# Geophysical Applications of Electrical Impedance Tomography

## Ph.D. Defence

Alistair Boyle

Systems and Computer Engineering
Carleton University

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# Motivation

Derailment of 39 railway cars carrying crude oil
Gogama, ON, Canada (2015)[1]

Average 600 derailments per year, 74 with dangerous goods (Canada, 2008-2012)[2]
Gogama clean-up costs will be "in the millions" – MPP F. Gelinas[3]

[1] Transportation Safety Board of Canada, *Railway Investigation Report R15H0021*, Mar 2015

[2] Transportation Safety Board of Canada, *Statistical Summary - Railway Occurrences 2013*, Feb 2014

[3] M. Stackelberg, CBC News, *Ontario bills CN $350K for Gogama derailment clean-up*, Dec 2015

# Motivation

Mount Polley mine tailings spill, Likely, BC, Canada (2014)[4]
spilled 4.5 mil. $m^3$ of tailings with clean up costs of $200–500 mil.

[4] CBC News, *"Mount Polley mine tailings spill"*, Aug 2014

# Motivation

Manage *slope stability* risks

- a tool for real-time monitoring of slope movement
- robust, reliable, informative reconstructions

Our tool of choice:

Electrical Impedance Tomography
Electrical Resistivity Tomography

# Motivation

Manage *slope stability* risks

- a tool for real-time monitoring of slope movement
  electrode movement & resistivity
- robust, reliable, informative reconstructions
  algorithm, implementation, data

Our tool of choice:
Electrical Impedance Tomography
Electrical Resistivity Tomography

