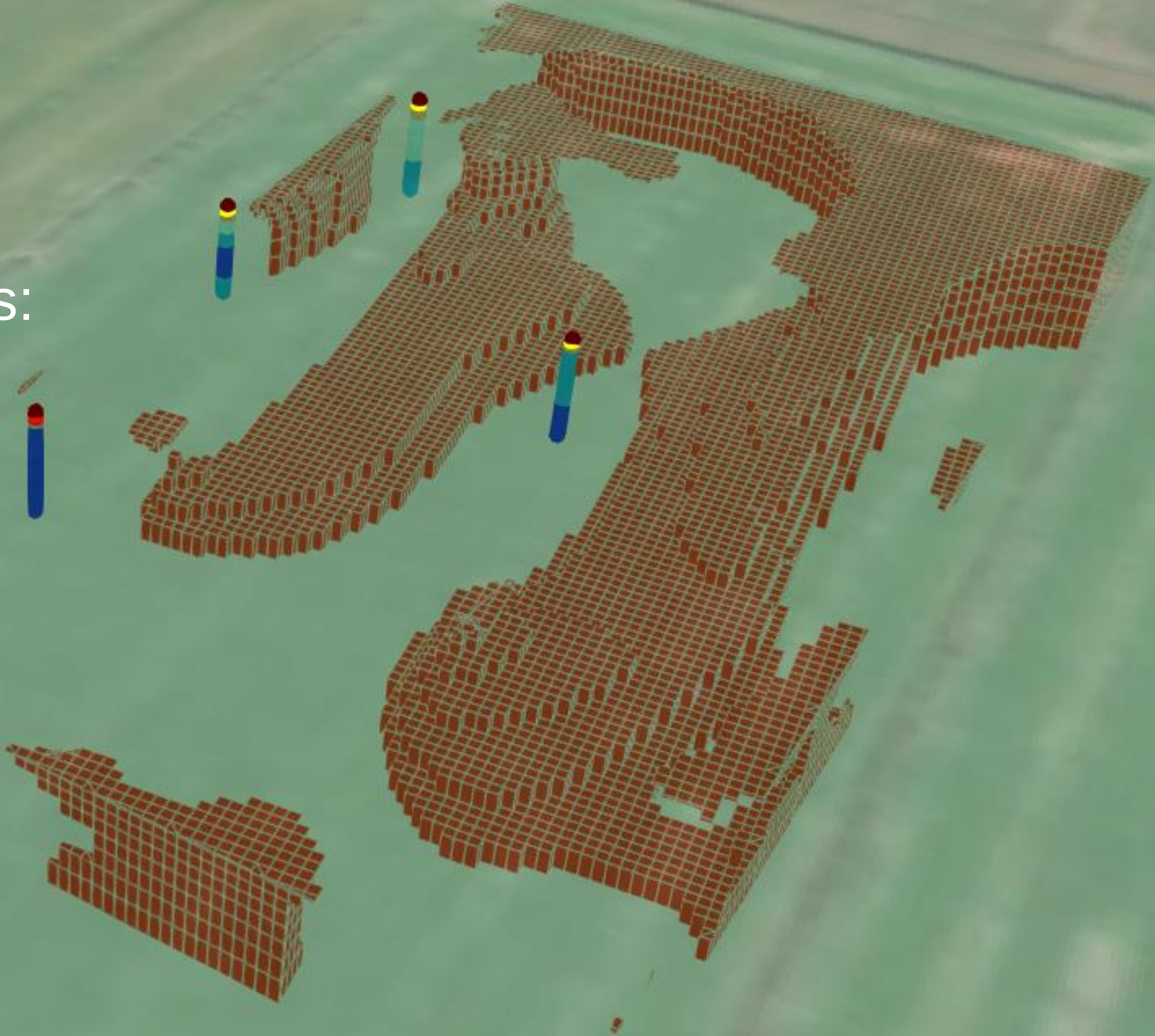
Geophysics and Geohazards: Non-intrusive 3D ground models for mapping unseen hazards



Jim Whiteley
Principal Geophysicist, Atkins

11/04/2023

Introduction

Part 1: The case for geophysics

- 3D Geoscience: the rise and rise of remote sensing
- Why geophysics?
- What is geophysics?
- Why geophysics (again)?

Part 2: Welby Tank 3D Resistivity Survey case study

- Data cost vs data value
- Summary

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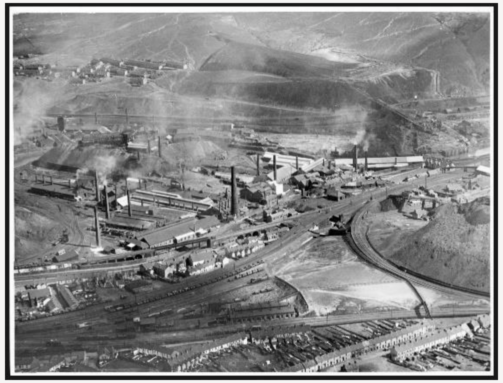
The case for geophysics

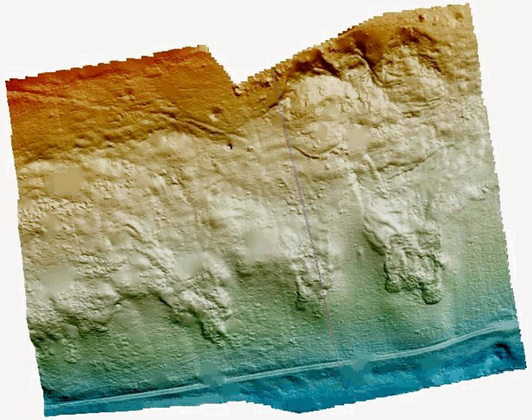
3D geoscience: the rise and rise of remote sensing

New York Public Library, 1870s



National Museum Wales, 1920s

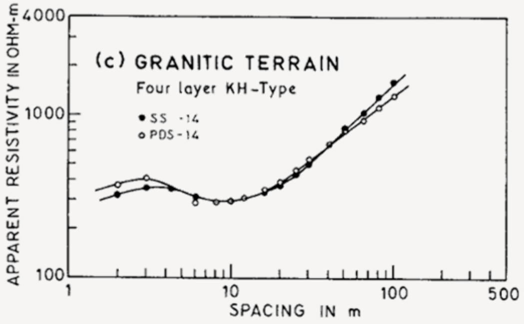
Maptech, 1990



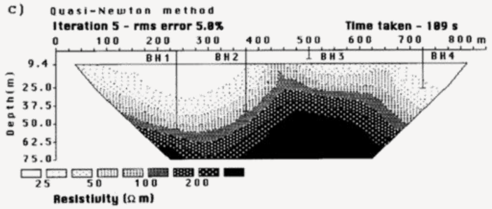
Whiteley et al, 2021

Pre-1900 **1930** **1990** **2020**

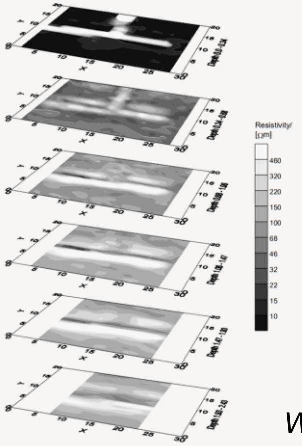
Schlumberger, 1910s



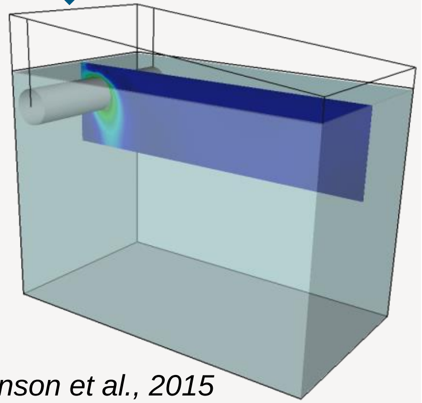
Yadav, 1988



Loke and Barker, 1996



Loke and Dahlin, 1997



Wilkinson et al., 2015

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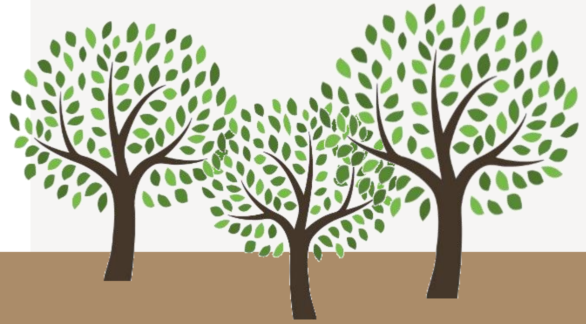
Why geophysics?

- Intrusive GI cost:



Why geophysics?

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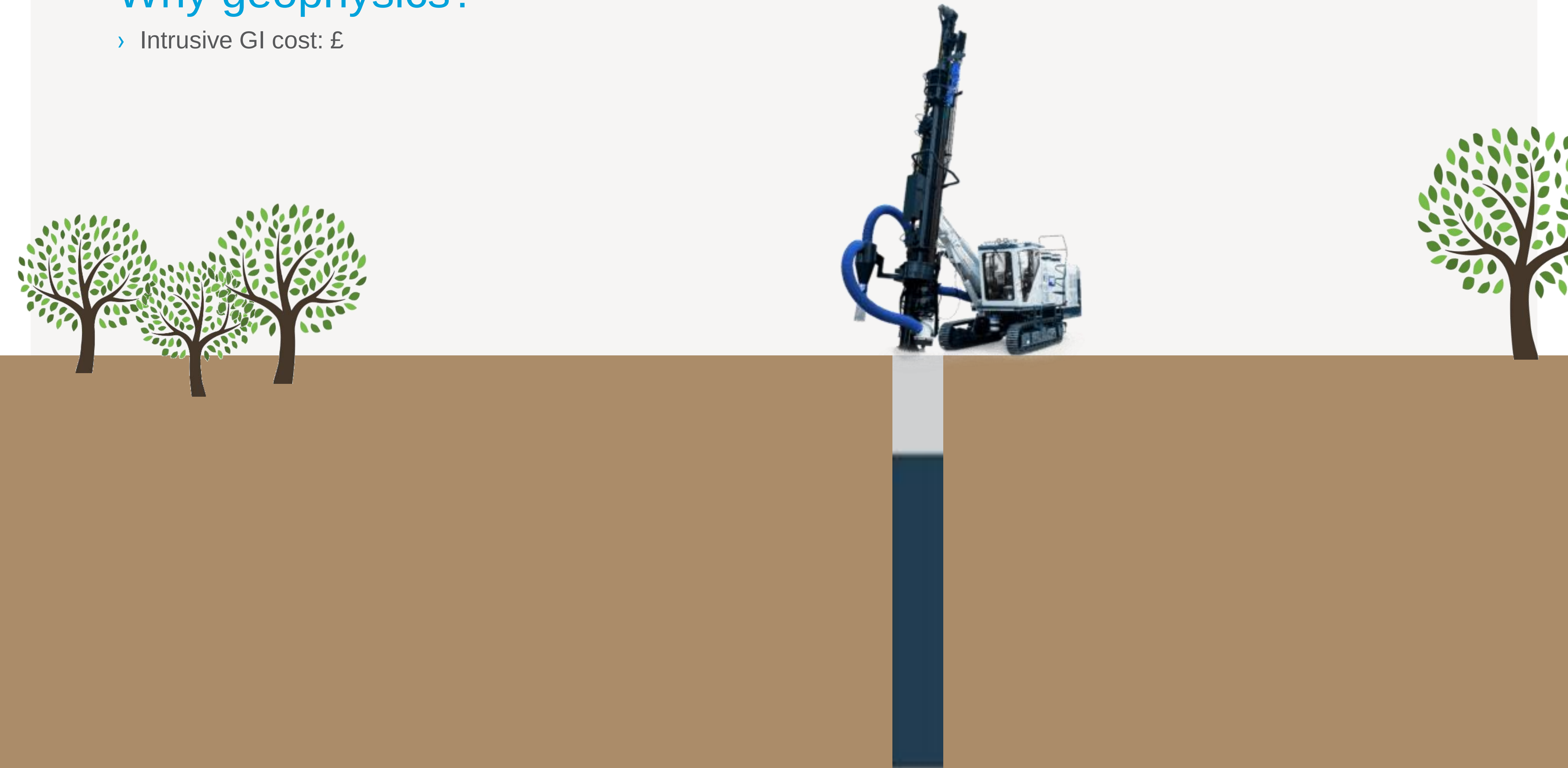

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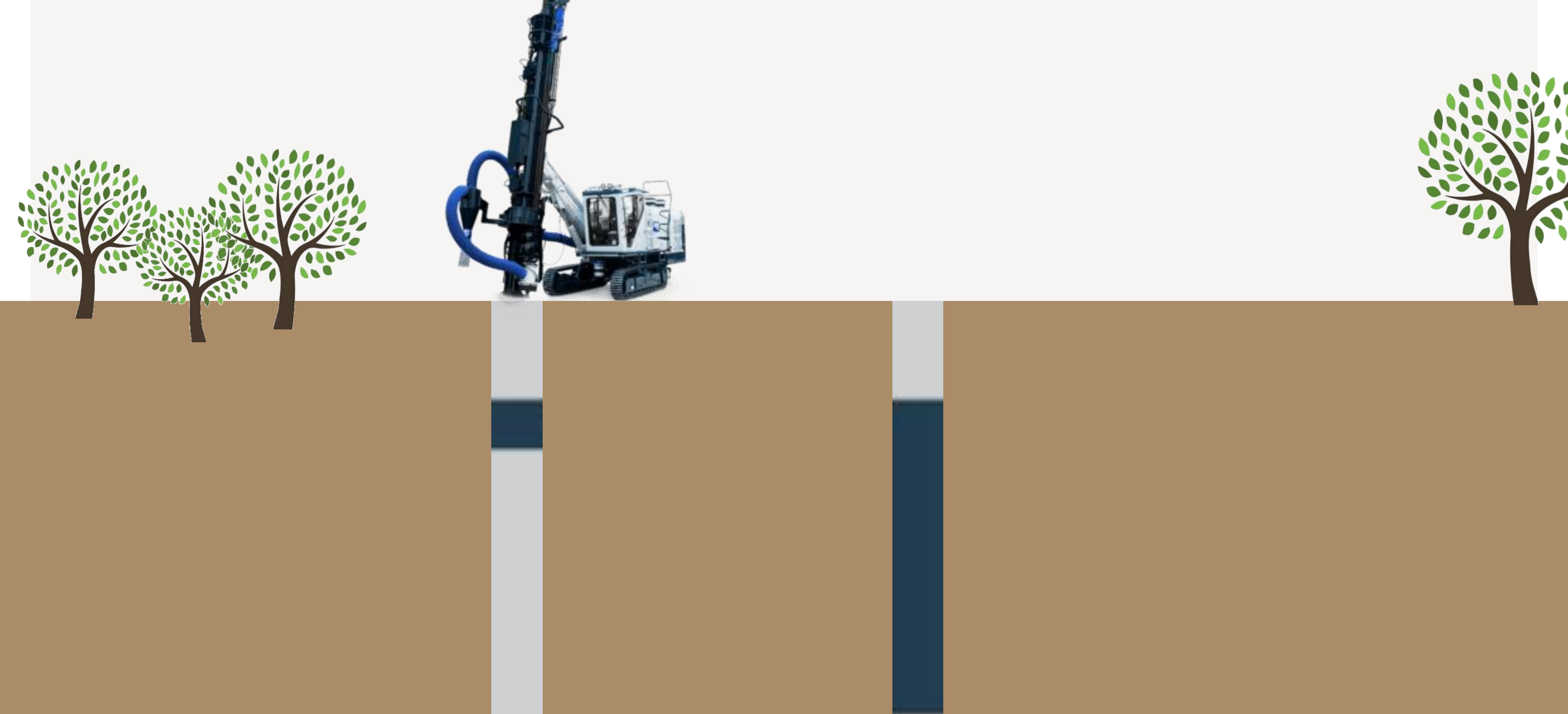

