2019 Mankato

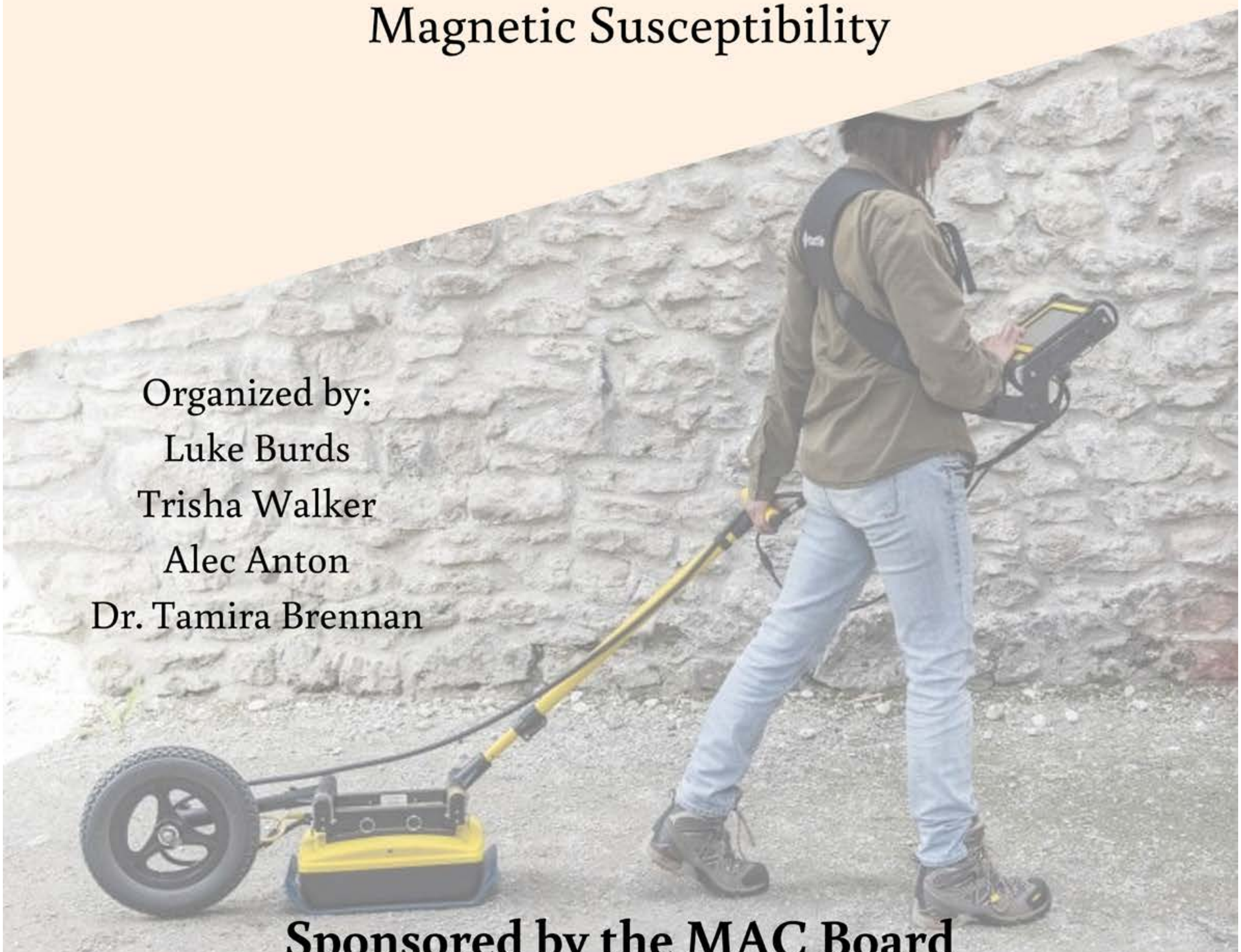
Midwest Archaeology Conference 2019

GEOPHYSICS IN ARCHAEOLOGY WORKSHOP

Ground Penetrating Radar

Resistivity

Magnetic Susceptibility



Organized by:
Luke Burds
Trisha Walker
Alec Anton
Dr. Tamira Brennan

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Dr. Harry Jol

Dr. Harry Jol earned his B.Sc. and M.Sc. from Simon Fraser University (Canada) and Ph.D. from the University of Calgary (Canada). He then was awarded two post-doctoral fellowships (Killam & NSERC) before accepting a position at the University of Wisconsin-Eau Claire where he is presently a professor and has been awarded Fellow of the Geological Society of America. During his Master's degree, he worked on the Fraser River Delta conducting a high resolution shallow seismic program in collaboration with the Geological Survey of Canada. During his Ph.D. research through to the present, he has utilized ground penetrating radar (GPR) at more than 1200+ sites in North America, Europe, Israel, New Zealand, Australia, and Antarctica. Dr. Jol has a broad background in the earth sciences, particularly geomorphology, stratigraphy, and geoarchaeology. His research has resulted in numerous publications, and conference presentations including 3 co-edited GPR volumes (Ground Penetrating Radar in Sediments, Stratigraphic Analysis using GPR, and Ground Penetrating Radar: Theory and Applications).

Mr. Don Johnson

After graduating with a MS degree in Geophysics from Michigan Technological University in 1977, Mr. Johnson has been a career geophysicist conducting geophysical investigations for Mineral Exploration for Geoterrex, Ltd. and Exxon Mineral Co. from 1977 to 1984, environmental and hazardous waste investigations for CH2M Hill and Geosphere Midwest from 1984 to 1997, archaeological investigations for Hemisphere Field Services, and self-employed from 1997 to 2017. He has conducted geophysical investigations in numerous countries using a variety of methods. Countries include the U.S., Bolivia, Ecuador, Italy, Philippines, and Turkey. Minnesota projects include the Silvernale, Bartron, Bryan, Spring Lake and Sheffield Sites, Fort Abercrombie, Fort Ripley, and Foster Cemetery to name a few. Methods used were electrical (resistance, resistivity, and electromagnetics), GPR, and magnetometry.

Dr. Rinita Dalan

