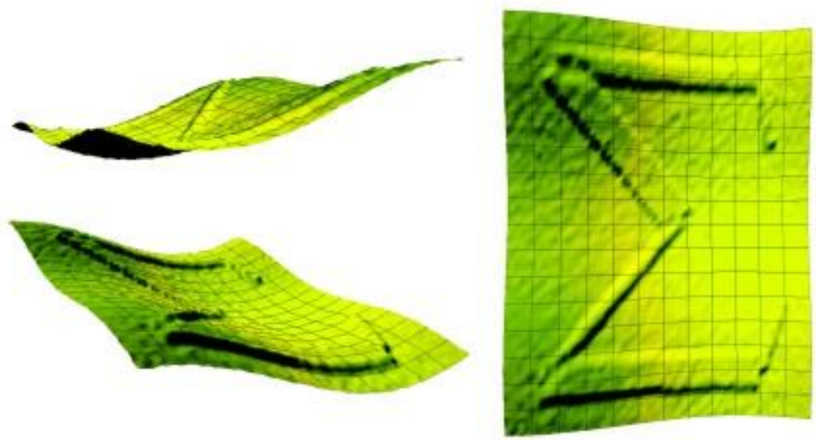
Subsurface Investigation

Are quantum technology sensors the answer?



Dr George Tuckwell *(RSK)*
Dr Nicole Metje *(University of Birmingham)*
Dan Boddice *(University of Birmingham)*

SIGMA

Study of Industrial Gravity Measurement Applications

Outline

- What is SIGMA?
- What can we currently detect?
- The difference new technology might make
- How we intend to find out

What is SIGMA?

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SIGMA – Study of Industrial Gravity Measurement Applications

£350k Innovate UK funded research into the next generation of quantum technology based geophysical instruments, quantifying their potential to create a step change in how the ground is investigated

UK Trade & Investment

Innovate UK
Technology Strategy Board

EPSRC
Pioneering research and skills

RSK

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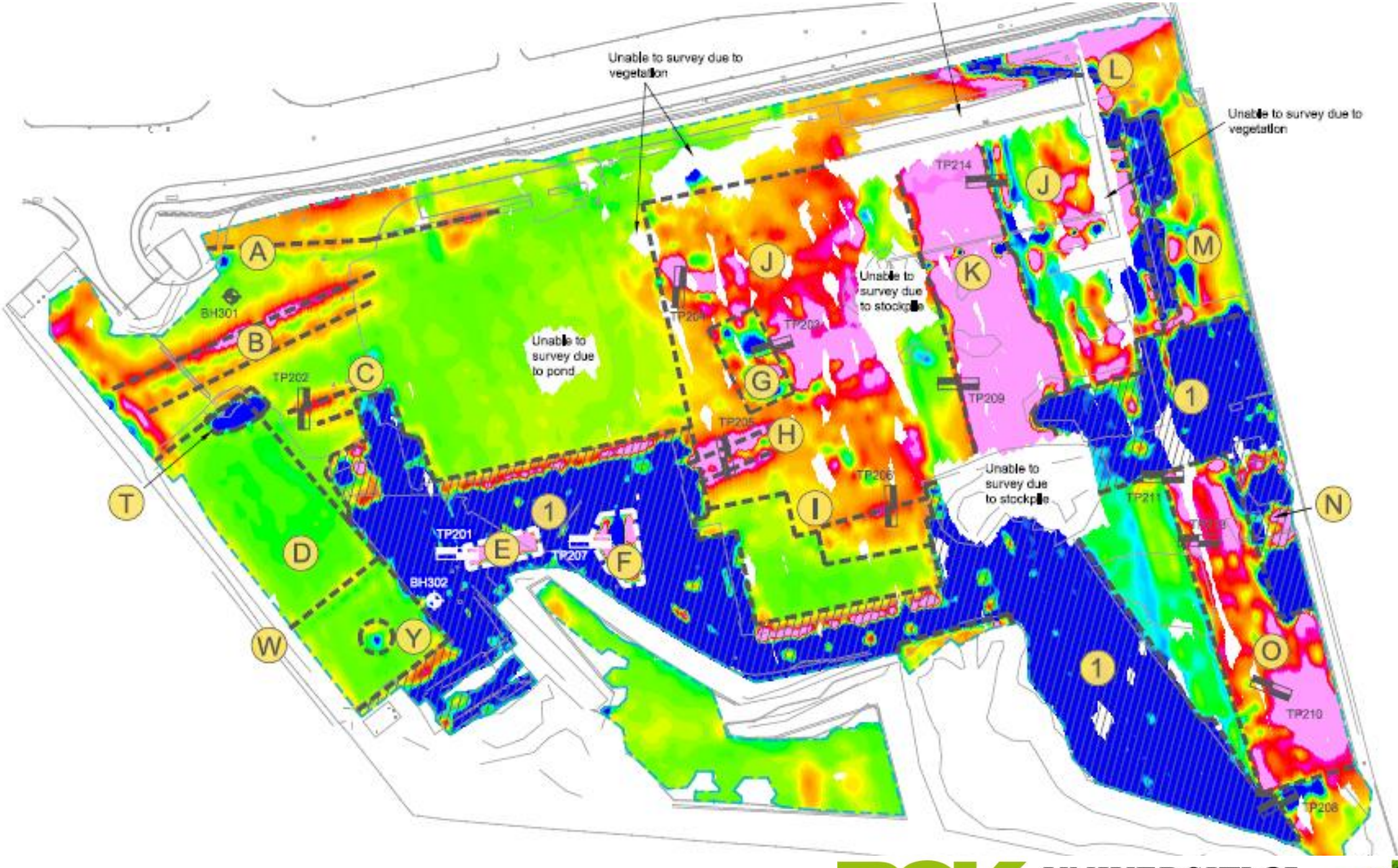
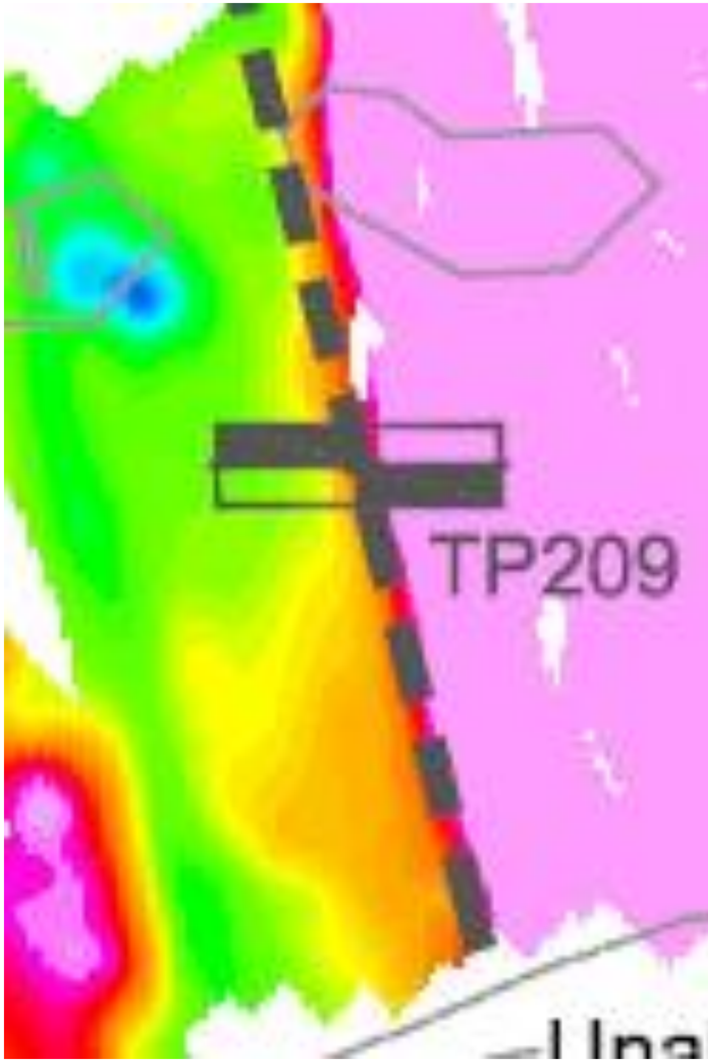
When would you use geophysics?

