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Migrating and Merging Polarised GPR Profiles: Does it matter if migration is before or after merger?

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Abstract **- A group of radar profiles was gathered across what may have been the site of a canal that was part of the late 16th to early 18th century landscaping at Castle Ward, an estate in Northern Ireland. The canal was filled early in the 19th century, and its exact location was unknown since then. Two sets of profiles were acquired for each of the three survey lines: one set had the antennas perpendicular to the line direction, the common cross-line survey configuration; the other set had the antennas parallel to the survey direction, which we call here the inline orientation. In all cases, transmitting and receiving antennas were parallel to each other. The raw data were compared and there are the obvious differences expected when acquiring data using different polarisations. In addition, we also tested migrating then merging the profiles, versus merging then migrating, to look for any systematic difference in the results.**

In principle, the final profiles should be the same. However, it appears that migrating first, then merging yields a clearer image of the shallower subsurface (the upper part of the profile image), whereas merging then migrating yields a clearer image of the deeper parts of the profiles. The same features are readily apparent in both profiles; there is no net loss of information nor any difference in interpretation in either case. Nonetheless, the interpretation is aided by processing using both orders – migrating then merging and merging then migrating – so that all relevant features are clearly identified.

Keywords **– polarisation; migration; archæology; processing.**

I. INTRODUCTION

The ground penetrating radar (GPR) response is polarised [1], and the reflection profile will differ depending on the orientation of the antennas relative to the reflectors [2 – 6]. In principle, then, GPR surveys should be carried out using the two main antenna orientations: once with the antennas perpendicular to the survey line direction, the usual cross-line configuration; and again with the antennas parallel to the survey direction, which is here called the inline orientation. The transmitting and receiving antennas were always in "broadside" mode, i.e. parallel to each other, using the terminology of Nobes and Annan [2] and Kruk and Slob [6]. The results can then be combined to yield a more complete picture of the GPR response of the subsurface [1, 6].

In August 2007, GPR profiles were acquired across what may have been the site of a canal that was part of the late 16th to early 18th century landscaping at Castle Ward, an estate in County Down, Northern Ireland [7, 8; McErlean & Reeves-Smyth, 1986, unpublished report]. The canal was filled early in the 19th century, and its exact location has been unknown since. Thus, two sets of GPR profiles were acquired along each of the three lines: one set was perpendicular to the survey direction whereas the other set was inline. The raw data for the two polarisations as expected yield different results when crossing a feature such as a canal [1,6], and the canal's location is clear. However, once the profiles for the different polarisations are combined, then in principle, the final results should be essentially the same.

We test this hypothesis by first migrating then merging the polarised profiles, versus merging then migrating. It appears that migrating first, then merging yields a clearer image of the shallower subsurface (the upper part of the profile), whereas merging then migrating yields a clearer image of the deeper parts of the profiles. The same features can be clearly delineated in both profiles, so that there is no net loss of information nor any difference in interpretation in either case. Nonetheless, the interpretation is aided by doing the processing using both orders – migrating then merging and merging then migrating – so that all relevant features, in this case the canal, are clearly identified.

II. SITE DESCRIPTION AND SURVEY DESIGN

2.1 Site History and Description

The Castle Ward estate is located close to Strangford, County Down, Northern Ireland, and comprises over 240 hectares of woodland, park and gardens. The estate was in the Ward family since the second half of the 16th century, until it was acquired by the National Trust of Northern Ireland in 1950. The present house was built *c.*1765. Prior to that the family occupied an early 18th century, Queen Anne period house (Figure 1) located on a different site close to the estate's original centre, 'Old Castle Ward' - a late 16th or early 17th century tower house built adjacent to a sheltered inlet of Strangford Lough [7,8; McErlean & Reeves-Smyth, 1986, unpublished report].

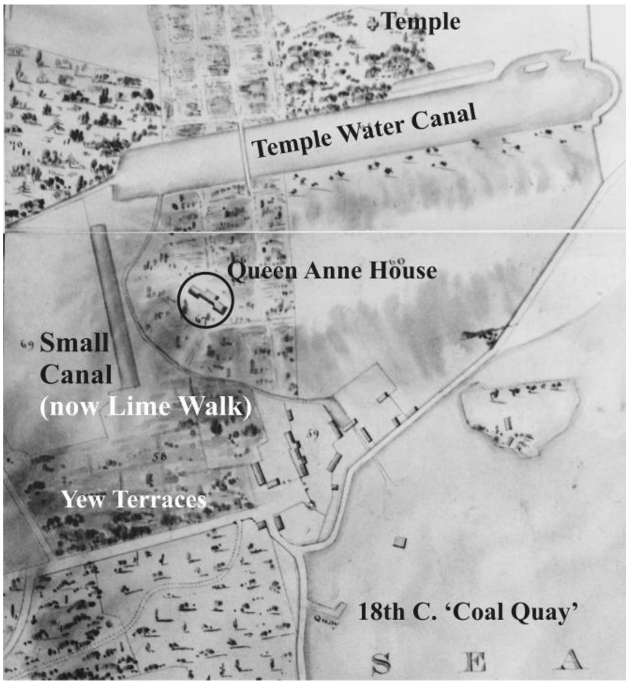

Figure 1. Late 18th C. map of the Castle Ward site, showing in particular the mapped location of the target, the Small Canal.

