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Changing the scale of hydrogeophysical aquifer heterogeneity characterization

Daniel Paradis[1,2], Laurie Tremblay[1], Paolo Ruggeri[3], Patrick Brunet[1], Gabriel Fabien-Ouellet[1], Erwan Gloaguen[1], Klaus Holliger[3], James Irving[3], John Molson[4] & René Lefebvre[1]

1: Institut national de la recherche scientifique (INRS), Québec, Canada
2: RNCan, Geological Survey of Canada (GSC), Québec, Canada
3: Université de Lausanne (UNIL), Lausanne, Suisse
4: Université Laval, Québec, Canada

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Objective

- Develop an integrated aquifer characterization approach at a few km^2 scale appropriate to understand and manage a contaminated site:
  - Has to define aquifer heterogeneity & inform on contaminant migration paths and fate
  - Has to produce data that can constrain conceptual and numerical aquifer models
- Develop a practical approach with proven field methods through the study of a real field site with an environmental issue (landfill leachate)

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Field Characterization Approach

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General Characterization Approach

- Characterize at a sub-regional scale covering source zones and receptors (5-20 km^2)
- Acquire a broad range of data (geological, hydraulic, geophysical & geochemical)
- Emphasize high-resolution and continuous 1D or 2D indirect geophysical data
- Use direct-push fully-screened wells to acquire high-resolution hydraulic data colocated with indirect geophysical data

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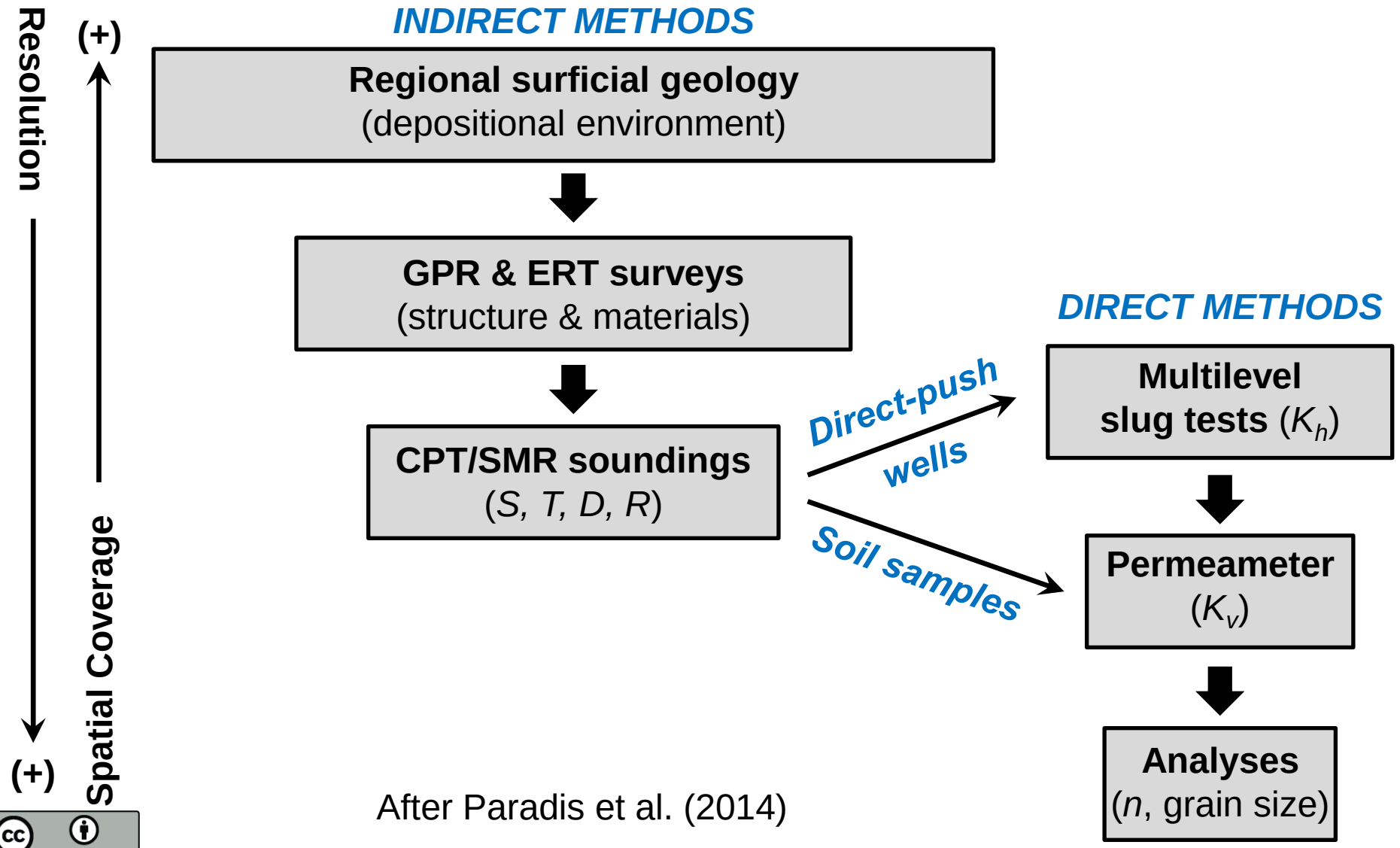
From Broad to Detailed Methods

Approach analog to petroleum exploration

(See Bradford & Babcock, *TLE*, July 2013)



After Paradis et al. (2014)