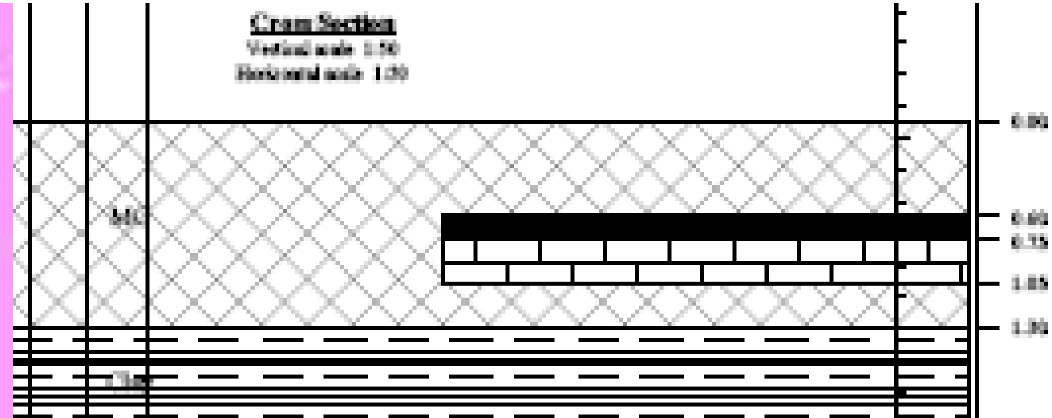
(some examples of detecting buried features using common techniques)

Electo-Magnetic (EM) Ground Conductivity



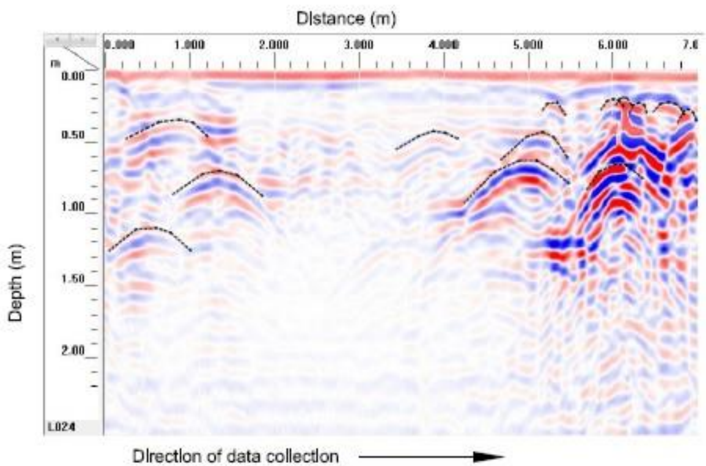
Electo-Magnetic (EM) Ground Conductivity



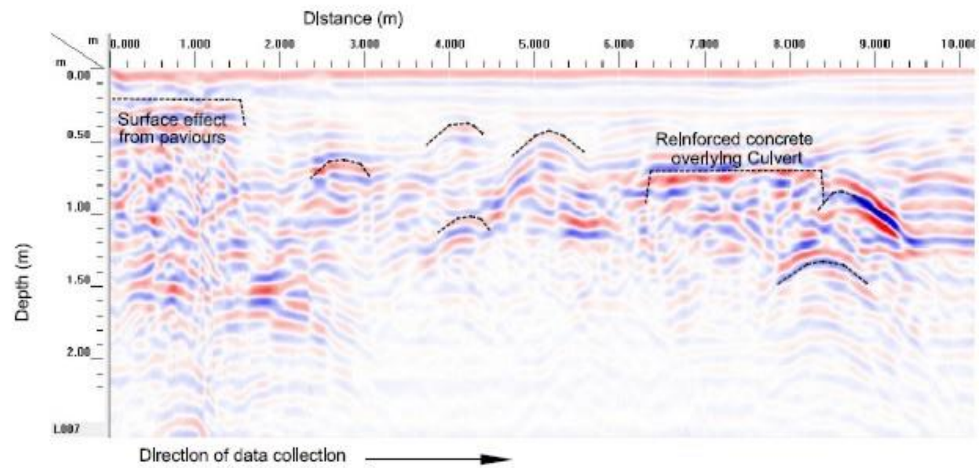


Ground Penetrating Radar – reflection sections

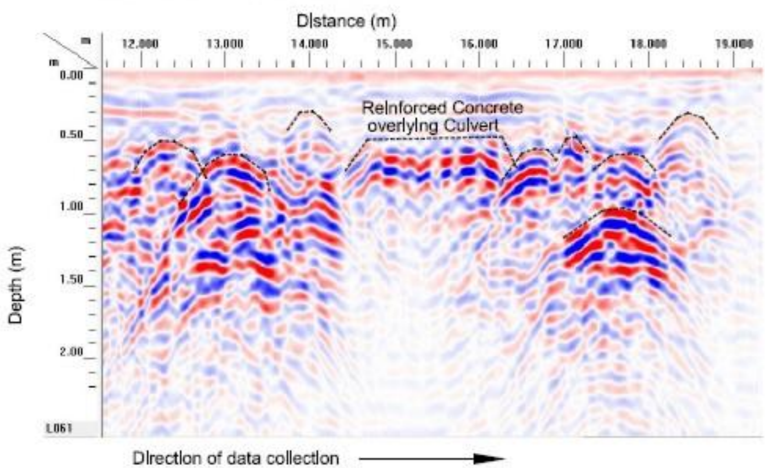
(A) GPR data showing buried utilities in East side of Market Square



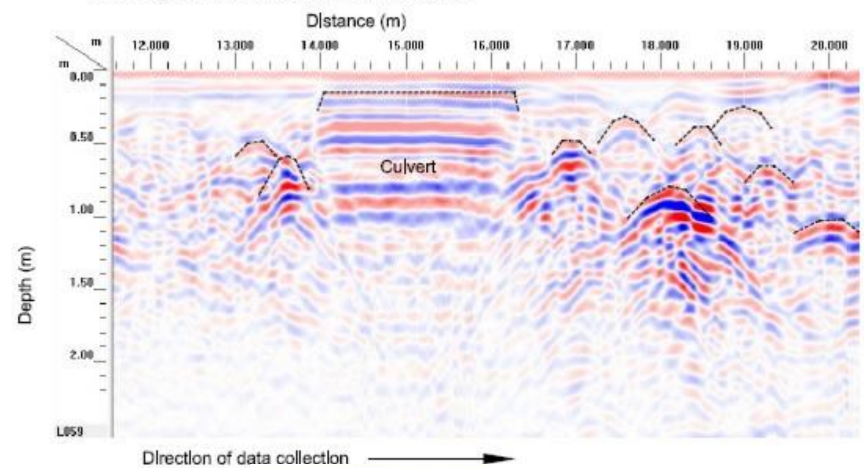
(B) GPR data showing Culvert and buried utilities in Southern section of Market Square.



(C) GPR data showing buried utilities and response from the Culvert indicative of reinforced concrete.



(D) GPR data showing buried utilities and a different GPR response potentially indicative of a change of construction of the Culvert.



