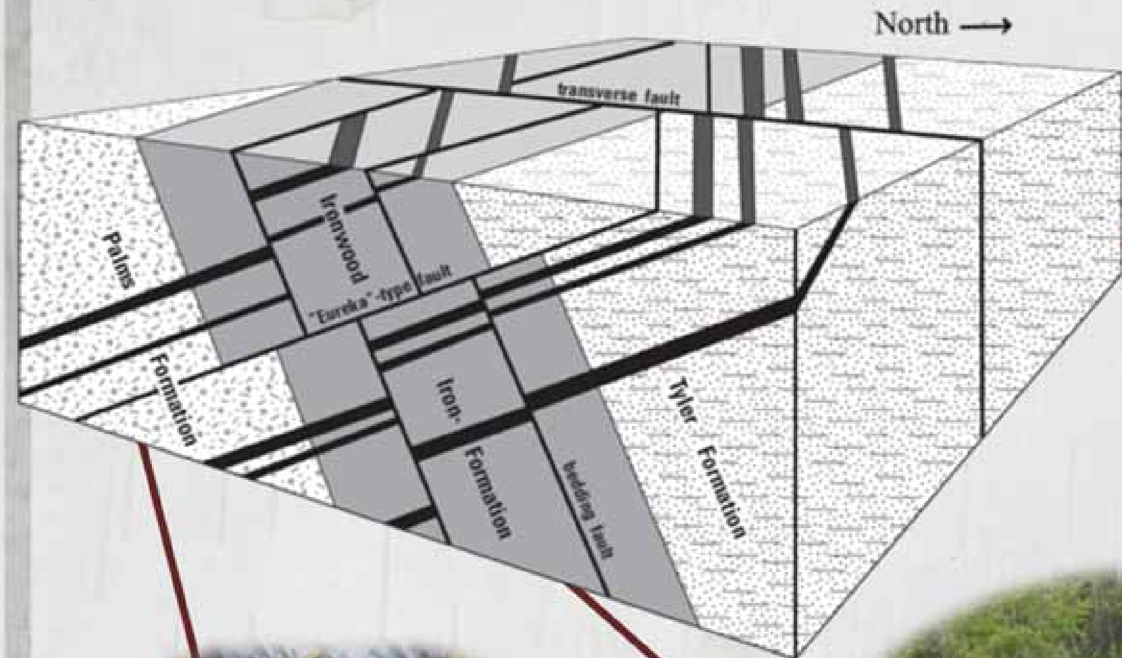
Geology of the Gogebic



- Mid-continental rift uplifts rocks; including iron formation

Source:
Daniels & Snyder

Geology of the Gogebic



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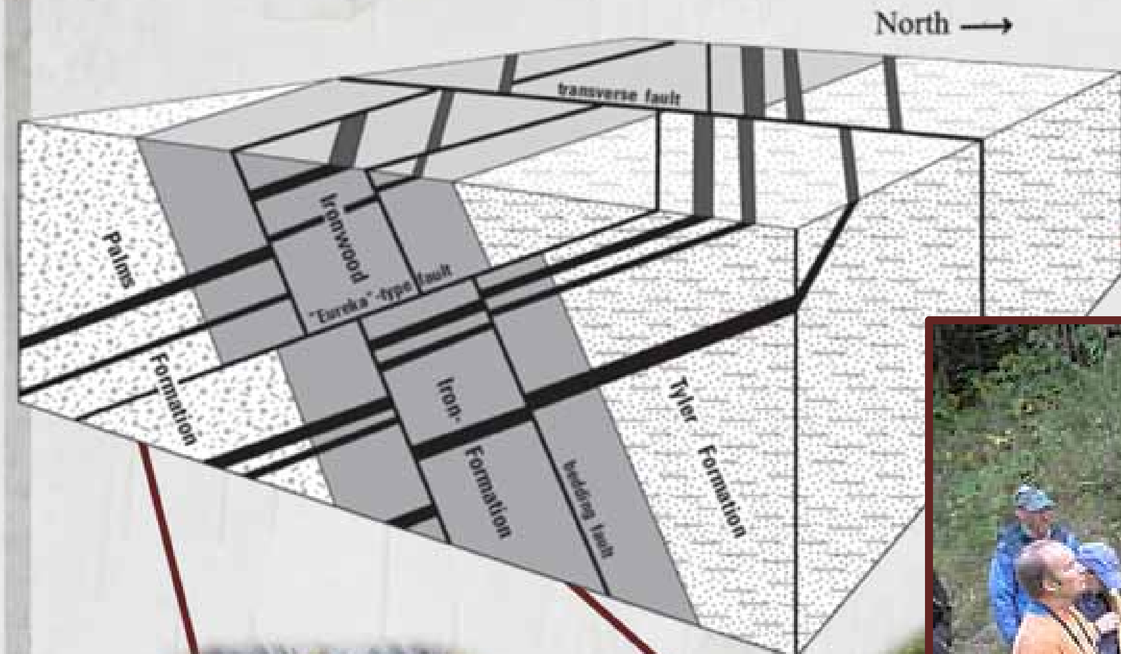
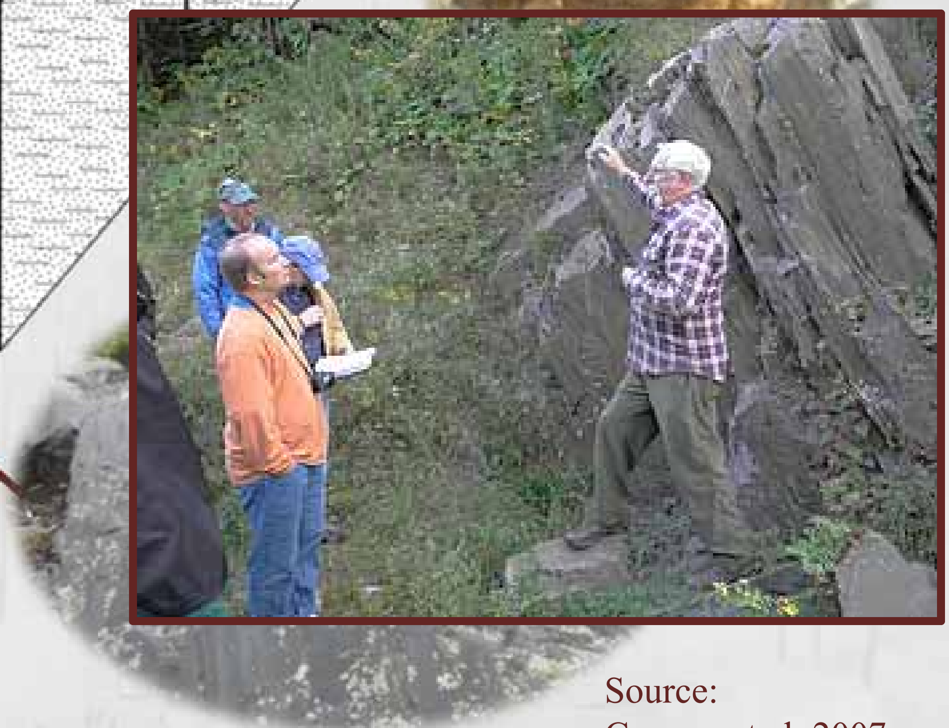
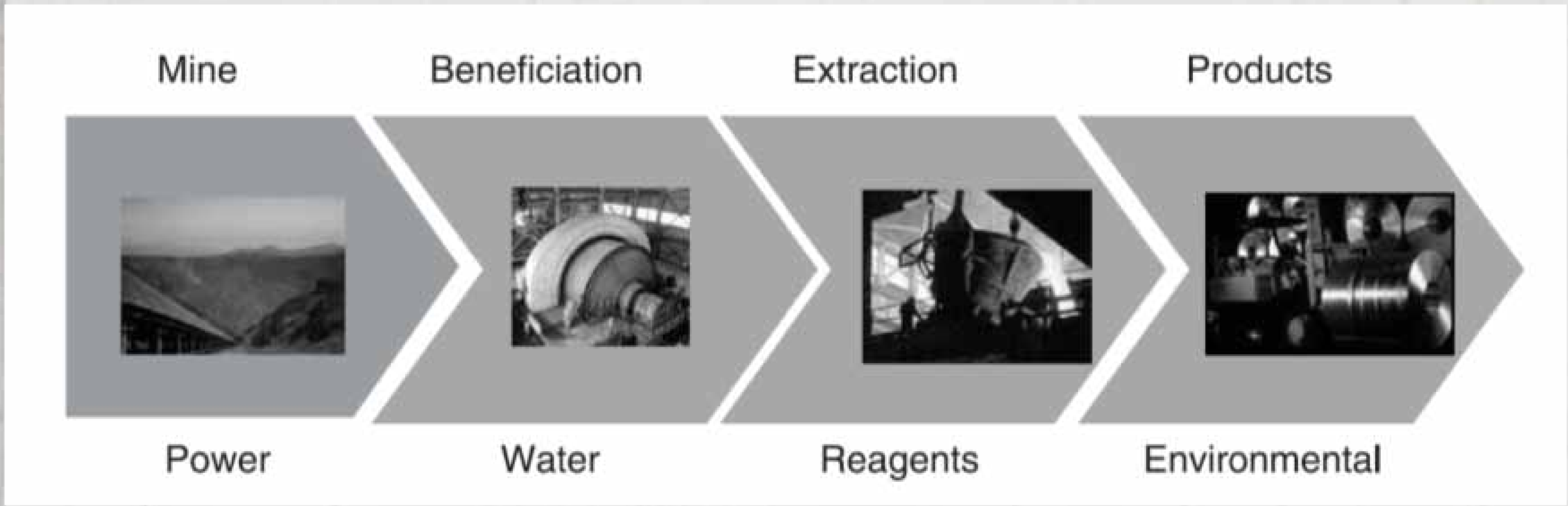




