Ground Penetrating Radar Survey: Kilmocholmóg (Lurgan)

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1. Objective

To determine the presence of buried structures and unmarked burials at SMR Site ARM006:016 (Kilmocholmóg, Lurgan, listed as graveyard and church [possible]).

2. Ground Penetrating Radar

Ground penetrating radar (GPR)[2] has become a popular geophysical method in the assessment of possible underground structures and burials (Appendix 1), being more rapid than other methods (electrical resistance; seismic), less prone to magnetic interference (e.g. on basaltic bedrock) such as magnetometry [sometimes, gradiometry) and sensitive to the detection of building foundations, organic remains and ground disturbance. Major disadvantages of GPR are: it is time-consuming compared to resistivity/magnetometry and has poor results on clay-rich/conductive soils.

3. Methods

The GPR deployed comprises a GuidelineGeo 450 MHz High Dynamic Range system. This Swedish-made (Mala Geoscience) machine is a current, state of the art device.
All profile locations were recorded using a Garmin E90 global navigation system (GPS) with barometer; cross-compared to the two in-built GPS receivers in the GPR antenna and control unit (provides a differential correction), further positioned using temporary ground markers imaged by orthogonal MavicPro drone[2] (also with GPS). Data was viewed on site, in order to assess increasing survey limits or conducting more detailed work.

4. Areas Surveyed

The site lies 4-5 km north-east of Lurgan, on the Kilmore Road between Lurgan and Moira. The position of the SMR site was used as a reference point, but was found to be cut by NW-SE land drains through the wet ground with *Juncus effusus* (Irish Bog Rush) to the north-east of the surveyed field (Figs. 1, 2). Nonetheless, the area around the SMR position was surveyed. Analysis of orthoimagery indicates a right-angle (?one edge of a rectangular structure) in the north-west of the area, which was also surveyed (Fig. 3). Two phases of

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[1] Fonts: main text: 12; figure captions: 10.5; Appendix: 9. [2]GPR – also 'radar'; orthoimagery – also aerial photographs

work were conducted: Phase One (23rd February, 2022) and Phase Two (1st March, 2022), with intervening review of Phase One results. Both phases concentrated on the north-western area of elevated ground in the Kilmocholmóg field (Figs 1, 2).

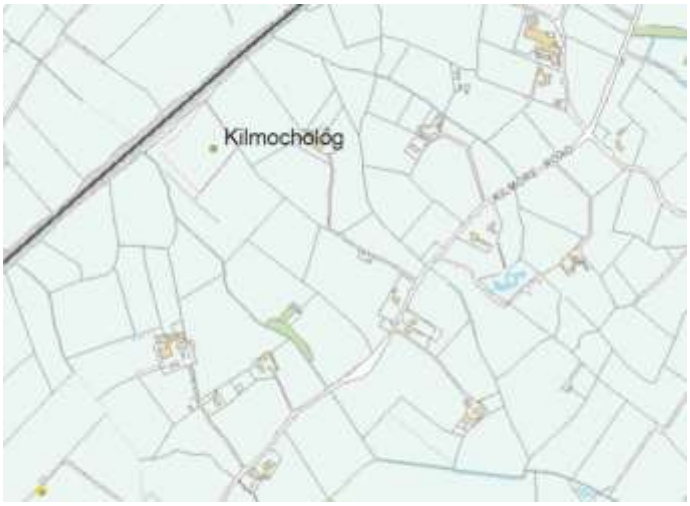

Figure 1. Site location and area surveyed (red dashed box).