Dr. Rinita Dalan is a professor of Anthropology and Earth Science at Minnesota State University Moorhead. She has been involved in the archaeological application of geophysical methods since the 1980s and research on North American prehistoric anthropogenic landforms since 1987. She was the principal investigator on several NCPTT and NSF grants focused on the development of a high-resolution downhole susceptibility instrument and its application within archaeological practice.

GPR

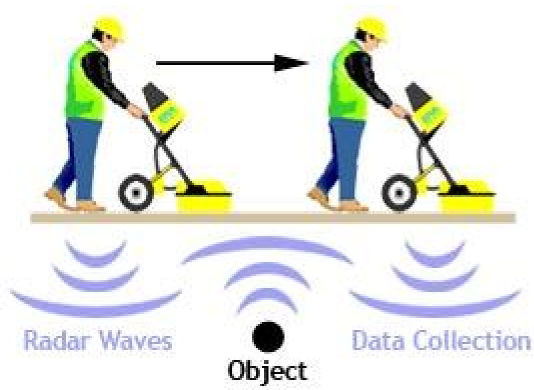
Overview

The ground penetrating radar (GPR) technique is based on the propagation, reflection, and measurement of pulsed high frequency electromagnetic (EM) energy. This field technique can provide near surface, high resolution, near continuous profiles of sediments with low electrical conductivity. GPR has become a popular method for investigation of the shallow subsurface because of the above properties, and the availability of portable, robust, and digital radar systems. Numerous publications resulting from past investigations have shown that GPR is a valuable, efficient, and effective research methodology (see references).

Sensors and Software GPR system configurations (Sensoft.ca).

Data Acquisition

GPR acquisition systems for geoscience applications often vary in antennae frequencies, ranging from 25 – 1200 MHz as well as in transmitter power. As one chooses an antenna frequency for a site investigation or specific target, there are multiple items to consider (after a field test) such as desired depth of penetration, vertical resolution, and horizontal resolution. These considerations, among others, will guide your survey step size, sampling rate, trace stacking, antennae separation, and grid line separation (Jol, 1995; Jol and Bristow, 2003). During data collection in the field, it is important to collect appropriate geospatial data and record these in a field notebook, including accurate coordinates of your lines and high-resolution topography (so that when lines are processed, they can be geometrically corrected). Once your survey(s) is collected, the digital data is processed (2D or 3D) using a robust GPR processing package and an appropriate near-surface velocity (often determined from field measurements). The application of radar stratigraphic analysis (distinct signature patterns) on the collected data during interpretation provides the framework to investigate both lateral and vertical geometry and stratification of the geoarchaeological features being assessed (Jol and Bristow, 2003; Jol and Smith, 1991).