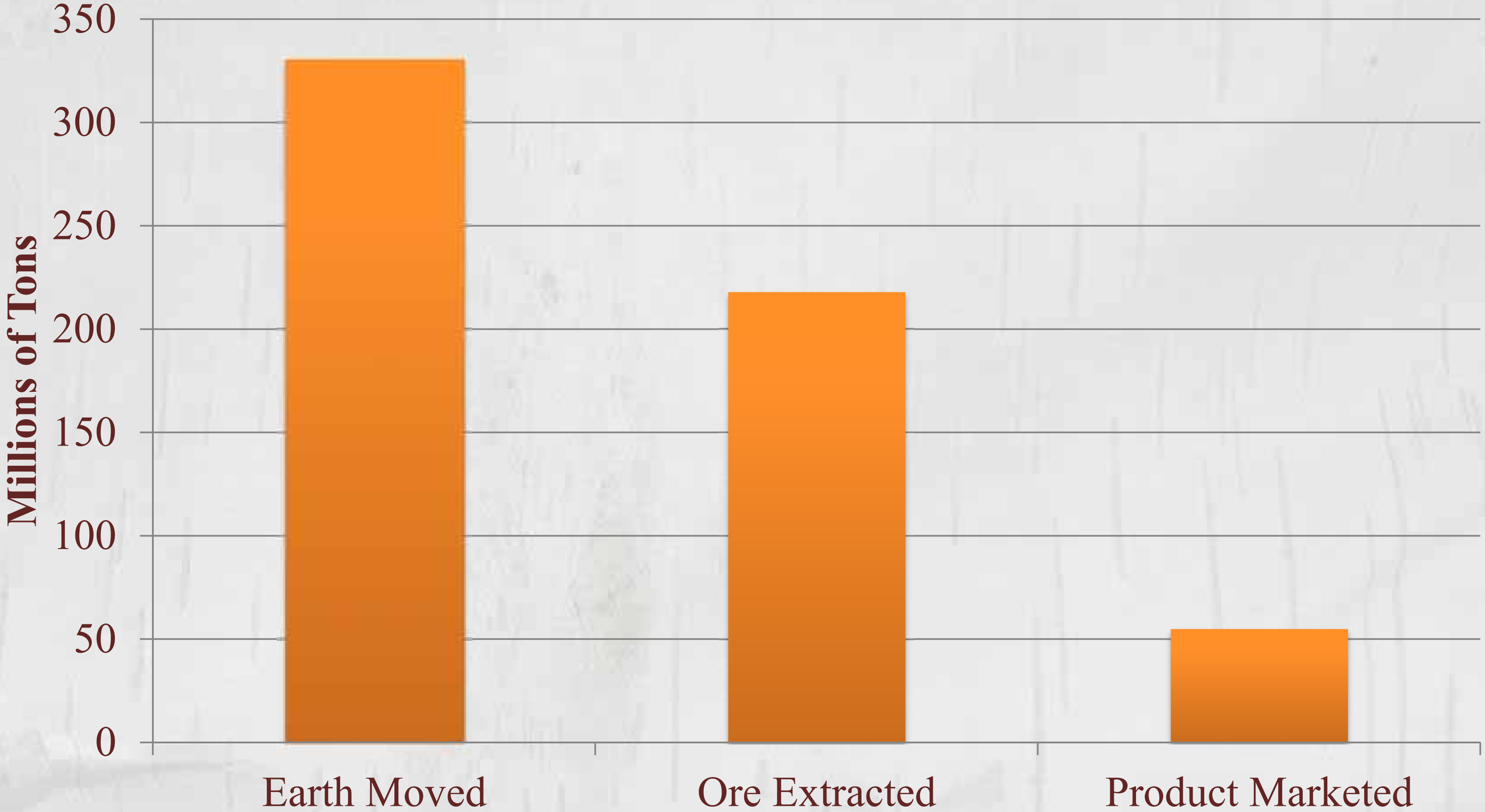
Source:
Cannon et al. 2007

The Mining Process



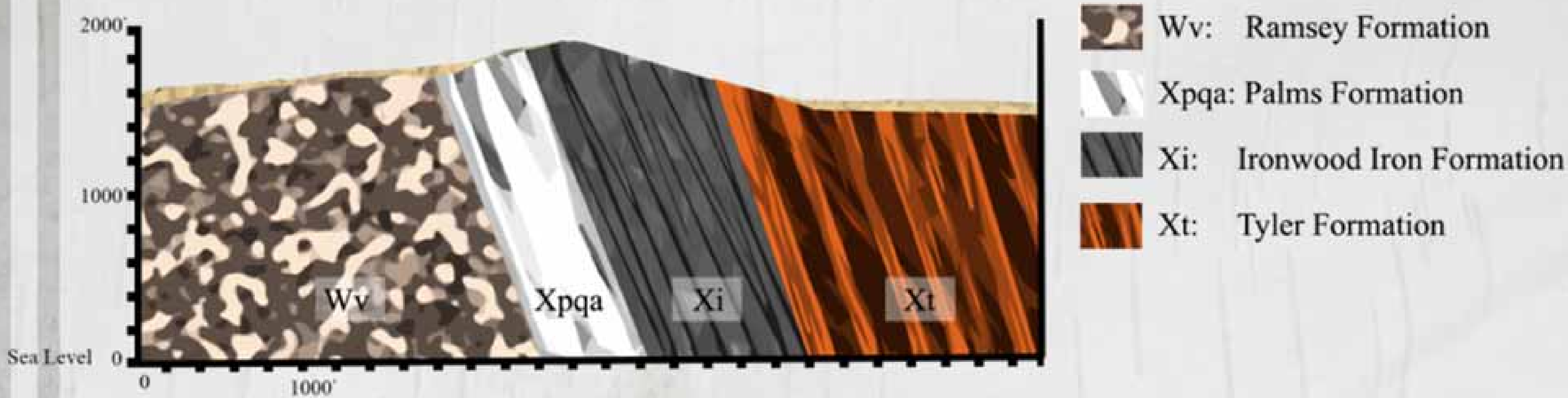
Source: Dowling & Marsden 2004

Extraction : Product Ratio

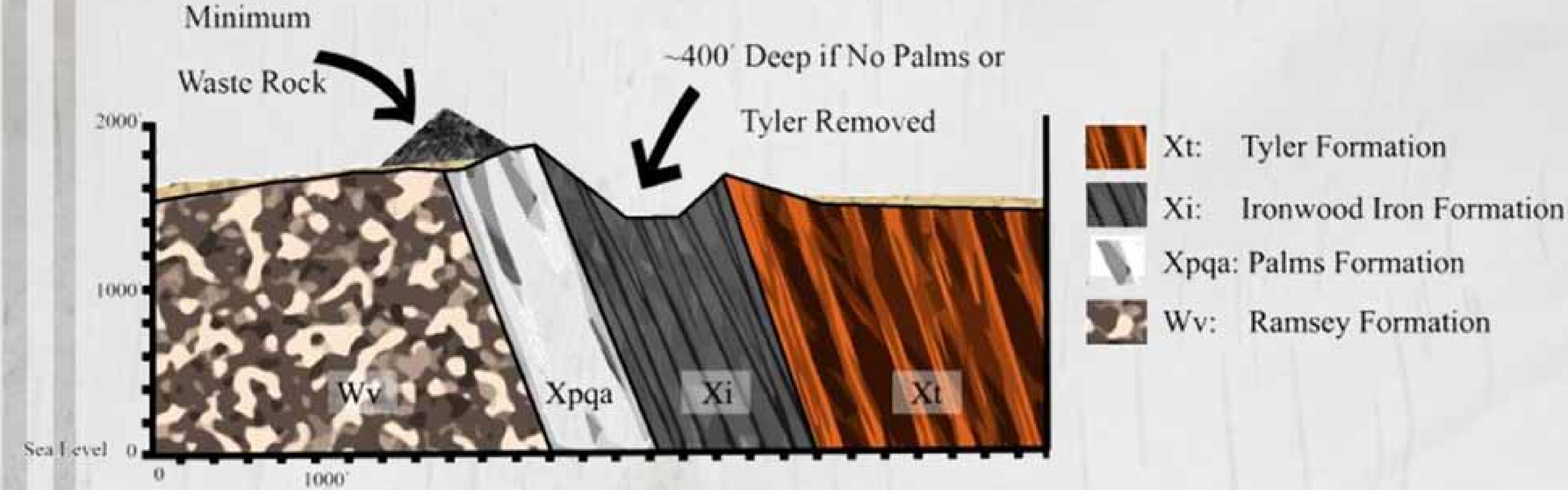


Source: EPA 1994a

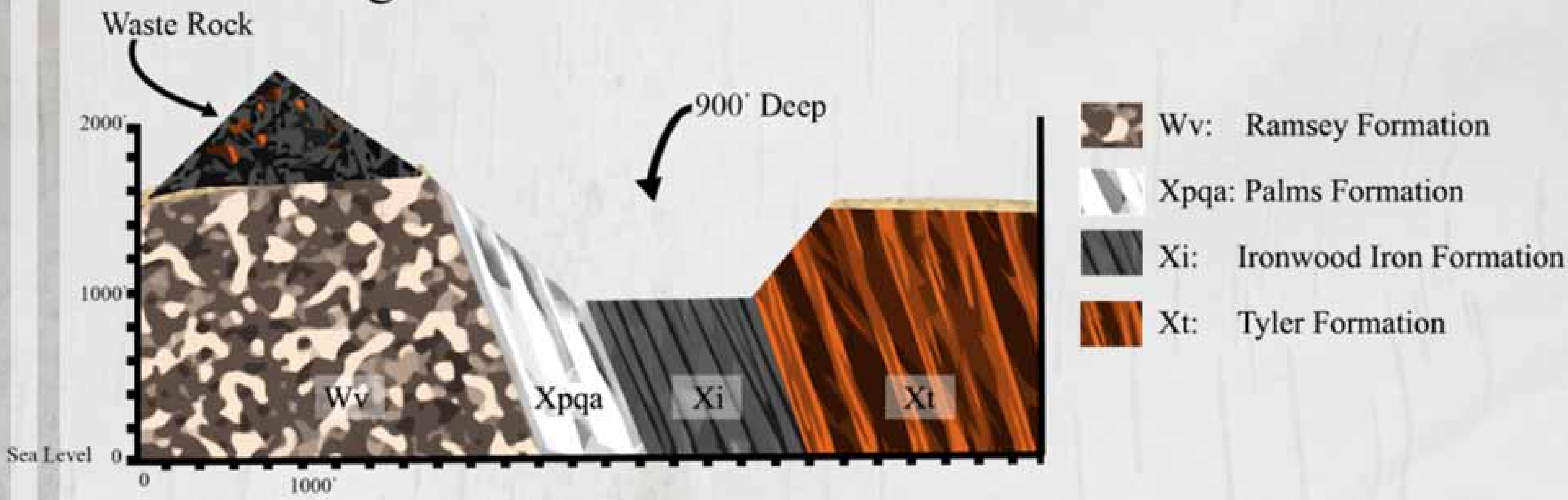
Extant Geology and Land Surface



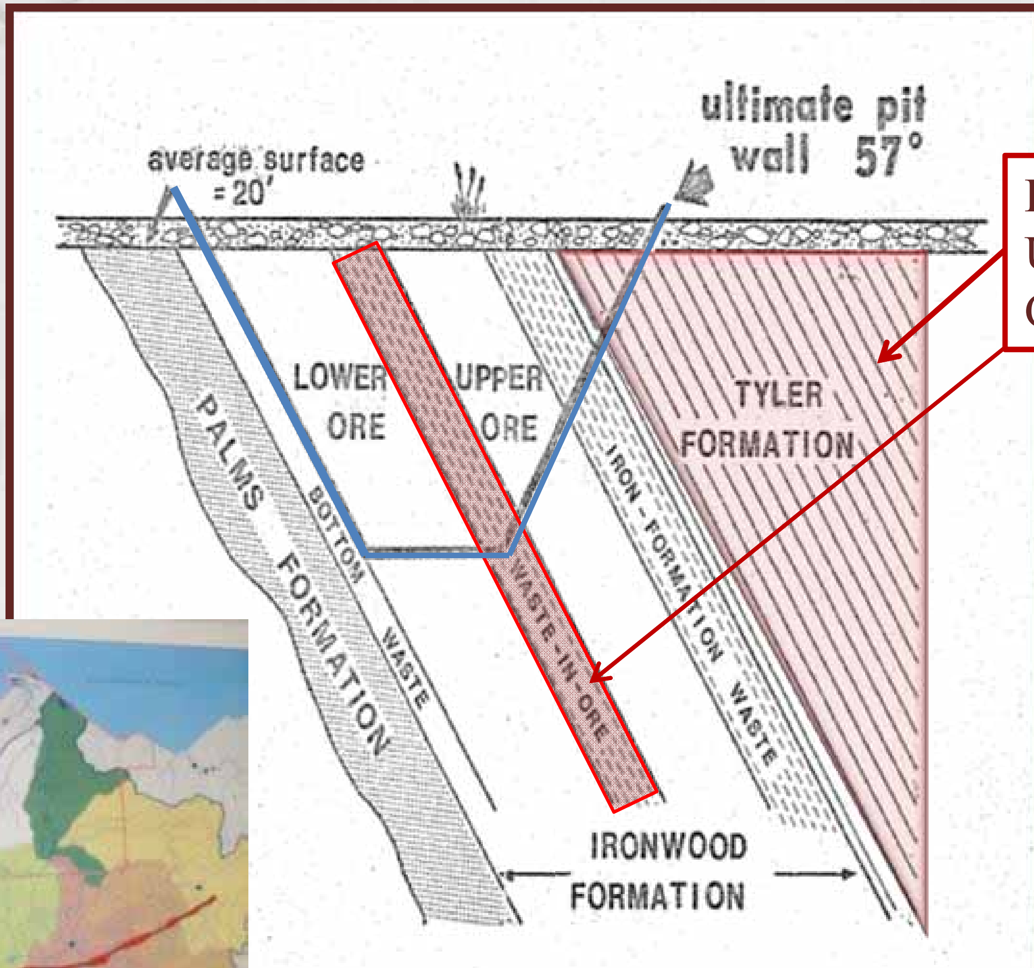
"Small-Mine" Cross Section



"Big-Mine" Cross Section



Pyrite In the Gogebic



Pyritic Shale of Unknown Concentrations

Source:
Marsden 1978

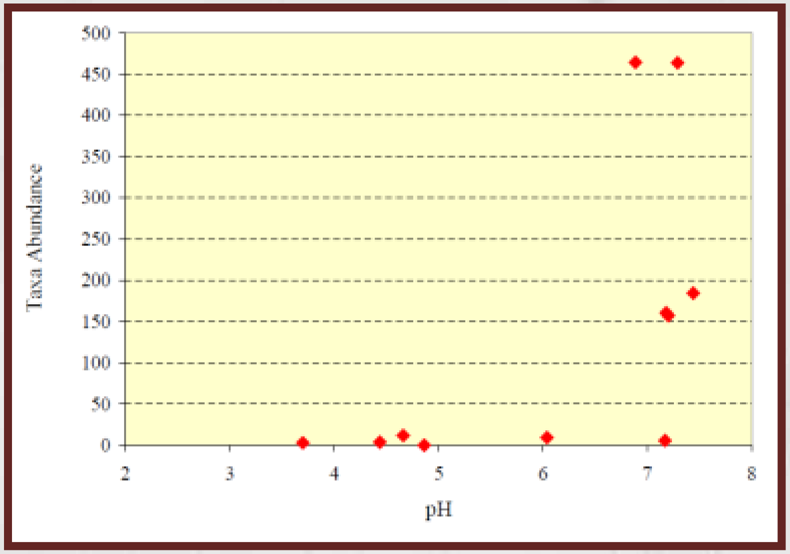
Acid Rock Drainage

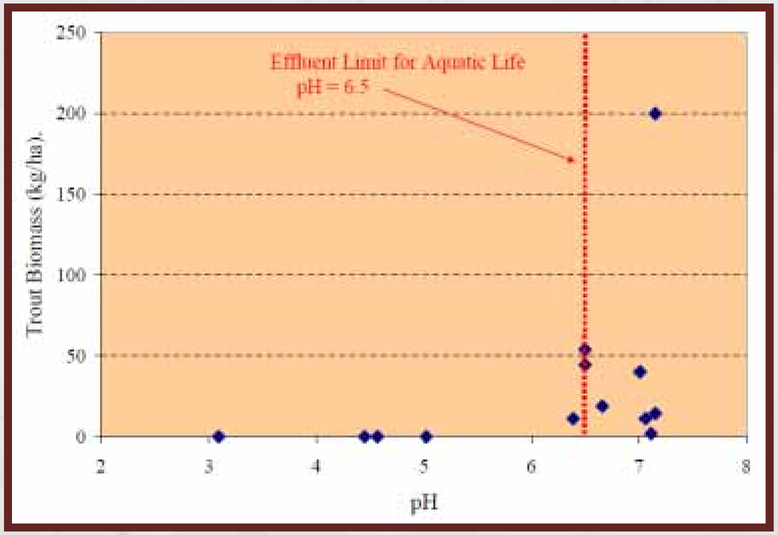
- From East:
  - 7,000 km of streams affected by ARD (Kim et al. 1982)
- To West:
  - 20,000-50,000 mines generating acid on USFS lands = 8,000 – 16,000km of streams (USFS 1993)
- Mineralogy + Air + Water

Acidity and the Food Chain

1. $2FeS_2(s) + 2H_20 + 7O_2 \rightarrow 4H^+ + 4SO_4^{2-} + 2Fe^{2+}$
   – Product: Hydrogen Ions & Sulfate
2. $4Fe^{2+} + O_2 + 4H^+ \rightarrow 4Fe^{3+} + 2H_2O$
   – Oxidation of Ferrous ion to Ferric ion
3. $2FeS_2(s) + 14Fe^{3+} + 8H_2O \rightarrow 15Fe^{2+} + 16H^+$
   – Ferric ion + pyrite = dissolves pyrite
   – Product: More acid + Ferric iron precipitates
4. $Fe^{3+} + 3H_2O \leftrightarrow Fe(OH)_3(s) + 3H^+$
   – Product: "Yellow Boy" - precipitated yellow-orange, hydrated iron oxide deposits on stream bottoms

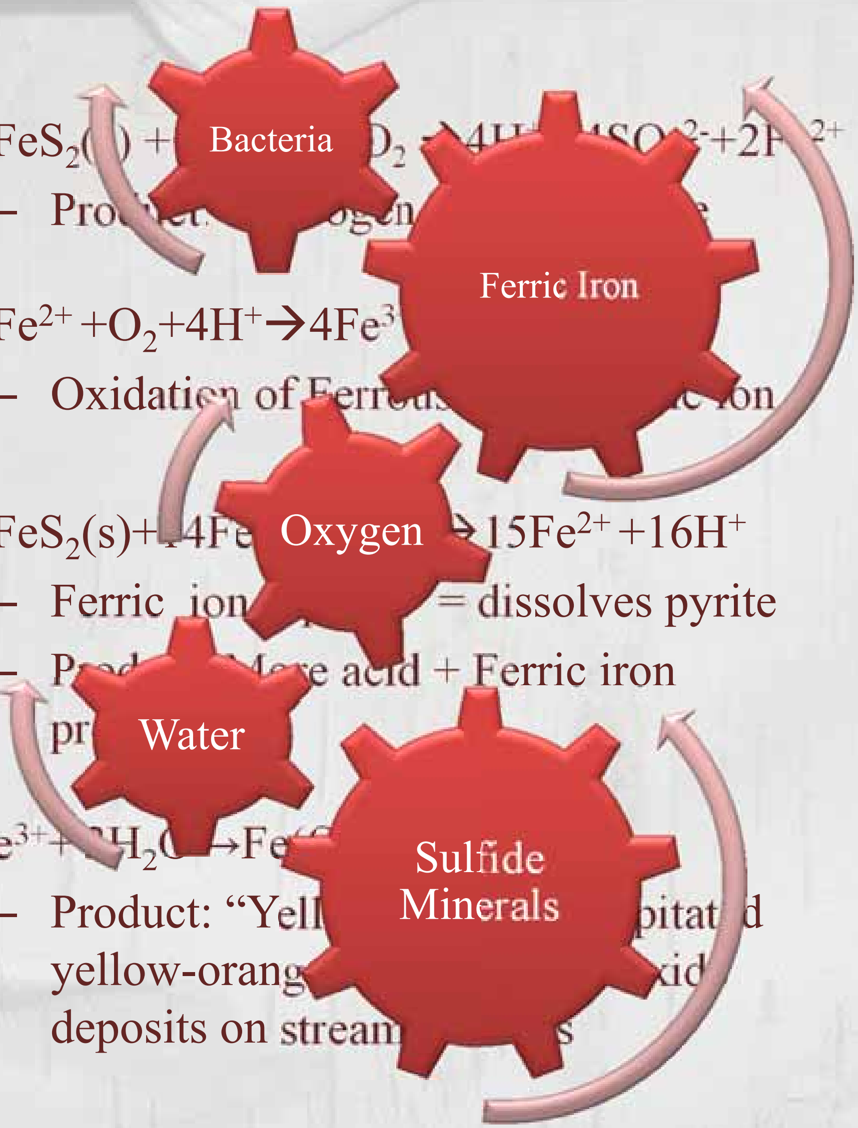
Source: EPA 1994b





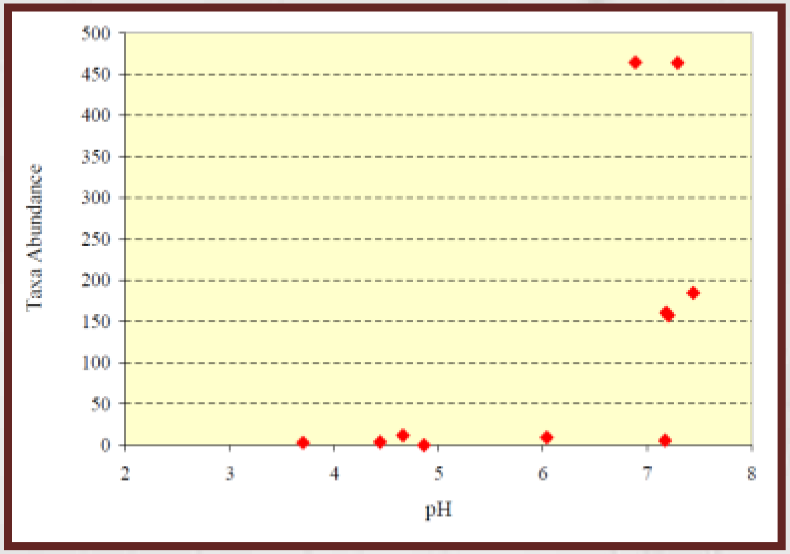
Source: Bird et al. 2006

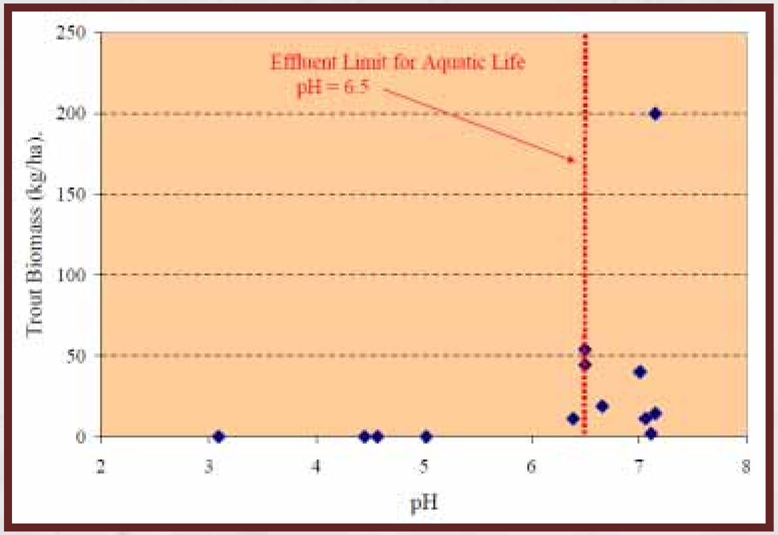
Acidity and the Food Chain



1. $2FeS_2$(…) + … O_2 → $4H^+$ … SO_4^{2-} + 2F… $^{2+}$
   – Pro… …ogen… …e
2. $4Fe^{2+} + O_2 + 4H^+ \rightarrow 4Fe^{3}$…
   – Oxidation of Ferrou… …c Ion
3. $2FeS_2(s) + 14Fe$… → $15Fe^{2+} + 16H^+$
   – Ferric ion … = dissolves pyrite
   – Pr… More acid + Ferric iron pr…
4. $Fe^{3+} + 3H_2O \rightarrow Fe$(…
   – Product: "Yell… …pitated yellow-orang… …xid… deposits on stream… …s

Source: EPA 1994b





Source: Bird et al. 2006

Acidity and the Food Chain

1. $2FeS_2(s) + 2H_2O + 7O_2 \rightarrow 4H^+ + 4SO_4^{2-} + 2Fe^{2+}$

2.

3.

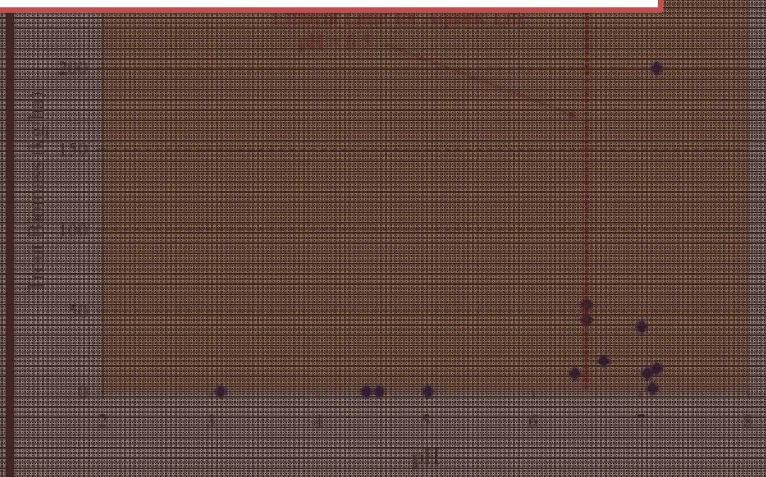
“Rock with 2.1 wt% sulfur from the Duluth complex had a lag time of **581 weeks** before it started producing acid.” (Lapakko 2003a *in* Maest & Kuipers 2005)

Industry Standard is **20 weeks**

(Orvana Resources USC 2011)

– Product: More acid + Ferric iron precipitates

4. $Fe^{3+} + 3H_2O \leftrightarrow Fe(OH)_3(s) + 3H^+$
   – Product: “Yellow Boy” - precipitated yellow-orange, hydrated iron oxide deposits on stream bottoms



