Patterns in Geophysical Data and Models

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Near-surface geophysics

- Using geophysical tools to explore the shallow subsurface
- Scale of interest: Tens of centimeters up to tens of meters
- Common techniques:
  - Magnetics
  - Seismics (reflection and refraction)
  - Electrical resistivity and EM induction methods
  - Georadar (GPR)
  - Borehole and logging techniques
- Typical applications are from the fields of...

- Geology	- Engineering geology and geotechnics
- Sedimentology	- Hydrogeology
- Soil sciences	- Environmental sciences
- Archaeology	- Agriculture
- Civil engineering	- ...

⇒ Research topics are directed towards developing and improving geophysical techniques for specific applications

Patterns in Geophysical Data & Models

- What is a pattern?
  - “Opposite of chaos” (Watanabe, 1985)
  - “A regular repetition of values in an image” (Sheriff, 2002)

General flow of a geophysical experiment

Data gathering
(employing magnetics, seismics, electrics, georadar, borehole techniques, ...)

↓

Processing
(editing, analyzing, filtering, inversion, ...
In part specially developed techniques)

⇨

Analyzing & enhancing specific features in the **data space**

Examples from seismic & georadar:

- Residual statics (cross-correlation)
- Velocity analysis (coherency analysis of CMP gathers)
- NMO stacking
- Coherency & dip filtering

Patterns in Geophysical Data & Models

- What is a pattern?
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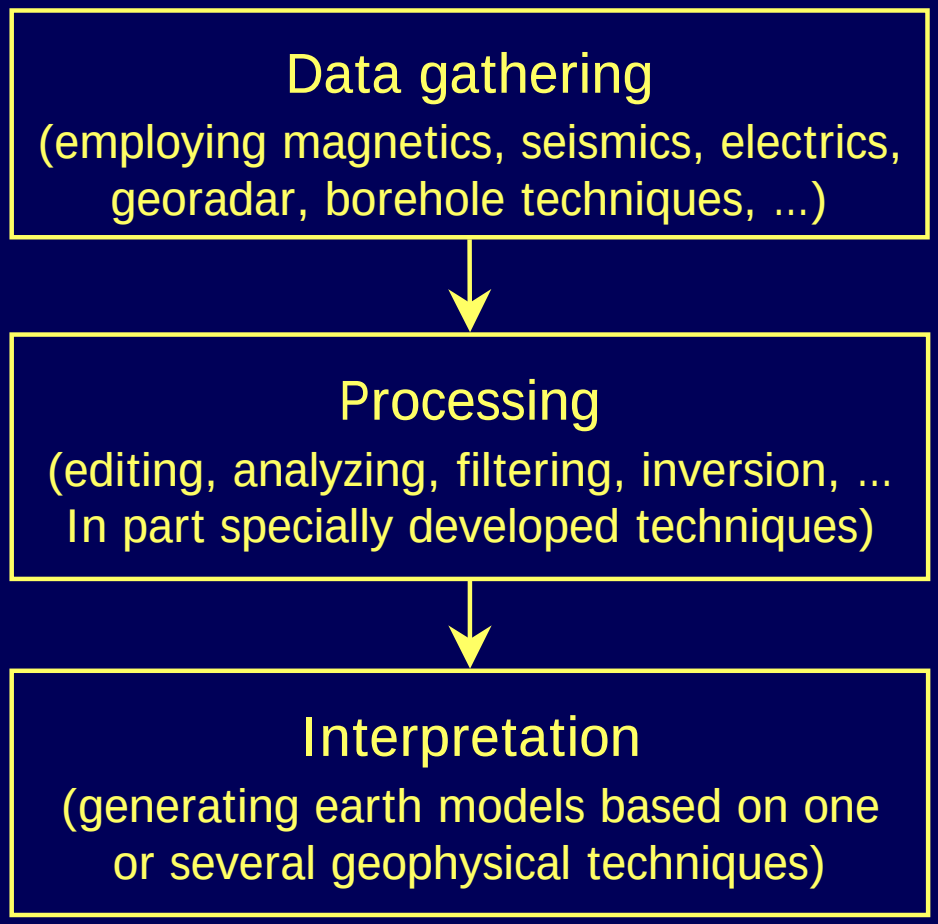
General flow of a geophysical experiment



Analyzing, extracting patterns & features in the **model space**, e.g.:

- Visualizing specific structures (faults, sedimentological units, archaeological features, ...)
- Integrating all available models & data (including non-geophysical information, e.g., core data, geological background, geo-technical or hydrological data, ...)

Overview

Selected examples from geophysical data interpretation

- 3-D georadar data:

  Attribute analysis to extract fault related features

- Multi-technique data sets:

  Integrated earth models based on cluster analysis

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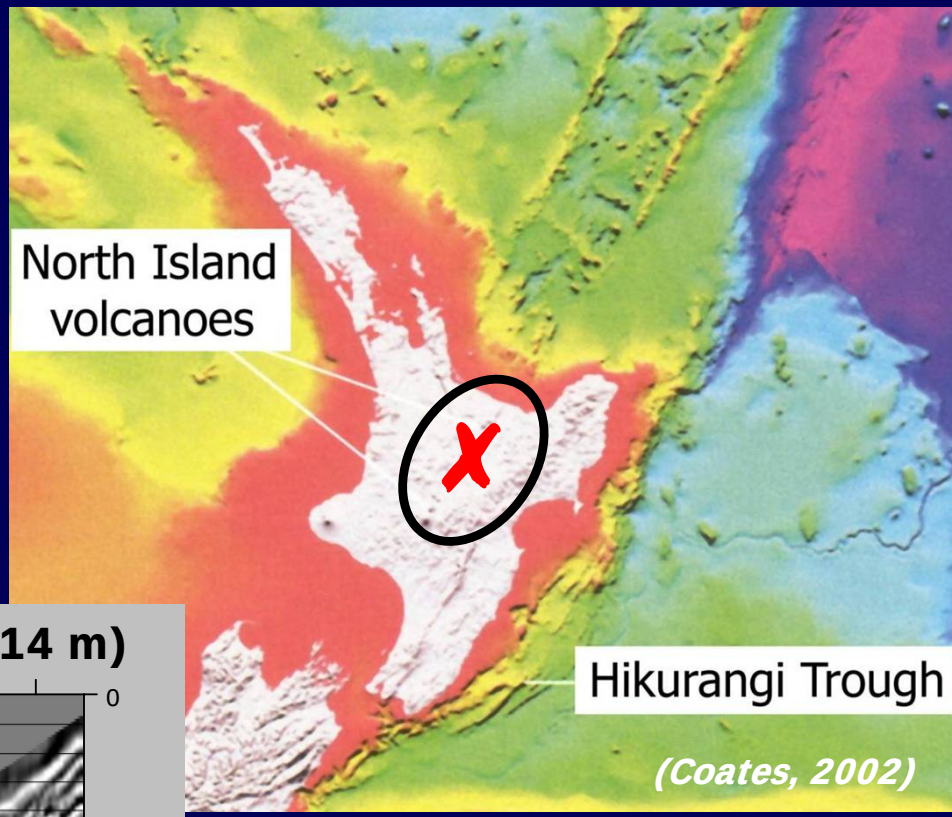
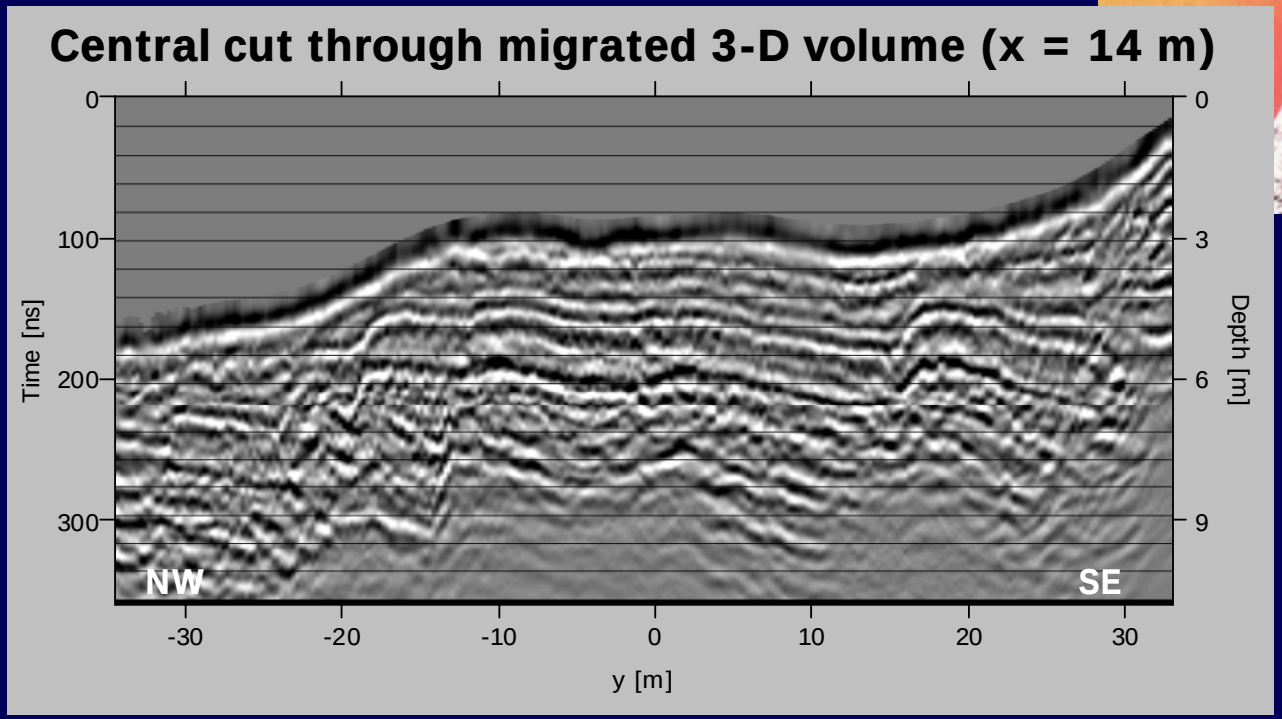
Maleme Fault Zone, New Zealand