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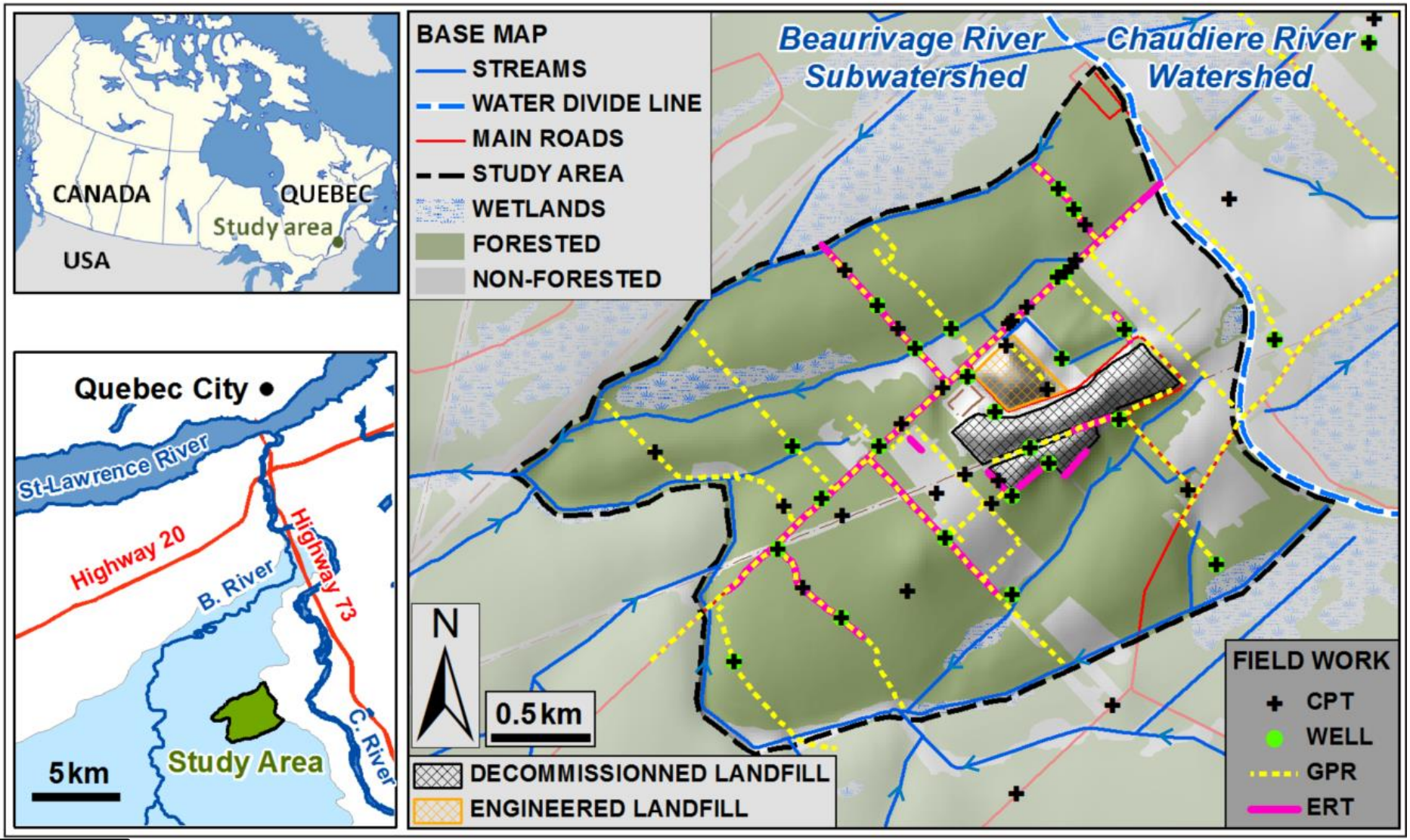
The St-Lambert 12 km² Study Area



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Tremblay et al. (2013)

Measurements of Hydraulic Conductivity *K*

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Adapted Direct *K* Measurements

- Role: provide detailed *K* control
  - Establish relationships with indirect data
- Need: high-resolution and complete
  - Continuous horizontal and vertical *K* (K_h & K_v)
- Methods: fully-screened direct-push wells
  - No filter pack to avoid short-circuits
  - Continuous & colocated *K* (w/ CPT/SMR, ERT)
  - Multi-level slug tests provide high-resolution *K*
  - Flowmeter K_h profiles to decrease testing time
  - New vertical interference tests to obtain ***K_v***

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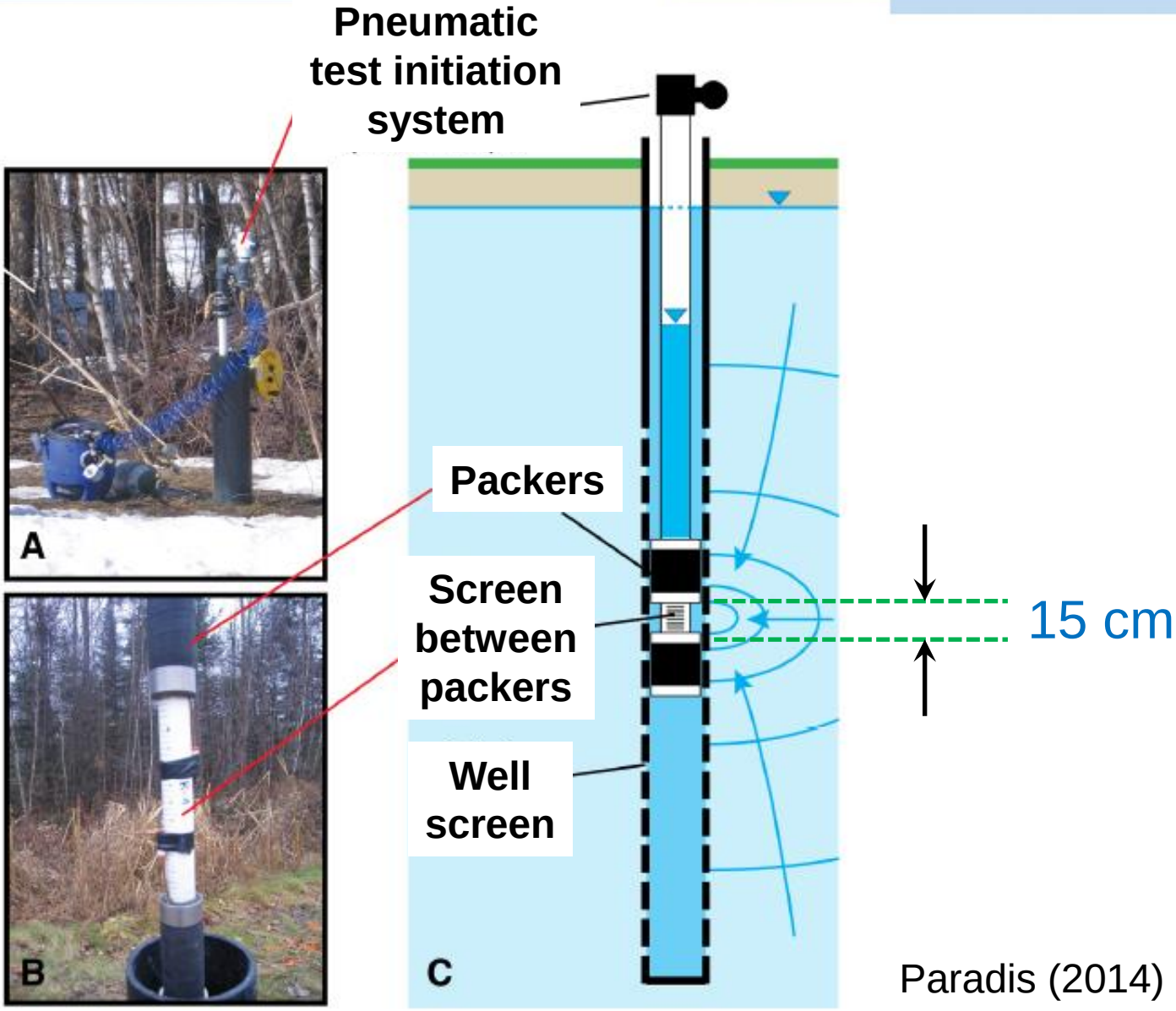
Multi-level Slug Tests (K_h)



Paradis (2014)