Source: EPA 1994b

Source: Bird et al. 2006

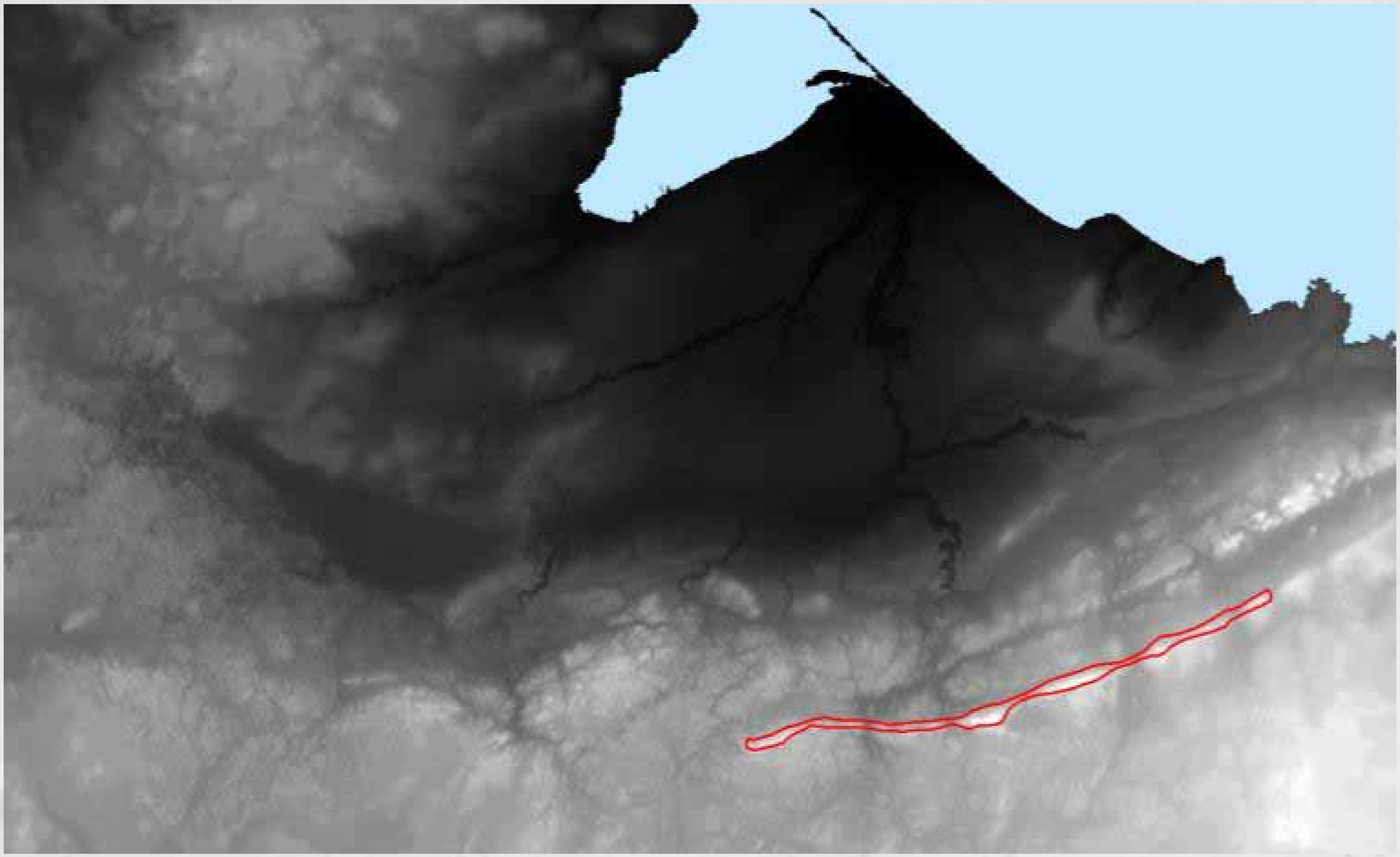
Ground Water Beneath Tailings

- High concentrations of:
  - Arsenic
  - Fluoride
  - Molybdenum
  - Manganese
  - Nitrite + Nitrate
- Fluoride, Manganese, and Nitrite + Nitrate exceeded MN drinking water standards

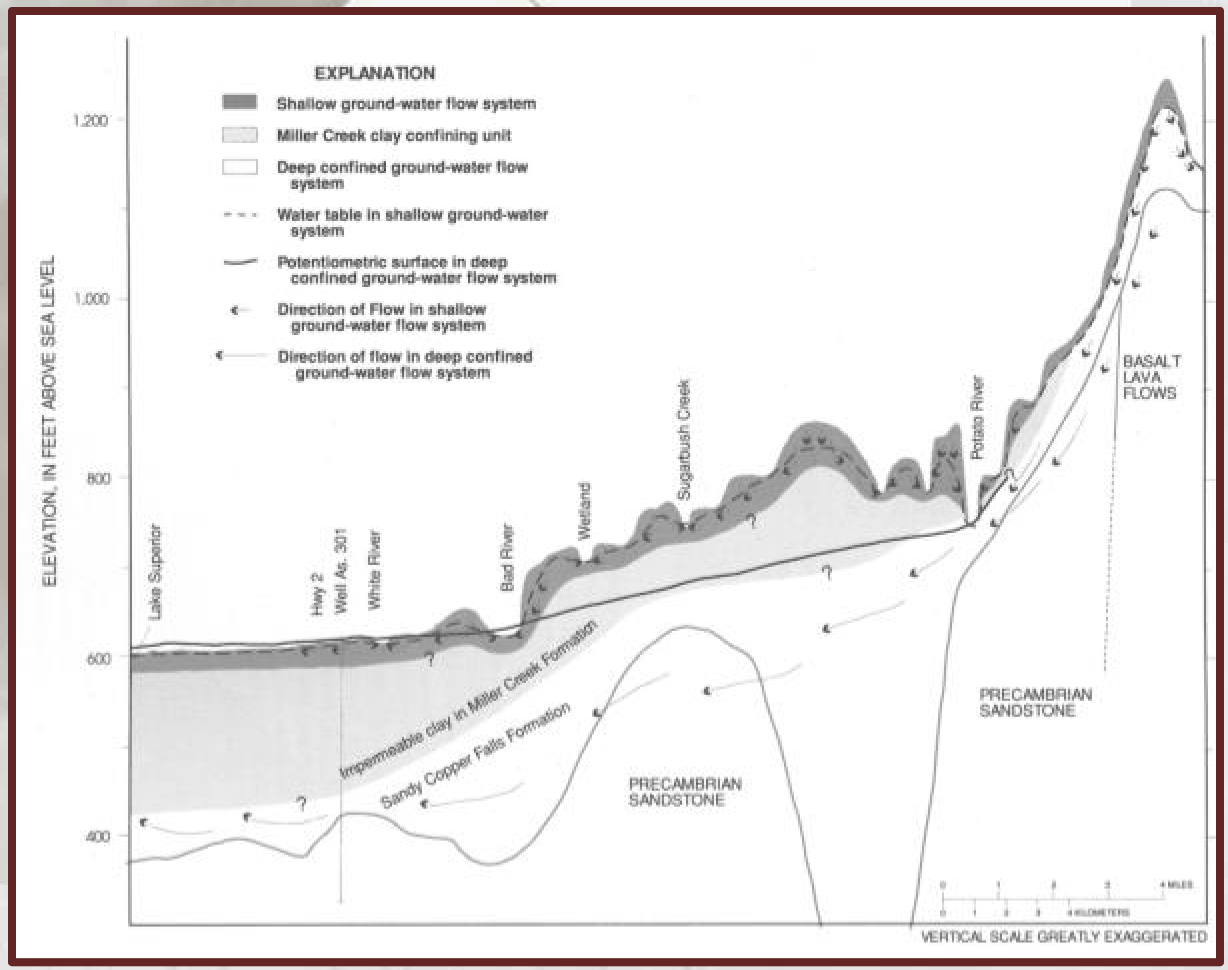
Photo Credit: C. Rasmussen

Source: Myette 1991

Hydrologic Transport



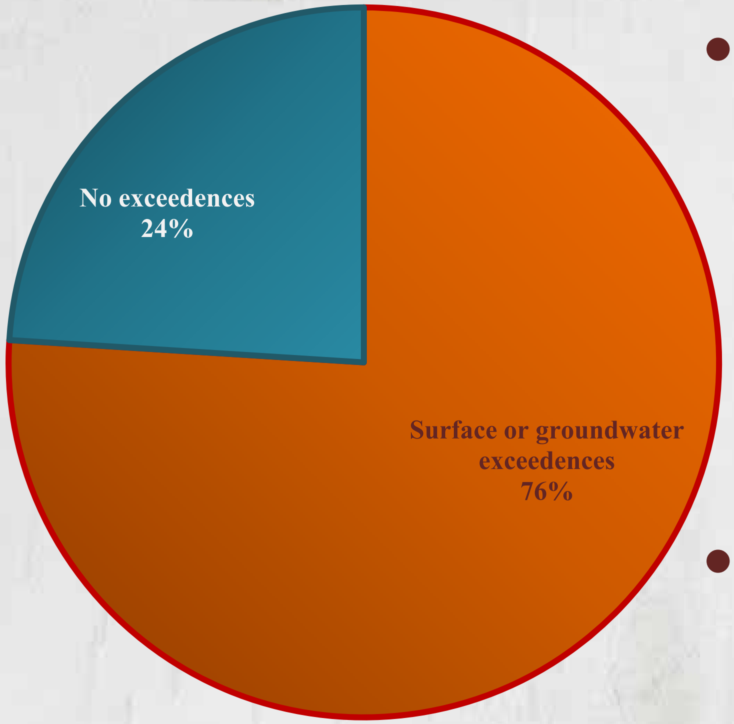
Hydrologic Transport



Source: Batten & Lidwin 1995

Prediction & Success

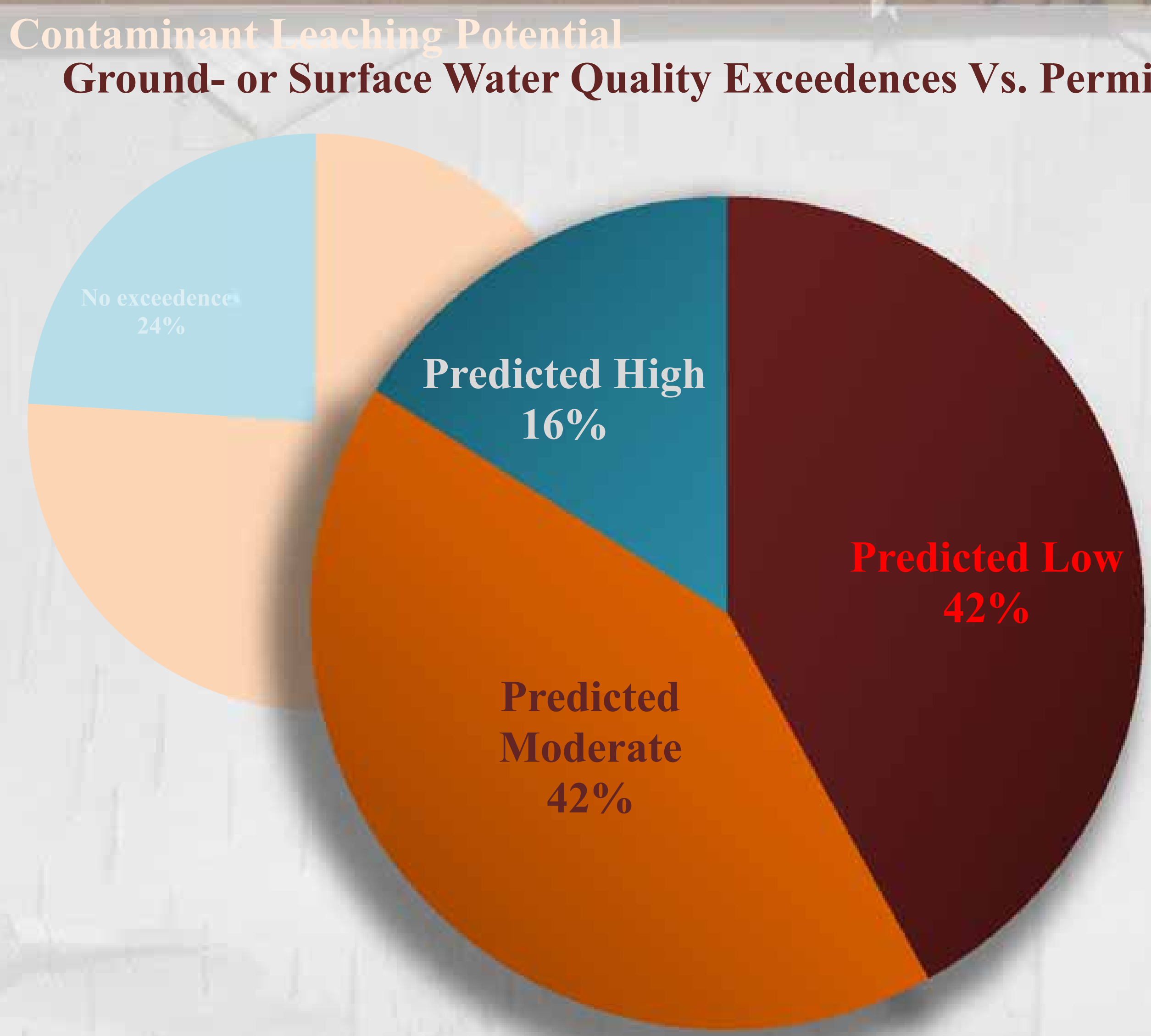
Contaminant Leaching Potential



- Study emphasized Gold, Silver, Copper, etc.
  - Process and geochemical impacts potentially different for iron
- Value = Capacity for Industry to Predict Impacts & Lessons Learned

Source: Kuipers et al. 2006

Prediction & Success



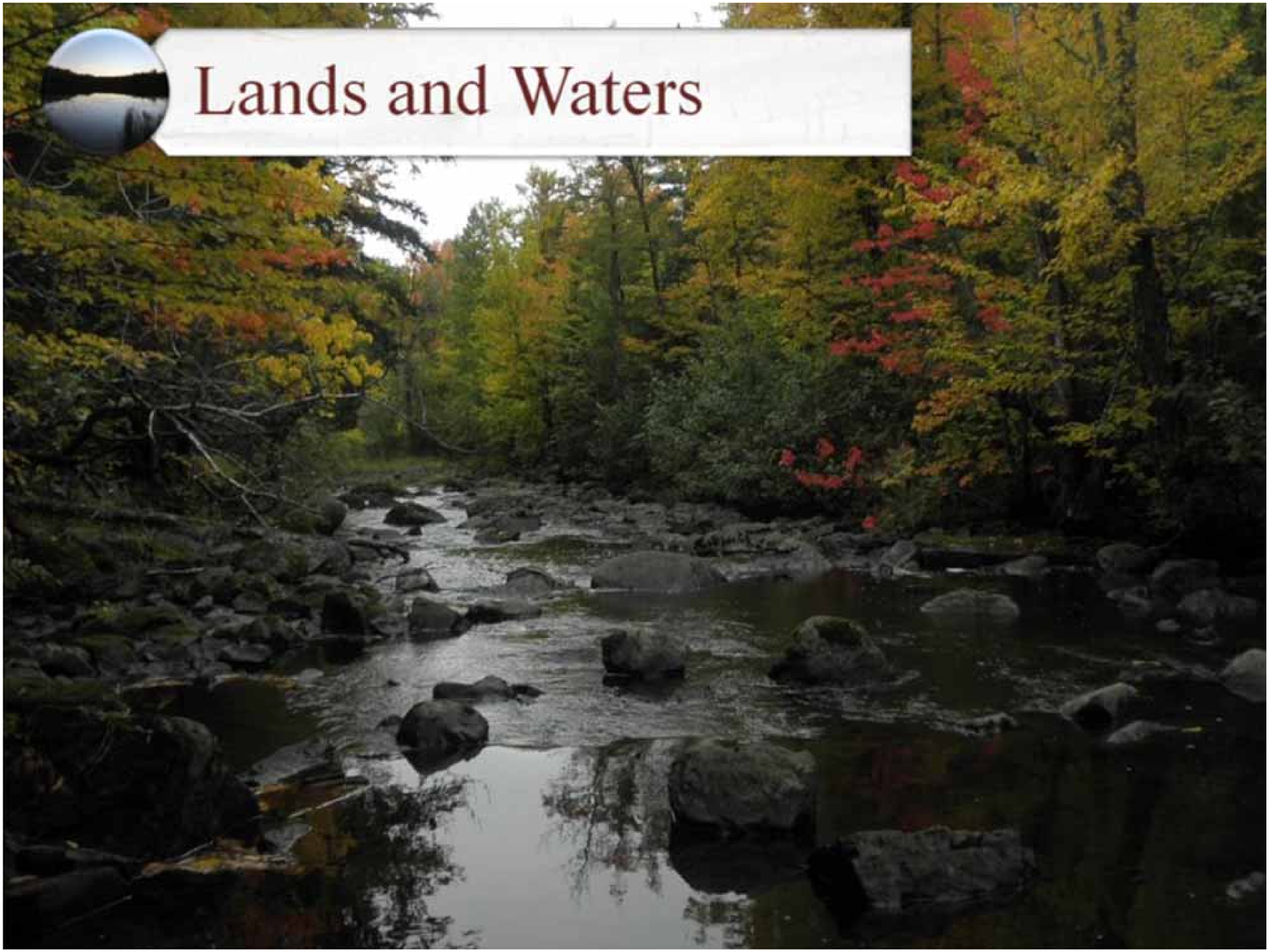
Source: Kuipers et al. 2006

Prediction & Success

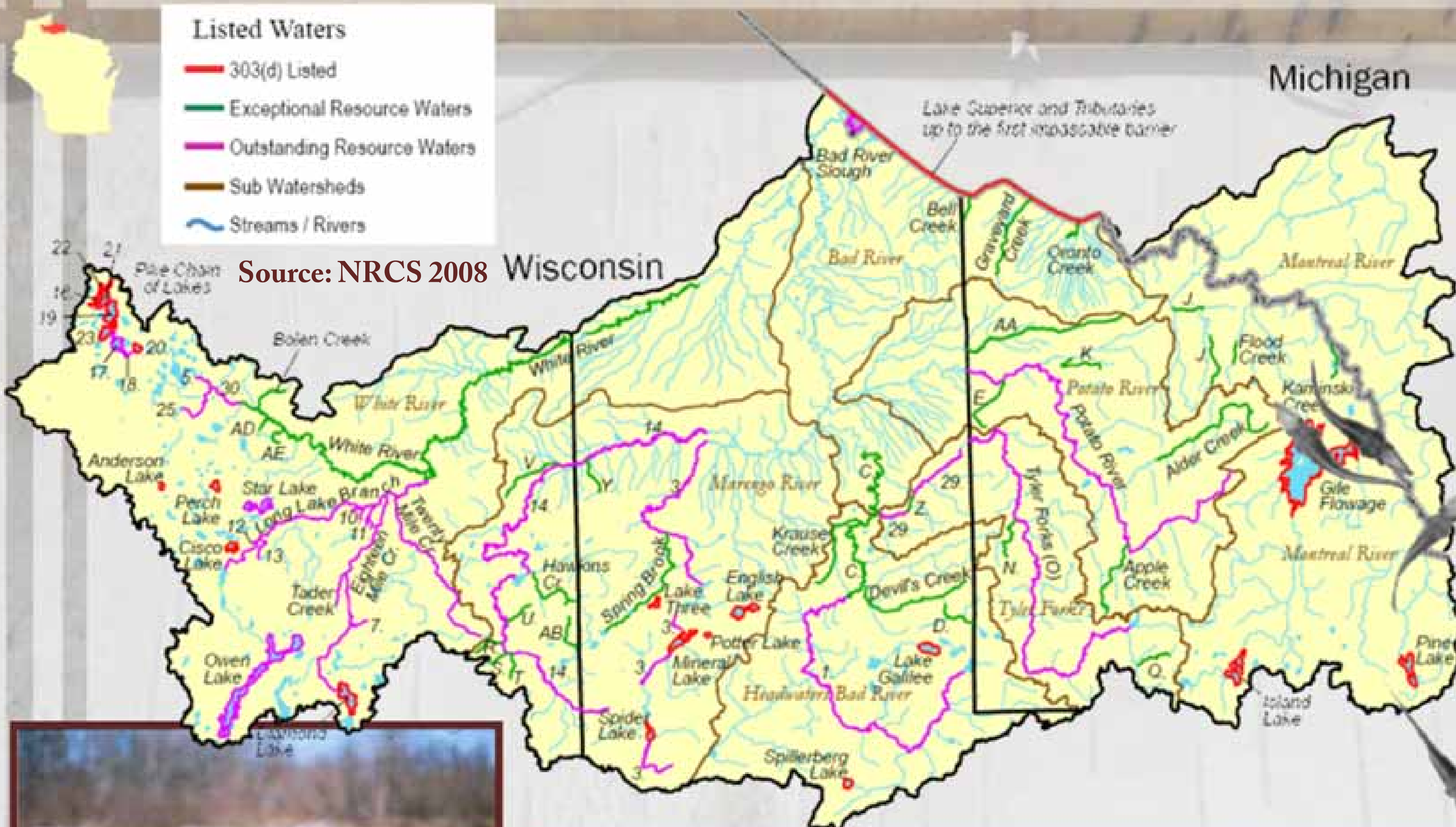
- Some Lessons Learned:
  - Actual water quality **impacts are often closer to pre-treatment predictions** than post-mitigation (i.e. treatments often fail to perform according to plan)
  - Lack of **adequate geochemical** characterization is single greatest root cause of failure to predict impacts
  - Hydrological failures are most often associated with **predicting over dilution**, failure to recognize **hydrological features**, or **underestimation of water production** quantities
  - Mines in **close proximity to water** resources require more scrutiny