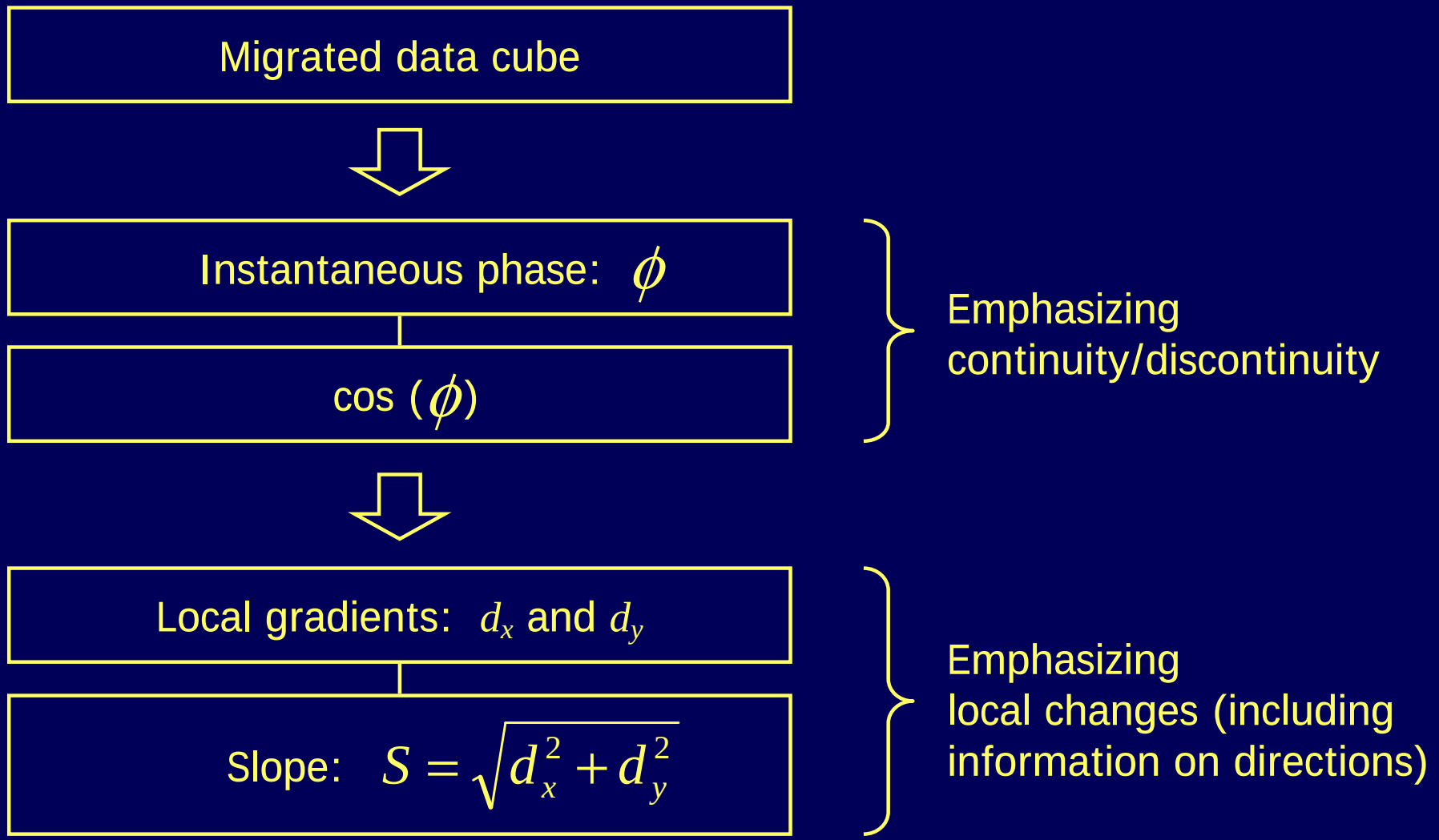
- Goal of the study: Mapping shallow geometry of the fault zone and stratigraphic details within near surface sediments using 2-D and 3-D georadar
- 3-D data set (100 MHz antennas) covering an area of ~ 20 x 70 m



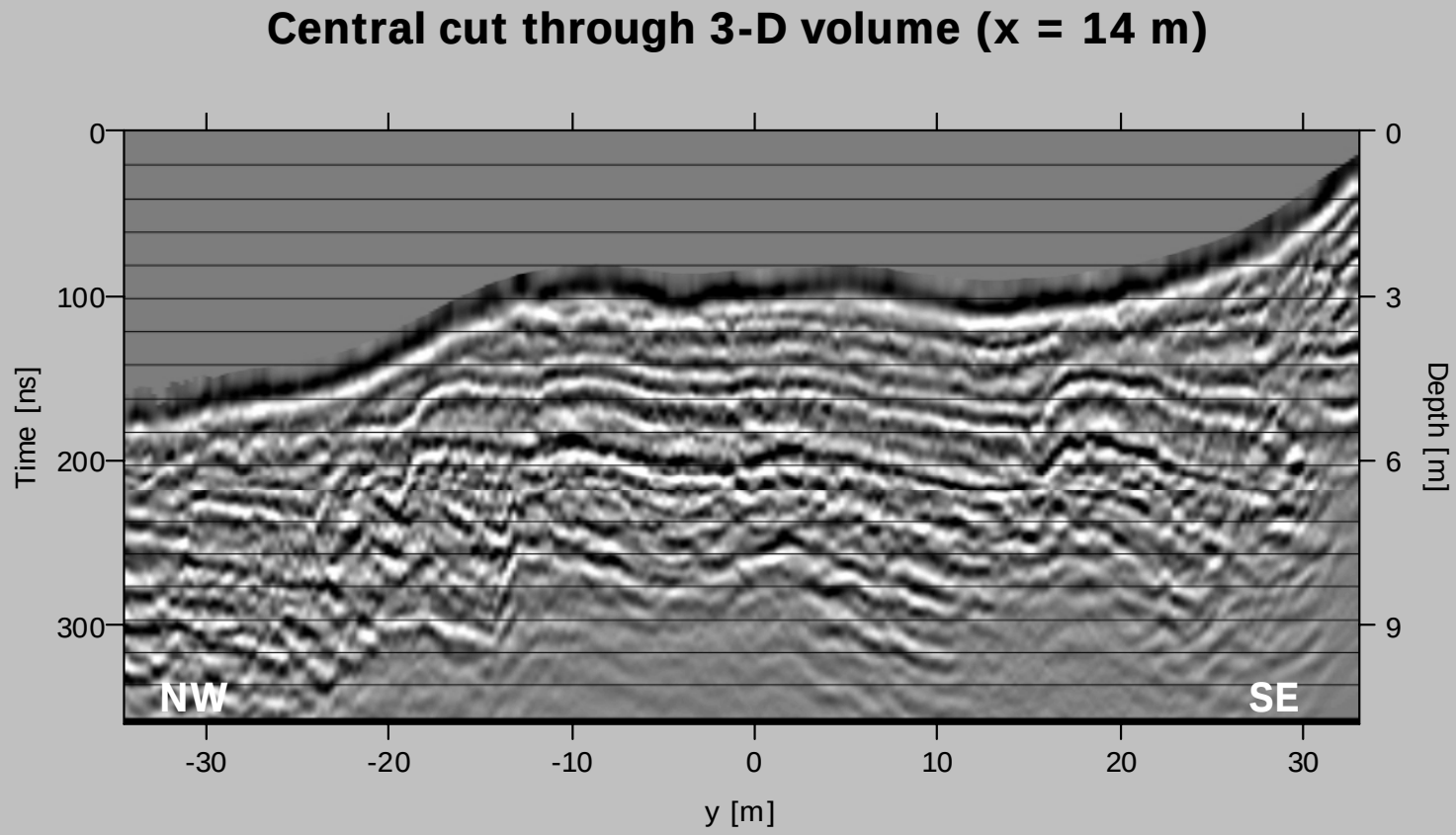


Attribute analysis (3-D data)

- Post-processing sequence to visualize near vertical features



Maleme Fault Zone: 3-D data



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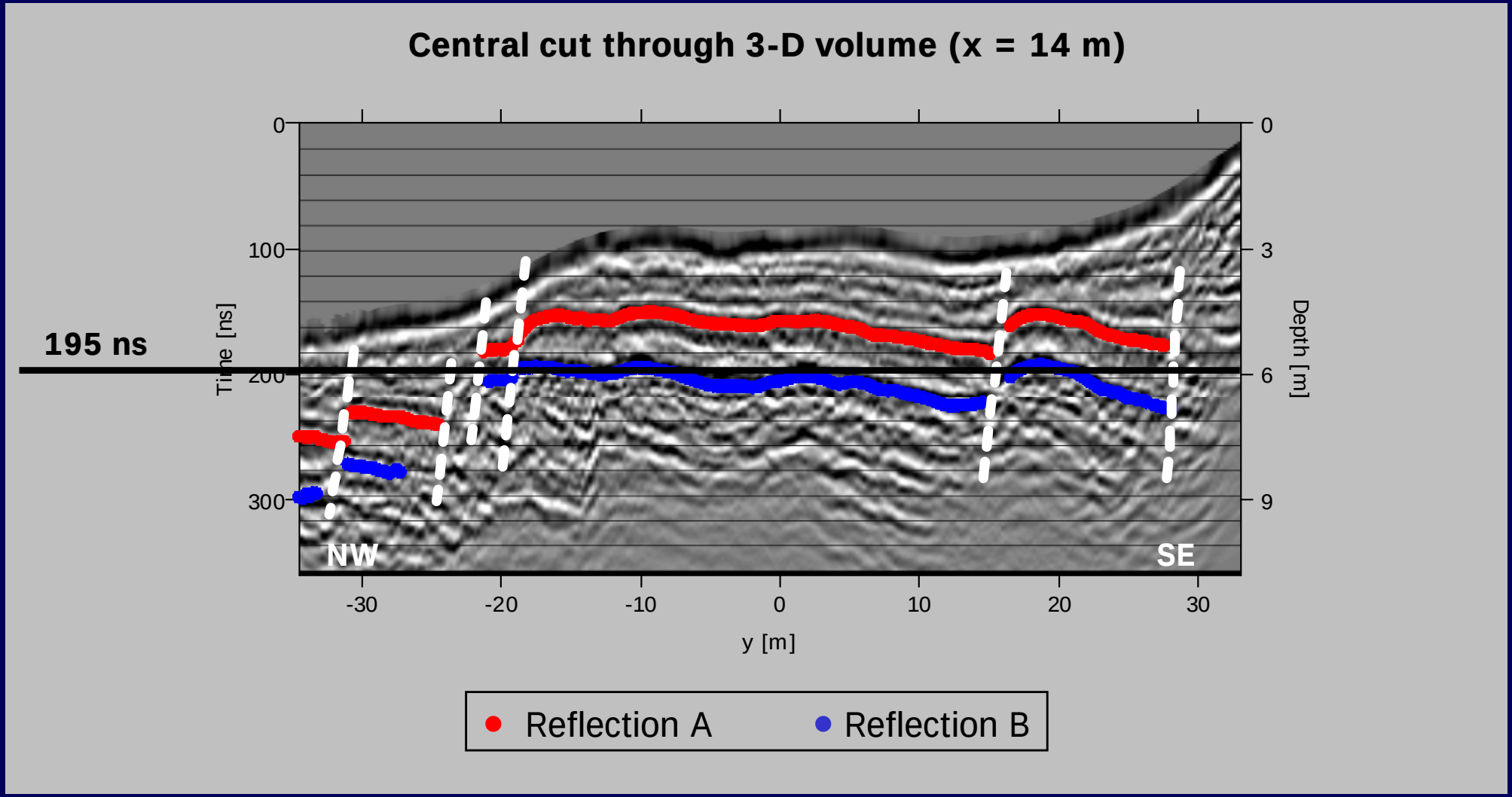

