SAGA

The Soil Science & Archaeo-Geophysics Alliance

Training School 1

Magnetic Survey

for Archaeological Prospection

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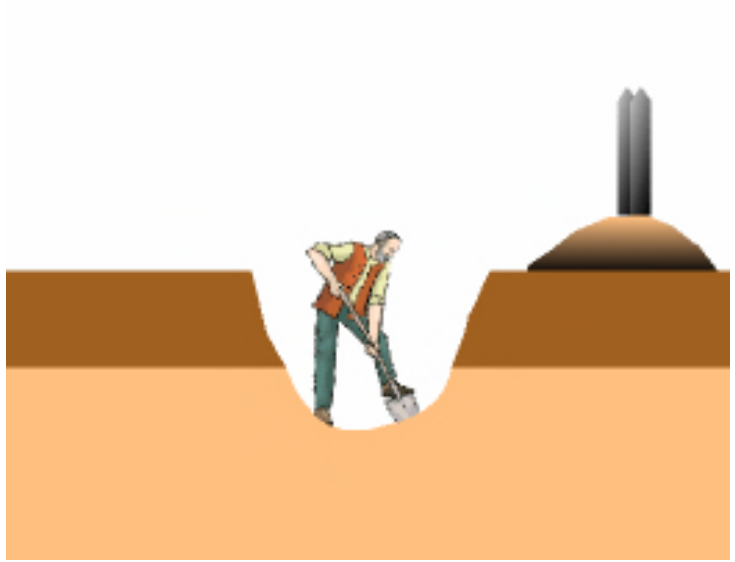
ISAP

Taphonomy

The Remains of Human Habitation

- Human habitation
- Remains in the ground, pits, ditches, foundations
- Covered, ploughed, destroyed
- Changes to soil
- Contrast between features and soil
  - excavation
  - geophysical survey



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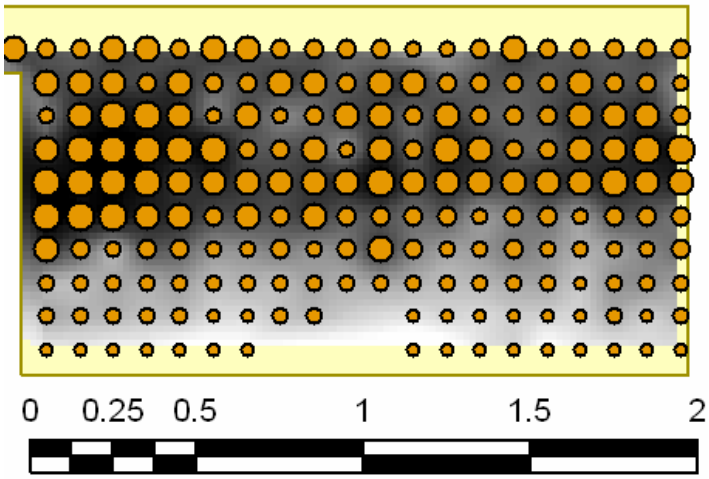
Excavation

- Trace the contrast directly
  - colour
  - texture
- Destructive

Geophysical Survey

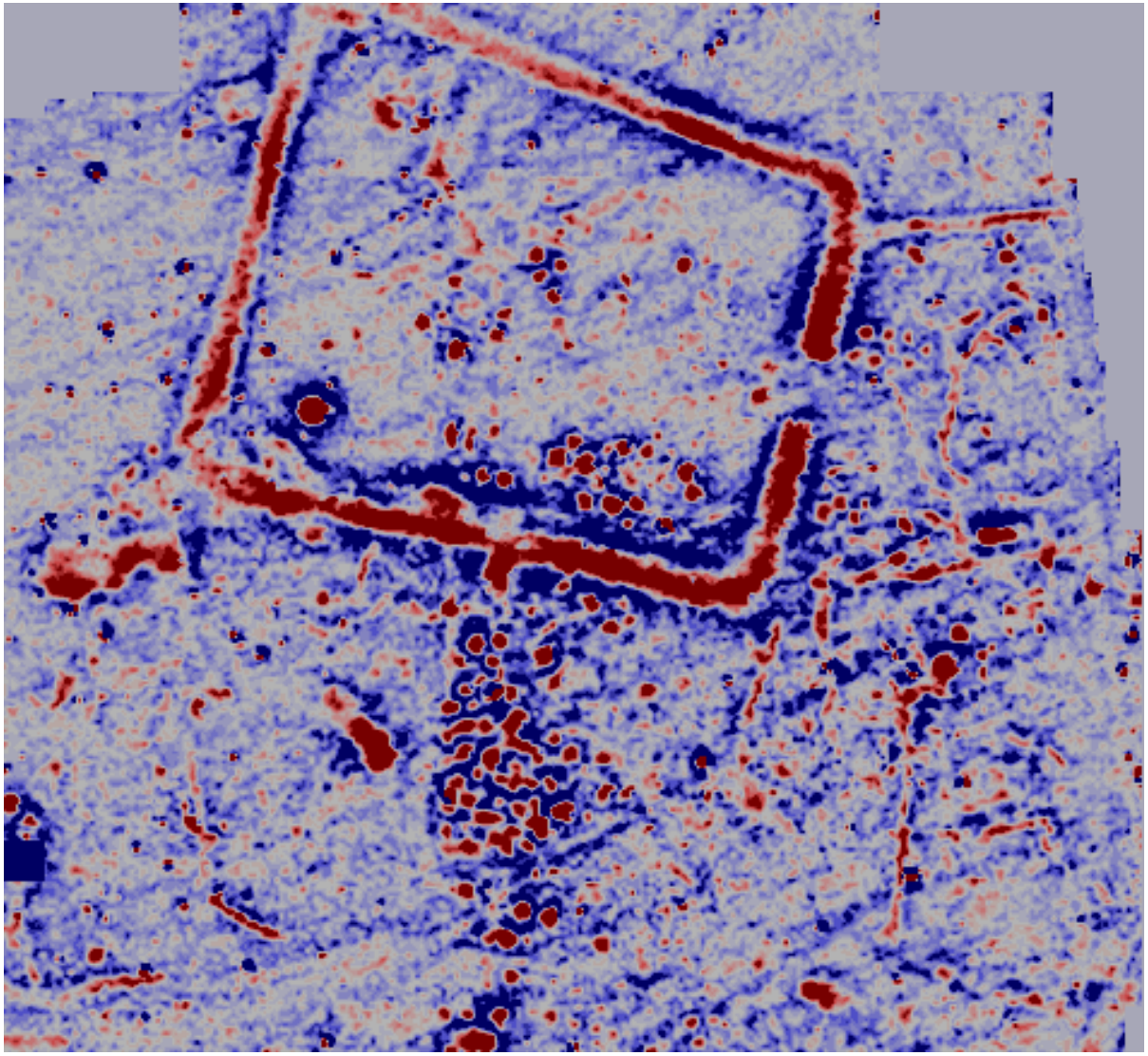
- Contrast in soil leads to contrasts in geophysical properties
  - mineralogy
    → magnetic susceptibility
  - heating
    → magnetic remanence
  - soil porosity
    → electrical conductivity,
    → dielectric permittivity



Geophysical Survey

- Measurement of geophysical signal at the surface caused by contrast in geophysical properties
  - distance
- Non-destructive

Magnetometer Survey



Temple Guiting
Middle Ground

+3 nT

-4 nT

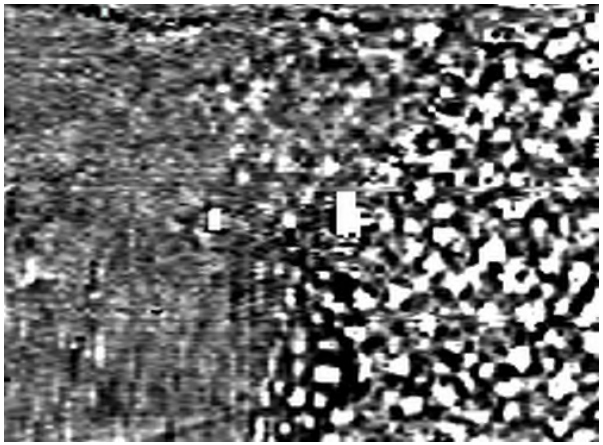
0 40m

Forward

- Human habitation
  ↓ *reasonably well understood*
- Soil contrast (e.g. mineralogy)
  ↓ *well understood*
- Geophysical contrast (e.g. magnetic susceptibility)
  ↓ *very well understood*
- Geophysical measurement (e.g. magnetic anomaly)

Inverse

- Human habitation
  ↑ *interpretation*
- Soil contrast (e.g. mineralogy)
  ↑ *not unique, but reasonable assumptions*
- Geophysical contrast (e.g. magnetic susceptibility)
  ↑ *not unique, especially with noise*
- Geophysical measurement (e.g. magnetic anomaly)



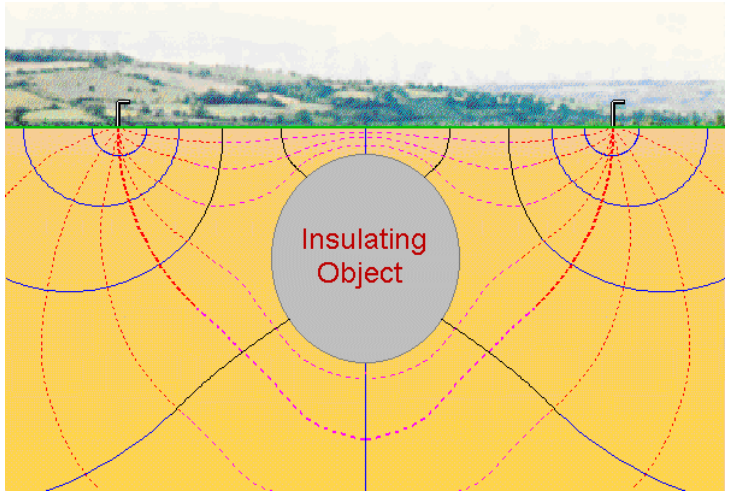
Terminology

Archaeology and ‘Contrast’

- Initially: value of contrast is not important
  - but shape of features is
- Further examination of contrast
  - properties of features
  - colour, texture, soil
  - magnetic susceptibility, electrical resistivity
- Value alone is meaningless (’30 Ωm’), difference between feature and background is important

Features and Anomalies

- Buried archaeological **features**
  - ditch, wall, pit, …
  - contrast
  - buried in the ground



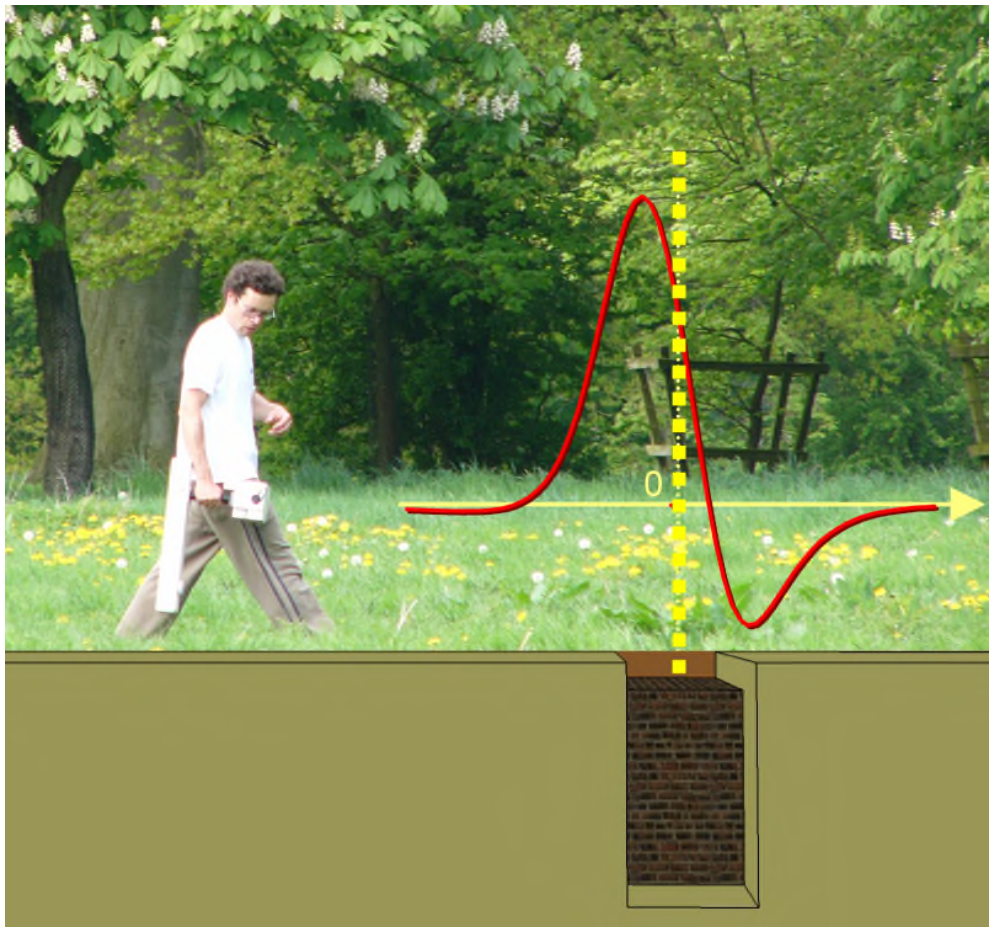
- **Anomalies** measured on the surface
  - distant effect of feature on the geophysical measurement
  - deviation of measurement from background
  - anomaly

