Data-driven hydrostratigraphic modeling

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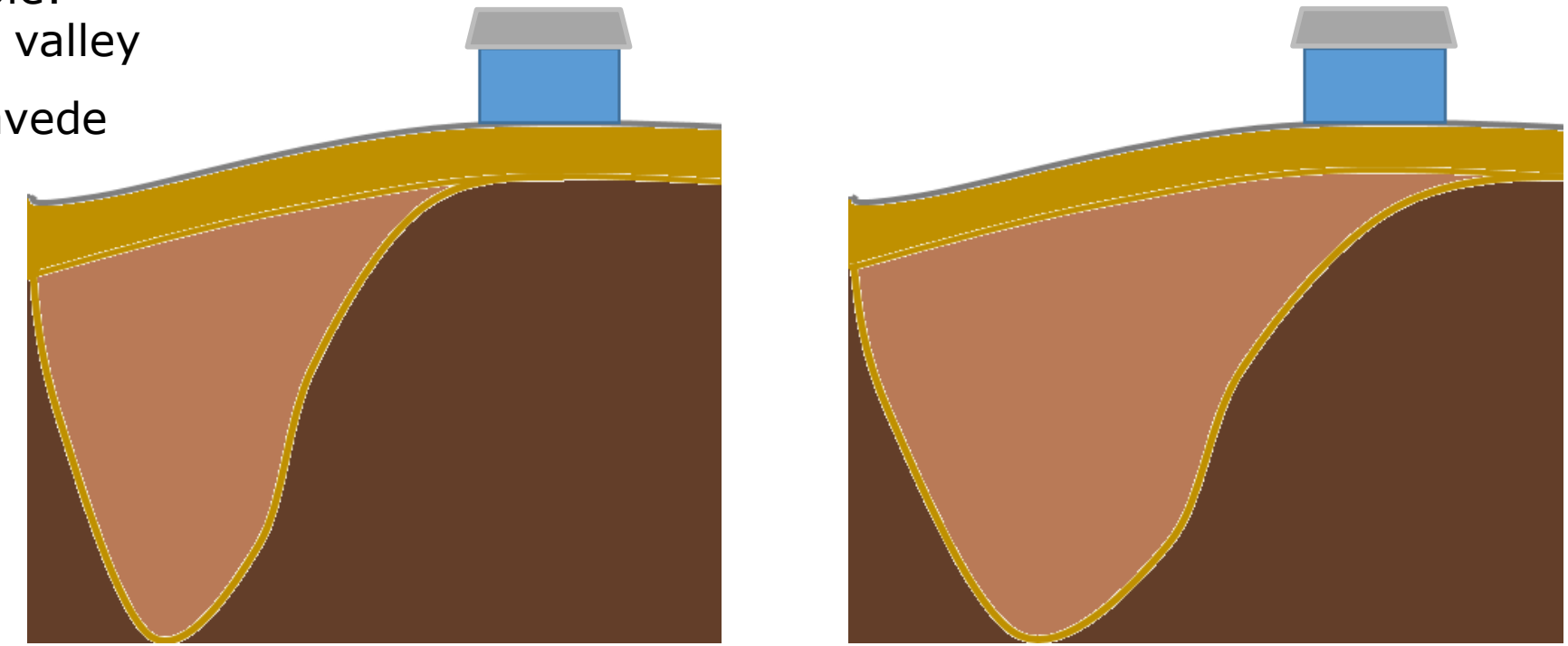
HydroGeophysics Group
AARHUS UNIVERSITY

Motivation

- Incorporation of **structural uncertainty** in groundwater models and transport
  - Structural uncertainty can have a high impact on subsurface transport model results
  - Traditional groundwater models can have difficulties in reflecting this uncertainty

Example:
Buried valley

(Begravede dale)



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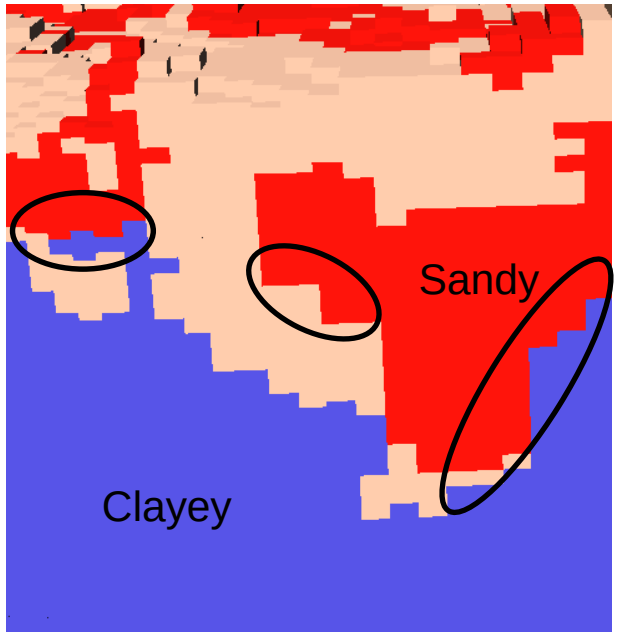
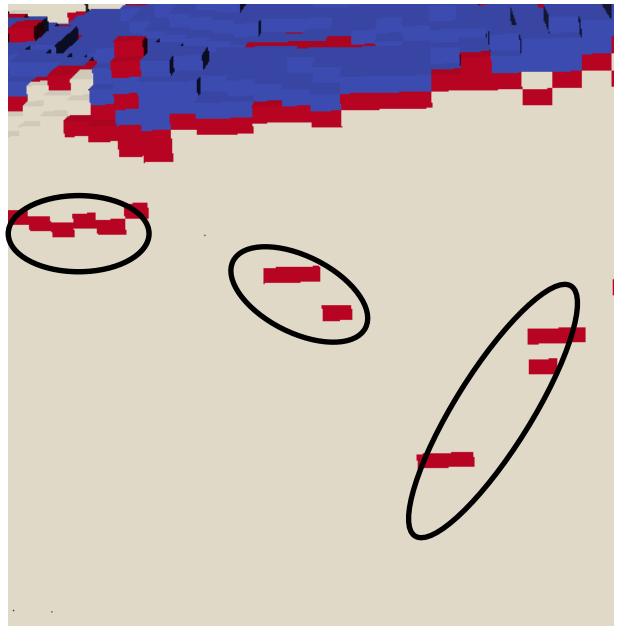
- **Redox conditions** in the subsurface can be **highly heterogeneous** and spatial variable
  - Redox conditions can have a **complex structure**, related to the hydrogeological structure
  - Complex structures result in **uncertainty** in 3D representation of redox conditions in the subsurface





Oxidized

Low reduction rates

High reduction rates

Motivation

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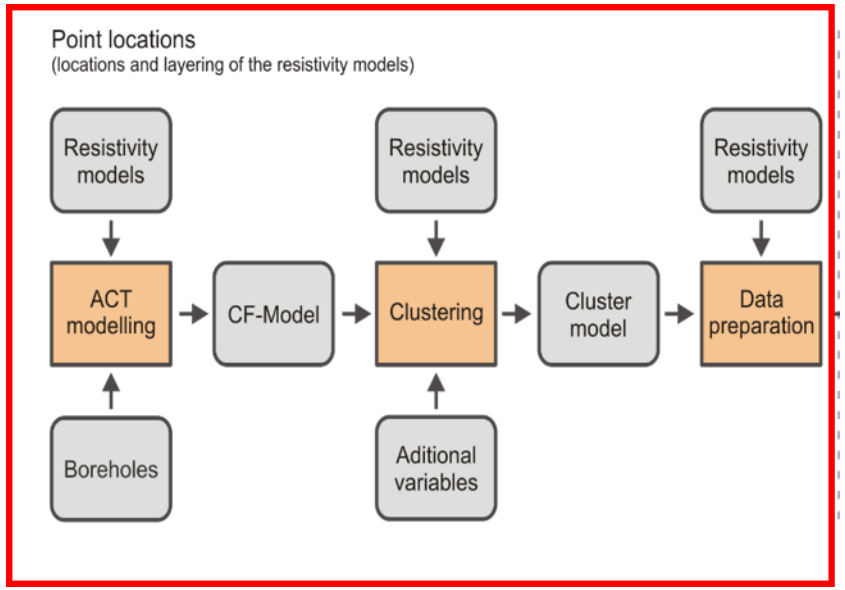
  - Redox conditions can have a **complex structure**, related to the hydrogeological structure
  - Complex structures result in **uncertainty** in 3D representation of redox conditions in the subsurface

The goal is to **include** these **complex structures** and associated **uncertainties** in groundwater model structural input

Contents

- From data to model
  - ACT modeling
  - Clustering
  - Data preparation

Combining **geophysical, geological** and **geochemical** data through multipoint statistics



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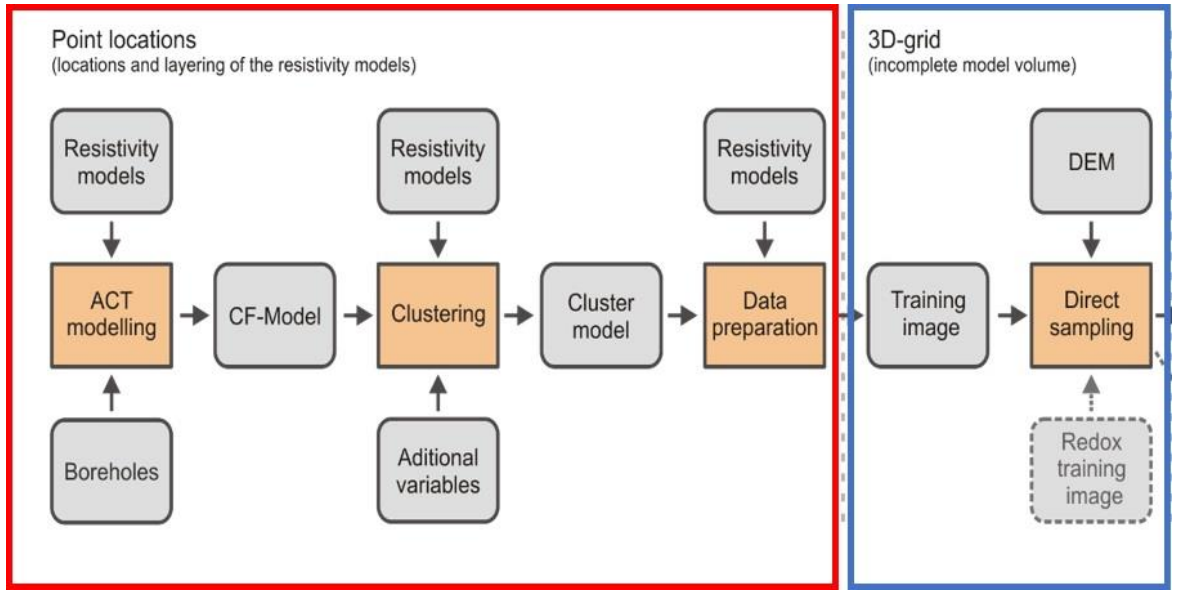