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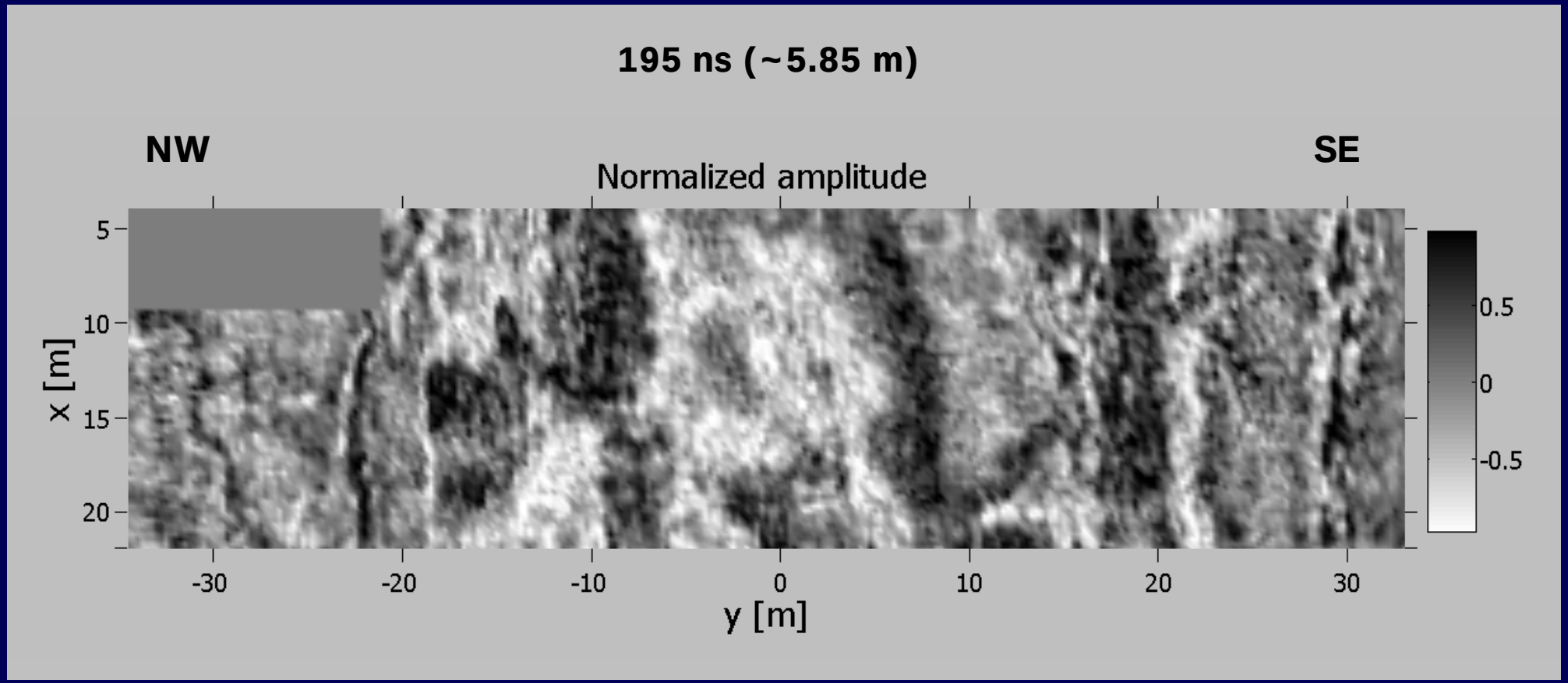

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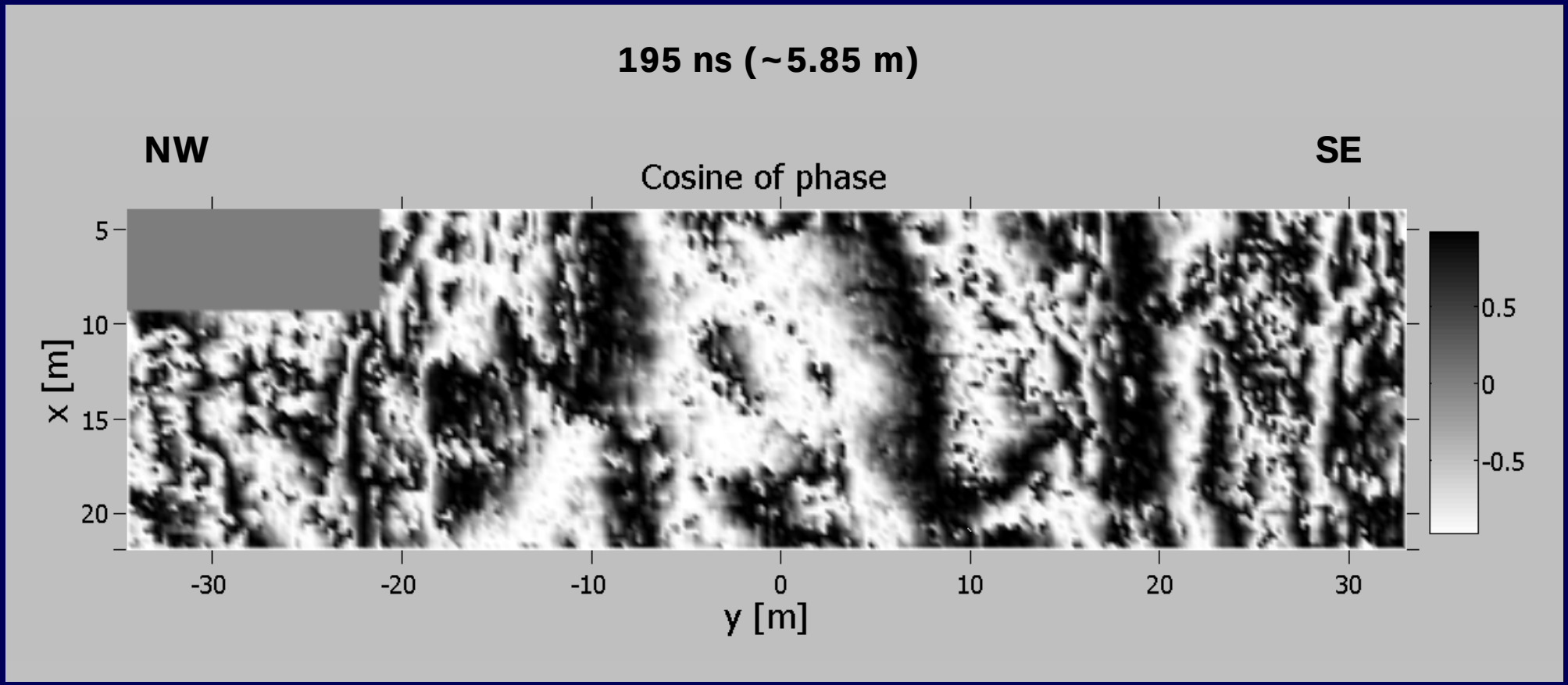

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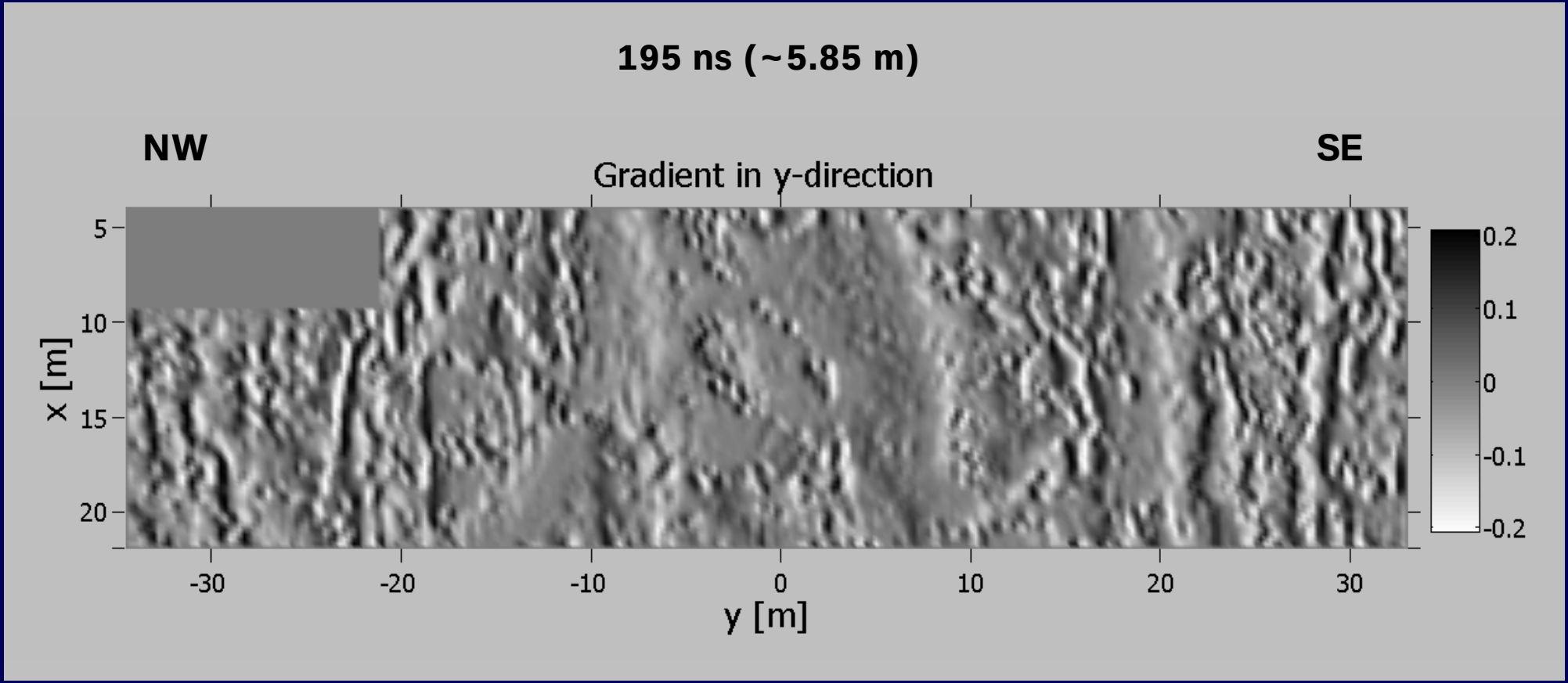