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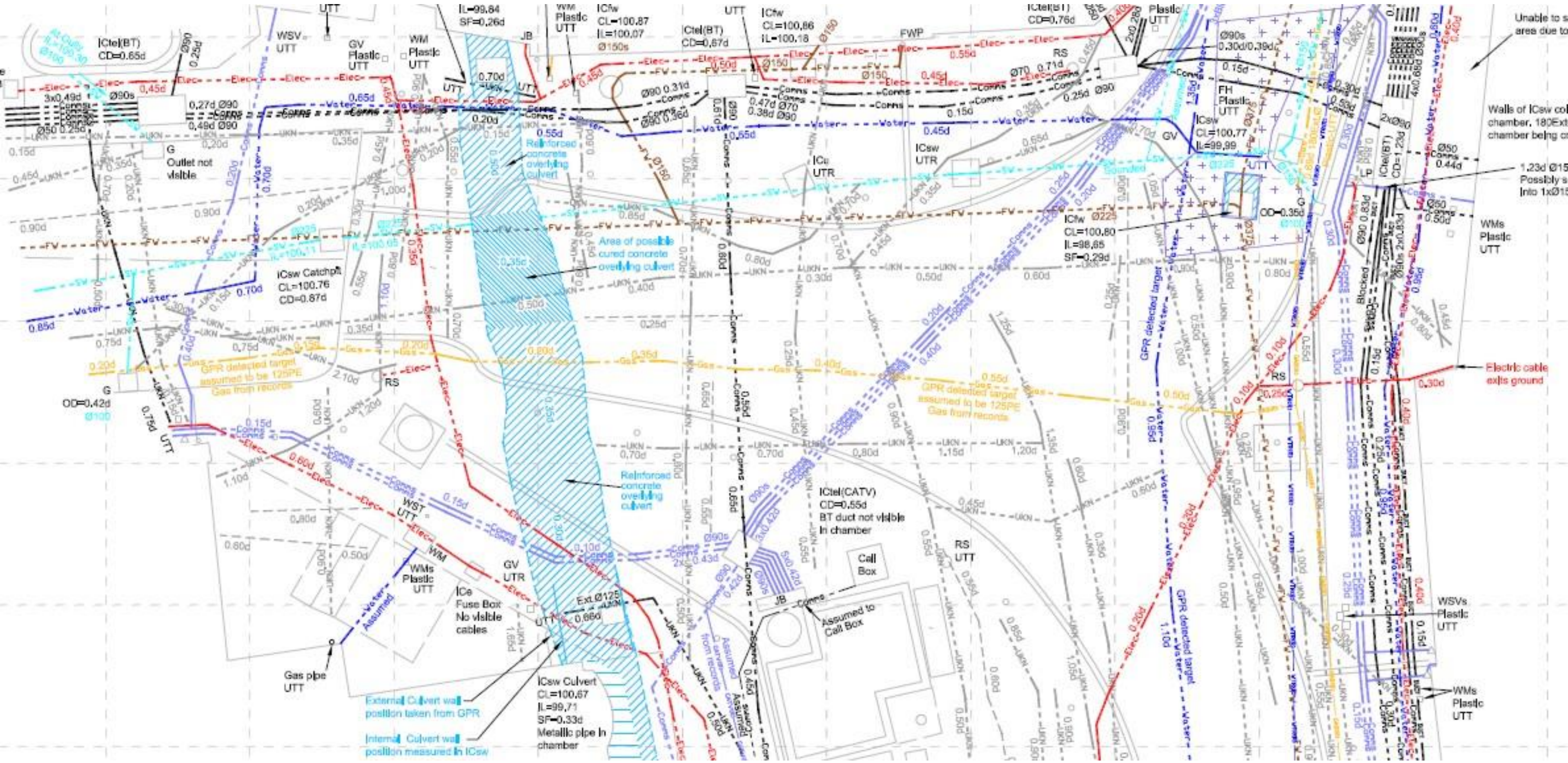
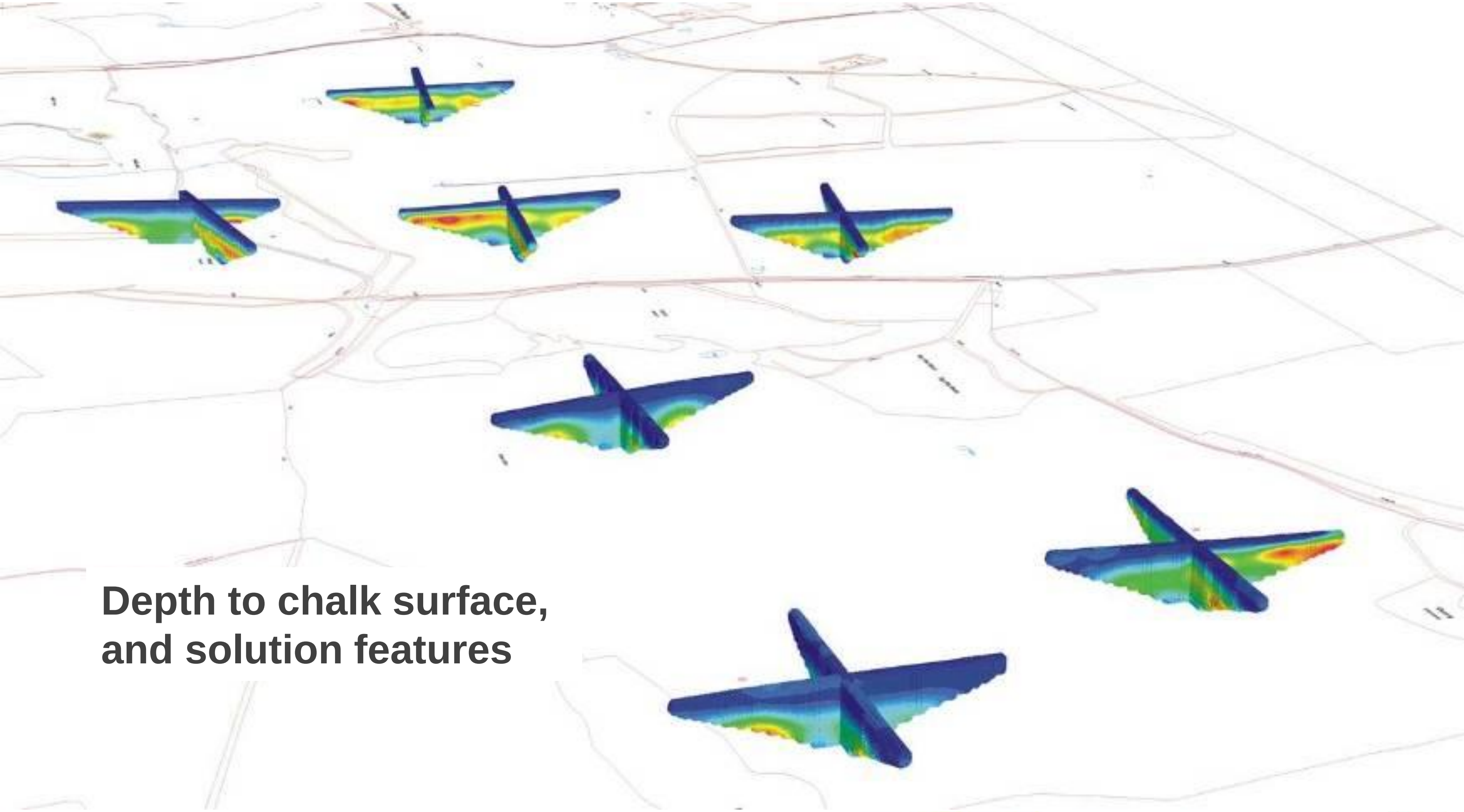
Ground Penetrating Radar – services and much more