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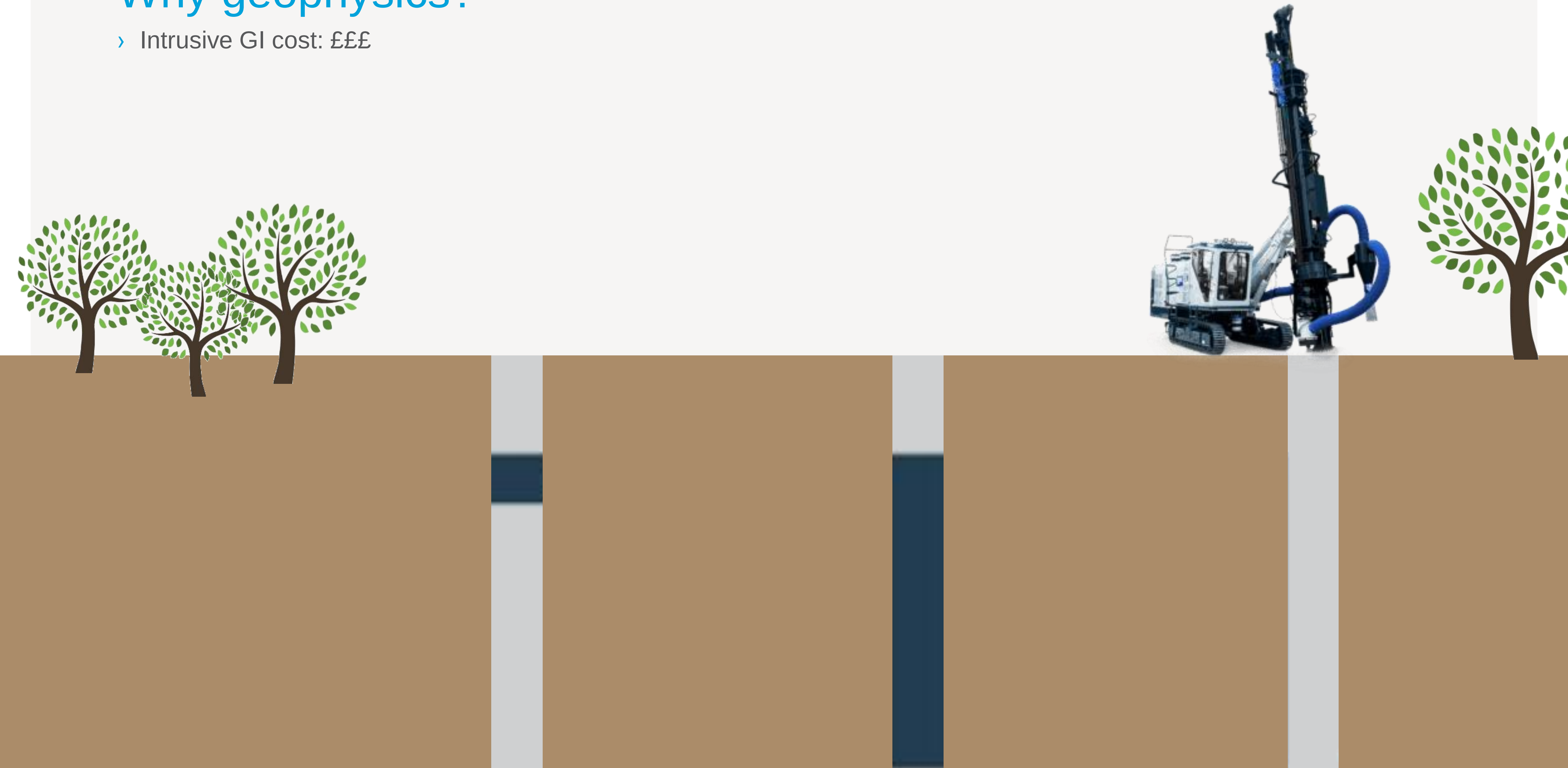

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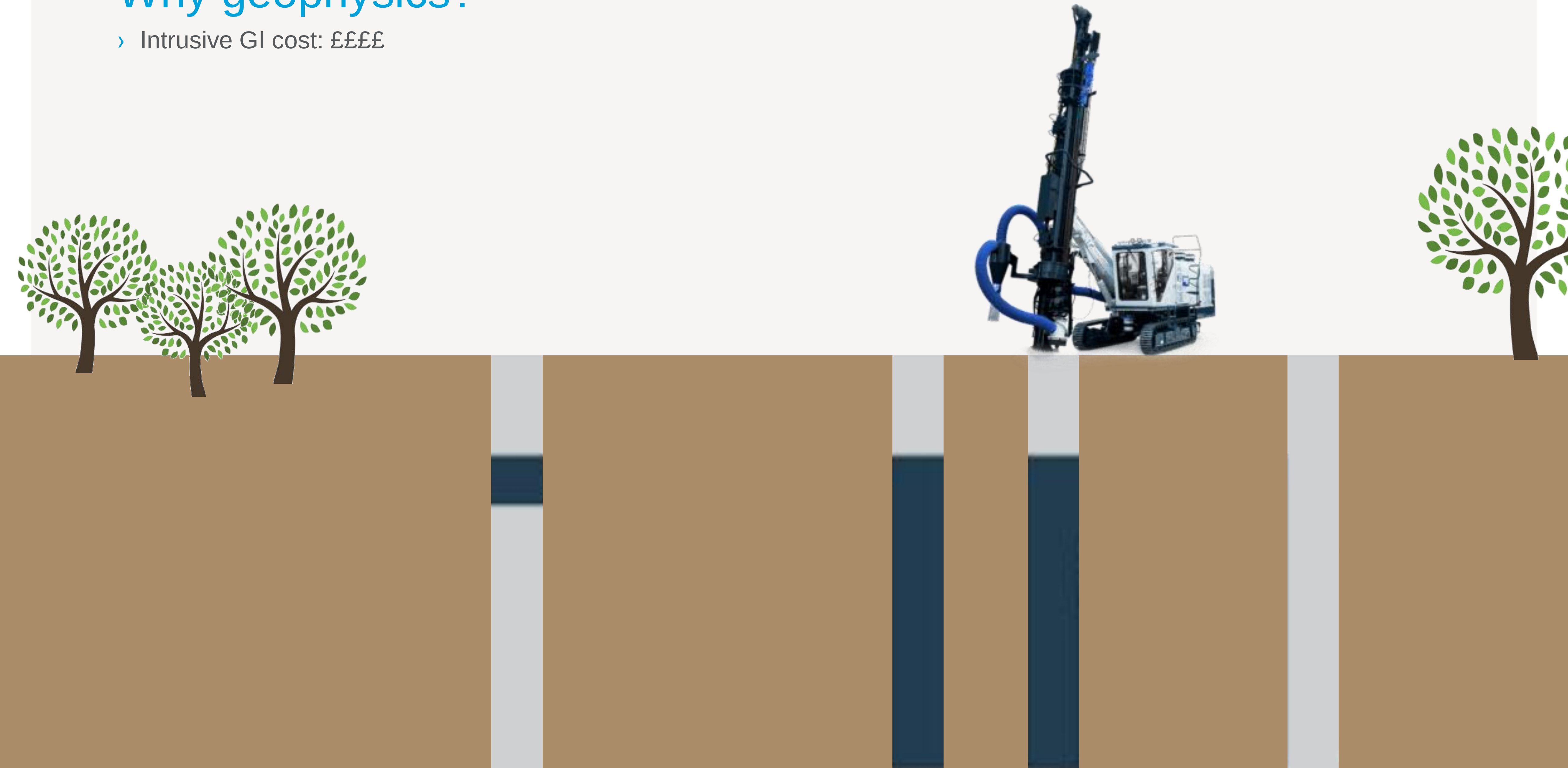

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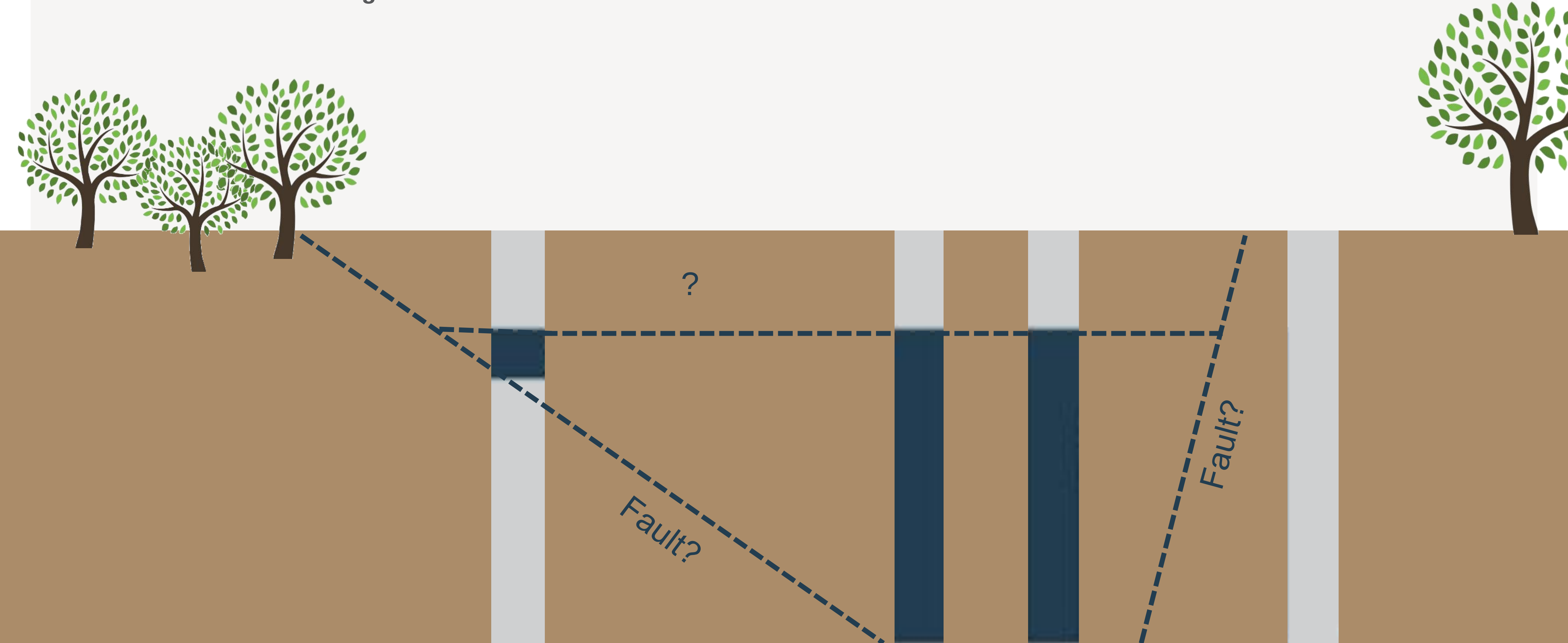

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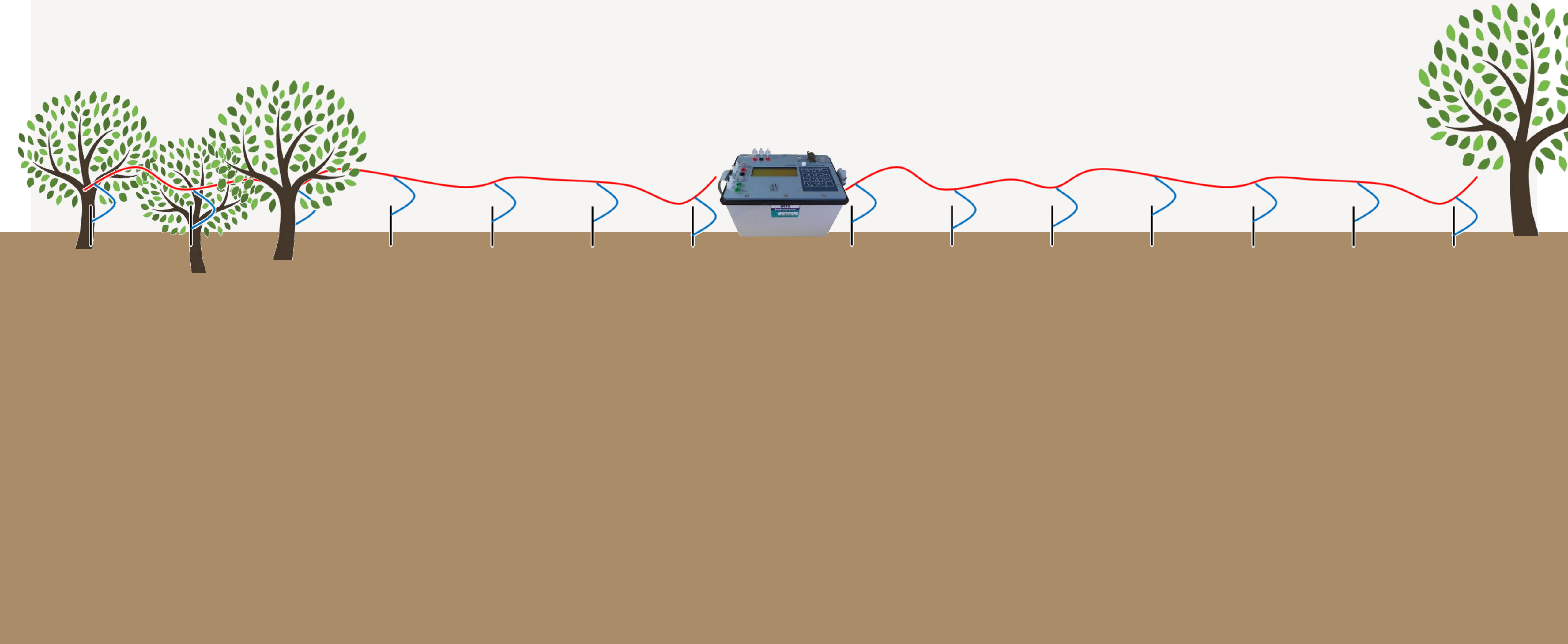
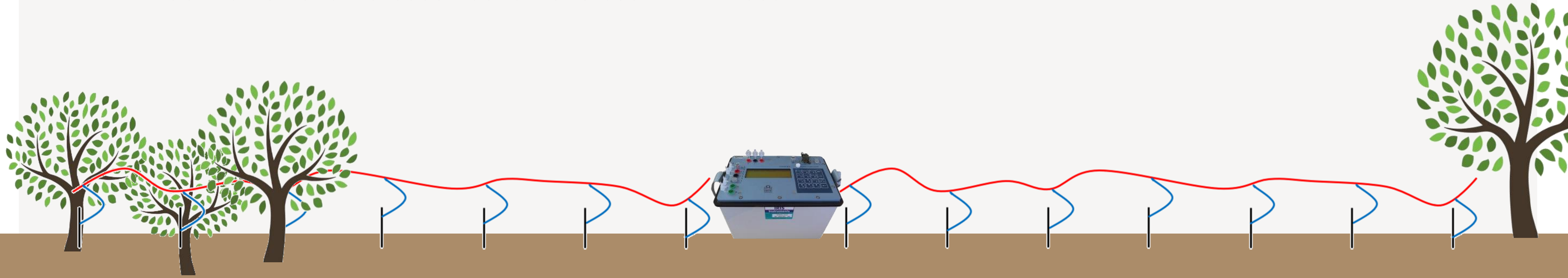


