# ARCHAEOLOGICAL GEOPHYSICS: SENSOR SELECTION AND SITE SUITABILITY

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## FUNDAMENTAL CONCEPTS IN ARCHAEOLOGICAL GEOPHYSICS

Passive vs. active methods

1. Passive sensors only "listen" (e.g. magnetometry)
2. Active sensors generate their own signal and measure response (e.g. resistivity, GPR, EMI)

## FUNDAMENTAL CONCEPTS IN ARCHAEOLOGICAL GEOPHYSICS

Raster Vs. Vector

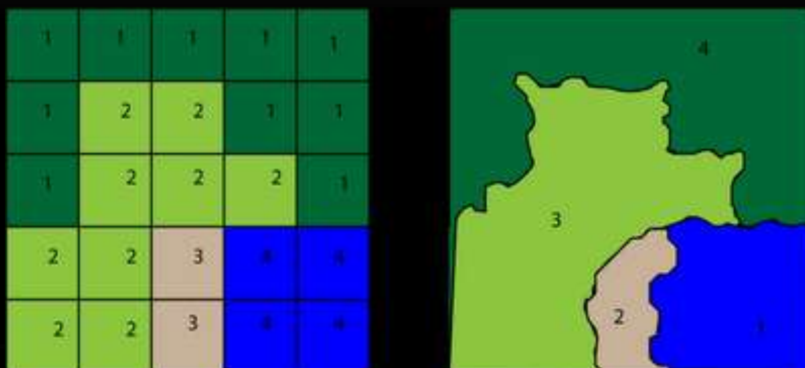
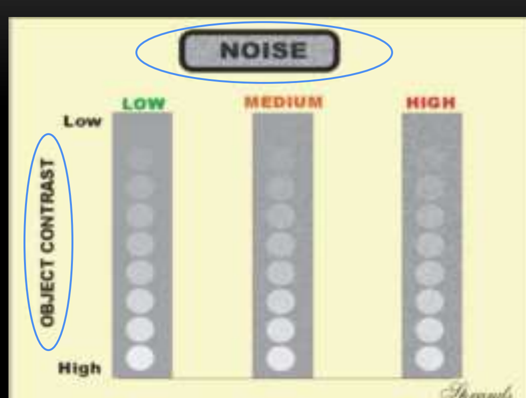


Image source: http://outsidetheneatline.blogspot.com/

## FUNDAMENTAL CONCEPTS IN ARCHAEOLOGICAL GEOPHYSICS

Relative differences between target features and surrounding matrix

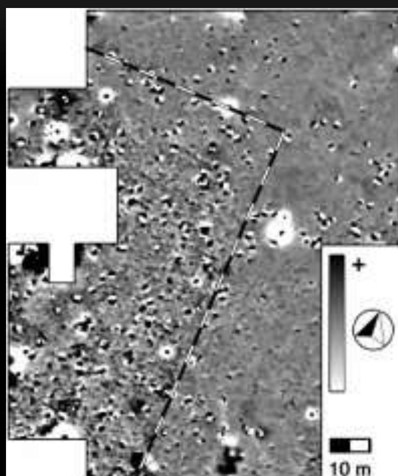



Unwanted, random signals

- Spikes
- Radio interference
- “static”
- Data collection errors

Image Source: http://www.sprawls.org/resources/IMGCHAR/module/

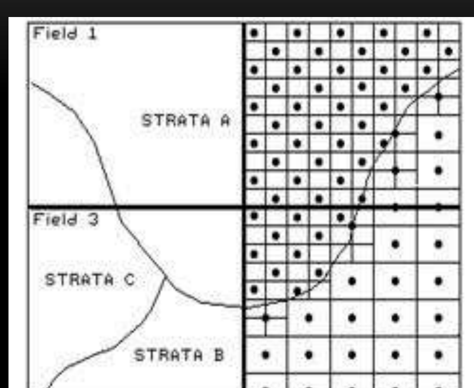
## FUNDAMENTAL CONCEPTS IN ARCHAEOLOGICAL GEOPHYSICS




Clutter – unwanted signals from various sources such as:

- rodent burrows
- tree roots
- geological layers
- metal debris
- Lightning strikes
- Anything that could be confused with an archaeological signal.

## FUNDAMENTAL CONCEPTS IN ARCHAEOLOGICAL GEOPHYSICS




Data Density – number of readings per meter.

## FUNDAMENTAL CONCEPTS IN ARCHAEOLOGICAL GEOPHYSICS

Resolution – ability to resolve detail. Can refer to data density or sensor's ability to detect small features.

