Ground-Penetrating Radar (GPR) data – in Archaeological Prospection

*Guidance on '**Archaeology to Precision Agriculture (PA)**' data exchange via API platforms and Ecosystem Services (online GIS platforms)*

Part one: Descriptions

Ground-penetrating radar (GPR) data are collected with either ground-coupled or air-launched systems which measure electromagnetic contrasts in the soil by directing pulses of energy groundward and recording the strength (amplitude) and travel-time of reflections from subsurface interfaces and objects. A system's ability to penetrate the ground and resolve targets at depth is governed by a combination of the chosen antenna frequency, and the ability of underlying materials to store and transmit the energy of the signal (relative dielectric permittivity). Common antenna frequencies in field-based archaeological applications range between 200MHz – 600MHz. Depth measurements are estimations based on signal travel-time (two-way) and wave velocities.

Data Types – common to archaeological prospection

Radargrams

The primary result of a GPR survey transect is a profile or vertical depth section also referred to as a radargram. File format can vary according to manufacturer, but radargram data typically (but not necessarily) comprise two mandatory files with auxiliary file(s):

- an ascii format header file containing parameters relating to the collection of binary data (mandatory)
- a binary data file which stores a succession of reflected wave data as recorded along a survey transect (mandatory)
- a corresponding ascii format file with GPS location data (auxiliary)

Specialist software is needed to convert the raw binary radargram data into vertical 2D raster image files for display and processing purposes. Processing functions (see below) are necessary to clean and enhance signals within the data for interpretation.

- Processed radargrams – 2D raster format image file of a vertical profile where changes in amplitude are visualized using a colour legend, typically greyscale. (e.g., jpeg, tiff, etc.)

Common Data Derivatives

- Archaeological interpretation of radargrams – graphically annotated 2D raster format image file of the (above) processed radargram (e.g., jpeg, tiff, etc.); text, lines and shapes are drawn over the vertical profile in a graphics editor programme, to describe and explain the shape and extent of various responses for interpretation

Time slices

Where multiple radargram profiles are collected over an area, either at regular intervals (gridded method) or irregular intervals/patterns (non-gridded method), data values between vertical profiles can be interpolated across the entire survey area, thereby creating a data cube. A secondary dataset is derived by slicing the data cube horizontally to produce plan-view maps at multiple depths, known as time slices.

- Time slice (grid) data – a single, or stack of, horizontal 2D raster format files where a matrix of cells visualize the processed numeric data from multiple depths using a colour legend; the attribute represented by each cell is the processed amplitude value (grid file format)
    - Supplementary image format files (e.g. jpeg, tiff, etc.) are sometimes derived from time slice (grid) files, usually after processing such as clipping of the range of values or stretching the range of values on a different scale to enhance contrast and make features of interest more visible; image format file derivatives are often georeferenced (e.g. geotiff, etc.).

Common Data Derivatives

- Archaeological interpretation of time slice data – a single, or stack of, 2D vector format files of individual features, or sets of features, overlaid and interpreted from processed time slices of multiple depths as represented geometrically by points, lines or outline polygons.
    - Interpreted features are typically classified according to set categories relating to some, or all, of the following:
        - Geophysical signal response (high/low amplitude)
        - Archaeology – feature type (wall, ditch, etc.)
        - Archaeology – potential (probable, possible etc.)
        - Geology and/or pedology
        - Modern activity (agriculture, utility, infrastructure, military, disturbance, sporting, leisure, etc.)
- Other classed/clustered data (e.g. management zones, etc.)
- Vectorised interpretation classifications and features might be alternatively represented either individually or collectively, as image format files (e.g. jpeg, tiff, etc.) usually georeferenced (e.g. geotif, etc.)

Vocabulary – common to archaeological prospection

(Thematic tags, term lists, thesauri)

Basic description or interpretation of geophysical anomaly

- Electrical conductivity: high / low; strong / enhanced
- In-phase magnetic susceptibility: high / low; strong / weak; enhanced / decreased; ferrous, overwhelming disturbance, etc.

Classification of soil characteristics

- Customized descriptions: fills (possible / probable, linear / discrete), areas (texture, highlights), cultivation (trends), drains (possible / probable), boundaries (former / modern), trackways (former / modern), etc.

Archaeological interpretation by response and form

- General classification (archaeology (possible / probable), modern structure, etc.)
- Detailed classification (wall (possible / probable), ditch (possible / probable), pit (possible / probable), kiln (possible / probable), etc.