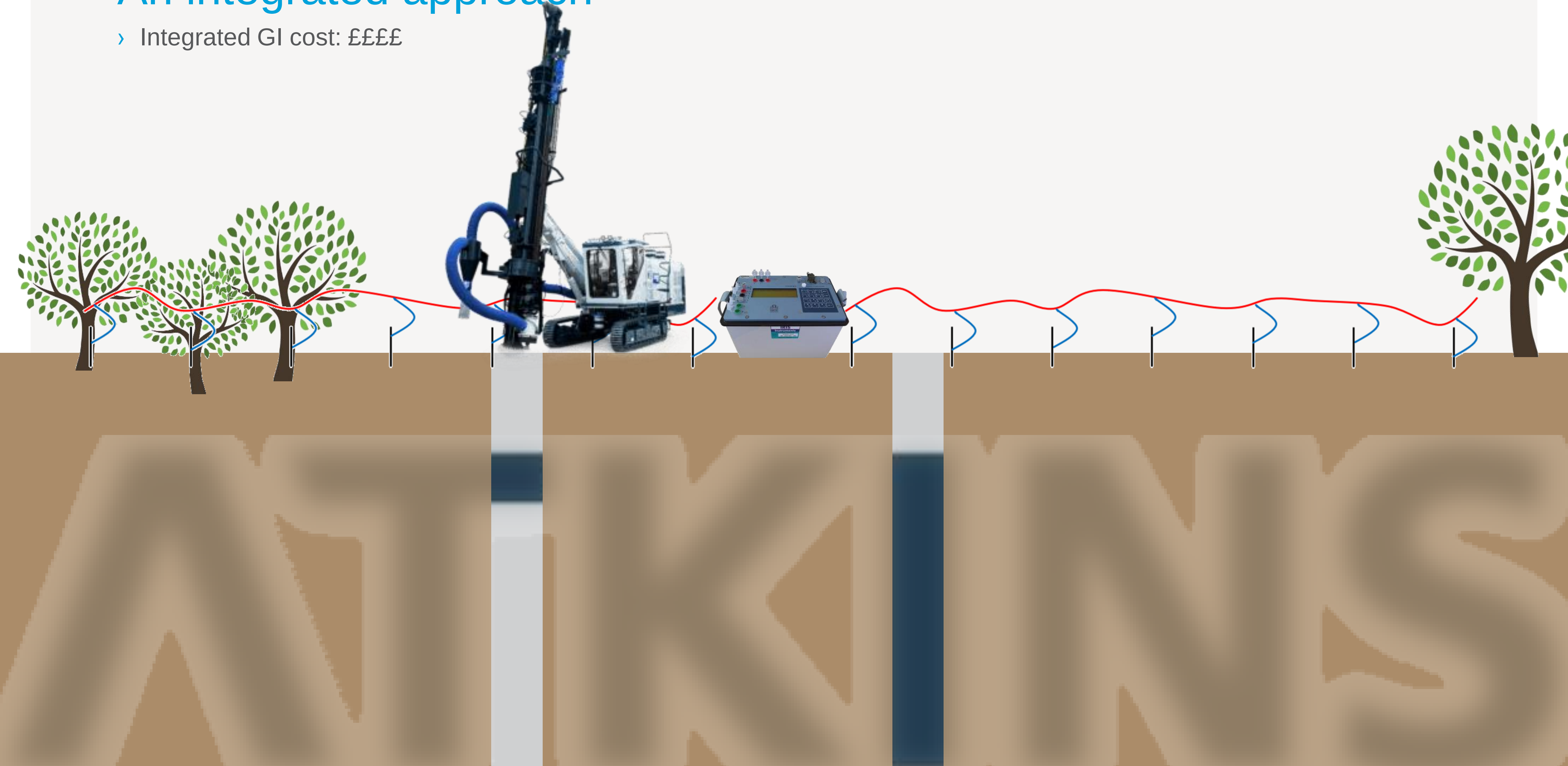
Why geophysics?

- Non-intrusive GI cost: ££
  - **Have we fully characterised the ground?**
  - **Has the risk of unforeseen conditions been minimised?**



An integrated approach

- Integrated GI cost: ££££



What is geophysics?

- Geophysical surveys involve **the measurements of signals**, either artificially generated or naturally occurring, that tell us something about a property in the ground

- Benefits include:
  - **Non-intrusive**
  - **Inexpensive** - compared to trying to achieve the same coverage with intrusive GI
  - **Multi-dimensional** – data can be acquired, processed and visualised in two-, three- and four-dimensions

- Limitations:
  - Most methods have **limitations on their depth** of investigation or have decreasing resolution with depth
  - They require a **measurable contrast** in some property of the ground – no contrast = no detection
  - The signals we measure are **rarely direct measurements** of the thing we actually want to know
  - Geophysical signals can be **sensitive to more than one property** in the ground
  - Measurements are **subject to errors**, and require careful processing and interpretation by a geophysicist
  - Often the measurements we make needs to be ‘inverted’ (i.e., a process opposite to forward modelling) to produce **a model of the property** we have measured – inversion is an ‘ill-posed problem’ (math term) with a ‘non-unique solution’

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Long

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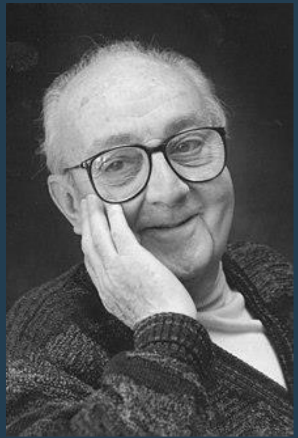

*“... all models are approximations. Essentially, **all models are wrong, but some are useful.** However, the approximate nature of the model must always be borne in mind....”*

- George E. P. Box

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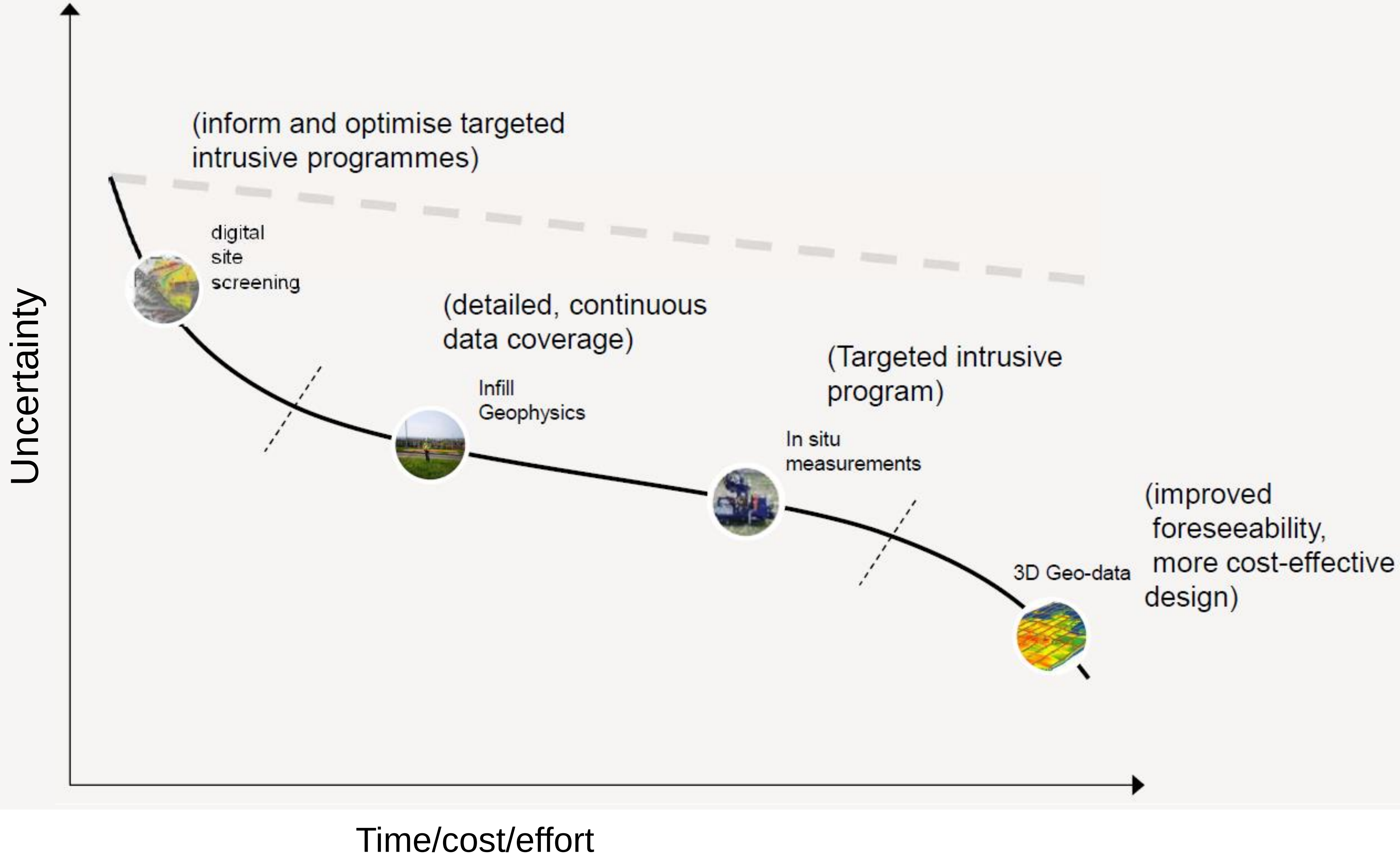
Why geophysics (again)?



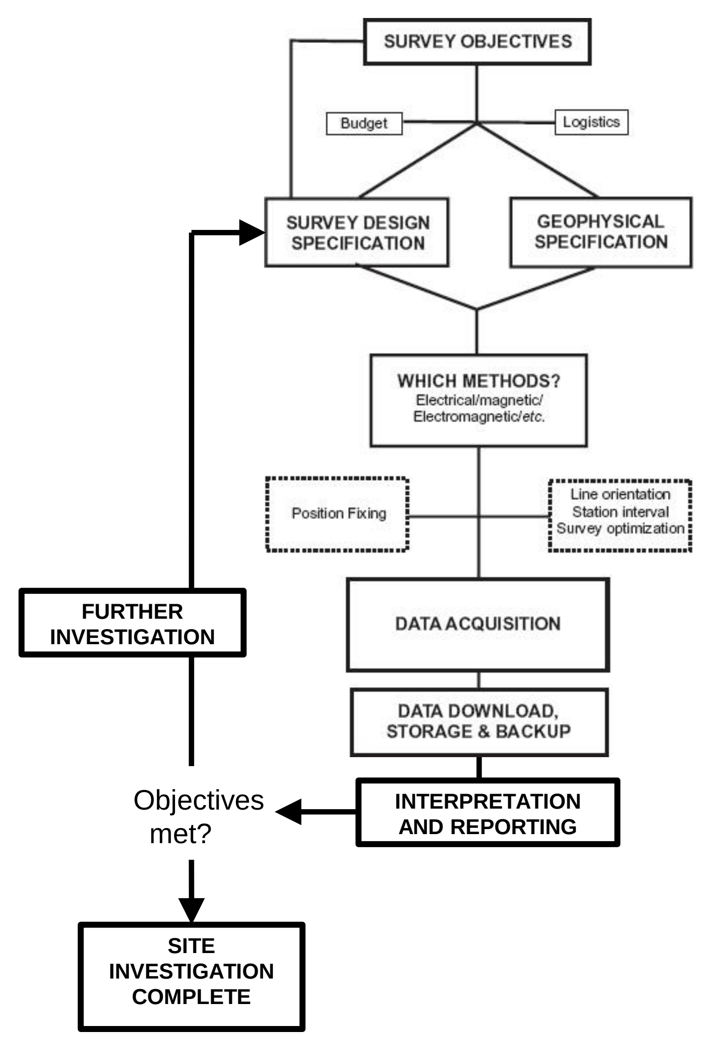
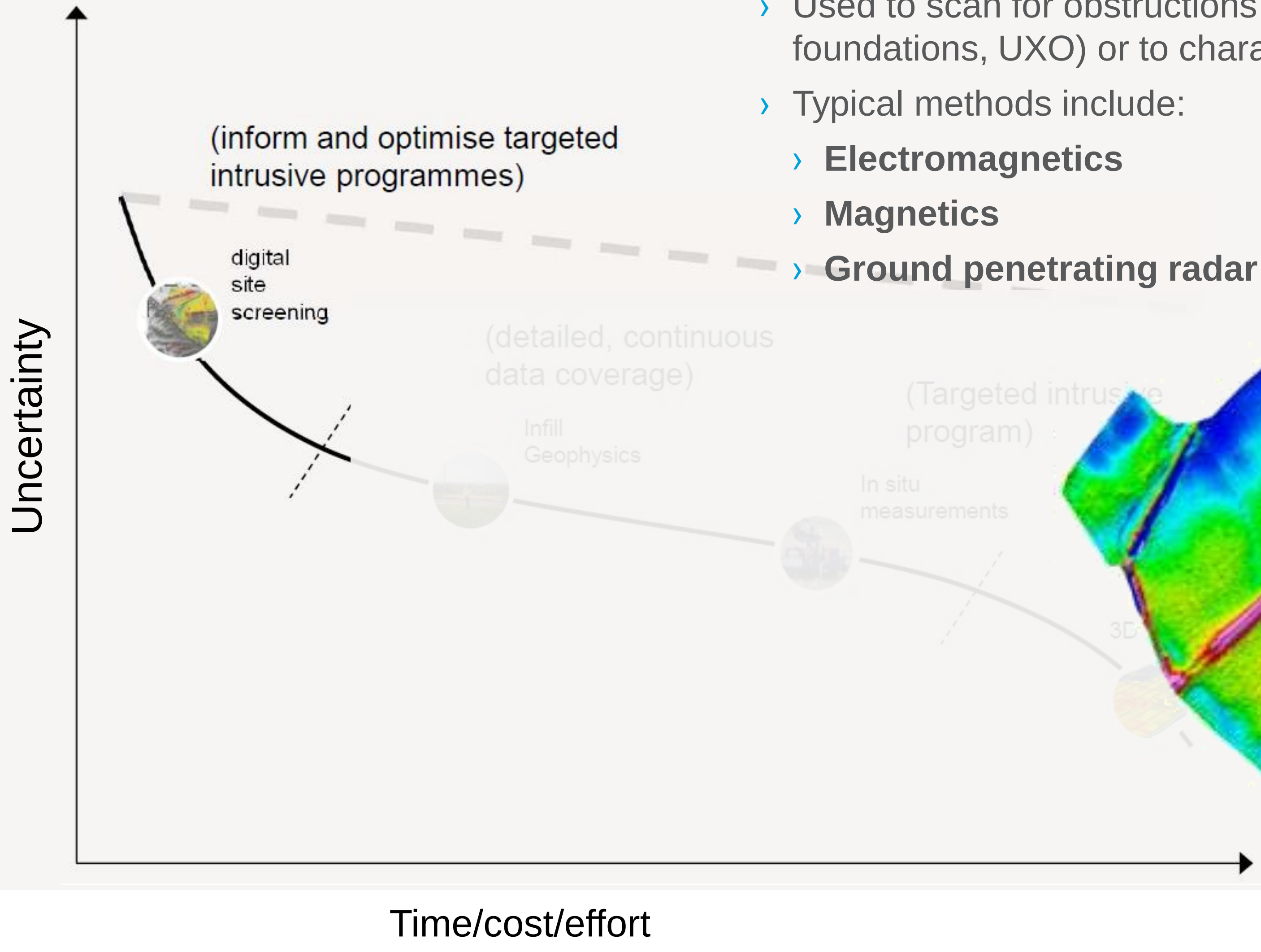


Image from Rod Eddies / Ed Cox

Digital site screening

- Rapid, broad-scale that provide site-wide information, typically in the form of 2D maps
- Used to scan for obstructions (e.g., buried foundations, UXO) or to characterise site
- Typical methods include:
  - **Electromagnetics**
  - **Magnetics**
  - **Ground penetrating radar**