- Spatial Resolution of the data = data density (aka sampling density)
- Resolution of the sensor = size of objects that can be detected
- Resolution of the recording device = precision of recorded values
- You cannot improve resolution after data collection. Therefore sampling strategy and instrument configuration and settings are critical.

## PRINCIPLES OF ARCHAEOLOGICAL GEOPHYSICS

- Detects Subsurface features without need for surface expression
- Large contiguous areas generally better than small ones
- Need **contrast** in order to detect features
- Limited to shallow depths (a few meters usually), resolution decreases with depth.
- Multiple methods are almost always better than one

## OVERVIEW OF ELECTRICAL RESISTANCE

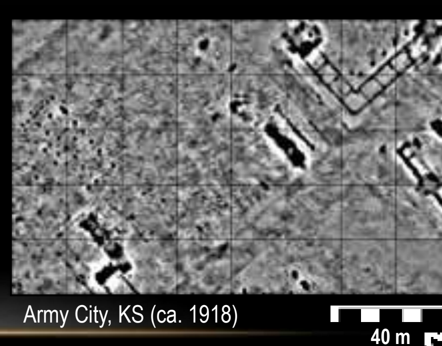
1. *What* property is measured? What fundamental property is being exploited so that archaeological features can be detected?
2. *How* is the property measured? Theoretical background.
3. How is the instrument *configured* for data collection?
4. What are the instrument's limits in terms of *depth* and *resolution*?
5. What are the method's *advantages* and *disadvantages*?

## ELECTRICAL RESISTANCE

What property is measured?

- The degree to which a material resists the passage of an electrical current, measured in Ohms.
- strongly related to moisture

RM15 Resistance Meter




Army City, KS (ca. 1918)

## ELECTRICAL RESISTANCE

How is resistivity measured?

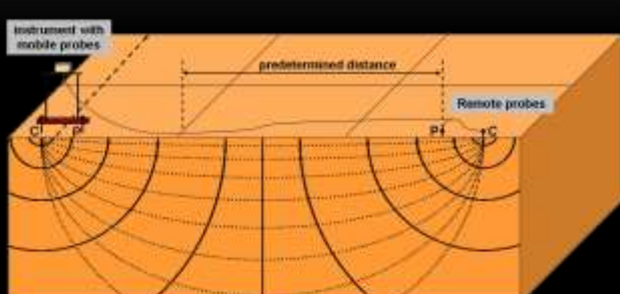
- Pass a current through a medium and measure it with a voltmeter.
- If the current (I) is kept constant and the voltage (V) is measured, resistance (R) can be calculated with Ohm's law:

$$R = V/I$$

## ELECTRICAL RESISTANCE

Configurations:

- Many options (Wenner, Schlumberger, etc.), but twin probe array most practical for archaeology.




The Current (C) probes create a constant, known current that is sampled by the Potential (P) probes.

Distance between mobile and remote probes must always be at least 30x the mobile probe separation.

## ELECTRICAL RESISTANCE

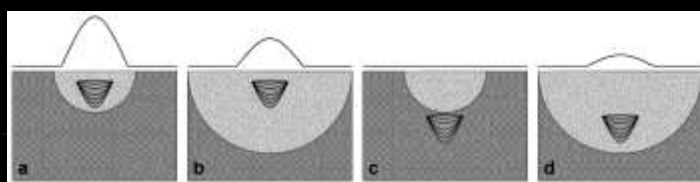
Depth:

• As probes in array are moved farther apart, targeted depth increases

• For twin probe array, depth = mobile probe separation. This is where measurement is focused, but features in immediate vicinity are also detected.

Resolution:

• As probe separation increases, resolution decreases. This is because a larger volume of earth is measured, so the volume of features represents a smaller percentage of the sampled volume, making detection less likely.




## ELECTRICAL RESISTANCE

Advantages

• Works well as long as there is moisture contrast

• ability to target different depths by changing probe separation

• not influenced by metal from pin flags, trash, shell casings, etc.

Disadvantages:

• Slow compared to other methods

• Lower data density owing to slow rate of data collection.

• need to insert probes, so need soft soil and some surface moisture

• Somewhat bulky for travel

## OVERVIEW OF EMI

1. *What* property is measured? What fundamental property is being exploited so that archaeological features can be detected?
2. *How* is the property measured? Theoretical background.
3. How is the instrument *configured* for data collection?
4. What are the instrument's limits in terms of *depth* and *resolution*?
5. What are the method's *advantages* and *disadvantages*?

## ELECTROMAGNETIC INDUCTION (EMI)

What property is measured?

