# Circus Activity: Electrical ground probing – Earth-resistance surveying

**Topic addressed:**
Electrical resistance and electric fields used to provide sub-surface images.

**Physics GCE AS and A Level specification references:**

| | |
|---|---|
| AQA A | 3.1.3 Module 3, Current Electricity. Most sections within the module are covered in this activity. |
| AQA B | 3.4.3 Module 3, Imaging the Invisible. C Resistivity and seismic surveys. Review of how concepts in waves and electricity learned in AS are used in mineral exploration. |
| CCEA | 1.11 Resistance, resistivity.<br>1.11.5 recall and use the equation: R = ρ*l/ A.* |
| EDEXCEL Concept-Led Approach | 2.4 DC Electricity.<br>57 investigate and use the relationship $R = \rho l/A$. |
| EDEXCEL Context-Led Approach | 8.5 Digging up the Past (DIG).<br>57 investigate and use the relationship $R = \rho l/A$. |
| International Baccalaureate (IB) | 5.1 Electric potential difference, current and resistance.<br>5.1.7 Apply the equation for resistance in the form $R = \rho l/A$ where $\rho$ is the resistivity of the material of the resistor. |
| OCR A | G482 Module 2: 2.2 Resistance. 2.2.4 Resistivity.<br>(b) select and use the equation $R = \rho l/A$. |
| OCR B | Module PA 1: Communication. PA 1.2 Sensing.<br>1, knowledge and understanding of phenomena, concepts and relationships by describing and explaining cases of:<br>(iii) resistance and conductance, including a series and parallel combinations. |
| WJEC | PH1.5 RESISTANCE<br>(h) recall and use $R = \rho l/A$ and understand that this is the defining equation for resistivity. |
| SQA Higher | 2.1 Electric fields and resistors in circuits<br>16 Carry out calculations involving potential differences, currents and resistances in circuits containing resistors. |

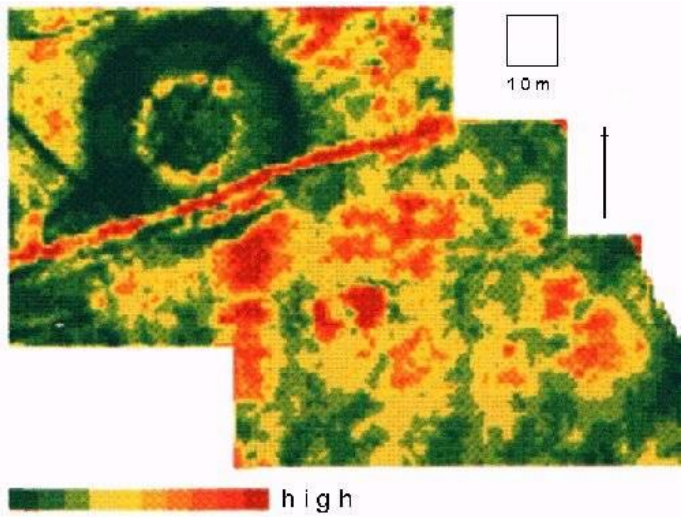
**Student practical or teacher demonstration:**
Mainly a student practical.

**Time needed to complete the activity:**
Approximately 30 minutes.

**Preparation and set-up time:**
Approximately 10 minutes.



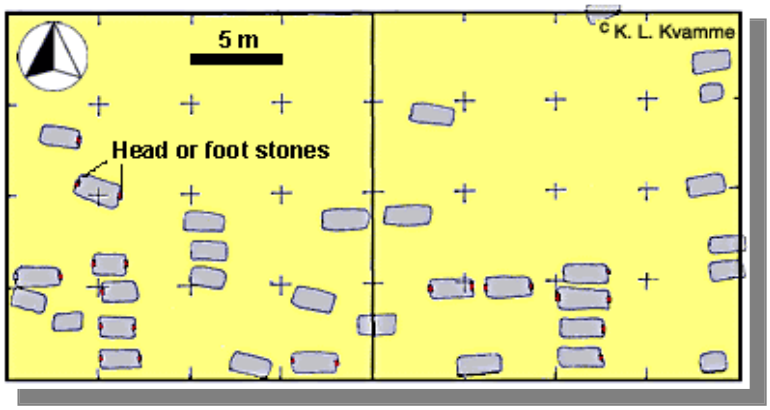
(© Quiller Barrett)