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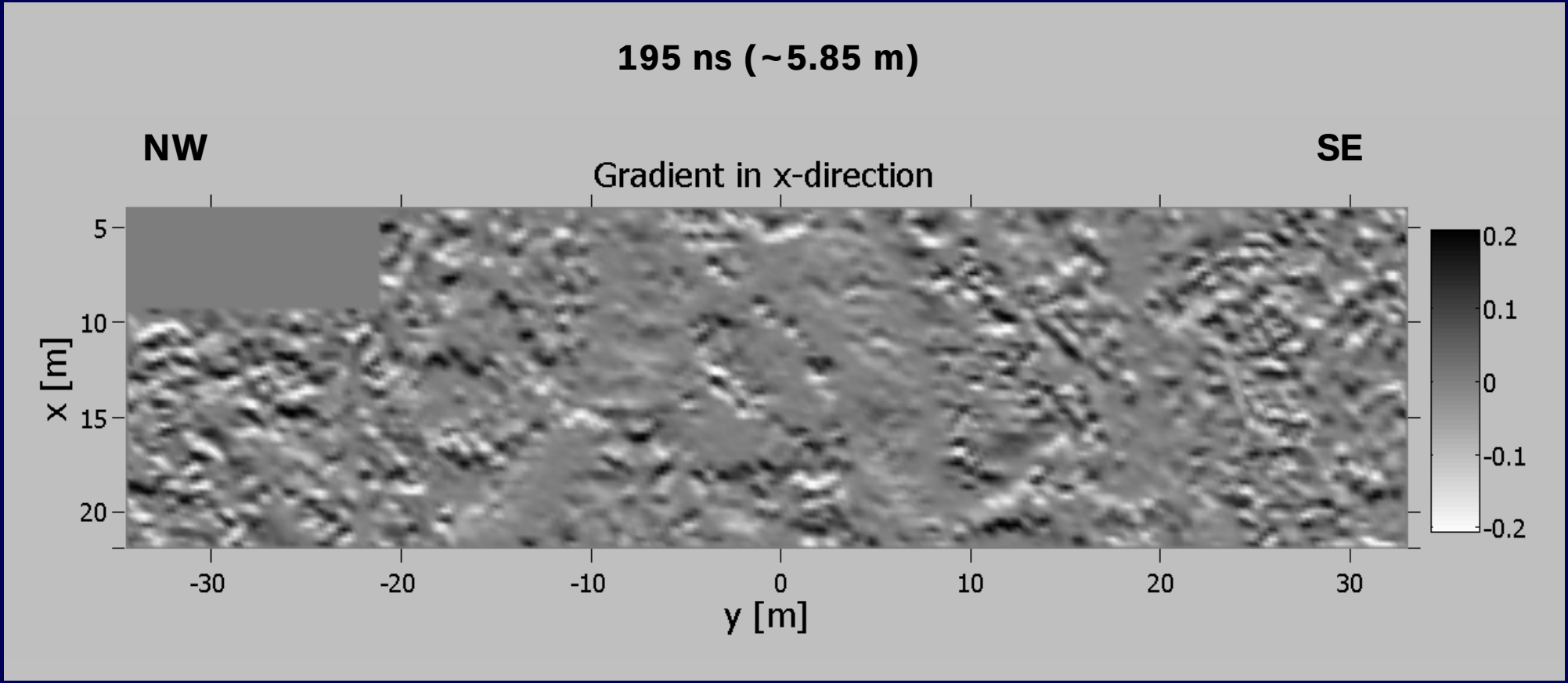

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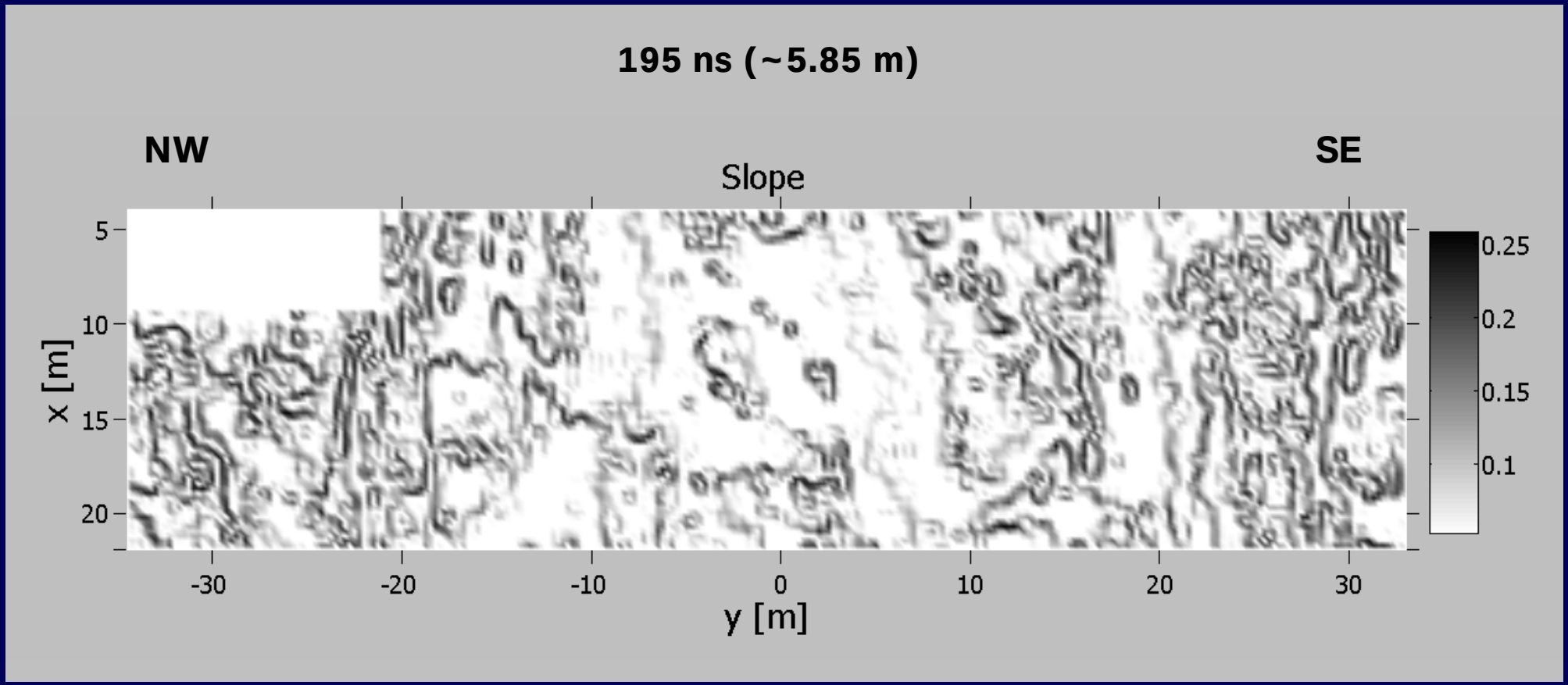

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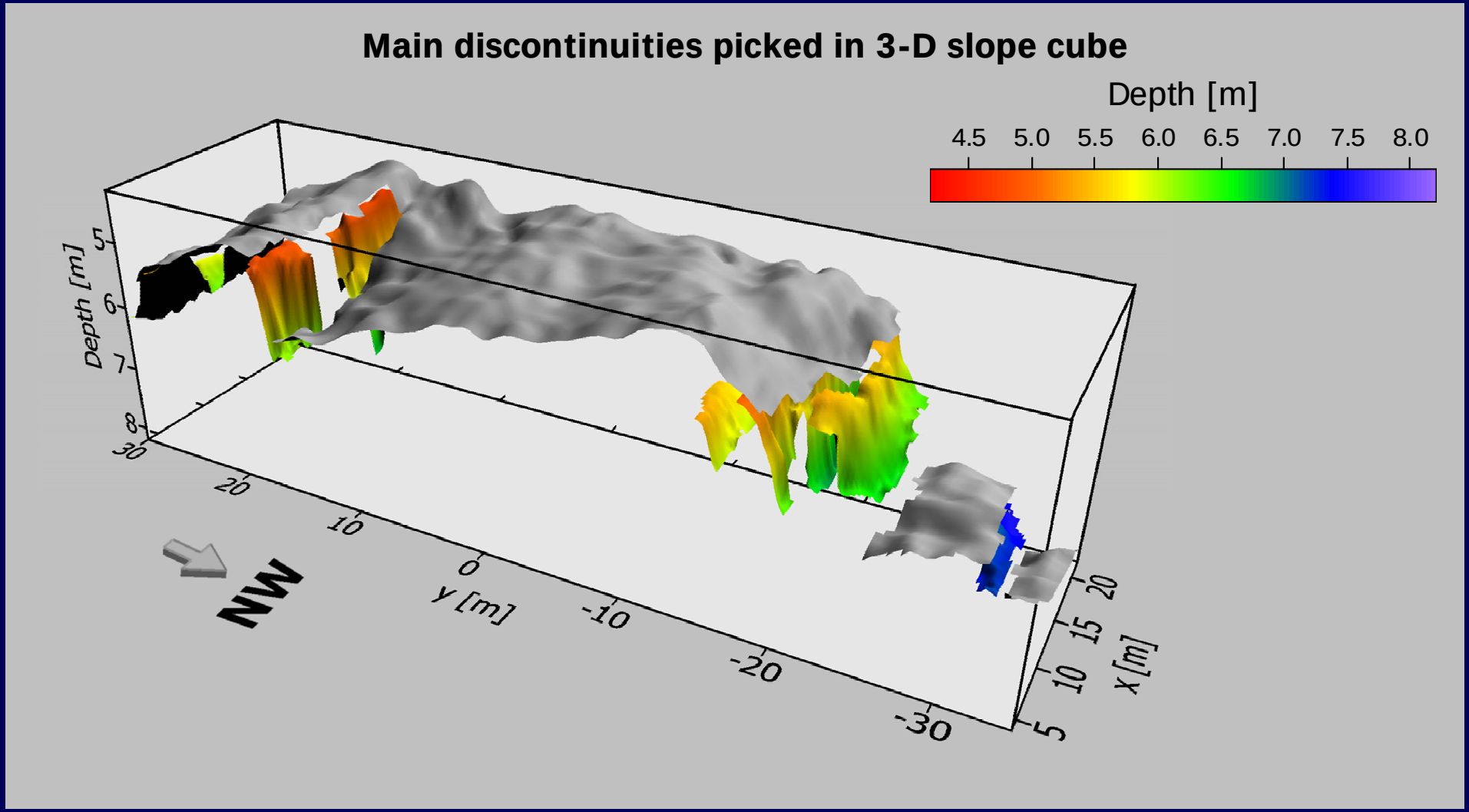