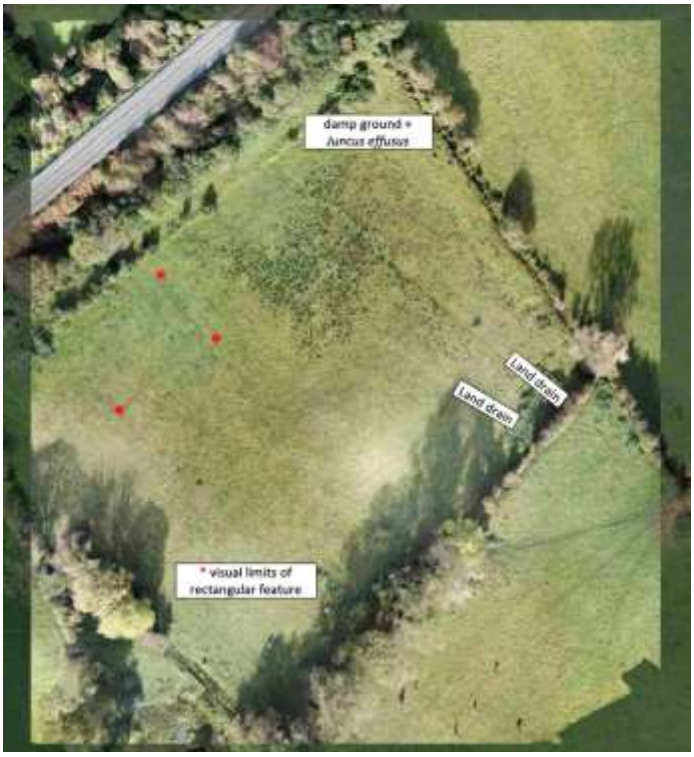

Figure 2 . Drone imagery montage (October, 2021 – c/o Ben Rocke, QUB PhD student) positioned on GoogleEarth©. Abundant *Juncus effusus* (reeds) can be observed, crossed by NW-SE land drains in the NE quarter of the field: the NW corner has a right-angled, possible corner of rectangular feature.

Figure 3. October 2021 drone image, enhanced relief using Q-GIS© remote sensing plugin.

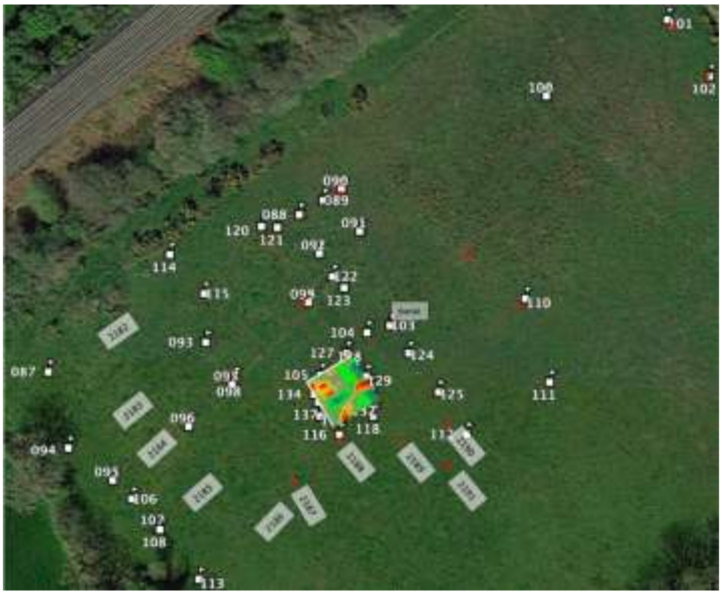

Figure 4. Reconnaissance GPR lines (red dashes), with Phase One 3D grid (coloured box). Numbers are GPS waypoints of 2D start and end points, plus anomalies noted in real-time. On GoogleEarth© aerial view.

5. Results – Phase One

Ten 2D lines were gathered on 23rd February, 2022 (Fig.4), followed by a 10 m x 10 m 3D grid, also on 23rd February.