Electrical resistance plot of Guiting Power 3 round barrow – a prehistoric burial mound
(© Alistair J Marshall/Geophysical Surveys of Bradford)

## Resistivity: The Bozeman Cemetery, Arkansas

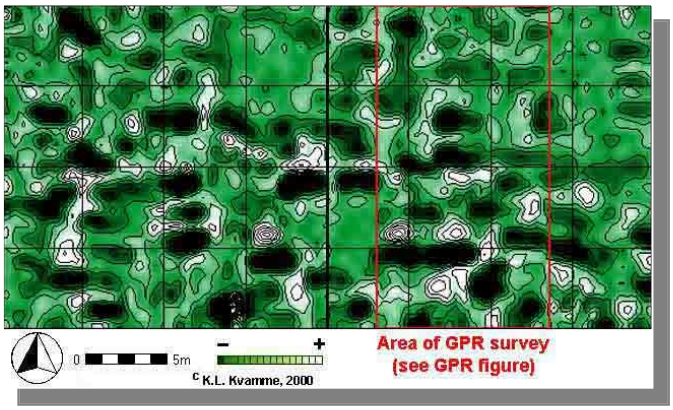

**Map of unknown burials**



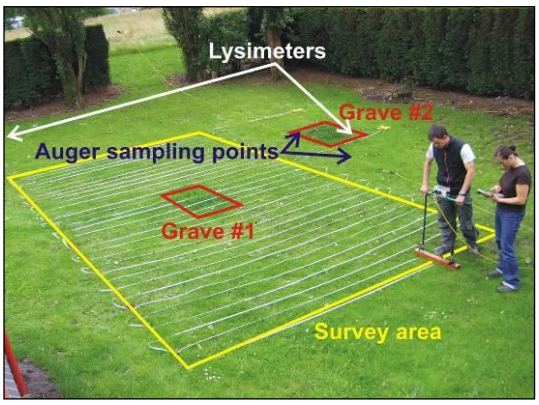

Burials in the Bozeman Cemetery from 1850 – 1950

Contains the graves of a number of prominent families and a number of unmarked/unknown graves, including probable graves of slaves

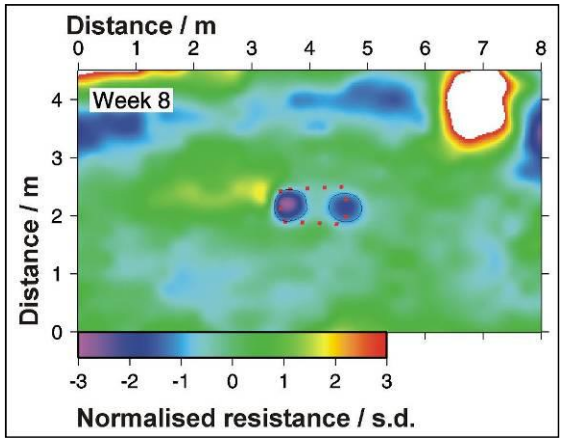
**Resistivity Image**




(© Archeo-Imaging Lab, Department of Anthropology, University of Arkansas)




Resistance surveying over a simulated grave (buried pig body)
(© Jamie Pringle, Keele University)




Earth resistance over a simulated grave (buried pig body)
(© Jamie Pringle, Keele University)

**Resource list:**

**Activity A - Soil resistance**

- 3 beakers (500ml) each with about 400ml of dry sand
- 150ml tap water
- 150ml saturated brine (salt water)
- multimeter
- 2 x 4mm leads
- a piece of wood/plastic (to which the ends of the leads are fastened with an elastic band/tape so that the metal and about 1cm of the plastic is clear of the wood and the ends are about 3cm apart)
- iron bar that will fit lengthways inside a beaker

**Activity B - Electric field lines demonstration or simulation**

Either a demonstration using:

- electric fields apparatus comprising:
  - stand containing petri dish and 2 x 4mm socket terminals
  - point electrodes mounted on 4mm plugs
  - castor oil (enough for 0.5cm depth in petri dish)
  - semolina in a shaker
- EHT supply to deliver 3000 to 4000 volts
- 2 x 4mm leads to connect EHT supply to electrodes

Or a computer simulation as found at http://www.youtube.com/watch?v=bG9XSY8i_q8

See http://www.iop.org/activity/education/index.html and click on Teaching Advanced Physics (TAP), click on Fields and then episode 406.1 which takes you to a very good worksheet with full instructions and safety notes.