Event description

- FISH Event Types Thesaurus (non-intrusive/geophysical/insert type)
    - http://purl.org/heritagedata/schemes/agl_et/concepts/145134

Part Two: Recommendations to increase interoperability

Identifiers – recommended

Unique identifier for published dataset (for example as provided by an open access digital repository)

Data structure – recommended

Core attributes of data types (see above)

Critical information for inclusion

Radargrams

File formats and file structure can vary according to manufacturer

- an ascii header file containing keywords followed by a value or text relating to important parameters relating to the accompanying data file (such as samples per scan, antenna frequency, time window, line length, number of traces and sampling interval amongst others)
- a binary data file (8-, 16-, or 32-bit) which stores the succession of reflected waves data as recorded along a survey transect
- a corresponding ascii file with GPS location data of each transect start, end, and / or measurement points

Some single file formats allow locational data (such as start and end points) to be incorporated directly into a single file format data structure (e.g. SEGY – a geophysical, open-source exchange format). However, locational data derived from GPS measurements are more typically appended to individual radargrams, or sets of radargrams, by an auxiliary text format file.

For examples of contrasting GPR file formats see: Hagelund and Levin 2017; Huber 2021; Lucius and Powers 2002; Mala 2021.

Time slices

- Raster data. Processed grid or image data – a grid matrix of cell (pixel) rows and columns where each cell contains the numeric amplitude value; the extent is defined by a bounding box
    - A supplementary, georeferenced version of this grid file, in an image file format where each amplitude value is represented by a colour value (e.g. geotiff, etc.), might be useful for non-specialists
- Vector data. Vectorised interpretation – features or areas of interest as represented by lines or polygons each of which is linked to a database element or row which describes its essential attributes such as line start, line length, line bearing, polygonal area, as well as any additional data; extent is defined by a bounding box

Data processing – recommended minimum

Relating to data types discussed above

Raw radargram profiles require specialist software to undertake data editing and processing enhancements:

Basic processing includes temporal filtering (removing very low frequency components), selecting signal gain (to adjust for fall off over time), and spatial filtering (to enhance or suppress reflectors, or remove noise spikes), all of which should not significantly alter the raw information collected (Anan 1999).

More advanced processing techniques may include further enhancing the visibility of weaker signals (e.g. background or average trace removal filter), reducing multiple reflections (e.g. impulse response function removal (deconvolution) process) or rectifying specific components of the data to enhance visualisation, imaging, and/or interpretation of the data (e.g. pulse transformation (Hilbert), velocity adjustment (migration) process). It may be noted that advanced processing steps usually alter the original raw data significantly and have the potential to introduce 'data artifacts', which are open to misinterpretation (see Anan 1999, Conyers 2004, Goodman and Piro 2013).

Specialist software is required further to perform 3D interpolation between processed radargrams to create and slice the data cube necessary to produce horizontal time slices (if desired).

Metadata standard – recommended

For minimum metadata requirements, the BonaRes Metadata Schema for soil surveys is recommended (see Appendix 1 metadata ipaast template for a list of mandatory metadata elements). In addition, IPAAST-CZO recommends the following core elements (Schmidt and Ernenwein, 2011, Section 5.3) for inclusion with geophysical datasets:

Geophysics Metadata		See Appendix 1 metadata ipaast template for full definition
(All survey techniques and data types)		
Duration/Collection date	Mandatory	Date (ISO 8601)
Survey type	Mandatory	Character String (Controlled List Value): tbd
Instrumentation	Mandatory	Character String (Free text)
Area surveyed	Mandatory	Character String (Free text)
Method of coverage	Mandatory	Character String (Controlled List Value): Gridded/Line/Non-gridded/Scanning/etc.
Line separation (cross-line)	Mandatory	Decimal / Numerical
Reading interval (in-line)	Mandatory	Decimal / Numerical
Additional remarks/notes e.g. weather	Mandatory	Character String (Free text)

Metadata for specific techniques		
Ground-penetrating Radar Surveys		
Antenna information	Mandatory	Character String (Free text)
Timing information	Mandatory	Character String (Free text)
Estimated subsurface velocity	Mandatory	Decimal / Numerical (m/ns)
Velocity estimation method	Mandatory	Character String (Controlled List Value):td

Additional Metadata for specific data type (See above)		
Survey Methodology (for raw datasets)		
Data grid layout	Mandatory	Character String (Free text)
Data grid size	Mandatory	Character String (Free text)
Resolution	Mandatory	Character String (Free text)
Survey direction	Mandatory	Character String (Free text)
Line sequence	Mandatory	Character String (Free text)
Sampling position (if applicable)	Mandatory	Character String (Free text)
Data processing (for processed datasets)		
Processing history list	Mandatory	Character String (Free text)
Archaeology (for Interpretation datasets)		
Monument type	Mandatory	Character String (Controlled List Value): tbd
Monument period	Mandatory	Character String (Controlled List Value): tbd
SM /Heritage List number	Mandatory	Decimal / Numerical

Part Three: Scope Notes and Schema (to encourage exchange)