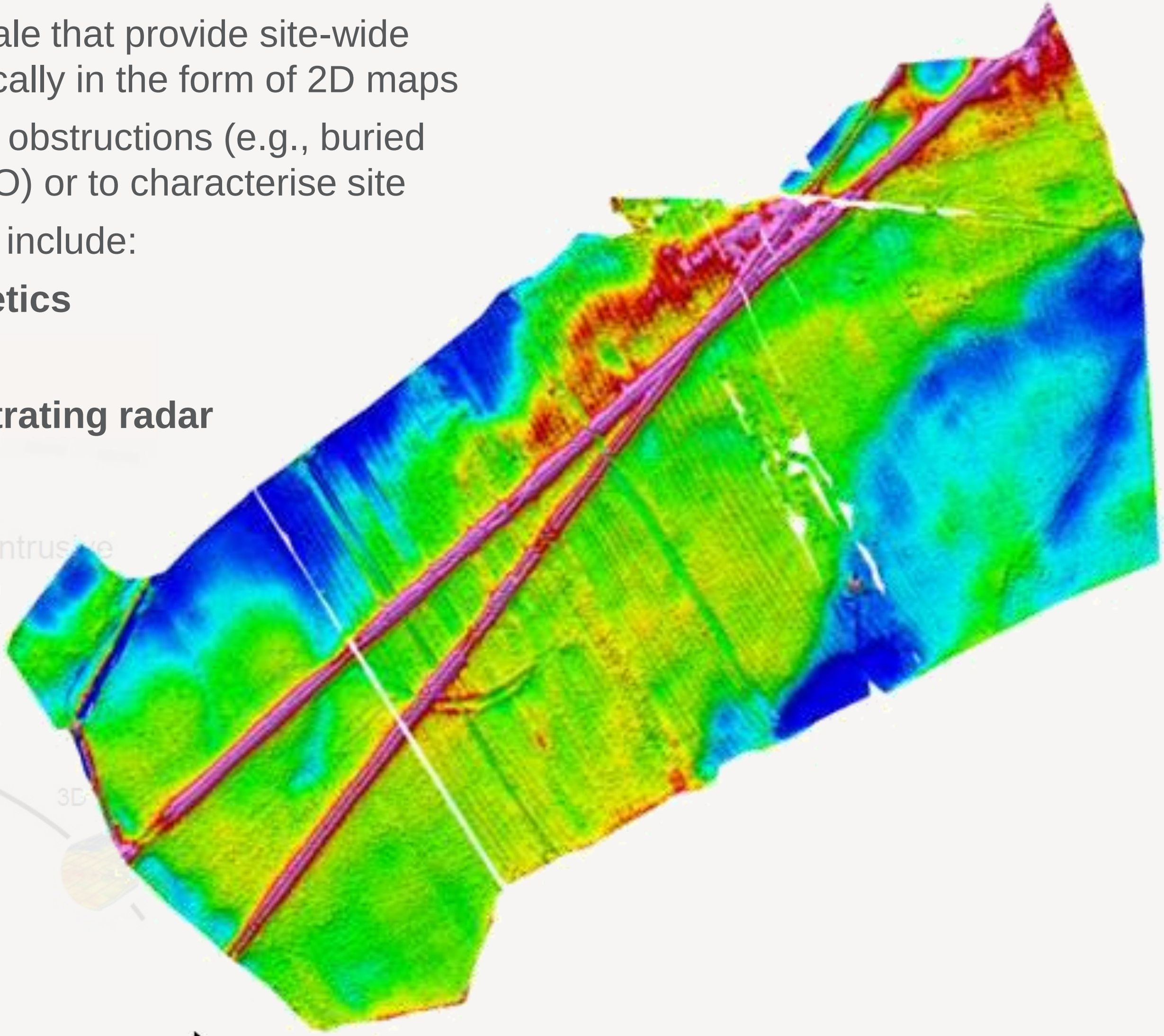
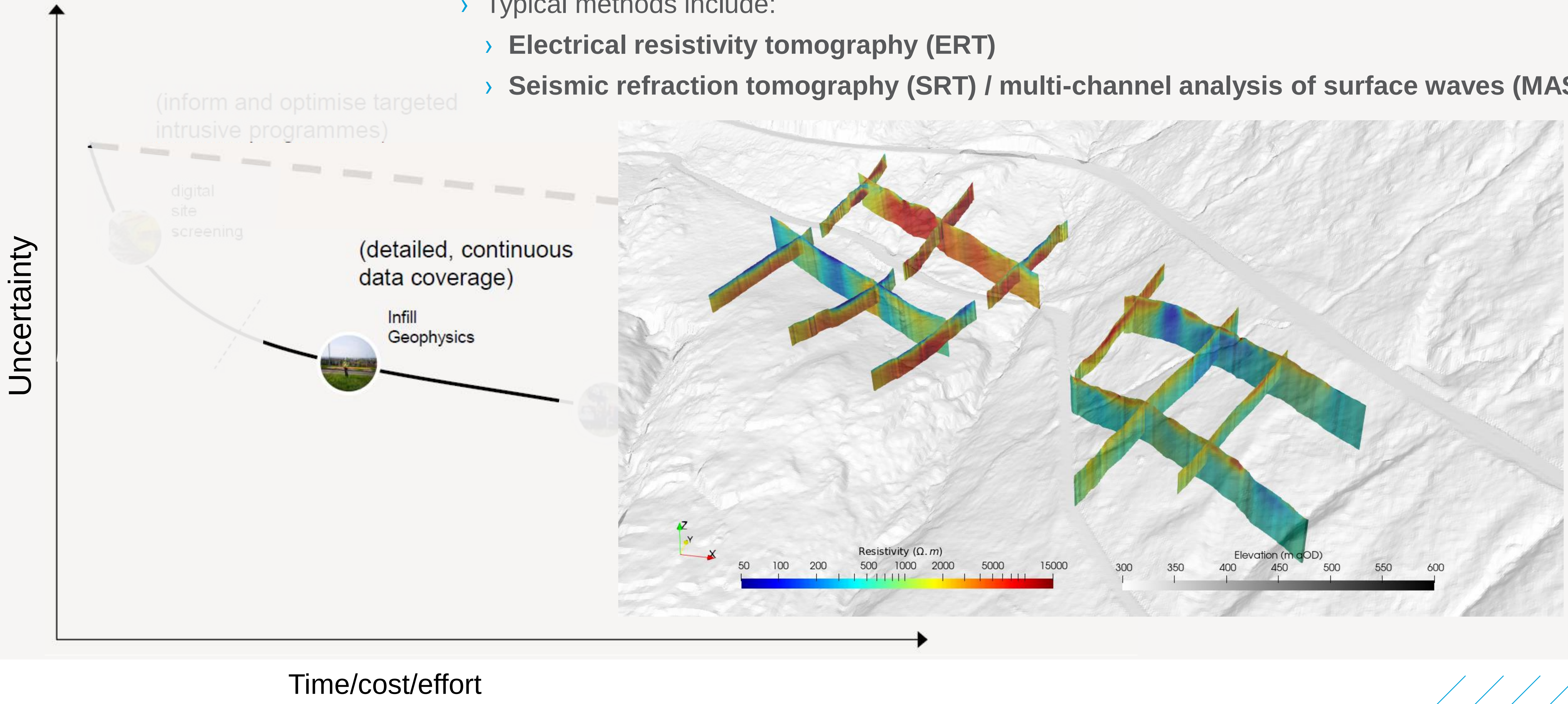


Image from Rod Eddies / Ed Cox

Infill geophysics

- More detailed, typically cross-section data between intrusive data or to provide depth information on geophysical anomalies from 2D maps
- Typical methods include:
  - **Electrical resistivity tomography (ERT)**
  - **Seismic refraction tomography (SRT) / multi-channel analysis of surface waves (MASW)**



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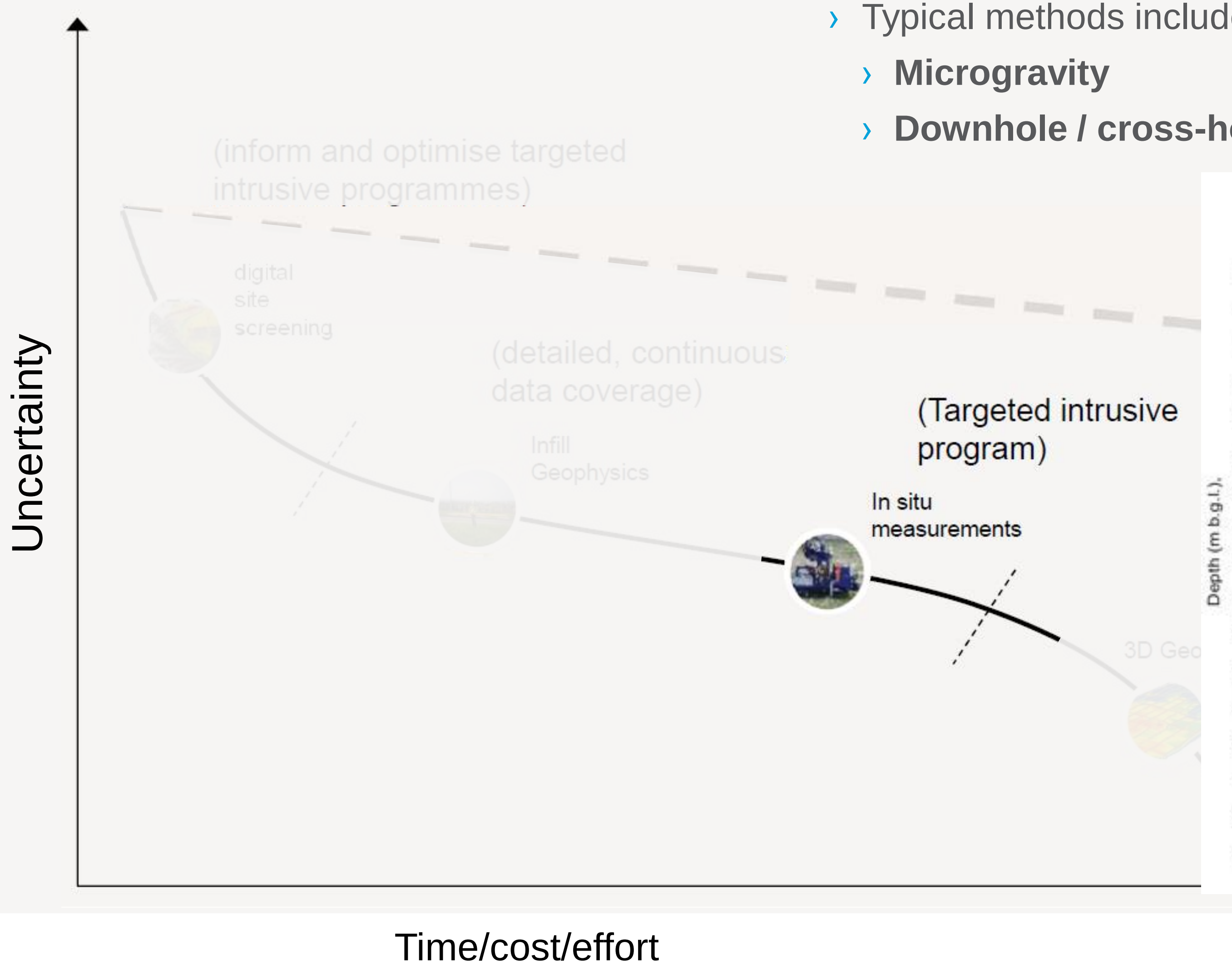
In situ measurements

- Surveys designed to measure a specific response or estimate an engineering property
- Typical methods include:
  - **Microgravity**
  - **Downhole / cross-hole and wireline methods**



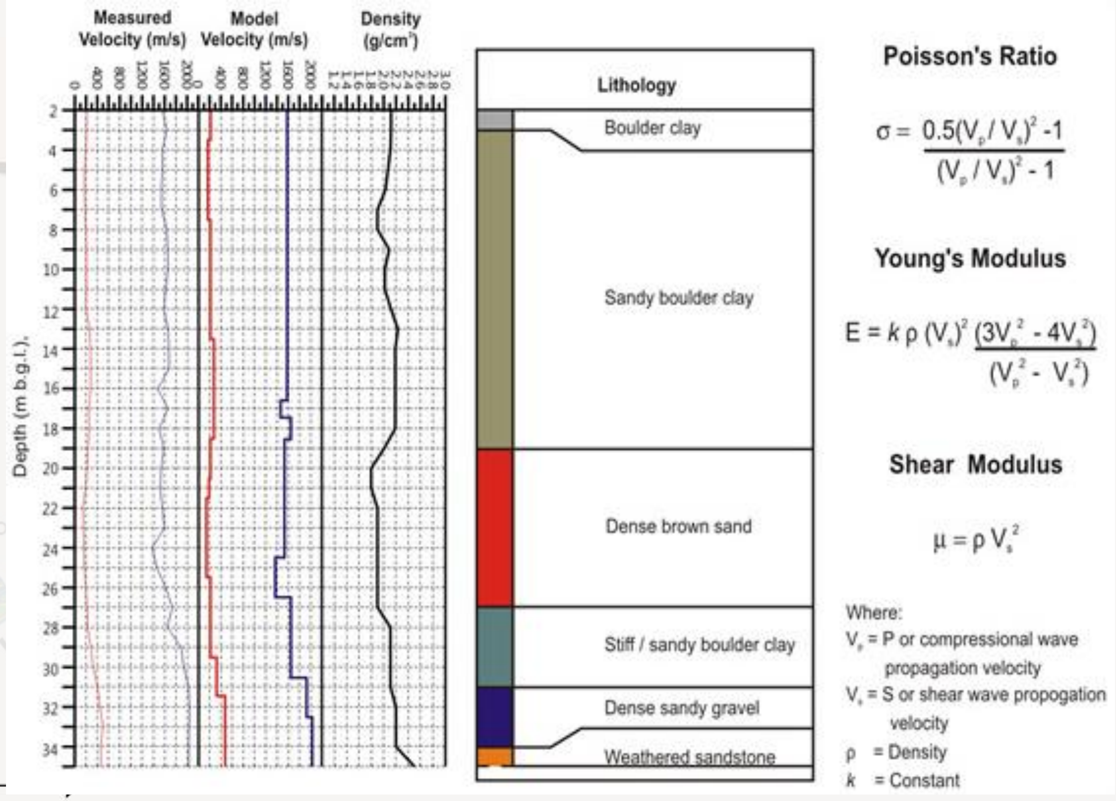


Image from Rod Eddies / Ed Cox

3D geo-data

- Surveys designed to characterise the ground in three- and four-dimensions
- Provide detailed site-wide information on engineering properties
- Better integration with 3D modelling environments
- Can be applied to any tomographic methods with correct survey specification and processing