**Activity C - Resistance survey**

- multimeter
- 2 x 4mm leads with clean ends (to clean, sand with emery paper)
- hardboard sheet, about 30cm square, with a grid of ready-drilled holes (if the hardboard does not have holes, make them about 2cm apart and just big enough to take the ends of the leads)
- Teledeltos™ paper, the same size as the hardboard sheet (Teledeltos™ paper is electrically conductive, but still fairly resistive paper)
- paper glue
- cooking foil
- cork tile, same size as the hardboard sheet or slightly larger
- strips of wood to make the frame (alternatively use elastic bands or clips to secure everything together)
- pen
- access to a computer running a spreadsheet and graphing package

**Ideas for introducing/leading into the activity:**

Time Team video clips can be downloaded from:
http://www.channel4.com/history/microsites/T/timeteam/

**Brief activity outline:**

**Activity A - Soil resistance**

A very quick practical activity or demonstration to show how the resistance (conductivity) of sand depends on what fluids the sand contains and how buried metal objects can be found.

**Activity B - Electric field lines demonstration or simulation**

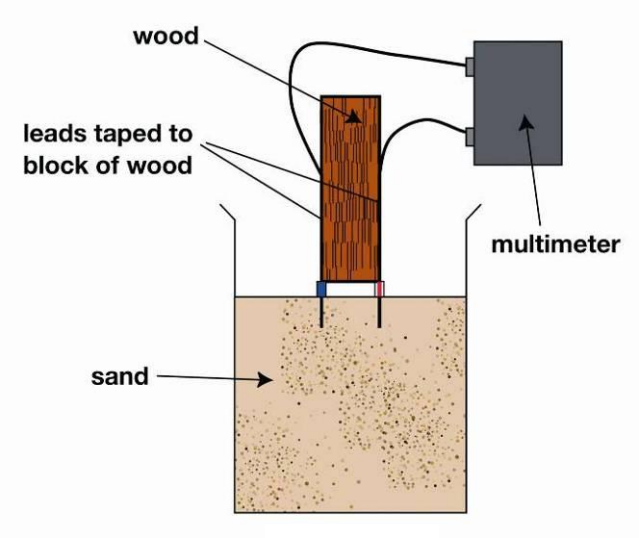
What are we measuring in Activity A? A teacher led discussion, demonstration or computer simulation of the electric fields that are producing the results seen in Activity A. Discussion of the effect of ions on the results.

**Activity C – Resistance survey**

Practical: model of a resistance survey.

**Description of activities in detail:**

**Activity A - Soil resistance**
A simple investigation into how the resistance of soil (sand is used as 'soil' in this demonstration) depends upon the types of fluid it contains. Note that resistance is the opposite of conductivity; the lower the conductivity, the higher the resistance of the material.

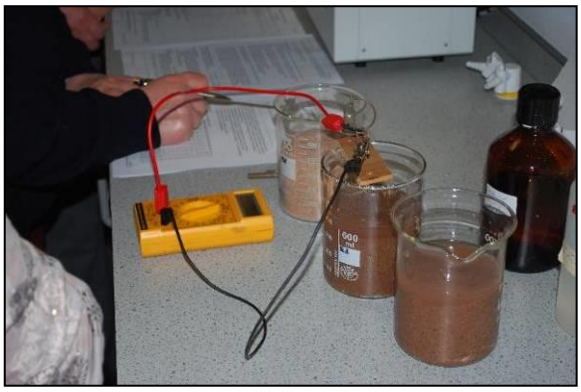


(© ESEU)

- A multimeter is used to measure the resistance of 'soil' in three different beakers; one containing dry sand, one containing sand soaked in tap water and one containing sand soaked in salty water. The results recorded.
- Ask participants to watch what happens to the readings if you leave the meter in the salty wet sand for a minute.
- Then try adding the iron rod, lengthways, to each beaker in turn to see what difference, if any, this makes to the resistance.