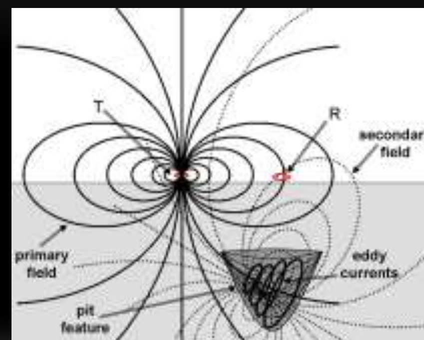
• Conductivity - How easily an electrical current will flow through a material (mS).

• inverse of resistivity, theoretically

• and Magnetic Susceptibility (ability of something to become magnetized)

## EMI – CONDUCTIVITY AND MAGNETIC SUSCEPTIBILITY

How is it measured?




## EMI

Advantages

- Works where resistivity does not
- more portable than resistivity
- MS more sensitive than magnetometry

Disadvantages:

- generally less precise than resistivity
- less depth penetration than magnetometry (MS)

## MAGNETOMETRY

Depth & Resolution

• Ability to detect features depends on their magnetic properties and distance from sensor. A particular depth cannot be targeted.

• Depth – usually uppermost 1-2 meters, but deeper for very large or strongly magnetic features.

• Strength of magnetic field falls off with third power of distance from sensor. So, if a features measures 1 nT when buried 1 m deep, would measure only .125 at 2 m deep (this is the limit of detection for most magnetometers)

• Half-width rule: width of an anomaly at half its max value equals either the depth of the feature, or its width if that number is greater. Better than nothing but not that reliable…

• As a feature's depth increases, the change in magnetic measurements from the maximum value outward is more gradual. So, deeper anomalies will have more widely spaced isolines.

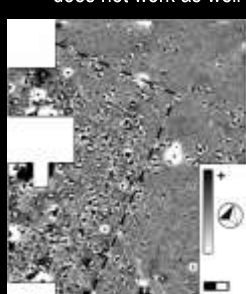
## MAGNETOMETRY

Disadvantages:

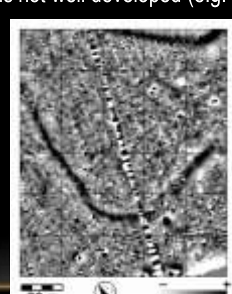
• sensitivity to metal debris

• problem with igneous bedrock

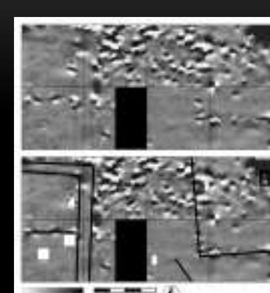
• does not work as well if soils not well developed (e.g. deserts)




Pin flags




culvert




andesite cobbles, but recent wall on right is visible, and interior wall of sunken temple (left)

## MAGNETOMETRY – "NATURE'S GIFT TO ARCHAEOLOGY"

Advantages

- "Magnetometry is Nature's Gift to Archaeology" – Dr. Kenneth L Kvamme
    - it is particularly sensitive to human actions on the landscape…
- rapidly covers large areas, especially with multi-sensor carts

Presidio Los Adaes

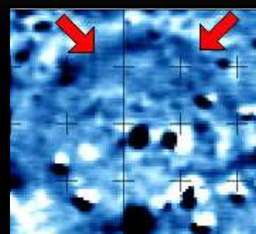

## CAUSES OF MAGNETIC VARIATION: MAGNETOTACTIC BACTERIA

Certain soil microbes control the intracellular deposition of magnetite ($Fe_30_4$) or greigite ($Fe_3S_4$) contributing to the formation of ferromagnetic materials and sources of soil/sediment magnetism.

Magnetotactic bacteria (e.g., *Magnetobacterium bavaricum*) shown in a TEM photomicrograph

## ACCUMULATION AND REMOVAL OF TOPSOIL

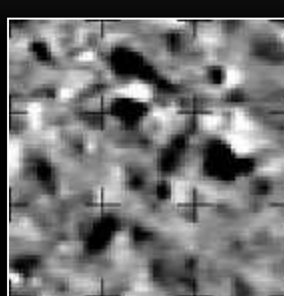
Induced magnetism



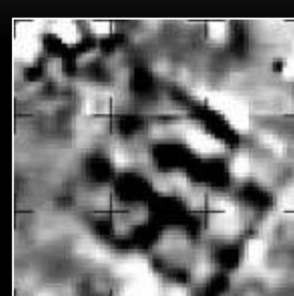
Example: Earthlodge at Double Ditch, ND (courtesy Ken Kvamme)