GPR data collection process.
(www.worksmartinc.net)

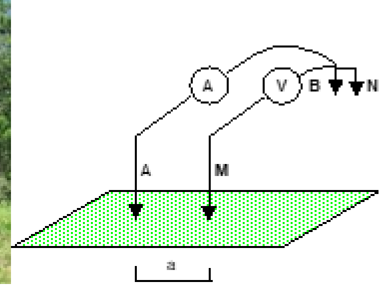
Resistivity

Overview

- Resistivity is a physical property of material.
- Resistivity of the soil depends on many factors:
  - Moisture content
  - Porosity
  - Compactness
  - Presence of archaeological and other subsurface features.
- Field measurements are "apparent resistivity" since they are a combination of the resistivity of multiple soil layers and buried features.
- Apparent resistivity is measured using a 4-electrode system.
  - 2 electrodes inject current into the ground.
  - 2 electrodes measure a corresponding voltage.
  - A geometric factor, based on electrode locations, is applied to the voltage and current readings to calculate apparent resistivity.
- Typical targets are pits, foundations, ditches, floors, middens, and any other feature that has a resistivity that contrasts with background soils.

Resistivity Equipment

Often resistivity equipment used in archaeology is made by Geoscan Research. The original system is the RM15 system which was replaced by the RM85 system.



RM15 System Twin Probe Configuration
Images provided by Mr. Johnson.

- The Geoscan systems are designed to use the twin-probe electrode configuration as shown. It has four probes: one current and one voltage probe mounted on a mobile frame to collect survey readings, and the other current probe placed remotely along with a voltage reference probe.

- No geometric factor is applied to the readings because the factor is a constant assuming the remote electrodes are a great enough distance from the mobile ones.

Field Procedures

Almost all archaeological geophysics is collected in a grid such that plan maps can be prepared from the data. Plan maps are used to interpret the results by allowing the identification of patterns in the data that can be related to archaeological features. It is no different with resistivity data. The Geoscan data logger is programmed with data collection parameters that include line spacing and data interval along each line.

Line and reading intervals are dependent on the size of the target and the objectives of the investigation.

- Typical line spacing is 1 meter.
- Typical data interval along a line is either 0.5 meter or 1 meter.
- The Geoscan data logger is designed for specific grid sizes with the 20 x 20 meter grid being a common size.
- The depth-of-investigation depends on the electrode separation on the mobile frame. The electrode separation is typically 0.5 or 1 meter.
- Data collection over a 20-meter grid using a line spacing of 1 meter and measurement interval of 0.5 meters is about 45 minutes.

Example

Silvernale Site (21GD03)

Near Red Wing, MN

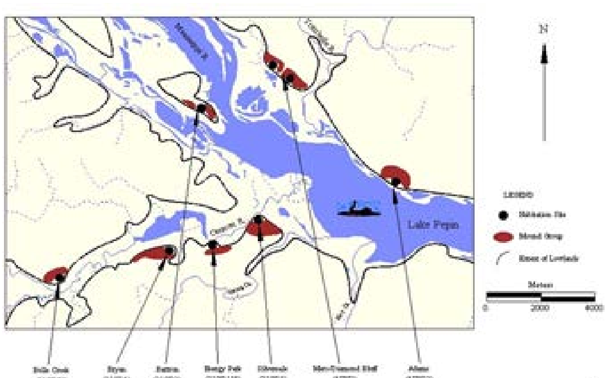


Image provided by Mr. Johnson.

- Local environments:
    - Lake Pepin & rivers
- Local patterns:
    - Ca. A.D. 1050 - 1300
    - Large village complexes
    - Settlement geography
- Cultural interaction:
    - Mississippian-related
    - Oneota
    - Plains
    - Late Woodland