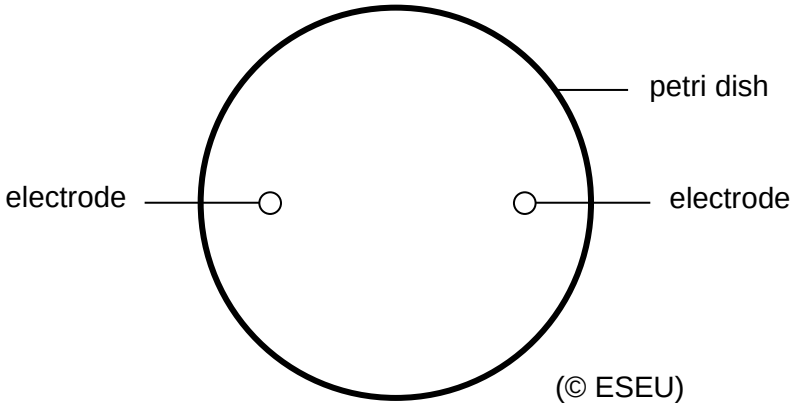
The results show infinite resistance for dry sand, high resistance for sand plus tap water and a lower resistance for salty wet sand because the ion-rich water is a good conductor. The iron rod causes even lower resistance in waterlogged sand.

There are two problems with this activity. The first is that there is a very high contact resistance between the electrodes and the sand so the difference between tap water and salty water is relatively small. Secondly the ions dissolved in the water in the sand are very mobile and the measuring current polarises the ions, which collect round the electrodes. This has the effect of increasing the measured resistance over time so the results are not steady. Commercial resistivity survey apparatus gets over this problem in various ways.


Resistance Measurer (© ESEU)

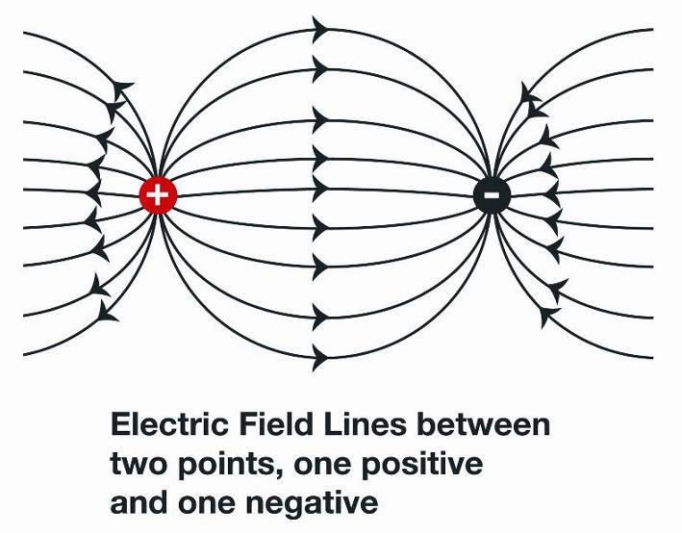
**Activity B - Electric field lines demonstration or simulation**
Carry out the demonstration as follows:

- Fill the petri dish with castor oil to a depth of about 0.5cm.
- Sprinkle a thin layer of semolina over the surface (better to begin with too little rather than too much).
- Put the two electrodes in the castor oil in the positions shown.



(© ESEU)

- Connect the two electrodes to the leads and the leads to the EHT supply.
- Adjust the supply to give 3000 to 4000 volts and turn on.
- Watch the field lines become visible in the semolina as in the diagram below.



**Electric Field Lines between two points, one positive and one negative**

(© ESEU)

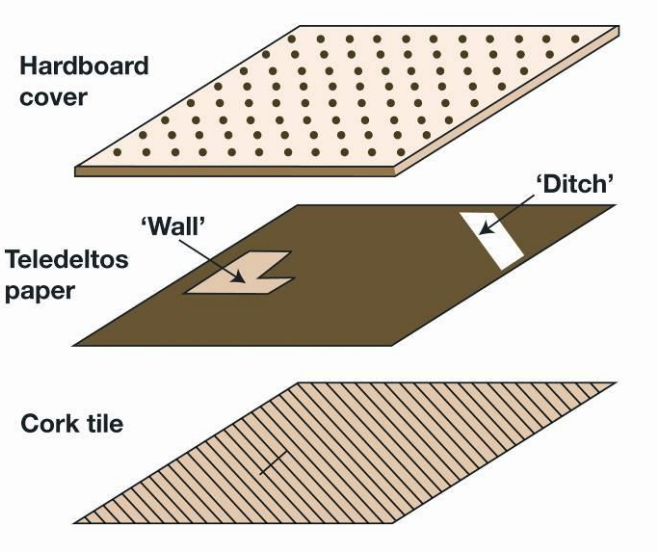
- This site has instructions for the demonstration: http://www.iop.org/activity/education/index.html. Click on Teaching Advanced Physics (TAP), click on Fields and then episode 406.1 which takes you to a very good worksheet with full instructions and safety notes.
- This demonstration simulates the paths of the ions travelling between the electrodes in Activity A.
- Add a short iron bar to the oil, away from the electrodes, to simulate how the iron bar changes the electric field in Activity A.