## BURNED/FIRED FEATURES

Remanent magnetism

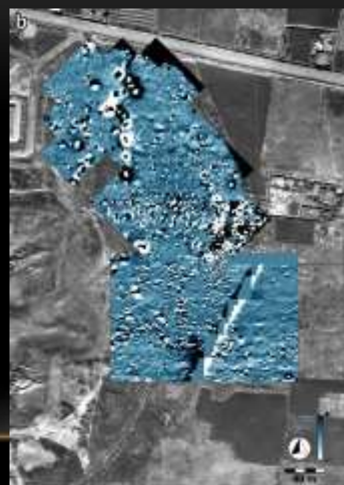


Hearth



Burned structure

## STONE CONSTRUCTIONS

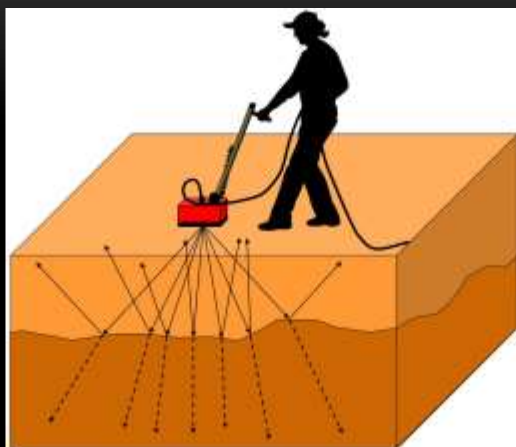


## GROUND-PENETRATING RADAR

What property is measured?

- Strength of reflections (in decibels, dB) and the time it takes for radar pulses to transmit, reflect, and be received, usually measured in nanoseconds (ns; 1 ns = one billionth of a second).
- Wave velocity is inversely proportional to RDP
- RDP strongly controlled by moisture (increased moisture = increased RDP = decreased velocity). Also can be affected by magnetic permeability, but only in rare cases such as when iron or iron oxides are present in high concentrations.
- Strength of reflections depends on contrast between target and medium.
- ideal conditions = moderate contrast. If too strong, robust reflections can block deeper penetration (e.g. metal is a perfect reflector). If too weak, some features are invisible.

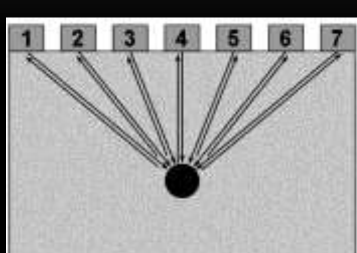
## GROUND-PENETRATING RADAR



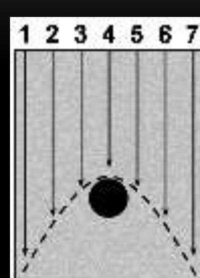
- Reflection
- Refraction
- Transmission
- complicated ray-paths
- lost reflections
- multiples
- shielded vs. non-shielded antennas
- cone of illumination

## GROUND-PENETRATING RADAR

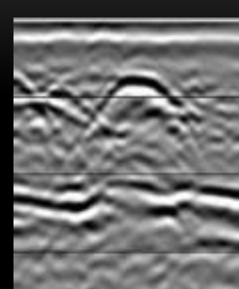
Origin of Hyperbolic Reflections




Travel time (TWTT) to point source changes as antenna passes over top.




Reflections plotted as if they are directly beneath antenna

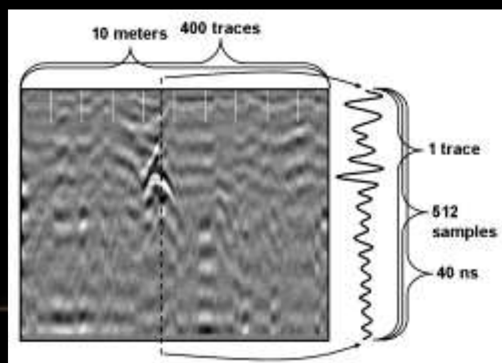


Reflection hyperbola from steel rebar (bar test)

## GROUND-PENETRATING RADAR

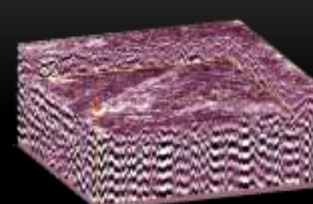
Method of measurement

- continuous “scanning” – scans (traces), samples, time, distance
- profiles are often best source of information for interpretation