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Selected examples from geophysical data interpretation

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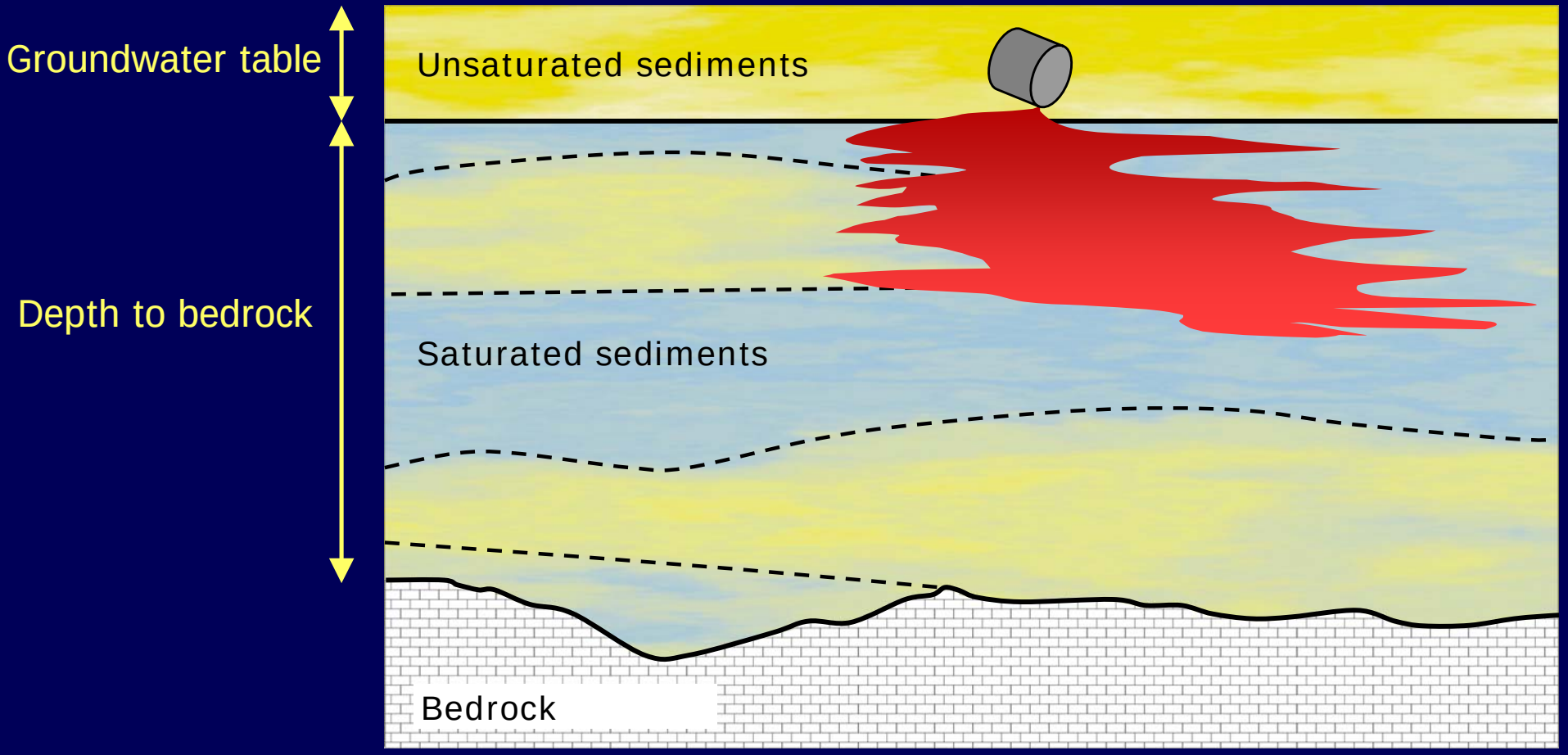
Geophysical tools for aquifer characterization

For example: contaminant site characterization

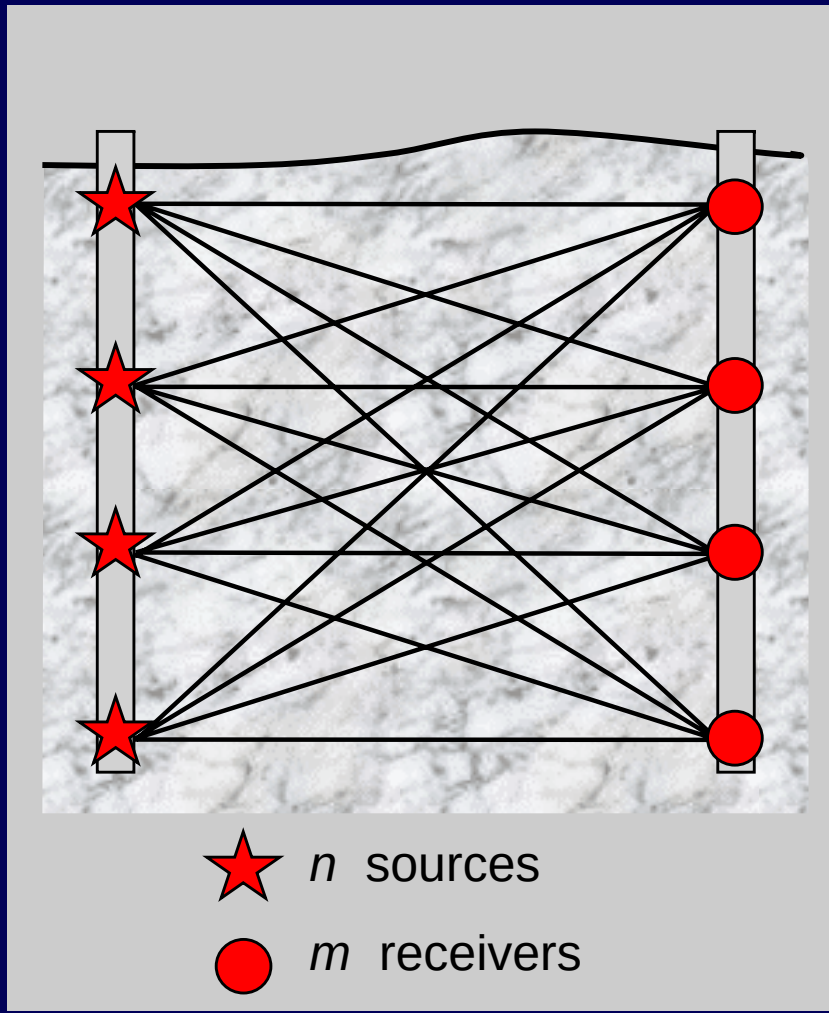


- Borders of the aquifer
- Internal structures
- Hydraulic relevant parameters (e.g., porosity, permeability)

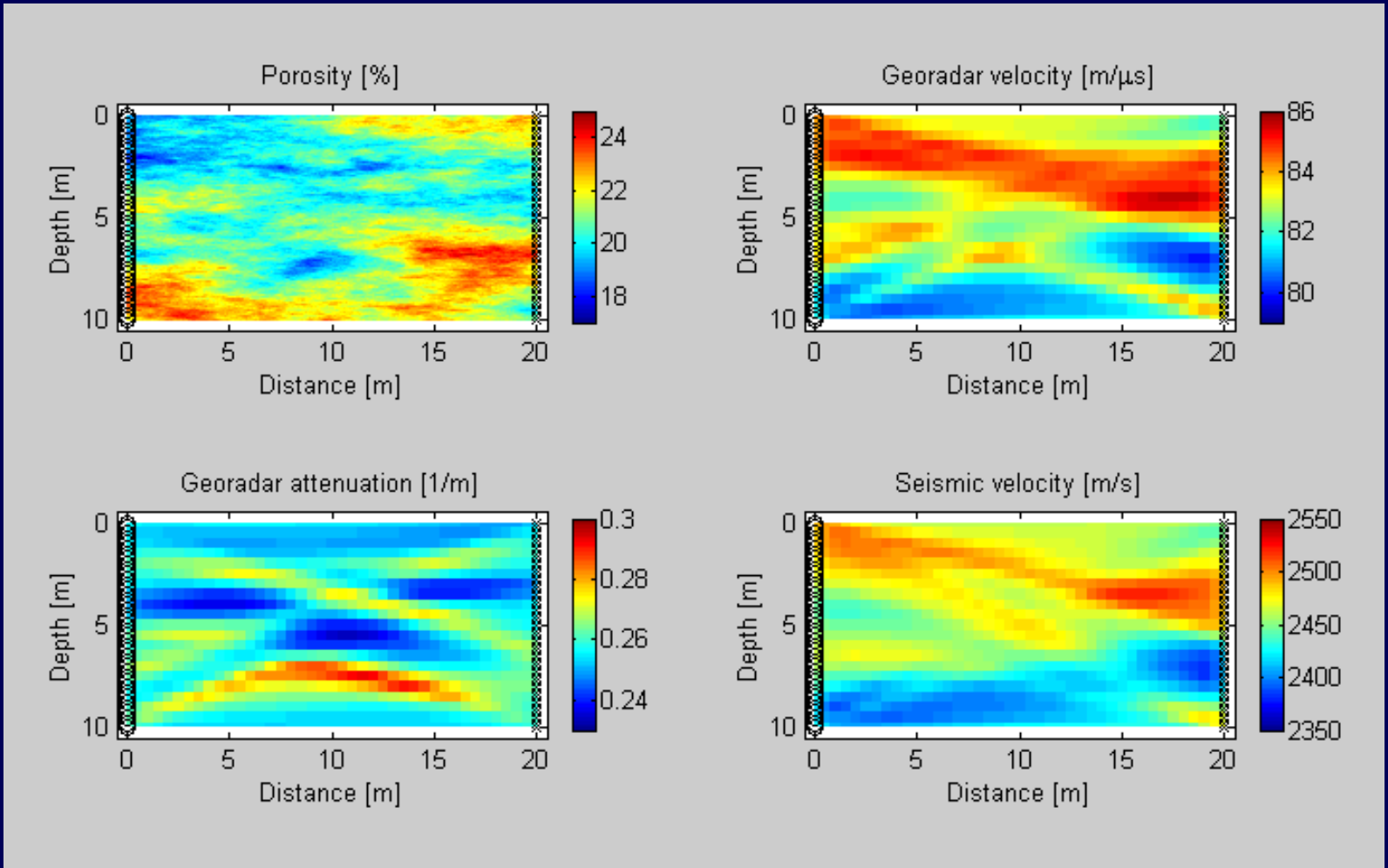
Crosshole georadar and seismic tomography

- Exploring the inter-borehole plane
  - Traveltime of the signals $\Rightarrow$ velocity v
  - Amplitudes of the signals $\Rightarrow$ attenuation α
- Scale of such experiments:
  several meters to tens of meters
- Resolution: ~ 1 m
- Sensitive to hydrological relevant parameters:
  water content, porosity, ...