Features and Anomalies

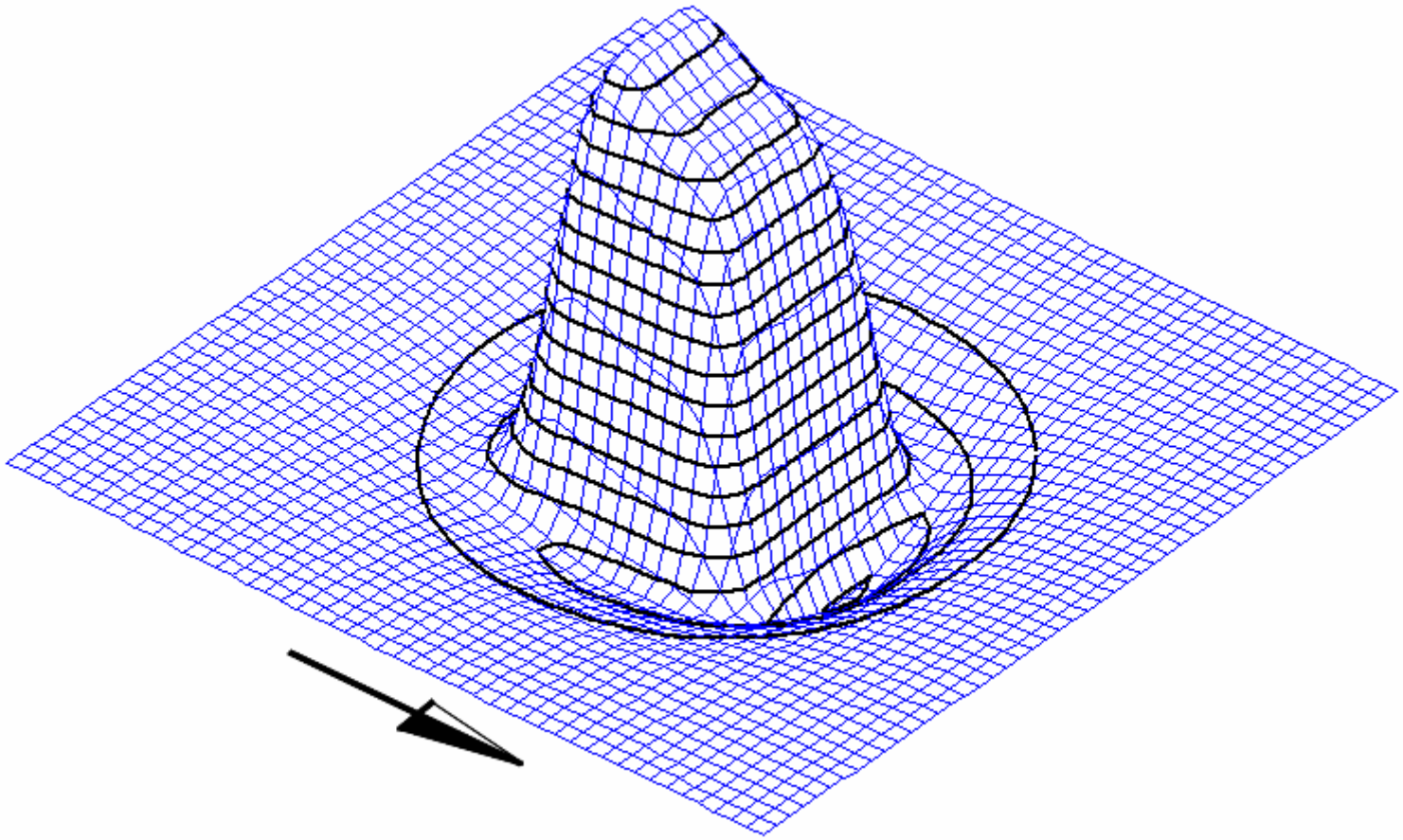
- Aerial photography
  Cropmarks ‘look like’ features

Features and Anomalies

- Geophysics
  Anomaly different from shape of feature

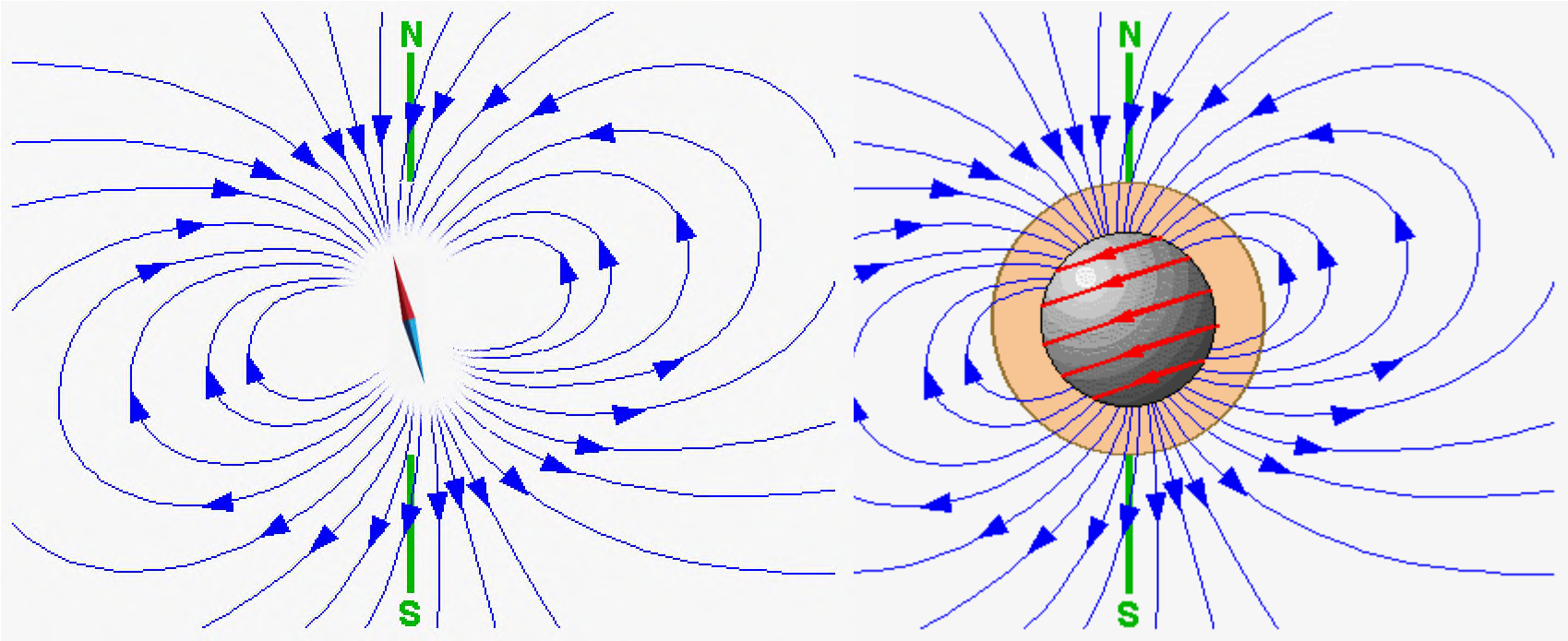


Fundamentals of Magnetism



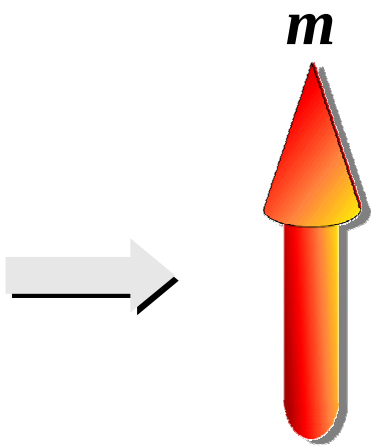
Magnetic Field of the Earth

- Earth is like a bar magnet,
  it produces a magnetic field that can be utilised for measurements.



Magnetism

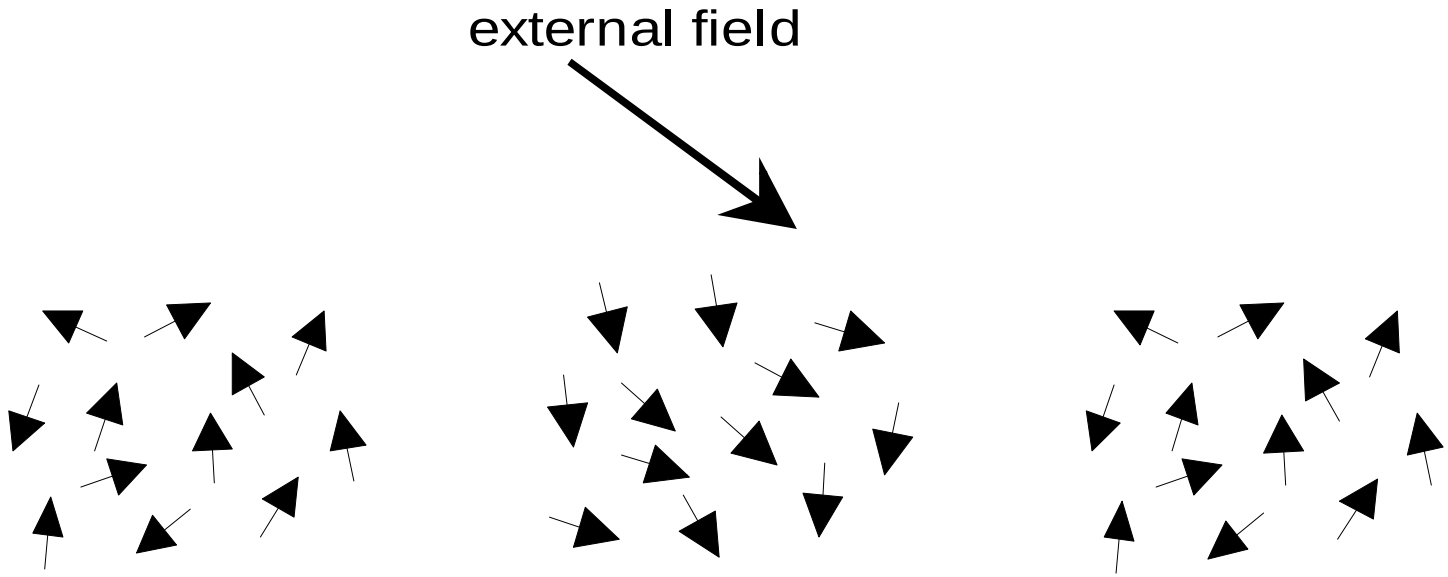
- All materials contain elementary magnets due to spinning and orbiting electrons



magnetic moment

Induced Magnetisation

- External magnetic field (e.g. earth's field) partially aligns elementary magnets – to enhance the field.
- Without the field they would revert to random alignment.



Magnetic Susceptibility

- Ease of alignment determines strength of enhancement and is described by the *magnetic susceptibility*
  - volume specific susceptibility: κ [no units, 'SI']
  - mass specific susceptibility: χ [in m^3 / kg]
  - total susceptibility: k [in m^3]

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Topsoil Magnetic Susceptibility Enhancement

- Change of minerals (iron oxides):

$$\text{Haematite} \xrightarrow[\text{reduction}]{} \text{Magnetite} \xrightarrow[\text{re-oxidation}]{} \text{Maghaemite}$$

weak *very strong* *strong*

- burning with organic matter (200 °C)
- microbes living in rotting organic material facilitate conversion (not ‘fermentation’)

Bacterial

- Magnetotactic bacteria have magnetite in their body

- When they die these crystals remain
  soil becomes magnetic

External Input

- Hammerscale
  when driving slag
  out of smelted iron
- Ferrous objects
- Pottery fragments
- Airborne pollutants

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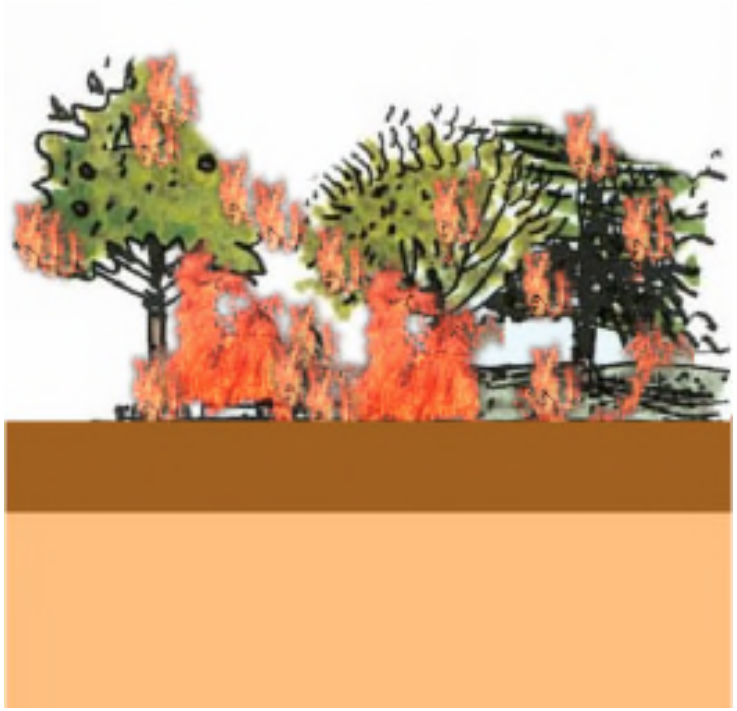
Archaeological Features