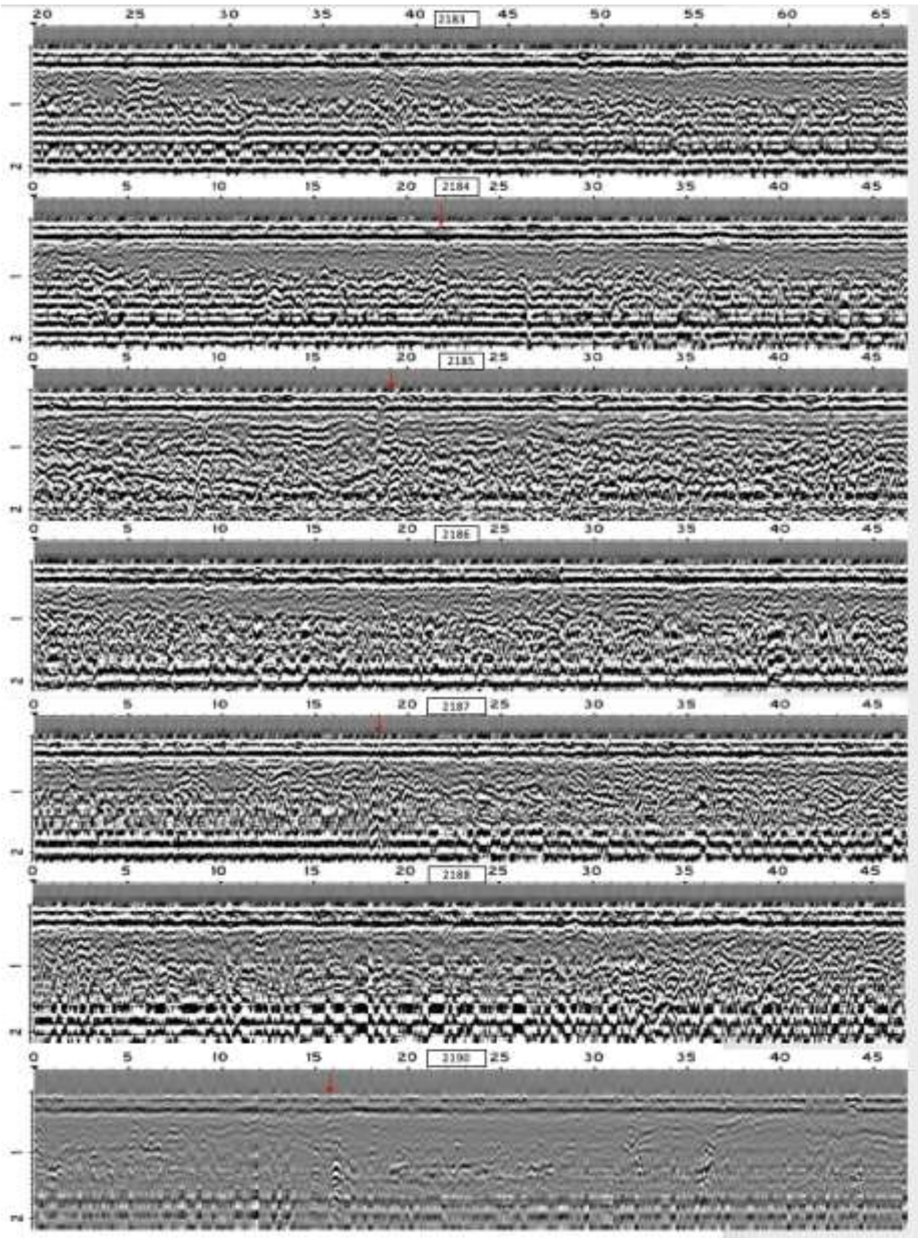

Figure 5. Selected reconnaissance 2D lines (see Fig. 4 for location), showing the bulk of the ground surveyed is without significant anomalies that could be buried features: those observed are arrowed (red) and relate to GPS positions within lines on Fig. 4. Most of these (arrowed features) were found to coincide with linear anomalies of the 3D surveys.