Scope Note 1

Applications of GPR data in precision agricultural management decisions

GPR data can record changes in soil structure that are influenced by moisture content. Under optimal soil conditions, (dry with low conductivity – see also limitations below) it can map geomorphological variability horizontally, as well as estimating distinct changes at depth. Abrupt subsoil changes such as between highly reflective bedrock and less reflective subsoil can provide the necessary contrast (especially in more sandy soils – see King *et al*. 2003, 10). Strong contrast can also be provided from areas of compacted soil such as tramlines created by agricultural vehicles. Soil compaction impacts the ability of crop roots to access moisture in the subsoil, particularly in summer (Blanchy *et al.*, 2020). Some service providers offer GPR survey to gauge the effects of subsoiling at a whole field scale, producing variable compaction maps for comparison with yield outputs (e.g. http://www.tigergeo.com/agric.php).

Limitations

The efficacy of GPR surveying is influenced by the potential for signal attenuation. In soils with increased electrical conductivity (i.e. due to increased moisture content, clay content or salinity) signal attenuation increases resulting in poor signal to noise ratios which can effectively prevent successful data collection. The loss of signal could in theory be used to identify areas of higher clay/moisture content.

GPR anomalies:

- continuous horizontal reflection layers in radargrams profiles indicate interfaces between contrasting subsoil materials and could be used to estimate topsoil thickness, and the extent and thickness of subsoils or overburden, as well as gauging depth to bedrock or water table (see Romero-Ruiz et al., 2019)
- point reflectors in radargram profiles indicate discrete buried objects, either naturally occurring inclusions such as flint nodules or larger stone/rock, or anthropogenic features such as utility or drainage pipes
- a linear series of point reflectors when viewed in time slices can indicate the line of a pipe, or a system of pipes, relating to drainage, irrigation or other services such as gas or electricity
- archaeological features interpreted from highly reflective materials as used in the construction of walls, foundations, floors or areas of compaction (surfaces or raised banks) can indicate a decrease in moisture (and indirectly, nutrient levels) and may impact negatively on crop roots and growth
- archaeological features interpreted from the weaker reflections of more absorbing materials such as ditch and pit fills can be indicative of increased moisture (and nutrient) levels and may impact positively on crop roots and growth
- depth estimations from GPR measurement of subsoil thickness could potentially indicate constraints on root depths of crops overlying certain archaeological remains
- Other abrupt changes in the subsoil such as the presence of concrete, rubble or voids found in cavities or tunnels, can provide strong contrast for detection

Scope Note 2

Data in precision agriculture potentially relevant to the interpretation of GPR datasets in archaeology

Undertaking electromagnetic induction (EMI) surveys in precision agriculture has become increasingly common, albeit at much courser resolutions in comparison to archaeological applications. Coarse soil conductivity maps can however still provide information relevant to the interpretation GPR surveys. For example, identifying gross areas of high conductivity could explain a drop-off or lack of GPR signals within a given survey area. Similarly, course conductivity maps could also assist in refining methodological planning decisions pre-survey (e.g. targeting or prioritising areas for GPR investigation).

Soil sampling is routinely carried out in precision agriculture to analysis the physical, chemical and biological properties of the soil under laboratory conditions. Potential benefits for the archaeological interpretation and fieldwork planning of electromagnetic induction (EMI) techniques, to which the GPR technique is related, are discussed elsewhere (see ipaast guidance for EMI data). The principal benefit of core sample data for GPR would relate to the validation of depth and thickness calculations of the processed / interpreted data (usually estimated from signal travel-time). Any additional information on soil moisture / texture variability could also be crucial in planning and interpretation of GPR data.

Complimentary data such as conductivity maps or core sample results could be recent, historic or from time-lapse analysis; any indicators of seasonal variation would be useful for survey planning.

Schema

(1) Related to – topography, geology, hydrology, complimentary soil mapping (moisture, texture, compaction), modern services, documented archaeological features (historic mapping, aerial photography, earthwork survey, geophysics, excavation)

(2) Recommended further processing / analysis

- translate vector data (reflective / absorbing anomalies; archaeological interpretation) into agricultural useful terms or soil management zones perhaps relating to geomorphology, areas of increased clay or moisture, erosion, disturbance, drainage, anthropic inclusions in soils, compacted soils, etc.
- radargram depth measurements are usually converted from signal travel-times using an assumed wave velocity commonly estimated in post processing by the hyperbola analysis of any point-source reflectors identified. Relative dielectric permittivity (RDP) testing in the laboratory of soil samples taken from survey area could potentially refine velocity estimates and created a more accurate velocity profile for adjusting depth calculations across a survey area (Conyers 2004: 112-115). This could benefit any survey where a more accurate estimation of depth is necessary.

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