One-dimensional inversion of airborne electromagnetic data: application to oil sands exploration

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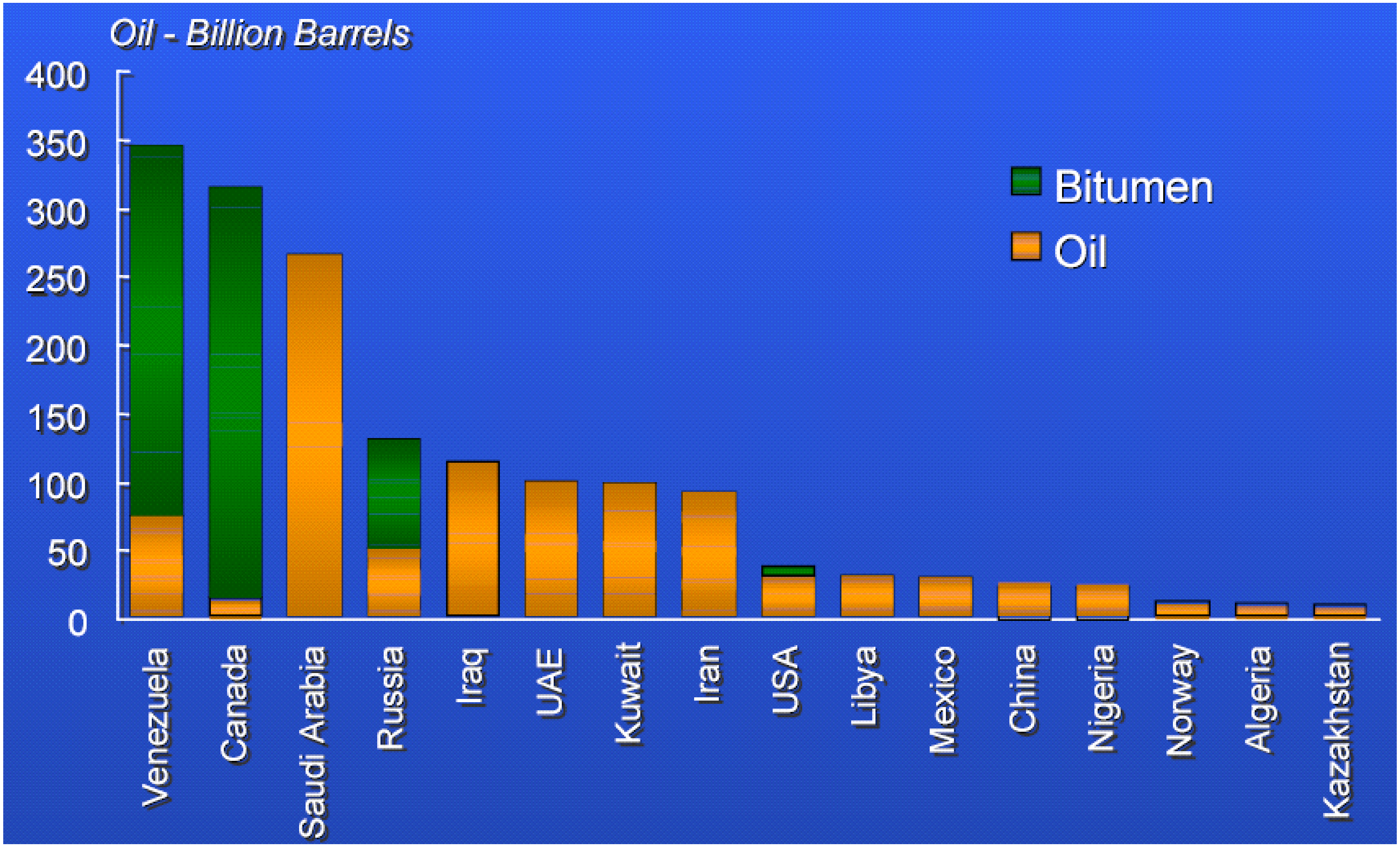
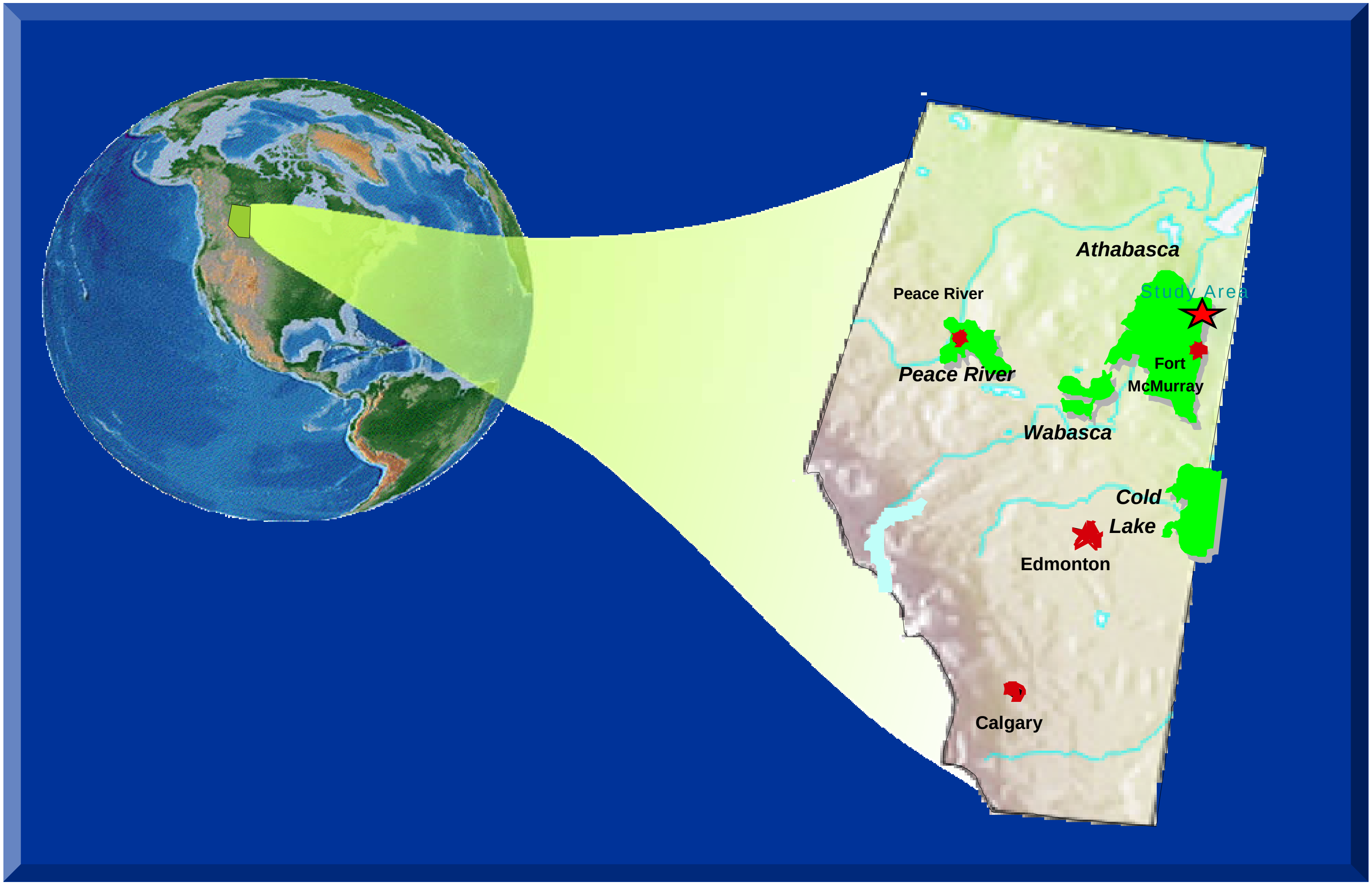
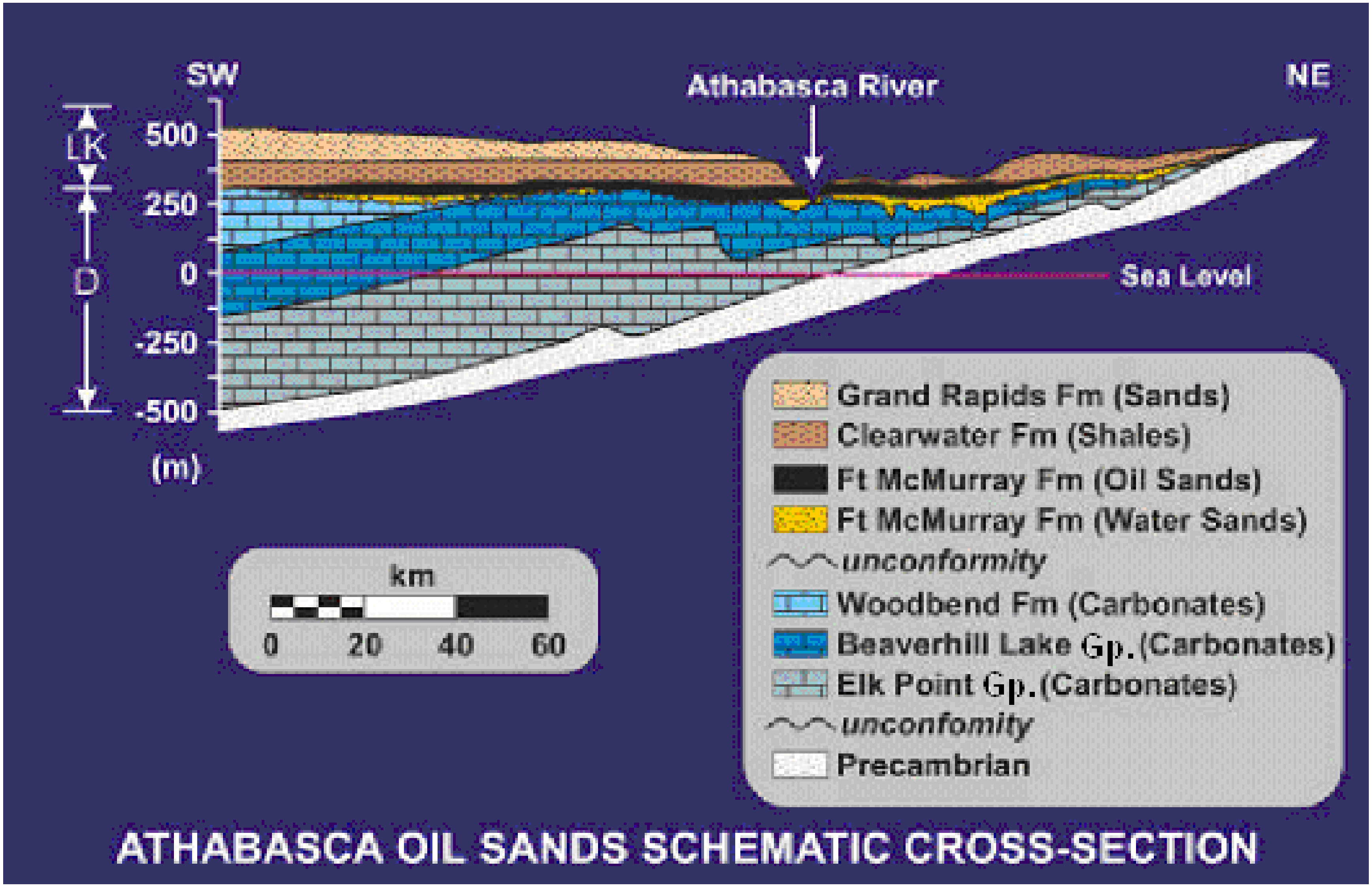
Oil sands in Canada