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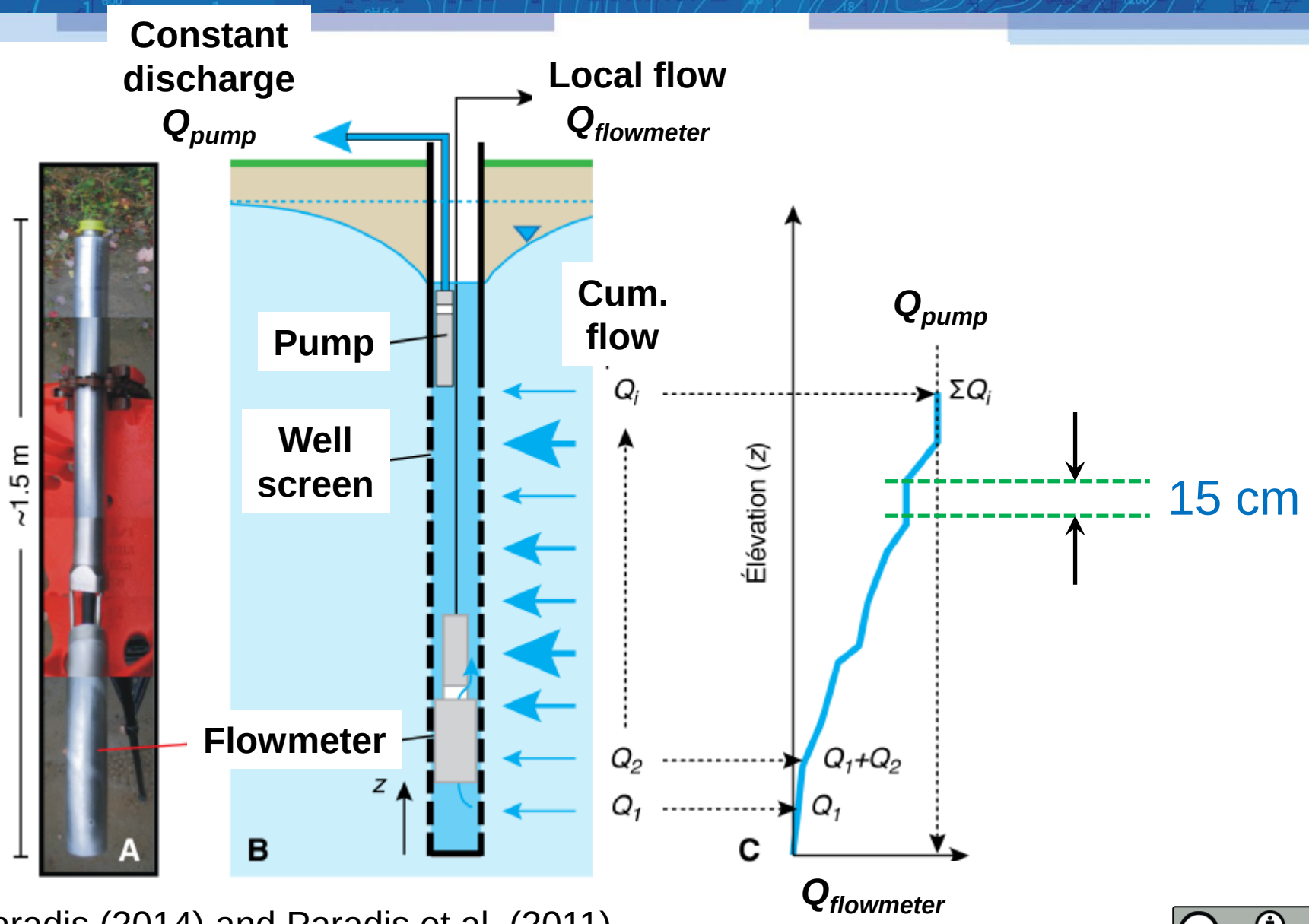
Flowmeter Profile while Pumping (K_h)



Paradis (2014) and Paradis et al. (2011)

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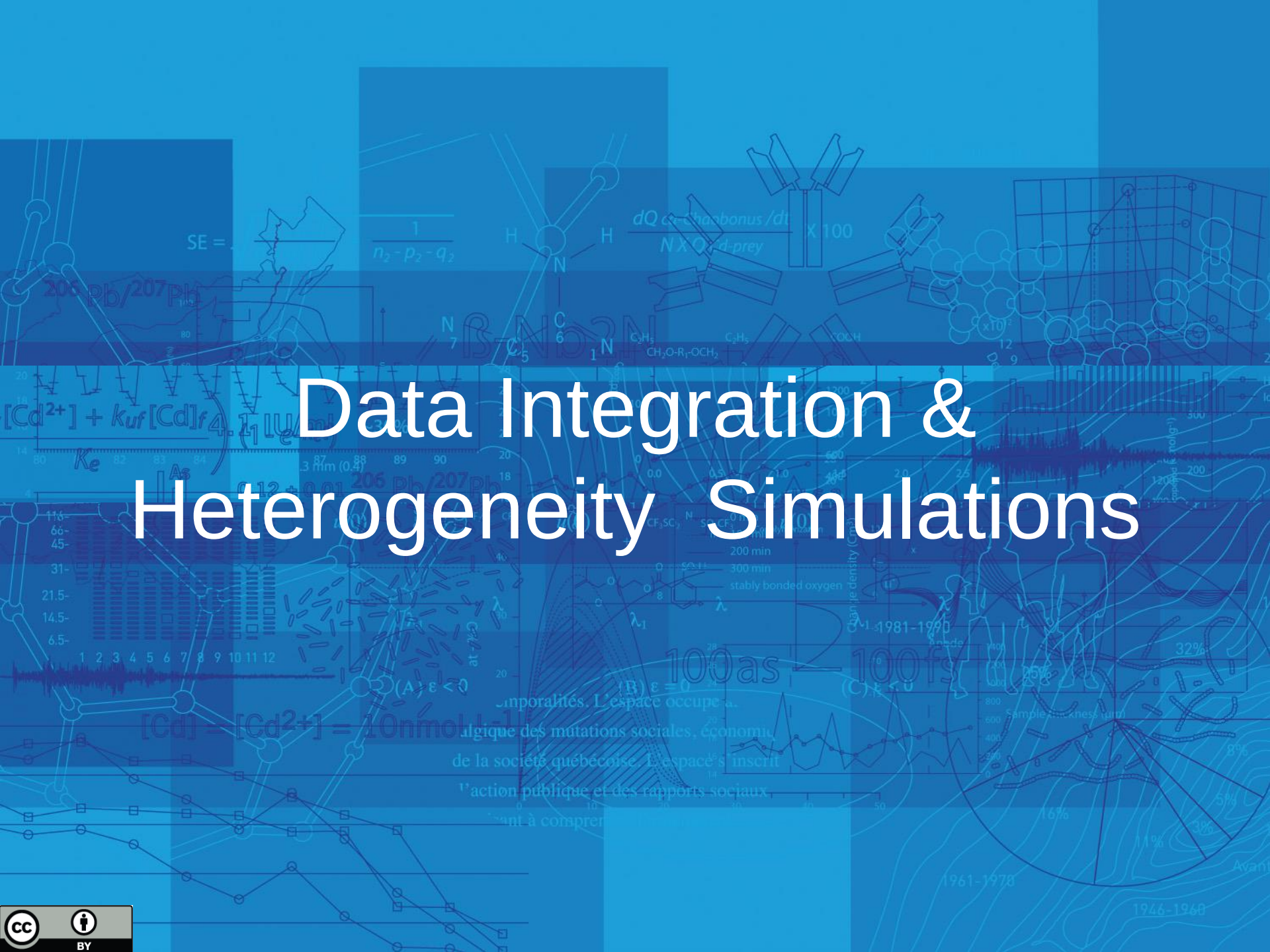
Data Integration & Heterogeneity Simulations