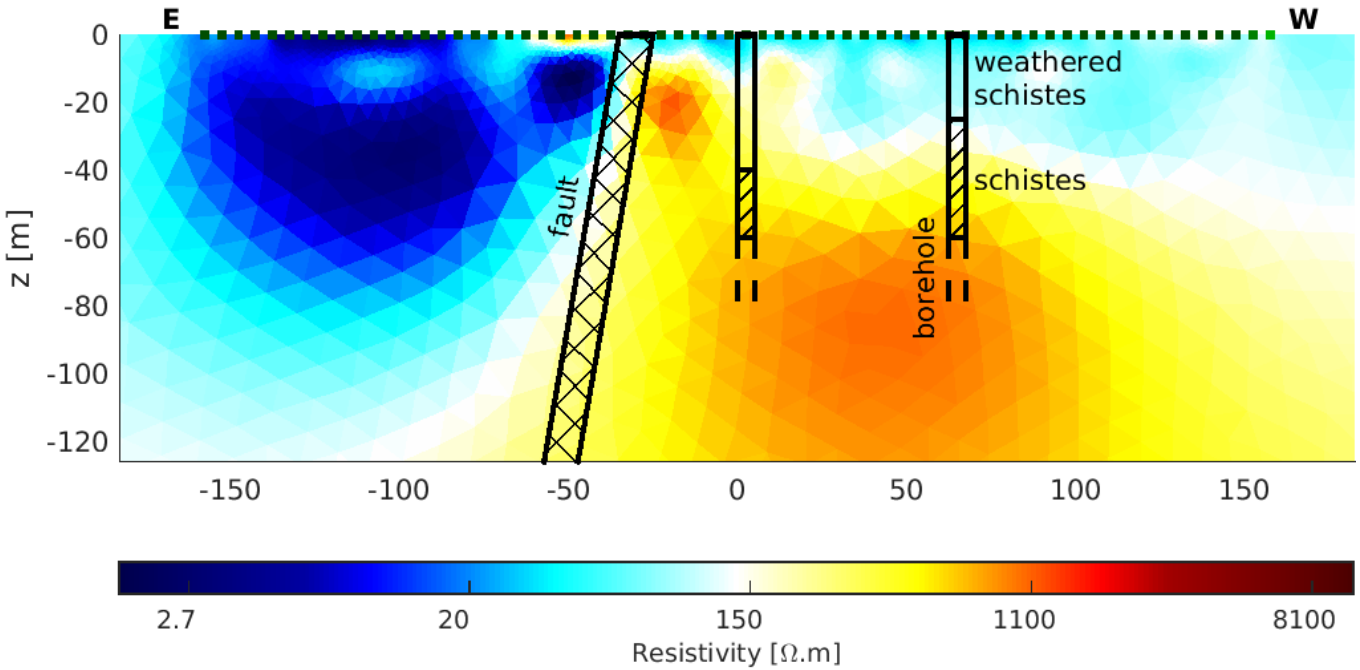
# Electrical Impedance Tomography


Typical ERT Survey Equipment

ABEM TerrameterLS[5]

[5] [http://www.ngi.no/upload/48876/TerrameterLS.jpg]

# Electrical Impedance Tomography




Typical ERT Survey

Pont-Péan, France[6]

[6] correct electrode wiring

# Electrical Impedance Tomography

Long-term remote monitoring

Hollin Hill, UK[7]

[7] Automated Landslide Electrical Resistivity Tomography (ALERT) system

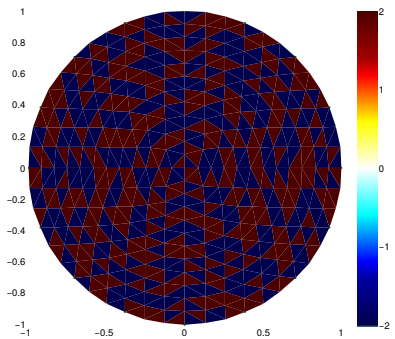
# Methods

Absolute imaging problem; large conductivity contrasts
... a Gauss-Newton nonlinear iterative solver

$$\min_x ||\mathbf{Ax} - \mathbf{b}||_2^2 \tag{1}$$

$$\delta \mathbf{x}_n = -(\mathbf{J}_n^\mathsf{T} \mathbf{J}_n)^{-1} (\mathbf{J}_n^\mathsf{T} \mathbf{b}) \tag{2}$$

$$\mathbf{x}_{n+1} = \mathbf{x}_n + \alpha_{n+1}\ \delta \mathbf{x}_{n+1} \tag{3}$$



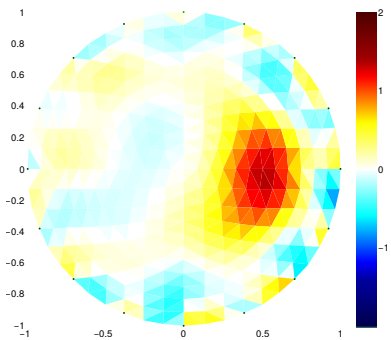
# Methods

Absolute imaging problem; large conductivity contrasts
... a Gauss-Newton nonlinear iterative solver

$$\min_x ||\mathbf{Ax} - \mathbf{b}||^2_{\mathbf{W}} + ||\lambda \mathbf{R}(\mathbf{x} - \mathbf{x}_*)||^2_2 \tag{1}$$