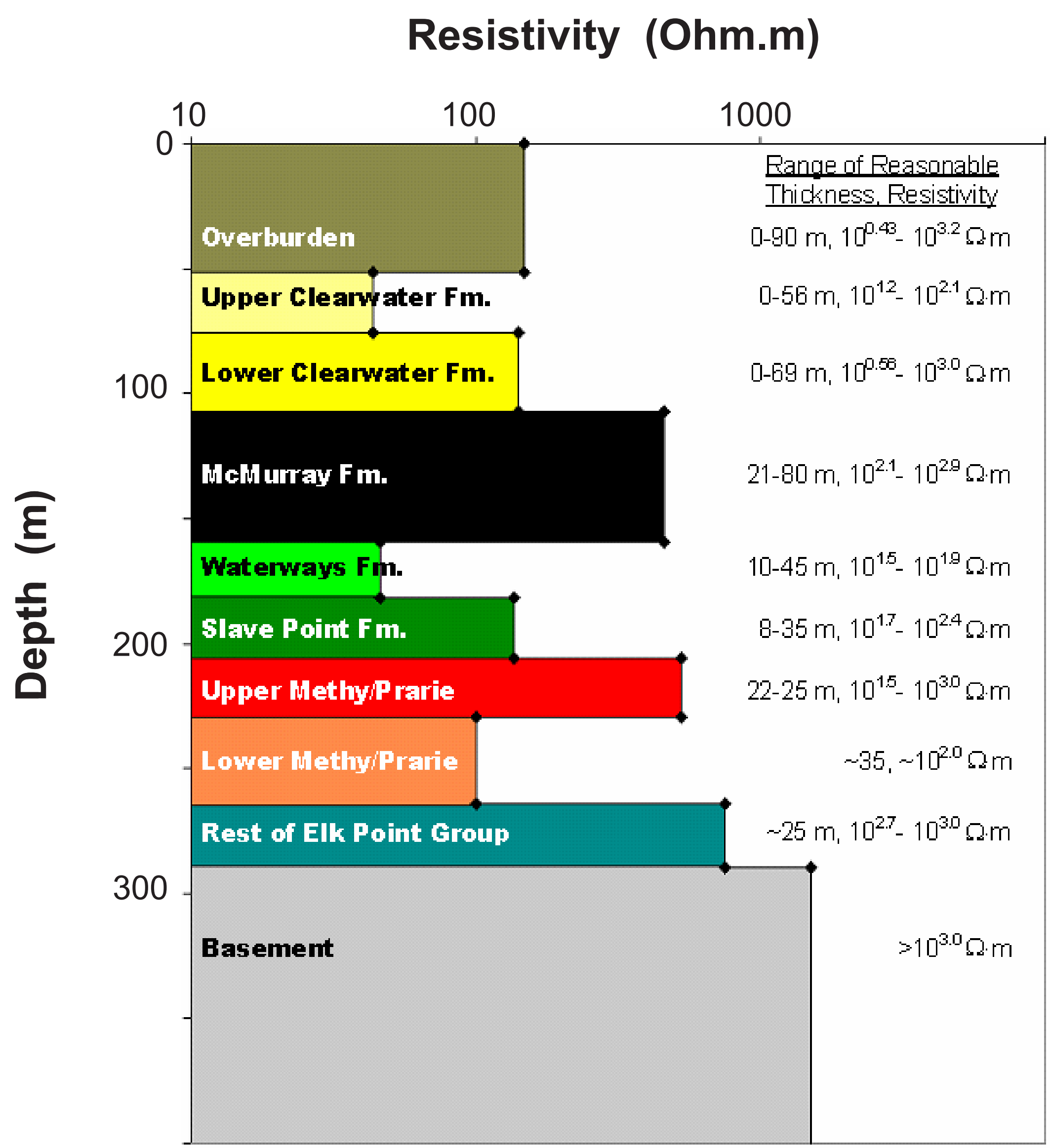
Oil sands in Canada



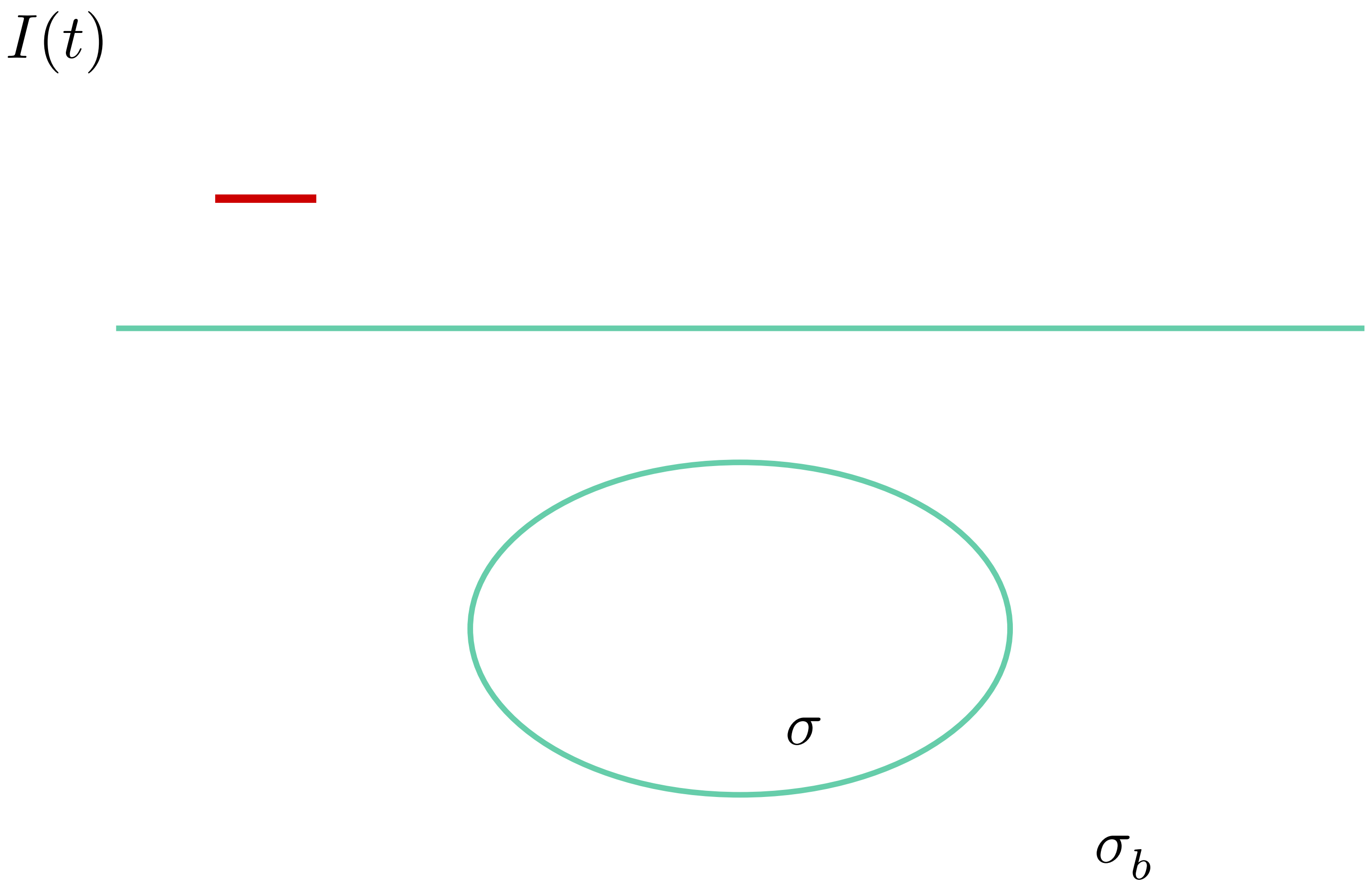
Oil sands in the Fort McMurray area



Electrical properties

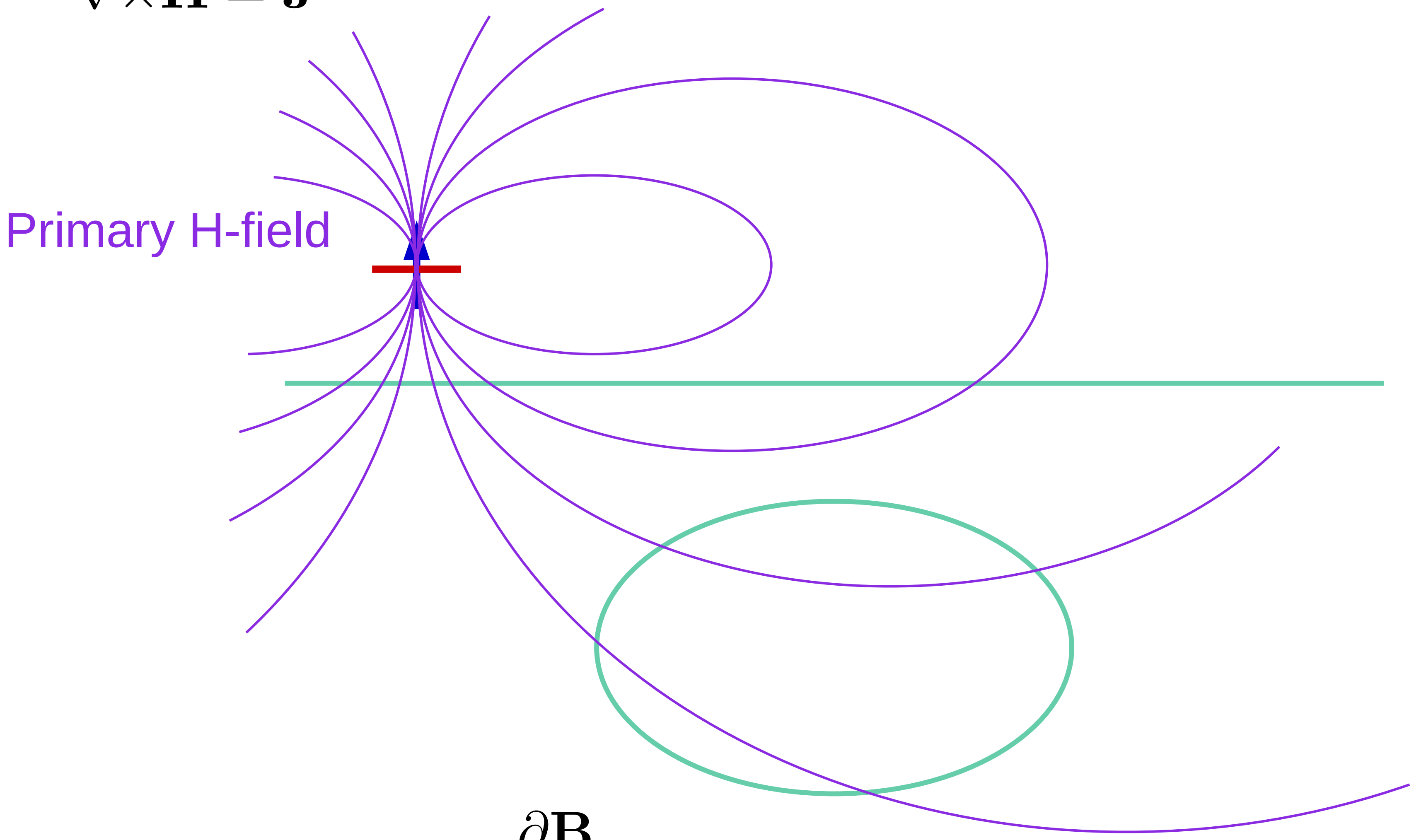


Electromagnetic induction



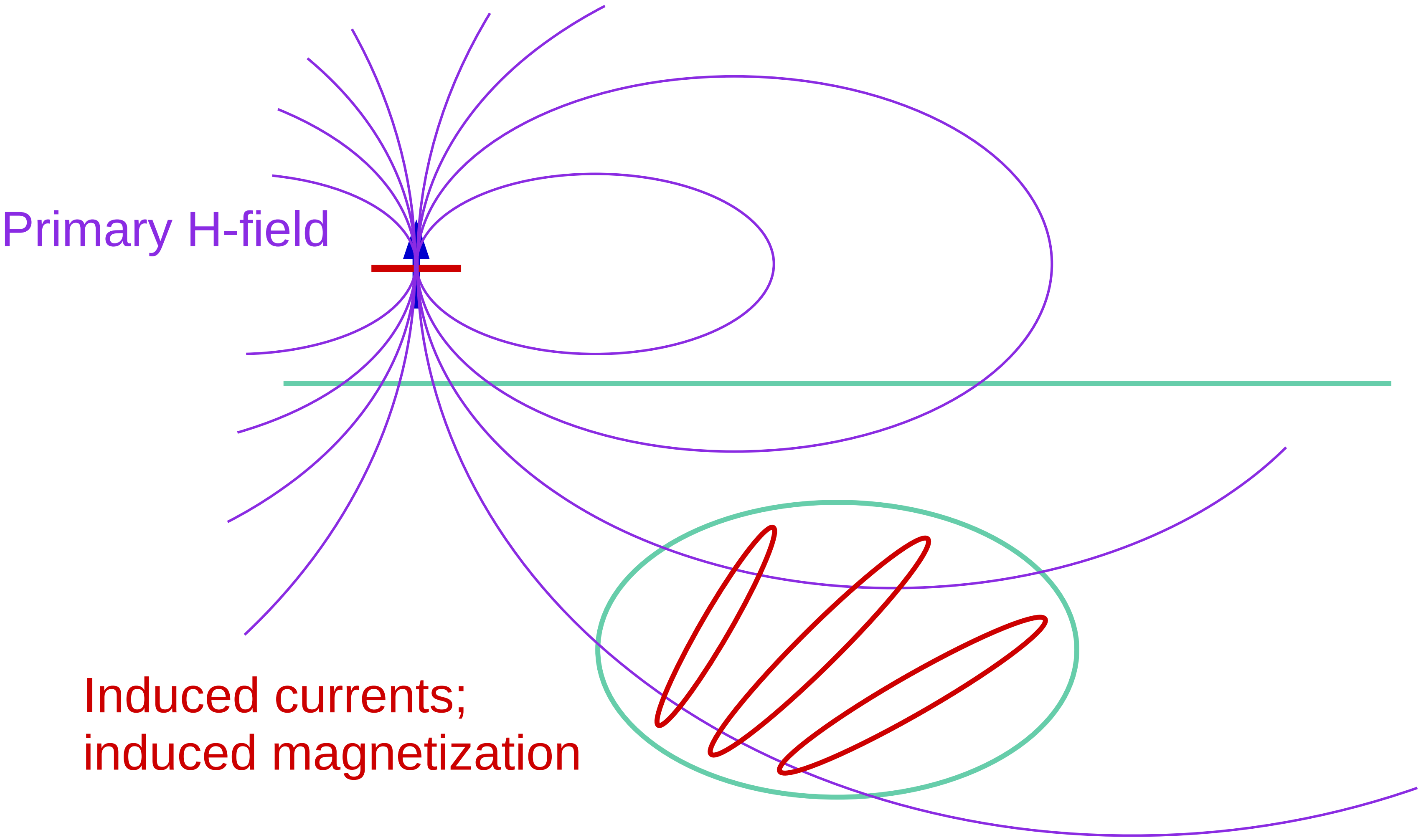
Electromagnetic induction