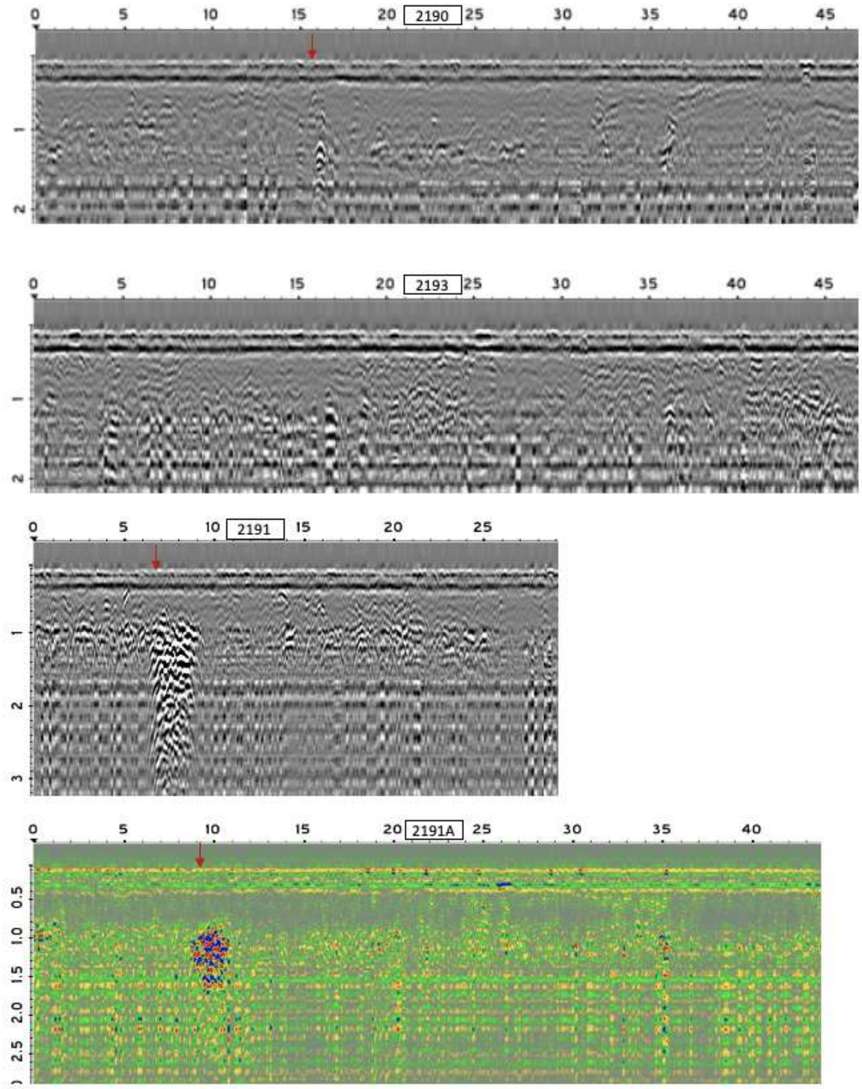

Figure 6. Further selected reconnaissance 2D lines (see Fig. 4 for location), showing the bulk of the ground surveyed is without significant anomalies that could be buried, upstanding or cut features: those observed are arrowed (red) and relate to GPS positions within lines on Fig. 4. The significant feature observed on Line 2191 is thus of note: this line (2191A) has been processed to accentuate radar amplitudes.

Figure 7. Detail of the Phase One 10 m x 10 m 3D survey (slice through the ground at 80 cm depth), same grid faded and overlain onto October 2021 drone orthoimage.

6. Discussion – Phase One

Possible explanations for the 3D depth-slice NE-SW linear feature (same as the major anomaly on vertical slice 2D Line 2191/Line 2191A: Fig. 6) were considered.

- Igneous dyke (Palaeogene): these are predominantly oriented NW-SE; if this is a dyke, it would be in the few percent in the north of Ireland and adjacent continental crust that are orthogonal, and would have to be very resistant to erosion, standing proud of bedrock (unknown depth below): none are mapped by Geological Survey of Northern Ireland in the area, possibly due to limited outcrop.
- A NE-SW oriented fault: these are known (overall NW-SE trend, Fig. 8) in the area, but like igneous dykes, have an orientation orthogonal to the feature :

Figure 8. Extrapolated faults in the area (from GSNI GeoIndex). https://mapapps2.bgs.ac.uk

- Land drain: other land drains in the area run from south-east to north-west (Fig. 2), a drain from the south-west into the wet ground (to the north-east) from this elevated position is possible, but would have to be deeper and of a far more substantial nature than others surveyed. The radar texture suggested the feature on Line 2191 comprises rocks.
- Remnant of railway construction: the feature on 3D is parallel to the railway: if an abandoned portion of track, it lies isolated and without an embankment; a substantial railway building would be unusual to have then been abandoned.
- Another linear feature: no small, shallow (>50 cm depth) isolated or large, deep (<1 m depth) metal was detected using a CEIA systems minimum mine detector, swept over the feature.