$\Rightarrow$ Often ideal complement to the more conventional hydrological field techniques



Synthetic example



How to generate an integrated model from different geophysical models ?

Fuzzy *c*-means (FCM) cluster analysis

n-dimensional model space

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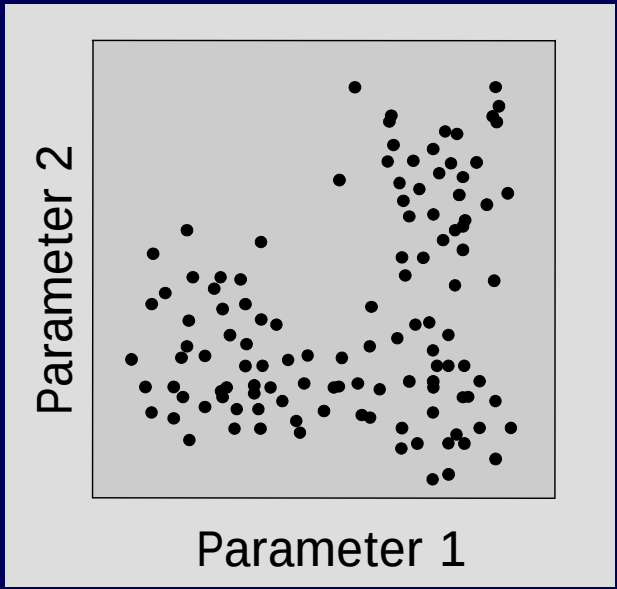
FCM cluster analysis
$\Rightarrow$ m_{ij} : membership of data point x_j to cluster i



Fuzzy *c*-means (FCM) cluster analysis

n-dimensional model space

FCM cluster analysis
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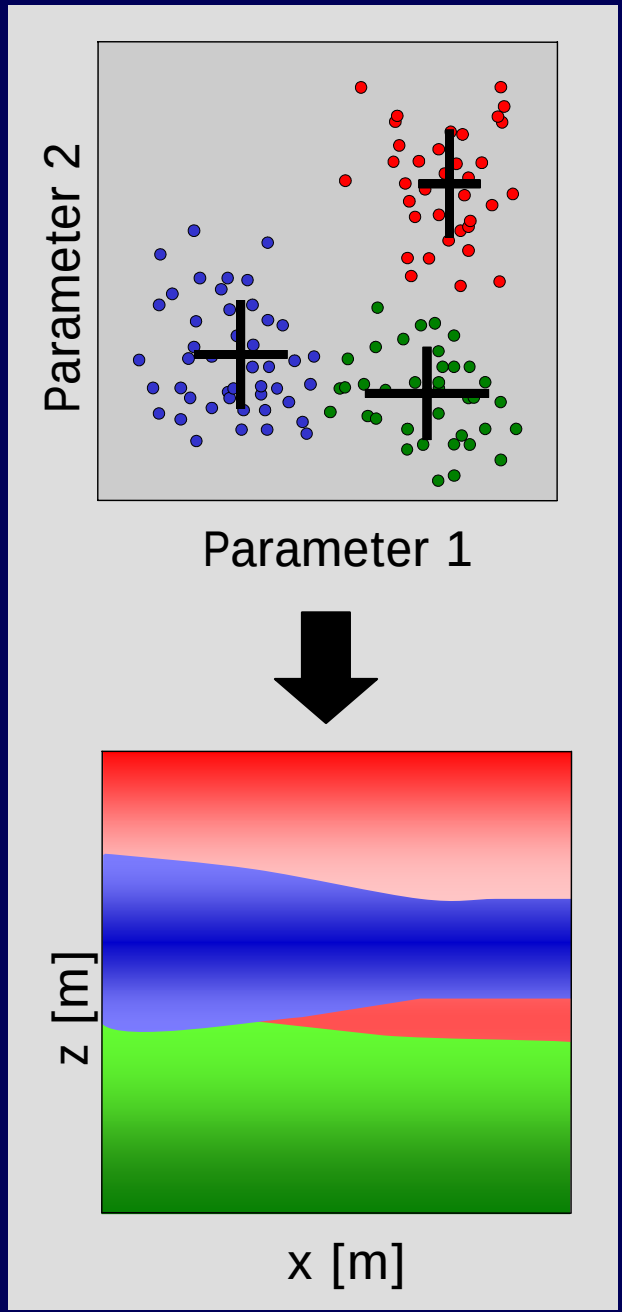
Defuzzification
$\Rightarrow$ “hard“ cluster separation

(Colour saturation pro-portional to membership)

Zoned multi-parameter model including information regarding its reliability



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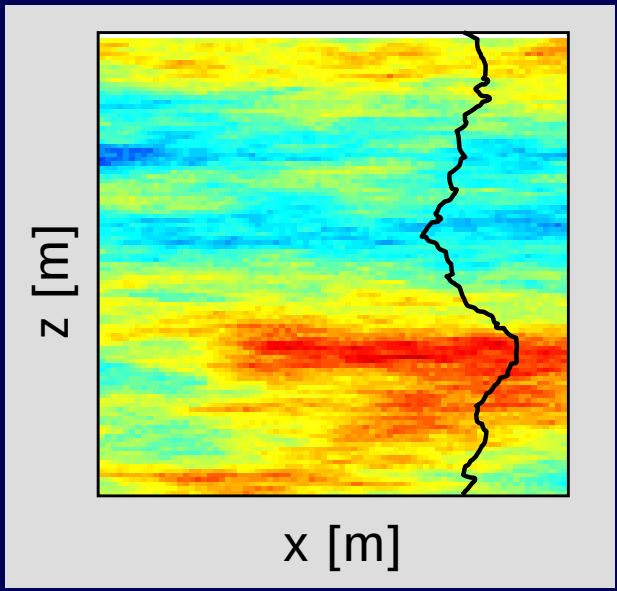


Defuzzification
$\Rightarrow$ “hard“ cluster separation

(Colour saturation pro-portional to membership)

Multi-prameter model:

$$p_j = \sum_{i=1}^{c} m_{ij}\,\bar{p}_i$$

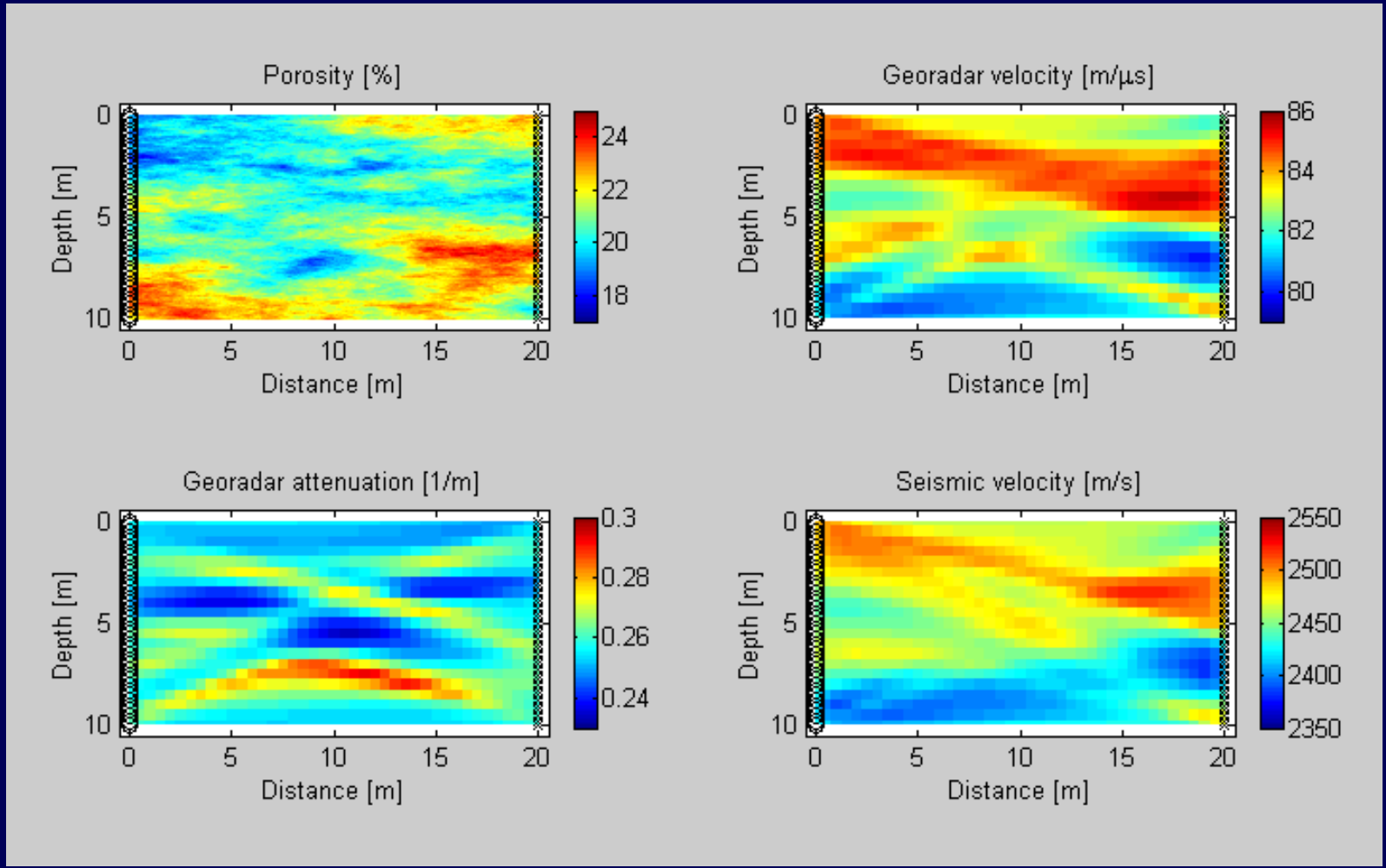
$\bar{p}_i$: mean of p for cluster i

Target parameter p (e.g. porosity-logs)