Source: Kuipers et al. 2006

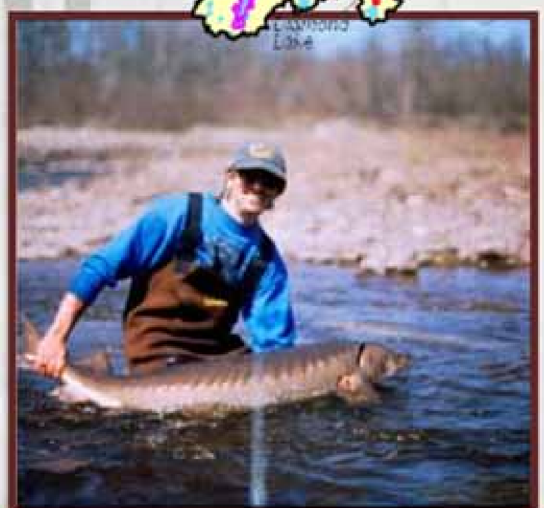
Lands and Waters



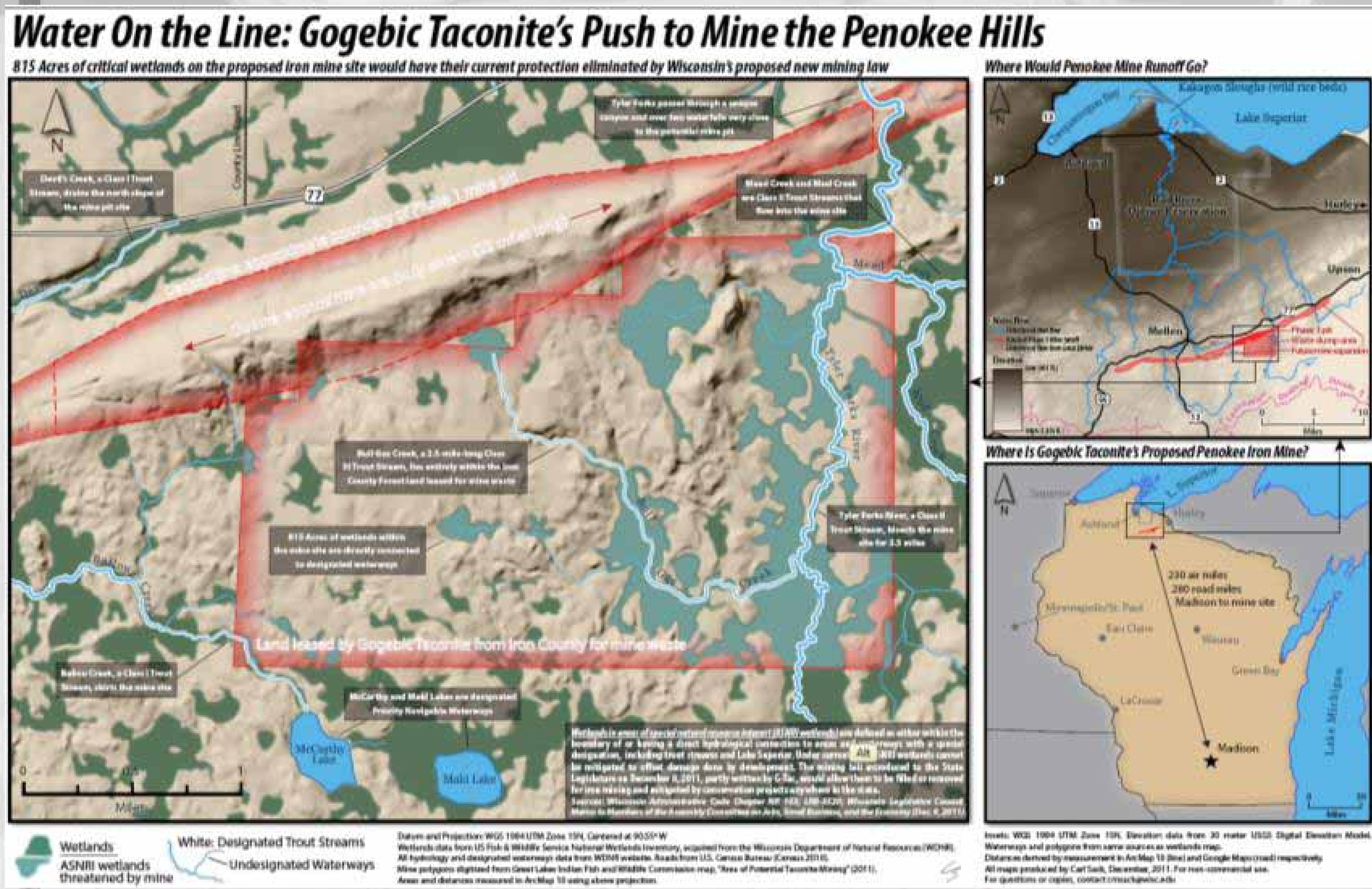
Health of the Waters



Source: NRCS 2008



Wetlands and Surface Waters

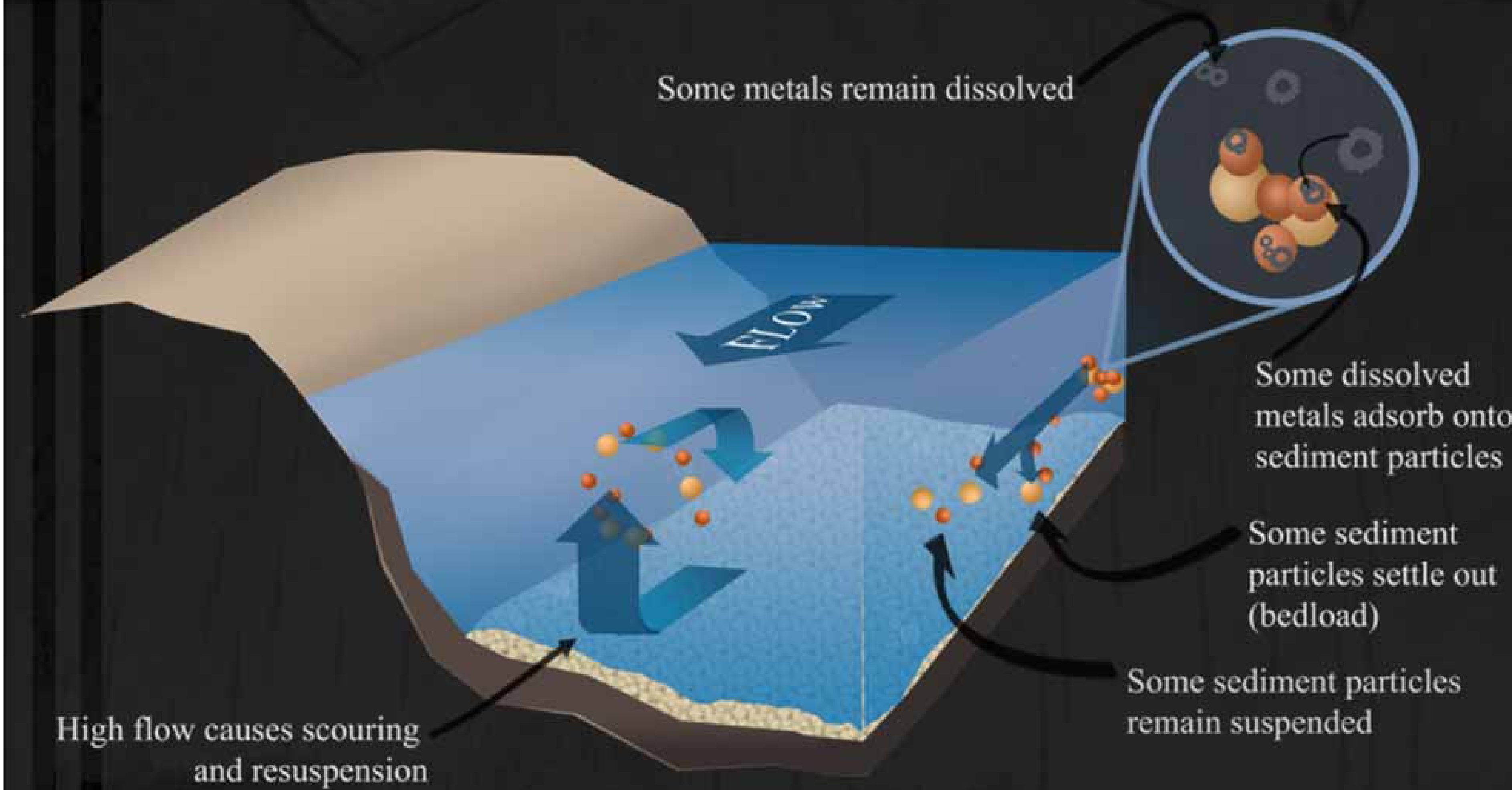


Map credit: C. Sack 2012

Sediment Runoff

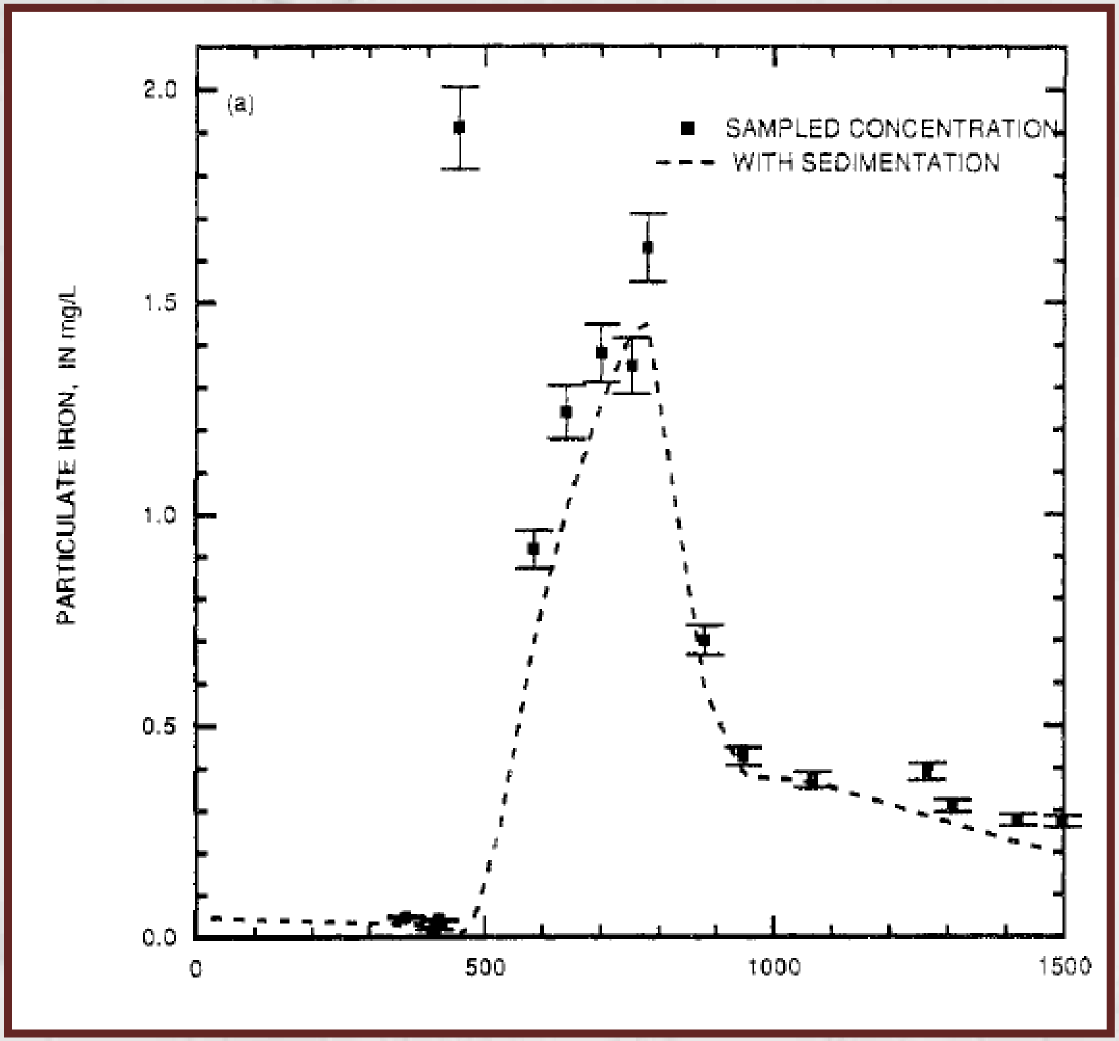
- Suspended Sediment Runoff (Myette 1991)
  - 1 mg/L at Low Flow
  - > 4,600 mg/L following Snowmelt
- 96% of particles smaller than 0.062mm in diameter (Myette 1991)

Sediment and Metal Transport



Adapted from P. McGrath 2011

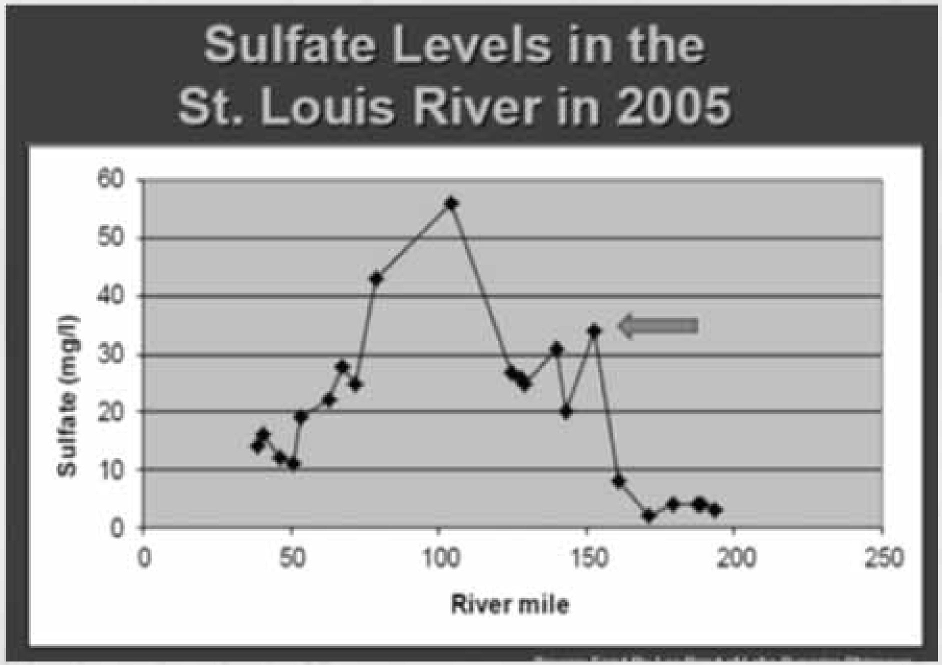
Sediment and Metal Transport



Source: Kimball et al. 1994

Sulfate Discharge

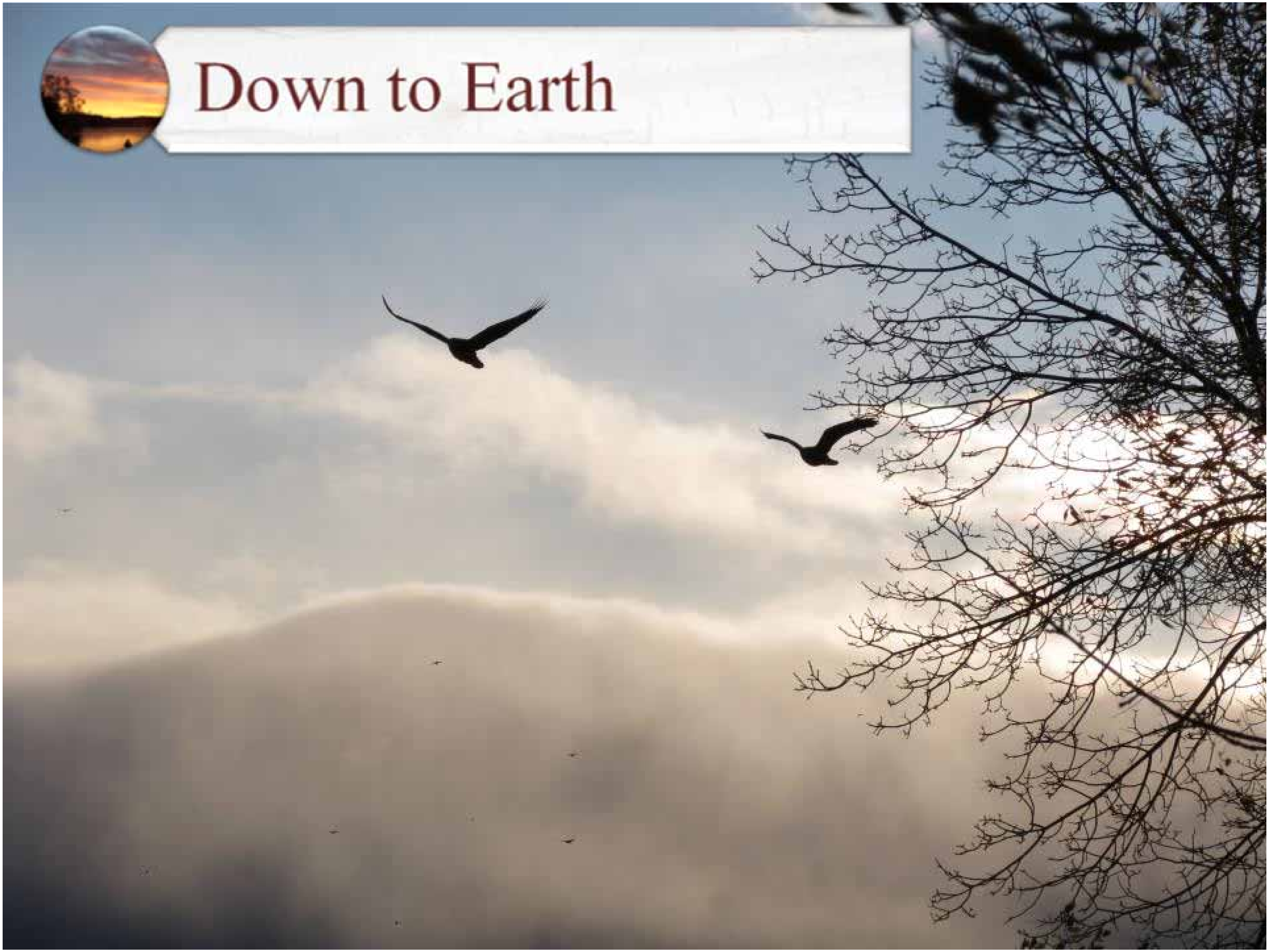
- St. Louis Watershed, MN
  - At river mile **171**, **wild rice** dominates and sulfate = **2ppm**
  - At river mile **120**, **mining sulfate** discharges enter the watershed
  - At river mile **100**, there is **no wild rice**, sulfate near **100ppm**
  - At river mile **20**, there is a **compromised stand** of wild rice, sulfate = **15ppm**