- Natural topsoil

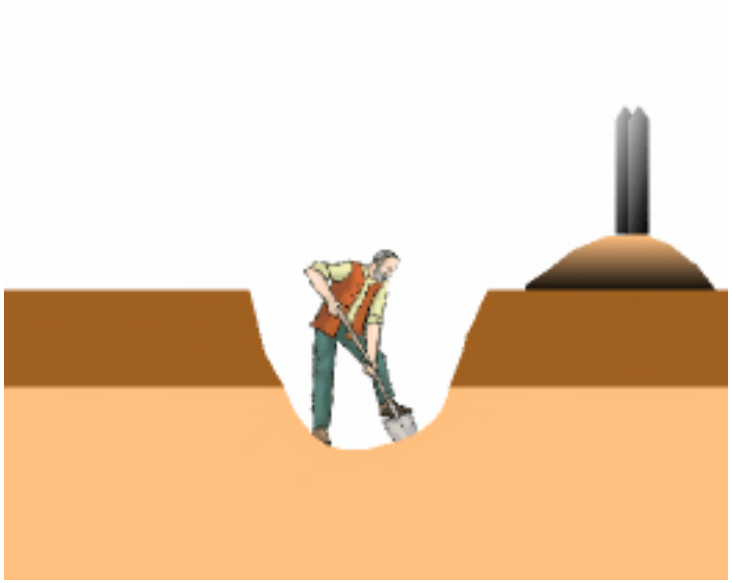
Archaeological Features

- Susceptibility of topsoil enhanced through burning



Archaeological Features

- Ditch cut into subsoil



Archaeological Features

- Gradual infill after abandonment

Archaeological Features

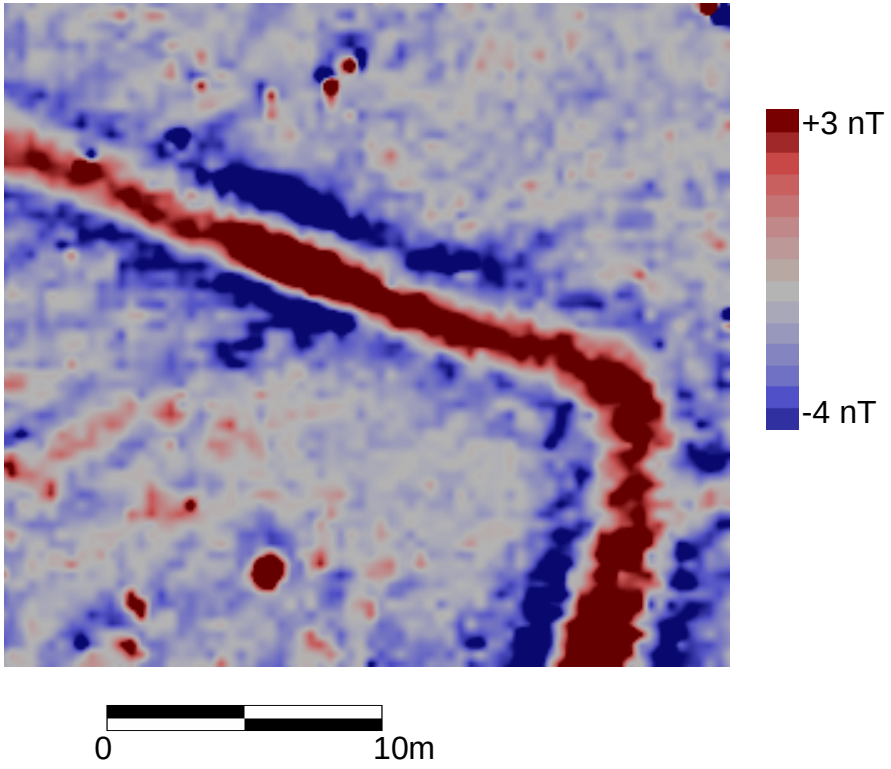
- Distribution of soil through ploughing

Archaeological Features

- Susceptibility **contrast**
- Examples: pits, ditches, burials …

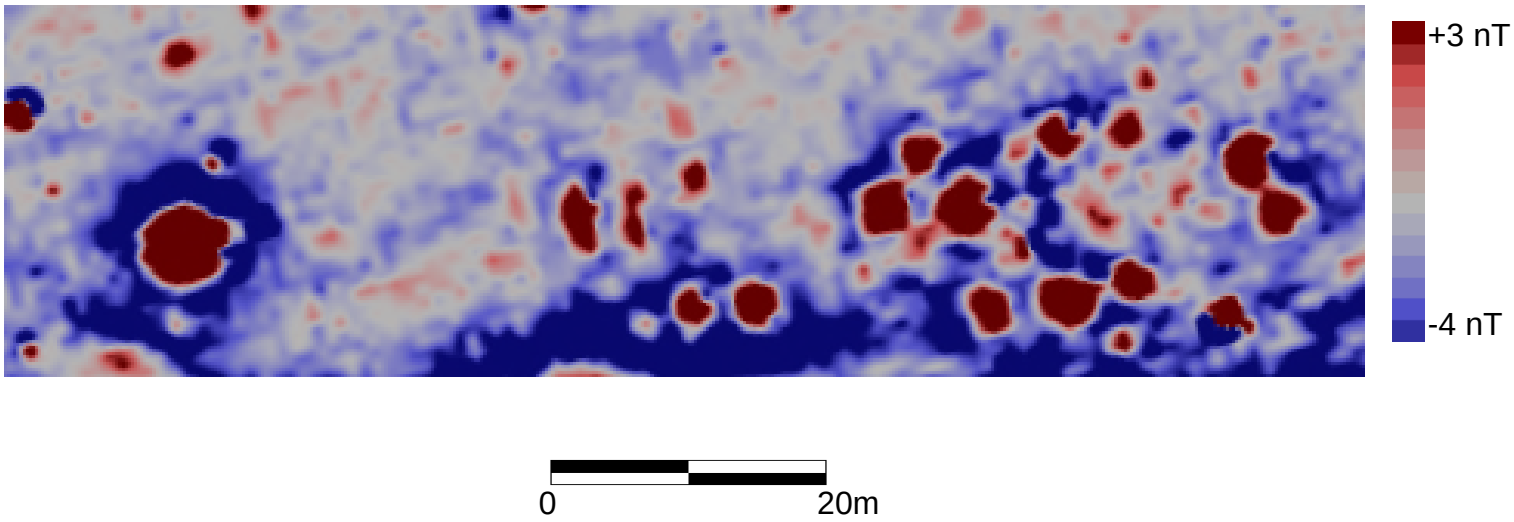
Ditch

- Infill with topsoil creates magnetic susceptibility contrast.



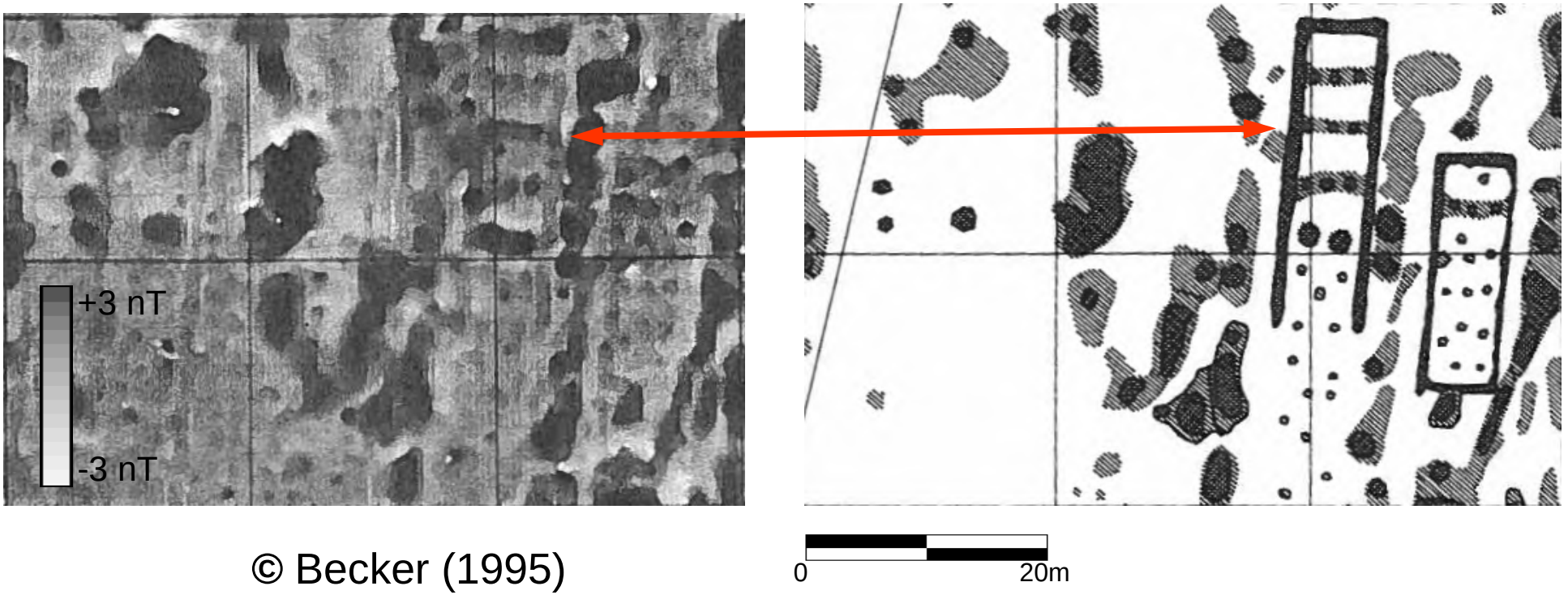
Pits

- Organic fill creates soil with higher magnetic susceptibility.



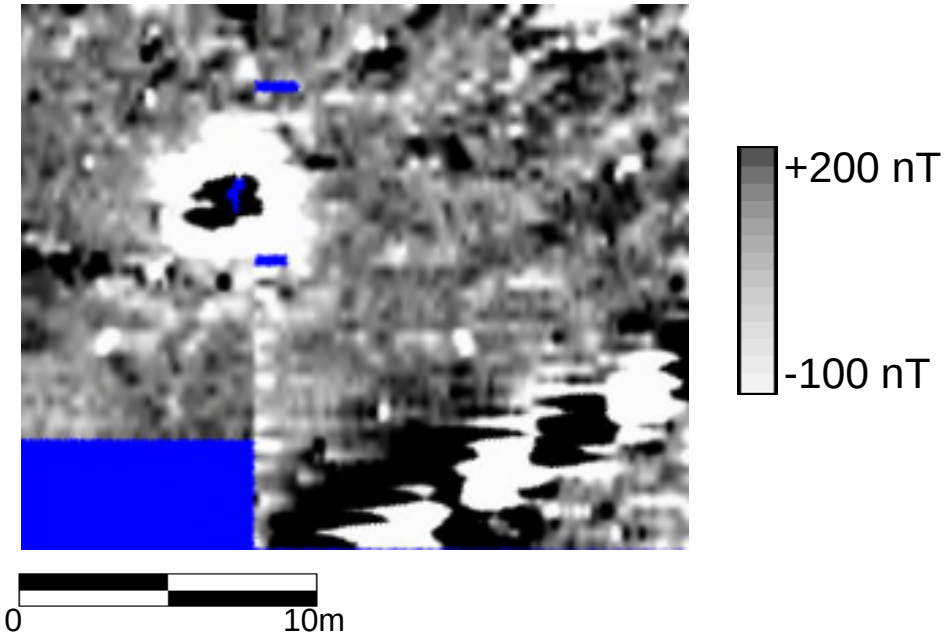
Postholes

- Magnetotactic bacteria in rotten wood create magnetic contrast in quiet background.



Ferrous objects

- Iron has very high magnetic susceptibility and can create massive magnetic signal that mask everything else.