Alternatively, view the computer simulation showing field lines in three dimensions at: http://www.youtube.com/watch?v=bG9XSY8i_q8

**Activity C - Resistance survey**

The Teledeltos™ paper is glued to the cork tile. A thin wooden frame round the edge raises the hardboard and makes it harder to see what is below. Make mystery features – a hidden wall (high resistance) by cutting out an L shaped section about 5 cm wide and a piece of treasure (low resistance) by gluing a strip of cooking foil onto the paper (use the glue sparingly avoiding the edges – only enough to stop the foil moving to avoid high resistance readings when one lead is on the foil and one on the Teledeltos™ paper). Number the gaps between the holes along the top and down the left hand side.

This is a simulation of an electrical ground survey where the fairly resistive ground is represented by the Teledeltos™ paper, with simulated 'buried features' added to it. This is covered by hardboard, 'soil' concealing the ground beneath. Electrical probes are used to map the variation in resistance and to detect the 'buried features'.




Model of resistance survey
(© Pearson Education Limited 2008)

- Set the multimeter on Ohms.
- Use the leads as probes to measure the resistance across each pair of holes, as described in the participant sheet.

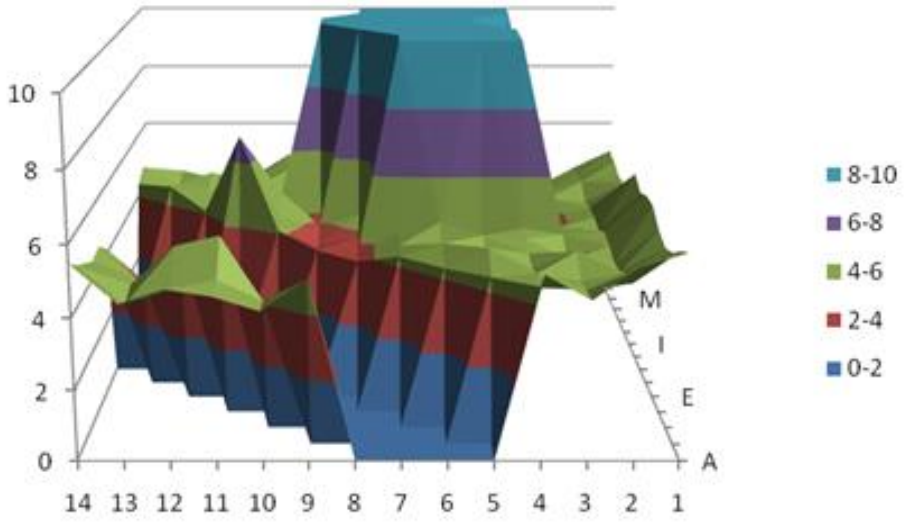
**Sample results:**

Simulation of a ground resistance survey

All values in kΩ (resistance values off the scale have been entered as 10 kΩ)

| Gaps | A | B | C | D | E | F | G | H | I | J | K | L | M | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 5.8 | 5.5 | 5.1 | 4.9 | 5.1 | 5.5 | 5.5 | 5.3 | 5.6 | 4.9 | 4.7 | 4.7 | 4.9 | 5 |
| 2 | 5.4 | 4.6 | 4.5 | 4.2 | 4.1 | 4.3 | 4.4 | 4.1 | 4.2 | 4.2 | 4.1 | 4.5 | 4.4 | 4.4 |
| 3 | 4.5 | 4.4 | 4.3 | 4.8 | 4.2 | 3.9 | 4.3 | 4.2 | 3.9 | 3.9 | 4.2 | 4.2 | 4 | 3.7 |
| 4 | 5.2 | 4.5 | 4.5 | 4.3 | 4.4 | 4.5 | 4.5 | 10 | 10 | 10 | 4 | 4.1 | 10 | 10 |
| 5 | 0 | 0 | 4.4 | 4.9 | 4.2 | 4.6 | 4.3 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| 6 | 0 | 0 | 0 | 4.3 | 4.7 | 4.3 | 4.7 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| 7 | 0 | 0 | 0 | 0 | 4.3 | 4.3 | 4.3 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| 8 | 0 | 0 | 0 | 0 | 0 | 3.8 | 3.8 | 3.9 | 4.3 | 10 | 10 | 10 | 10 | 10 |
| 9 | 5.1 | 0 | 0 | 0 | 0 | 0 | 3.8 | 3.6 | 3.9 | 3.6 | 10 | 10 | 4 | 4.1 |
| 10 | 4.2 | 4.1 | 0 | 0 | 0 | 0 | 0 | 4.1 | 4.2 | 4.7 | 3.8 | 4 | 4.6 | 4.9 |
| 11 | 4.6 | 4.7 | 5.6 | 0 | 0 | 0 | 0 | 0 | 6.8 | 4 | 4.2 | 4.2 | 4.2 | 4.1 |
| 12 | 4.8 | 4.4 | 5.3 | 4.9 | 0 | 0 | 0 | 0 | 0 | 4.1 | 4.6 | 4.8 | 4.3 | 3.9 |
| 13 | 4.4 | 4 | 4.2 | 4 | 3.6 | 0 | 0 | 0 | 0 | 0 | 4.6 | 4.1 | 4.1 | 4.3 |
| 14 | 5.5 | 5.1 | 4.8 | 4.5 | 4.6 | 4.2 | 0 | 0 | 0 | 0 | 0 | 4.4 | 4.7 | 4.3 |