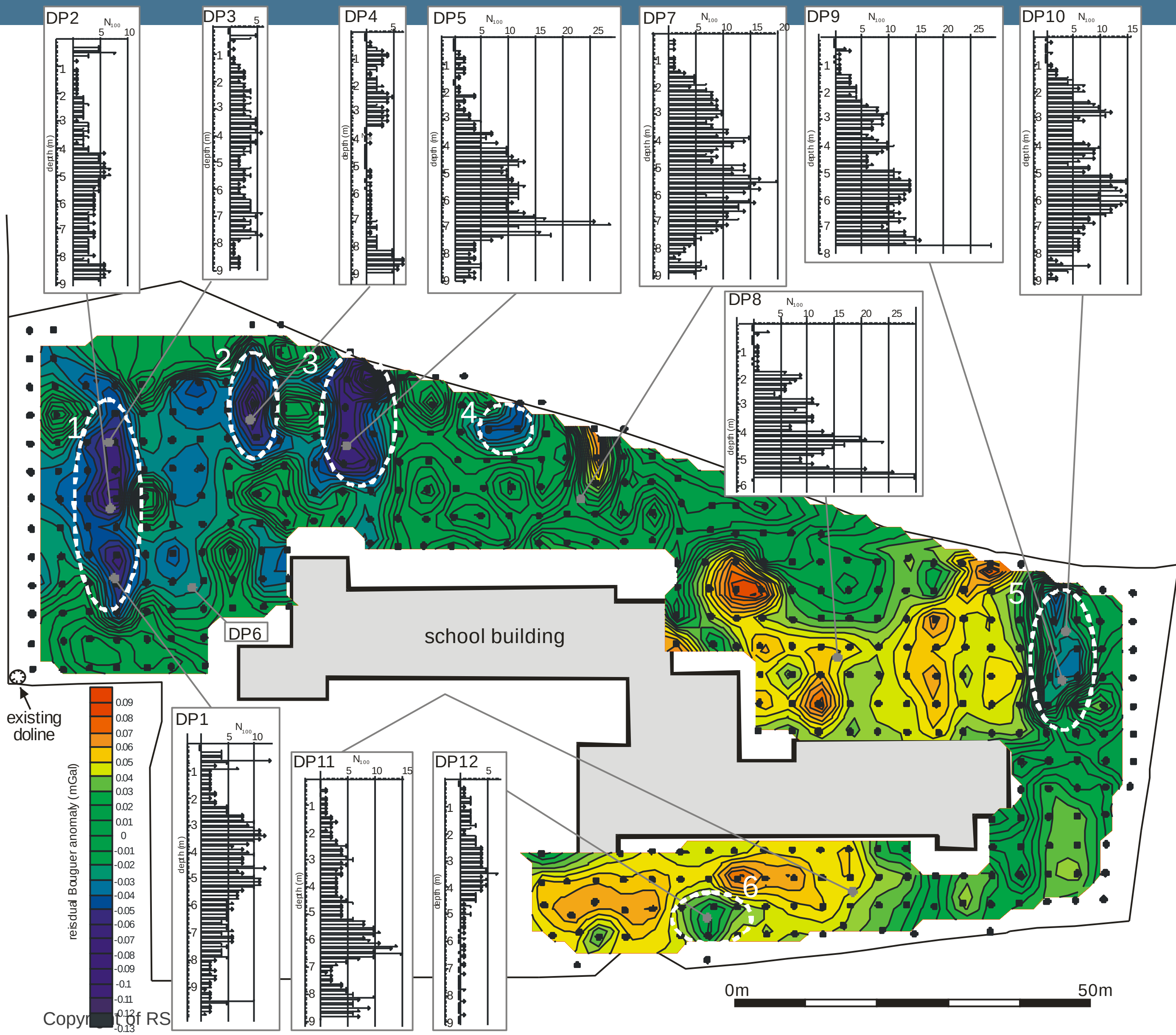
Electrical Resistivity



Depth to chalk surface, and solution features

‘conventional’ micro-gravity

‘conventional’ micro-gravity

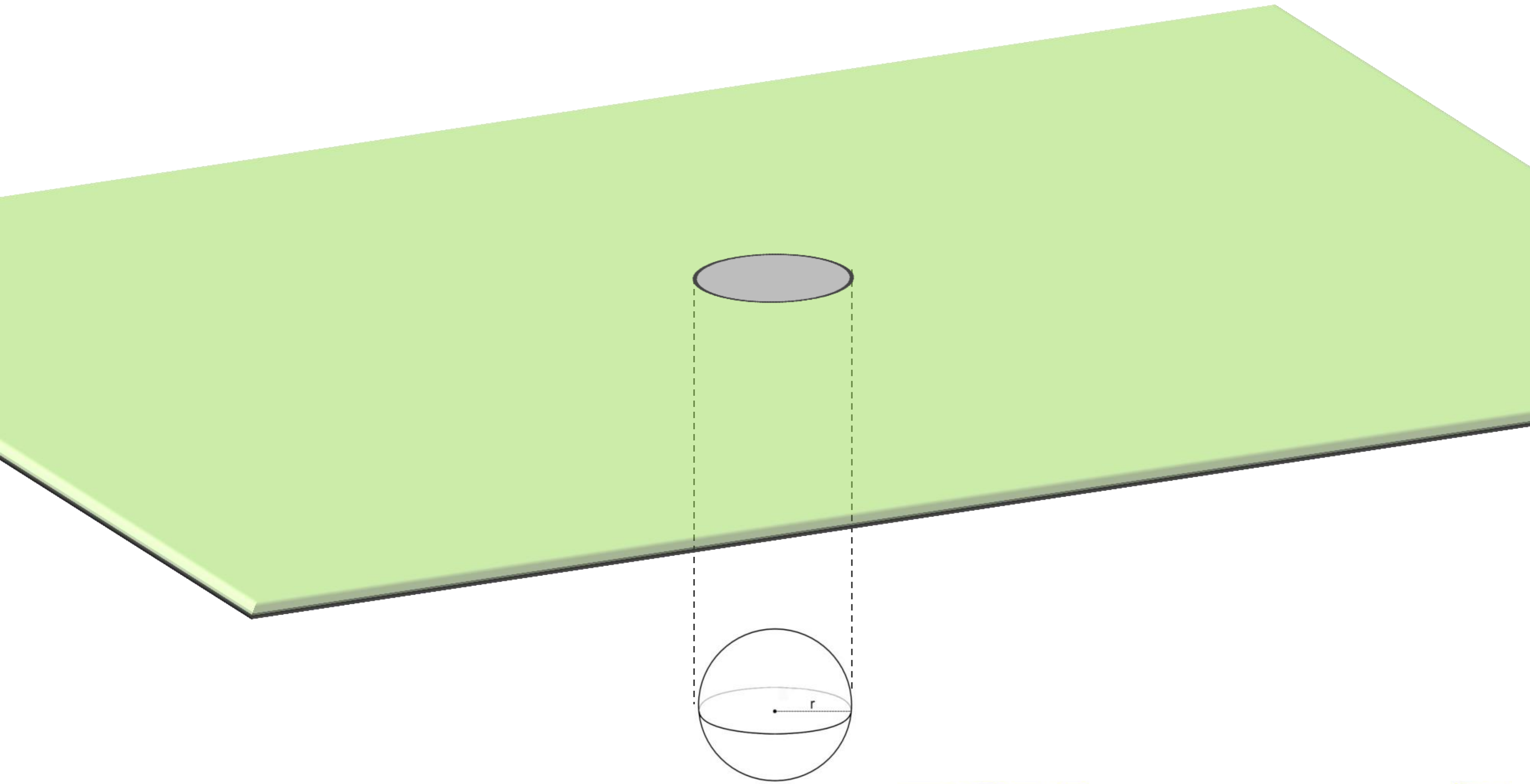


Gravity lows confirmed as voids or loose ground by dynamic probe.

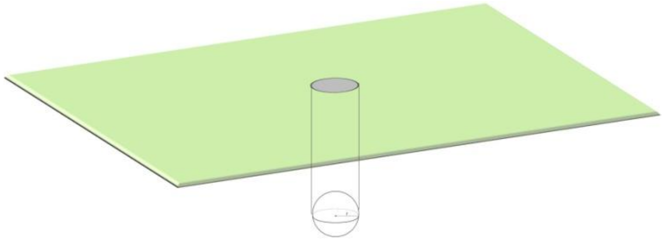
Tuckwell et al. QJEGH v41 n3

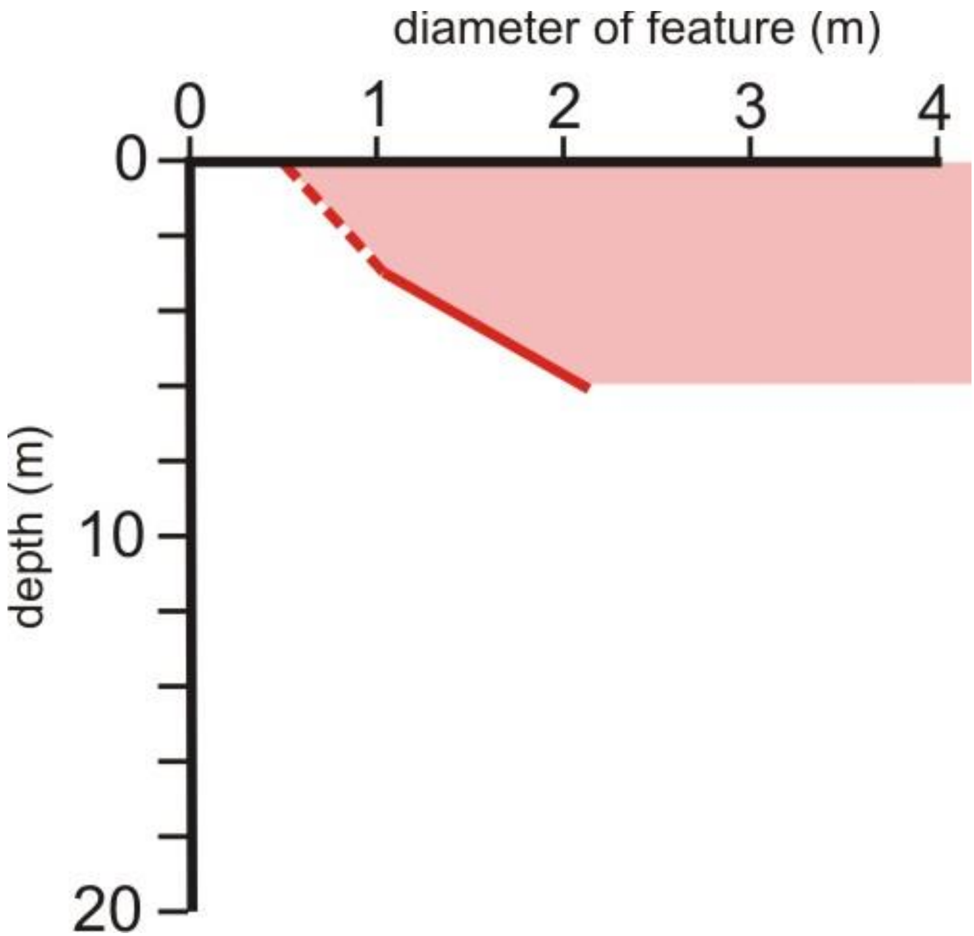
"Detectability"

Imagine a spherical object at depth...



EM conductivity detectability





- Good quick method to look at the upper 5m or so
- No depth resolution
- No penetration below ~7m

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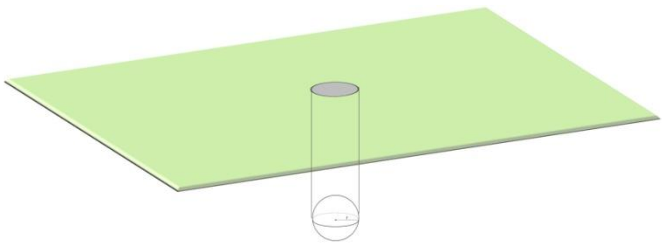
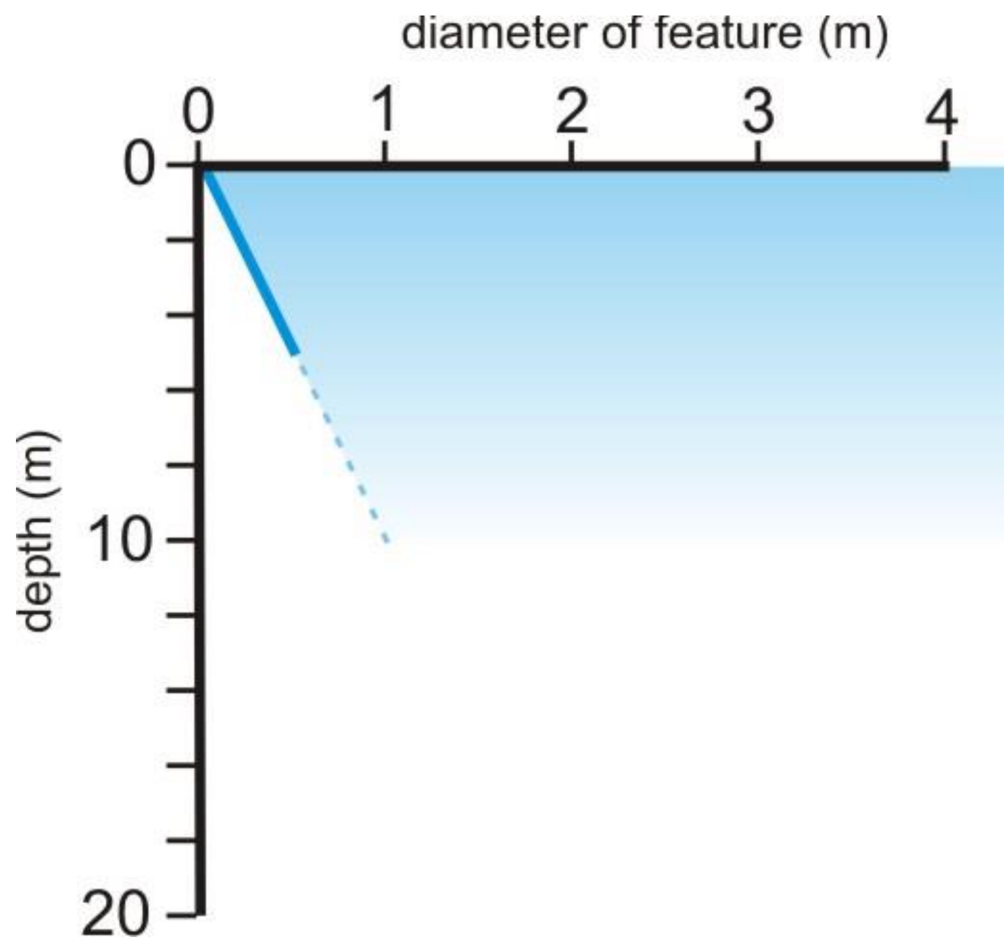
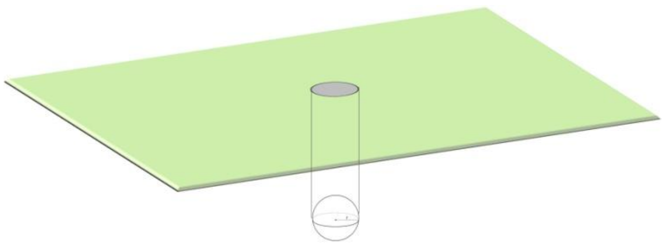
GPR detectability