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  - Uncertainty description

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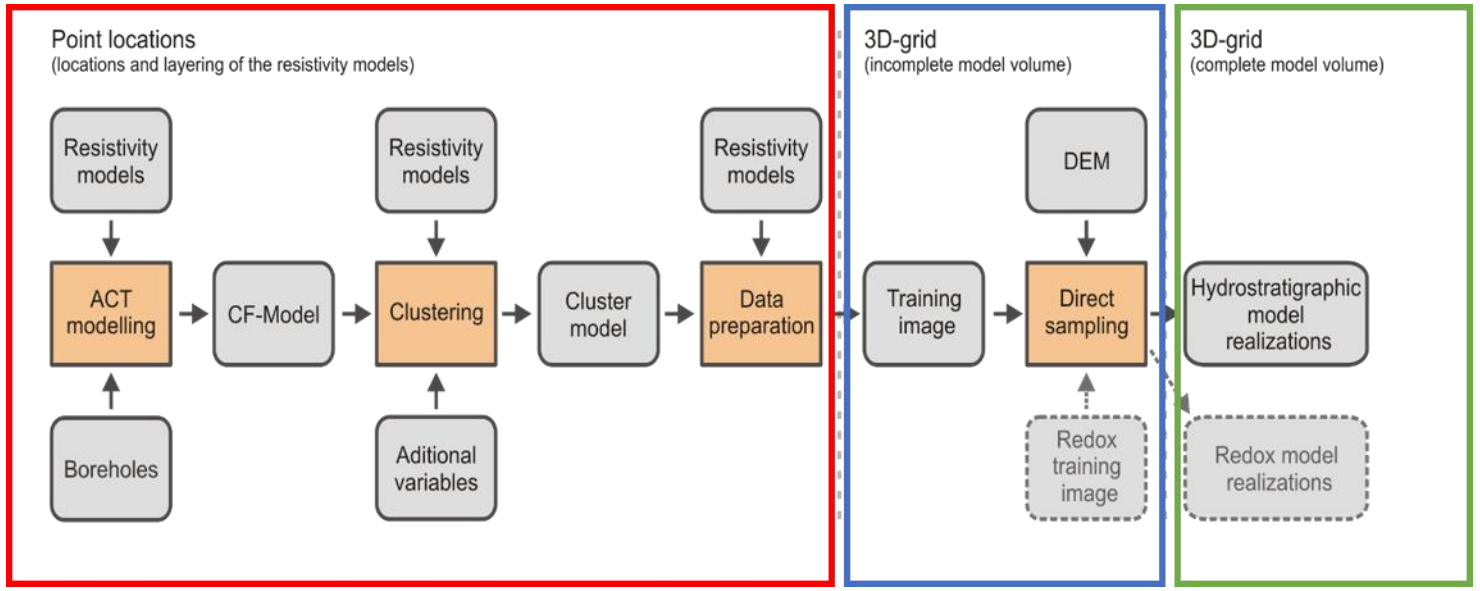

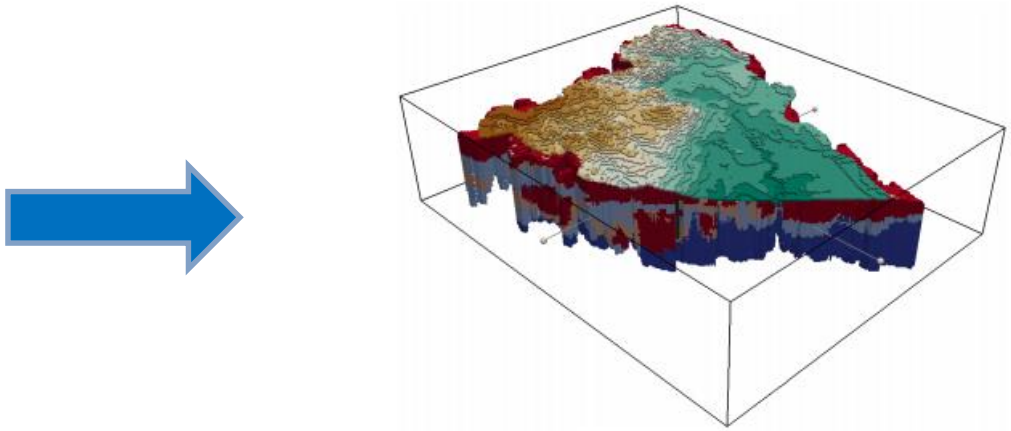

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- Outlook and Conclusion

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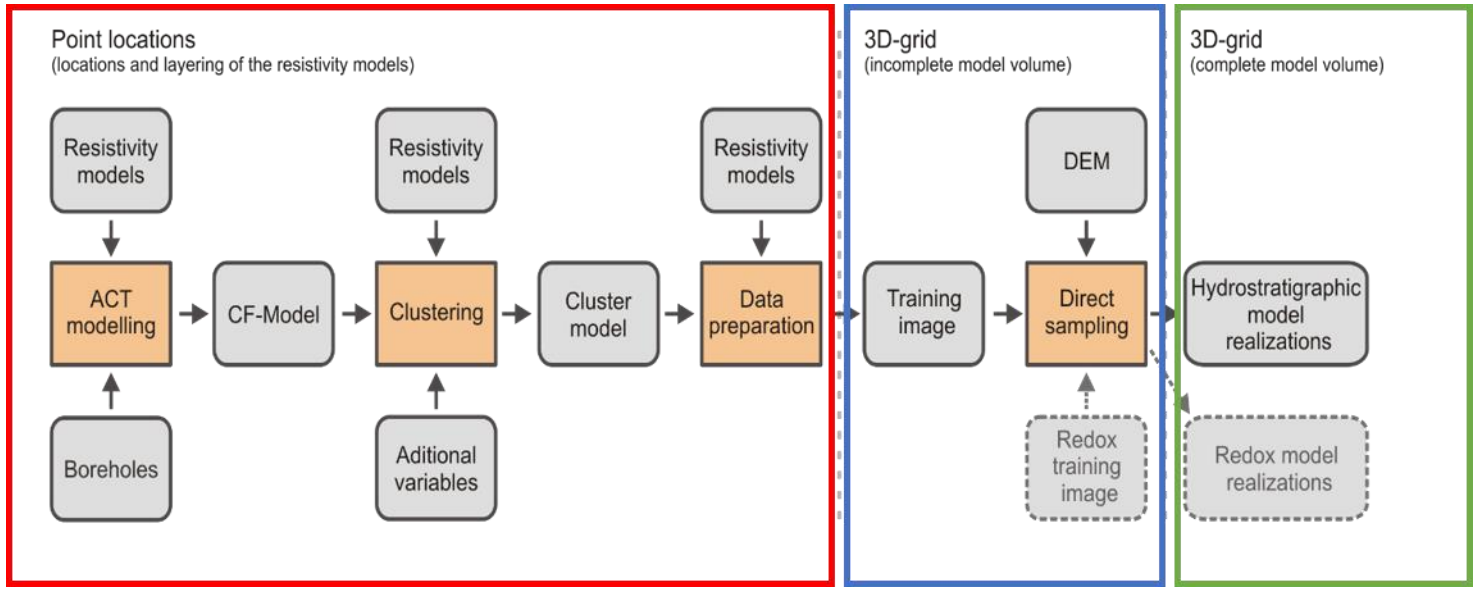
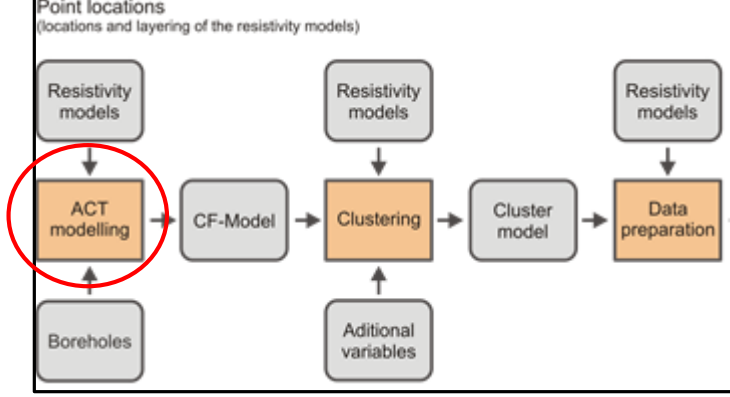
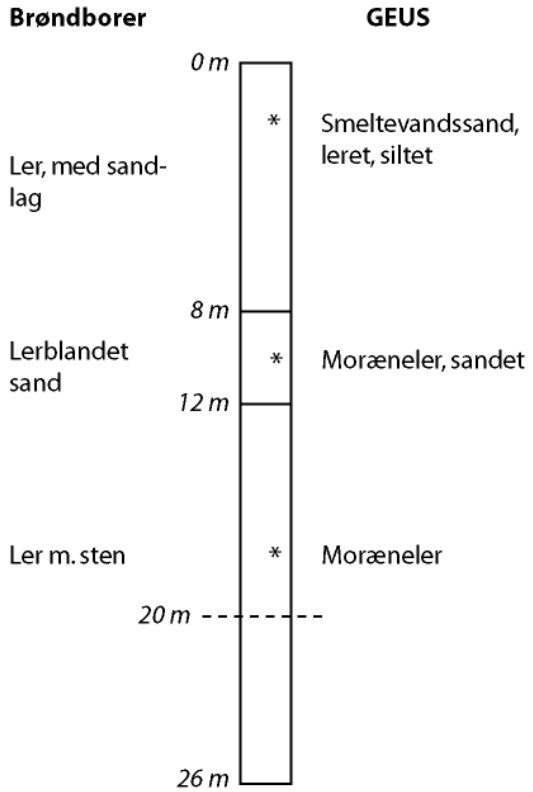


The **result** is an **ensemble** of **hydrostratigraphic** and **redox models**

From data to model

- Borehole
  - + Primary source of **lithological information**
  - + Vertical resolution: Good, ~uniform
  - - Spatial coverage: Poor
  - - Quality: varying and often unknown