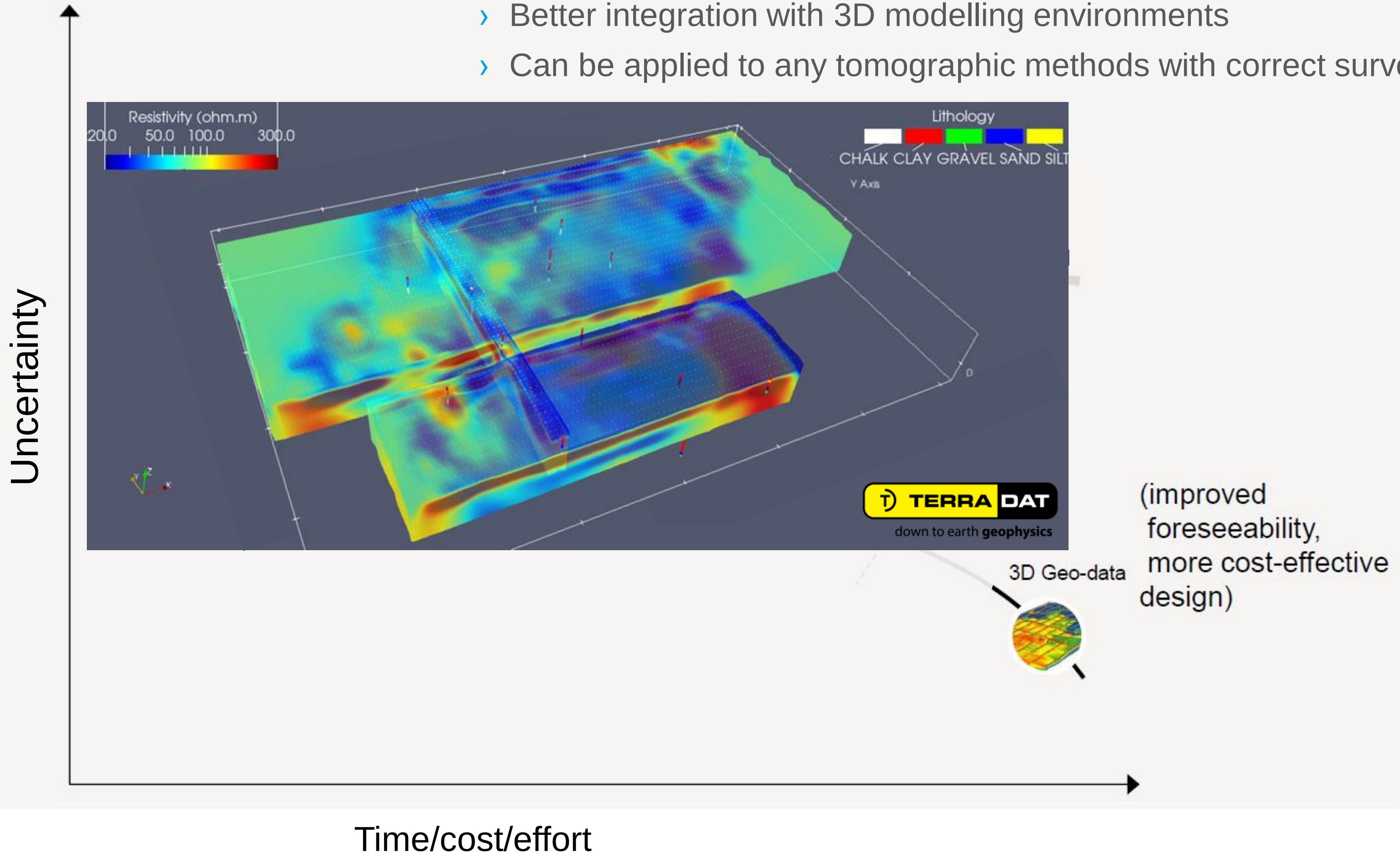


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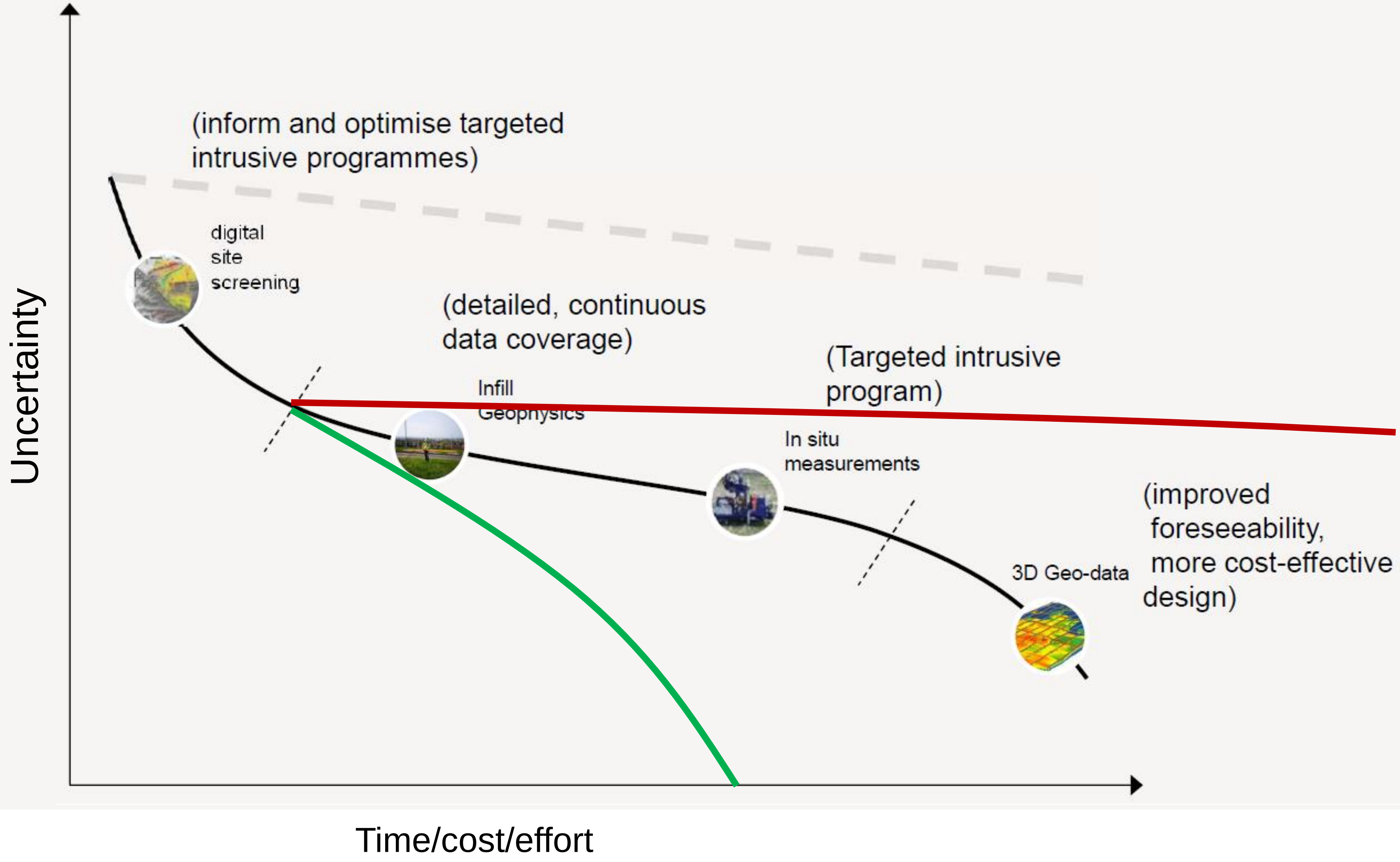
Image from Rod Eddies / Ed Cox

Why does Atkins have geophysicists?



Bad geophysics:

- Poorly specified
- Unsuitable or unnecessary method(s)
- Poor processing and unsuitable visualisation
- Interpretation with no additional context
- No digital integration (images of data only)

Good geophysics:

- Appropriate specification
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- Integration with digital ground model

Image from Rod Eddies / Ed Cox

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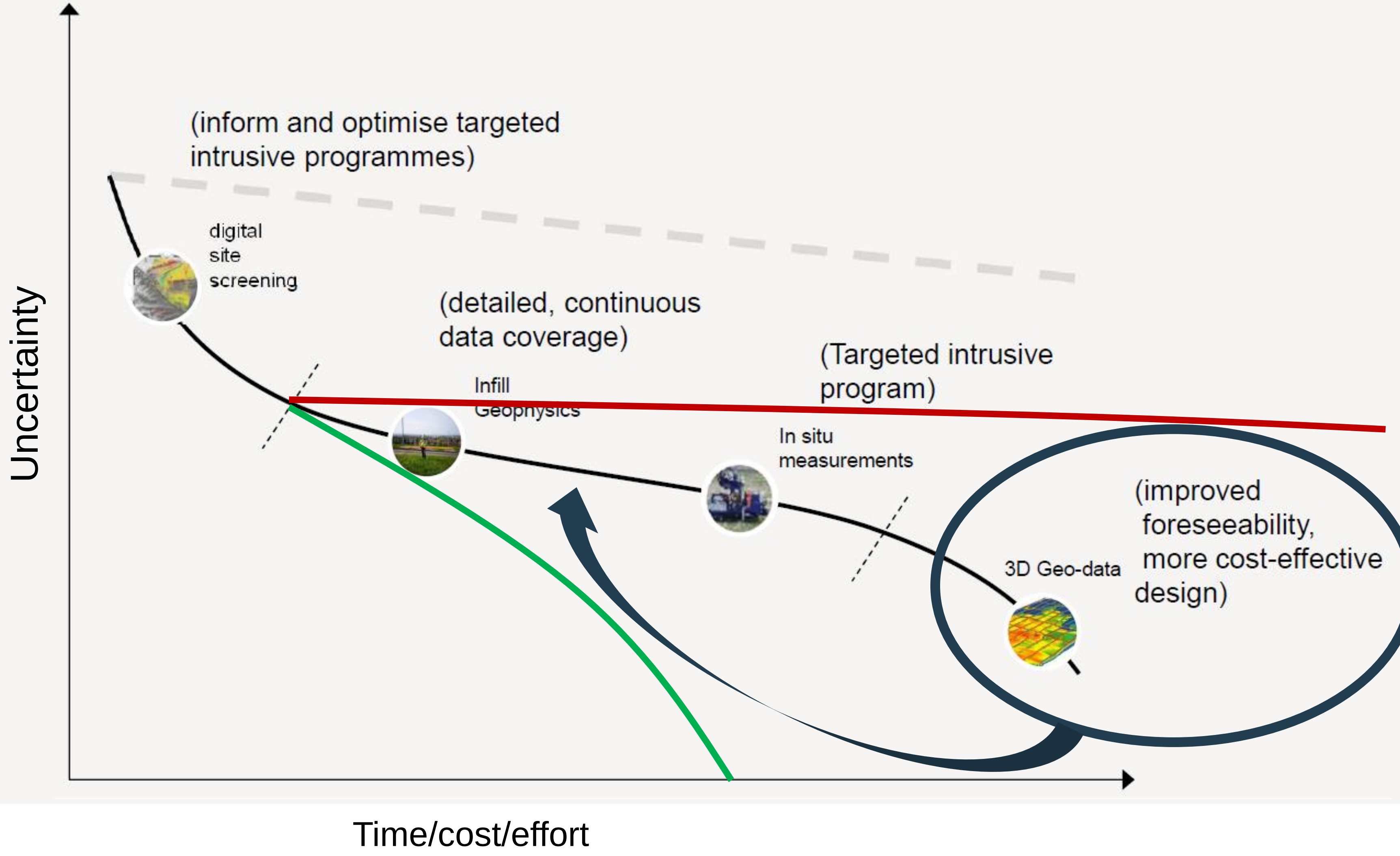

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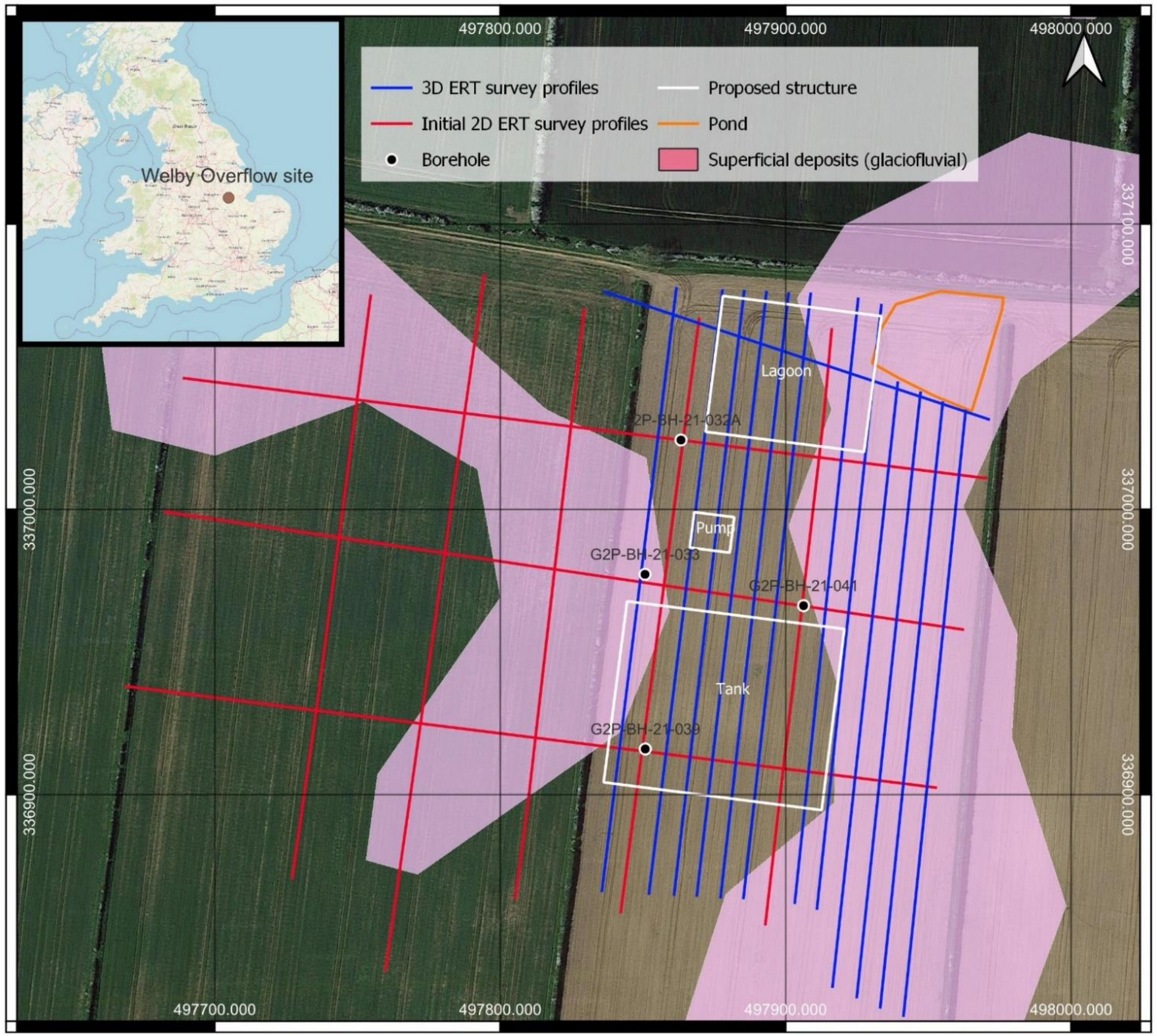
Case Study: Welby Tank 3D Resistivity Survey

Welby Tank 3D Resistivity Survey

- Welby tank the largest of two tanks built by Strategic Pipeline Alliance (Anglian Water)

- Hazards in Jurassic limestone:
  - Karst: dissolution, sinkholes, voids
  - Eroded bedrock: Glaciofluvial erosion and associated infill with clay-rich materials

- A multi-phase, multi-method approach to GI:
  - Phase 1: Reconnaissance geophysical survey
  - Phase 2: Intrusive ground investigation
  - Phase 3: 3D resistivity survey
  - Phase 4: Intrusive ground investigation