Resistance Map

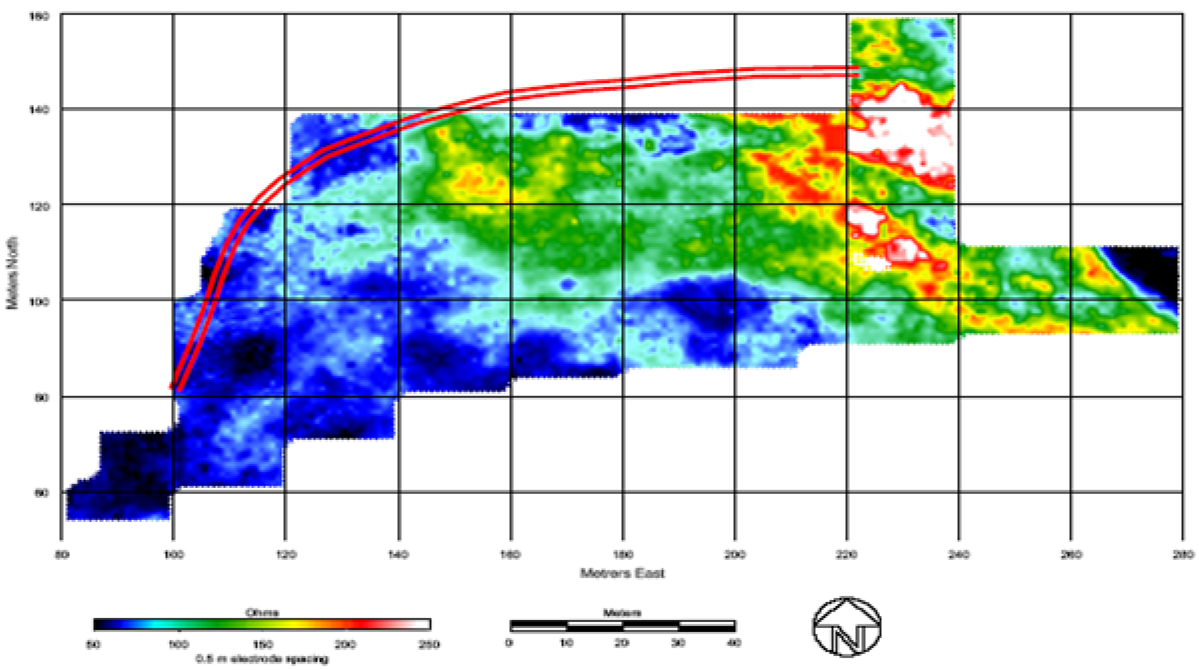


Image provided by Mr. Johnson.