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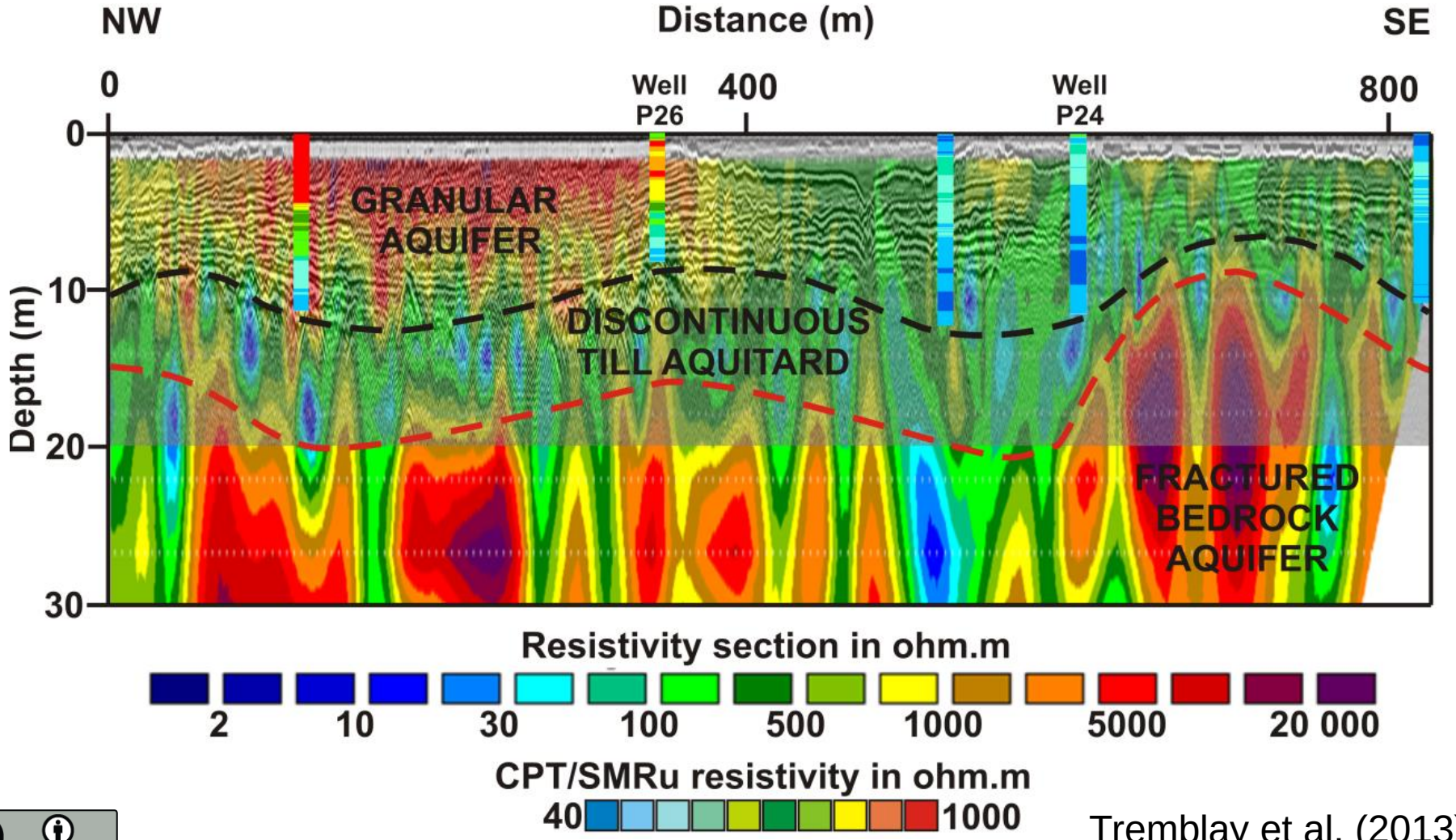
Qualitative Integration – Infer Conditions

GPR (structure), ERT (materials) & CPT/SMR (control)



Tremblay et al. (2013)

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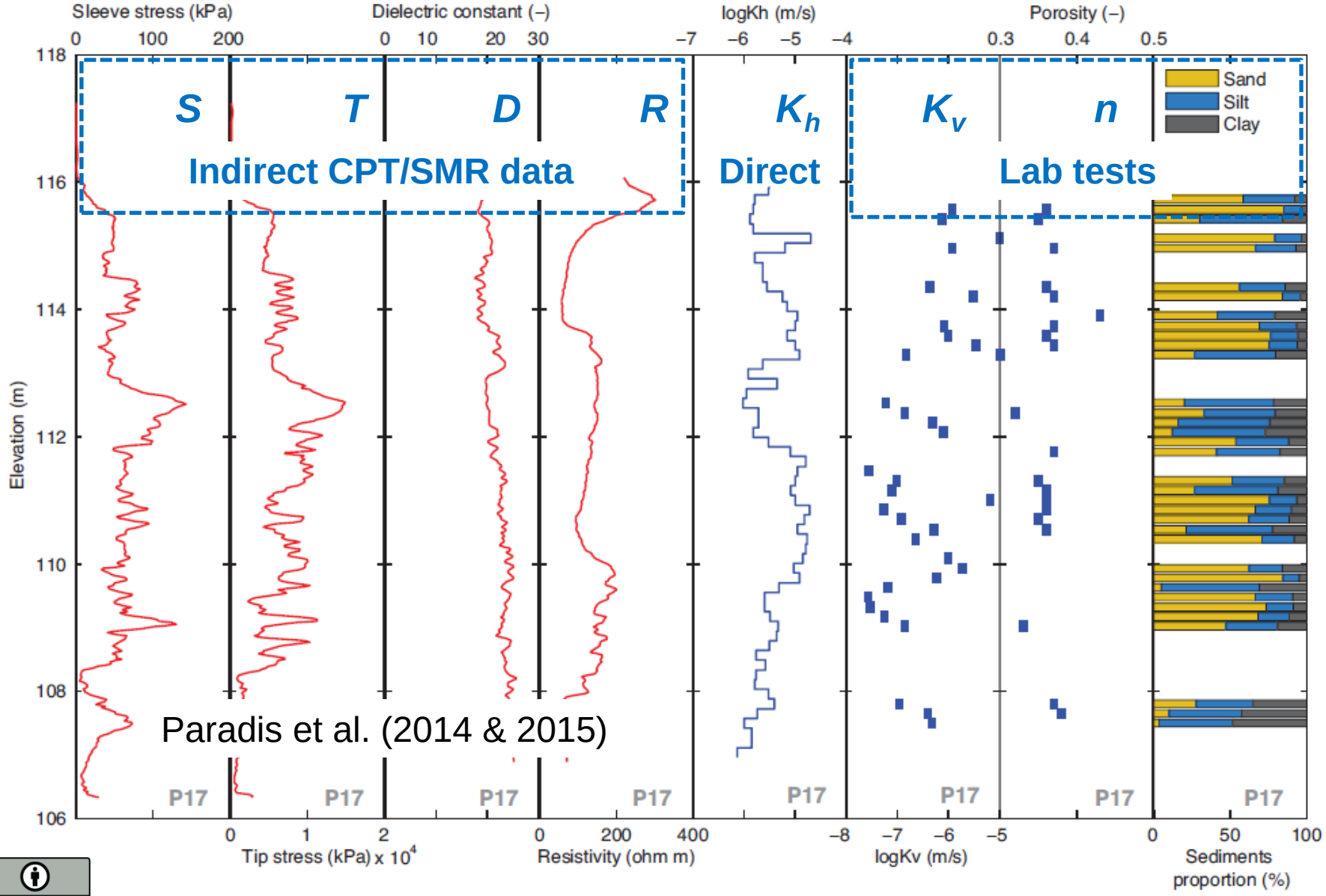
Hydrofacies & *K* Prediction Data Set