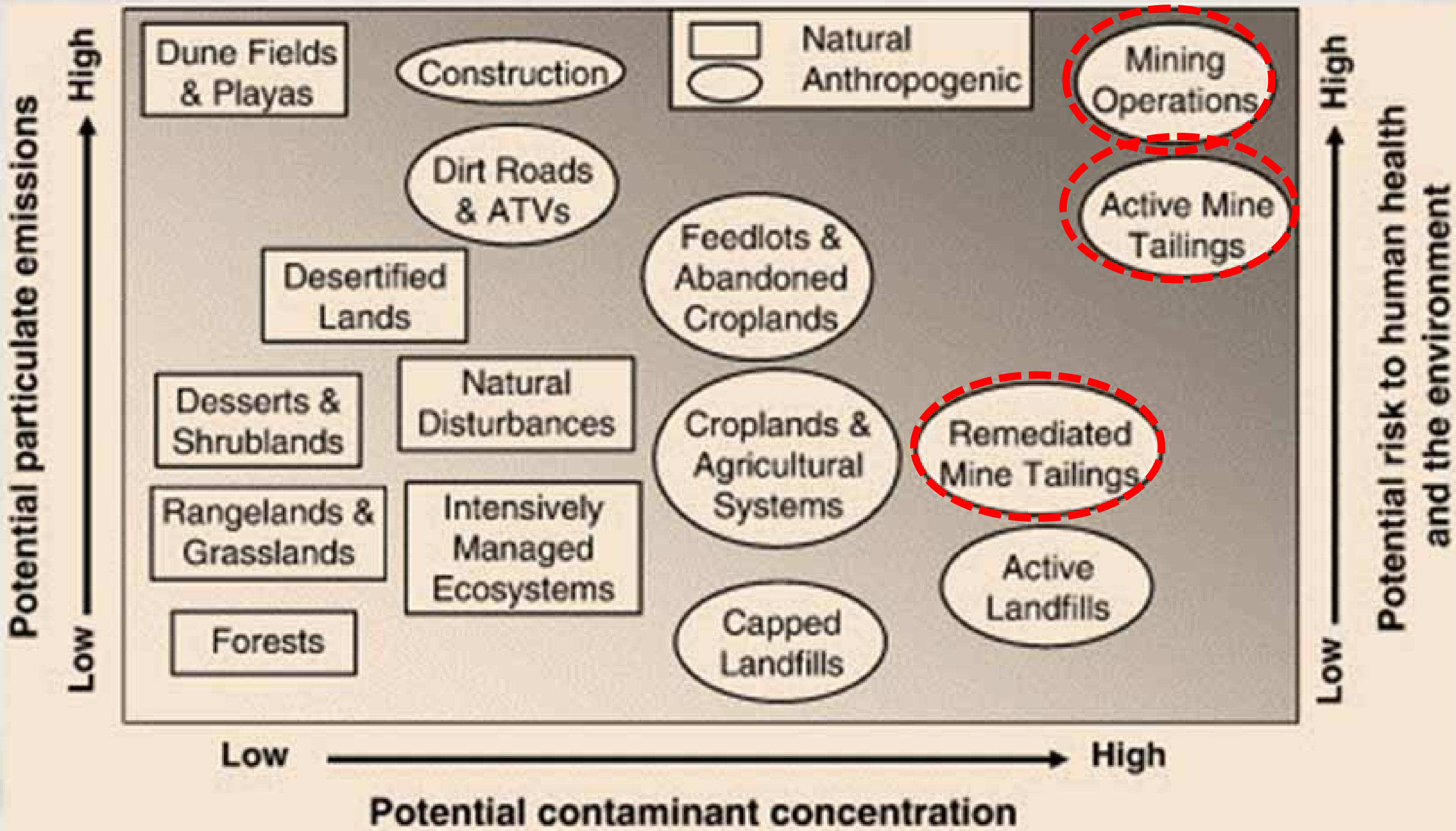
Source: Fond Du Lac Band 2005

Sulfate and Wild Rice

- **90%** of wild rice waters ≤ **10ppm** and "there were no large and important natural and **self-perpetuating** wild rice stands in MN where the sulfate ion content exceeded 10ppm." (Moyle 1975)
- **Sulfates** convert to **hydrogen sulfide in sediments**, especially under anaerobic conditions.

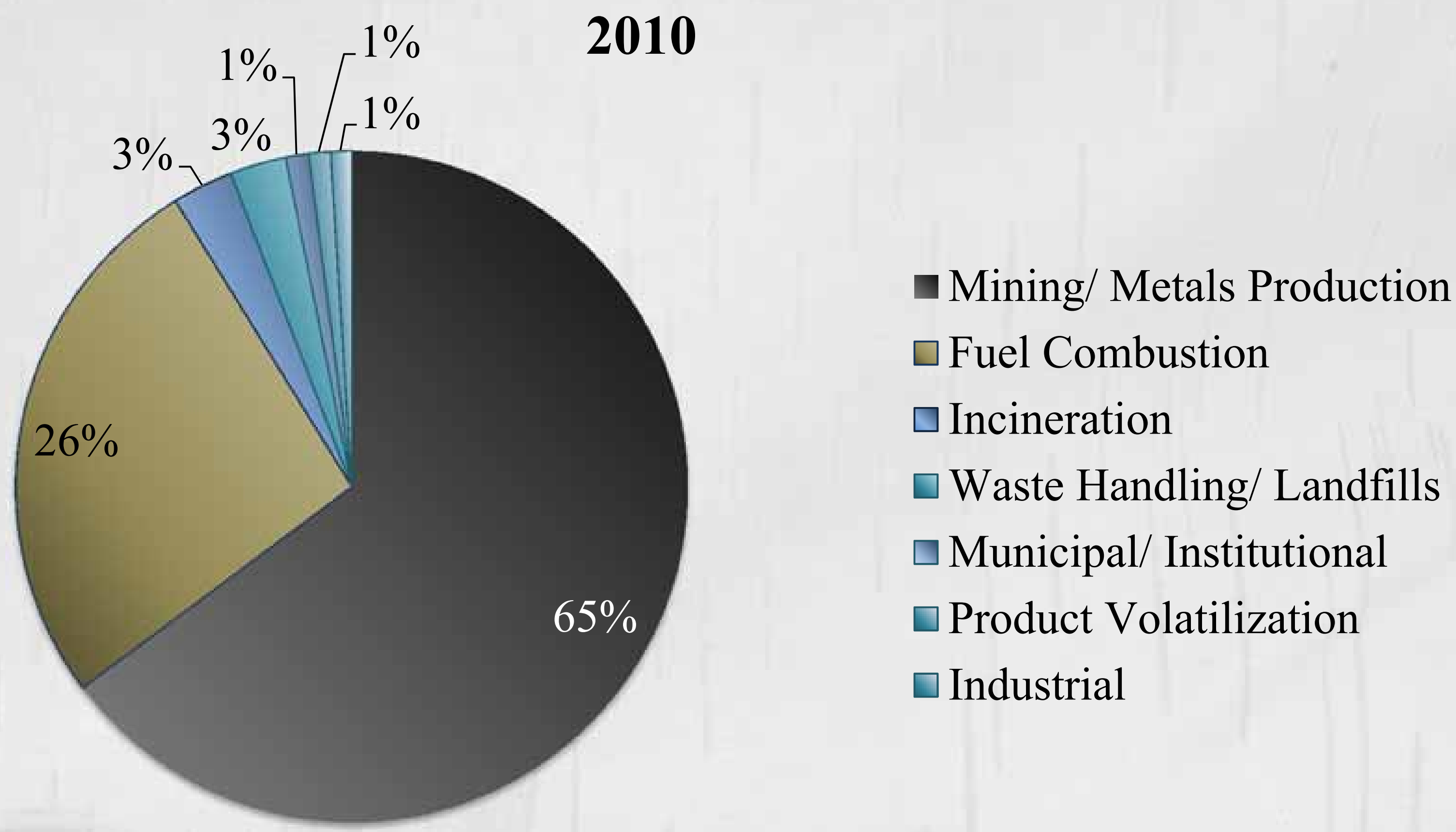


Down to Earth

Metal & Metalloid Contaminant Sources - Atmospheric



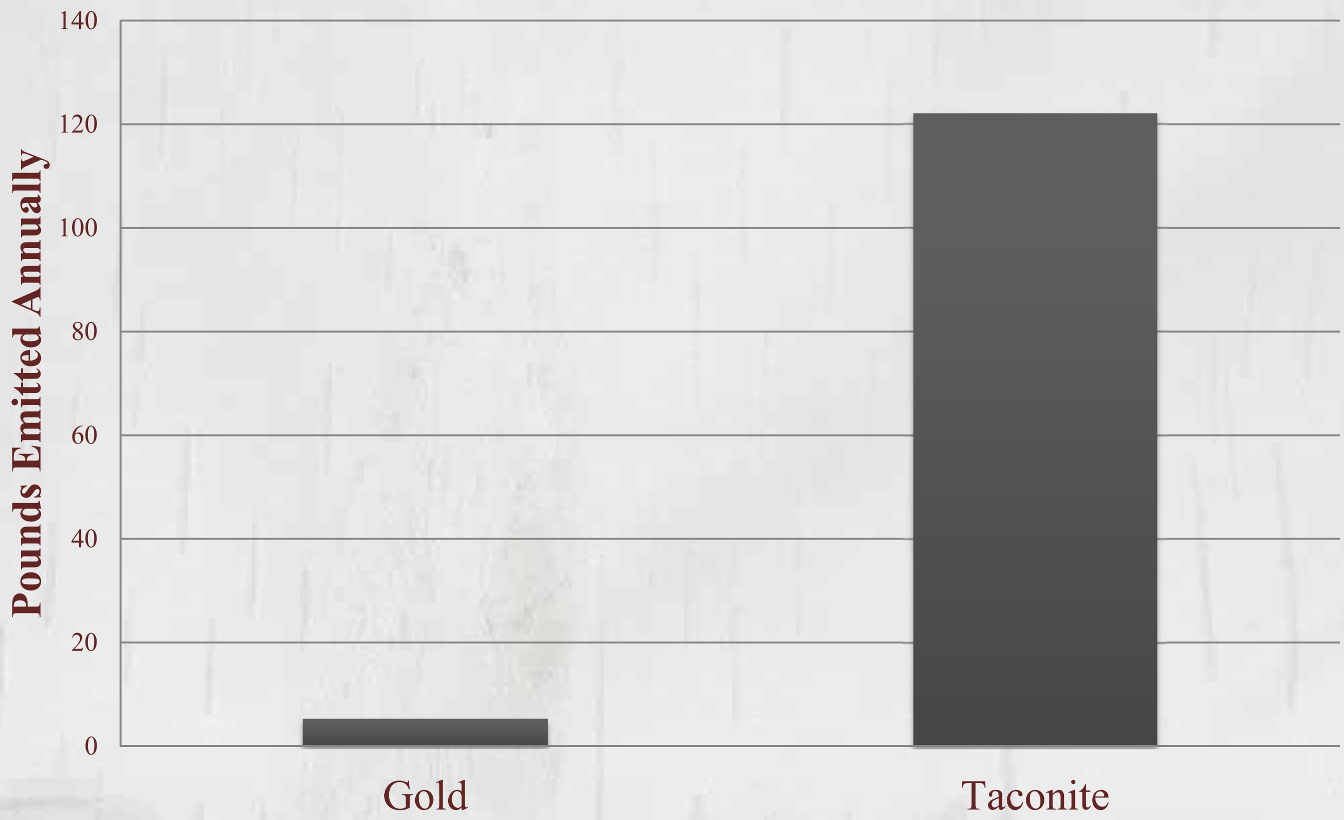
Source: Csavina et al. 2012

Mercury Emissions



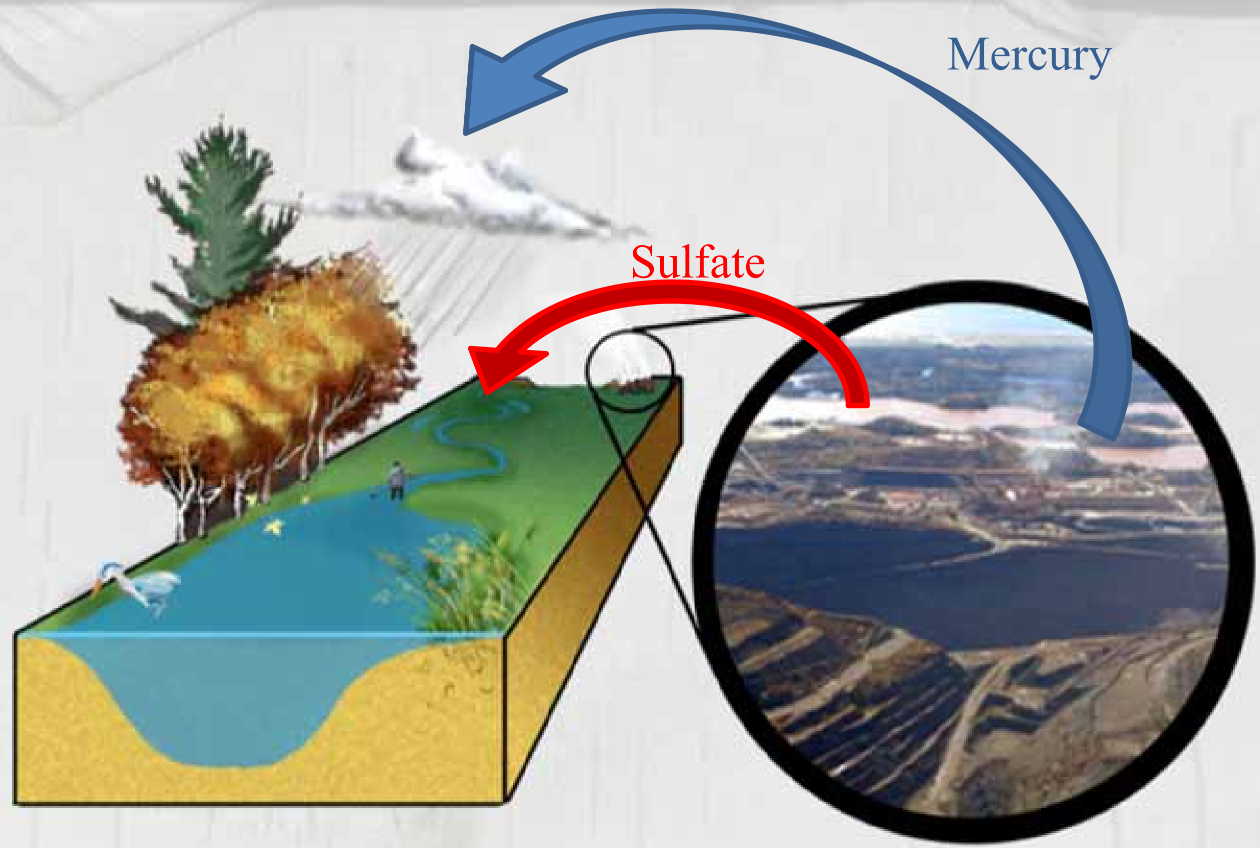
Source: Lake Superior Binational Program