Measuring Magnetic Susceptibility

Laboratory Measurements

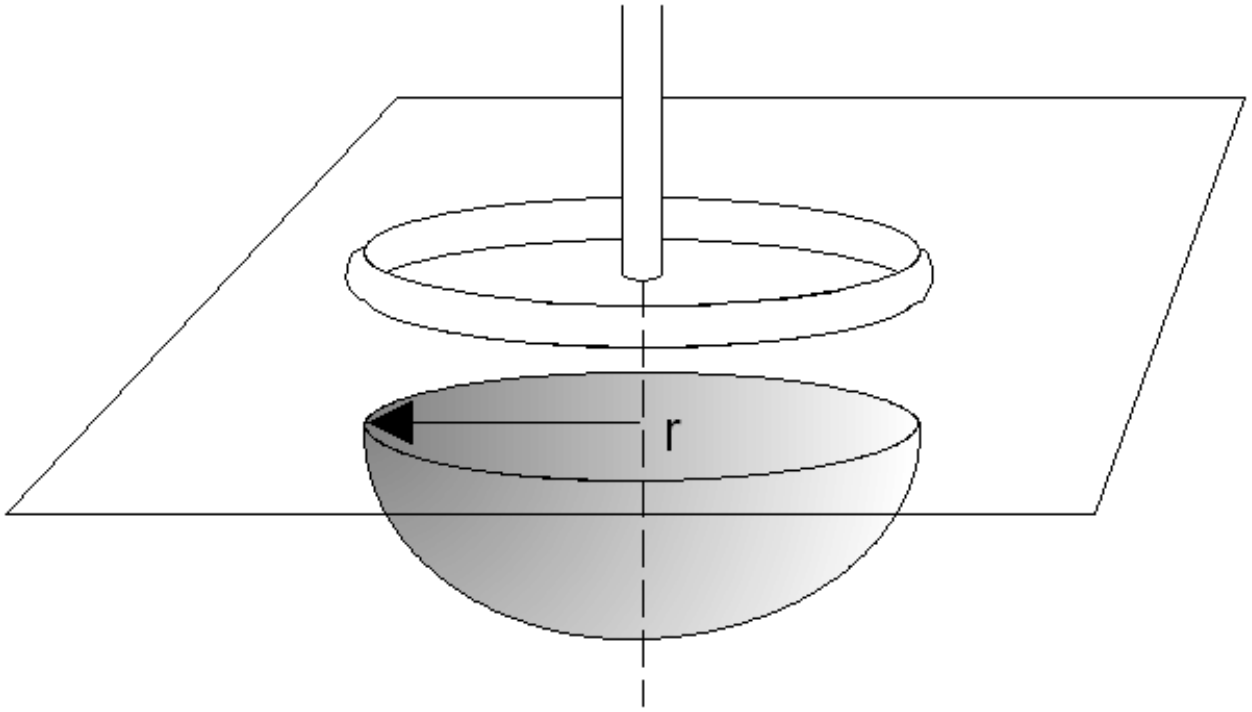
- Collect samples in the field
- Moisture and grain-size control of samples
- Laboratory measurements with small coils

Field Measurements

- ‘Field coil’ allows rapid on-site measurements.

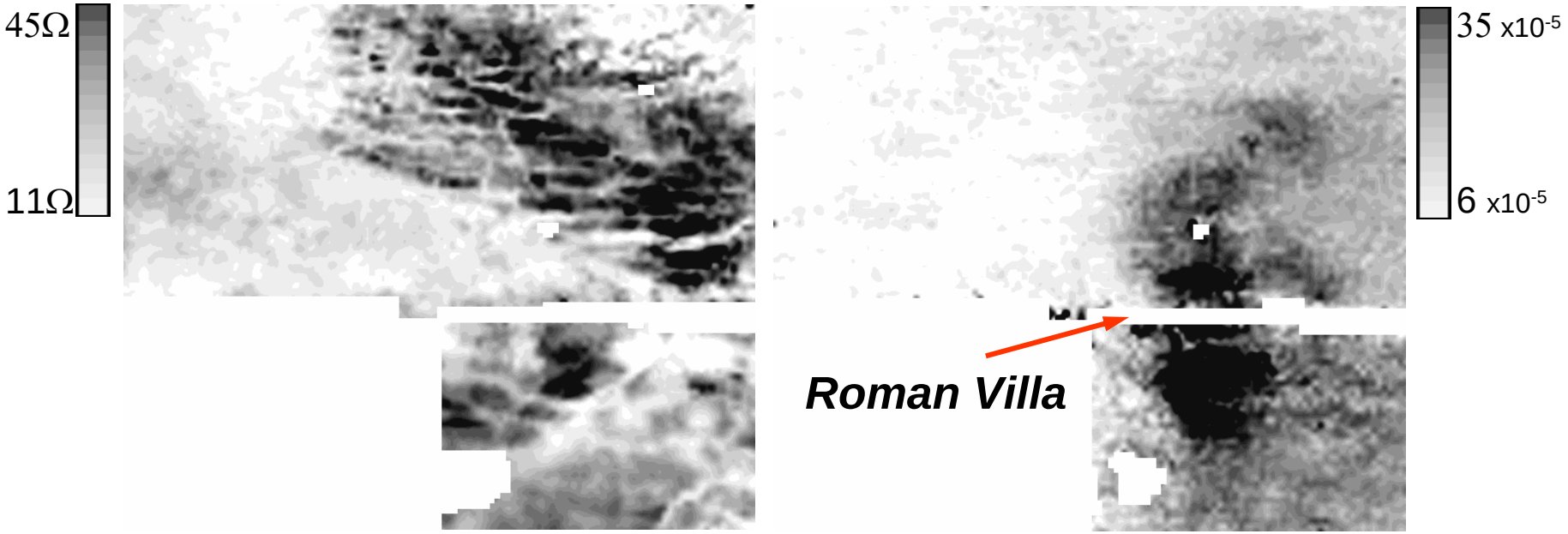
Field Coil (e.g. Bartington MS2)

- Limited penetration depth
  (ca. 0.1 m for 0.2 m diameter)



Magnetic Susceptibility Surveys

- Dense sampling (e.g. 1m) to reveal features



Earth Resistance

Magnetic Susceptibility

Magnetic Susceptibility Surveys

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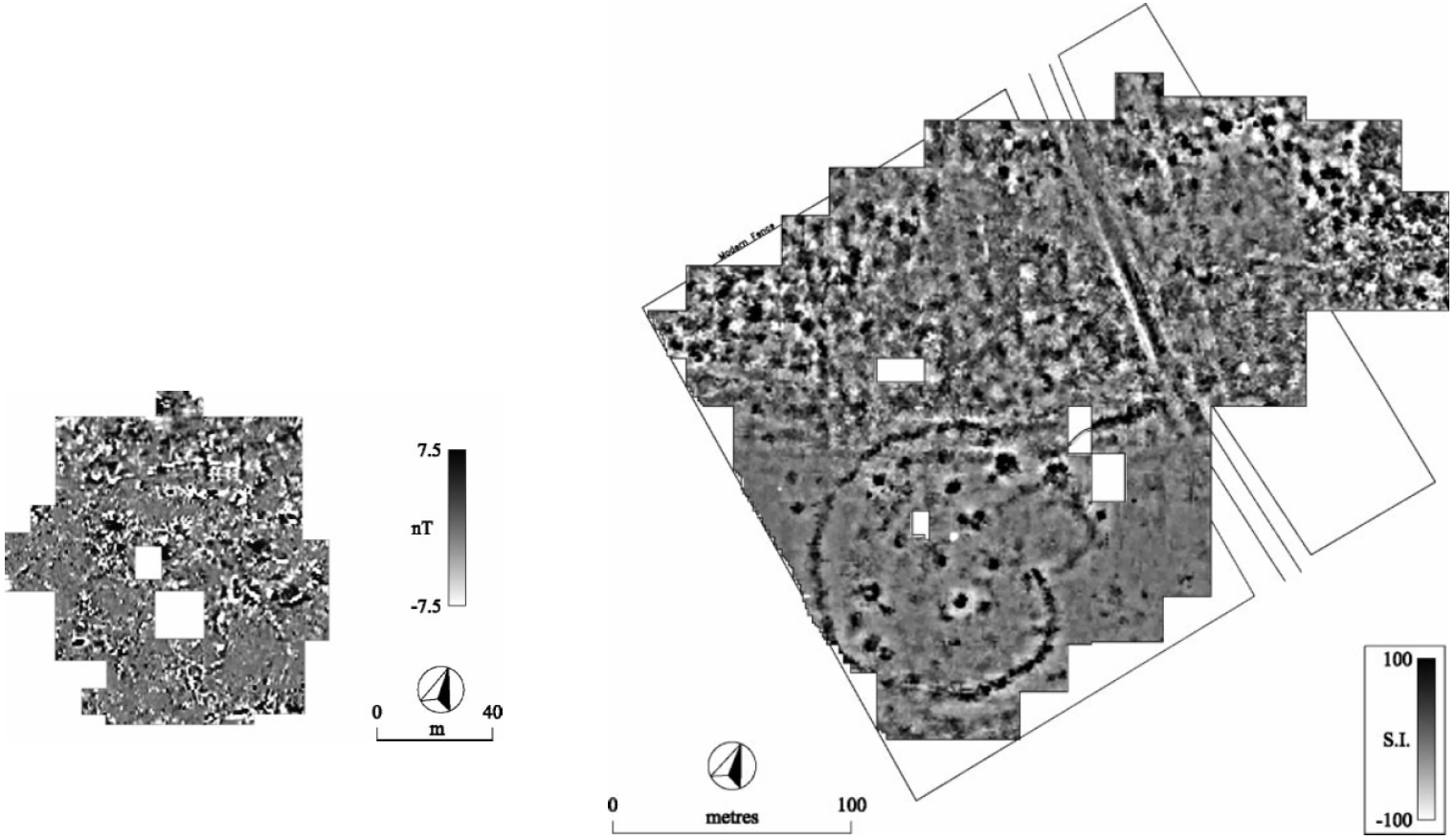
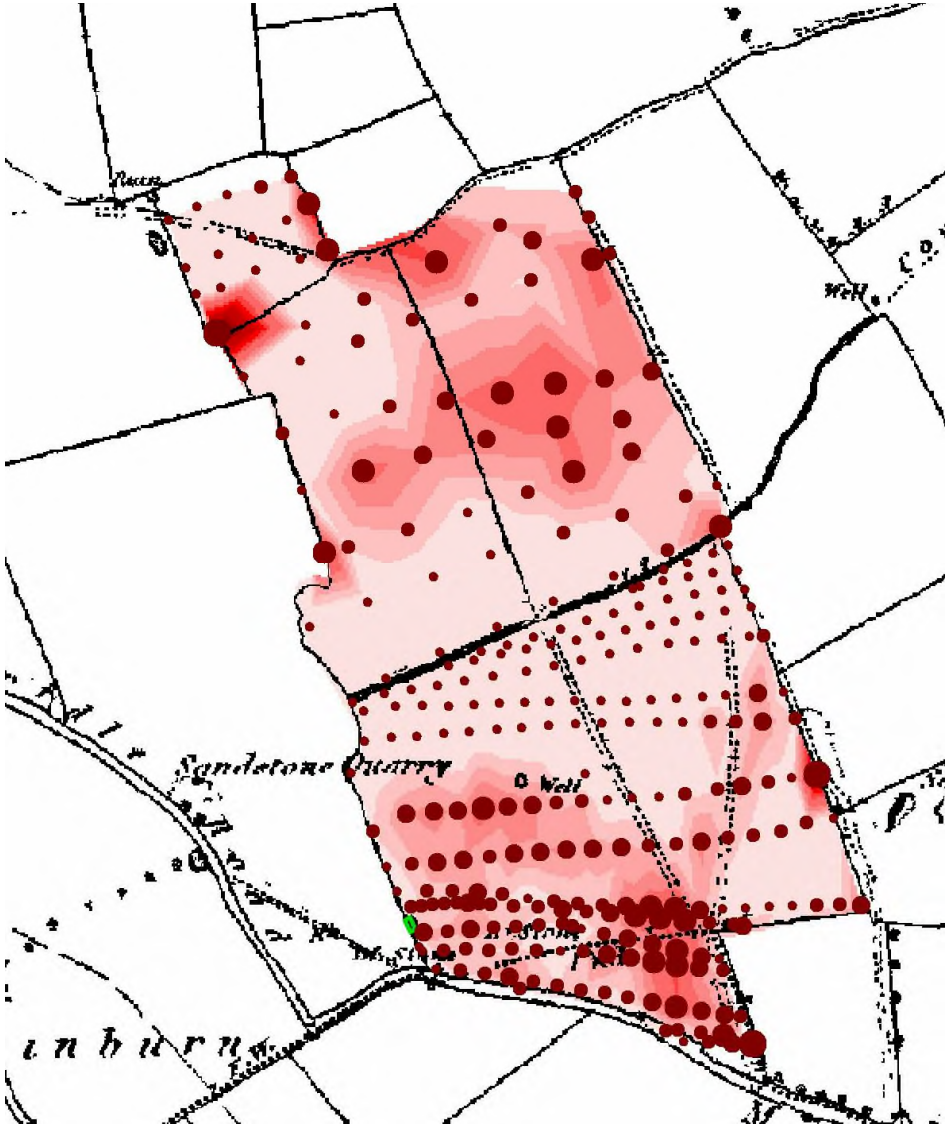


© Gaffney et al (2005)

Magnetic Susceptibility Surveys

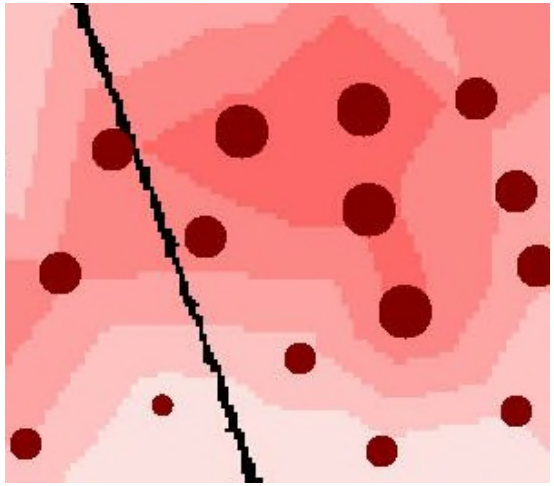


Sparse sampling (e.g. 20m) to achieve overview and identify ‘hotspots’

Kirkby Overblow

Magnetic Susceptibility Surveys

- Plotting smooth variations may be misleading as values can vary widely even over 1m
- Symbol plots may be more appropriate