Paradis et al. (2014 & 2015)

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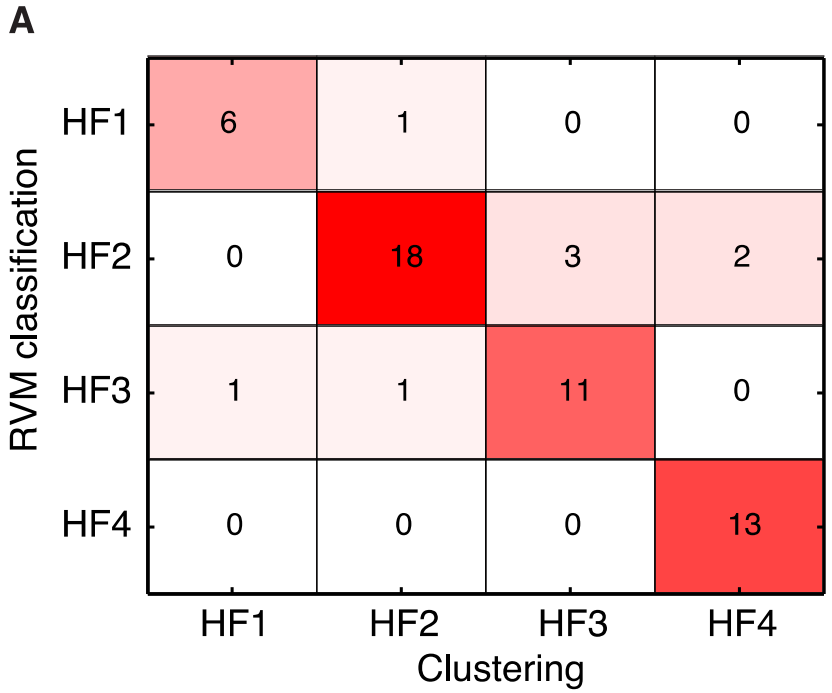
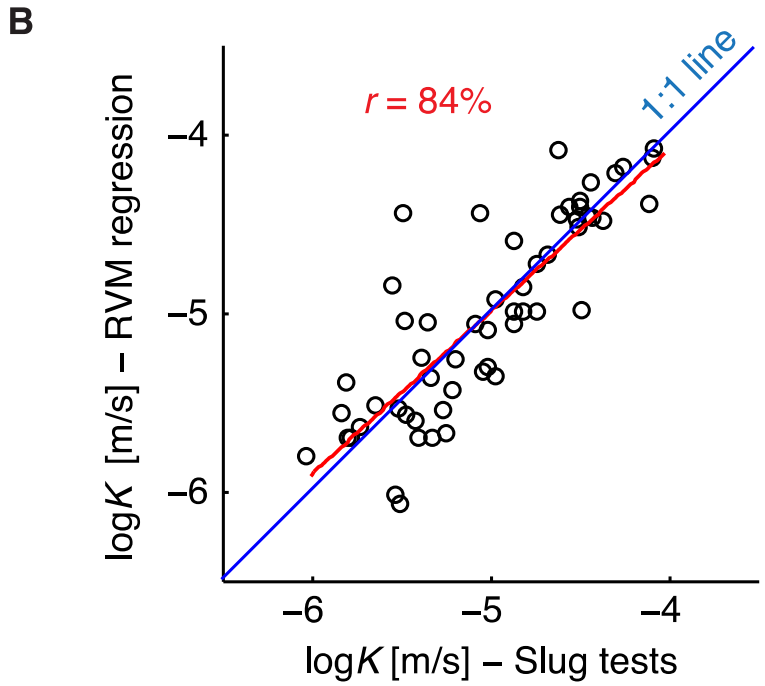
Non-parametric Data Integration

RVM to predict HF & *K* from CPT/SMR

Hydrofacies (HF) (RVM classification)



Hydraulic conductivity (*K*) (RVM regression)



RVM: Relevant Vector Machine

Paradis et al. (2015)