Mercury Emissions

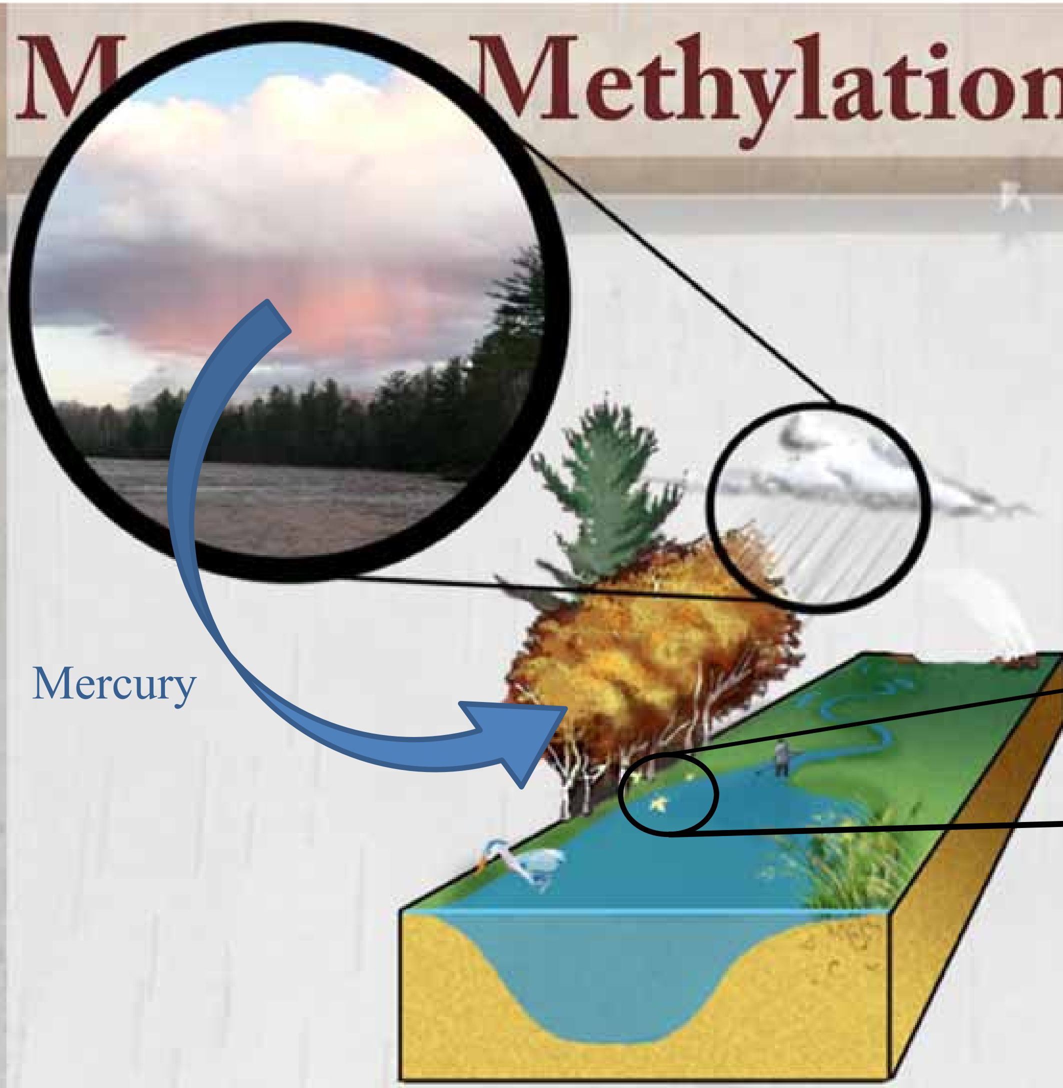


Source: Lake Superior Binational Program 2010

Mercury Methylation

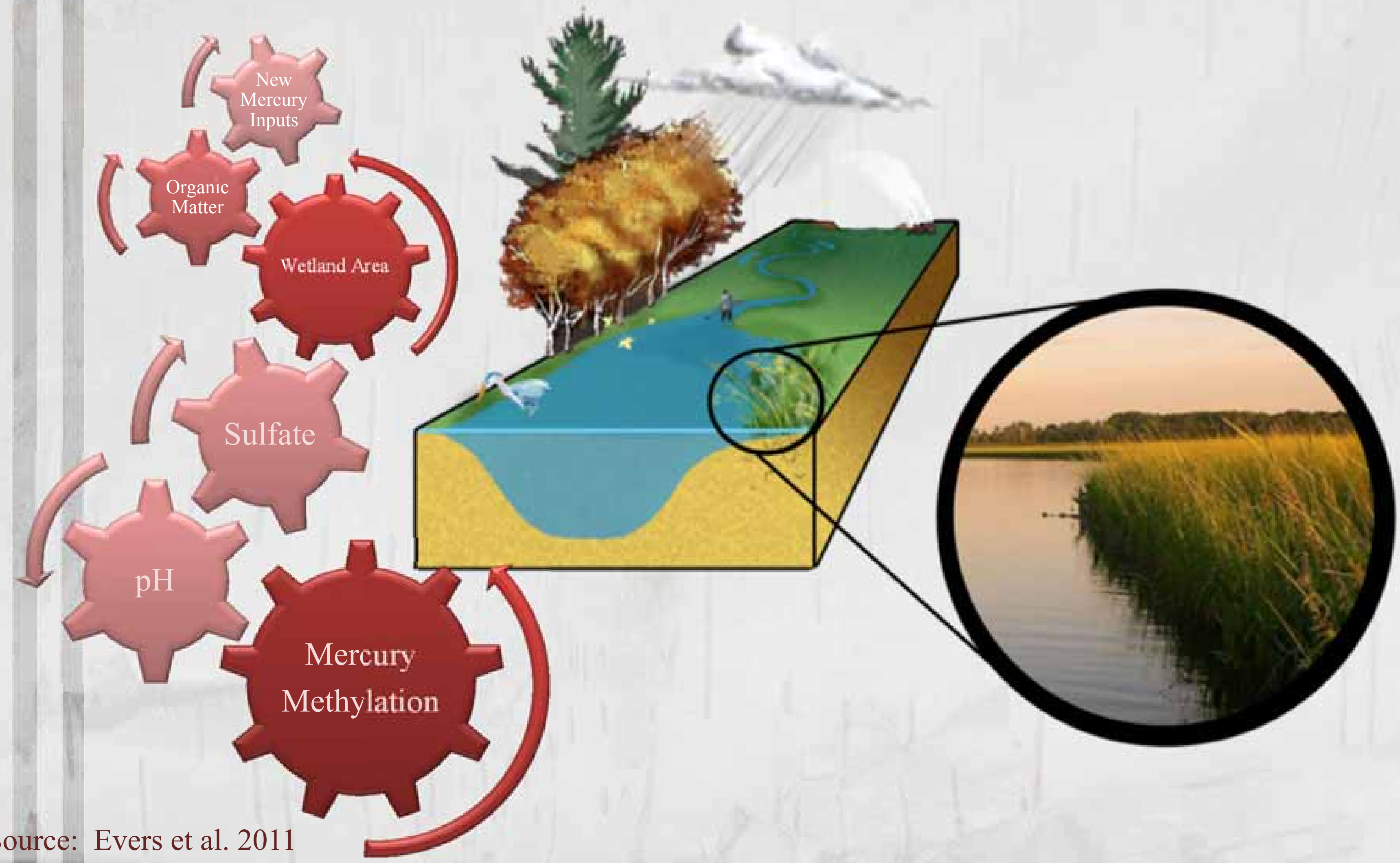


M Methylation



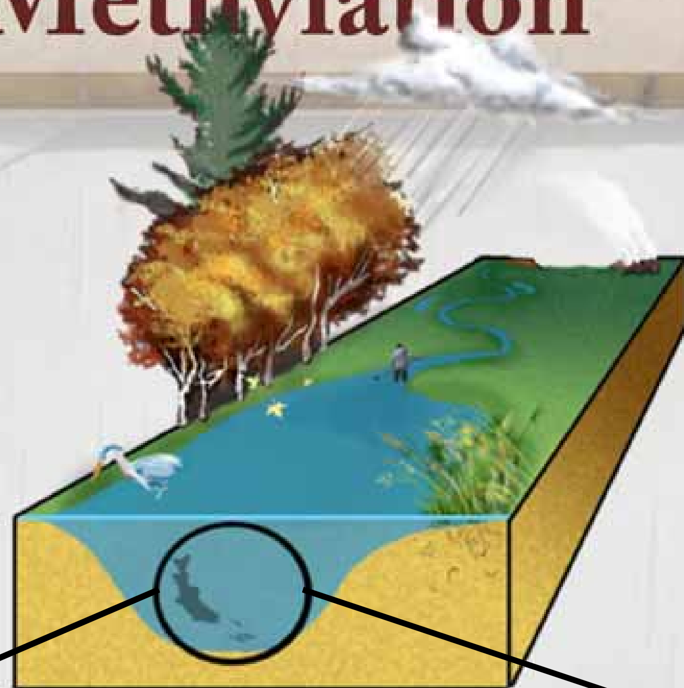
- Dry Deposition
- Wet Deposition
- Litterfall
- Runoff
- Shallow Groundwater Flow

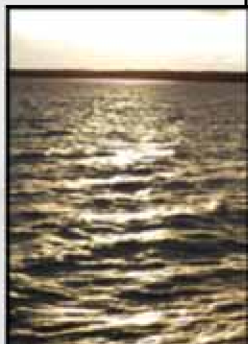
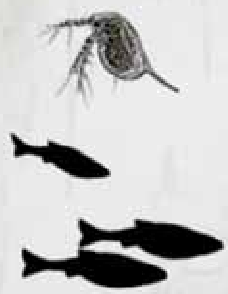
Mercury Methylation



Source: Evers et al. 2011

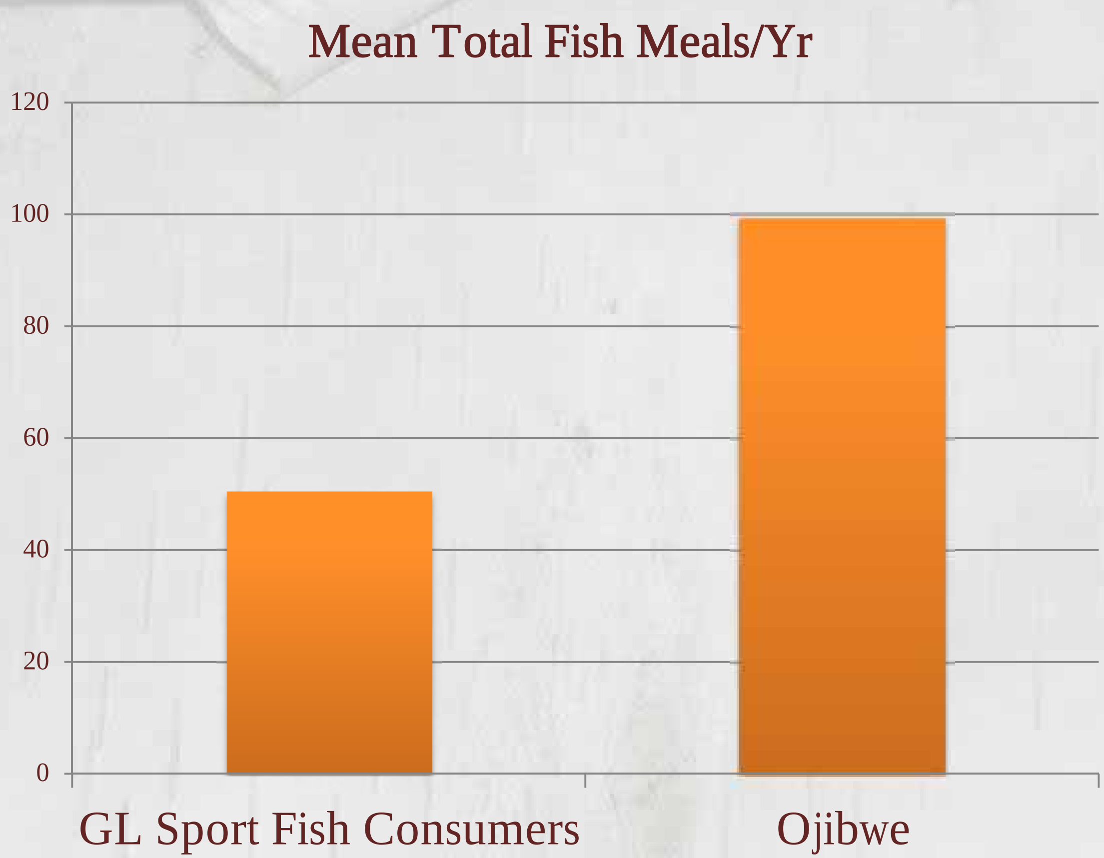
Mercury Methylation

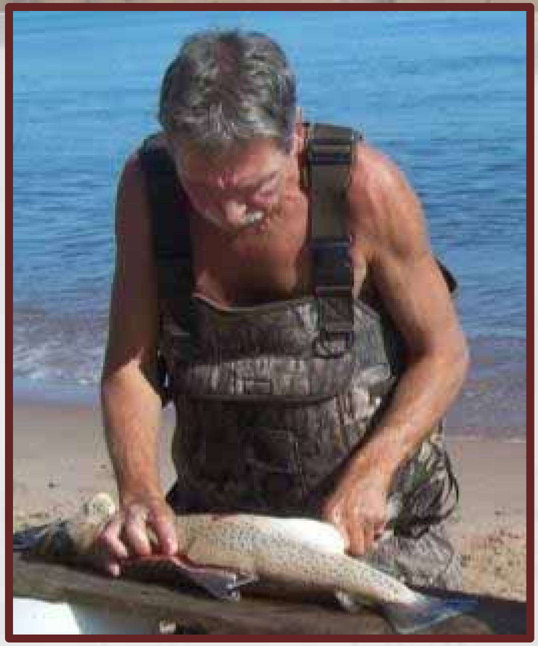


	Water	Phytoplankton	Zooplankton Plant-eating Fish	Fish-eating Fish
Methylmercury Bioaccumulation Factor:	1*X*	10,000*X*	100,000*X*	1 Million*X*
				

Source: Evers et al. 2011

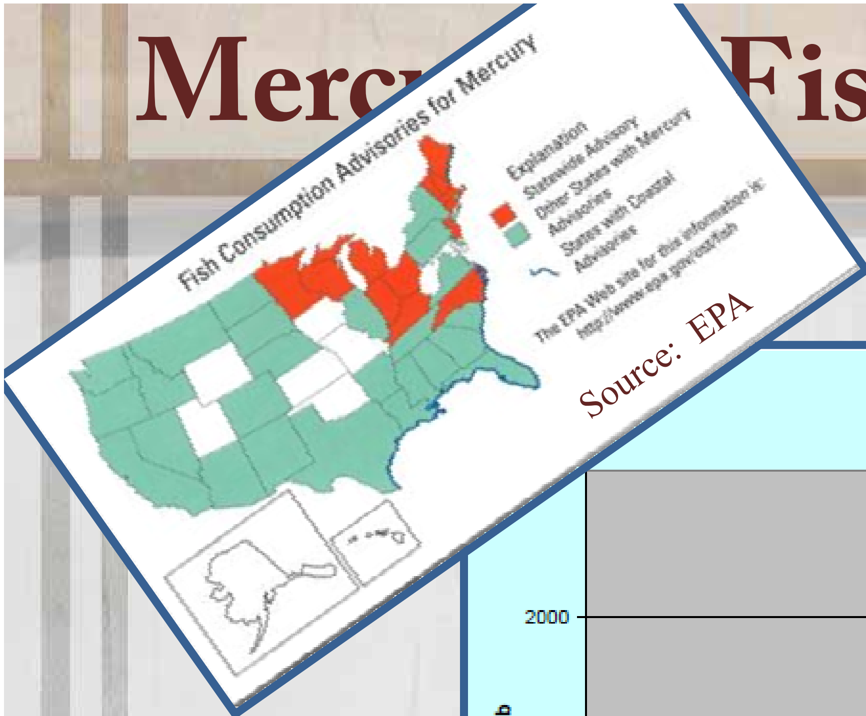
Mercury & Fish Consumption



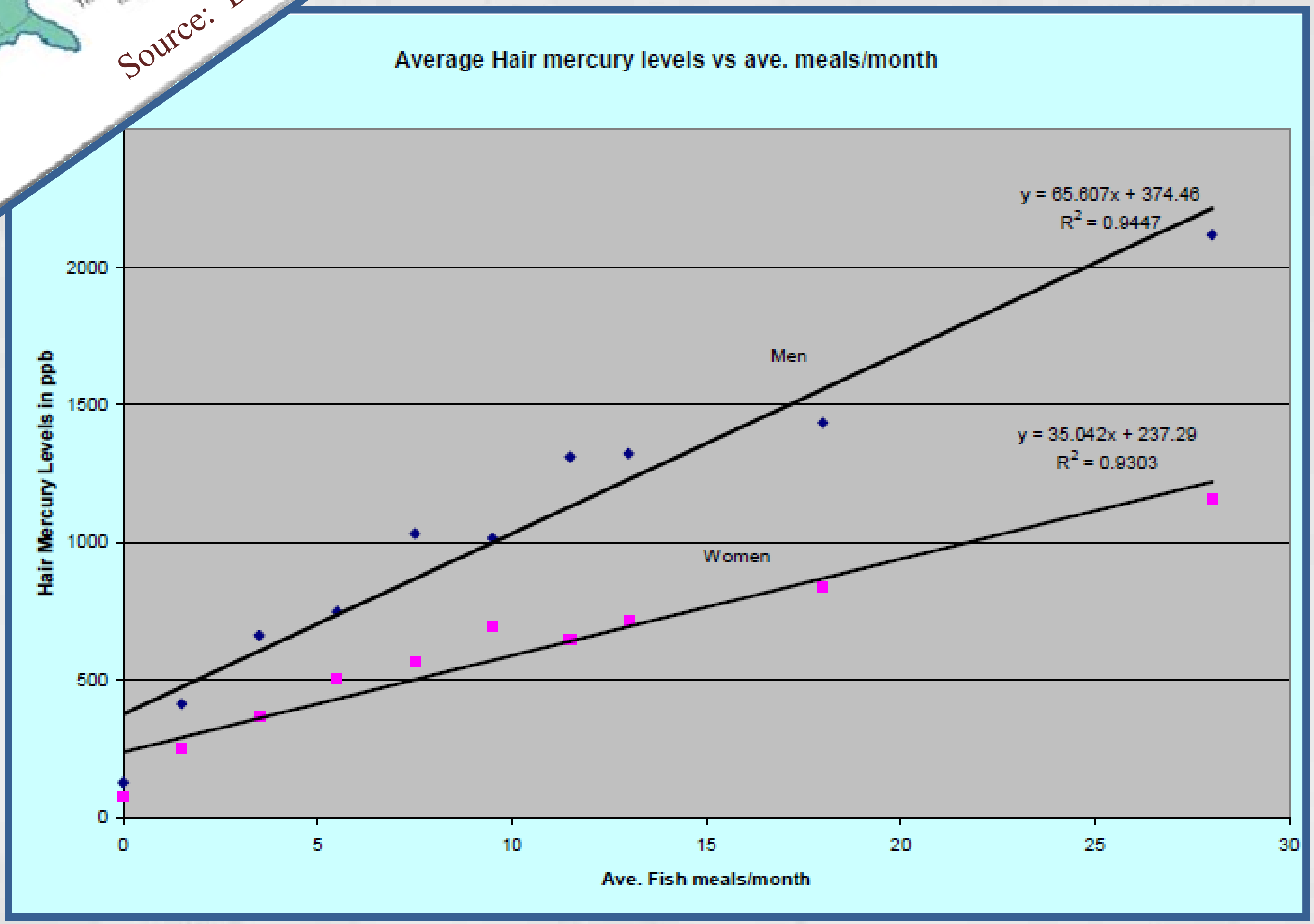


Source: Turyk et al. 2012

Merc… Fish Consumption



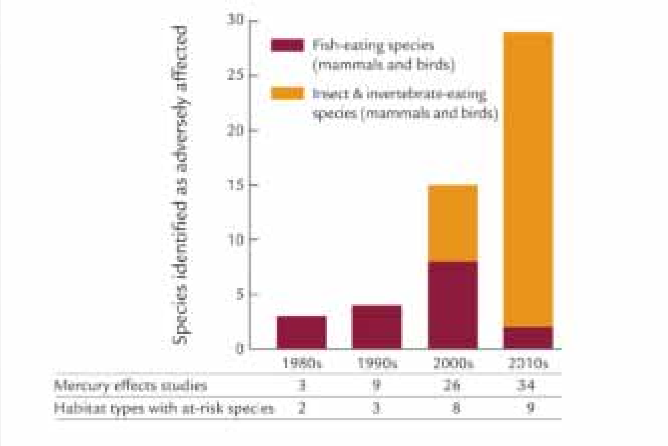
Source: EPA



Source: Knobeloch & Anderson 2005

Mercury Effects

- Persistent bioaccumulative toxin
- Accumulates more readily in muscle tissue of fish and prey (NRC 2002)
- Passes more readily between placental and blood-brain barriers
- ↑Hg = ↓Cortisol ≈ ↓metabolism + ↓immune response + ↑blood pressure (Gump et al. 2012)
- 61% of Great Lakes study area > EPA human health criterion in 6 commonly eaten fish species (Evers et al. 2011)