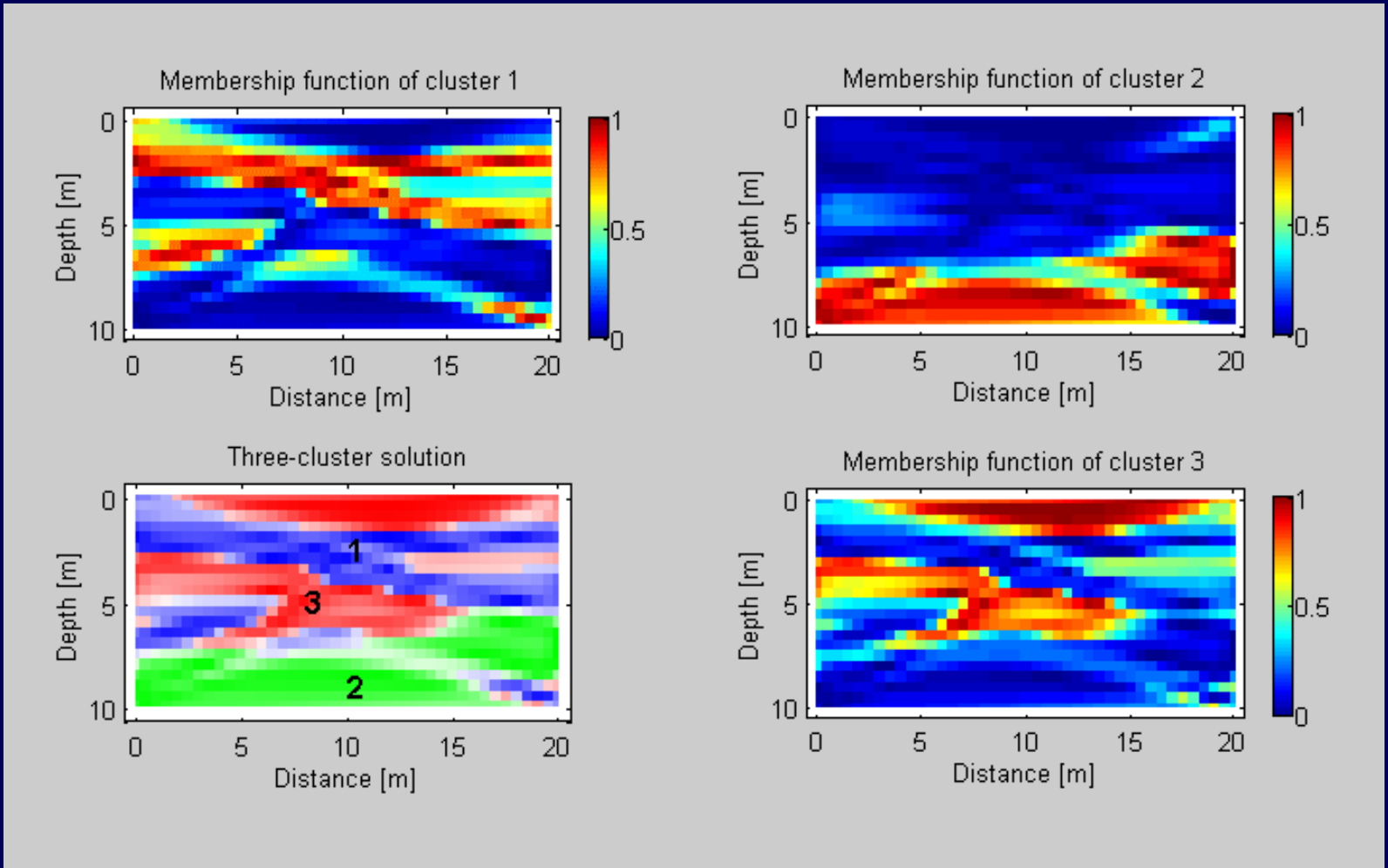
Zoned multi-parameter model including information regarding its reliability

Spatial model of the petrophysical target parameter

Synthetic example

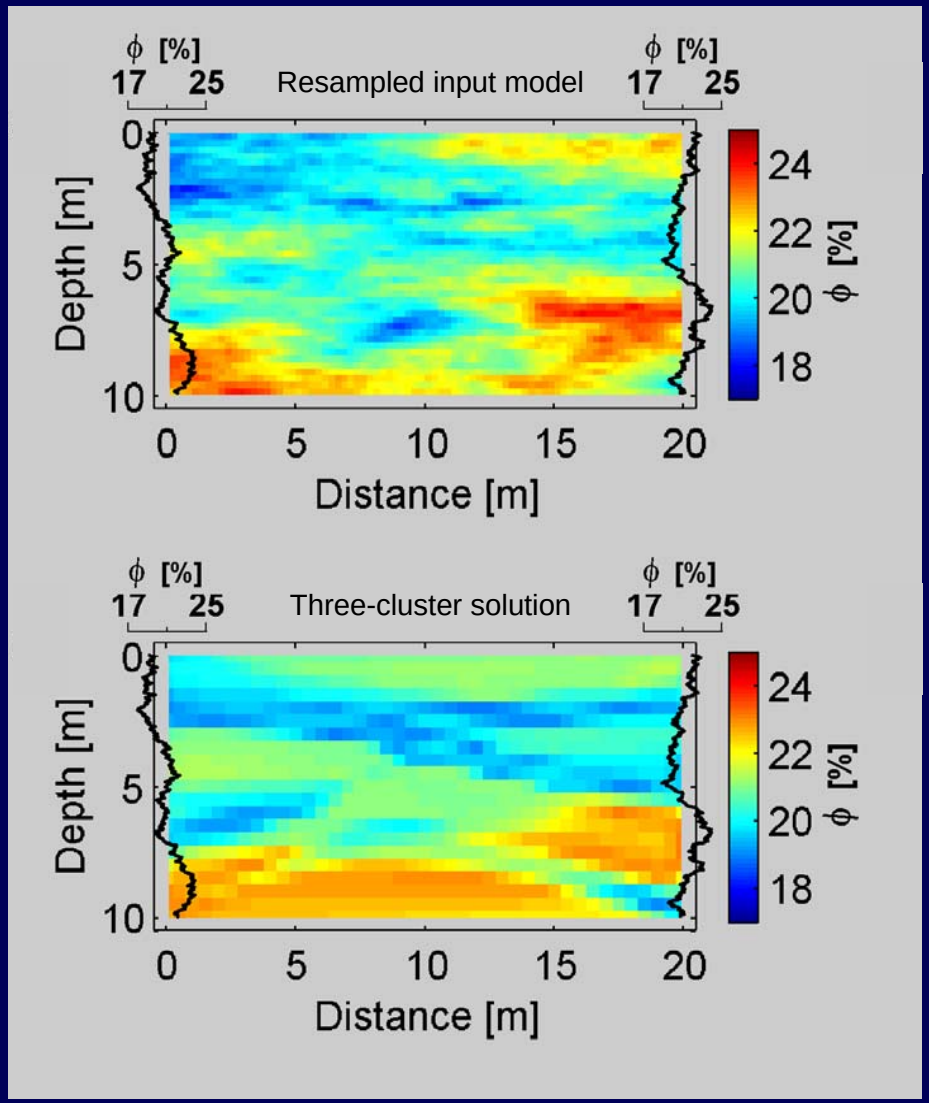


Results FCM cluster analysis



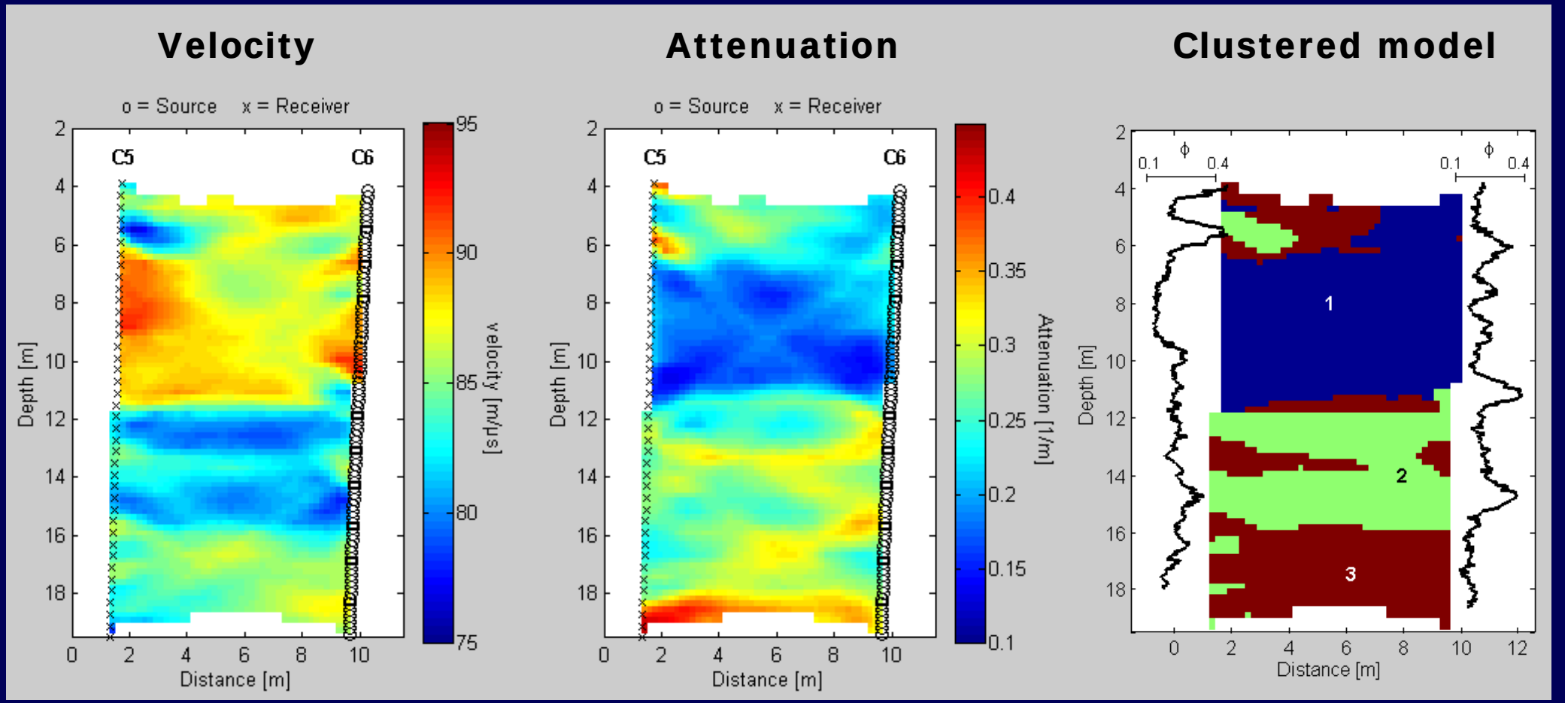
- Colour saturation reflects reliability of the zonation