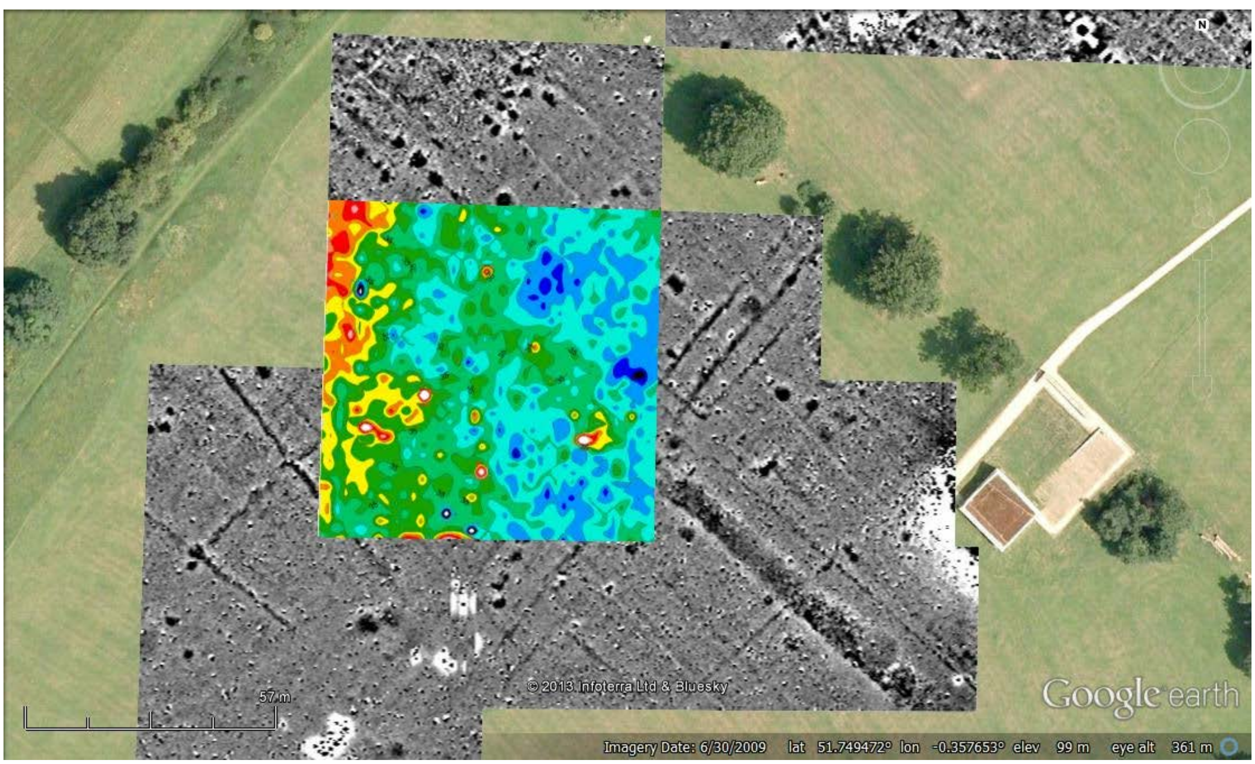
Magnetic Susceptibility

Magnetic susceptibility surveys occupy a unique niche in archaeological research distinct from other near-surface geophysical methods. Susceptibility surveys have not been as widely employed as magnetometry, resistivity, or ground-penetrating radar surveys, although they are becoming increasingly common. A susceptibility study, applied in conjunction with soil magnetic techniques, may go beyond locating archaeological features to answer questions regarding formation and post-depositional processes. Susceptibility studies are applicable to a broad range of archaeological sites, features, and environments, and, through the use of different sensors, are used in applications across a broad range of scales.

Magnetic susceptibility provides a measure of a material's ability to be magnetized. As its full name, low field magnetic susceptibility, suggests, this property quantifies the response of a material to a weak magnetic field (i.e., one on the order of the Earth's field). Magnetic susceptibility can be expressed either as a susceptibility per unit volume (κ, a dimensionless quantity in the SI system of units) or as a mass normalized susceptibility (χ, in units of m^3/kg in the SI system). Because archaeologists recognized that the success of magnetometer surveys depended on susceptibility contrasts, susceptibility studies followed quickly upon pioneering magnetometer applications in the 1950s. Magnetic susceptibility can be measured in the field or the laboratory. Instruments are divided into dual coil/slingram types (e.g., Geonics EM38, CMD Mini-Explorer) composed of separate transmitter and receiver coils or single coil/coincident loop types (e.g., Bartington MS2/3 susceptibility systems, ZH Instruments Kappameters). They may be further separated based on the volume that is measured and/or the context of the application (i.e., surface surveys including plow-zone surveys; surveys of excavation floors, walls, and other exposures; downhole applications; and measurements of whole- and split-cores or packed samples)

Magnetic susceptibility configurations.
Images from: Geospatial Modeling and Visualization 2012 (Left) and Zaman and Aquaal 2018 (Right)

In general, susceptibility surveys are not as rapid as other geophysical methods for large-area surveys. The depth of exploration provided by commonly used susceptibility instruments is relatively shallow and instrument drift must be managed. Down-hole surveys will be difficult where the ground is hard or gravelly. With single coil instruments, rough ground or thick vegetation can affect the accuracy of readings. There is no standard for the application of magnetic susceptibility surveys in spatial terms. The measurement spacing used will depend on problem orientation and can range from coarse sampling surveys of 20 m to 1-2 cm intervals in excavations or downhole surveys. Types of features most frequently investigated are fired features, filled ditches or pits, and other earthen features comprised of contrastive soils. Susceptibility instruments can identify subtle features as well as features with gradual boundaries. Susceptibility surveys have also been utilized to identify and map whole sites, activity areas, and archaeological landforms, including areas of intense occupation, industrial activity, agriculturally managed or stockyard soils, and to discriminate natural and cultural soils. The interpretive potential of susceptibility studies has made them a popular complement to other geophysical methods, including electromagnetic conductivity and magnetometer surveys.



Magnetic susceptibility results from Verulamium, a Roman site in Hertfordshire, England (Lockyear 2013).

Tips for Conducting Geophysical Surveys

Step 1: Know your context

Before you conduct any work using any geophysical equipment, you need to know your context. None of the geophysical methods that you worked with can show an x-ray image of what is going on below the surface. Context is important because when you see anomalies in the collected geophysical data context can give you a better idea of what those anomalies indicate, possibly a specific type of buried material.