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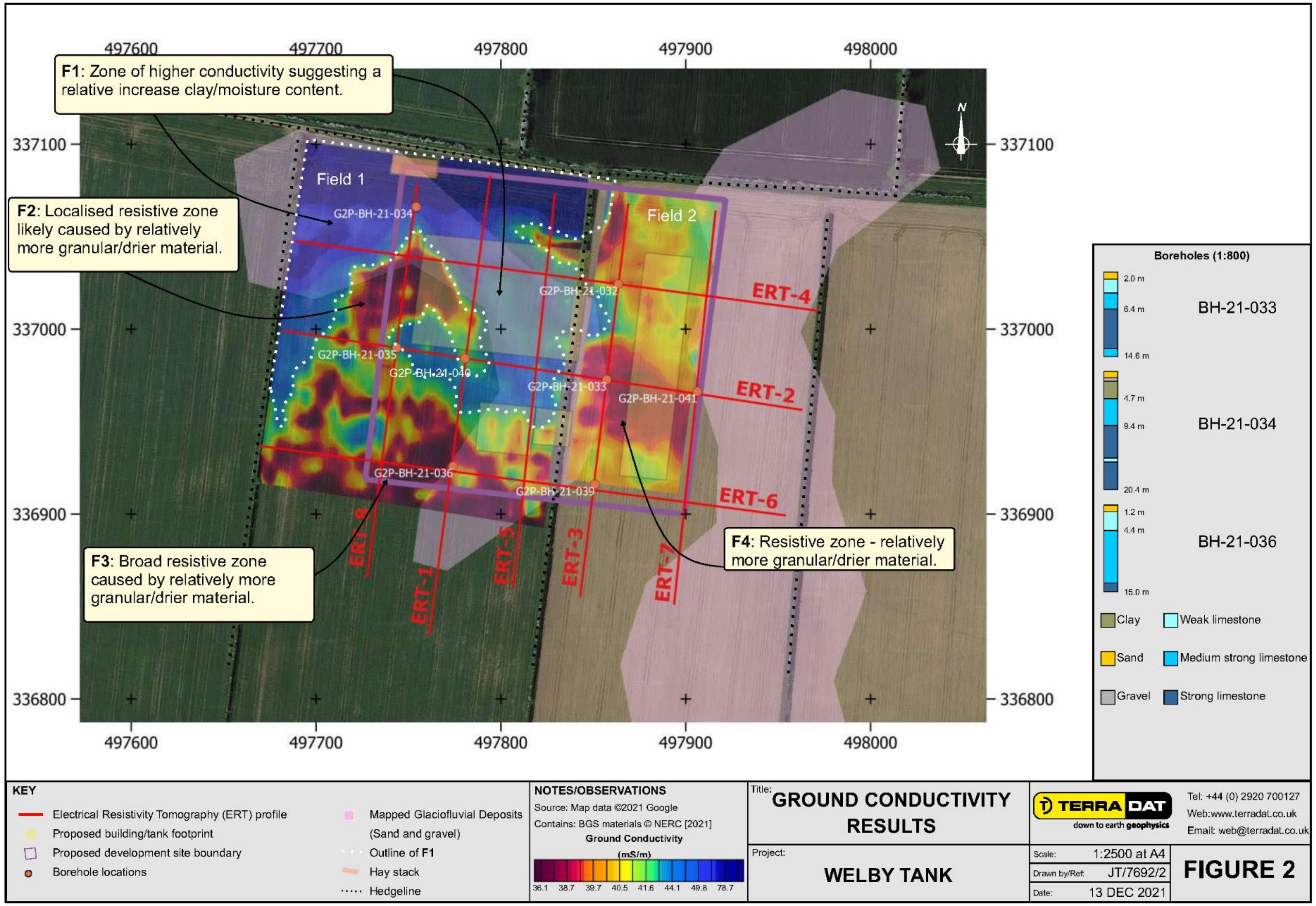
Phase 1: Reconnaissance geophysical survey

- Electromagnetic survey:
  - Mapped areas of shallow bedrock / clay-infill



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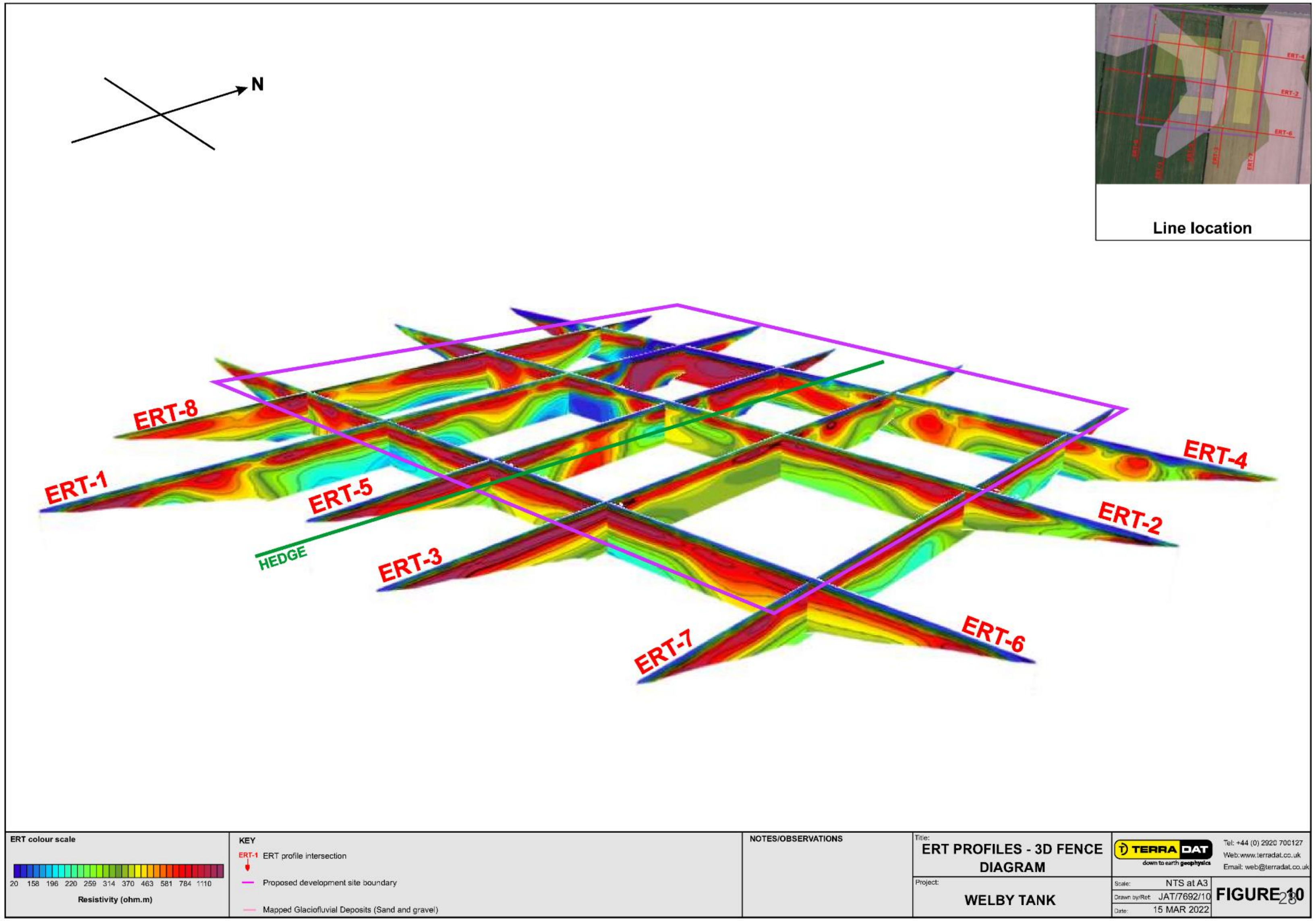
  - Thickness of superficial deposits
  - Dissolution?



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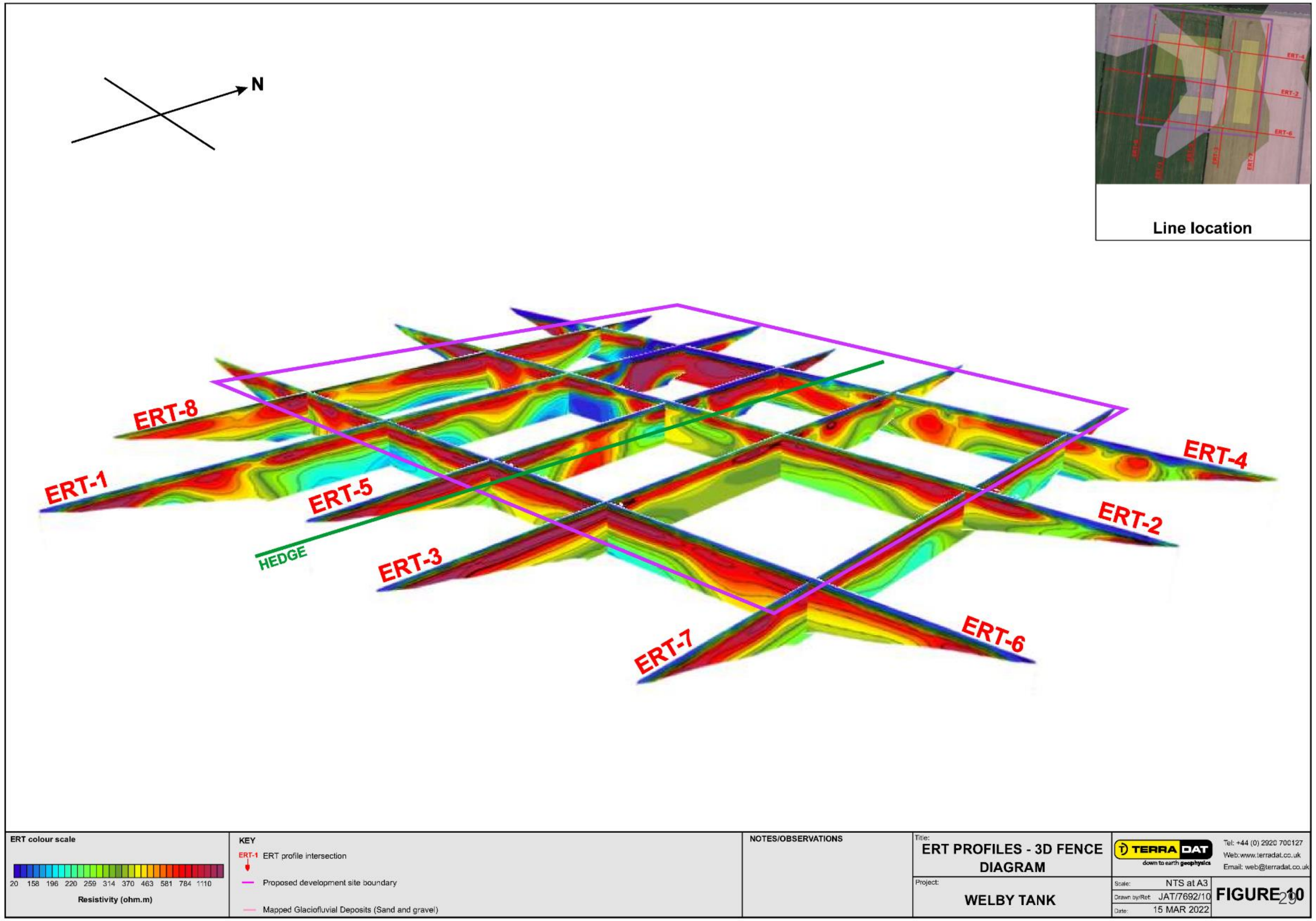

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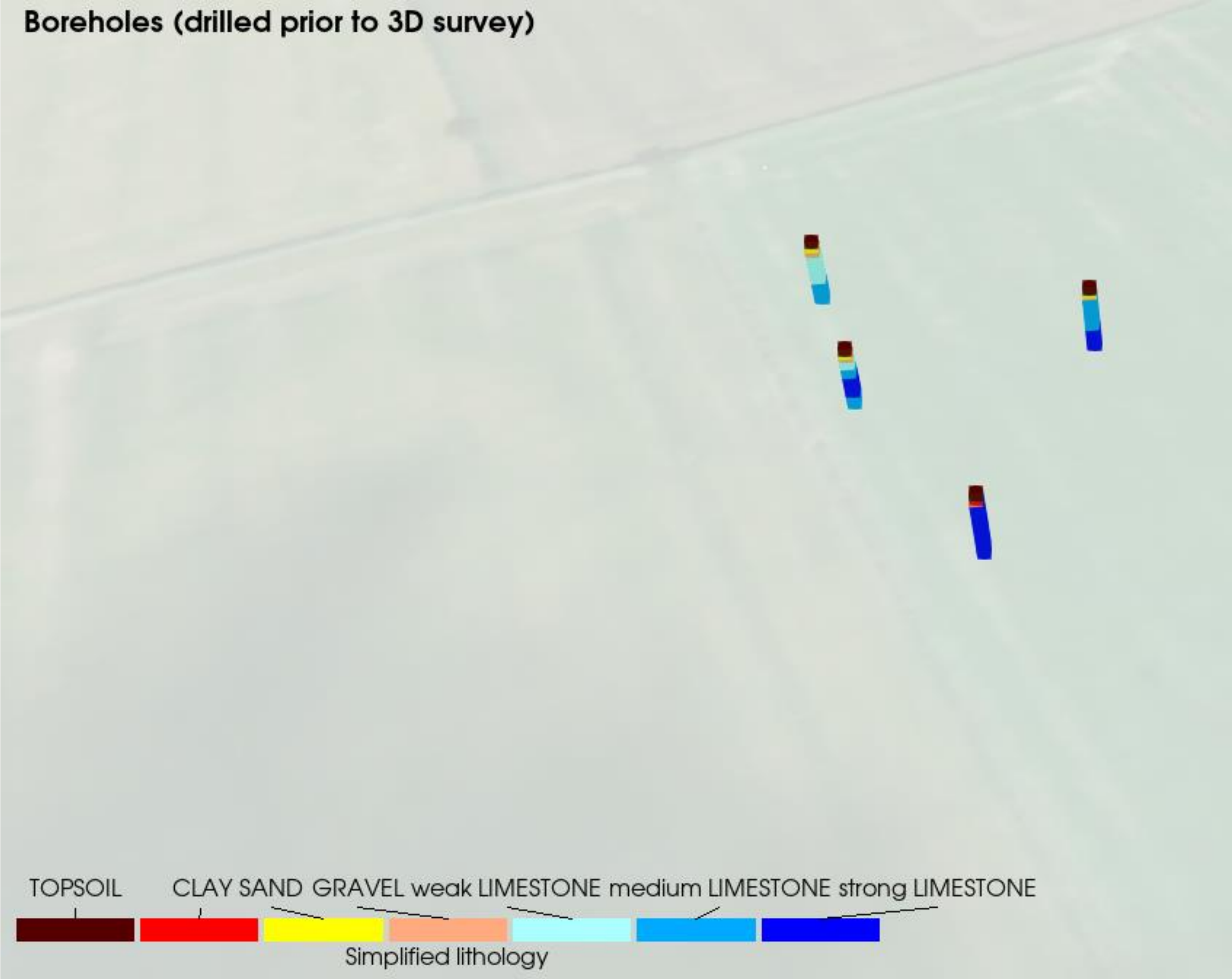
Phase 2: Intrusive GI

- Eight boreholes drilled (four within the revised footprint for development
  - Range of weak / medium / strong limestone logged
  - Strong limestone encountered in three boreholes – mostly good ground?