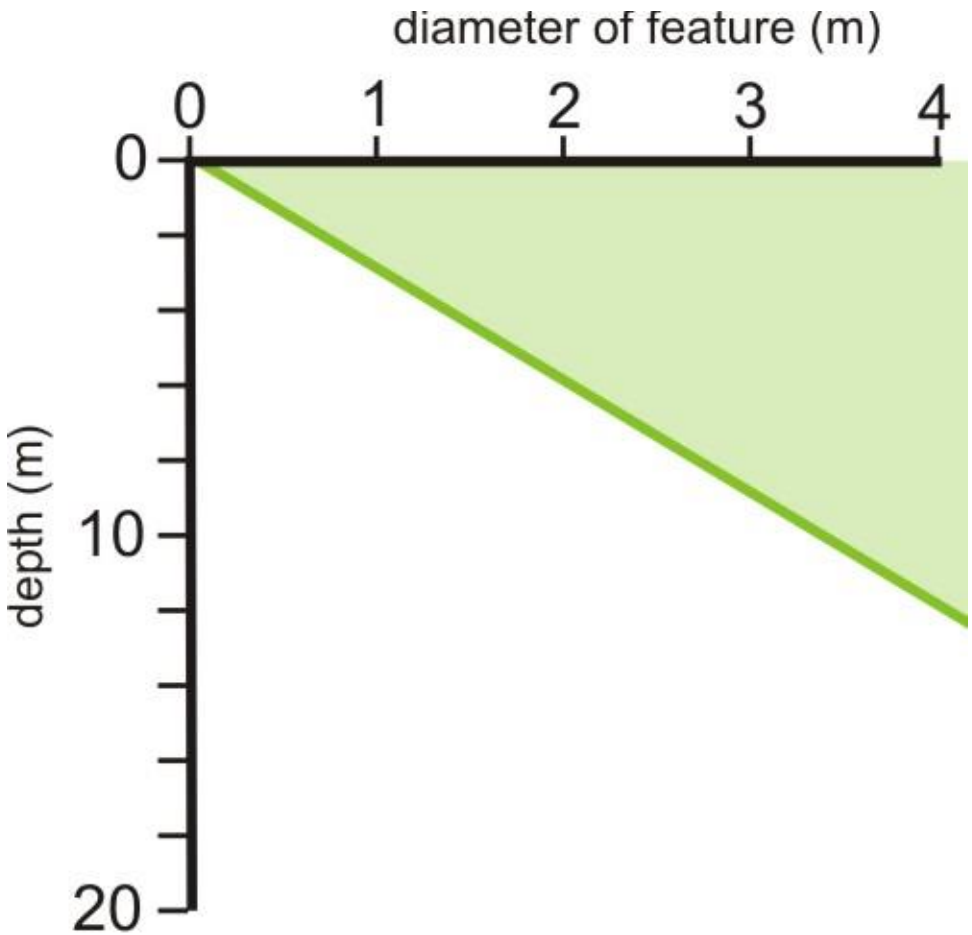




- Excellent resolution
- Excellent horizontal and vertical accuracy
- Limited depth penetration (sometimes none!)

Electrical Resistivity detectability





- Excellent depth penetration (to 200m)
- Limited horizontal and vertical accuracy
- Limited resolution

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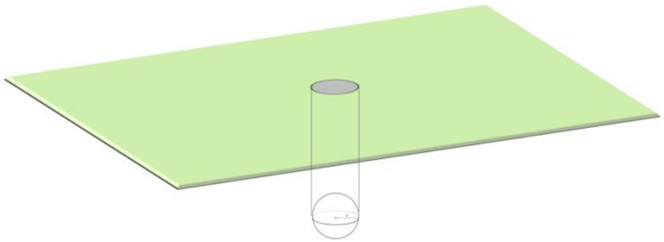
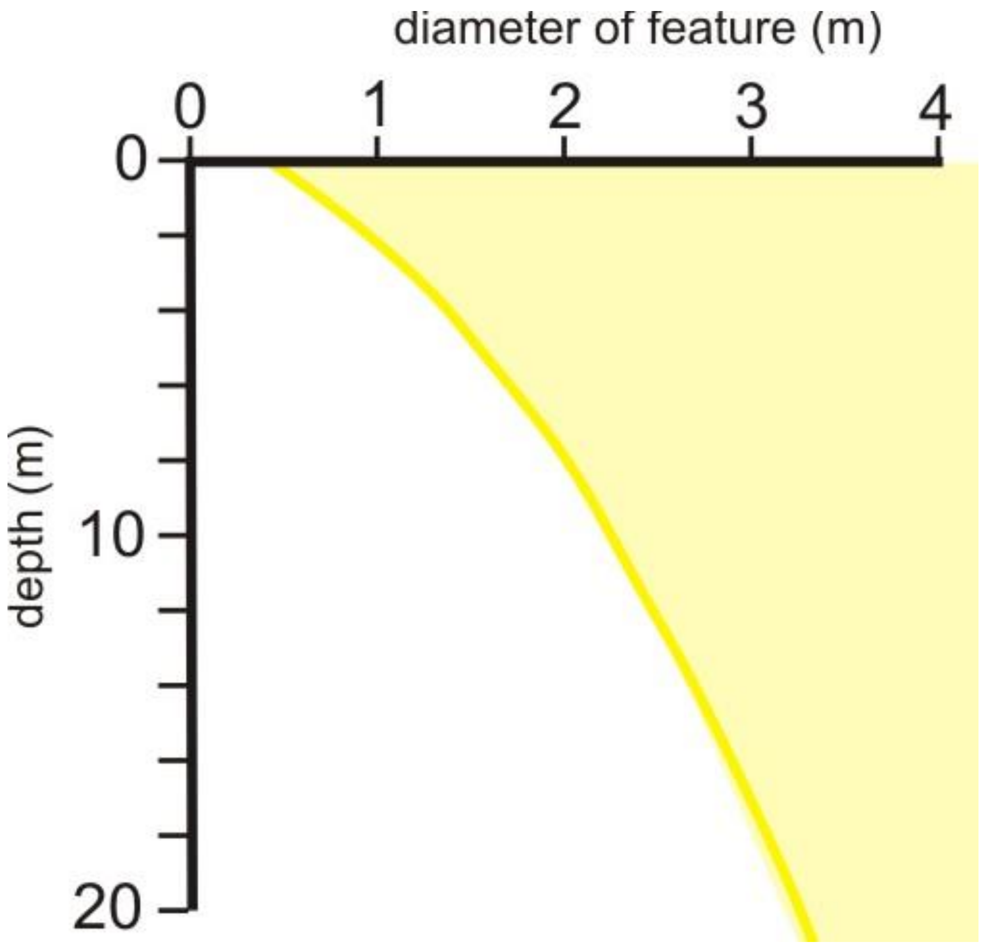
Micro-Gravity detectability





- •Depth not limited
- •Limited horizontal accuracy
- •Depth calculations use assumptions or require calibration
- **•Often best option**

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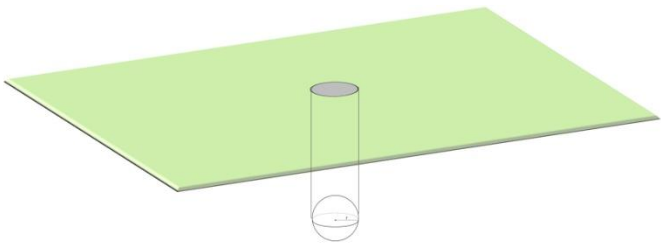
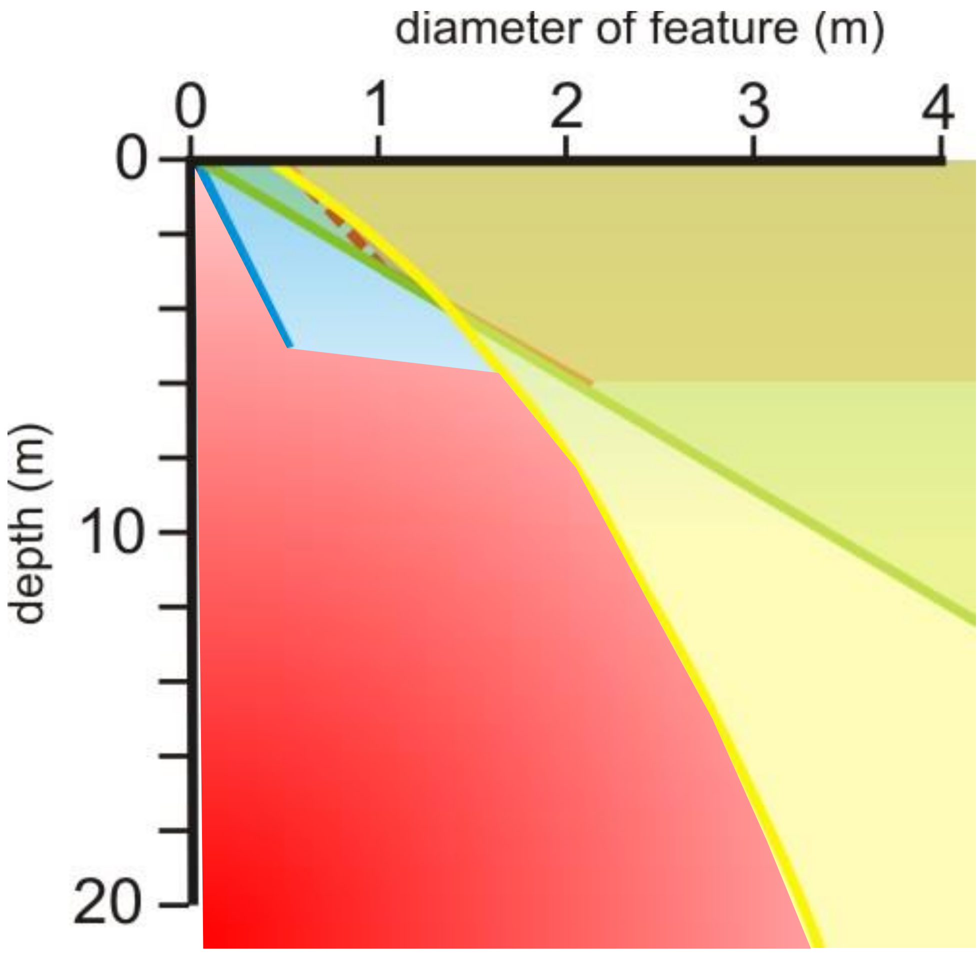
“Undetectable Zone”