From data to model

- Borehole
  - + Primary source of **lithological information**
  - + Vertical resolution: Good, ~uniform
  - - Spatial coverage: Poor
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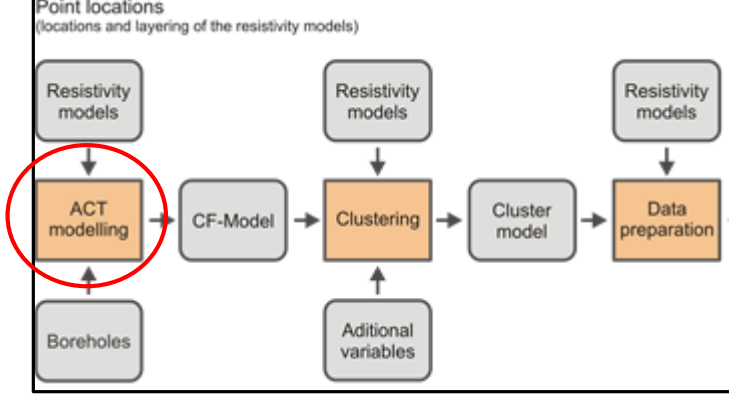
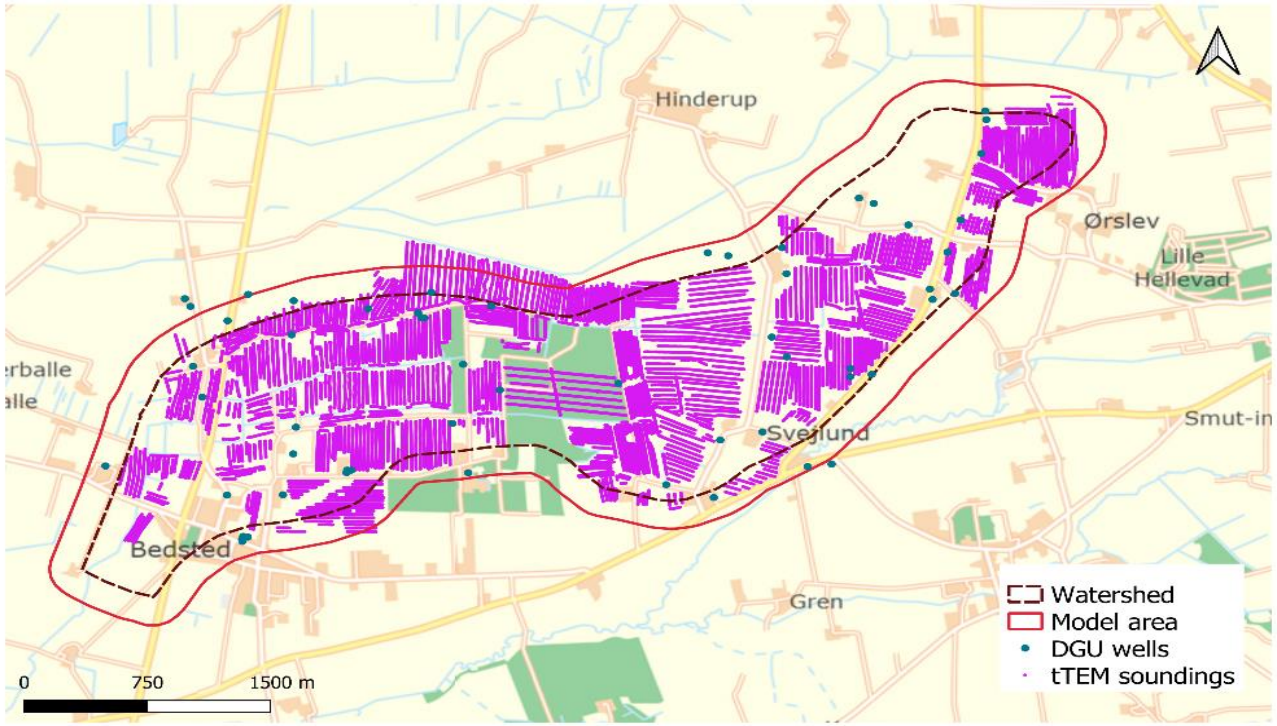
- Geophysics
  - + **Spatial coverage**: Good
  - + Quality: Well-known and often good
  - - Indirect lithological information
  - - Vertical resolution decreasing with depth





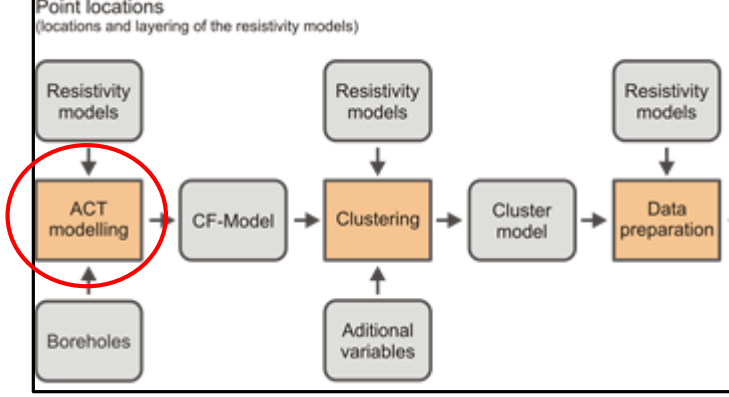
From data to model

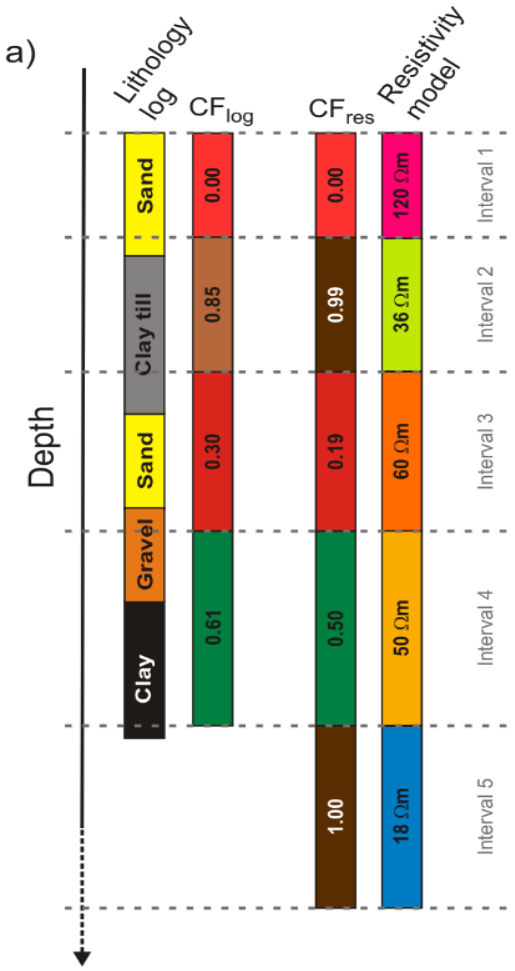
ACT modeling

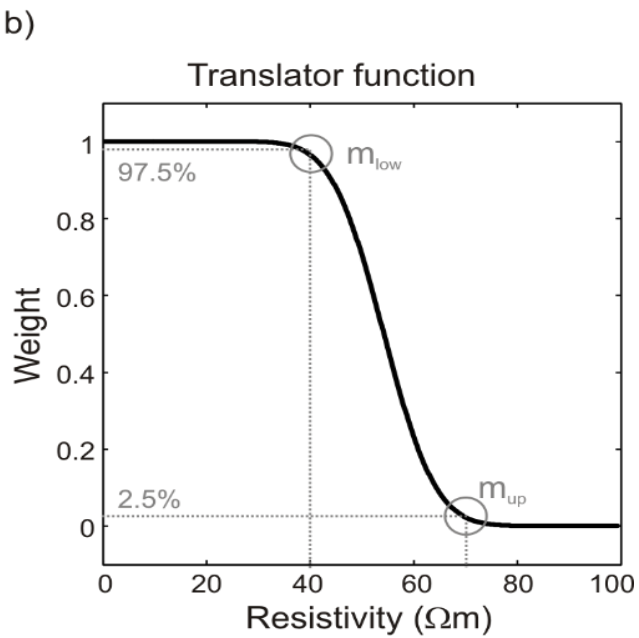
Accumulated Clay Thickness:

Resistivity values to Clay Fraction:

- Based on **Borehole lithology** and **Resistivity**
- **Spatially varying**







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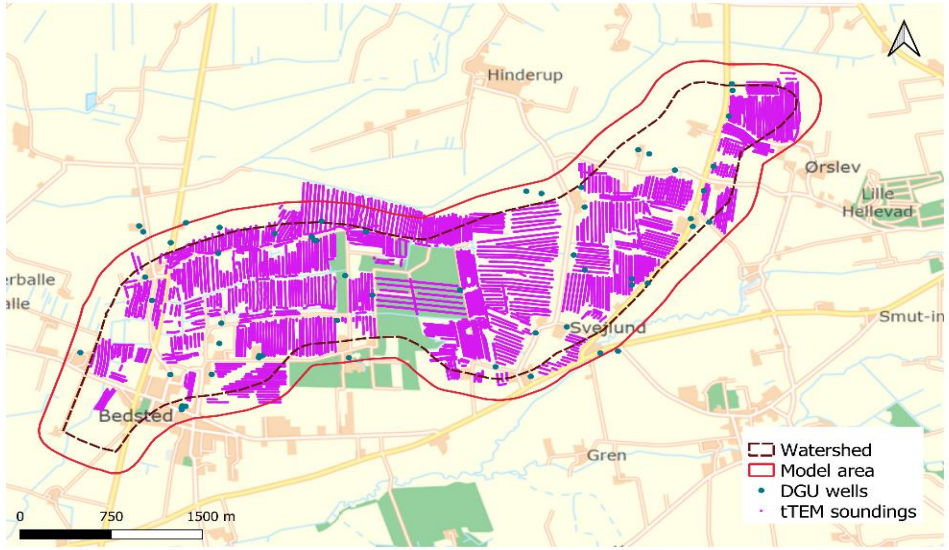