Source: Evers et al. 2011

Dollars and Sense

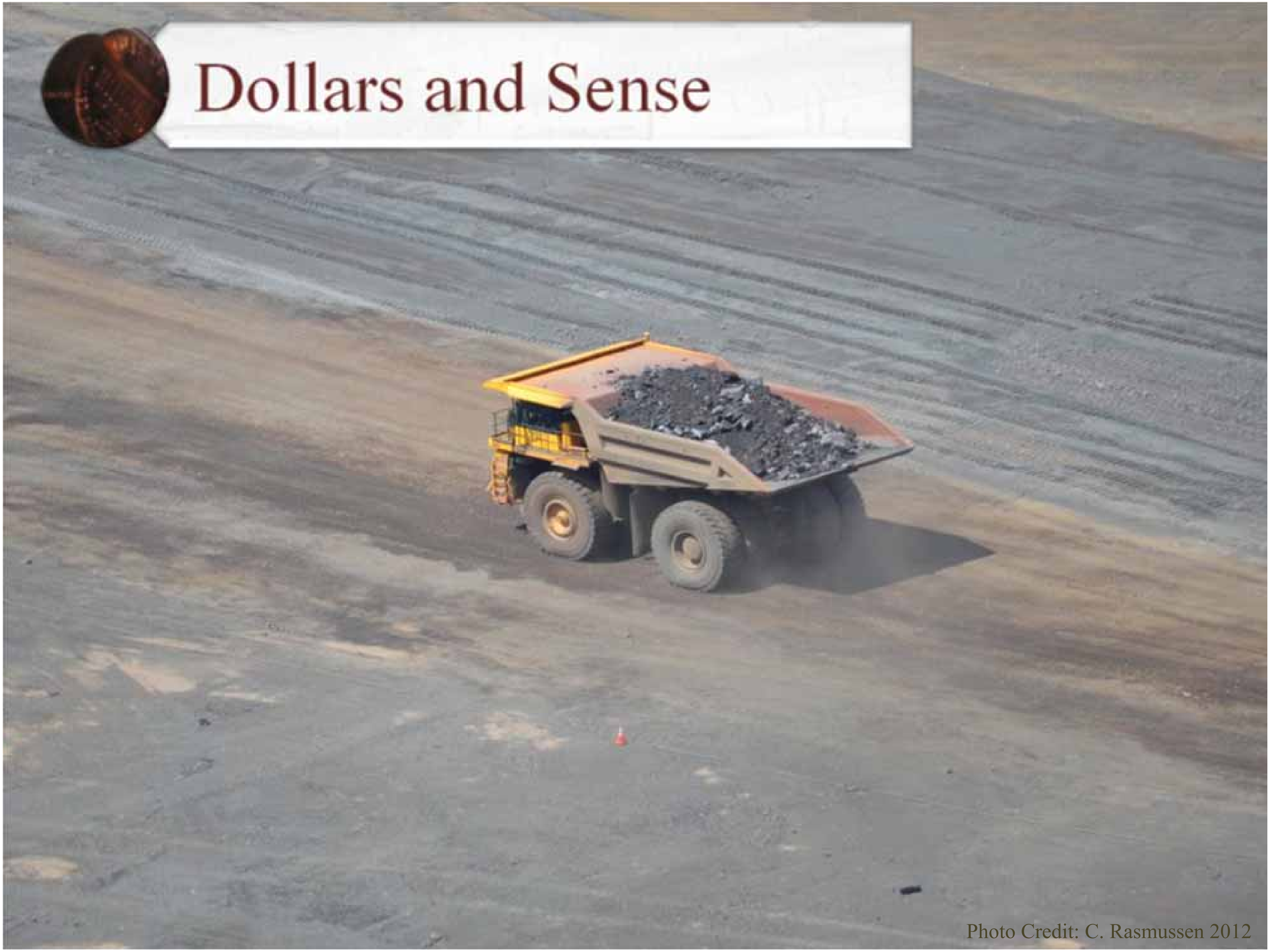
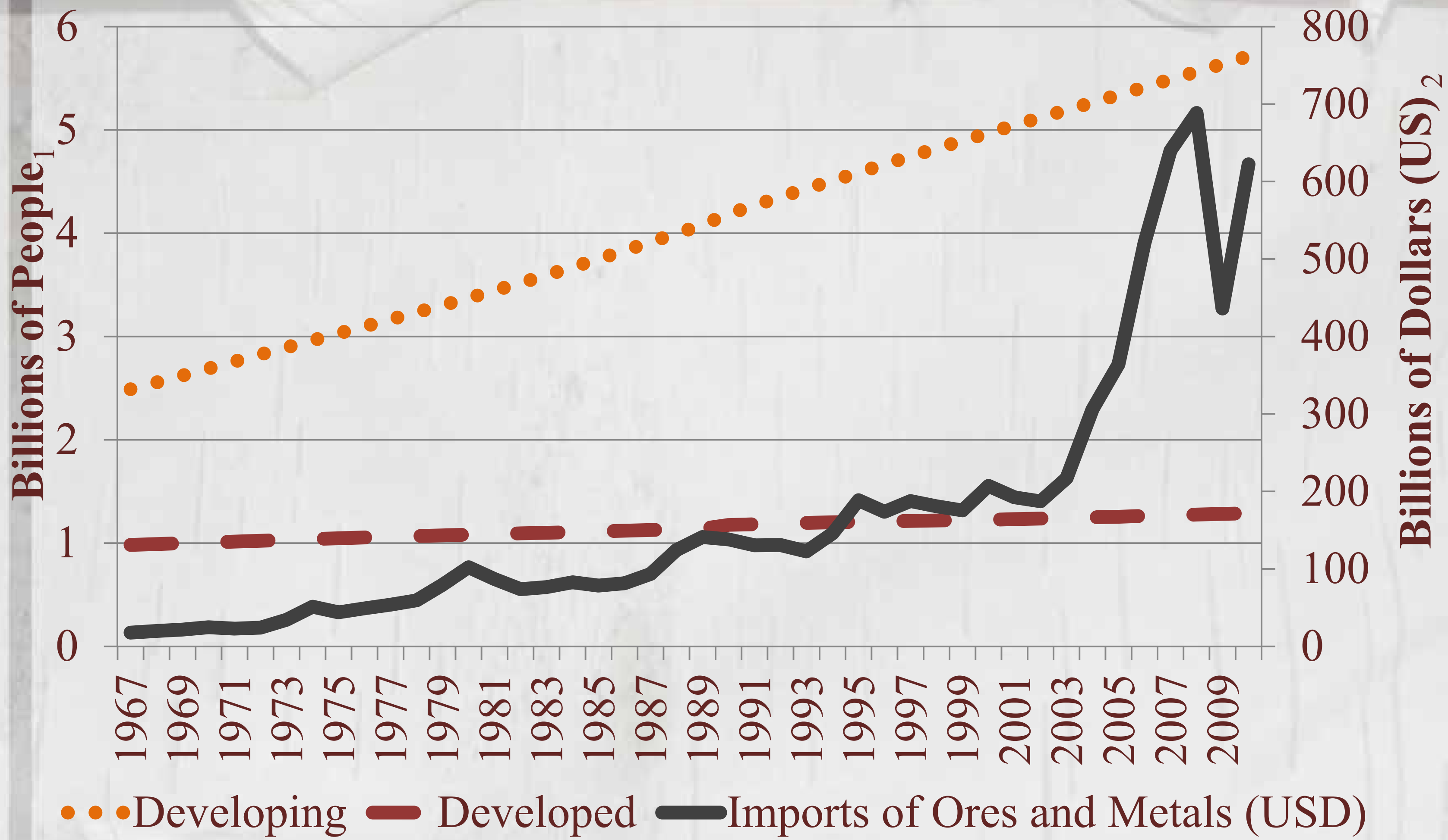