•Many undetectable ‘unforeseen ground conditions’ lie beyond the detection capability of current geophysical technologies

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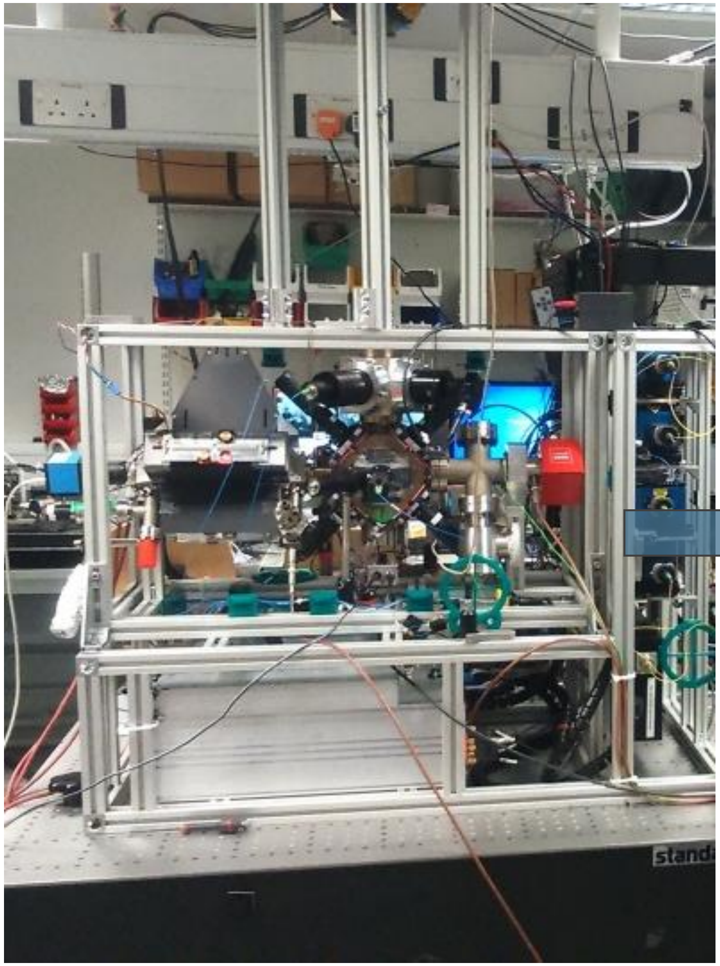
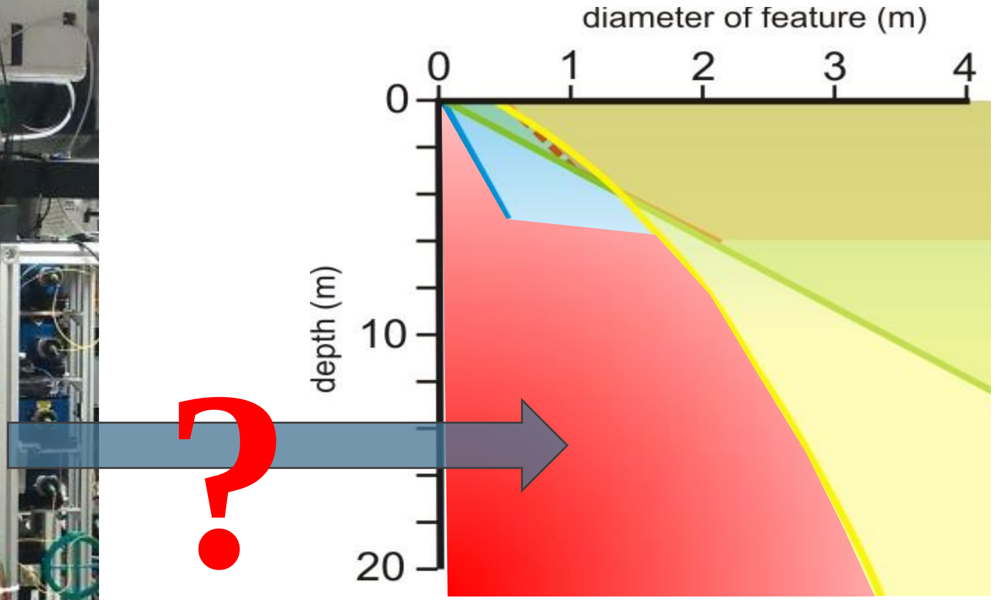
Are quantum technology sensors the answer?

The solution?

The GG-TOP quantum technology gravity sensor





The solution?

Quantum technology gravity sensors

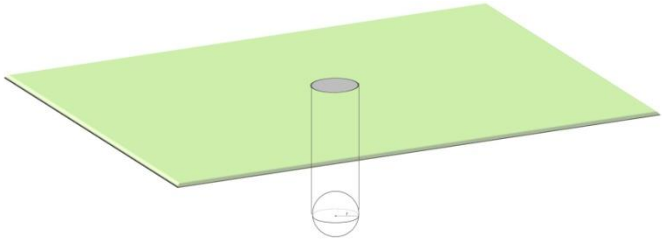
<u>In development – GG-TOP Gravity Gradiometer</u>

Could provide measurements <u>3 orders of magnitude</u> better than currently possible!

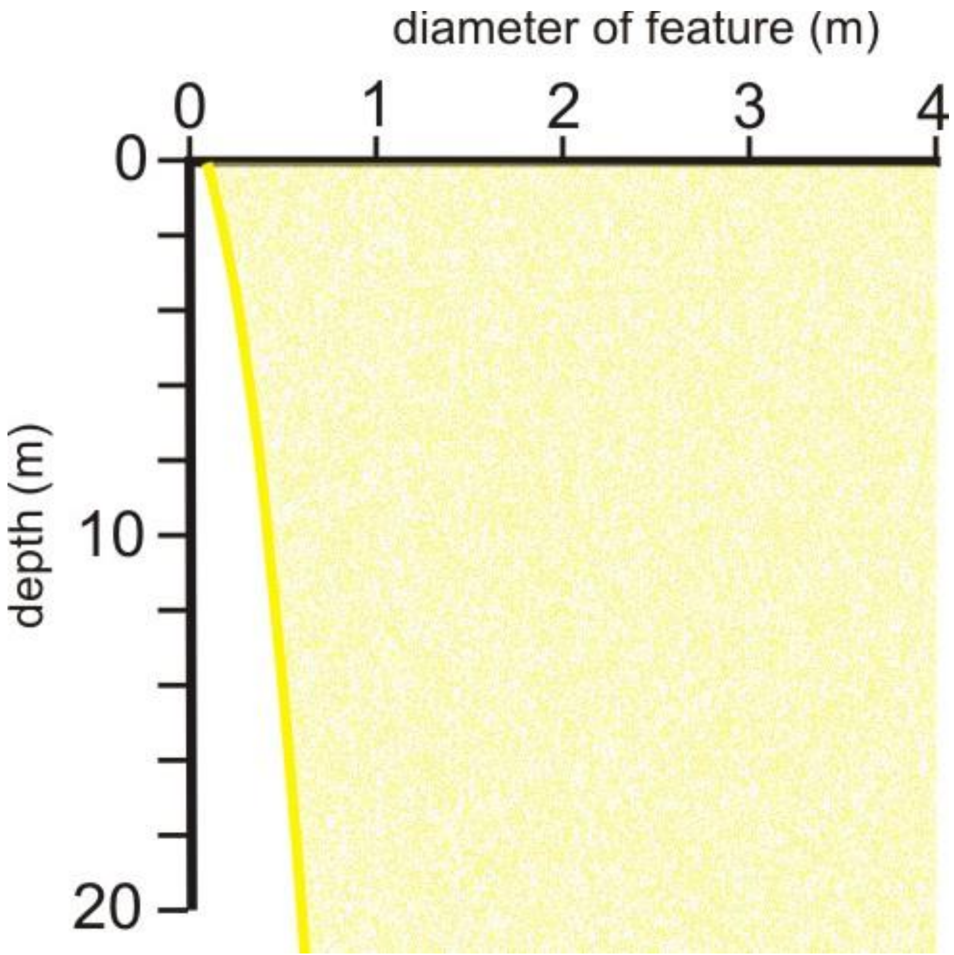
- Under development in Physics department in UOB
- Works by atom interferometry
- Is both more sensitive and stable than ‘conventional’ gravimeters
- The use of a gradiometer configuration gives many signal to noise improvements