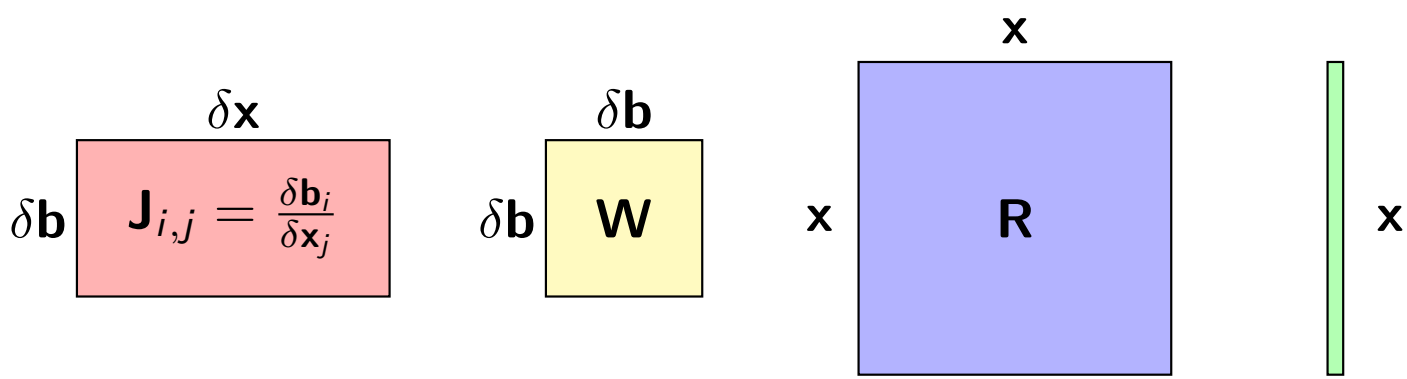
$$\delta \mathbf{x}_{n+1} = -(\mathbf{J}_n^{\mathsf{T}} \mathbf{W} \mathbf{J}_n + \lambda^2 \mathbf{R}^{\mathsf{T}} \mathbf{R})^{-1} (\mathbf{J}_n^{\mathsf{T}} \mathbf{W} \mathbf{b} - \lambda^2 \mathbf{R}^{\mathsf{T}} \mathbf{R}(\mathbf{x}_n - \mathbf{x}_*)) \tag{2}$$

$$\mathbf{x}_{n+1} = \mathbf{x}_n + \alpha_{n+1}\, \delta \mathbf{x}_{n+1} \tag{3}$$

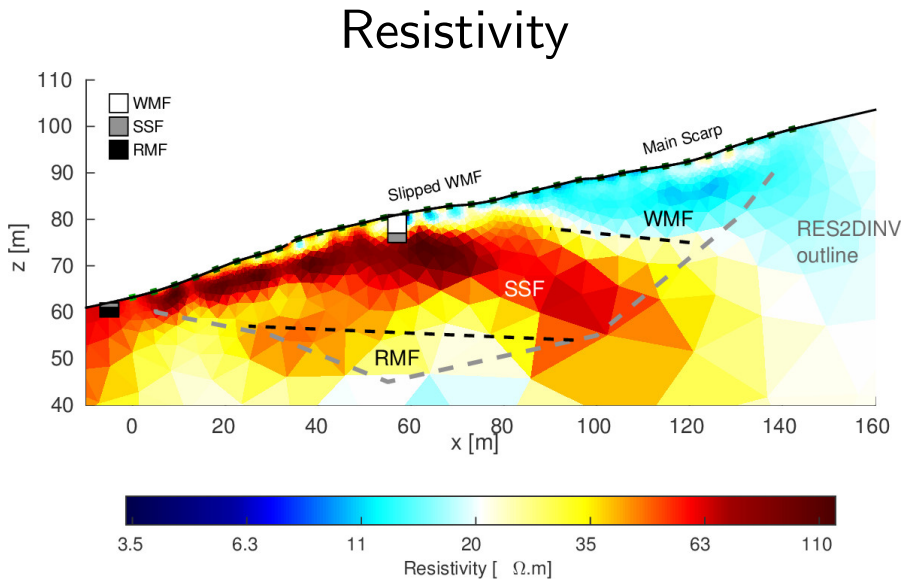


# Methods

$$\delta \mathbf{x}_{n+1} = -(\mathbf{J}_n^\mathsf{T} \mathbf{W} \mathbf{J}_n + \lambda^2 \mathbf{R}^\mathsf{T} \mathbf{R})^{-1} (\mathbf{J}_n^\mathsf{T} \mathbf{W} \mathbf{b} - \lambda^2 \mathbf{R}^\mathsf{T} \mathbf{R} (\mathbf{x}_n - \mathbf{x}_*))$$