Possible explanations for the 3D right-angle anomaly west of the linear feature were considered.

- Coincidence of two land drains (NW – SE and SW – NE): it would be unusual to position land drains away from wet ground, in a currently well-drained position.
- Footprint of a more recent building than any earlier structure (e.g. temporary railway structure): none are known from the area.

7. Results – Phase Two

Eight 2D lines were gathered on 1st March 2022 (to re-locate features, positions not relevant), followed by a 30 m x 30 m 3D grid, over the right-angle on 1st March 2022).

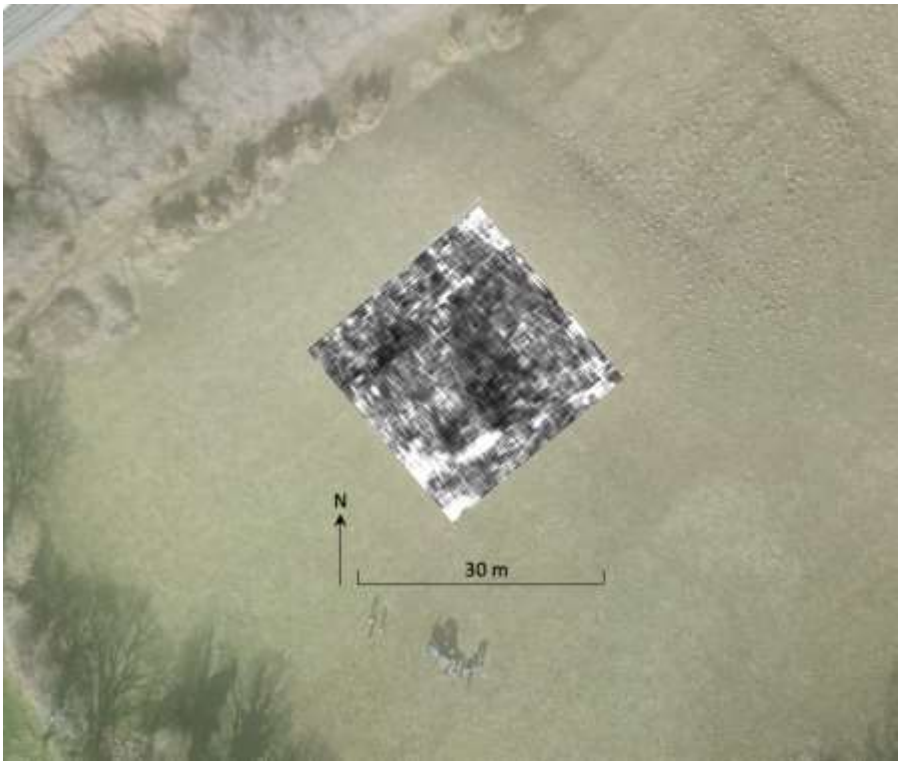

Figure 9. Greyscale 30 m x 30 m 3D slice at 1.35 m depth of the Phase 2 survey, overlain on March 1st drone flight orthoimage.

Figure 10. Greyscale radar amplitude 30 m x 30 m 3D slice at 1.35 m depth of the Phase 2 survey, overlain on March 1st drone flight orthoimage.