Measurement of resistance across each pair of holes from the model of resistance survey (© Frances Green)




3D plot using Excel of the Measurement of resistance across each pair of holes from the model of resistance survey (© Frances Green)

**Student learning outcomes:**
Students can:
- describe how archaeologists use the electrical properties of the ground to search for evidence and find sites suitable for excavation
- explain how electric fields spread in materials and how resistance measurements can help to find hidden structures
- use a spreadsheet to get a 3D plot of the area surveyed

**Ideas for following up the activity:**
Saline intrusion. Use the web to find out how the level of the water table or water salinity can be monitored using resistance measurements.
See: http://www.ozcoasts.org.au/indicators/saline_intrusion.jsp
Woodhenge http://physicsworld.com/cws/article/print/654 - the 'Archaeological prospecting' section.

**Extension ideas for more able or faster pupils:**
Use the web to investigate how commercial resistivity surveying equipment overcomes the problems encountered when just using a resistance meter.

**Possible misconception:**
That the current is just going from one probe to the other and the standard resistance formula for a wire applies ($R = l\rho/A$). This is where Activity B is useful to show that the electric field spreads out in arcs from the electrodes, dipping down into the sand and penetrating buried objects or damp areas.
It is important to keep the probes the same distance apart and always the same depth in the sand.

**Other useful information:**
Useful background information is available from:
http://physicsworld.com/cws/article/print/654 - useful general reference, particularly the 'Archaeological prospecting' section.
http://www.pastperfect.org.uk/archaeology/resistivity.html - useful brief guide.
http://www.radford.edu/~rherman/papers/ajp00943.pdf - a paper containing some useful ideas from an undergraduate geophysics course, with teaching from a physics perspective.

**Source of activities:**
Activity A ESEU's 'KS4 Physics in an Earth context' workshop.
Activity B Electric field lines demonstration taken from the Institute of Physics, Teaching Advanced Physics resource (TAP), Episode 406.1.
See: http://www.iop.org/activity/education/index.html
Activity C Resistance survey, is taken from Activity 3, page 264 of the Salters Horners Advanced Physics for EDEXCEL AS Physics Student book (ISBN 978405896023) Teacher/Technician pack (ISBN 978405896030), Pearson Education Limited 2008.

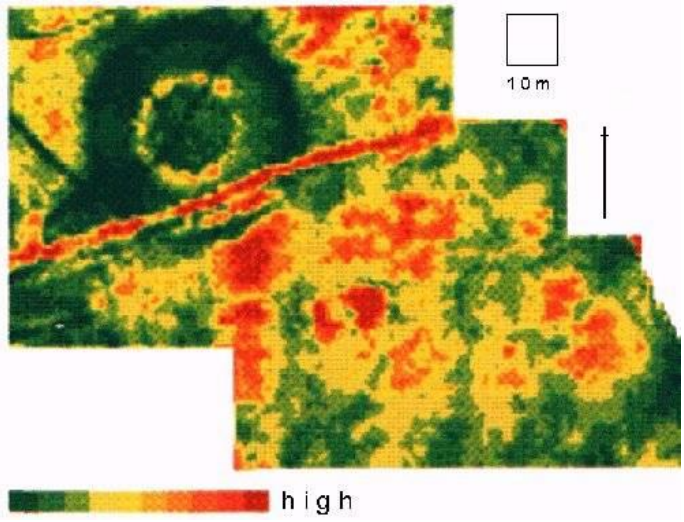

 