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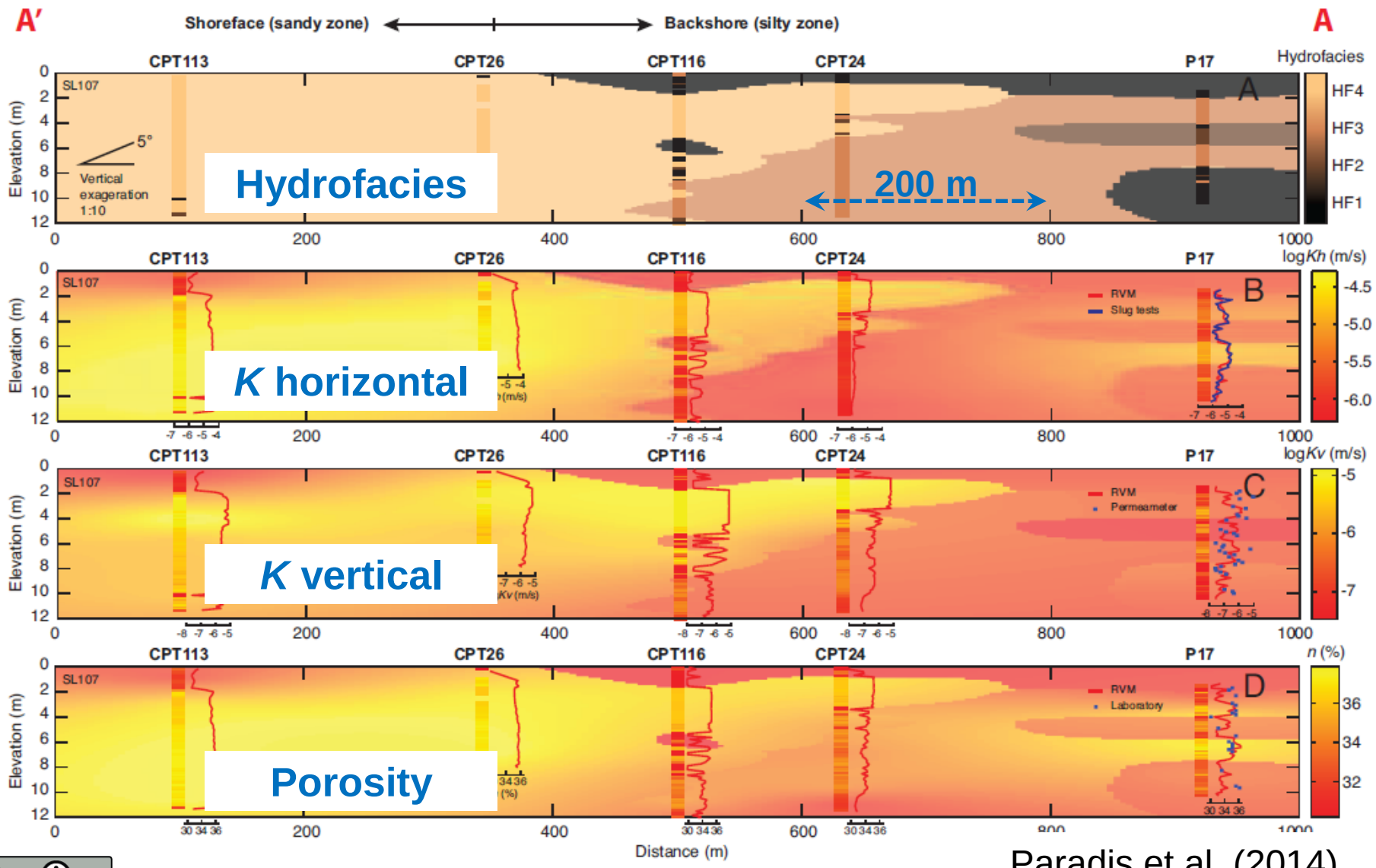
2D Image - RVM Conversion of CPT/SMR



Paradis et al. (2014)

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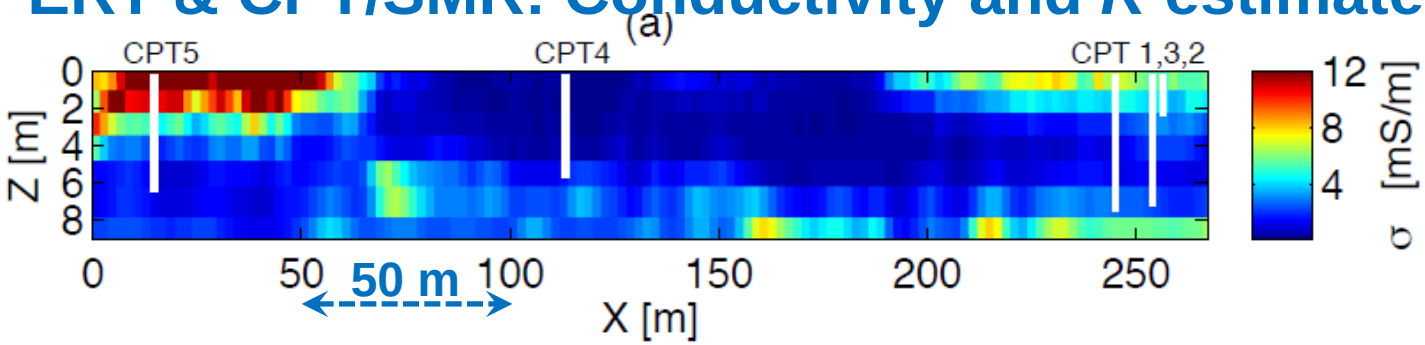
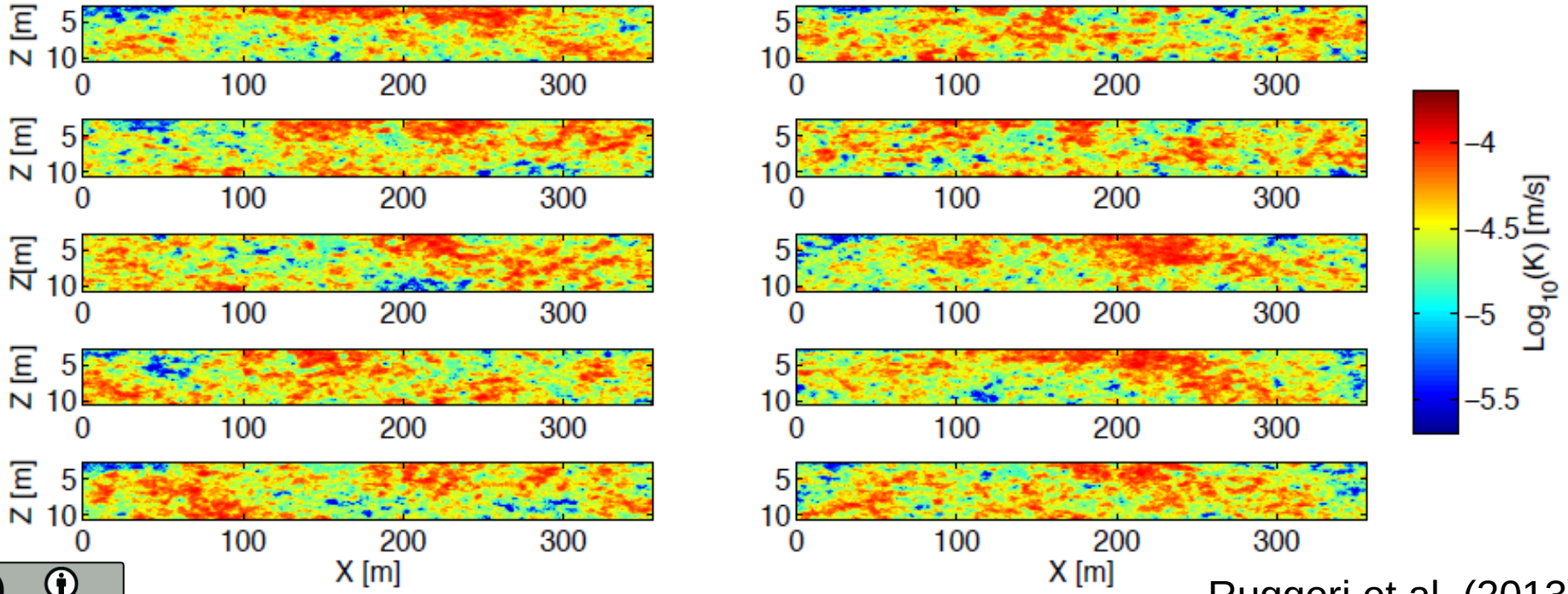
2D Geostatistical Data Integration