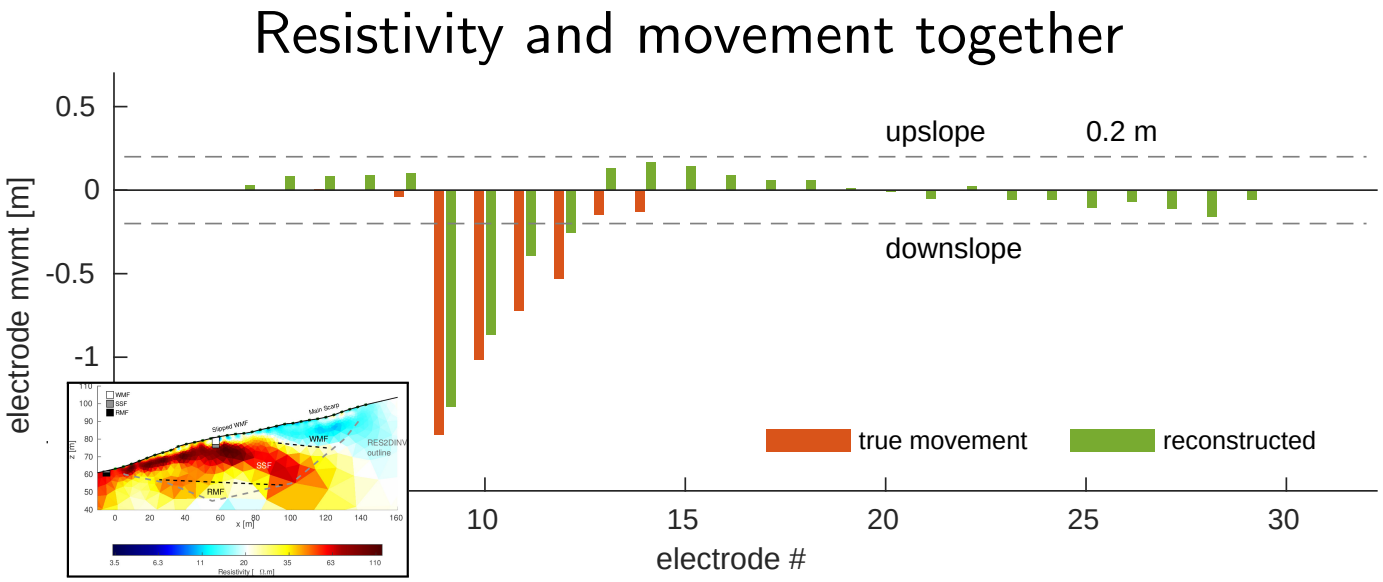


# Methods




$$\delta \mathbf{b} \; \overbrace{\boxed{\mathbf{J}_{i,j} = \frac{\delta \mathbf{b}_i}{\delta \mathbf{x}_j}}}^{\delta \mathbf{x}} \quad \delta \mathbf{b} \; \overbrace{\boxed{\mathbf{W}}}^{\delta \mathbf{b}} \quad \mathbf{x} \; \overbrace{\boxed{\mathbf{R}}}^{\mathbf{x}} \quad \boxed{\phantom{\mathbf{R}}} \; \mathbf{x}$$