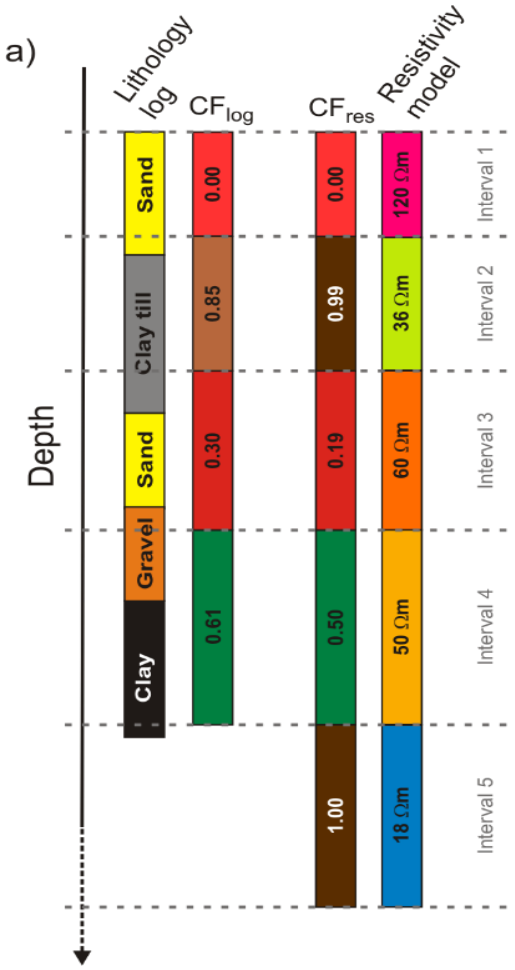

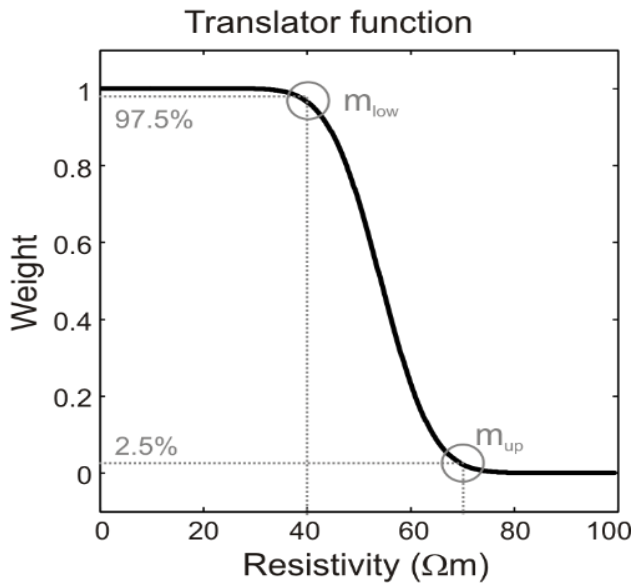

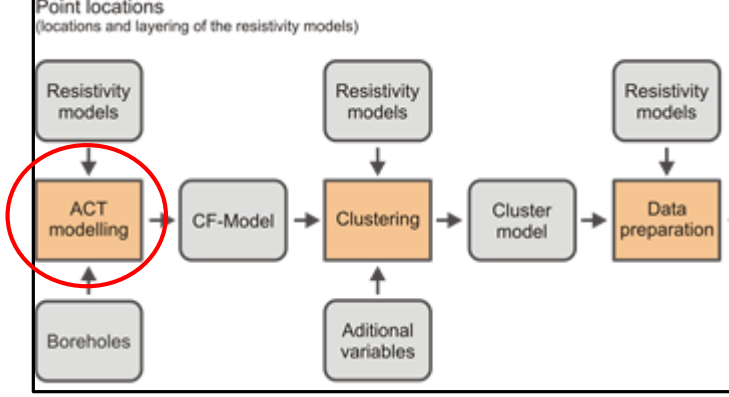

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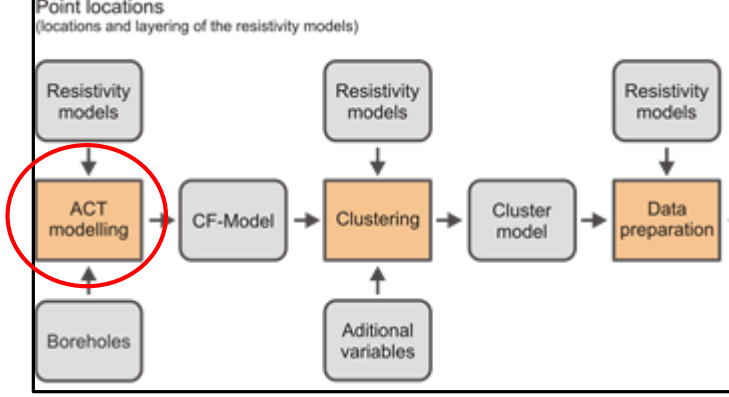
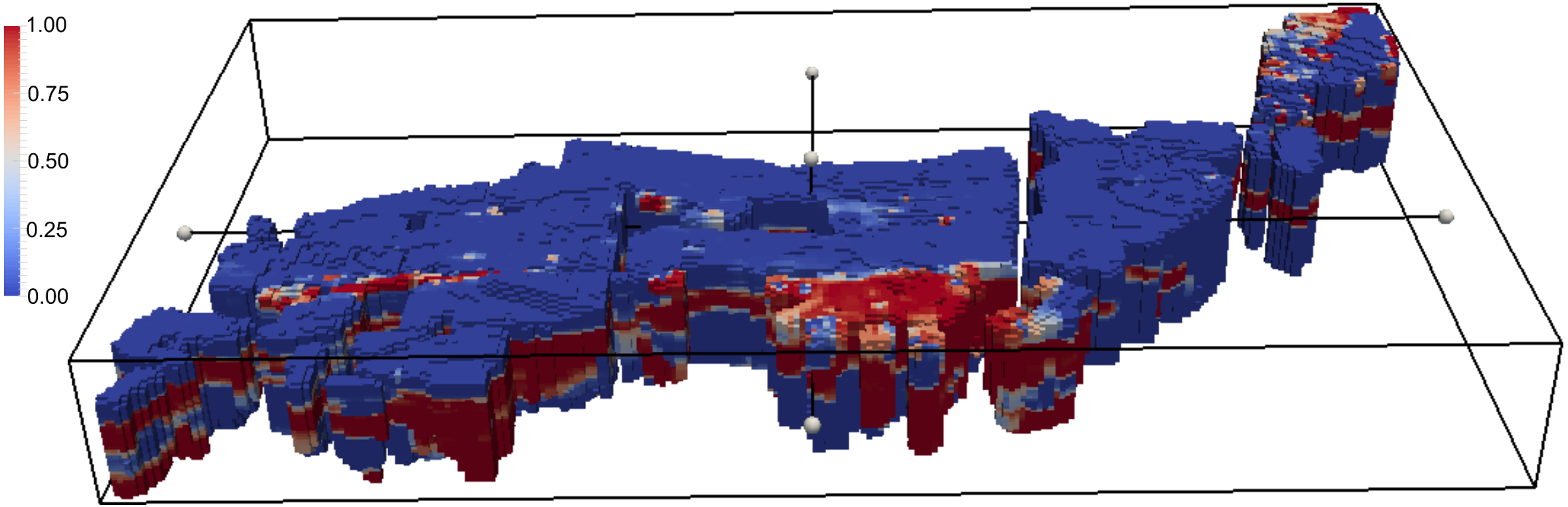


Clay Fraction [-]:



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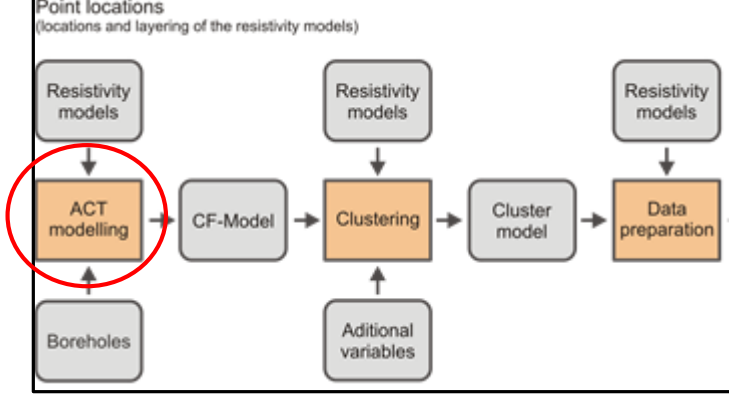
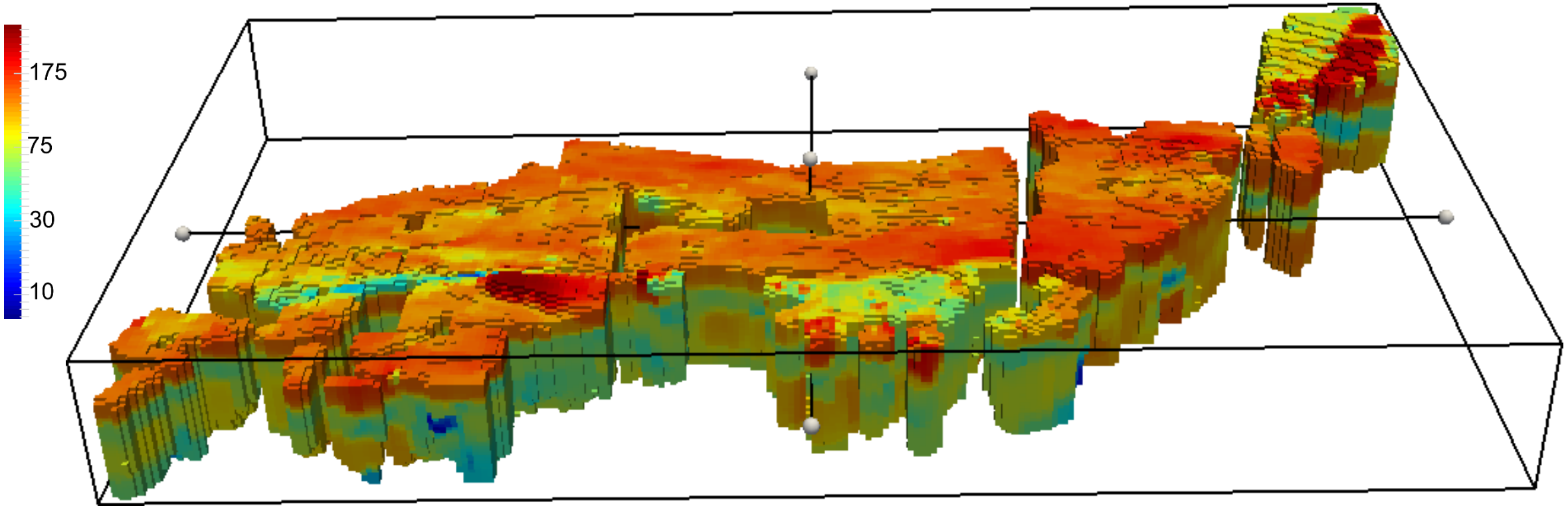
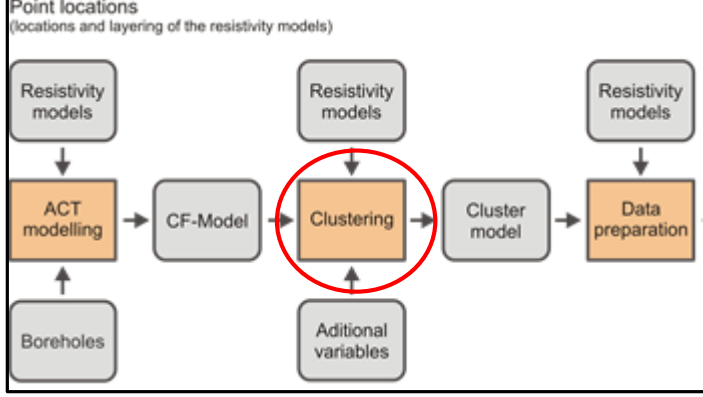


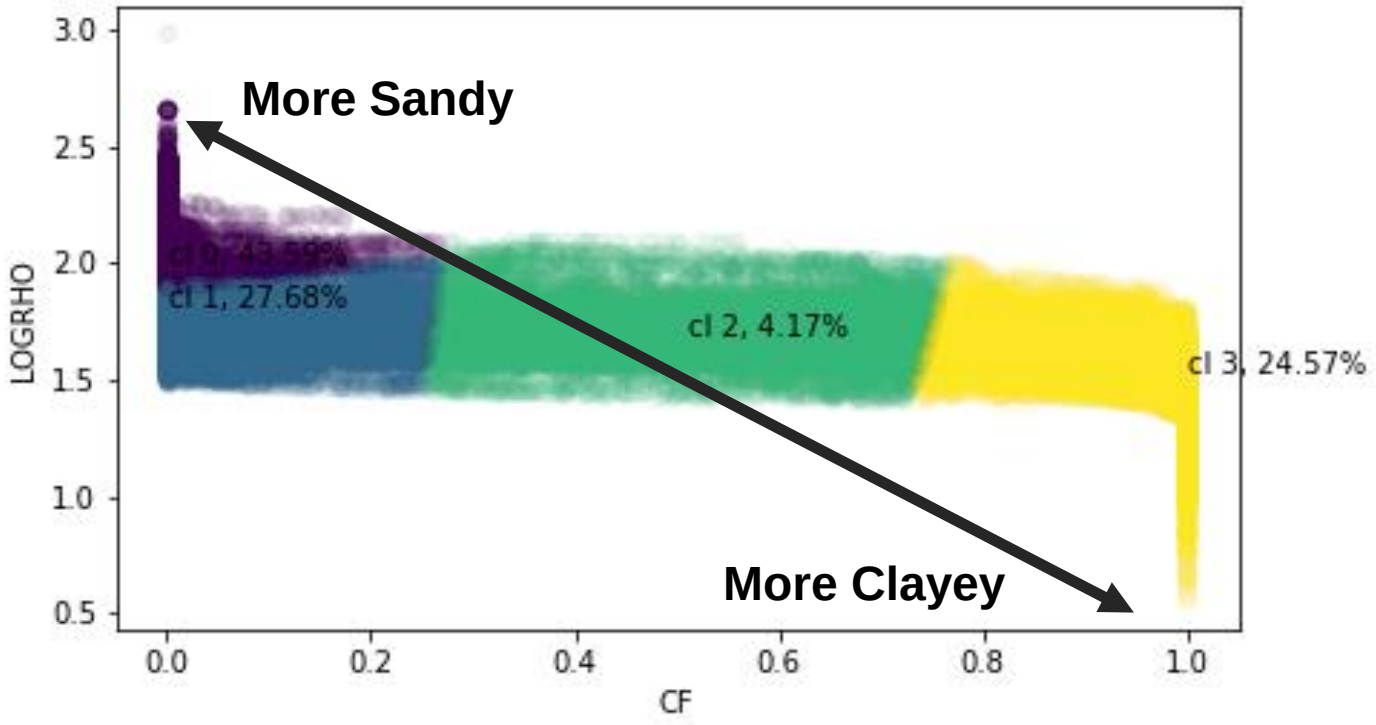
Resistivity [Ohm.m]:



From data to model

Clustering: From Resistivity – Clay Fraction to Hydrostratigraphic Unit





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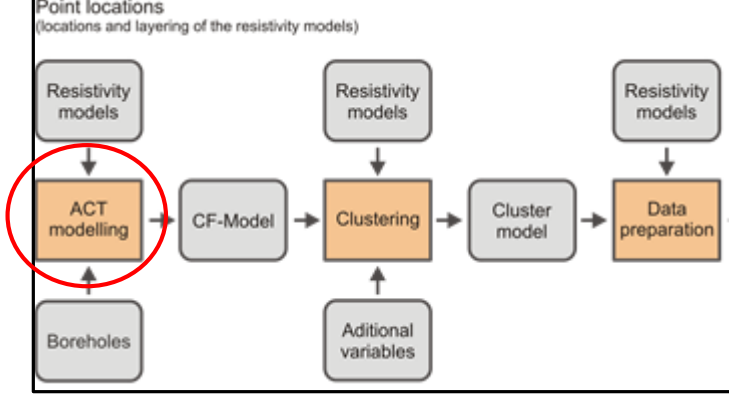

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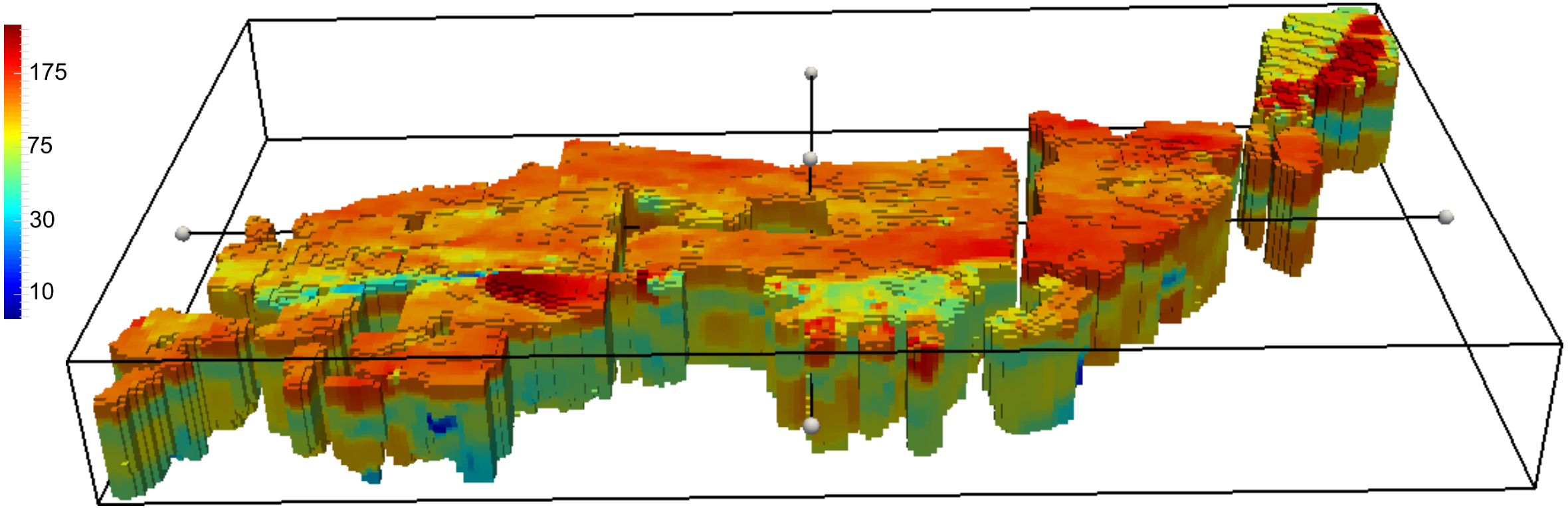

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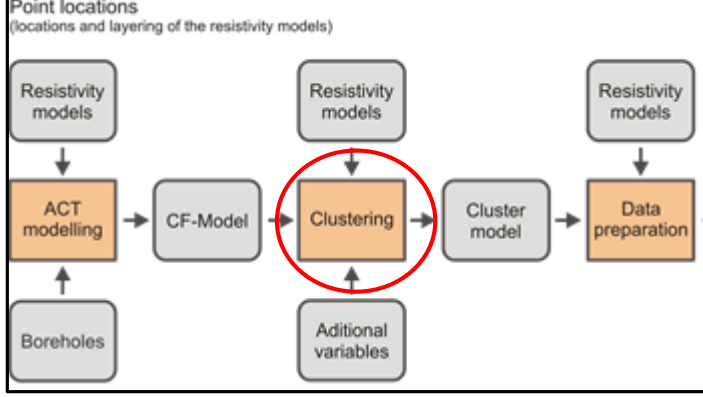
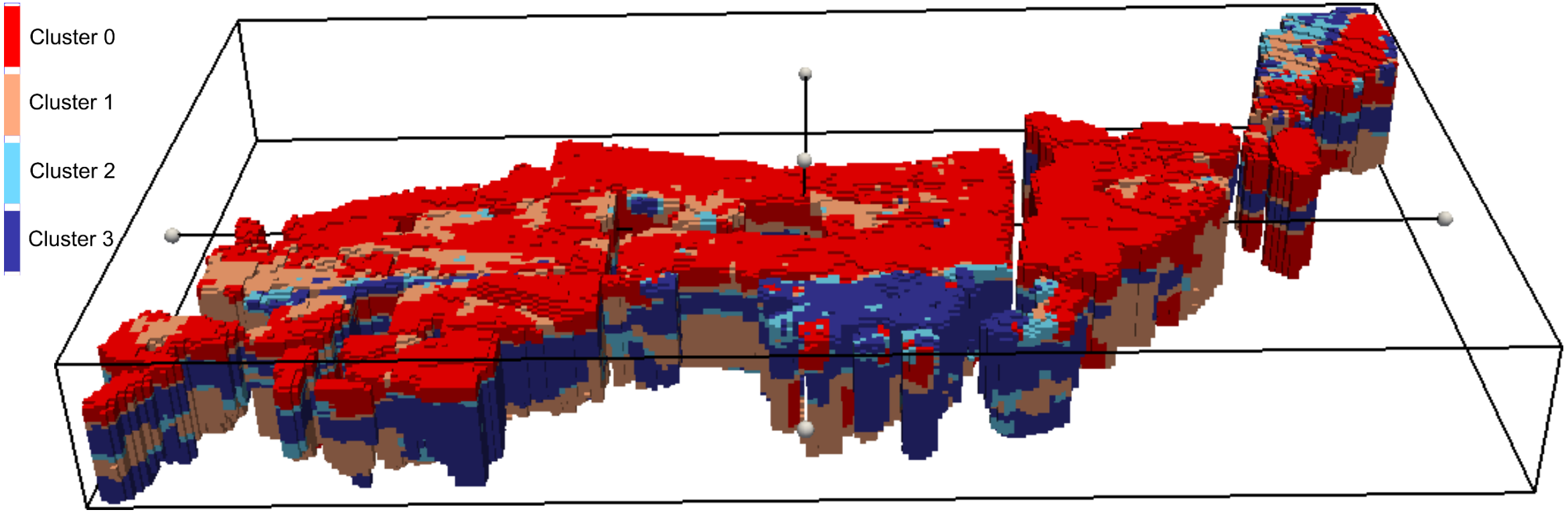


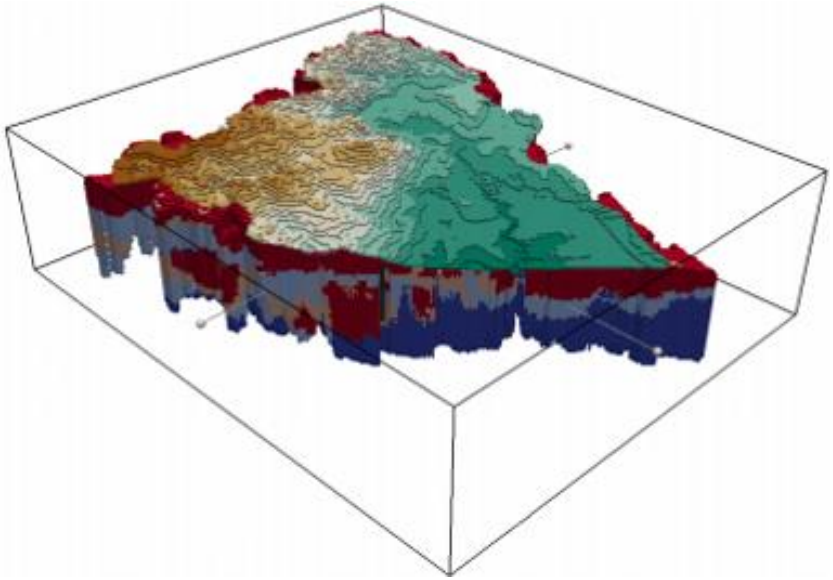
Clusters [-]:

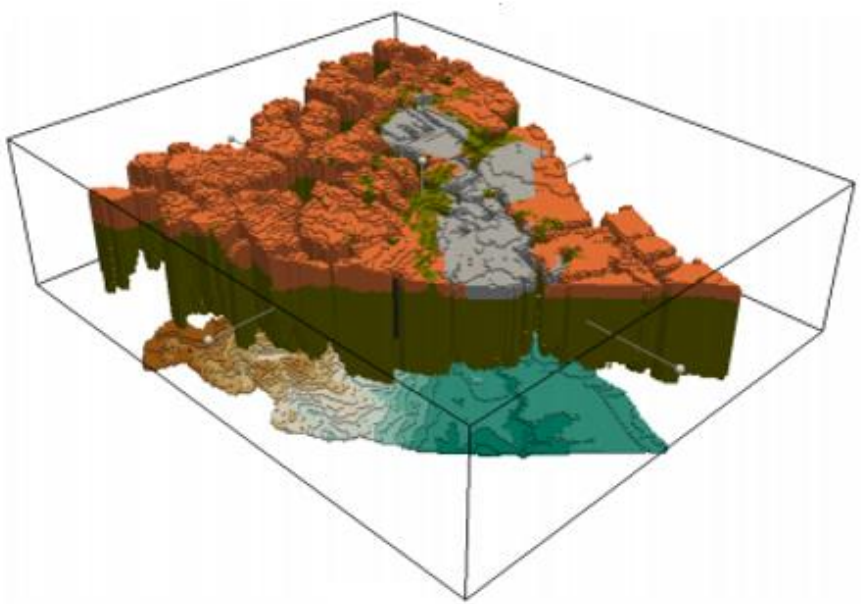


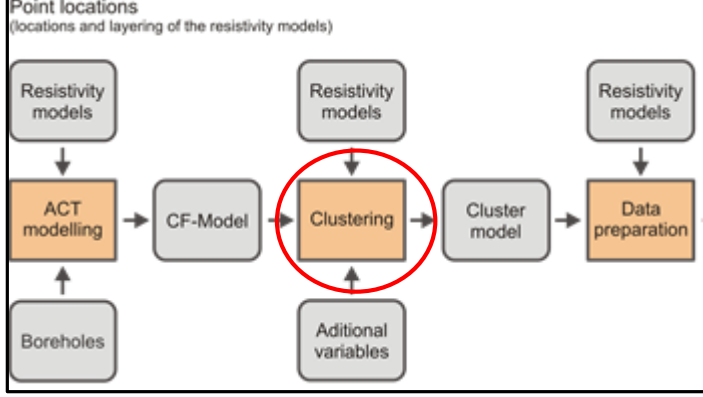
From data to model

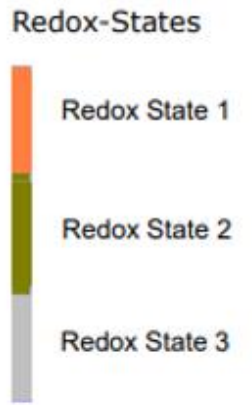
Data preparation

- Addition of Redox Training Image



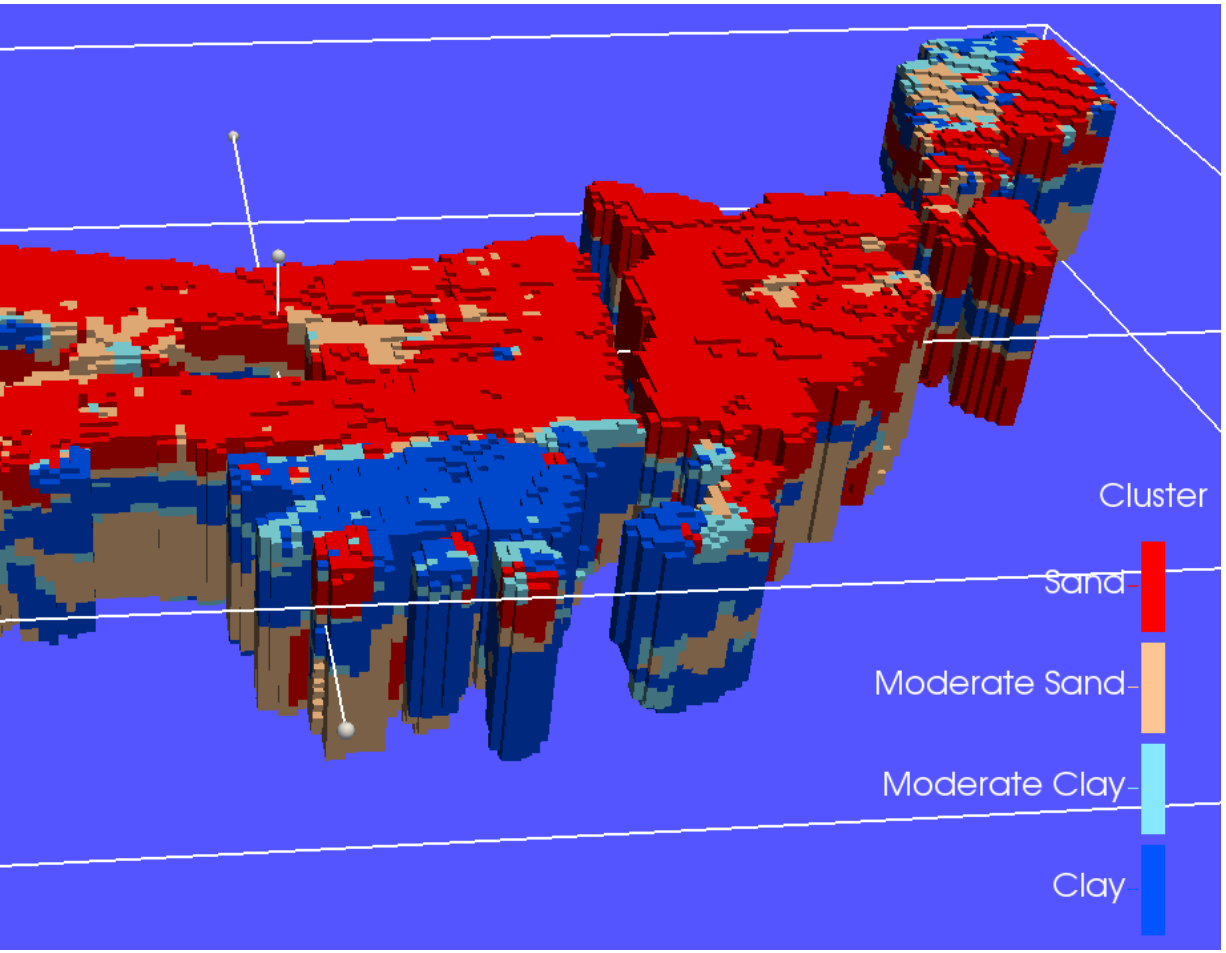


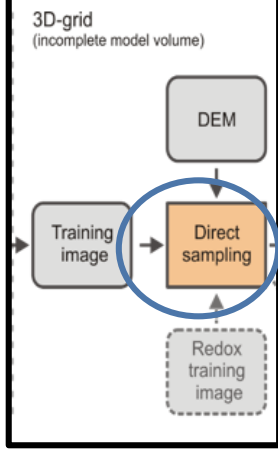




Geostatistical simulation

Direct Sampling:





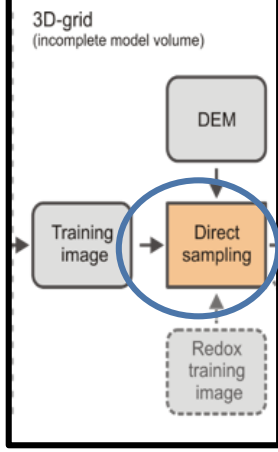
-Traditional Methods have difficulties to replicate **3D structural complexity**

-Even more complex if correlated **Redox** conditions need to be simulated

Direct Sampling

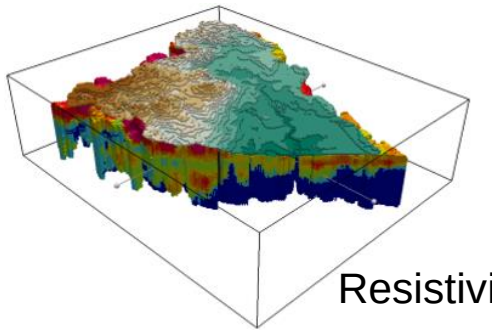
Simulation with the same geostatistical complexity as the Training Image

Geostatistical simulation

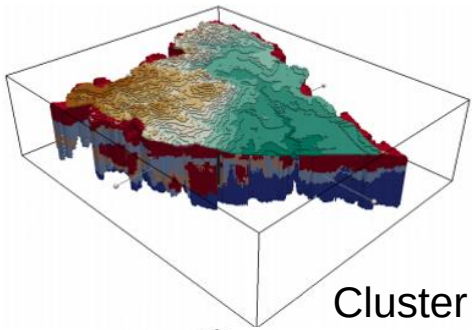


Direct Sampling:

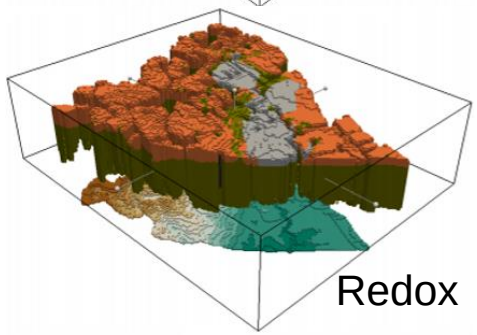
Training Image: All our measurements



Resistivity



Cluster

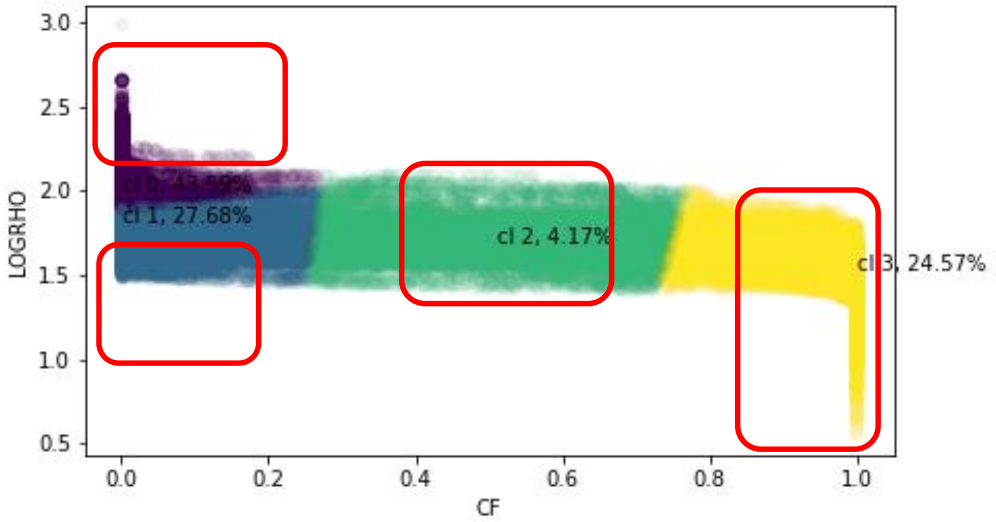


Redox

Minimizing risk of uncertainty underestimation

Filter out ‘least certain’ observations/measurements

Hard Data: data we place in the grid before the simulations, because of high probability



Geostatistical simulation

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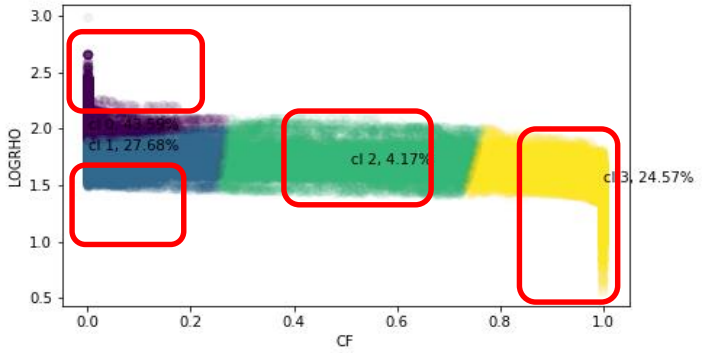
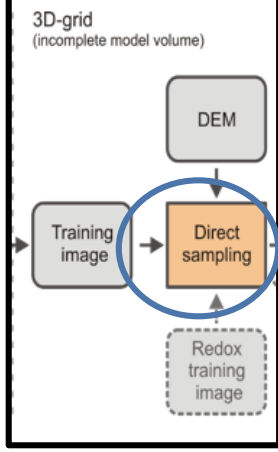