$$\nabla \times \mathbf{H} = \mathbf{J}$$



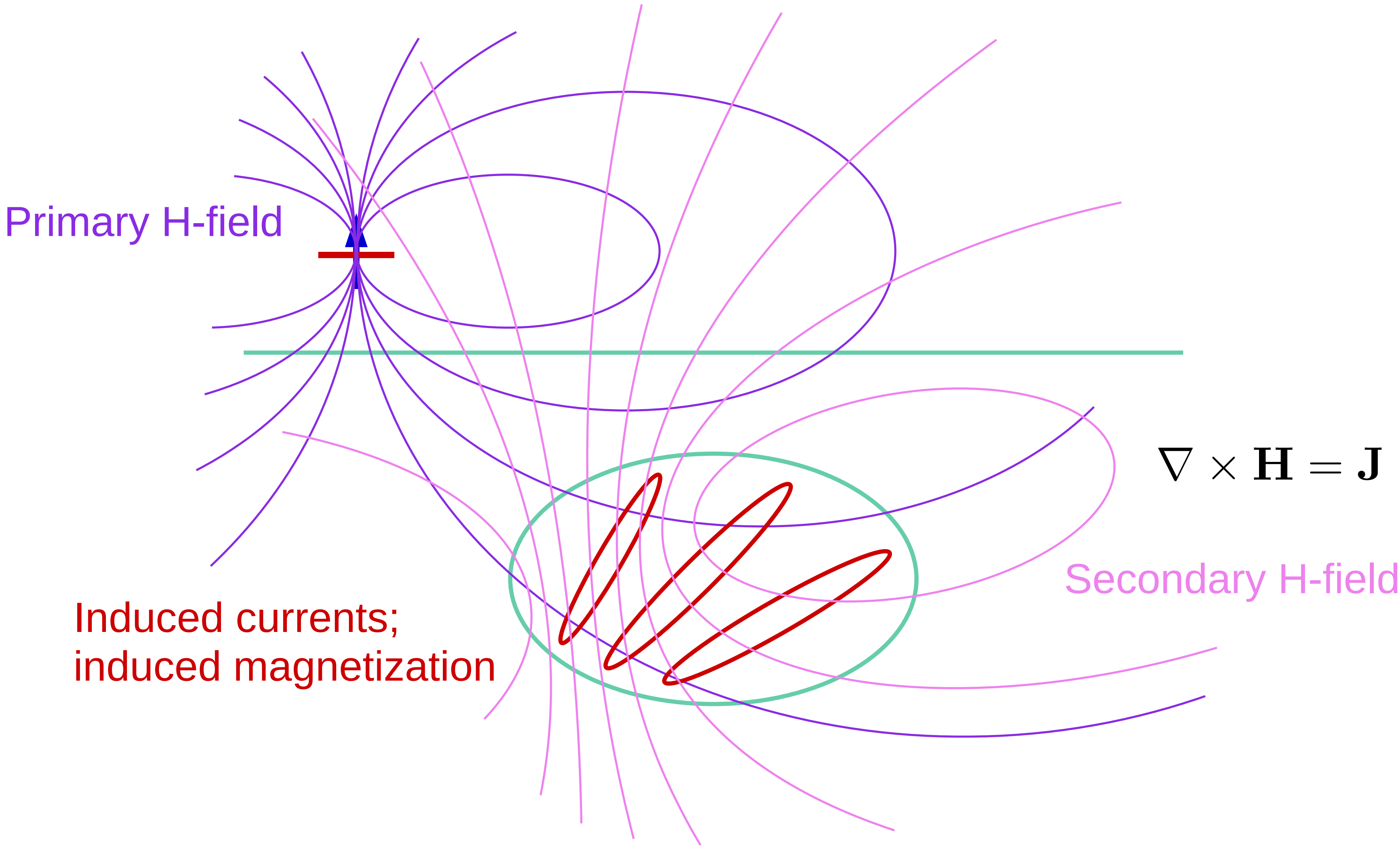
$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

Electromagnetic induction

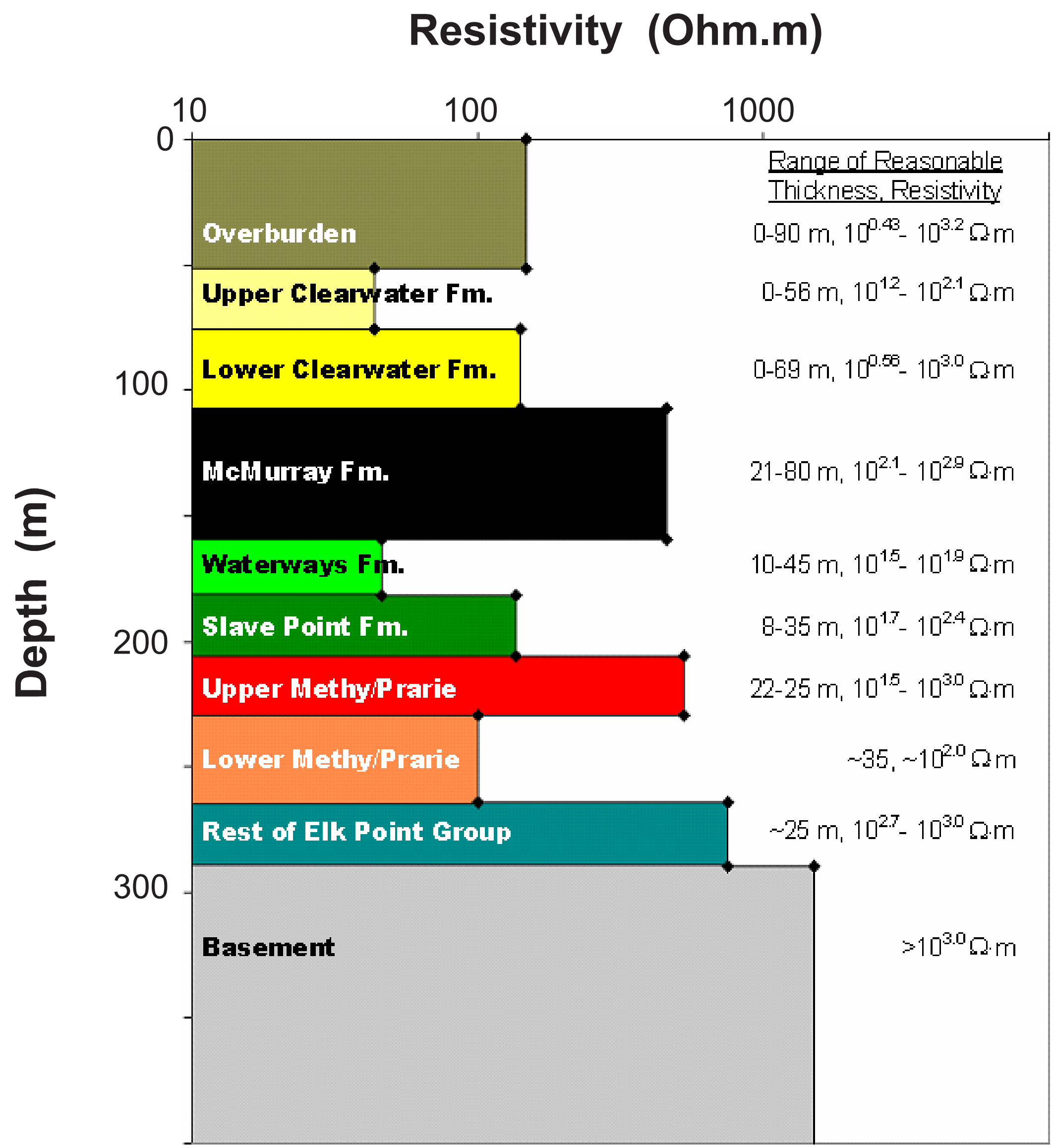


$$\mathbf{J} = \sigma \mathbf{E}; \quad \mathbf{M} = \kappa \mathbf{H}$$

Electromagnetic induction

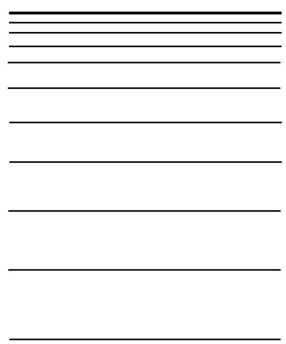


Electrical properties



Inversion methodology: model discretization

- For computations, discretize region of interest:



$$\longleftrightarrow \quad m(\mathbf{r}) = \sum_{j=1}^{N} m_j \, \psi_j(\mathbf{r})$$

∗ "More linear" inverse problem than when both physical property and cell boundaries are unknowns.