ERT & CPT/SMR: Conductivity and *K* estimates



Bayesian sequential simulation of *K* from BSS of resistivity



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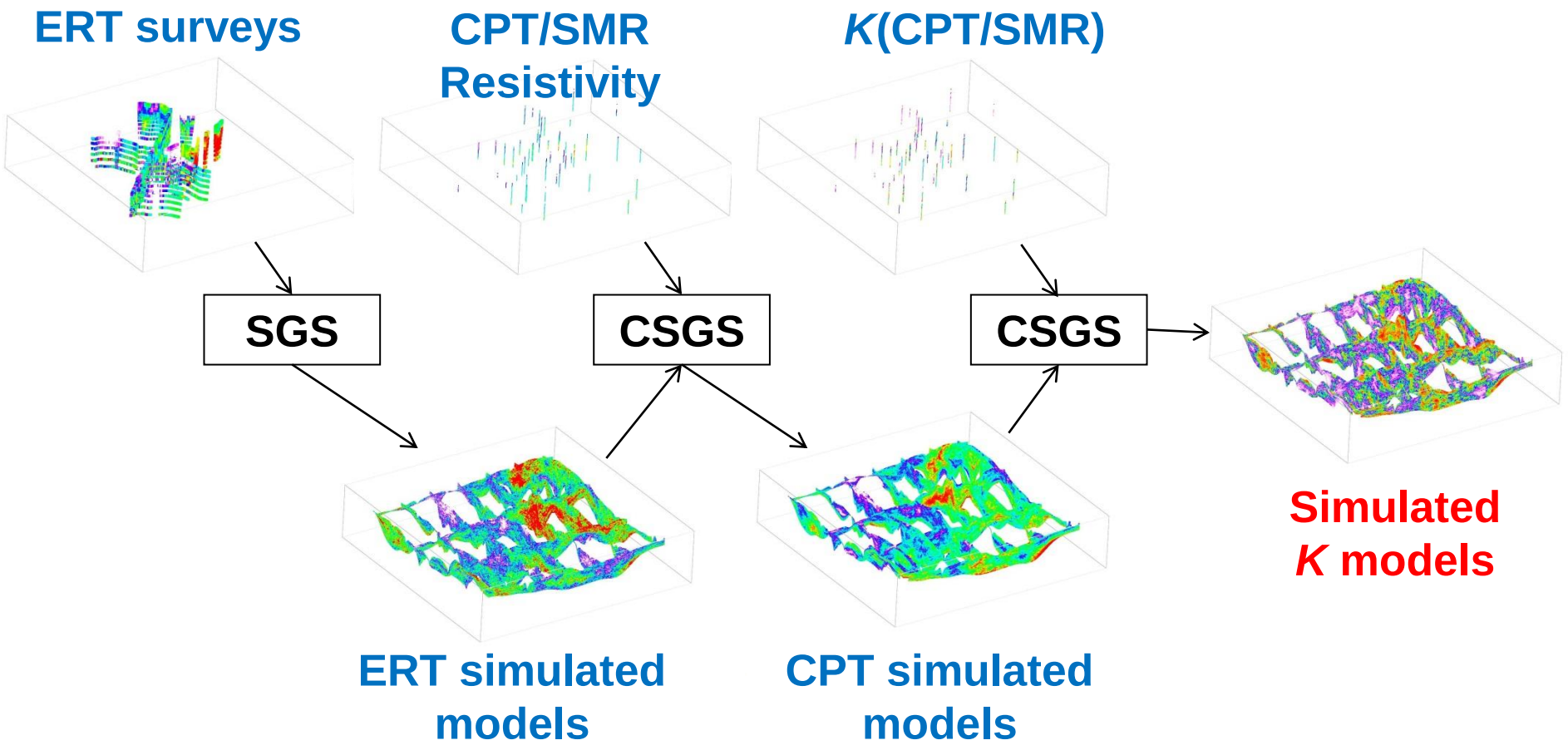
Ruggeri et al. (2013)

3D Geostatistical Data Integration

Three Colocated Sequential Gaussian Simulations (CSGS)



Fabien-Ouellet et al. (2014)

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Constraining *K* Simulations (History matching)

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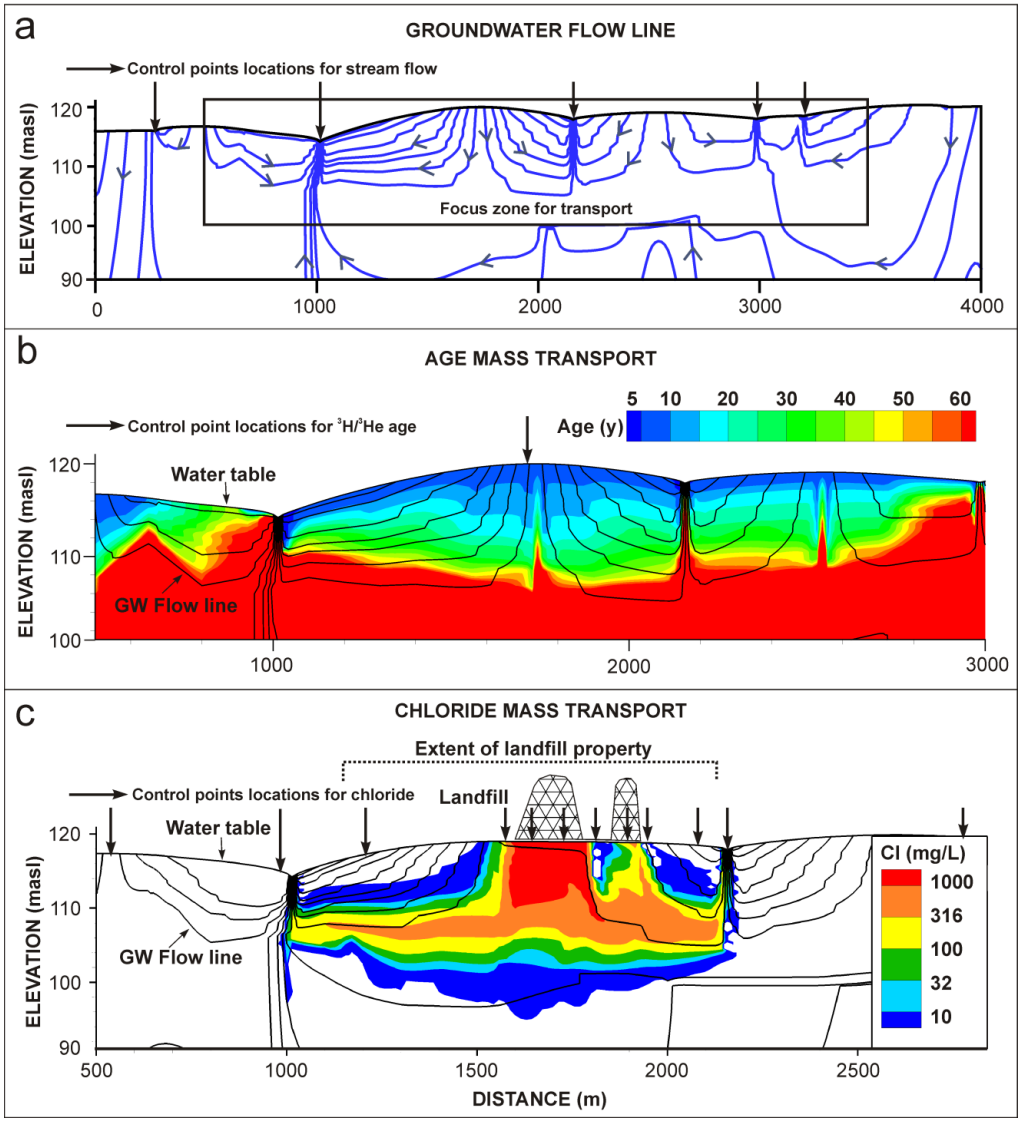
Flow and Transport Simulations