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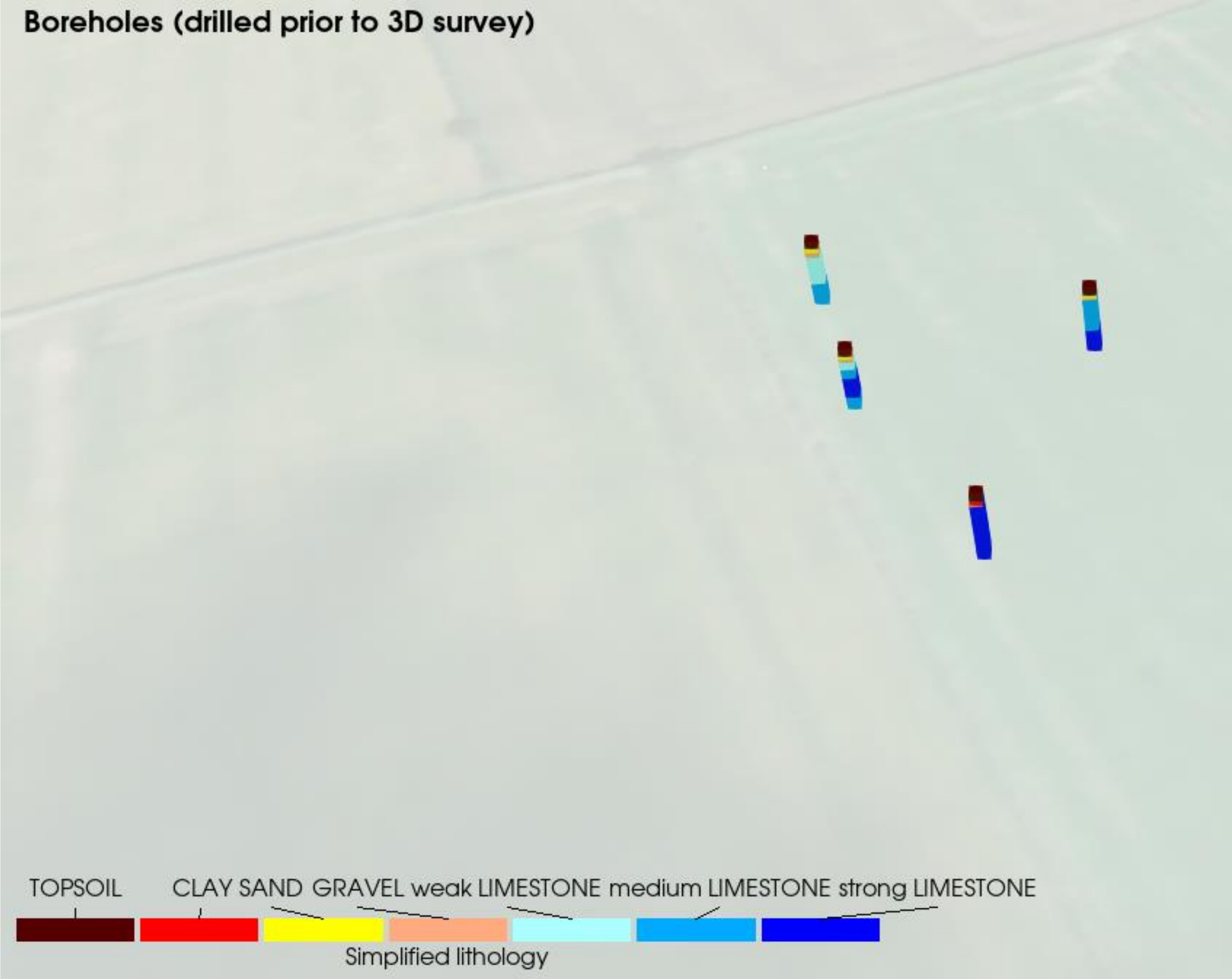

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- 15 ERT lines (2 from TerraDat recon. survey, reducing new acquisition by ~15%)
- ~8.5 m separated profiles (compared to 50 m separated profiles in TerraDat recon. survey)
- Four days in the field to collect, delivered in two weeks
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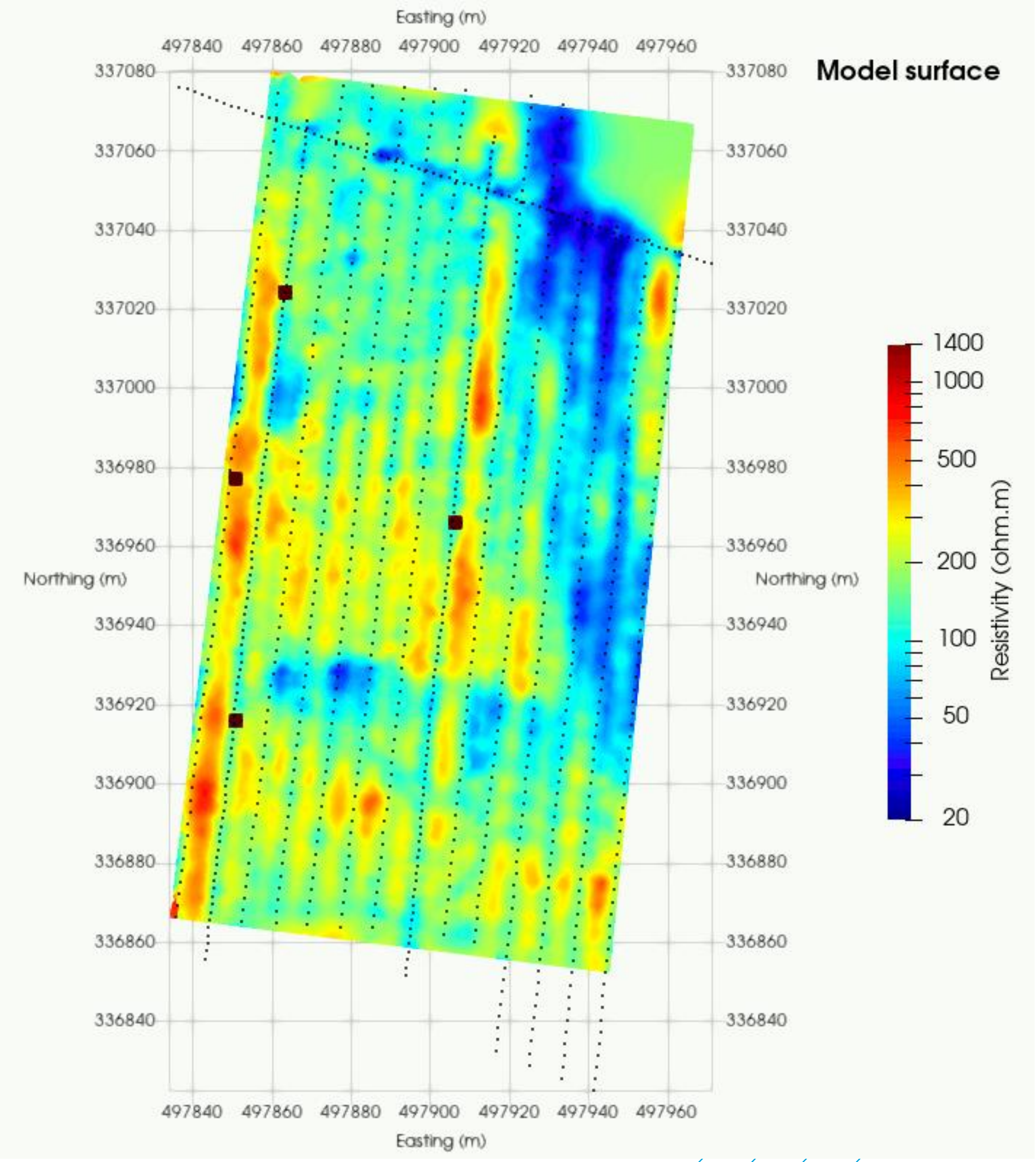

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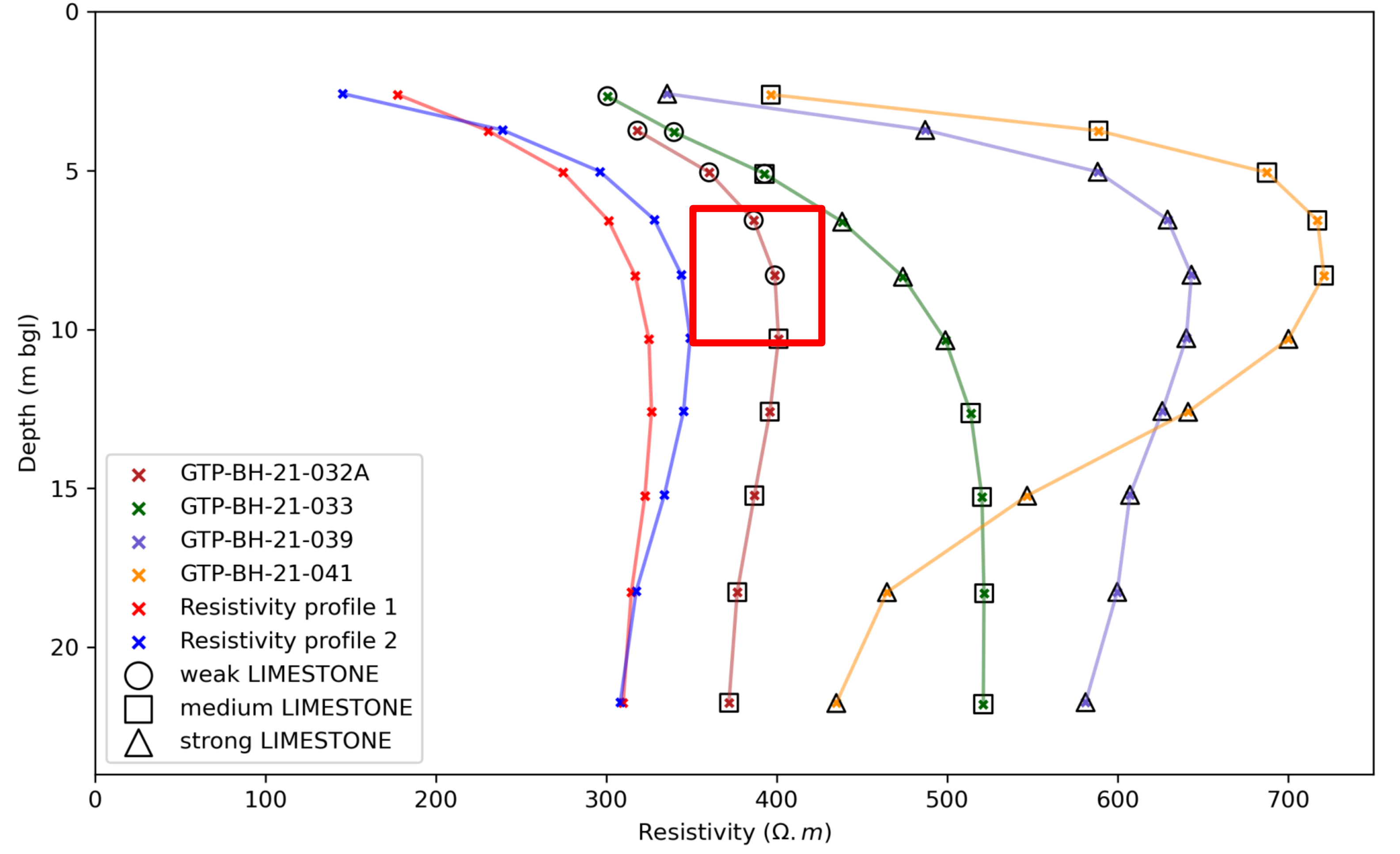
Phase 3: 3D geophysical survey – integrated analysis

- Analysis between intrusive GI and resistivity – depth relationships

- **Assumptions:**
  - Statistical significance between BH_032A and rest of site
  - If limestone between 6 m – 10 m bgl is weak, limestone above will also be weak (likely for dissolution, perhaps not for fracturing)



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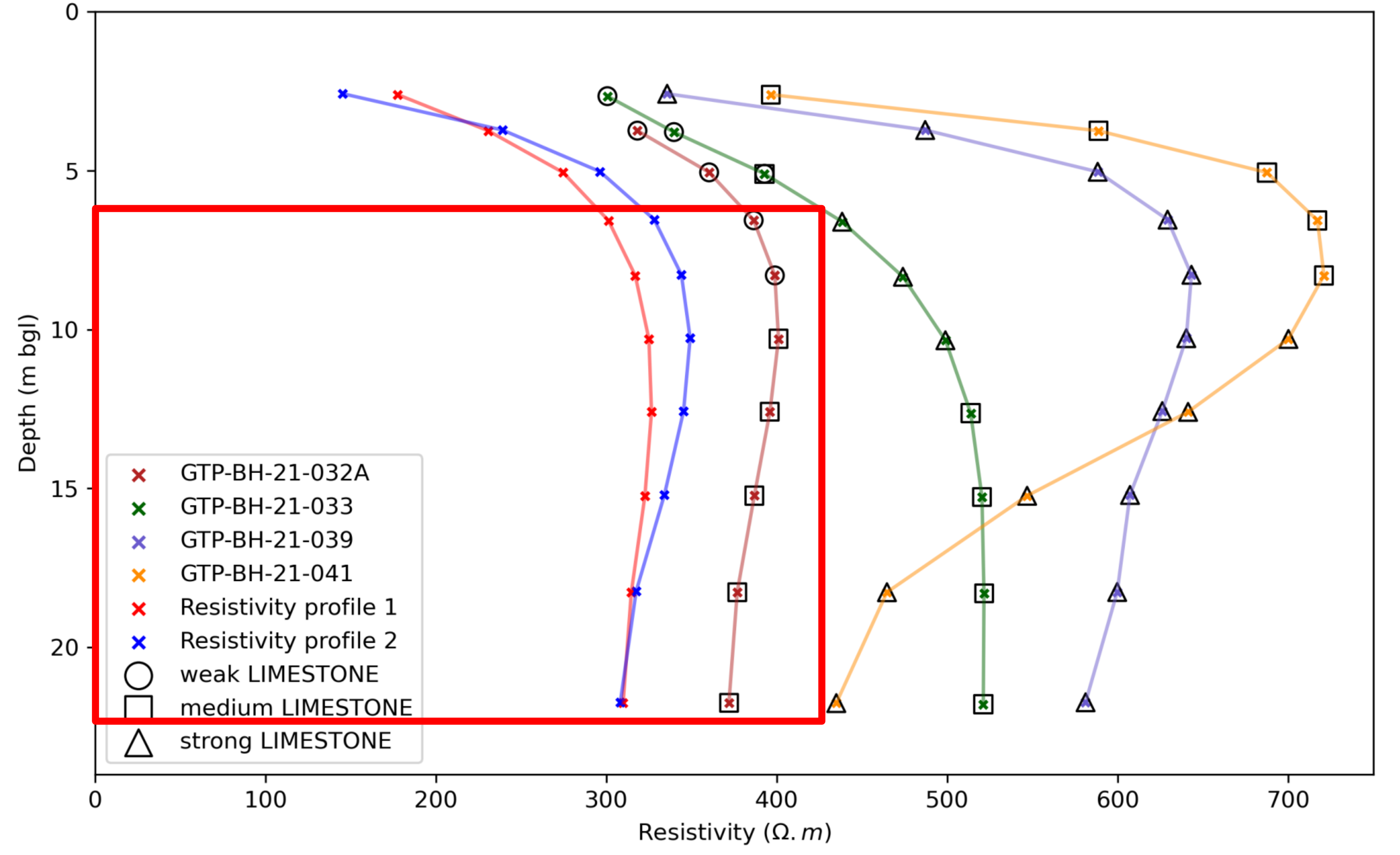

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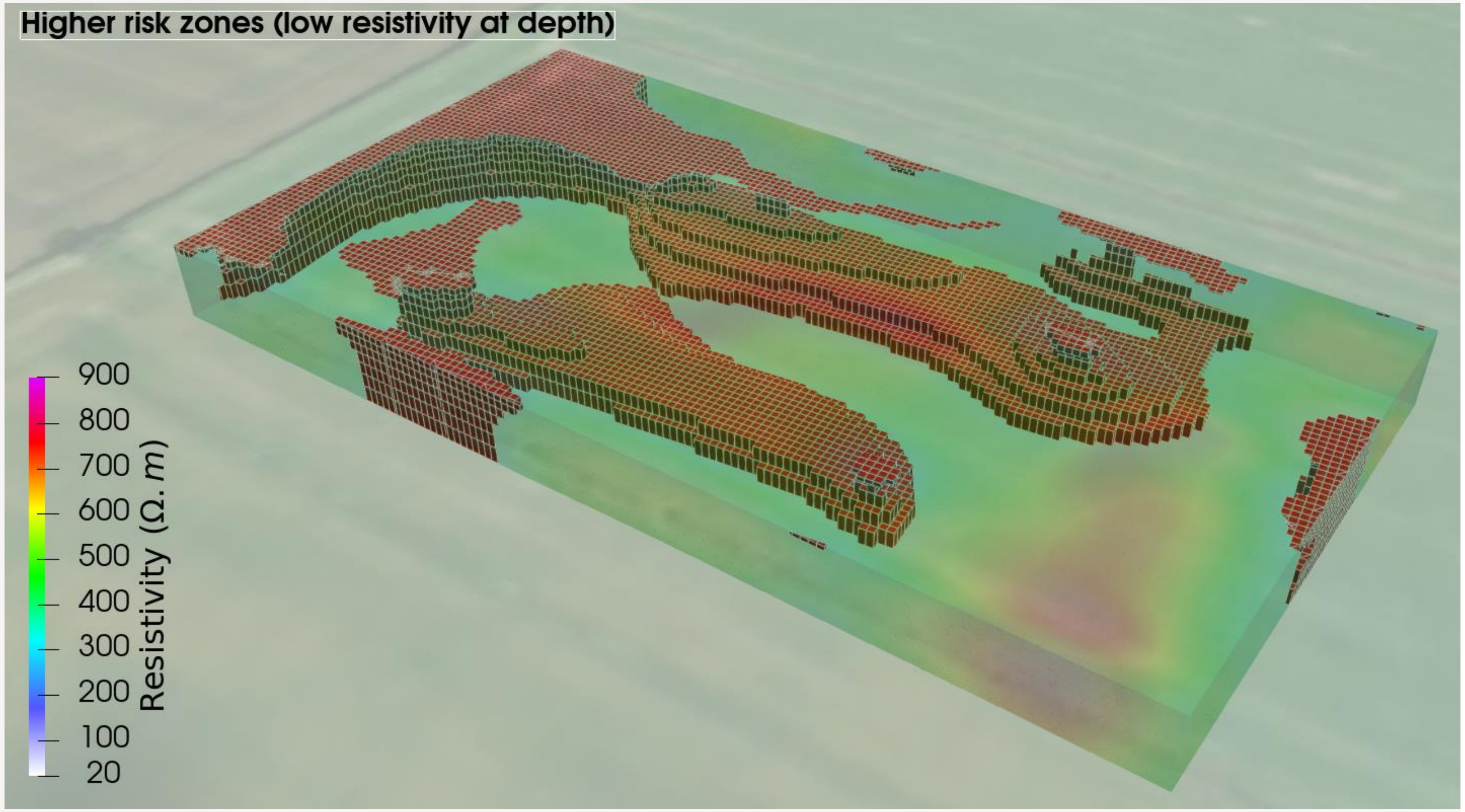