∗ To reproduce any spatial distribution, require very fine discretization.

∗ Mathematical inverse problem reflects non-uniqueness of original inverse problem.

Inversion methodology: misfit & model structure

- Fitting observations of utmost importance ...

  $\rightarrow$ measure of misfit: $\phi_d = F\Big(\mathbf{W}_d(\mathbf{d}^{\text{obs}} - \mathbf{d}^{\text{prd}})\Big).$

- To deal with non-uniqueness, construct a model with a particular character ...

  $\rightarrow$ measure of model structure: $\phi_m = F\Big(\mathbf{W}(\mathbf{m} - \mathbf{m}^{\text{ref}})\Big).$

Inversion methodology: objective function

- Find the model $\mathbf{m}$ that minimizes the objective function:

$$\Phi \;=\; \phi_{\rm d} \;+\; \beta\,\phi_{\rm m}.$$

  Choose β such that $\phi_d \leq \; tol.$

- Solution obtained by setting $\nabla_{\mathbf{m}}\Phi = 0$. Hence,

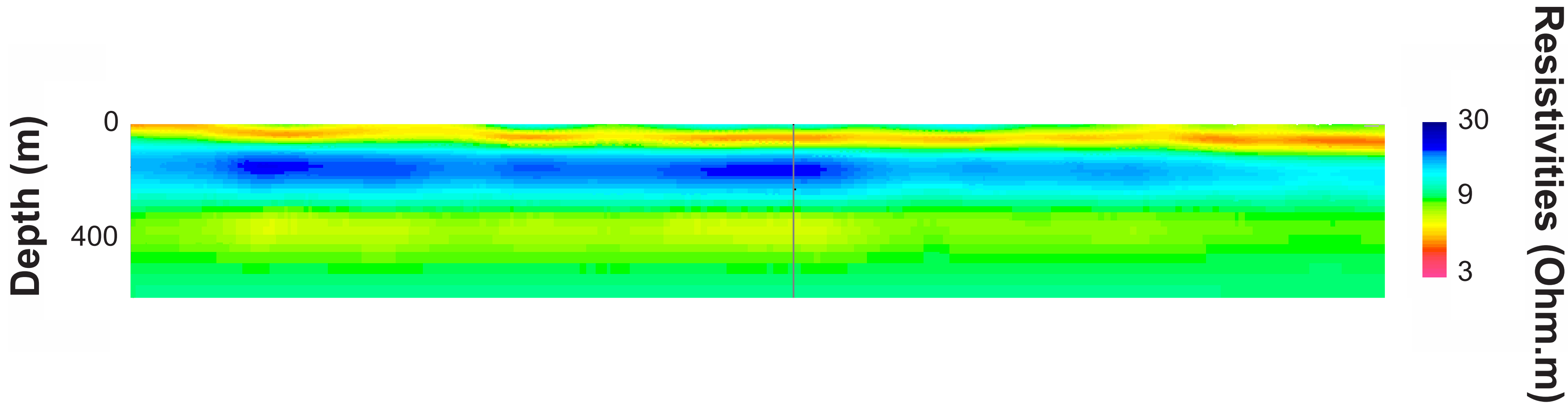
$$\big(\mathbf{J}^T\mathbf{W}_d^T\mathbf{R}_d\mathbf{W}_d\mathbf{J} \;+\; \beta\mathbf{W}^T\mathbf{R}\mathbf{W}\big)\,\delta\mathbf{m} \;= \\ -\,\mathbf{J}^T\mathbf{W}_d^T\mathbf{R}_d\mathbf{W}_d\big(\mathbf{d}^{\rm obs} - \mathbf{d}^n\big) - \beta\mathbf{W}^T\mathbf{R}\mathbf{W}\big(\mathbf{m}^n - \mathbf{m}^{\rm ref}\big),$$

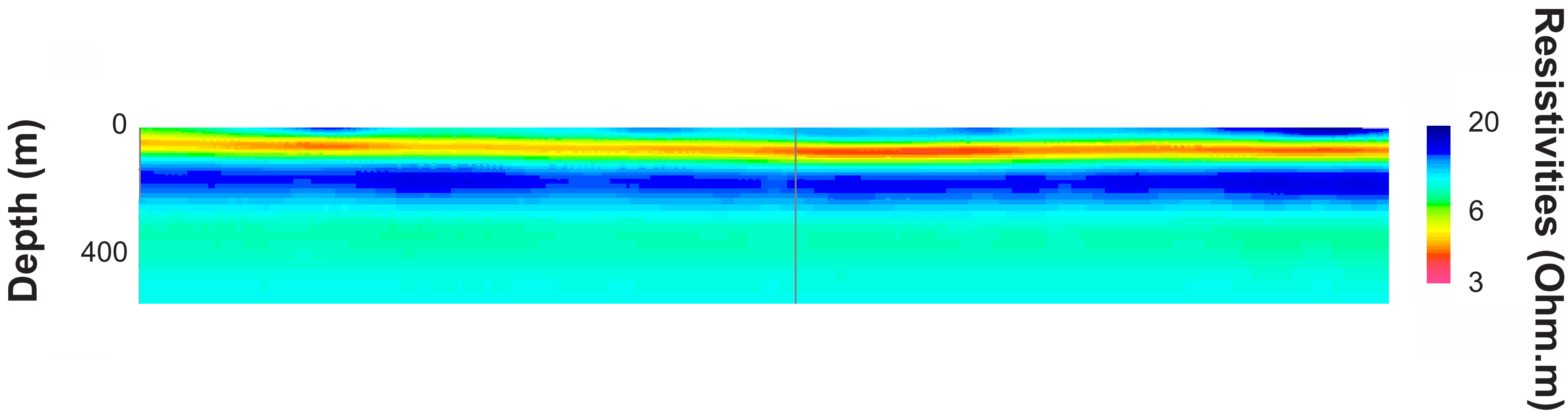
  where $\mathbf{J}$ is the Jacobian matrix of sensitivities:

$$J_{ij} \;=\; \frac{\partial d_i}{\partial m_j}.$$

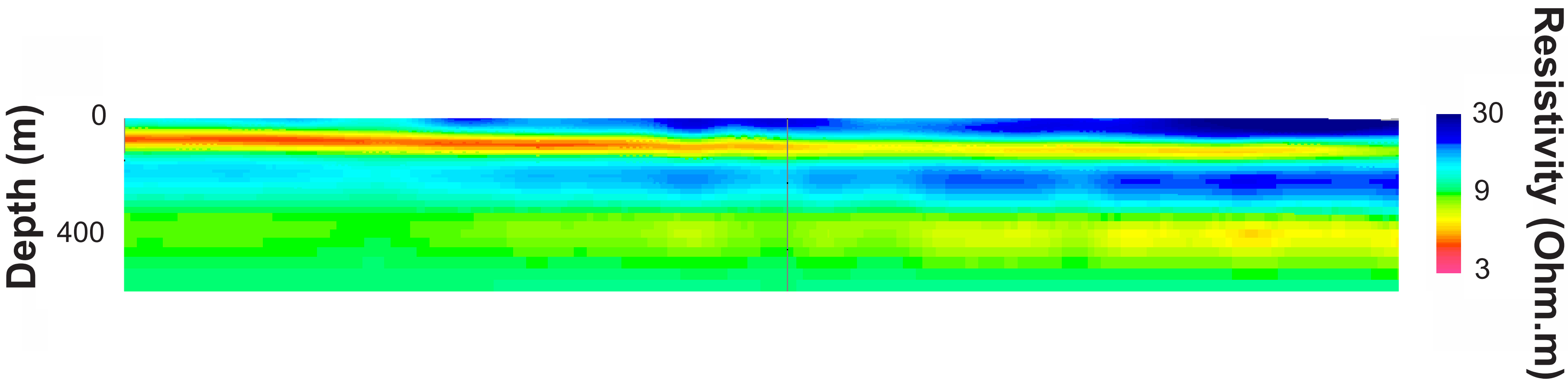
GEOTEM data from the Fort McMurray area

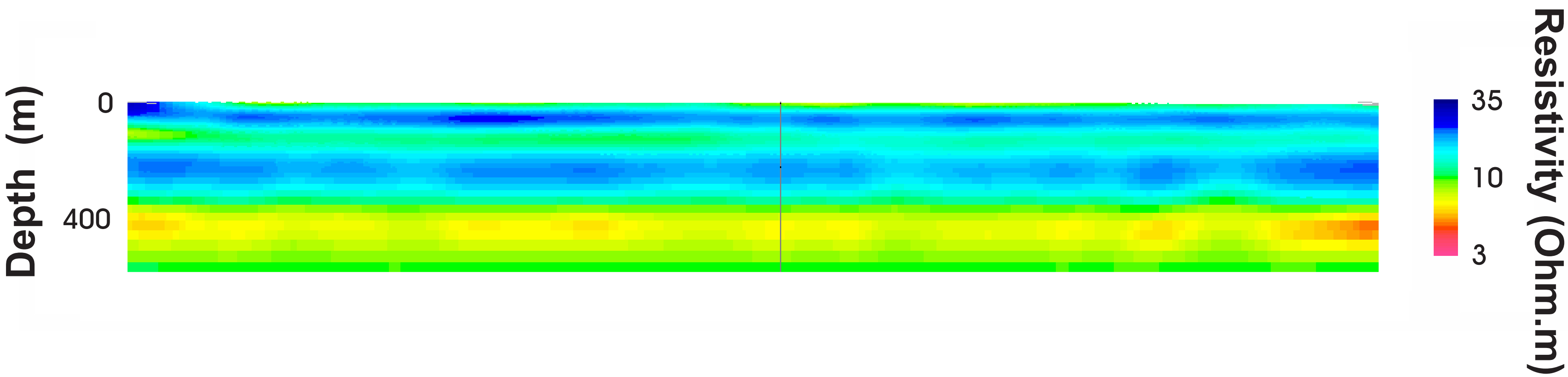
Inversion results – line 10101 – l2



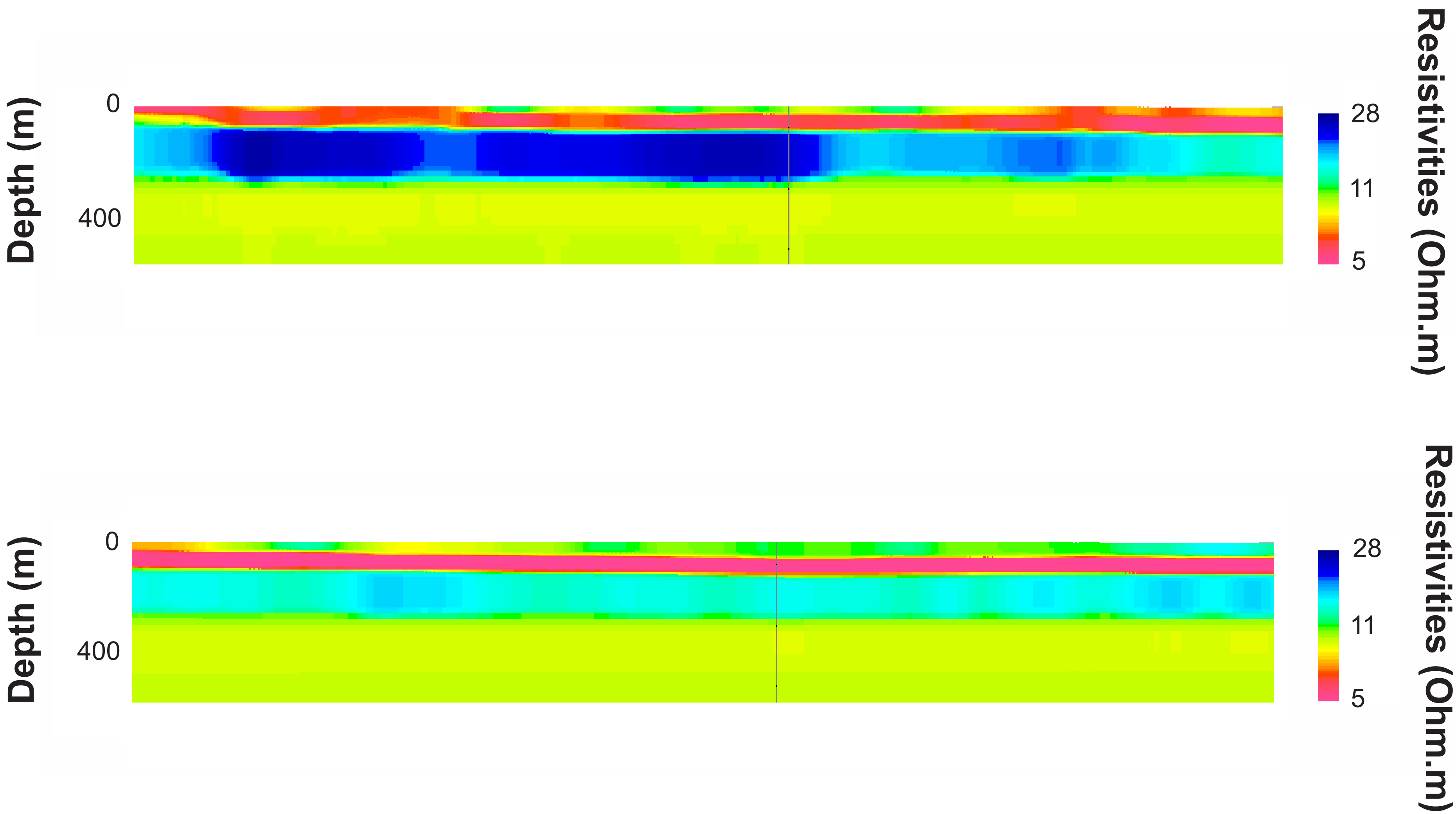


Inversion results – line 10101 (contd) – l2

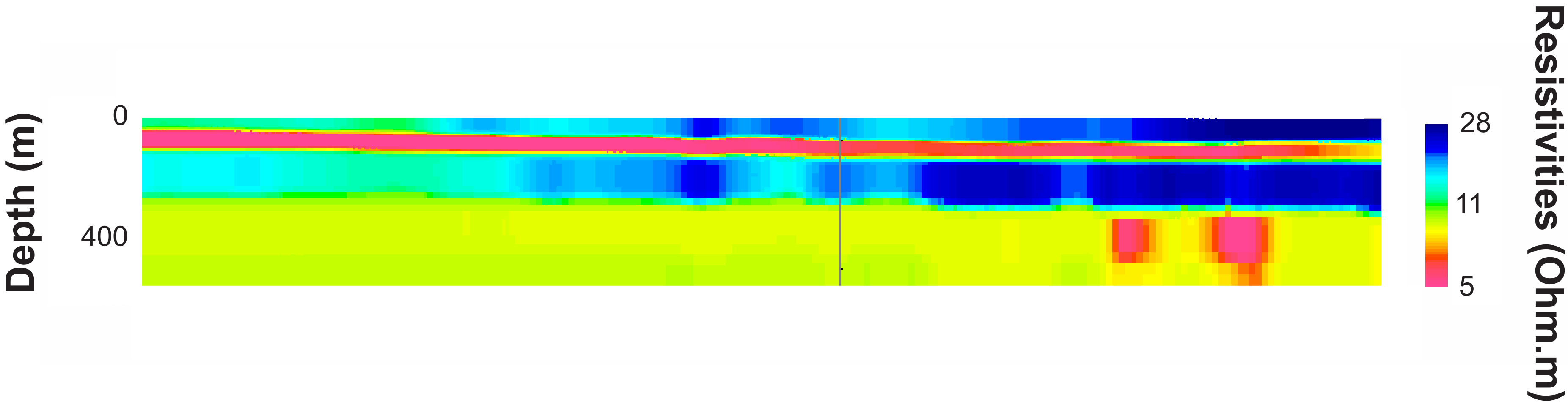