Hope to be field ready for trials later this year

Potential Quantum Technology Gravity detectability



- No depth limitation
- Excellent detection resolution

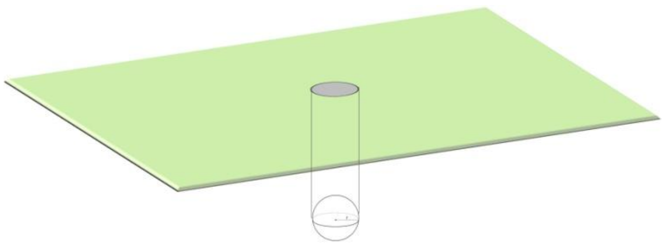


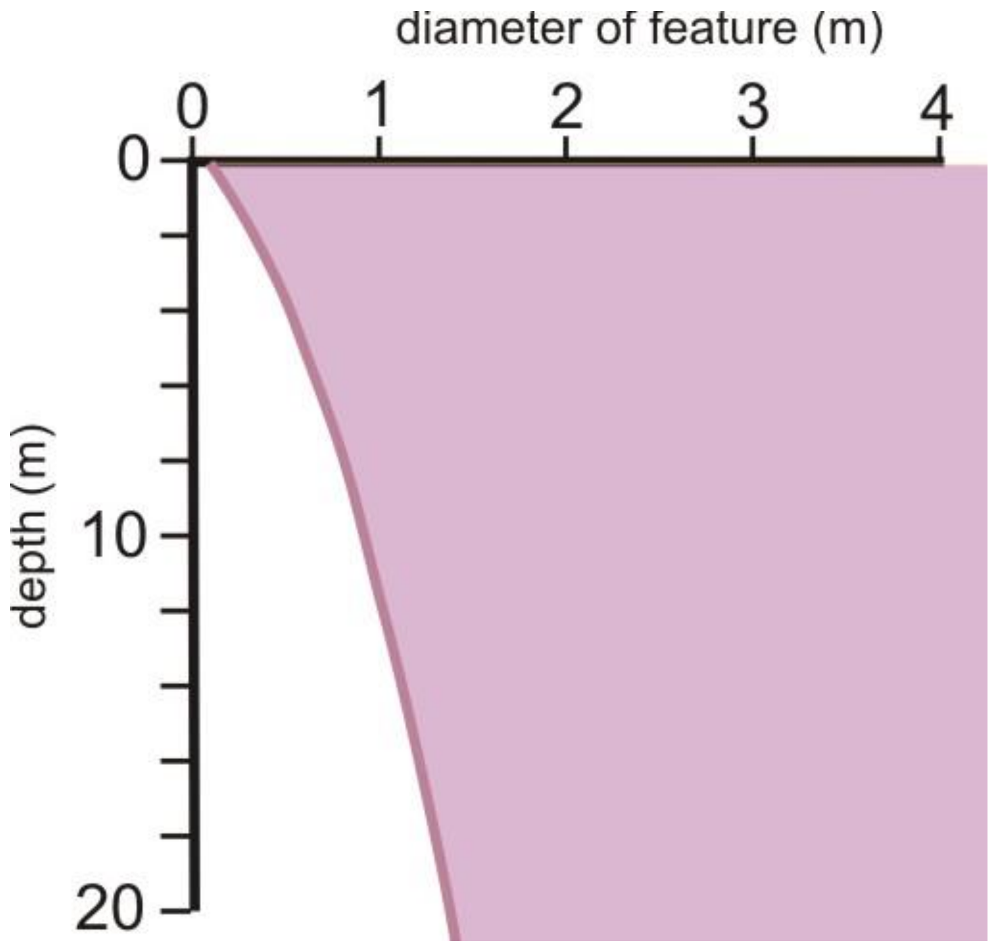
Difficulties

There will be some difficulties, which are well illustrated by one other geophysical technique that we haven't mentioned...

magnetic mapping

Magnetic detectability – in theory





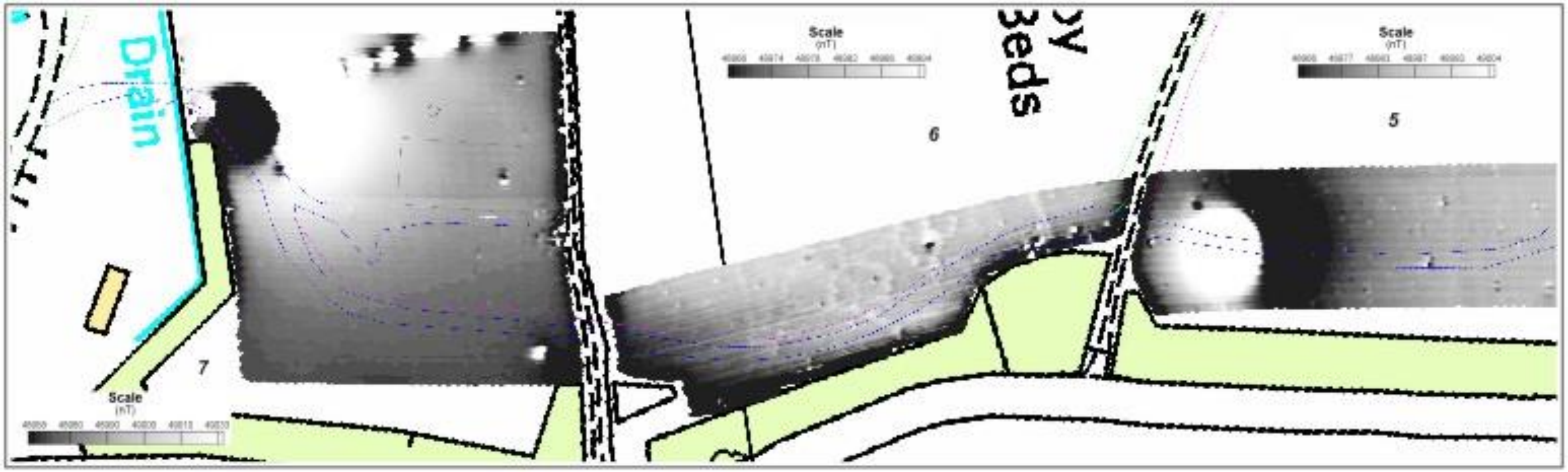
- Potential field method – just like gravity
- No depth limitation
- Excellent detection resolution –

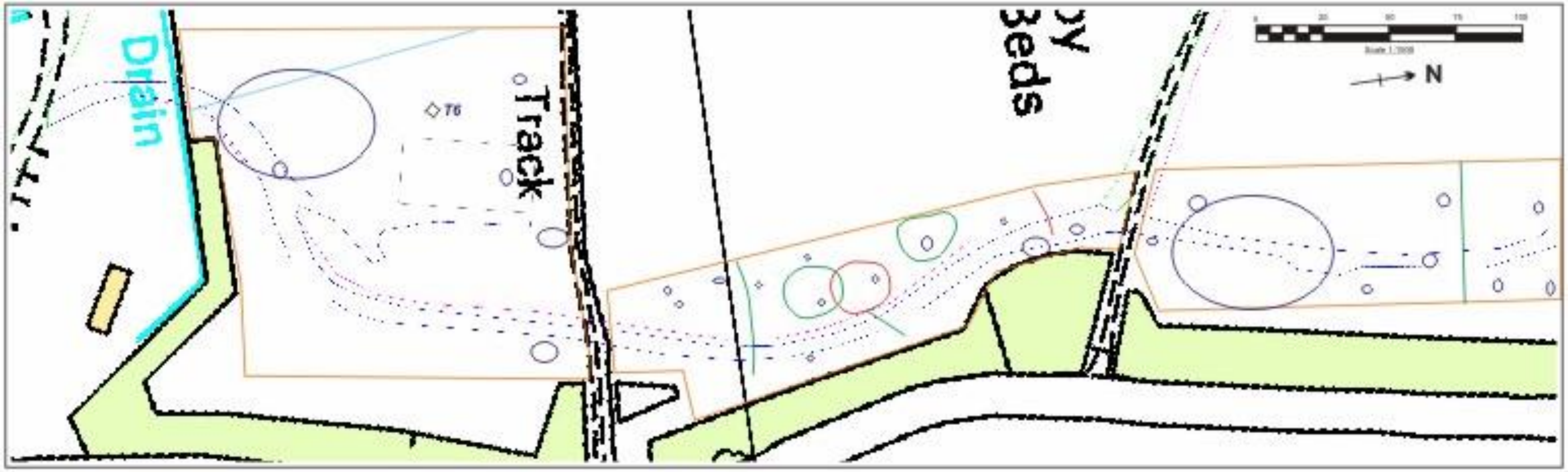
IN CERTAIN CIRCUMSTANCES

The problem is NOISE

(noise being anything and everything other than the signal you are interested in...)