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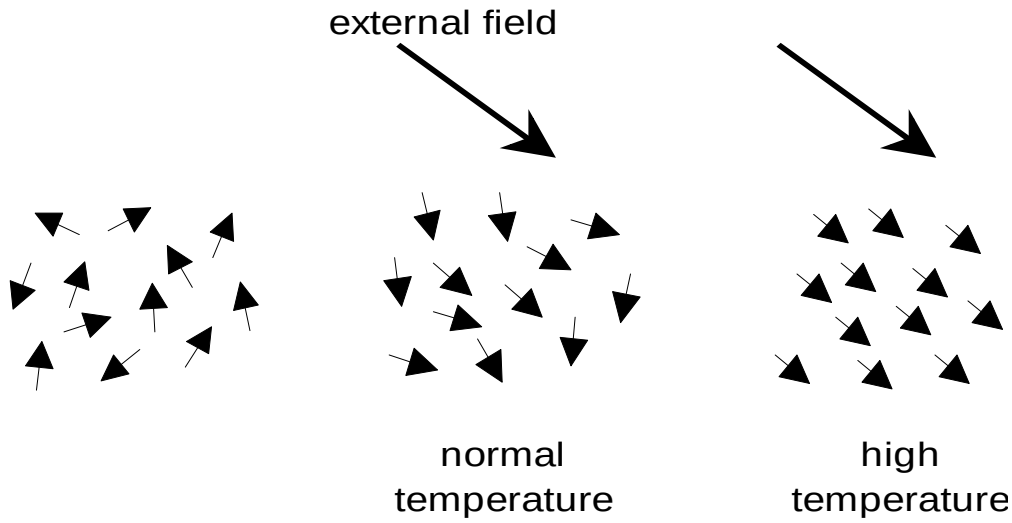
Remanent Magnetisation

- Very high temperature (>670°C):
  magnetic particles very mobile, align with mag. field



- Subsequent cooling:
  alignment is ‘frozen’, strong magnet created

Remanence in Archaeology

- Also for archaeomagnetic dating

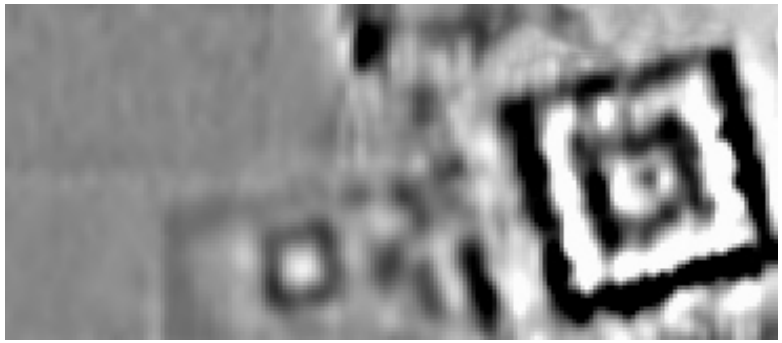
- Examples: kilns, hearths, fired bricks

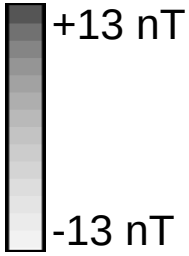
Kilns

- Fired kiln structure has remanent magnetism.

Bricks

- Fired bricks retain magnetisation, but are arranged randomly as blocks.

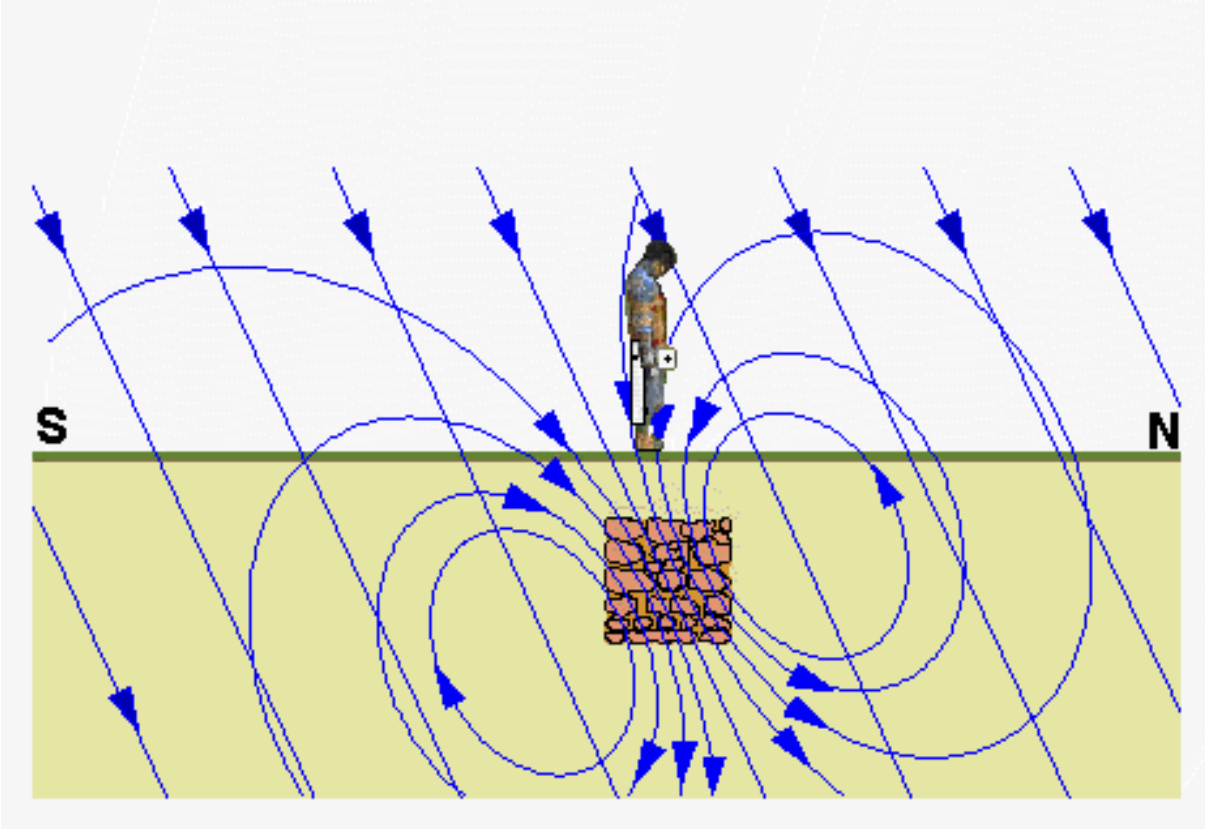




Measuring Magnetic Fields

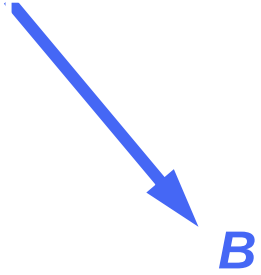
Magnetic Anomalies

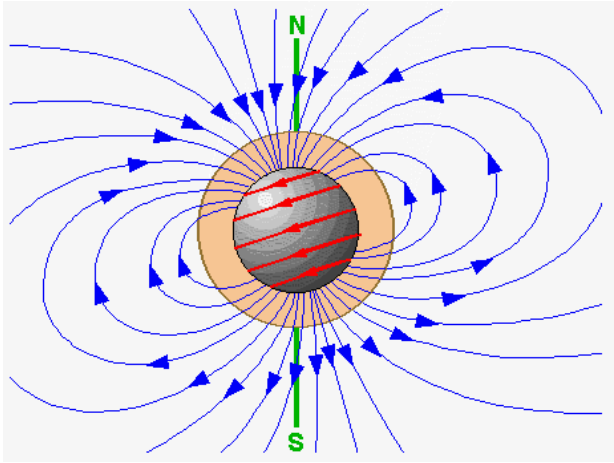
- Magnetisation creates magnetic field
- Magnetometer to measure the anomaly



Types of Magnetometers

- Magnetic field has direction and intensity (vector)





- Sensor **type**
  - fluxgate:
    measures only component of field in one direction
  - caesium vapour:
    measures field intensity, independent of direction.

Arrangement of Magnetometers

- Single sensor is affected by background variation of earth's magnetic field
  - Diurnal Variations

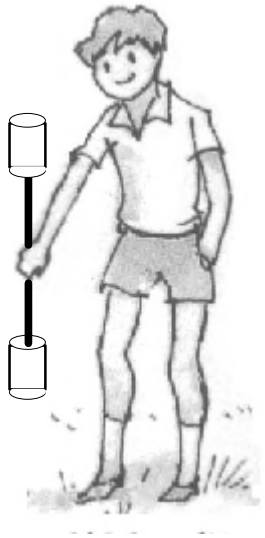
Arrangement of Magnetometers

- Single sensor is affected by background variation of earth's magnetic field
  - Magnetic Storms
    29 October 2003: ± 1000nT

Arrangement of Magnetometers

- Gradiometer eliminates all effects of changes in earth's magnetic field

Single Sensor



Gradiometer

Type and Arrangement

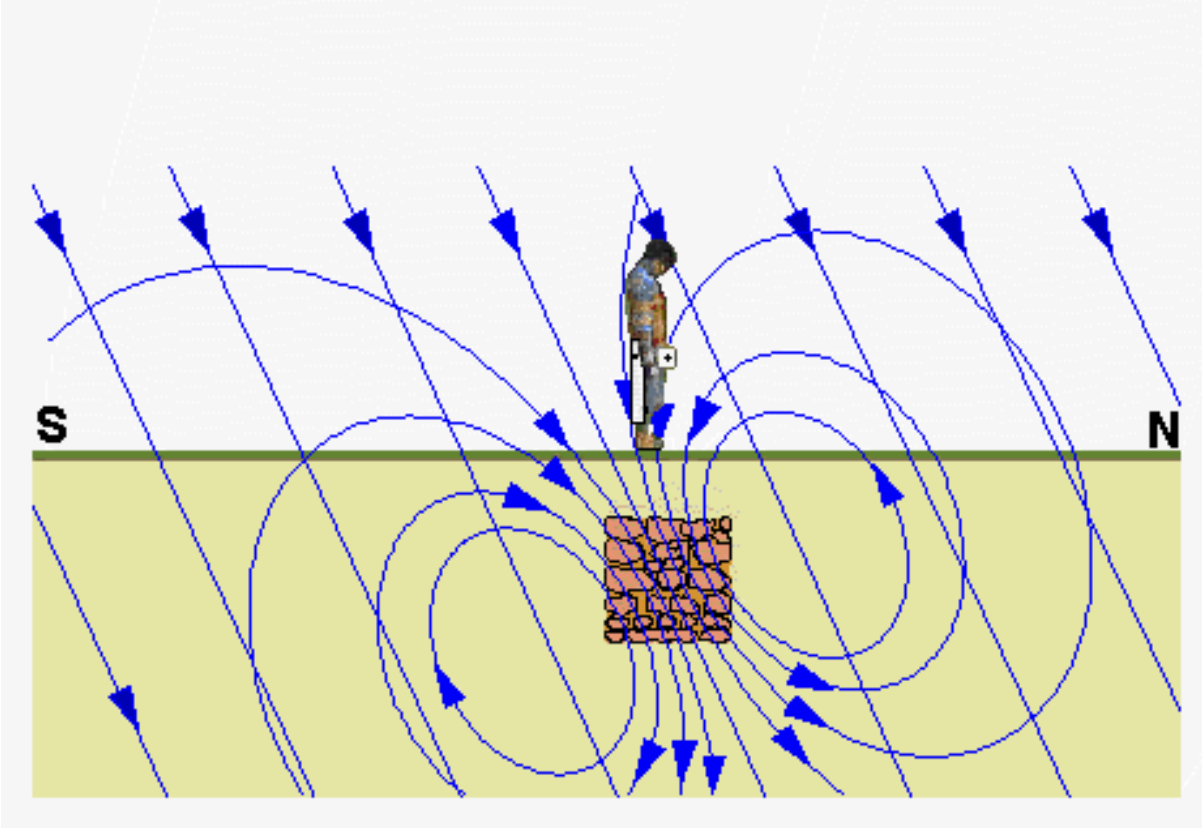
- Total field single sensor (or duo-sensor)