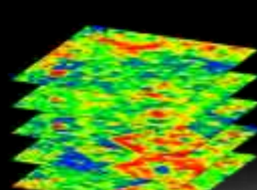



## GROUND-PENETRATING RADAR

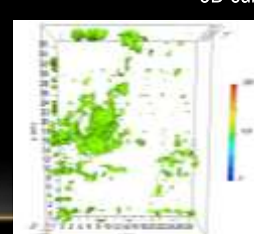
Profiles in a grid



3D cube



Horizontal Slices



isosurface

## GROUND-PENETRATING RADAR

Configurations:

- instrument model
- choice of antenna
- survey wheel
- cart, harness

400 MHz

270 MHz

## GROUND-PENETRATING RADAR

Depth & Resolution – data density

- Data density in x (transect spacing) - .25 to 1 m
- Scan rate and/or speed of walking for y – I like 40 scans/m
- samples/scan, time window, velocity, frequency – I like 512, 30-60 ns

## GROUND-PENETRATING RADAR

Depth & Resolution - attenuation

- depth sensitivity directly related to conductivity (basically moisture)
- higher conductivity means more attenuation (energy is converted to electrical currents and dispersed)
- continous loss of signal with depth
- "lossy" ground
- need for gaining signal
- moisture is king, but also clay minerals and electrolytes (salts)
- beware of salts in dry climates
- clay minerals versus clay-sized particles. "clay" is not always a deal-breaker.

## GROUND-PENETRATING RADAR

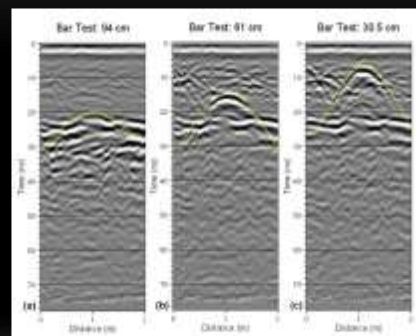
Depth & Resolution – antenna frequency

- lower frequency antenna = greater depth penetration, but loss of resolution.
- higher frequency antenna = less depth penetration, but better resolution
- rule of thumb = target must be at least 25% of the downloaded wavelength that reaches it
    - downloading = decreased frequency when energy passes into ground.
    - 400 MHz typically becomes about 300 MHz, wavelength changes from about .75 m in air to about 1 m in ground, so resolution is about .25 m
- but GPR antennas are broad-band, so you get a range of frequencies and therefore a chance for detecting smaller features.
- 400 MHz is often best, but 270 is very good for deeper targets.
- 900 MHz is sometimes useful for shallow, small targets but beware of increased noise and clutter.
- BUT, ultimate control is ground conditions. In some cases it is not possible to improve depth penetration with lower frequencies.

## GROUND-PENETRATING RADAR

Depth & Resolution – velocity and depth

- bar tests and known reflectors; hyperbola fitting


## GROUND-PENETRATING RADAR

Depth & Resolution – RDP (K)

1. Dielectric Permittivity is the degree to which a material resists the flow of an electrical charge.
2. Relative Dielectric Permittivity: ratio of dielectric permittivity of a material to that of free space. RDP for air is 1.
3. Therefore, RDP changes as moisture, temperature, porosity, and other physical properties change.
4. Variations in RDP directly affect velocity, depth of penetration, and reflection magnitudes.

| Material | RDP | V (m/nS) |
|---|---|---|
| *Air* | 1 | 0.300 |
| *Fresh Water* | 80 | 0.033 |
| *Ice* | 3-4 | 0.160 |
| *Sea Water* | 81-88 | 0.010 |
| *Dry Sand* | 3-5 | 0.150 |
| *Saturated Sand* | 20-30 | 0.060 |
| *Dry Silt* | 3-30 | 0.070 |
| *Saturated Silt* | 10-40 | 0.500 |
| *Clay* | 4-40 | 0.050 |
| *Granite* | 4-6 | 0.130 |
| *Limestone* | 4-8 | 0.120 |
| *Shales* | 5-15 | 0.090 |

$$\sqrt{K} = \frac{C}{V}$$

Where:
K = RDP of the material through which the radar energy passes.
C = speed of light (0.2998 meters/nanosecond).
V = velocity of the radar energy as it passes through a material (meters/nanosecond).

# GROUND-PENETRATING RADAR

Disadvantages:

- complexity and learning curve
- more time consuming to process and interpret

Advantages:

- often works when nothing else does
- can be used on pavement and around metal – great for urban areas
- often provides depth information
- can show discrete depth intervals
- can give idea of 3D shape and geometry of features