Some things to keep in mind when establishing your context:

- What evidence are you looking for?
    - Building foundations?
    - Fire Hearths?
- Where would the general location of these things be?
    - Were they ever mapped?
    - Should they be nearby known sites?
- What is the previous work done at the site?
    - Prior excavations and their results?
    - Past Geophysical work at the site?
- Are there any related geophysical studies that are similar to yours?
    - What similar work exists that was done in your area?
    - What similar work exists that looked for the same things you're looking for?

Step 2: Examine the survey area

Depending on where you plan on surveying, it is necessary to know what to expect from the landscape before beginning to collect data.

Some things to keep in mind when examining your survey area:

- What is the soil type? For example, with GPR:
    - Clay = Unlikely to work well with GPR
    - Silt = Somewhat suitable for GPR
    - Sand = Works great with GPR
- What is the topography like?
    - Are there areas you should avoid? I.E. a cliff.
    - Are there depressions or relief that suggest human activity?
    - Do you need to clear out any vegetation?
- What has recently occurred at the site?

    - Has any recent excavation been done?
    - Are there any buried objects that might create anomalies in your data, such as utility lines?
- What is the weather like?
    - Has it recently rained? How will that affect your data?

Step 3: Set up your survey area

After you have determined that your survey area is suitable to conduct geophysics on, your next step is to set up where you will survey. The size of your survey area will depend on how much time you have.

Some things to keep in mind when setting up a survey area:

- Make sure you have all the necessary tools to do so:
    - Tape Measures
    - Flags (preferably plastic flags)
    - Laser level system
        - (This works great but if you have some other way to measure elevation, keep it on hand)
- Pythagorean Theorem
    - $A^2 + B^2 = C^2$
- What is the area of your grid?
    - Your grid should be big enough to encompass what it is you are trying to find.
    - However, the bigger the grid, the more time it will take.
- What is your line spacing?
    - Tighter line spacing can yield better results but will also take longer.
- What are the coordinates of your survey area?
    - It is highly recommended to collect GPS points at at least all four corners of your survey area.

Step 4: Set up your machine

Every survey that you run is going to be different so you will need to calibrate your machine each time you decide to run a survey to make up for these differences. Below is an example of all that needs to be done for calibrating a GPR system. Other machines will likely require different calibrations.
Frequency:
- What antennae frequency are you using?

Time Window

- How long will the GPR system “listen” for the pulse it sent?
- This determines the depth of penetration

Step Size

- How often will pulses be sent into the ground?
- Usually ranges between 0.02m to 0.1m

Stacks

- How many pulses over a point will be sent into the ground?

Velocity

- How fast is the wave traveling through the ground?
- This will change depending on the medium the wave is sent through but also determines the depth a signal is returning from

Trigger

- Are you using an odometer or are you manually sending a pulse?
- If using an odometer, the odometer needs to be calibrated every time you use it.

Antenna Separation

- How far apart are your antennae?

<u>Step 5: Run your survey</u>

Once you have set up your survey area and your machine, you are ready to run your survey.

Some things to keep in mind while you run your survey:

- How fast are you/your machine operator walking?
    - Depending on the machine, the speed at which you move your system across the ground will affect the accuracy of your data.
- What objects are on the surface within your survey area?
    - Surface objects can appear in the collected data. It is important to record where these objects are in relation to your survey area so they can be picked out when data are analyzed.

<u>Step 6: Process your data</u>

After you have collected all of your data, the next step is to process it. There is a variety of robust processing software that exists to help visualize your data and make it more understandable for those who may have never experienced interpreting such data. Additionally, depending on the method used, data can be shown in a 3D format to better visualize subsurface anomalies. Data can also be attached to a GIS to see how they align with surface objects. This can be helpful in cases such as mapping graves within a graveyard or documenting buried building foundations.

Some recommended processing software are:

- GPR_SLICE
- EKKO_Project
- Surfer
- Voxler

Further Reading:

Beck, J.D., Burds, L.T., Mataitis, R.J., Jol, H.M., Freund, R.A., McClymont, A.F., and Bauman, P., 2018. Holocaust Archaeology: Searching for Nazi Mass Execution Trenches at Fort IX (Kaunas, Lithuania): Proceedings of the Seventeenth International Conference on Ground Penetrating Radar (GPR 2018), June 18-21, Rapperswil, Switzerland, p. 79-82.