Type and Arrangement

- Fluxgate Gradiometer

Magnetic Anomalies

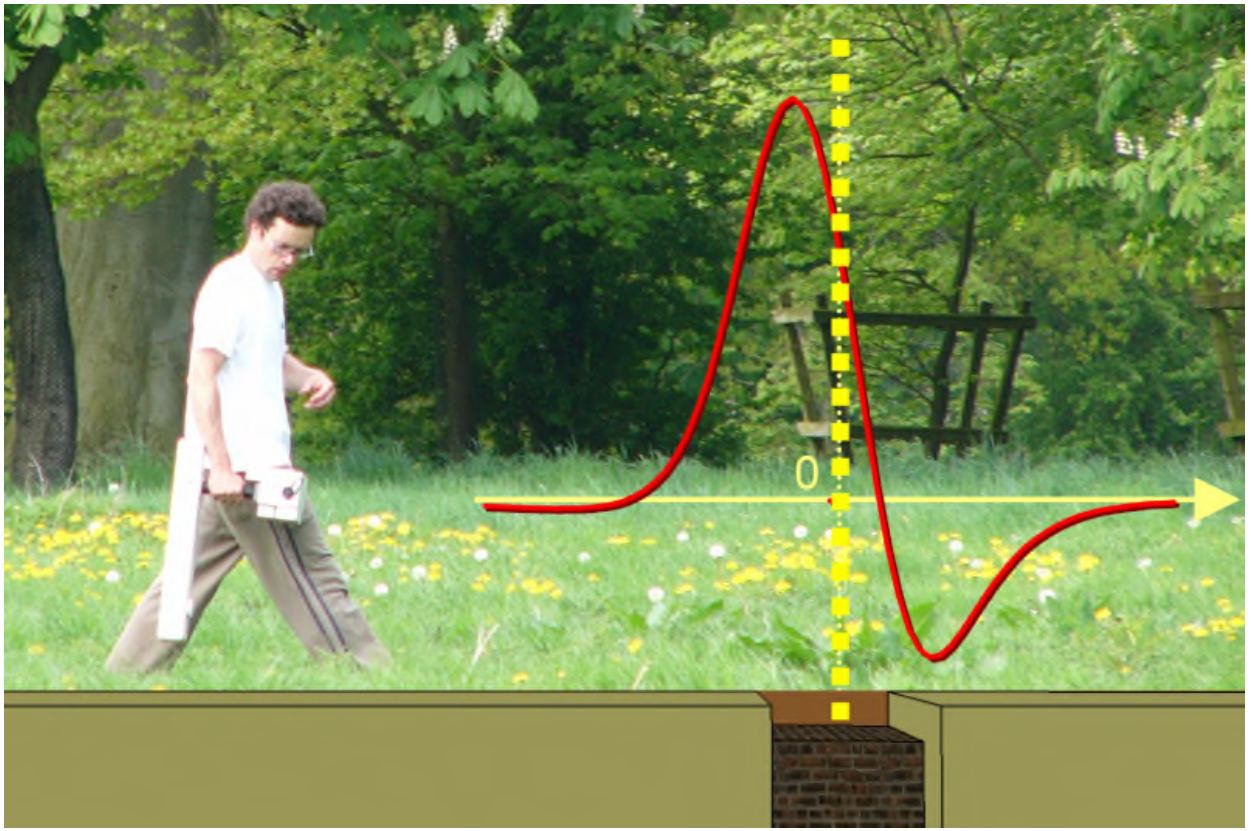
- Magnetisation creates magnetic field – anomaly



- Combination of earth's field and anomaly is total field [in nano Tesla – nT]

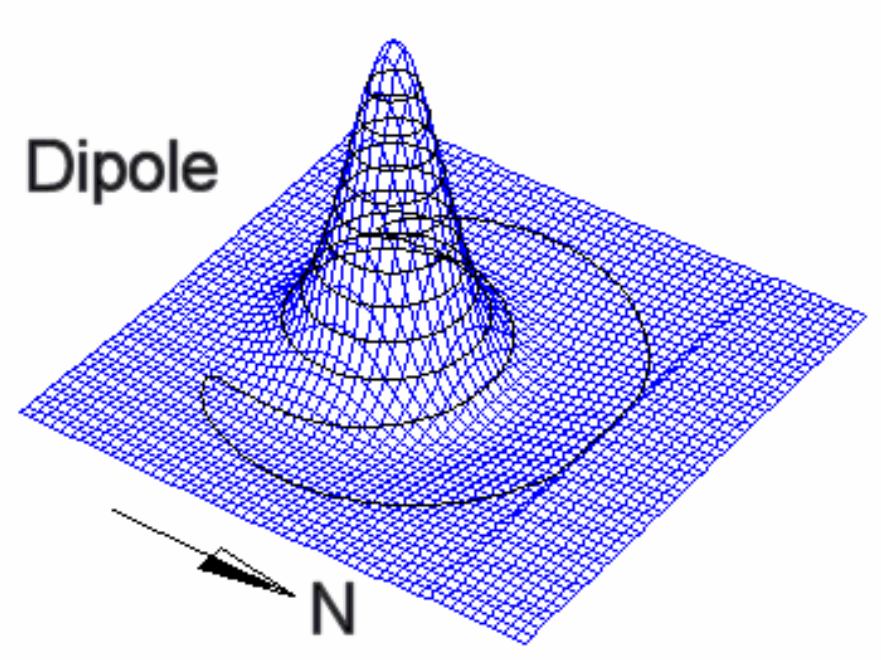
Magnetic Anomalies

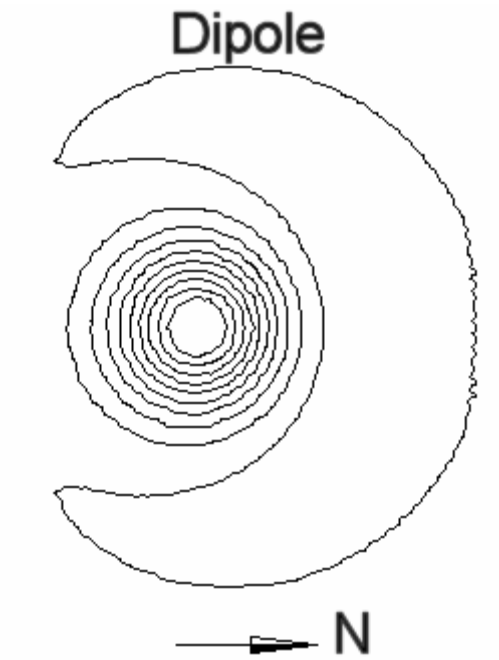
- Magnetic anomalies are not symmetric
- Positive maximum is shifted to the south, additional negative minimum to the north