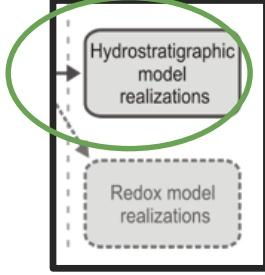
Training Image: All our measurements/data

Hard Data: data we place in the grid before the simulations, because we are confident in them

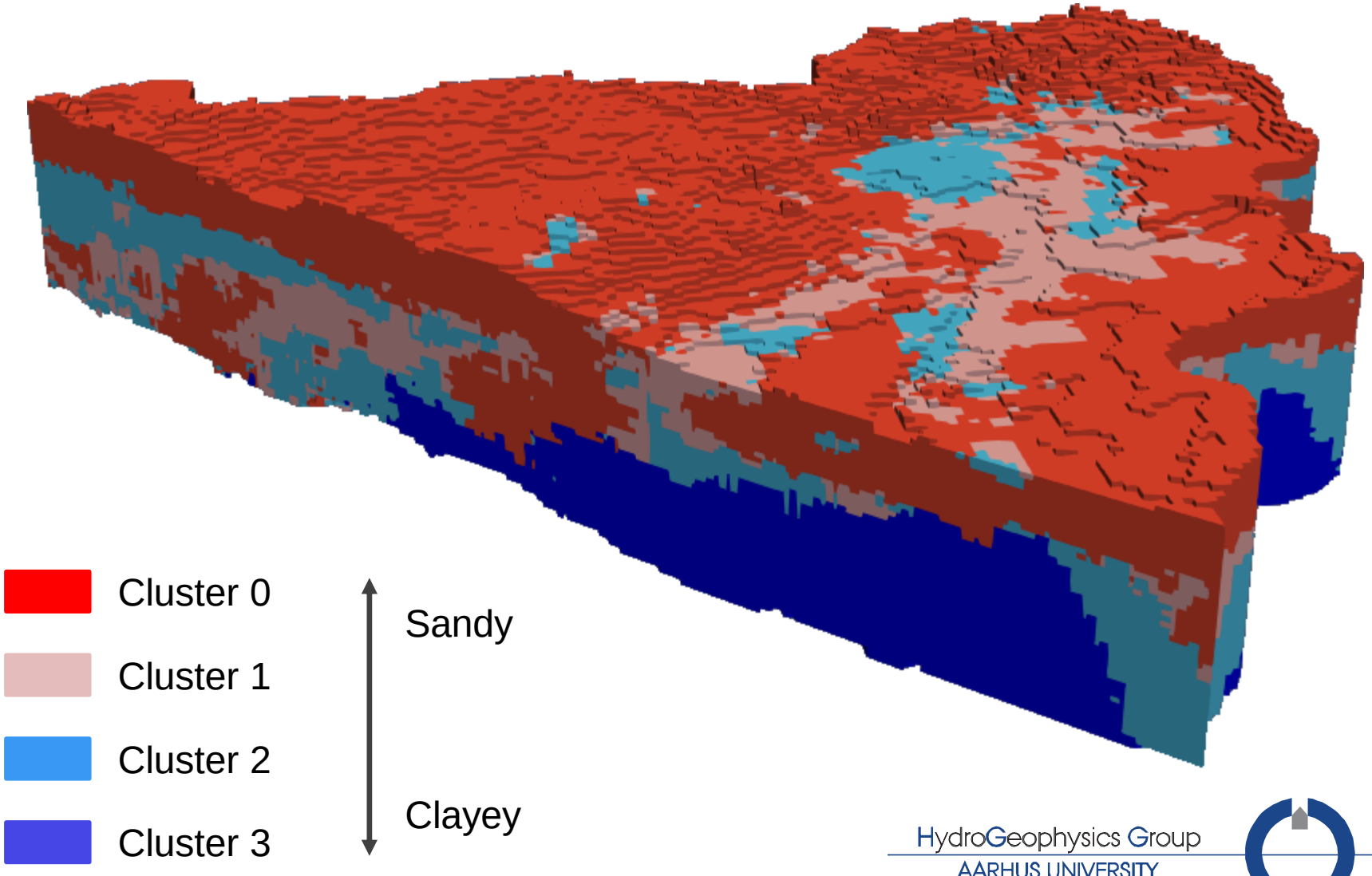
Minimizing risk of uncertainty underestimation

Filter out ‘least certain data’

Model Realizations



Example:



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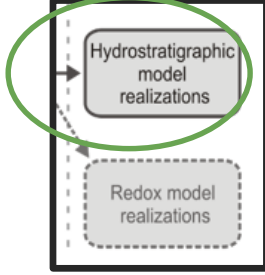

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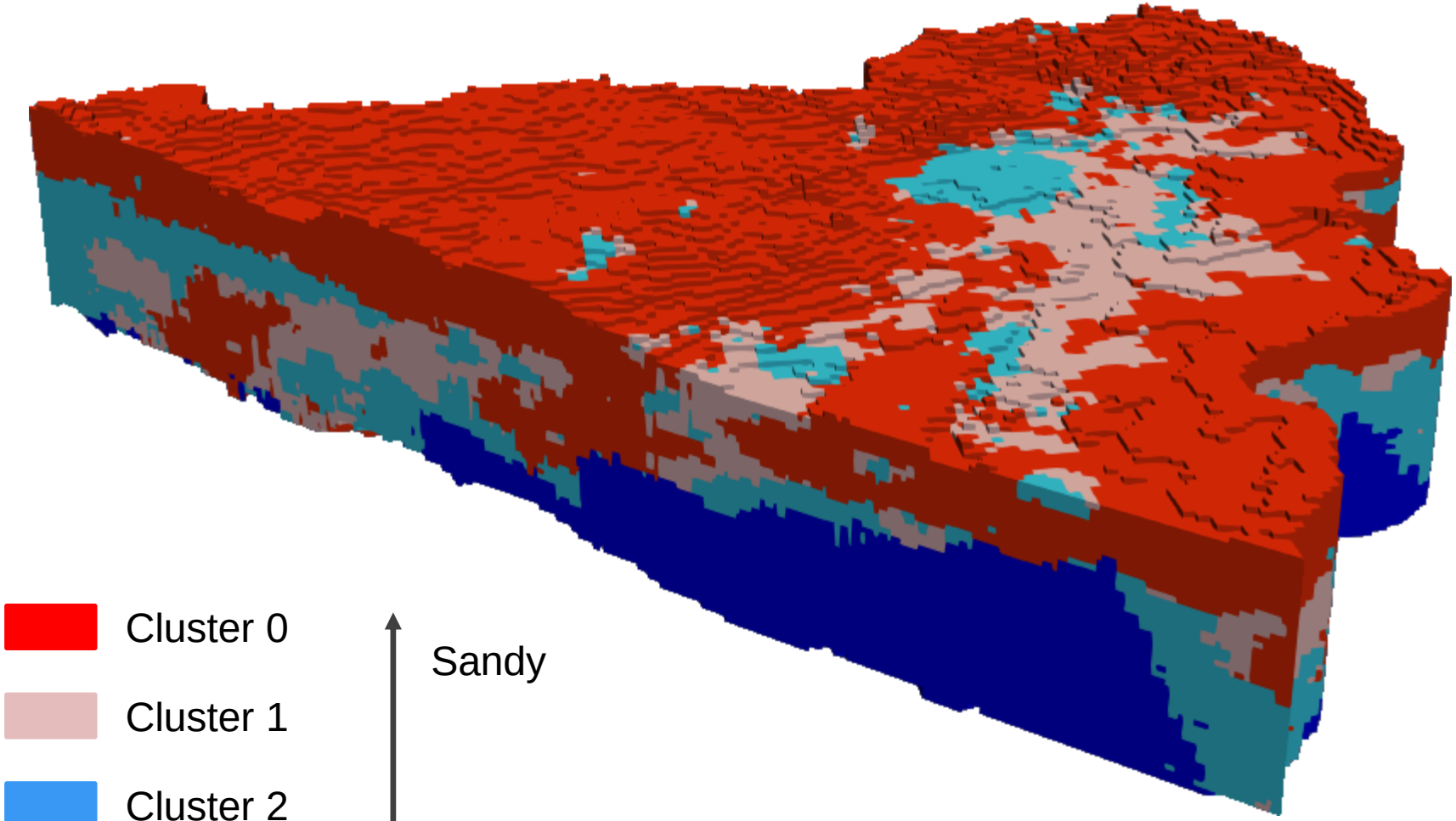

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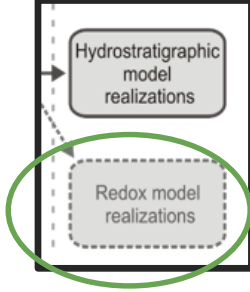

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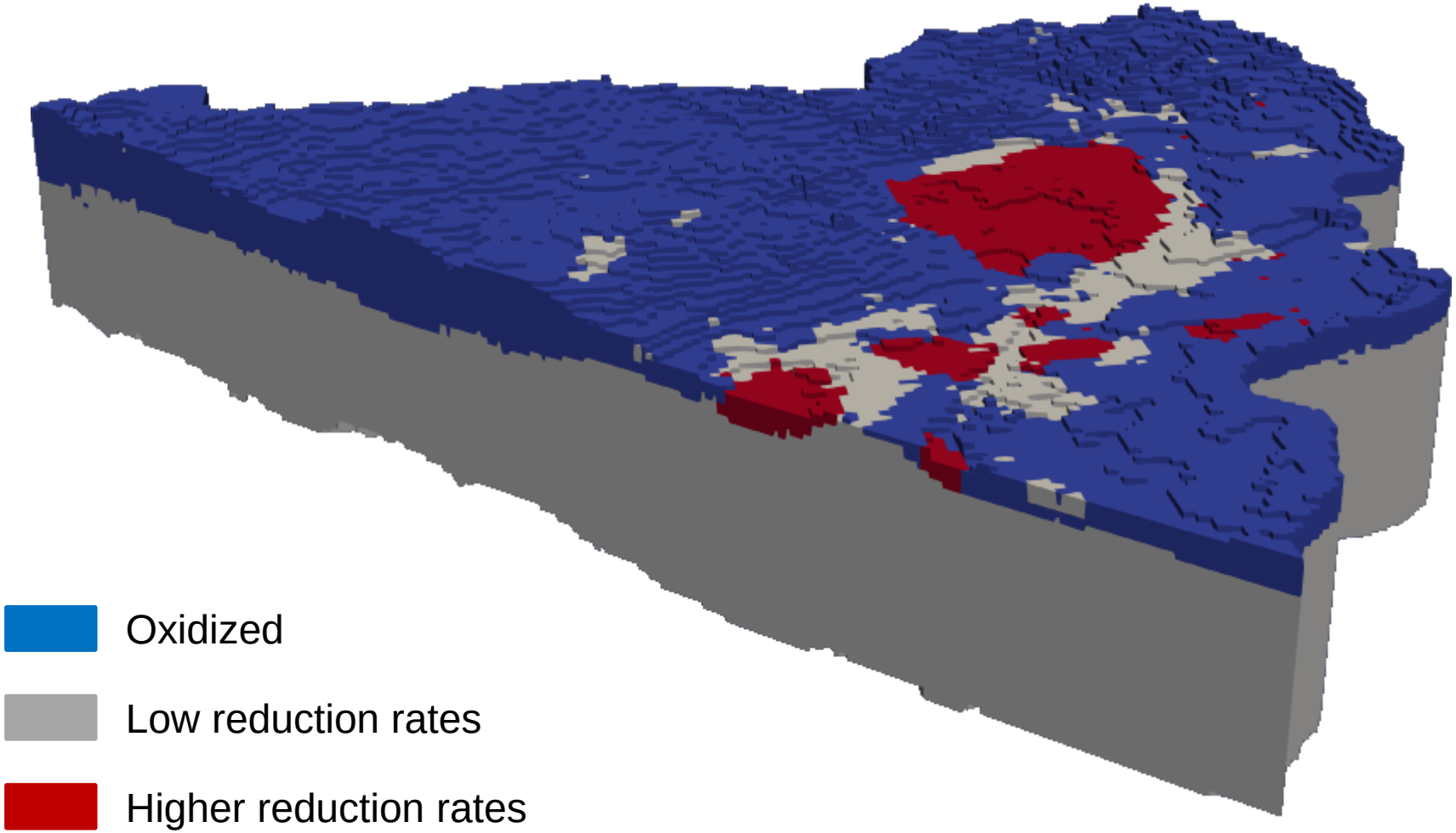
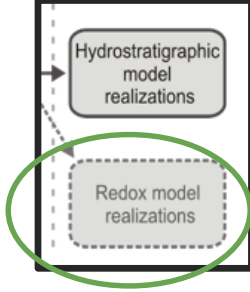