# Circus Activity: Electrical ground probing – Earth-resistance surveying

## Participant Sheet

Resistance Survey (© Quiller Barrett)

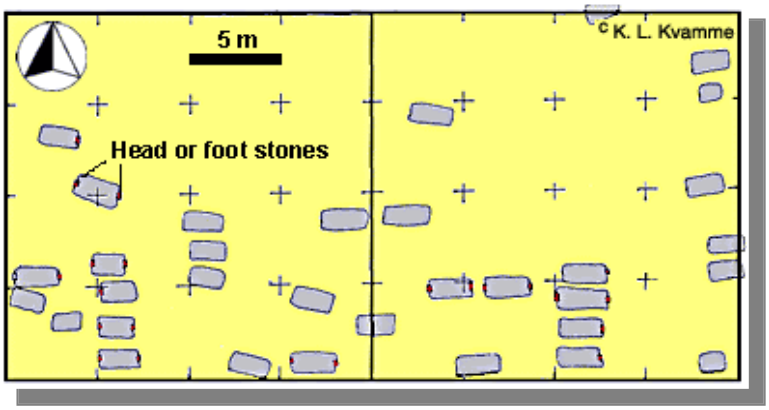
uses electrical and magnetic measurements to detect underground archaeology




Electrical resistance plot of Guiting Power 3 round barrow – a prehistoric burial mound.
(© Alistair J Marshall/Geophysical Surveys of Bradford)

## Resistivity: The Bozeman Cemetery, Arkansas

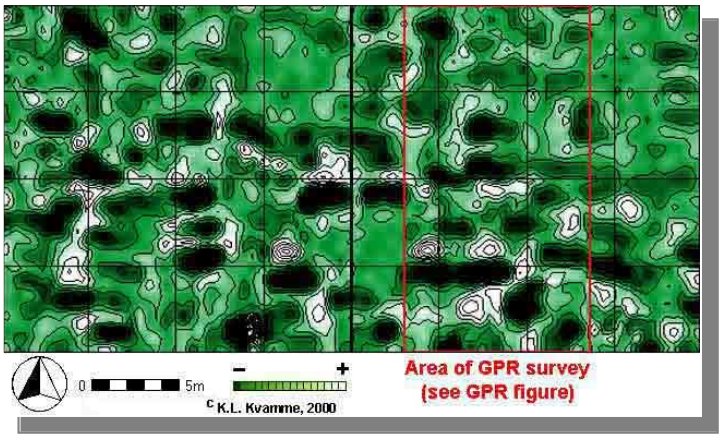

**Map of unknown burials**



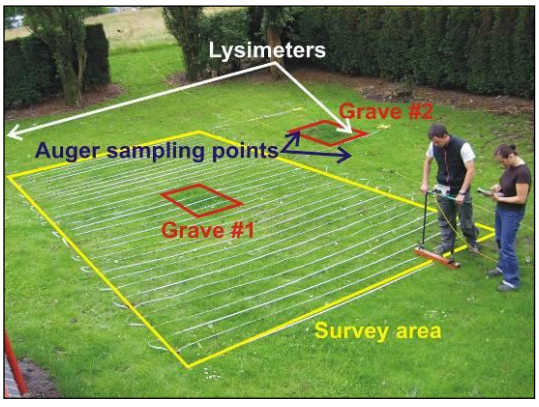

Burials in the Bozeman Cemetery from 1850 – 1950

Contains the graves of a number of prominent families and a number of unmarked/unknown graves, including probable graves of slaves

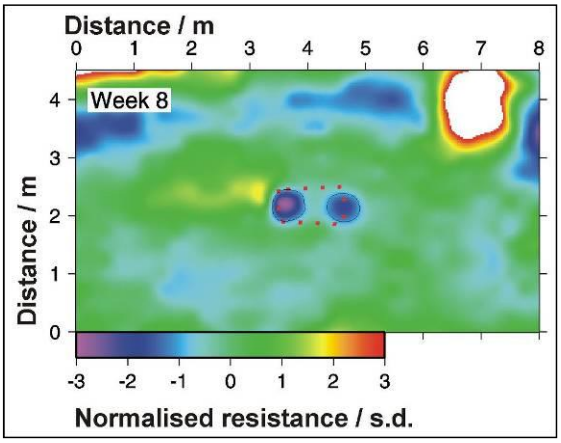
**Resistivity Image**




(© Archeo-Imaging Lab, Department of Anthropology, University of Arkansas)