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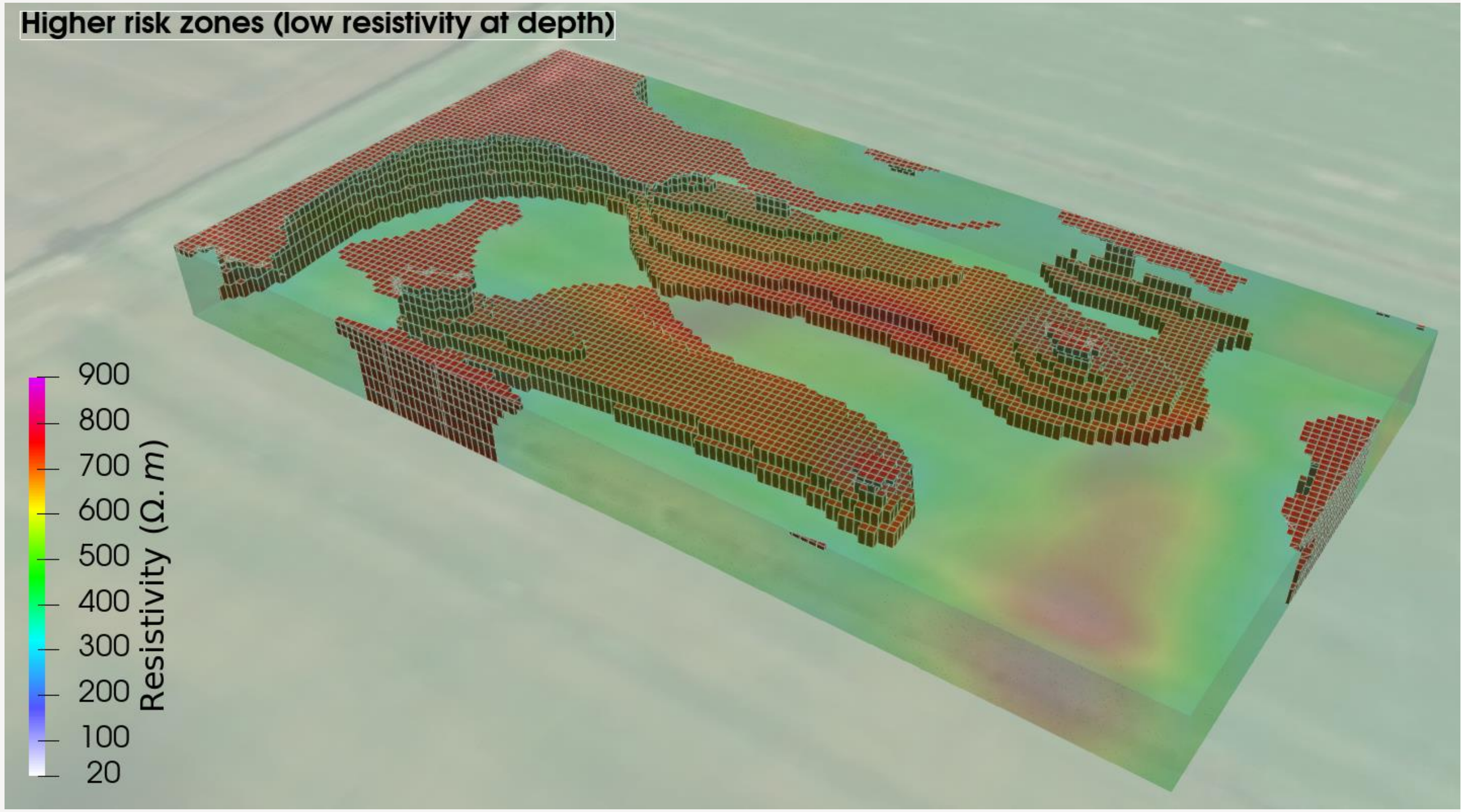

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TOPSOIL
CLAY
SAND
GRAVEL
weak LIMESTONE
medium LIMESTONE
strong LIMESTONE
Simplified lithology
Resistivity (Ω.m)
20 100 200 300 400 500 600 700 800 900

Data cost vs data value

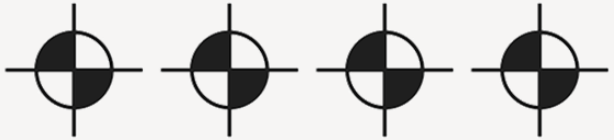
= cost of one borehole

Ground investigation

= ~1 m^3 of data

Data cost vs data value

 = cost of one borehole



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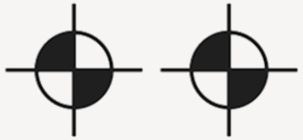

3D resistivity = ~500,000 m^3 of data

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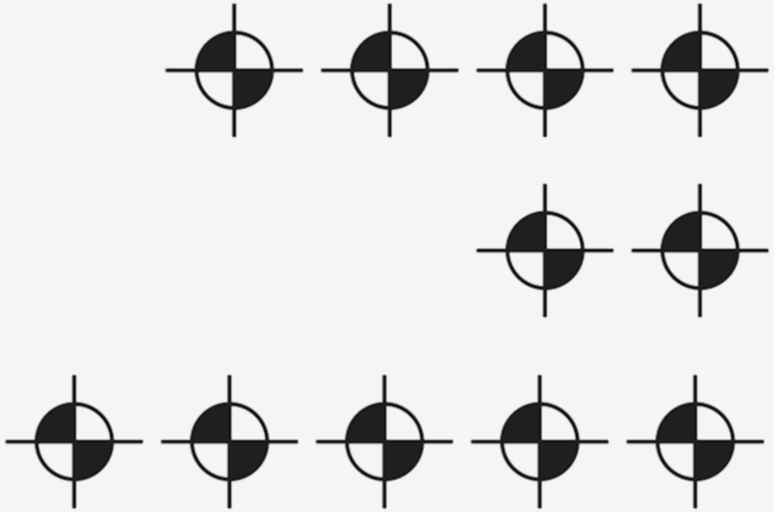

Ground investigation = ~1 m^3 of data

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(More) ground investigation = ~1.25 m^3 of data

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Data cost vs data value

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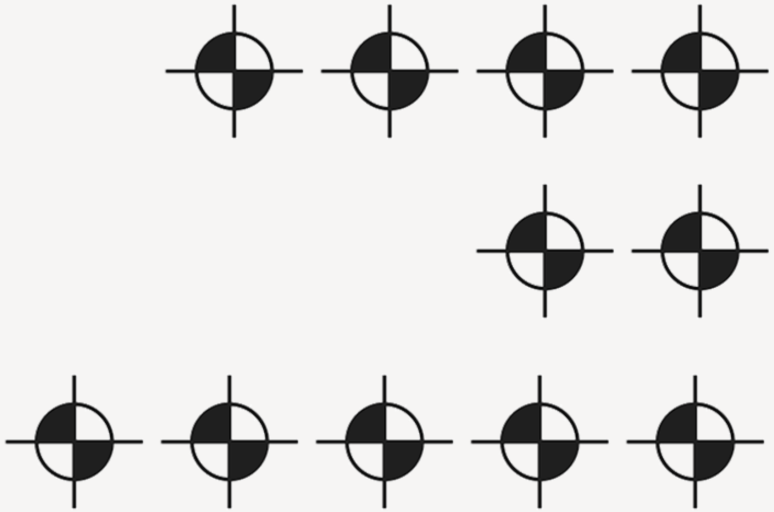

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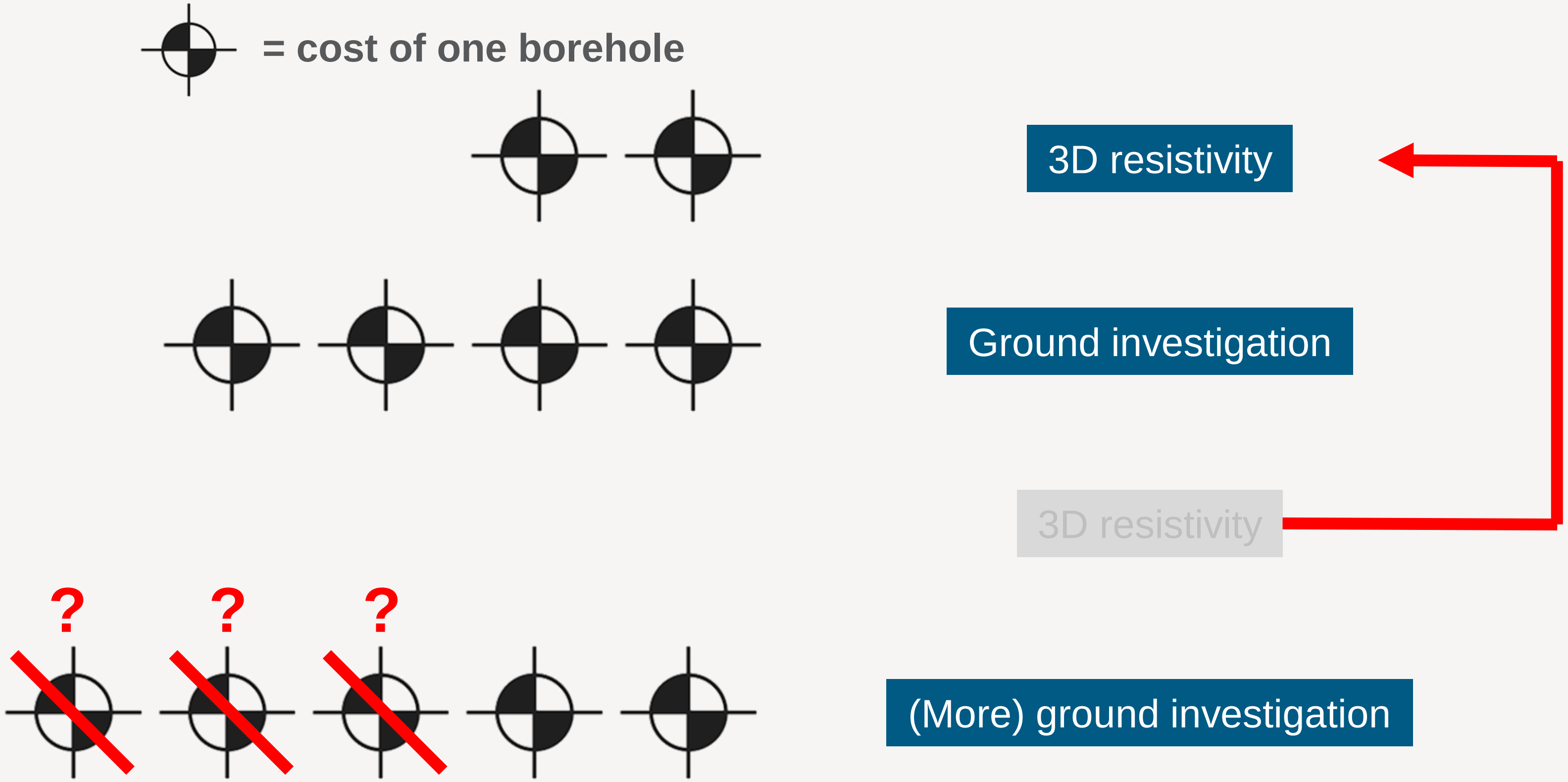
Cost: 1 m^3 of resistivity data is 10^6 cheaper than logged core

Data cost vs data value



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Cost: 1 m^3 of resistivity data is 10^6 cheaper than logged core

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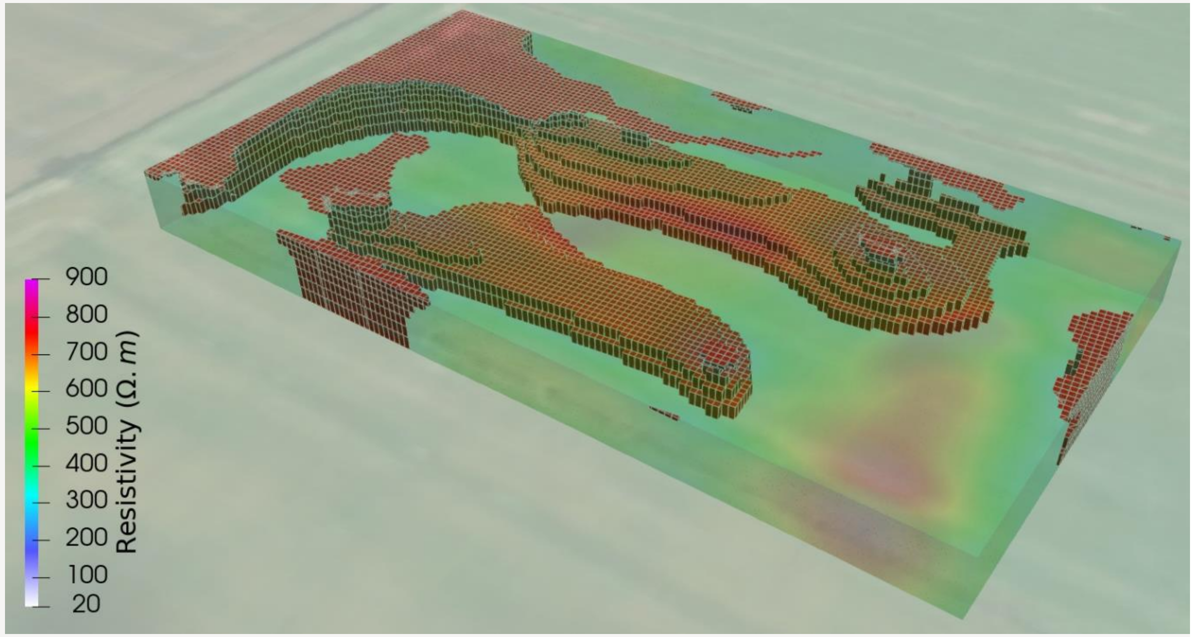
Conclusions

› 3D geophysical models can provide **site-wide, holistic evaluation** of geohazard systems

› Integration with intrusive data **minimises uncertainty and provides multiple lines of evidence** for geohazard presence

› 3D geophysical models are **dynamic, digital sources of information** and there are big opportunities for remote sensing integration and ground modelling



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