# Methods



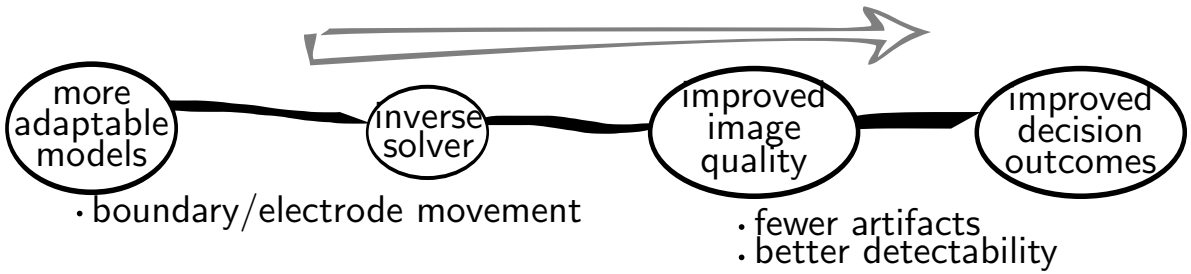

$$\delta\mathbf{b} = \mathbf{J}_{i,j} = \frac{\delta\mathbf{b}_i}{\delta\mathbf{x}_j} \quad \delta\mathbf{x}_\sigma \quad \delta\mathbf{x}_m$$

$$\delta\mathbf{b} = \mathbf{W} \quad \delta\mathbf{b}$$

$$\mathbf{x}_\sigma = \mathbf{R} \quad \mathbf{x}_\sigma \quad \mathbf{x}_m \quad 0 \quad 0$$

$$\mathbf{x}_\sigma \quad \mathbf{x}_m$$

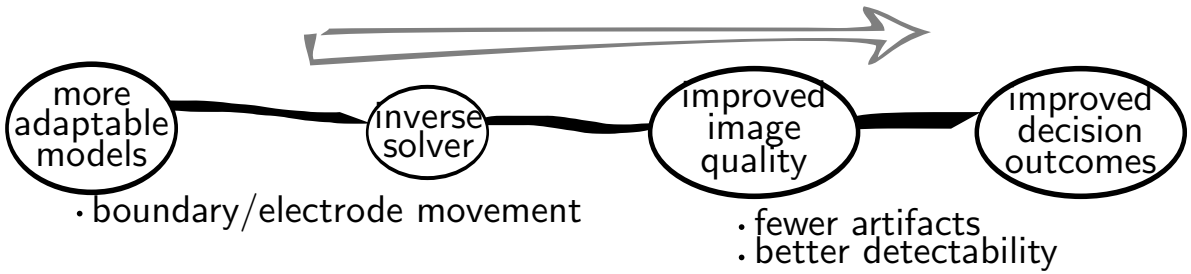
# This Work Addresses




Background material

- impedance imaging: fwd problem, hardware (Ch2)
- rocks and conductivity: a review (Ch3)
- inverse problems: composing algorithms (Ch4)

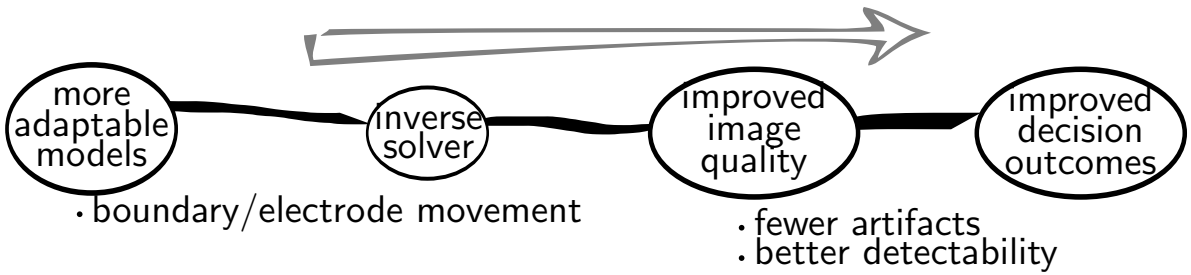
# This Work Addresses




Contributions; with geophysics applications

- problems with inverse problems: reliable algorithms (Ch5)
- data quality and model mismatch: reliable data (Ch6)
- electrode mvmt and modelling errors: reliable Jacobians (Ch7)
- reconstructing surface movement: $[\mathbf{x}_\sigma\ \mathbf{x}_m]^\mathsf{T}$ (Ch8)

# This Work Addresses



# Thank You