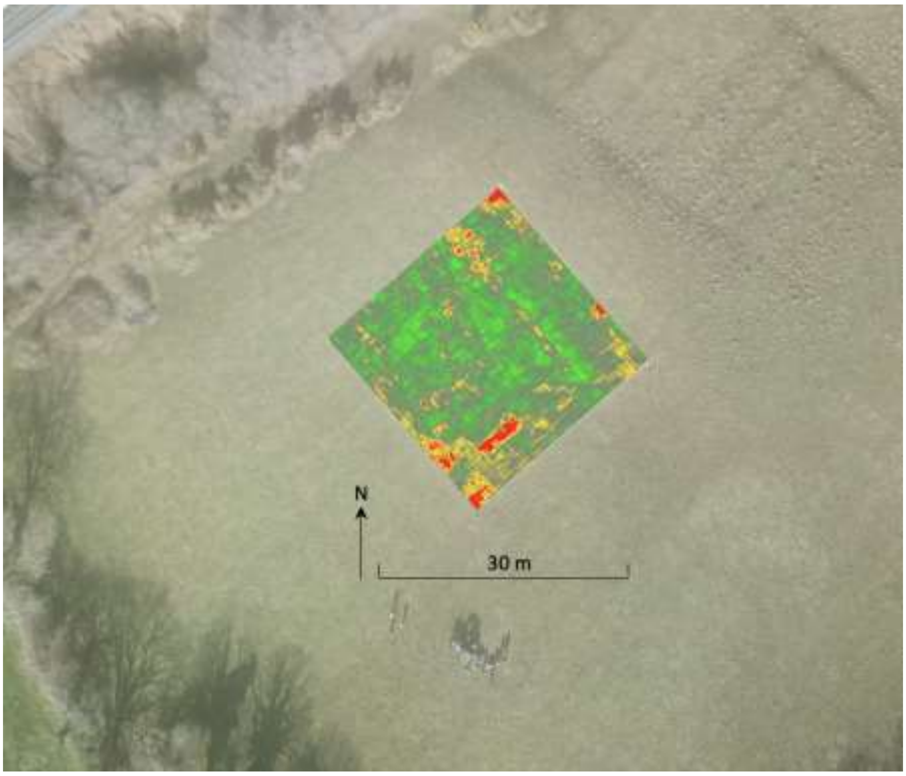

Figure 11. RGB 30 m x 30 m 3D slice at 1.35 m depth of the Phase 2 survey, overlain on March 1st drone flight orthoimage.

8. Discussion – Phase Two

Greyscale radar amplitude and colour plots confirm the shape, location, size and orientation of the right-angle feature identified in Phase One. However, this right-angle is offset from that seen on orthoimagery: a vague 3D lineament is observable coincident with the aerial photographs (Figs. 9, 10, 11).

9. Conclusions/Recommendations

The linear, south-west – north-east oriented feature is substantial and confirmed: the right-angle feature to the west of this is more subtle, and may comprise either two parallel corners (inner on orthoimagery, outer on GPR 3D slices), or an inclined, single feature at 1 to 2 m depth to the south-east, rising to surface north-west: no inclined surfaces were observed on 2D GPR data, but the frequency and design of the 450 MHz radar antenna may not be capable of resolving this.

For near-vertical and steeply-inclined structures, multiplexer GPR antennas[3] are capable of obtaining the imagery required: these are bulky (size of a fridge-freezer). A fully-licensed archaeological excavation, perhaps as two or three trenches to intersect radar anomalies at 90^0, would have the advantage of establishing makeup and retrieving artifacts.

10. Acknowledgements

The surveys were kindly funded by the Department for Communities: Historic Environment Division through the Historic Environment Fund; and the Armagh City, Banbridge and Craigavon Borough Council and The National Lottery Heritage Fund through the Lurgan Townscape Heritage Scheme (Lurgan TH). David Weir (Lurgan TH, Armagh City, Banbridge, & Craigavon Council) instigated this work and assisted on site. The permissions provided by the council, the Historic Enquiries Division and by landowner Finola Mulholland allowed this work to proceed. Charles Mulholland is also very gratefully acknowledged for his logistical help on both survey days. The help of Queen's University students Lauren Carberry-O'Neill and Lisa White was essential. Mike Langton of GuidelineGeo loaned the 450 MHz HDR radar system.