Oxidized

Low reduction rates

Higher reduction rates

Model Realizations



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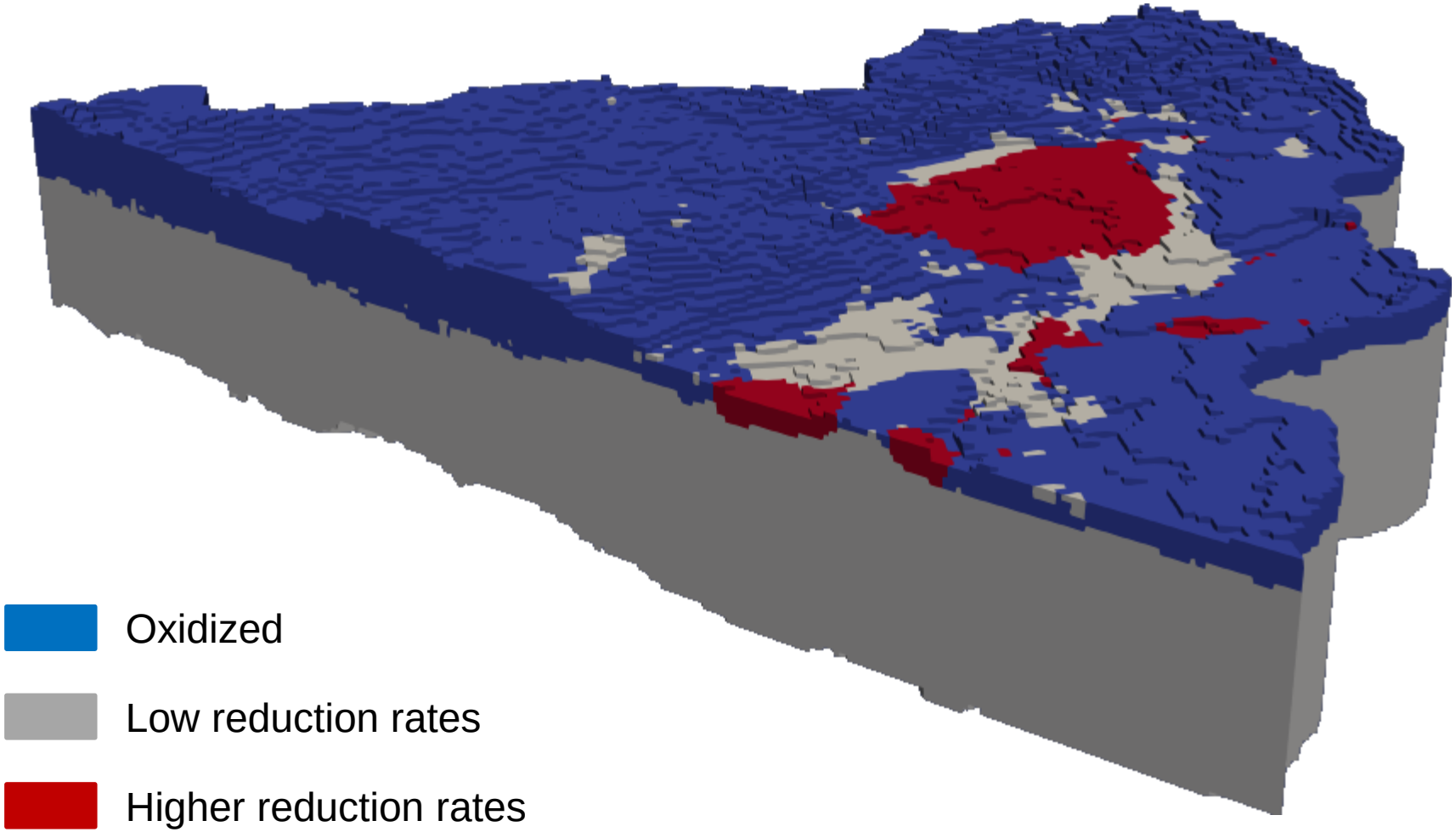

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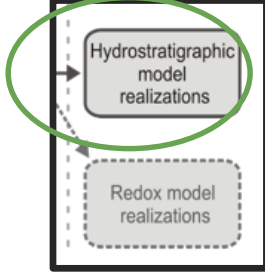
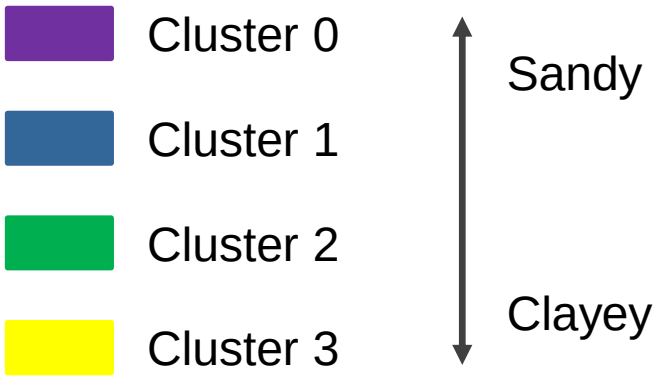


Uncertainty description

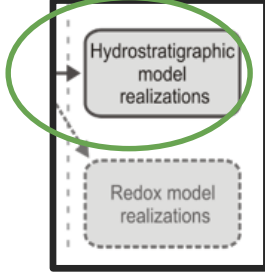
Cluster Hard Data

Hydrostratygraphy: Realization 1

Hydrostratygraphy: Realization 2



Model Realizations



Uncertainty description

Cluster Hard Data

Hydrostratygraphy: Realization 1

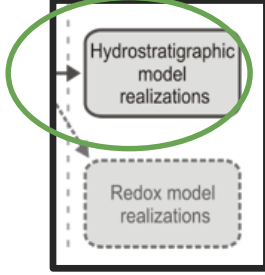
Entropy: 'variability indicator'

Value between 0 and 1:

- 0: **no variability** between each realization
- 1: each different type **equally represented** among the realizations

Hydrostratygraphy: Realization 2

Model Realizations



Uncertainty description

Cluster Hard Data

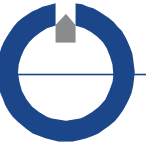
Hydrostratygraphy: Realization 1

Entropy: 0 1

Hydrostratygraphy: Realization 2

Conclusion

- **Uncertainty** and **complexity** included in groundwater model:
  - We can estimate the uncertainty on the subsurface hydro-geological structures based on collected geophysical and well data



Conclusion

- **Uncertainty** and **complexity** included in groundwater model:
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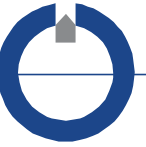
- **3D simulation redox** conditions, correlated to hydrogeological structure
  - We developed a method that simulates the subsurface redox conditions that is in agreement with the subsurface hydrogeological structures



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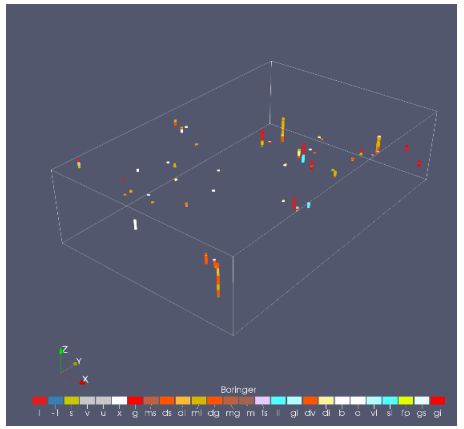

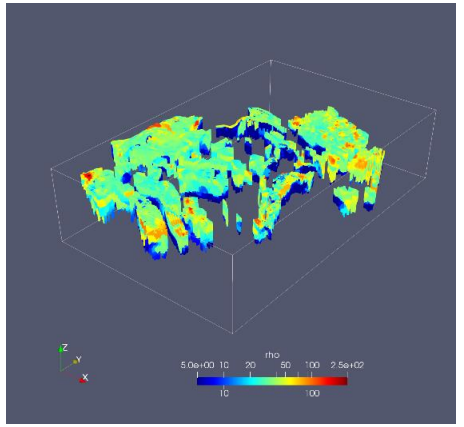

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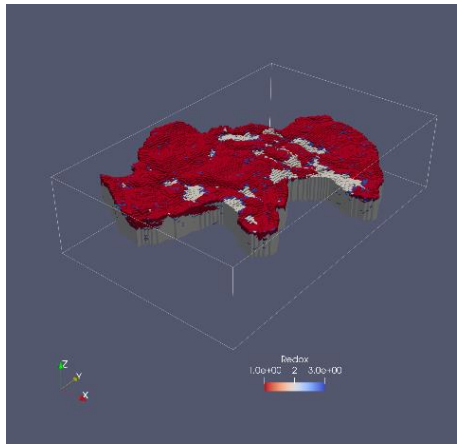

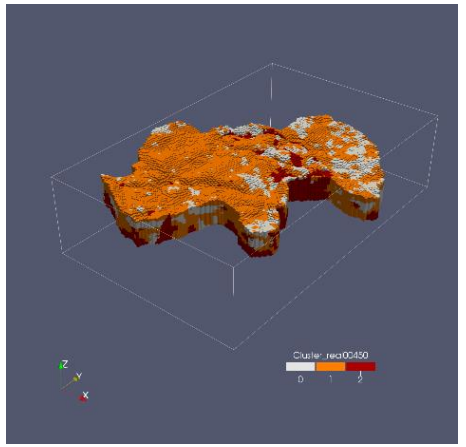

- **Transparent link** between wells and geophysical data:
  - The workflow from data collection to groundwater model input allows us to track the data through the process