Deterministic Heterogeneous Model



Flow Paths

Groundwater Residence Time

Chloride Migration After 35 y

Tremblay (2013)

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Constraints on the Numerical Model

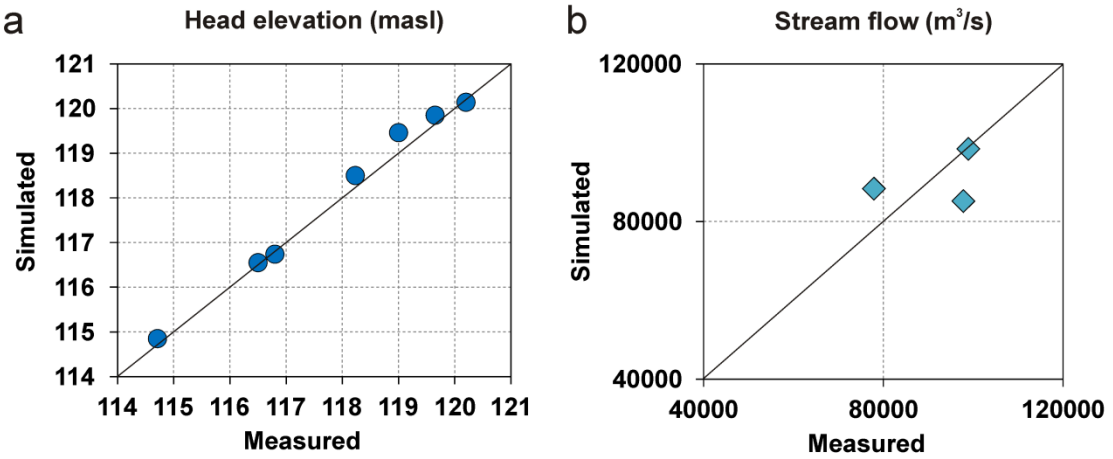
Heads

Baseflow

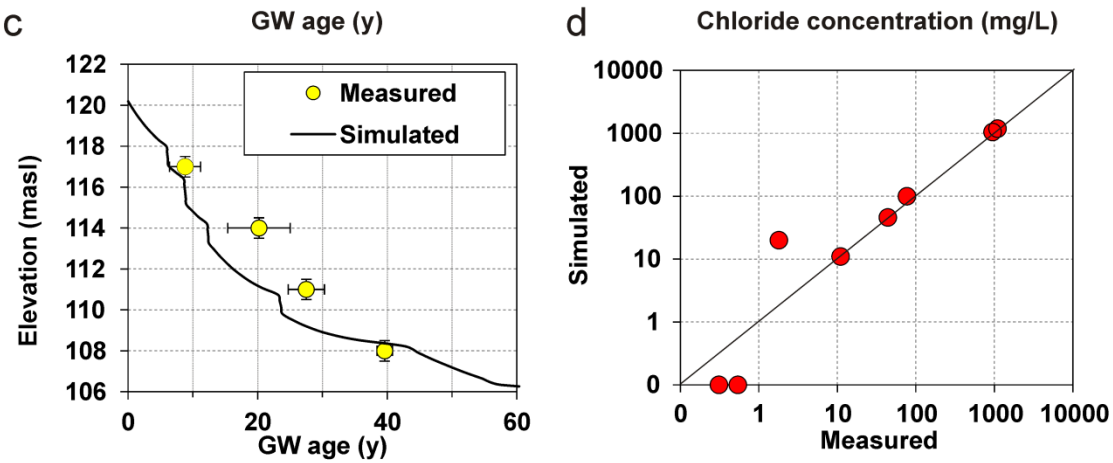
$^{3}He/^{3}H$ Age

Chloride

Flow Model



Transport Model



Tremblay (2013)

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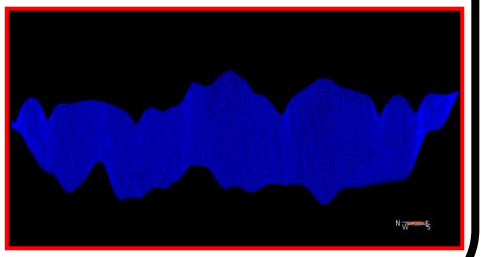
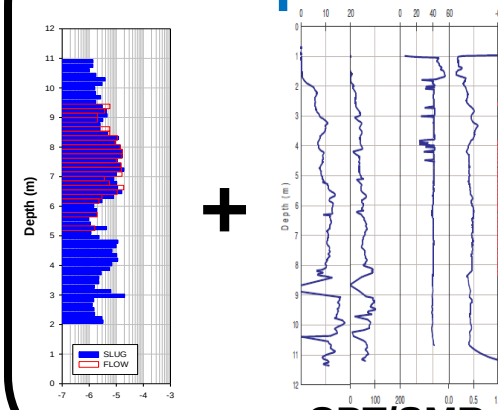
History matching & *K* heterogeneity

Step 1



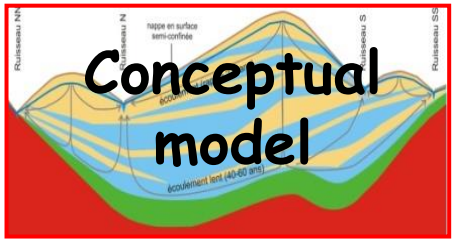
Build Cross-section

Step 2

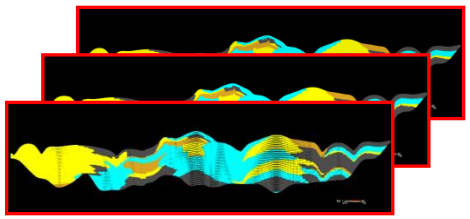


HF & *K* Predictions

Step 3



Step 4



HF/*K* from MPG

Step 5

Flow simulations

Extract head profiles for 2 heterogeneity levels

Step 6

Gradual deformation of MPG realizations

After Brunet (2014)

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Perspective

- Data: integrated hydrogeophysical characterization with multiple measurements
  - Efficient "general-to-details" approach
  - Regional geophysical data & high-resolution colocated geophysical and direct *K* data
- Processing: need robust integration methods
- Verification / history matching: "hydraulically plausible" or "optimal" heterogeneity models from large sets provided by geostatistical realizations (hydraulic data & tracers)

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Acknowlegements: grad studies

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