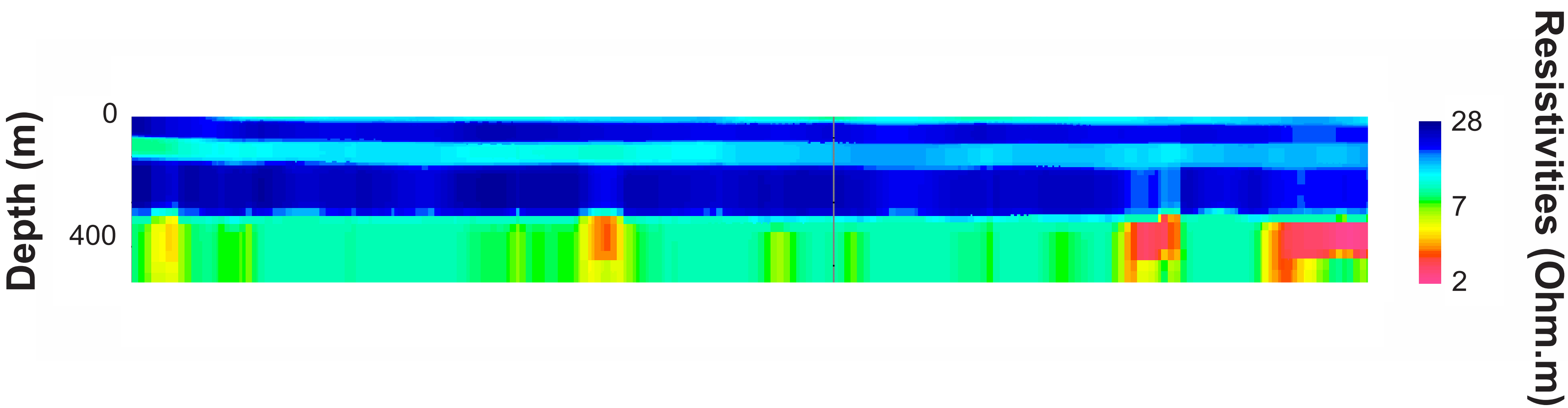


Inversion results – line 10101 – l1

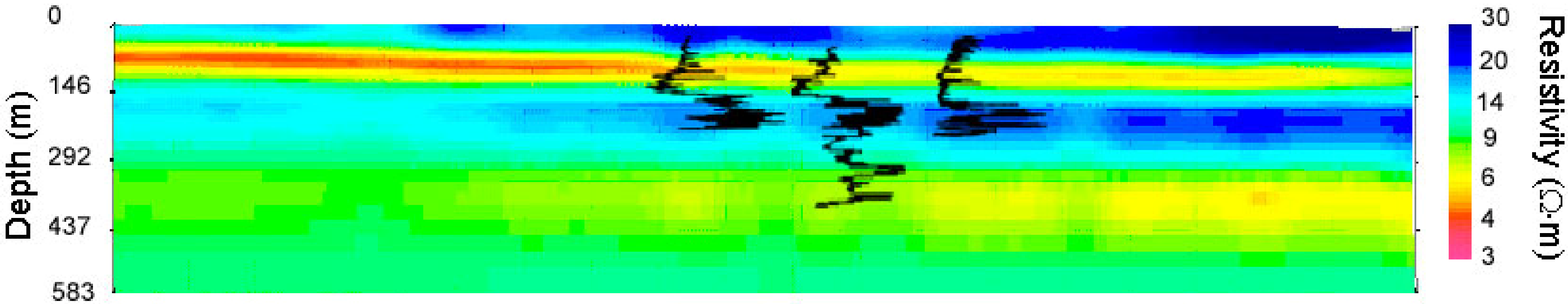


Inversion results – line 10101 (contd) – l1





Inversion results – comparison with well-logs



Summary

* A new, atypical application of electromagnetics in the investigation of the Earth's subsurface.

* Quantitative interpretation via inversion (even 1D).