11. Appendix

GPR – How the Method Works

GPR uses the transmission and reflection of radio waves (typically 25 to 2GHz) in imaging the subsurface. Radar waves, introduced in the ground, may reflect back to surface when they intersect objects or surfaces of varying dielectric permittivity. Thus a GPR system requires a source antenna and receiving antenna (built to measure the same central frequency). The transmitting antenna generates a pulse of radio waves that the receiver detects at a set time interval: the longer the time interval, (potentially) the deeper the waves will have travelled into the ground (or to a nearby surface object) and back again. When the ground has a slow radar wave velocity, so a buried object may appear deeper than in ground with a fast transmissive velocity. As the antennas pass over discrete objects with different dielectric properties to the surrounding medium (boulders, pipes, coffins, trenches), they may generate hyperbolae, or arc-like reflections, or depressions. Radar waves also travel horizontally from the transmitting antenna, which in open ground simply dissipate with distance. However, in areas with upstanding structures, especially those that have a significant dielectric contrast to their surroundings, interference from such surface objects can create artefacts on the radargram. When such isolated objects (powerlines, telegraph wires, metal poles, trees) are passed during a traverse, a series of hyperbolae may be generated that appear like a subsurface object but are simply out-of-plane reflections. Radar antennae are commonly elongate (bow-tie shape), generating radar waves in a widening arc from their long axis. Thus when moved in parallel to the antennae axis, the radar waves may reflect from a larger subsurface area in front and behind the antenna, (the so-called footprint) than when moved with the antennae at right angles to survey direction. Antennae may be shielded with radio-wave attenuating materials (e.g. aluminium) that reduce such out-of-plane interference. Unlike other forms of electromagnetic radiation used in geophysics, radio waves have far higher rates of attenuation, and thus penetration and reflection depths are typically low, but horizontal accuracy is high, coupled with rapid, real-time results, unlike all other geophysical techniques bar metal detectors and magnetometer raw data. The receiving antenna has either electronic or fibre-optic link to a recorder that converts incoming radio waves to digital format and displays these graphically as wavelets. As the transmitter-receiver array is moved, so these wavelets are stacked horizontally to produce a radargram, a kind of x-ray slice into the Earth, but recorded in the time taken for radar waves to penetrate and reflect, as opposed to real depth. The speed of radio wave propagation is determined by the makeup of the transmitting medium: in this case the speed of light and dielectric permittivity. Magnetic properties can also influence radar wave speed. Changes in dielectric permittivity can cause radar wave reflection, without which GPR profiling would be impossible. Radar wave attenuation, or signal loss is extreme in conductive media such as seawater, clays (especially hydrous) and some leachate. GPR has good depth penetration (tens to hundreds of metres) in ice (with minor fracturing/interstitial water), hard rocks like limestone and granite and clay-poor quartz silts or sands. Vertical resolution *vs.* depth penetration is of major concern when choosing antenna frequency. Low frequencies (15-50MHz) achieve deep penetration with poor horizontal resolution in the received signal, due to the long wavelength. High frequencies (500-1000MHz) show high resolution with weak penetration (centimetres to metres). Low-frequency antennae are

large (a few metres long), high frequency antenna are small (tens of centimetres). Again, this can influence the use of the method, as deeply-buried targets in enclosed spaces are virtually impossible to survey.
As with all geophysical methods, some intelligence concerning the likely size and makeup of the target is useful: where unknown or questioned, then a range of antennas should be used, and in very poorly understood locations, with other geophysical and invasive techniques (Blunderbuss Approach). Moisture contents influence radar wave velocity because in homogenous media porosity has a direct relationship to dielectric permittivity. Thus dry sand will allow increased wave propagation: sand with high freshwater content will give improved vertical resolution. A problem with unshielded antennas is the effect of 'out-of-plane' reflections (see above, trees, poles), analysed by surveying the same line with different antenna orientations; this is suppressed by shielding. It is easy to think of the radar wave as a focused beam (the ray-path at right-angles to the wave) when in fact the radar wave as it travels into the subsurface is more like a figure of eight bubble, ovates-shaped at first, expanding and becoming both a single oval and distorted as it travels at different speeds into the ground. Thus lateral to the antennae, on or in the ground surface may be structures that cause reflections at ground level. The effect of these surface features can be diminished by altering the orientation of the antennae, or by shielding the above-ground portion of the antennae, such that the radio wave is focussed to penetrate the ground. GPR has found its best uses in imaging glaciers, sand deposits (river, non-saline coastal sands), aquifers (porous nature), archaeological features (moats, buried buildings, graves) and concrete/pavements.