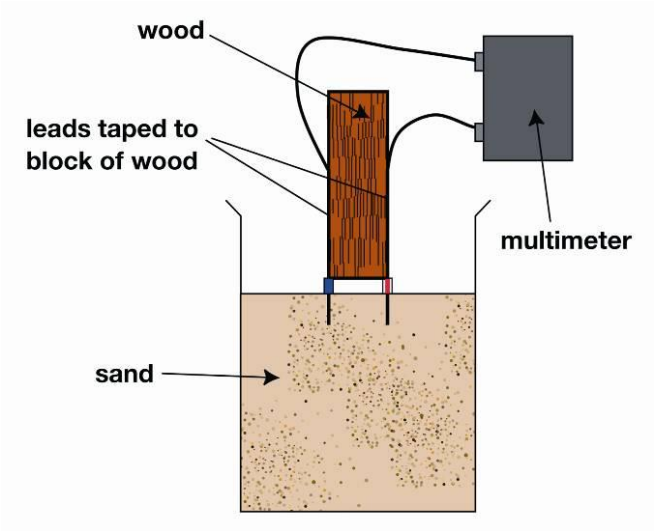

Resistance surveying over a simulated grave (buried pig body)
(© Jamie Pringle, Keele University)



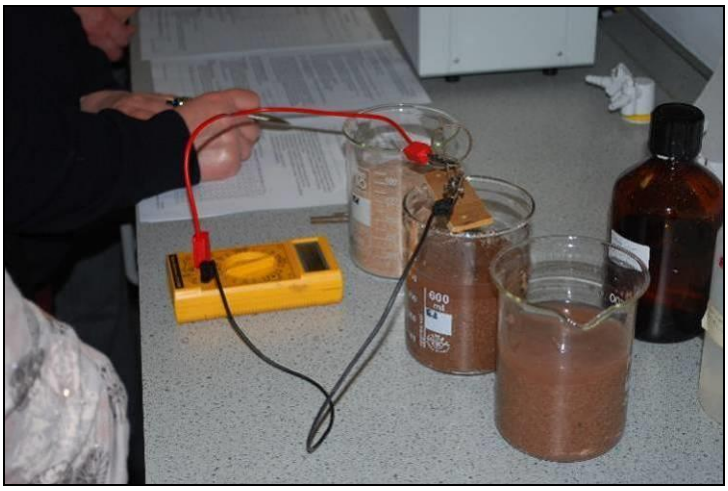

Earth resistance over a simulated grave (buried pig body)
(© Jamie Pringle, Keele University)

**Topic addressed:**
Electrical resistance and electric fields.

**Activity A - Soil resistance**




Picture – Model of a resistance survey
(© ESEU)



Resistance Measurer
(© ESEU)

- Use the multimeter to measure the resistance of dry sand, sand soaked in tap water and sand soaked in salty water. Record your results.
- Watch what happens to the readings if you leave the meter in the salty wet sand for a minute.
- Then try adding the iron rod to each beaker in turn to see what difference this makes to the resistance.

**Activity B - Interpretation of soil resistance findings**

- Watch the castor oil/electrical field demonstration or the simulation at: http://www.youtube.com/watch?v=bG9XSY8i_q8.
- What shape are the electric field lines between the two probes?
- If a Multimeter were used to measure resistance between the two probes in Activity A (by having a potential difference (p.d.) between the probes and measuring the current passing), does the standard resistance formula for a wire ($R = I \rho/A$) apply to wet sand?
- Why will a metal object someway below or beside the probes in Activity A be detected?
- What effect will the p.d. have on the ions?
- Explain what you saw when you left the meter in the salty wet sand in Activity A.

**Activity C - A simulated resistance survey**

- The hardboard grid represents the area to be surveyed. You should be able to find areas of low and high resistance within the grid.
- Measure the resistance across each pair of holes using the multimeter and record the results in a spreadsheet.
- Try to press equally firmly each time. It may be necessary to repeat readings and take an average. You could also estimate the error on each value.
- Use the graphing facility on the computer to display your results.
- Locate and describe the hidden features.