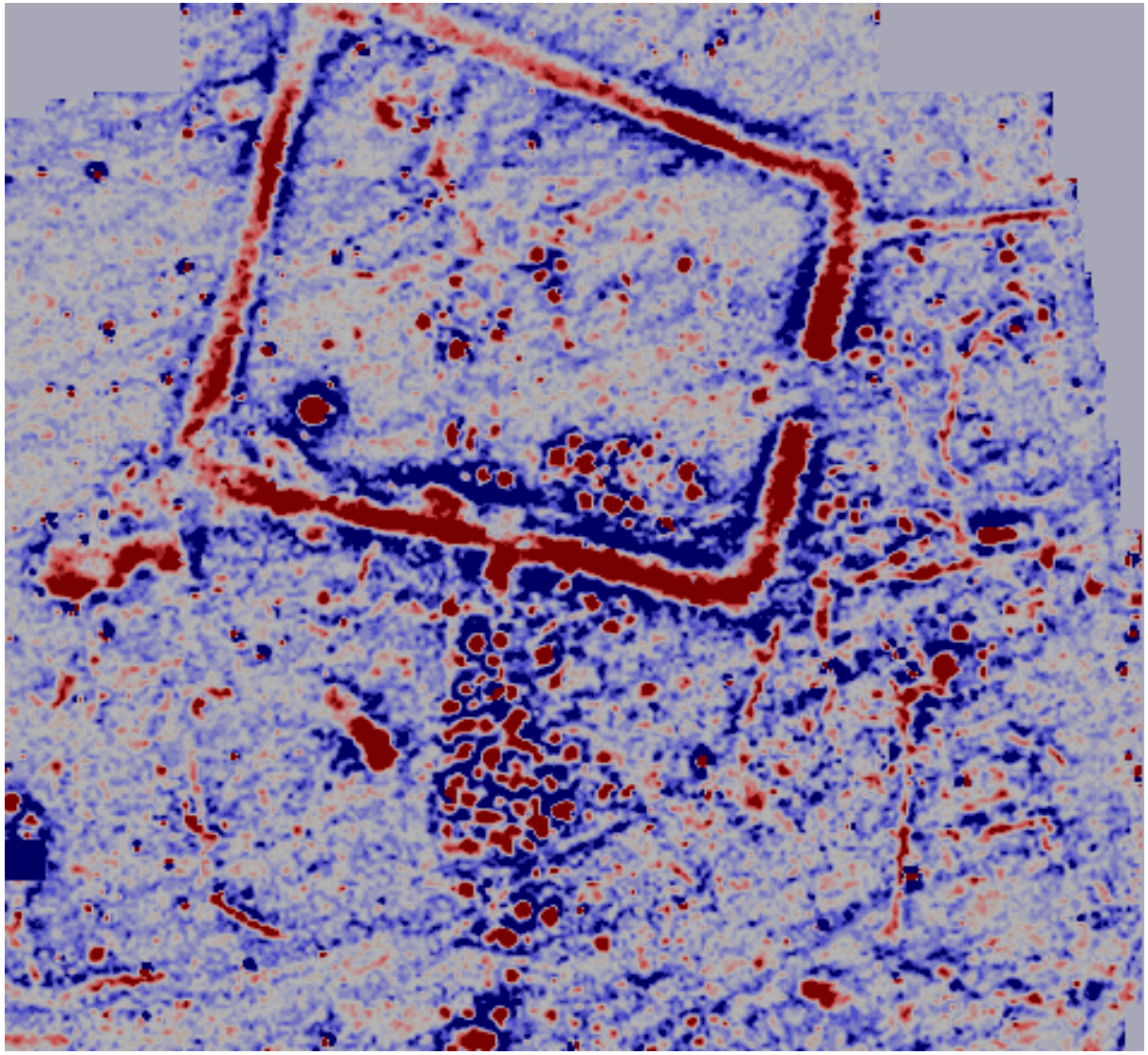
Magnetic Anomalies

- In 2D





Magnetic Anomalies



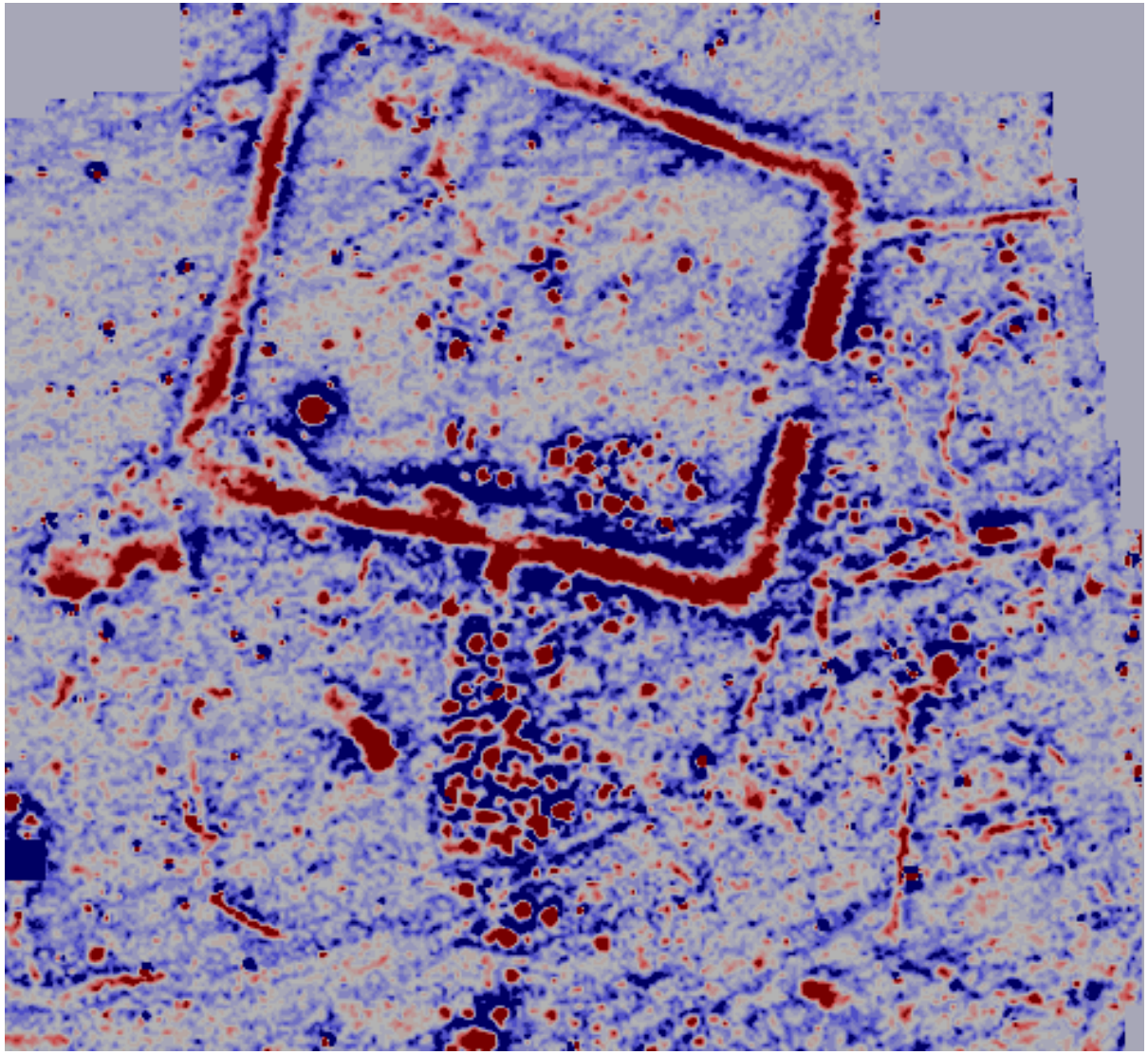
Temple Guiting
Middle Ground

+3 nT

-4 nT

0 40m

Magnetic Anomalies



Temple Guiting
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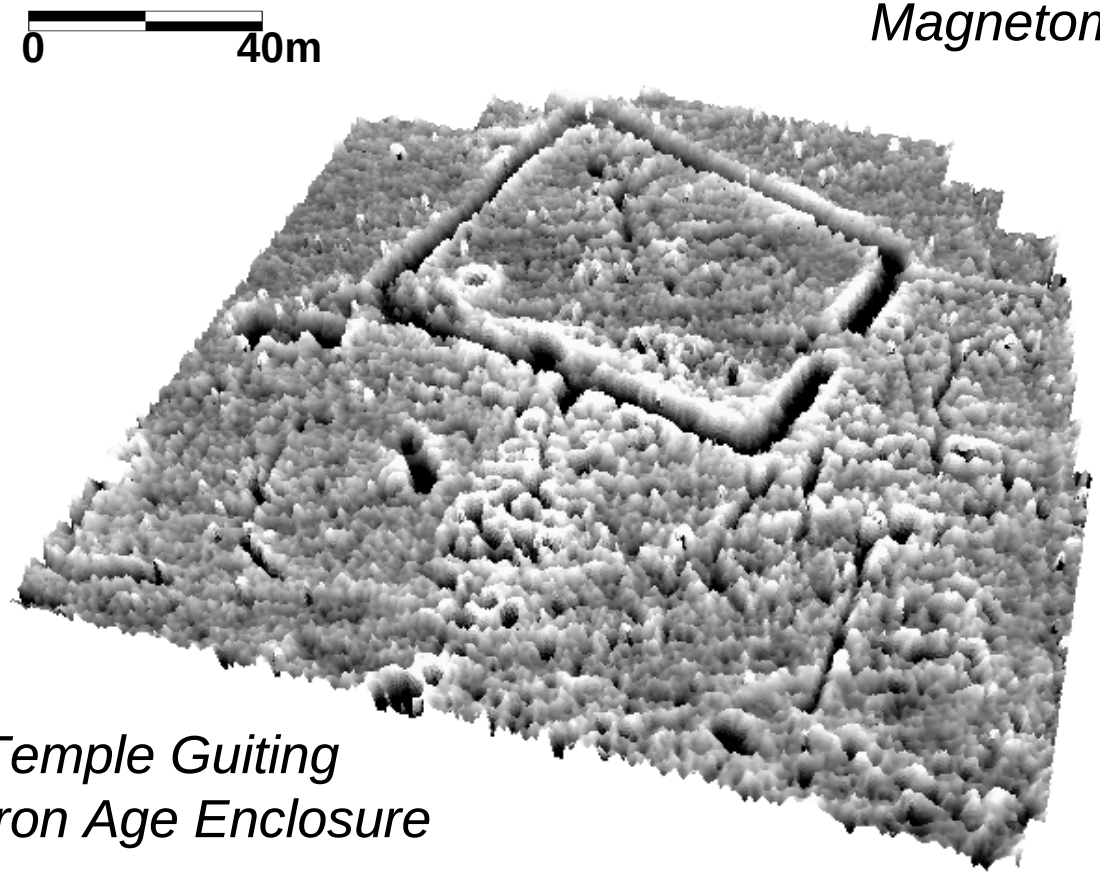
Magnetic Anomalies

- This visualisation: positive data point down.

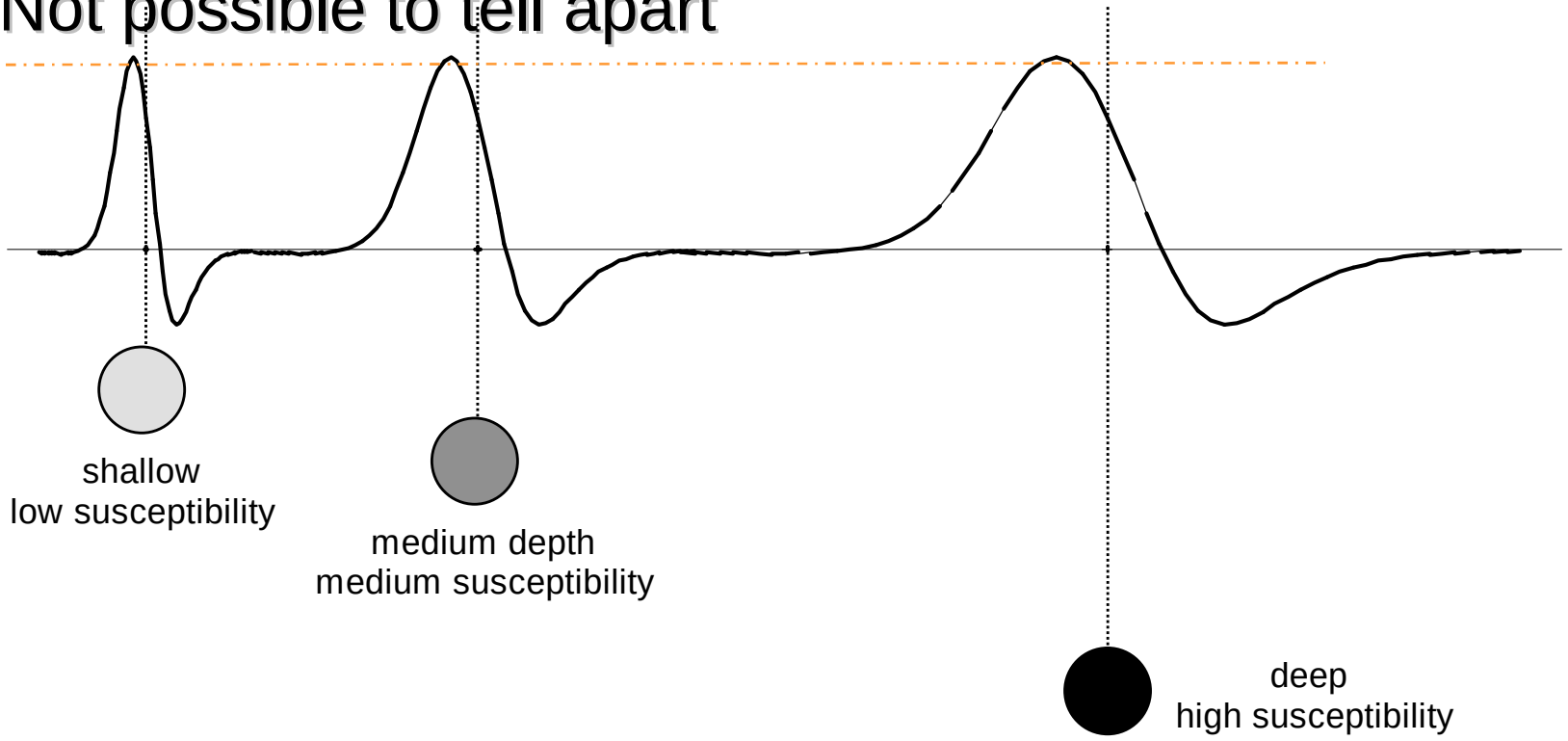


Magnetometer survey
+/- 4 nT

Temple Guiting
Iron Age Enclosure

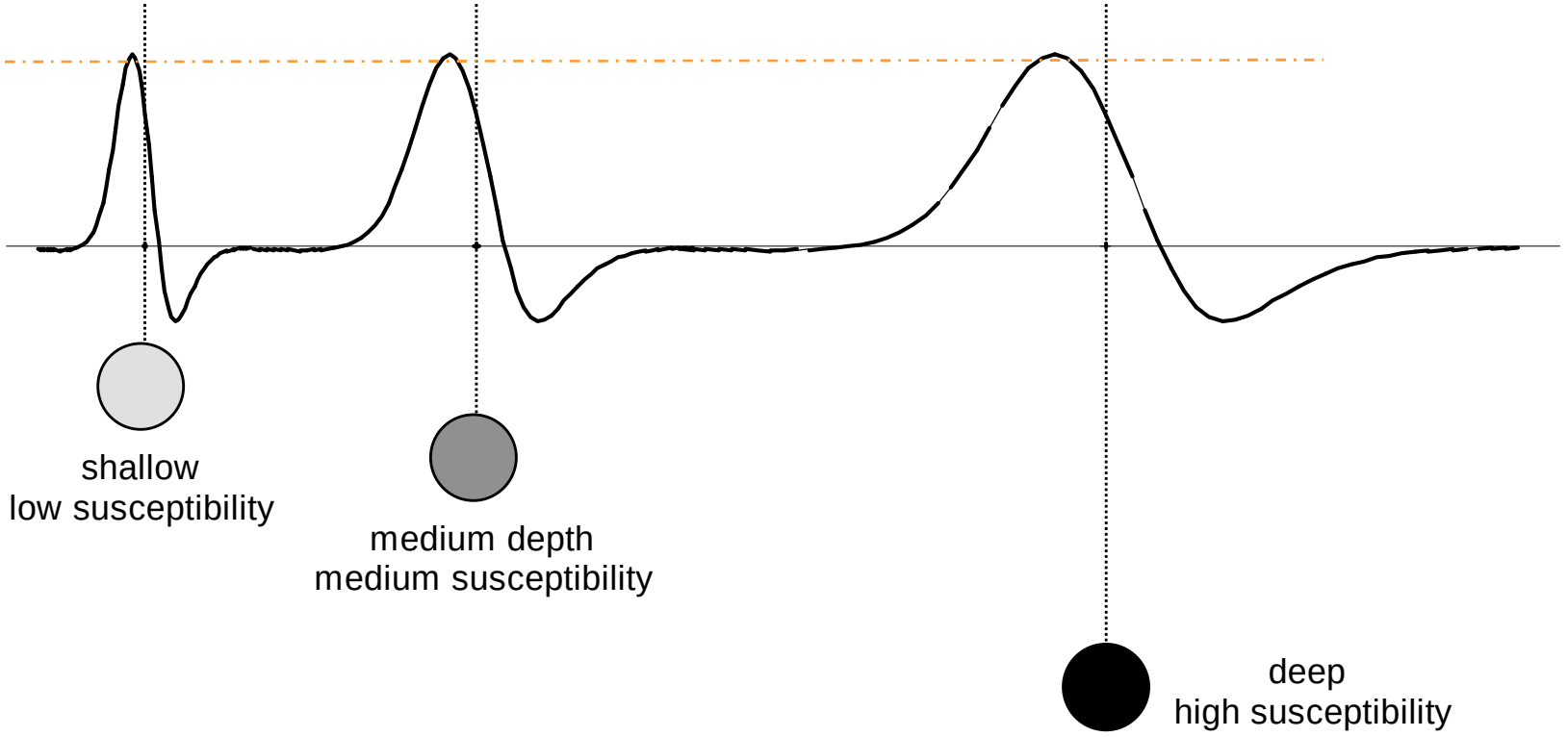
Magnetic Anomalies

- What does strength of magnetic signal mean?
  - depends on magnetisation ($\propto m$)
  - depends on depth ($\propto r^{-3}$)
- Not possible to tell apart



Magnetic Anomalies

- Smoothness indicates depth
- ‘broad=deep, sharp=shallow’



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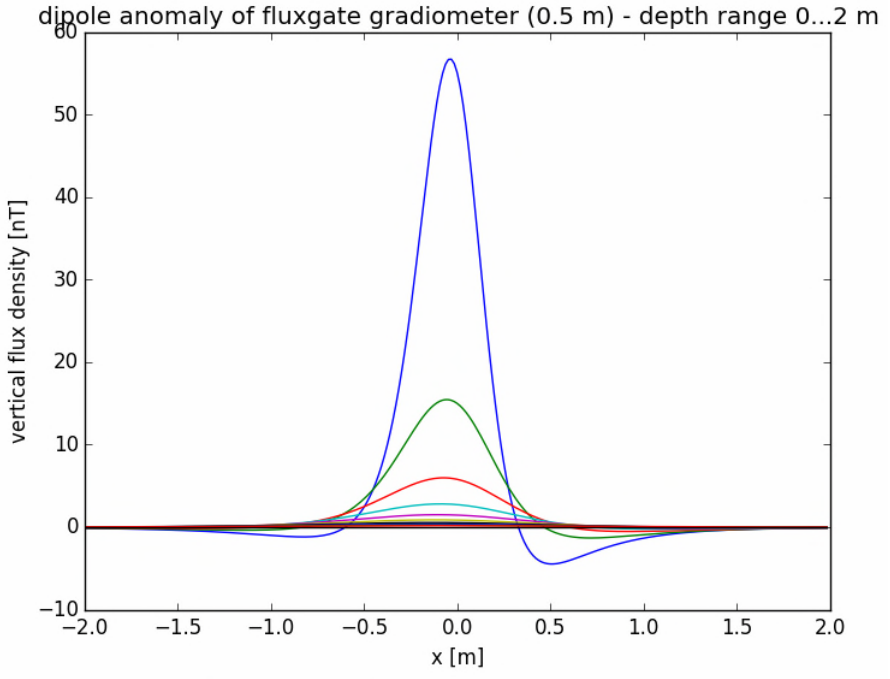