Bode, J.A., Jol, H.M., Reeder, P., Freund, R.A., Bauman, P., and Nahas, C., 2006, GPR investigation of the Nuestra Senora de la Blanca church site, Burgos, Spain: Preliminary Results: Proceedings of the Eleventh International Conference on Ground Penetrating Radar (GPR 2006), June 19 - 22, The Ohio State University, Columbus, Ohio, USA, Papers on CD-ROM.

Bode, J.A., and Jol, H.M., 2006, GPR investigation of Hapuna Beach, Hawaii: coastal and fluvial deposits: Proceedings of the Eleventh International Conference on Ground Penetrating Radar (GPR 2006), June 19 - 22, The Ohio State University, Columbus, Ohio, USA, Papers on CD-ROM.

Burds, L.T., Beck, J.D., Mataitis, R.J., Jol, H.M., Freund, R.A., McClymont, A.F., and Bauman, P., 2018. Holocaust Archaeology: Using ground penetrating radar to locate a Jewish mass grave in Kaunas, Lithuania: Proceedings of the Seventeenth International Conference on Ground Penetrating Radar (GPR 2018), June 18-21, Rapperswil, Switzerland, p. 70-73.

Bristow, C.S., and Jol, H.M., eds., 2003, Ground penetrating radar in sediments: Geological Society of London, Special Publication 211, 366 p.

Conyers, L.B., 2018, Ground-penetrating radar and magnetometry for buried landscape analysis: Springer International Publishing, 109 p.

Conyers, L.B., 2016, Ground-penetrating radar for geoarchaeology: Wiley, 160 p.

Conyers, L.B., 2013, Ground-penetrating radar for archaeology (3rd edition): Rowman and Littlefield, 258 p.

Conyers, L.B., 2012, Interpreting ground-penetrating radar for archaeology: Routledge, 220 p.

Dalan, R.A., 2017. Susceptibility. In *Encyclopedia of Geoarchaeology*, edited by Allan S. Gilbert, pp. 939-943. Springer Publishers, New York.

Dalan, R. A., 2008. A Review of The Role of Magnetic Susceptibility in Archaeogeophysical studies in the United States: Recent Developments and Prospects. *Archaeological Prospection* 15:1-31.

Dalan, R.A., 2006. Magnetic Susceptibility. In *Remote Sensing in Archaeology: An Explicitly North American Perspective*, edited by Jay K. Johnson, pp. 161-203. University of Alabama Press, Tuscaloosa.

Dearing, J. A., 1999. *Environmental Magnetic Susceptibility: Using the Bartington MS2 System*, 2nd edition. Chi Publishing, Kenilworth, Great Britain.

EM38-MK2. *Geospatial Modeling & Visualization*, Geospatial Modeling & Visualization, 6 Apr. 2012, gmv.cast.uark.edu/geophysics/hardware/em38-mk2/.

Jol, H.M., 2018. Ground penetrating radar subsurface imaging within the Cave of Letters: in Savage, C., Reeder, P., Freund, R.A. and Jol, H.M. eds., Dead Sea: New discoveries in the Cave of Letters: Peter Lange Inc., International Academic Publishers, Series: Crosscurrents: New Studies on the Middle East (Book 2), 296 pp.

Jol, H.M. 1995. Ground penetrating radar antennae frequencies and transmitter powers compared for penetration depth, resolution and reflection continuity. Geophysical Prospecting, 43, p. 693-709.

Jol, H.M., ed., 2009, Ground penetrating radar (GPR) theory and applications: Elsevier, 524 p.

Jol, H.M., Bauman, P., and Bahat, D., 2006, Looking into the Western Wall, Jerusalem, Israel: Proceedings of the Eleventh International Conference on Ground Penetrating Radar (GPR 2006), June 19 - 22, The Ohio State University, Columbus, Ohio, USA, Papers on CD-ROM.

Jol, H.M., +Bode, J.A., Freund, R.A., Darawsha, M., Bauman, P.D., Nahas, C., Reeder, P., and Savage, C., 2006, Nazareth excavations project: a GPR perspective: Proceedings of the Symposium on the Application of Geophysics to Engineering and Environmental Problems (SAGEEP), 19th Annual Meeting, Seattle, Washington, April 2-6, Papers on CD-ROM, p. 1407 – 1413.