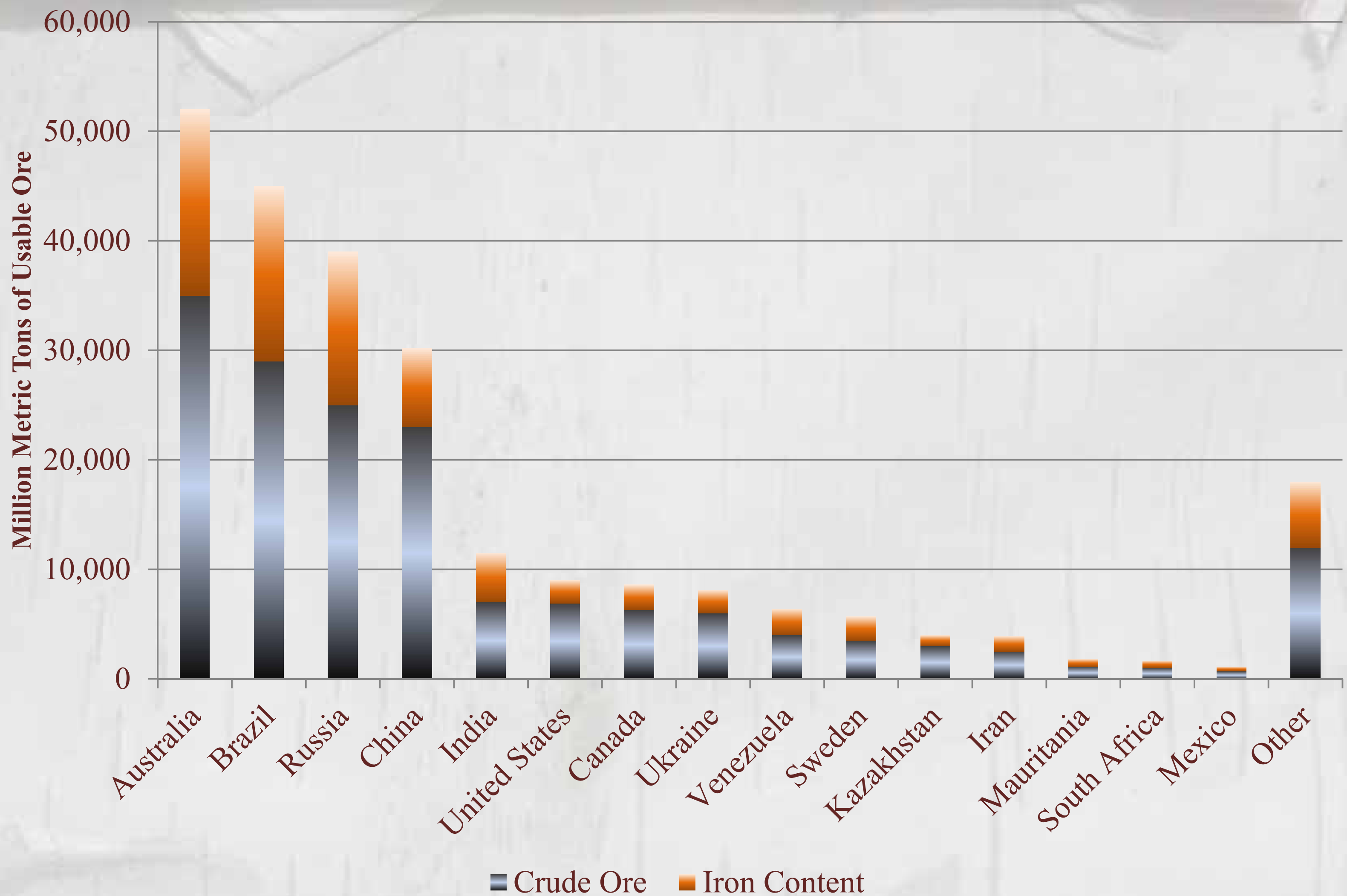
Photo Credit: C. Rasmussen 2012

Global Markets in the Anthropocene



1) Source: UN 2010
2) Source: Trading Economics 2013

Global Iron Reserves

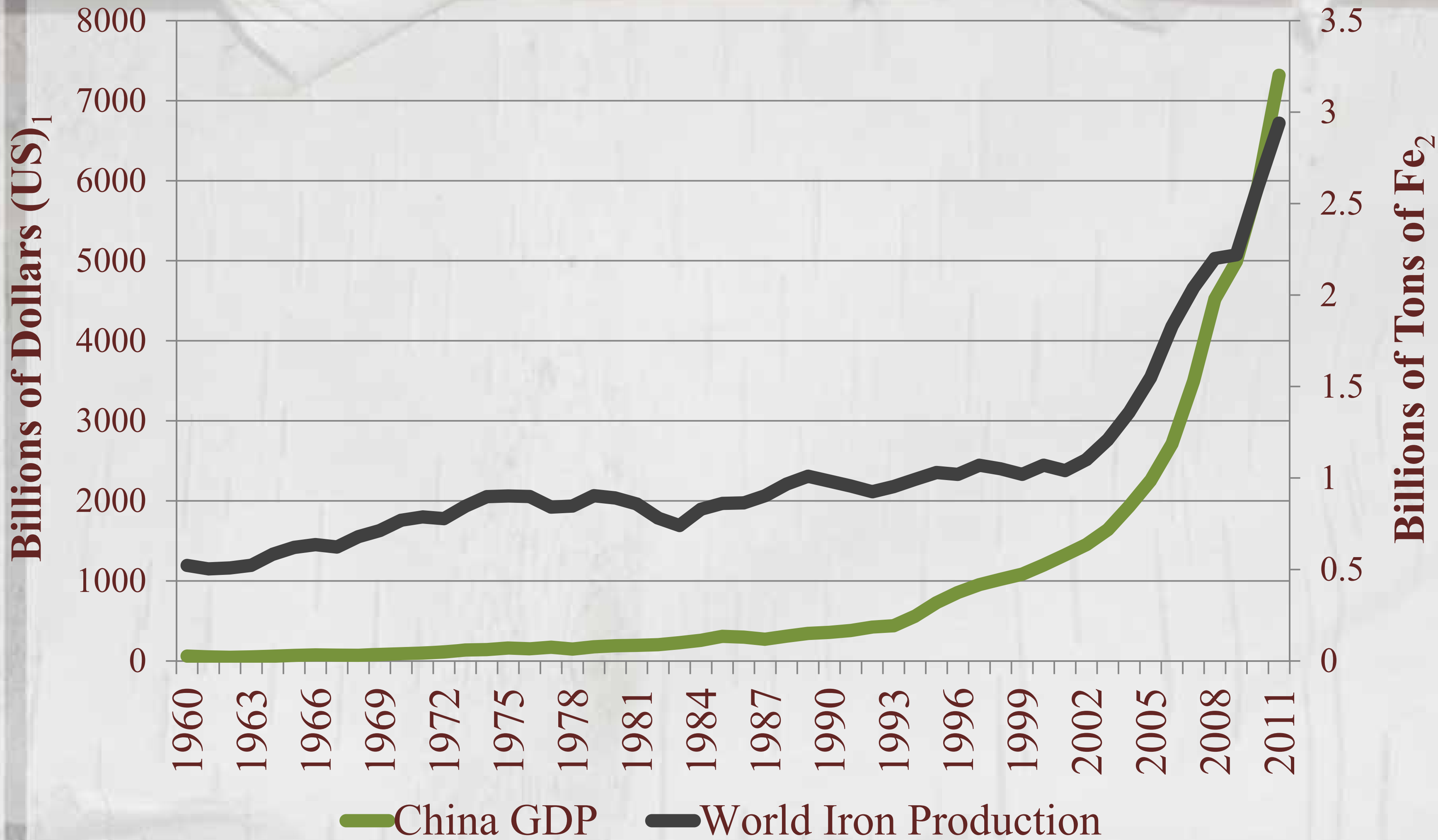


Source: USGS 2012

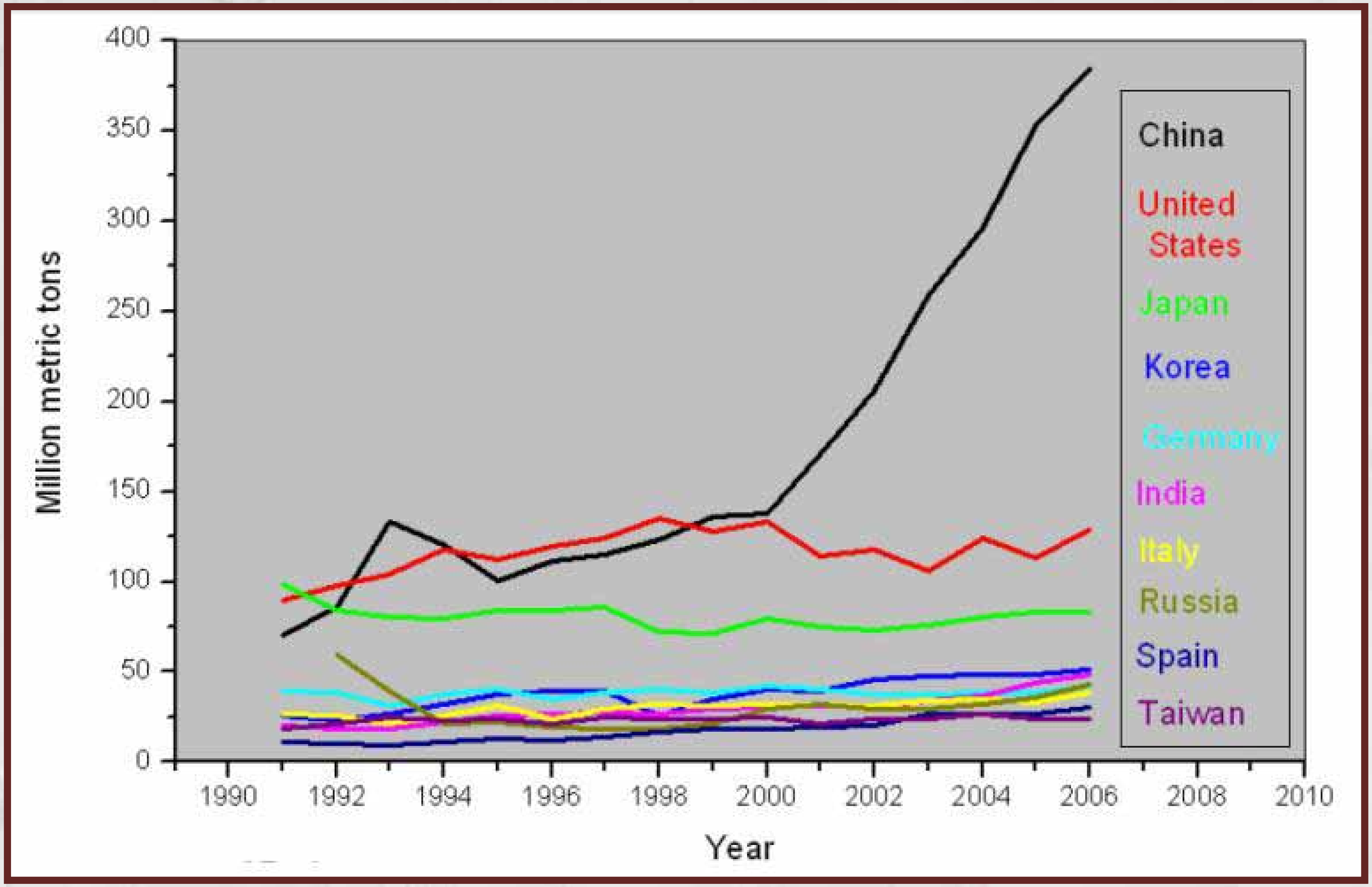
Iron Ore Unit Prices

Source: USGS 2011

Iron Ore Production



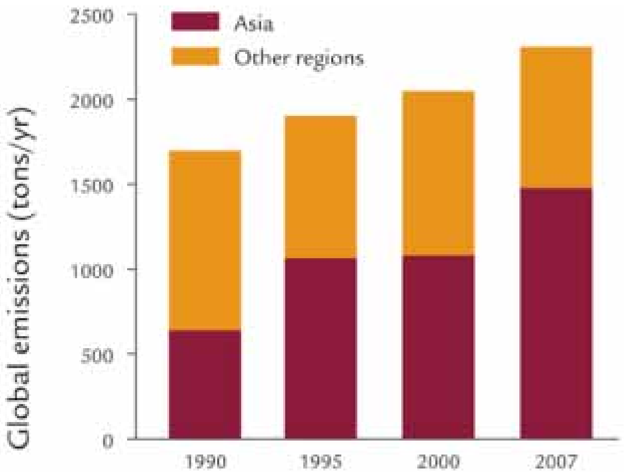
Iron Ore Consumption



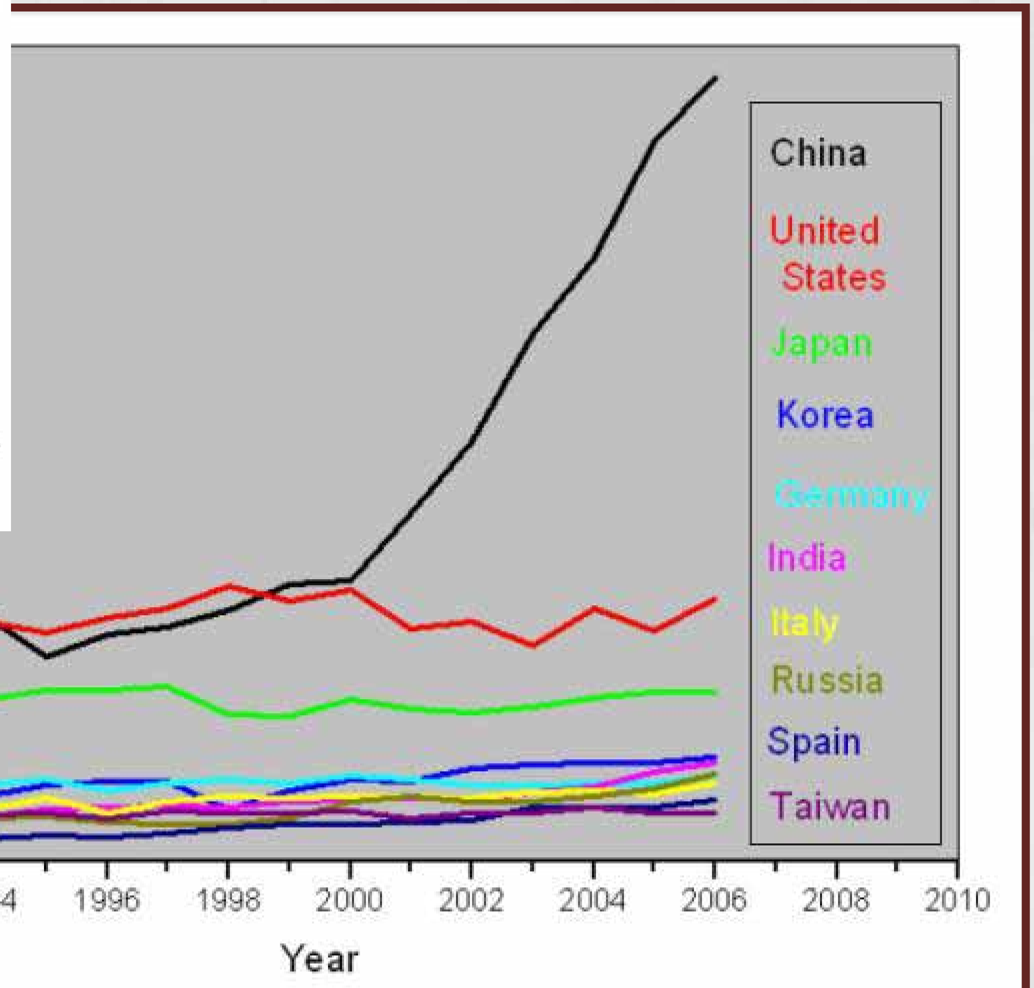
Source: Papp et al. 2008

Iron Ore Consumption

Mercury Emissions

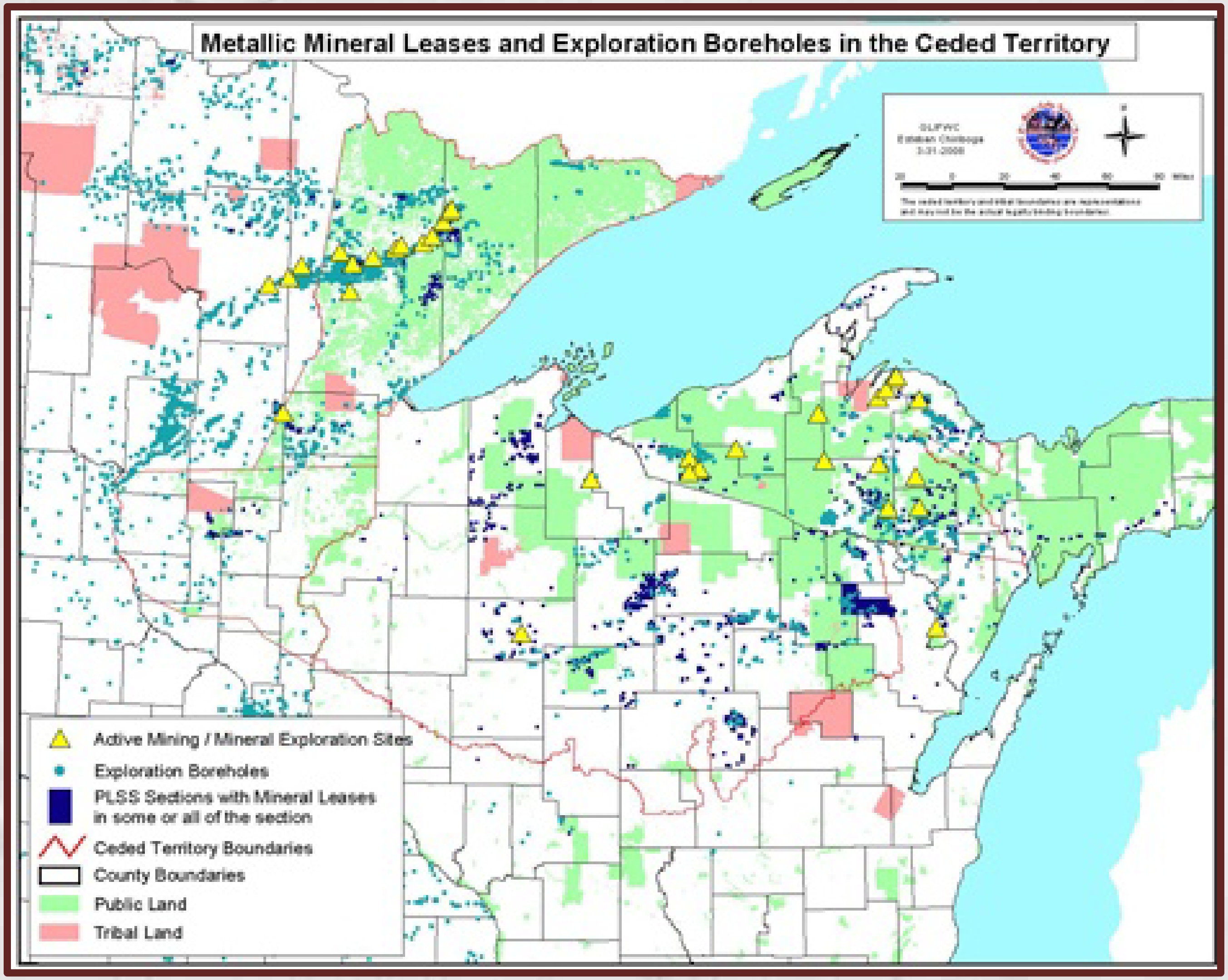


Source: Evers et al. 2011



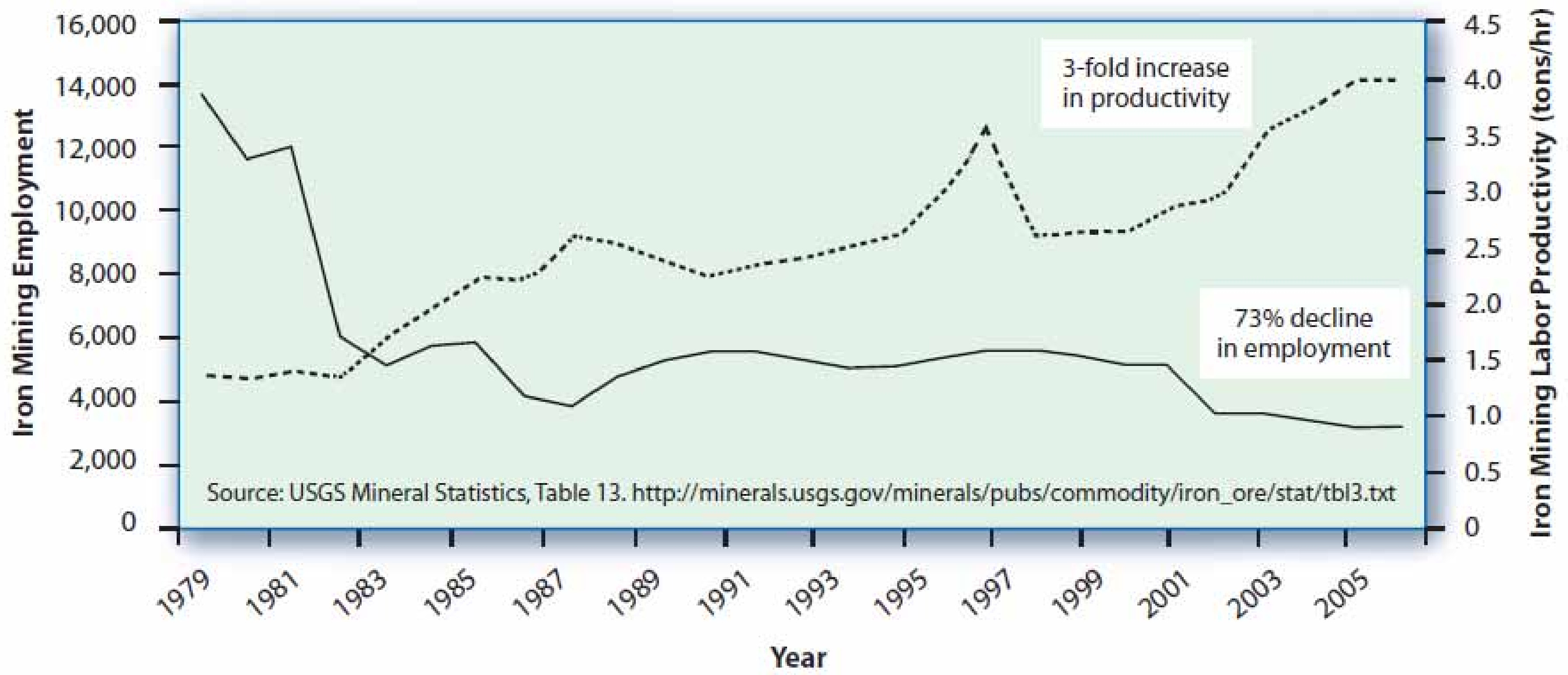
Source: Papp et al. 2008

Basin-wide Activity



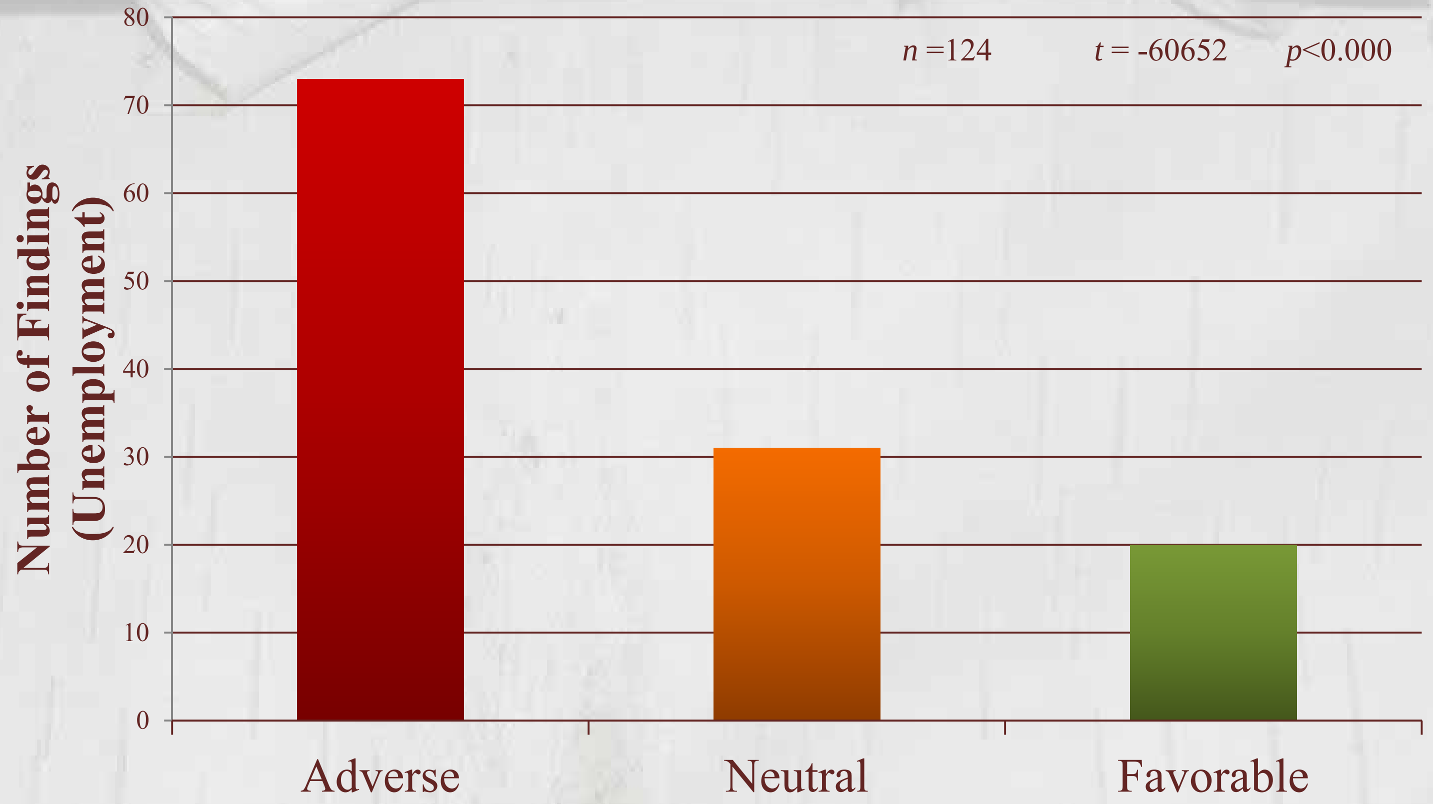
Map Credit:
Great Lakes Indian
Fish & Wildlife
Commission

Automation and Employment



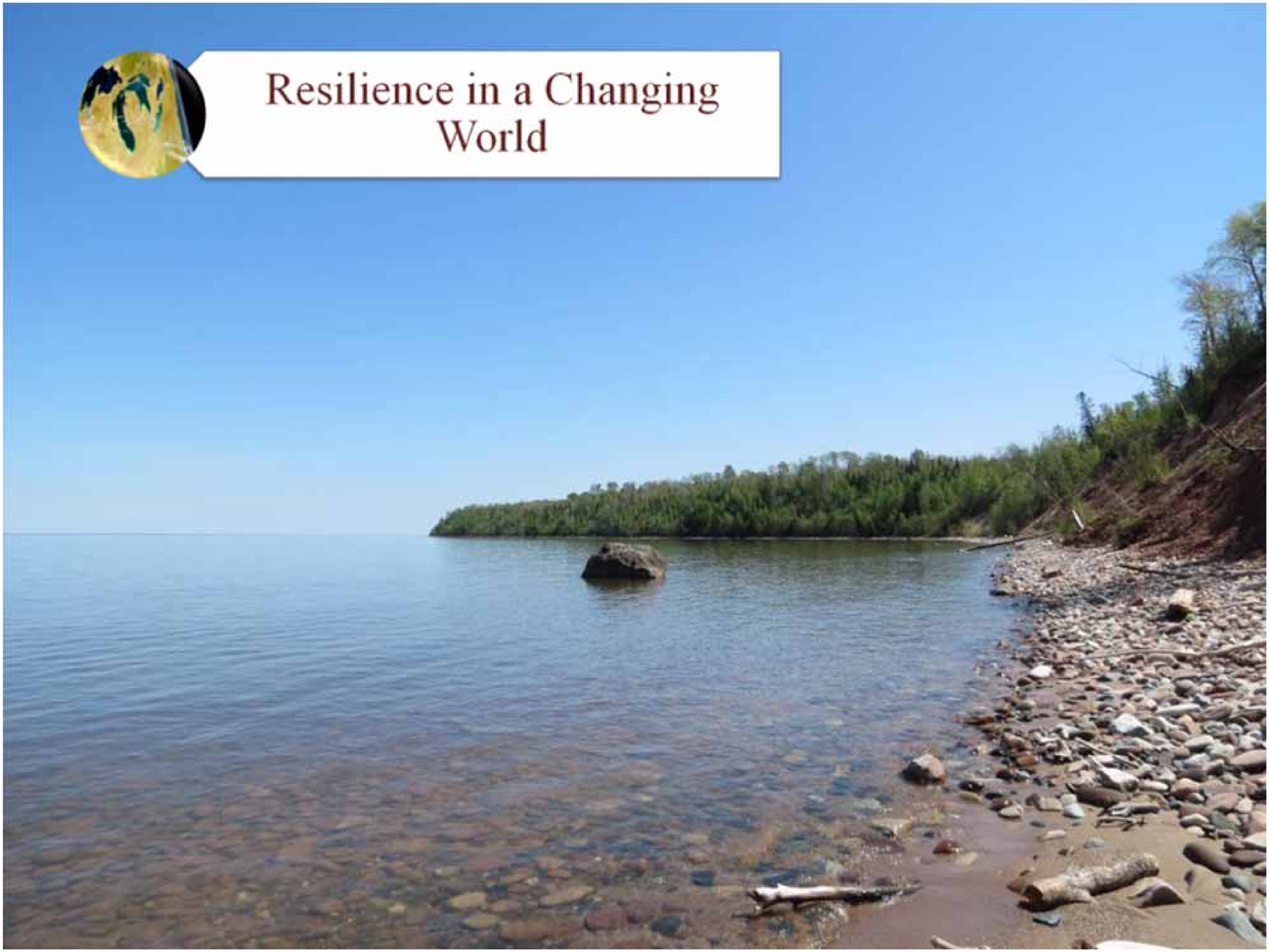
Source: Power 2007

Mining & Employment



- Unemployment Findings: Adverse > Favorable
- Income Findings: Favorable > Adverse
- Poverty Findings: Adverse > Favorable

Source: Freudenburg & Wilson 2002


Resilience in a Changing World

Resilience

"We are changing the Earth more rapidly than we are understanding it" (Vitousek et al. 1997)

- Economic model as driver a concern in Anthropocene – overlooks principal resources (e.g. water) and discounts waste generation
- Adaptation requires empowering communities with accurate science
- Public wellbeing requires balance between growth and regulation with holistic accounting of costs (e.g. waste, water use)

"It is only with a long-term perspective that we can identify which of the seemingly beneficial near-term actions truly contribute to long-term resilience and identify the ways in which some outwardly rational choices lead, in the end, to undesirable outcomes."

–Redman et al. 2009

QUESTIONS ?

From just north of the Penokee Mountain area to Lake Superior, our Tribe is ready to stand up and protect *Nibi* (water) for all peoples and **future generations**."

–M. Wiggins Jr. 2011

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