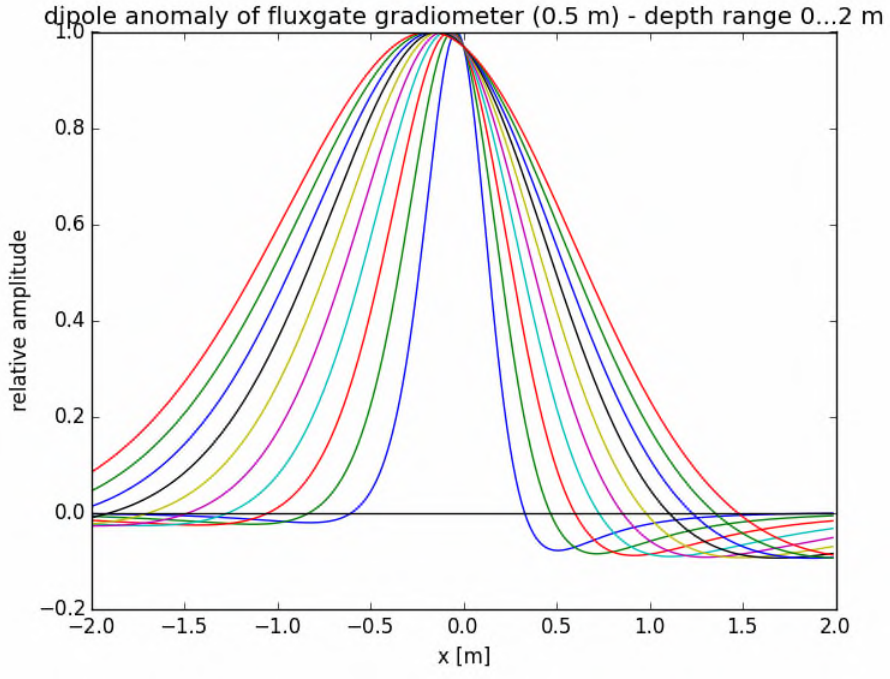

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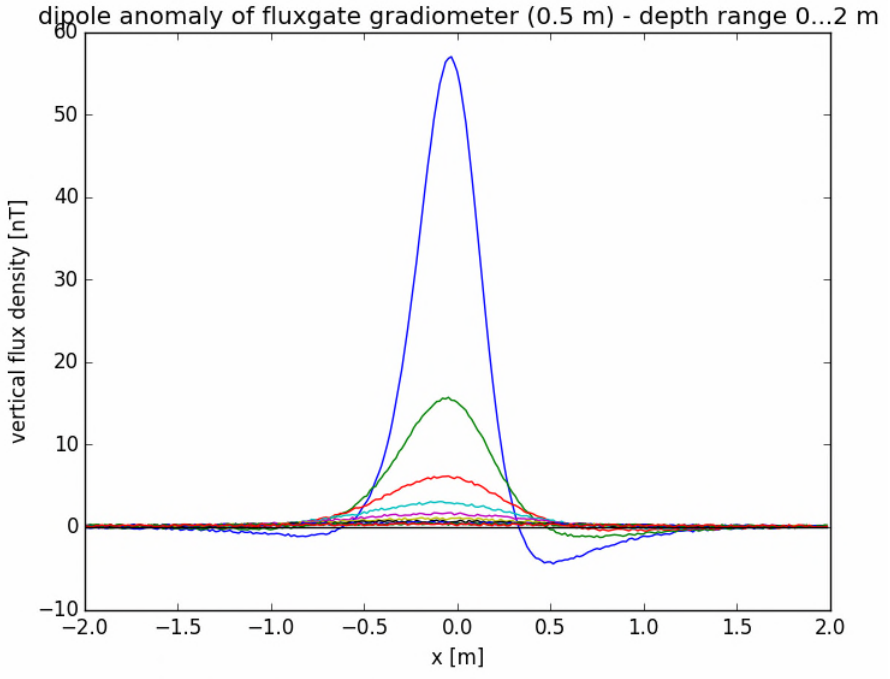
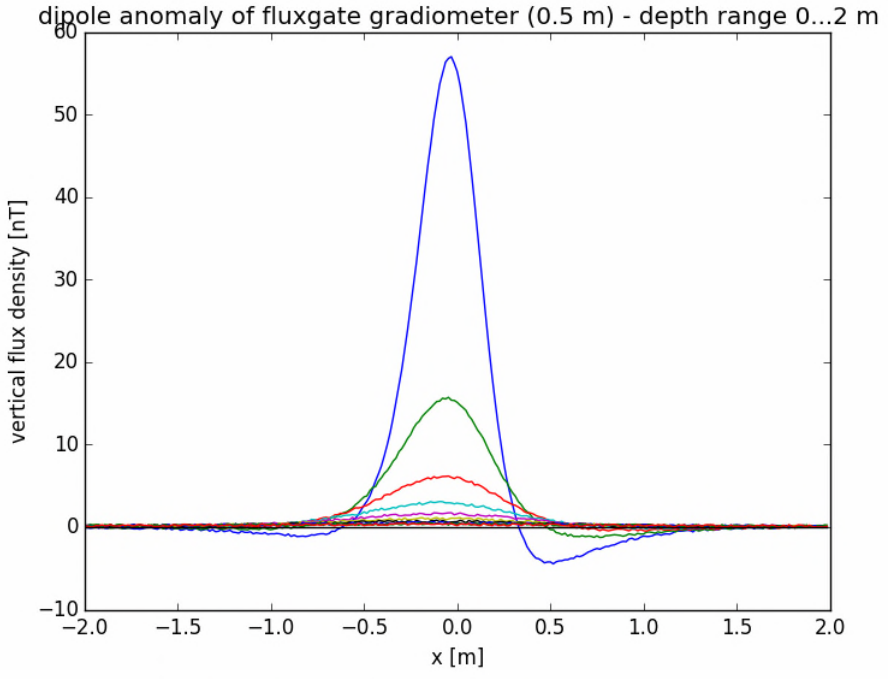
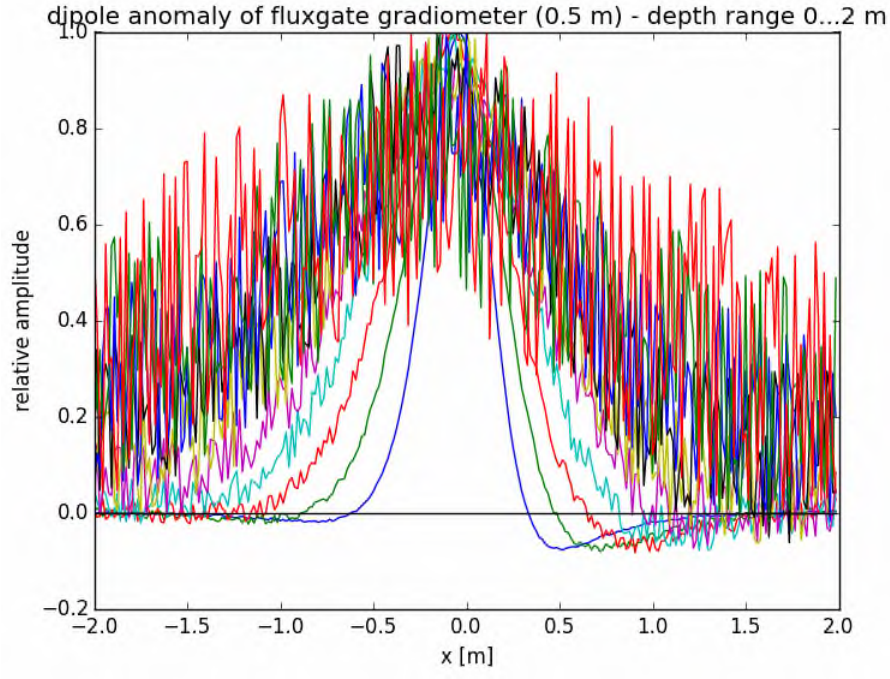


Magnetic Anomalies

- Smoothness indicates depth
- ‘broad=deep, sharp=shallow’
- Noise 0.3 nT – deep features unclear





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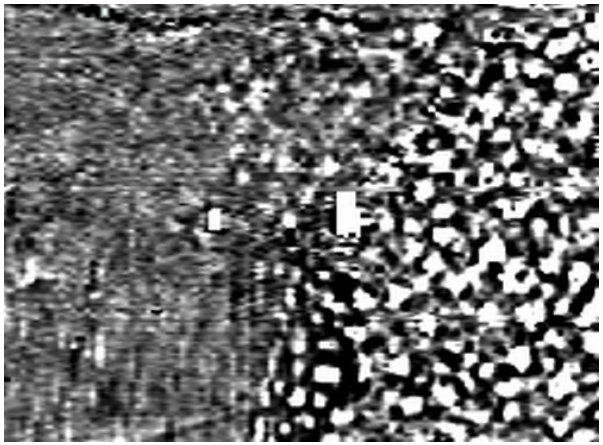
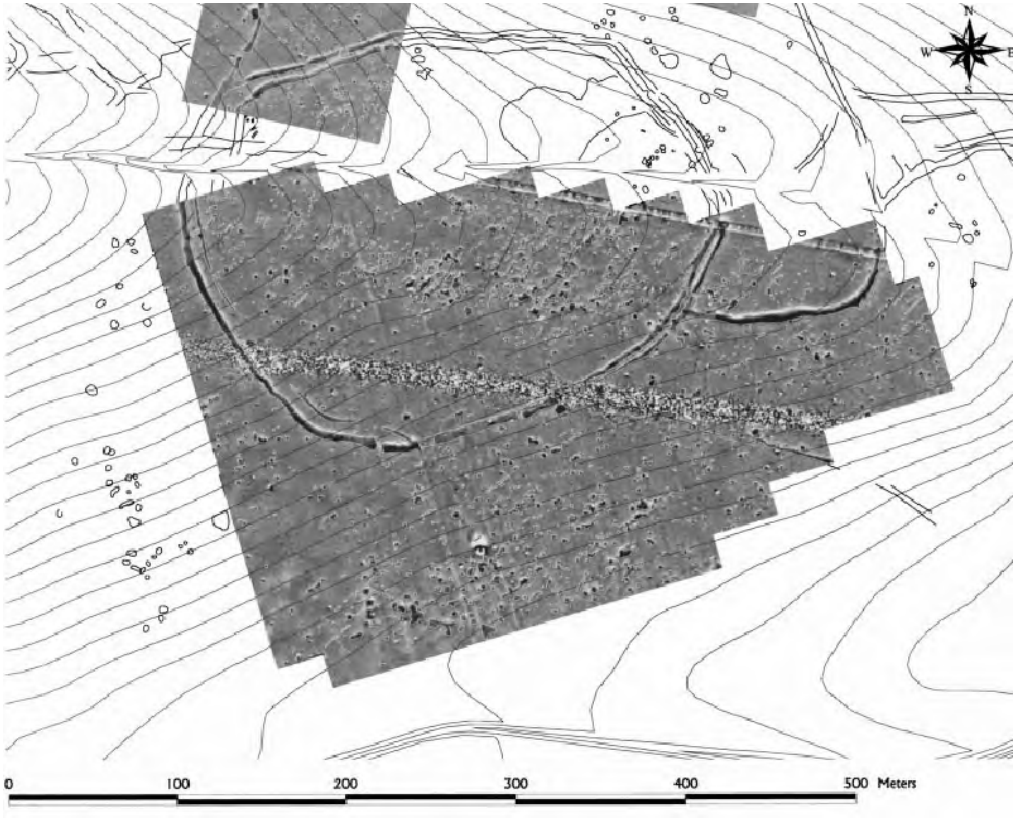
  ↑ *not unique, but reasonable assumptions*
- Geophysical contrast (e.g. magnetic susceptibility)
  ↑ *not unique, especially with noise*
- Geophysical measurement (e.g. magnetic anomaly)



Data Analysis

- Whether small areas or large areas:
  - Many anomalies - derive features
  - Provide archaeological meaning



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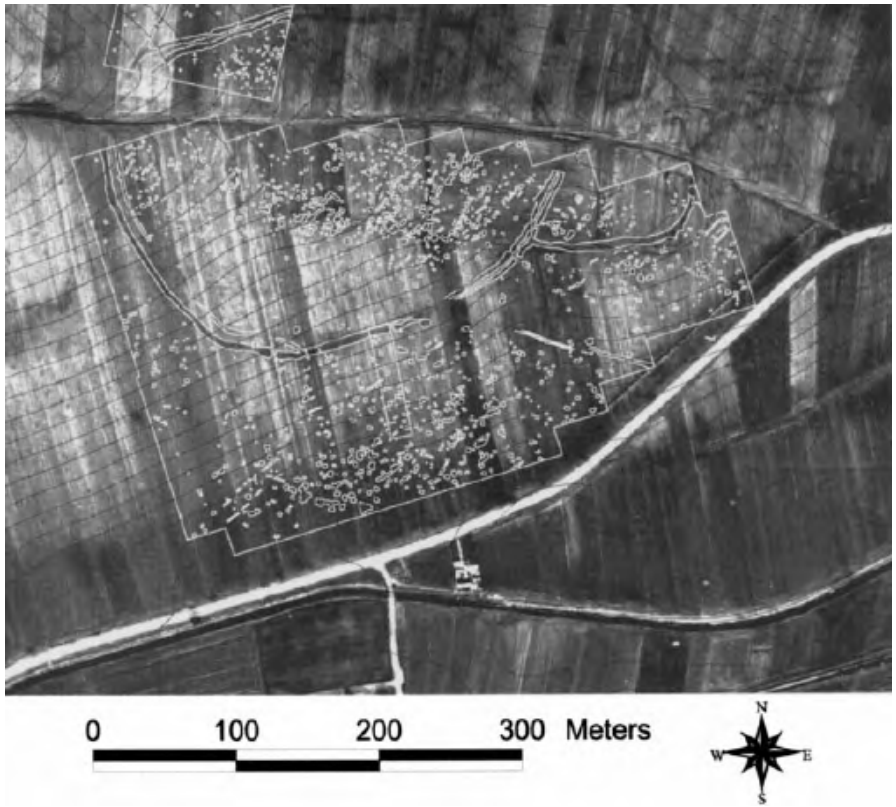

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