Jol, H.M. and Bristow, C.S., 2003. GPR in sediments: advice on data collection, basic processing and interpretation, a good practice guide. In: Bristow, C.S. and Jol, H.M. (eds.) GPR in Sediments, Geological Society of London, Special Publication 211, 9-27

Jol, H.M., Broshi, M., Eshel, H., Freund, R.A., Shroder, Jr., J.F., Reeder, P., and Dubay, R., 2002, GPR investigations at Qumran, Israel: site of the Dead Sea Scrolls Discovery, *in* Koppenjan, S.K., and Lee, H., eds., Ninth International Conference on Ground Penetrating Radar: April 29 – May 2, Santa Barbara, CA, Proceedings of SPIE (The International Society for Optical Engineering), v. 4758, p. 91-95.

Jol, H.M., DeChaine, R.J., and Eisenman, R., 2002, Archaeological GPR investigations at Rennes-Le-Château, France, *in* Koppenjan, S.K., and Lee, H., eds., Ninth International Conference on Ground Penetrating Radar: April 29 – May 2, Santa Barbara, CA, Proceedings of SPIE (The International Society for Optical Engineering), v. 4758, p. 125 – 129.

Jol, H.M., Schroder, J.F., Reeder, P., and Freund, R.A., 2000, Return to the Cave of Letters (Israel): a ground penetrating radar archaeological expedition, *in* Noon, D.A., Stickley, G.F., and Longstaff, D., eds., Proceedings of the Eighth International Conference on Ground Penetrating Radar (GPR 2000): May 23-26, Gold Coast, Australia, SPIE v. 4084, p. 882-886.

Jol, H.M. and Smith, D.G. 1991. Ground penetrating radar of northern lacustrine deltas. Canadian Journal of Earth Sciences, 28, p. 1939-1947.

Kloehn, N.B., [+]Junck, M.B., Jol, H.M., Running, G.L., Greek, D., and Caldwell, K., 2000, Ground penetrating radar investigation of the West Prairie Mound Group, central Wisconsin, U.S.A.: are they burial mounds or natural landforms?, *in* Noon, D.A., Stickley, G.F., and Longstaff, D., eds., Proceedings of the Eighth International Conference on Ground Penetrating Radar (GPR 2000): May 23-26, Gold Coast, Australia, SPIE v. 4084, p. 590-595.

Lockyear, Kris. Magnetic Susceptibility. Sensing the Iron Age and Roman Past: Geophysics and the Landscape of Hertfordshire, 21 July 2013, hertsgeosurvey.wordpress.com/2013/07/21/magnetic-susceptibility/.

Reeder. P., and Jol, H, 2006, Water resource utilization at the Qumran Archaeological site Israel: 29th Annual Applied Geography Conference, October 11 – 14, Tampa, FL, Papers of the Applied Geography Conference, v. 29, p. 224 234.

Reeder, P., Jol, H., Freund, R., and Savage, C., 2004, Geoarchaeology of the Qumran Archaeological Site, Israel: Focus on Geography, v. 48, p. 12-19.

Salmon, Y., Conyers, L., Jol, H., and Artzy, M., 2014. Early Second Millenium settlement landscape in the Nami Region, Israel, revealed by GPR investigations: Proceedings of the Fifteenth International Conference on Ground Penetrating Radar (GPR 2014), June 30-July 4, Brussels, Belgium, (digital, p. 60-65).

Sensors & Software: Ground Penetrating Radar: GPR: Georadar Systems. *Sensoft*, www.sensoft.ca/.

Treague, J.J., Jol, H.M., and Peterson, C.D., 2004, A ground penetrating radar investigation of an 1805 Lewis and Clark site, Oregon, USA, *in* Slob,E., Yarovoy, A., and Rhebergen, J., eds., Proceedings of the Tenth International Conference on Ground Penetrating Radar GPR 2004 (Institute of Electrical and Electronic Engineers, Inc.): June 21 - 24, Delft University of Technology, Delft, The Netherlands, v. 2, p. 471-474.

Zaman, Haider, and Adnan Aqeel. “Preliminary Magnetic Susceptibility Results from the Northwestern Part of Madinah, Saudi Arabia: Environmental Degradation of Wadi Aqiq.” *OJG*, vol. 8, no. 4, Apr. 2018, pp. 446–462. *Scientific Research*, doi:10.4236/ojg.2018.84026.