Magnetics – the signal of interest may be the smallest in the data set





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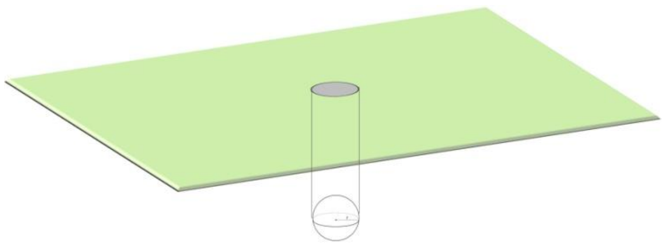
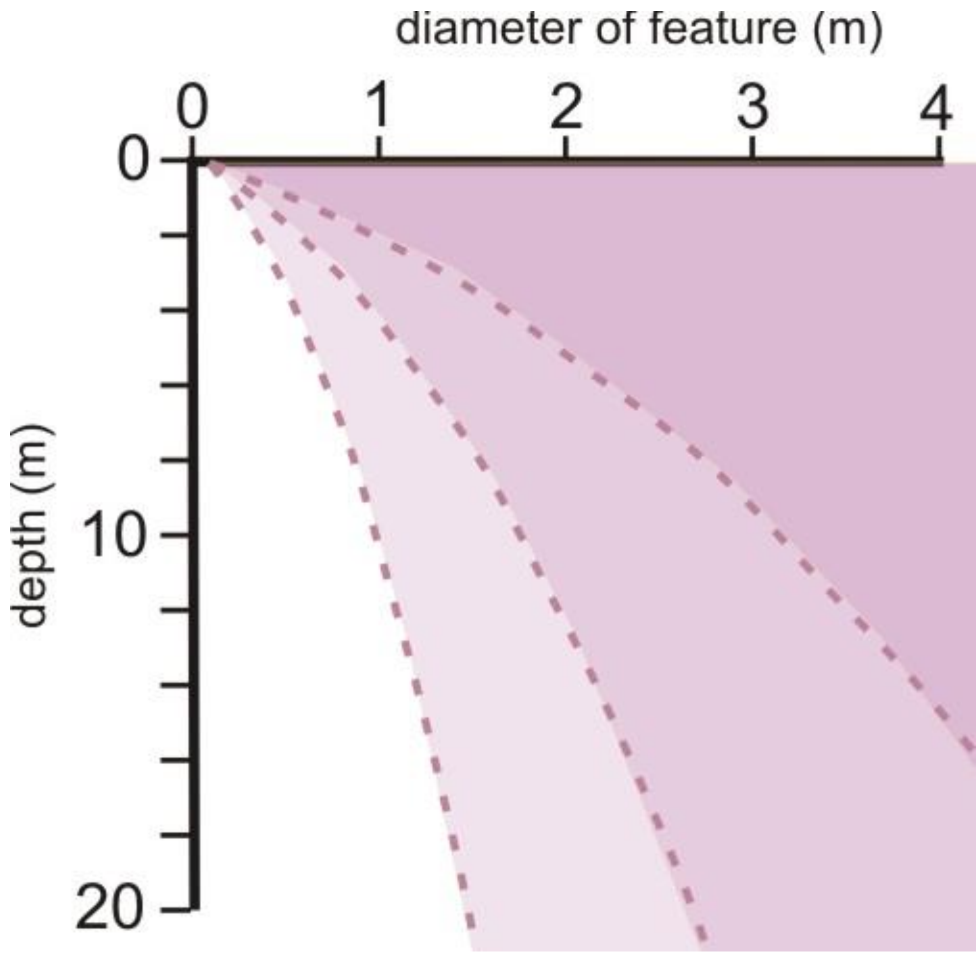
Magnetic detectability in practice





- Except in greenfield sites, the shallow surface is full of sources of magnetic signal
- The detectability of targets of interest can therefore be **compromised** or **zero**

Difficulties

Gravity measures density contrasts–

the variation in density from a heterogeneous shallow subsurface are far smaller than for magnetic contrasts –

so this should be much less of a problem...

...but

There are a lot of other unwanted signals in gravity measurements

Instrument noise

NOISE	Varies as a function of	Size of error	Correction	Will it cancel on the Atom interferometer?
Tilt from vertical	Time	Non linear. 0-900 μGal (depending on tilt)		✓
Temperature on sensor	Time	Varies between instruments. (Ours = 130 μGal /degrees MK)		✓
Linear creep on sensor springs	Time/Instrument	Varies between instruments but <2mGal per day		✓

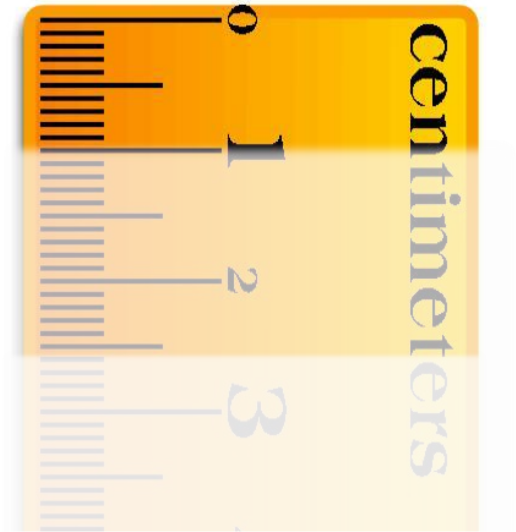
Environmental signals

NOISE	Varies as a function of	Size of error	Correction	Will it cancel on the Atom interferometer?
Celestial Tides	Time, Location	Up to 280 μGal in a day		✓
Ocean Tidal Loading	Time, Location	Similar frequencies but different phases to celestial tides making them hard to separate.		✓
Atmospheric Pressure	Time, weather, height	0.3 μGal per hPa Typically <3 μGal per day but can be up to 7 μGal per day		✓
Seismic noise (ocean waves and earthquakes)	Time, geology (Location?)	Roughly ±50μGal (Mudstone) Roughly ±75μGal (Sandstone) Roughly ±100μGal (Chalk) Earthquakes give very large but short disturbances		✓
Man Made Noise (Vibrations)	Time, Location geology	Highly dependent on activity		✓
Wind Noise	Time, weather, Location	Dependent on weather and if the measurement location is exposed		✓

Location effects

NOISE	Varies as a function of	Size of error	Correction	Will it cancel on the Atom interferometer?
Latitude	Location	Depends on latitude (0° -17 mGal 90° - 4 mGal) and is non-linear. At mid latitudes c. 0.8 µGal per m. For gravity gradient, values are about 0.8 Eotvos per km		✗
Height of sensor	Location	c.30 µGal per m		✗
Direct terrain effects	Location	Depends on density and amount of material under the sensor		✗
Nearby Terrain	Location	Depends on size and proximity of the terrain		?
Buildings	Location	Depends on size of the building and materials used		?
Natural Soil Density Variability	Soil Type	Currently estimating at c. 1-2 µGal based on normal distribution and variation of 0.5 g/cm³		✗

Conventional micro-gravity



like measuring the length of the British Isles to an accuracy of 10mm

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Quantum-technology gravity

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this is a dust mite
(not to scale)

like measuring the length of the British Isles to an accuracy of 10μm

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Summary

- Quantum technology sensors could provide a step change in what can be detected in the subsurface
- Currently undetectable unforeseen ground conditions may no longer be undetectable
- Detailed modelling of
  - **signals from the objects of interest, and**
  - **signals from the ‘noise’**

  are needed to quantify the feasibility of the technology to provide a commercially viable solution
- Field trials of quantum technology gravity sensors are tentatively scheduled for the end of this year.

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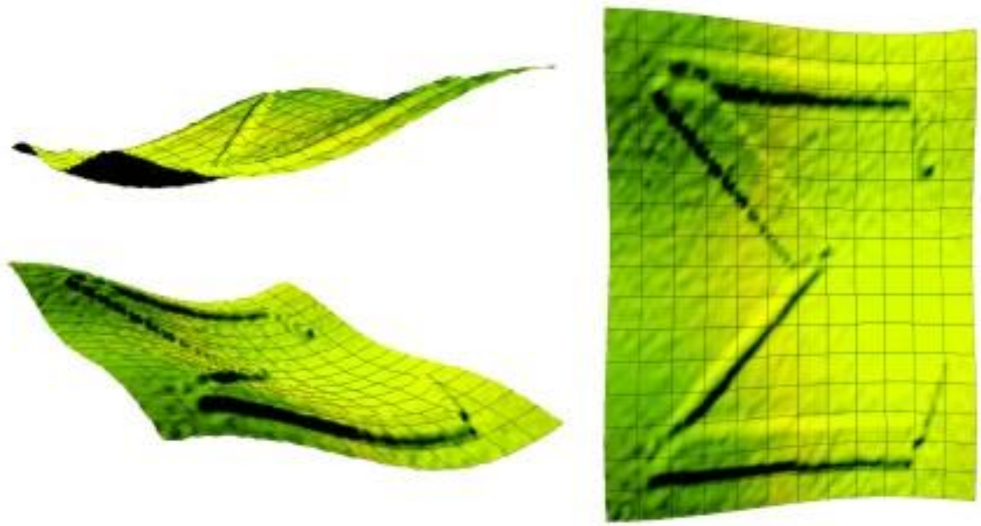
And finally...

"Things are always unnoticed until they are noticed."

Sir Richard Broadbent – former TESCO Chairman

SIGMA

Study of Industrial Gravity Measurement Applications



http://www.rsksigma.co.uk/