Reconstructed porosity distributions



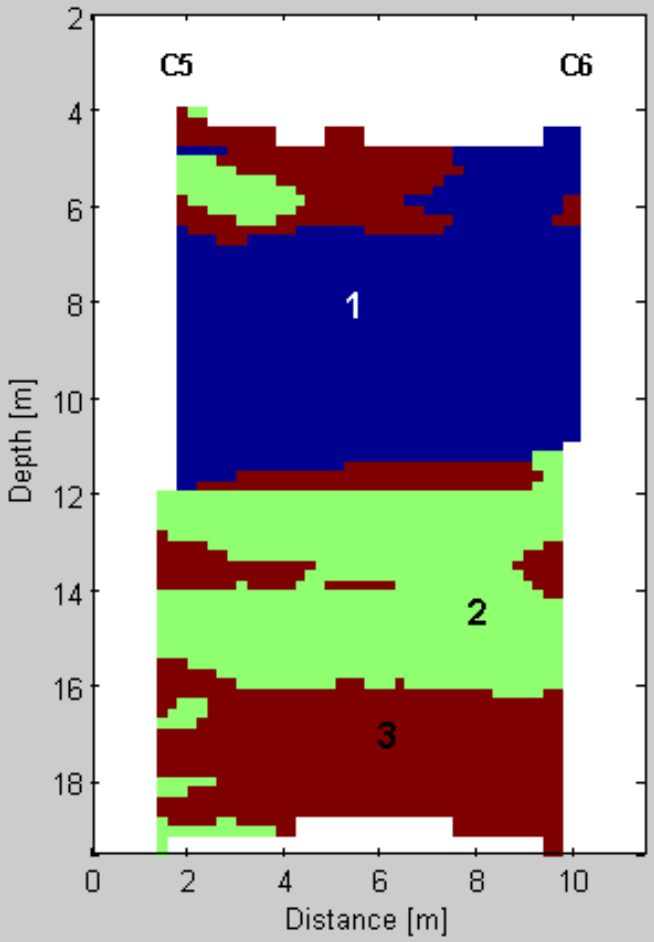
Results cluster analysis

Real data example: Boise Hydrogeophysical Research Site (BHRS)

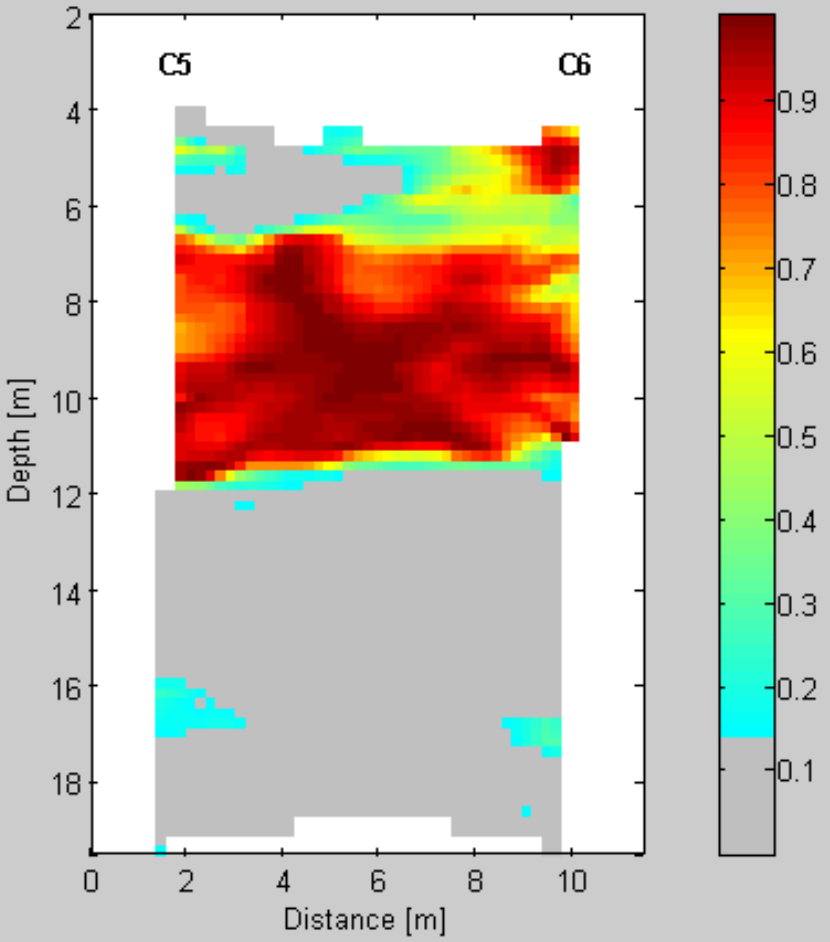


Analyzing reliability of the zonation

Fuzzy *c*-means (after defuzzification)

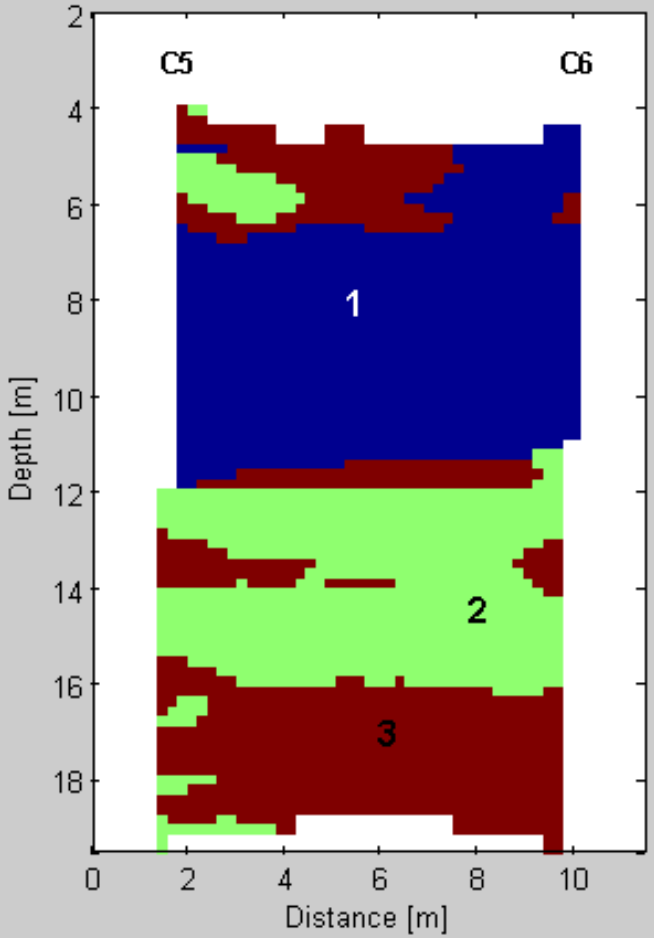


Membership function for cluster 1 ("low porosity cluster")

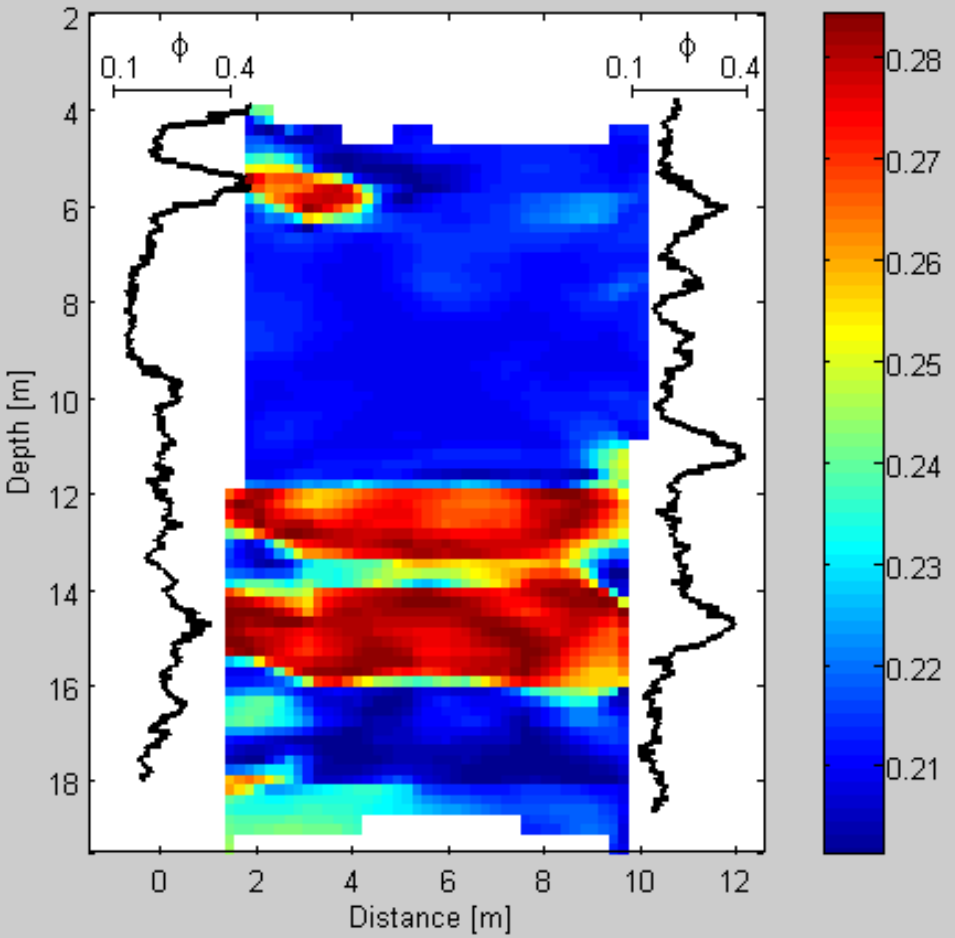


Petrophysical parameter reconstruction

Fuzzy *c*-means (after defuzzification)



Reconstructed porosity distribution



Conclusions

- Pattern & feature recognition and related methods are fundamental steps in the geophysical workflow
  ⇒ Data processing
  ⇒ Interpretation

- Examples illustrated the potential to ...
  - extract specific features in a data set
  - integrate different data sets in a quantitative fashion

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