The short canal was probably built around 1723-24 and was first depicted in a late 18th century estate map (Figure 1). This simple rectangular-shaped water feature (approximately 160 m long, and 15 m wide) was built following a northwest-southeast trend and set below the Queen Anne period house (between Irish Grid Refs. J57124992 and J57234981). Although featured on a demesne map of 1813, the canal had been filled in by the time of the first Ordnance Survey in 1834. At some point, the canal was replaced by the Lime Walk – a tree-lined avenue made up of two double rows of lime trees (felled and replanted in 1983). The earliest representation of the Lime Walk is a *c.*1860 drawing in which the trees are depicted as mature specimens, suggesting that the avenue was already of some age by this date.

2.2 Previous Geophysical Studies

A resistivity survey was undertaken on the Castle Ward estate in June 2007. The survey's aim was to identify garden features located within the immediate vicinity of the Queen Anne period house that had been demolished *c.*1846-59. The house was set within a large landscaped garden that included a number of important features including a set of yew terraces, a short canal (the "Small Canal" in Figure 1), a long ornamental canal known as the Temple Water, a mock Classical temple and a walled garden.

Although the resistivity survey had successfully identified the site of the demolished Queen Anne period house and a number of garden terraces (Figure 2), it failed to determine the position of the short canal as predicted by a study of the early estate maps of Castle Ward. This prompted us to undertake GPR profiling across the Lime Walk in August 2007. In addition to verifying the canal's location, and by extension the accuracy of the cartographic analysis, it was hoped that the GPR survey would identify the size, profile and depth of the small canal.

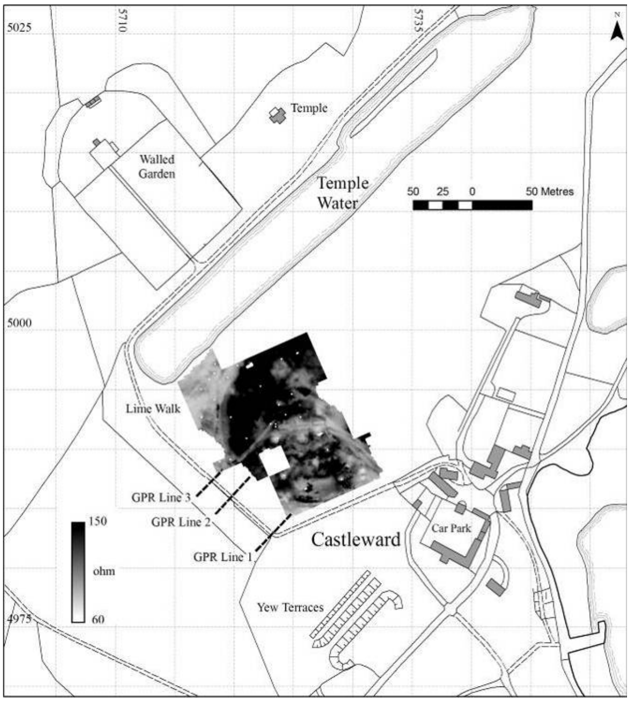

Figure 2. Resistivity surveys were placed to cross the Queen Anne House foundations (Figure 1) and the Small Canal, which was estimated to be just at the base of the slope NW of the Lime Walk, using the map in Figure 1 as the reference.

2.3 GPR Survey Profile Layout

The GPR lines were set out NE-SW, approximately perpendicular to the current NW-SE orientation of the Lime Walk (Figures 2, above, and 3, next page). All lines were acquired using the Malå system with 200 MHz unshielded antennas, step sizes of 0.1 m, and line lengths ranging from 30 m to 45 m. GPR Line 2 was repeated using 100 MHz antennas.

Line 1 was positioned between 4.1 and 4.2 metres southeast of the line of trees forming the Lime Walk. The first row of trees was located at 6.3 metres, the second row of tress at 13.1 metres, the third row of trees at 32.9 metres and the last row of trees at 39.4 metres along the line. Line 2 was located 45.8 metres to the northeast of Line 1. For Line 2, the first row of trees was at 6.7 metres, the second row at 13.3 metres, the third row at 33.3 metres and the last row at

39.9 metres. Line 3 was located 22.1 metres to the north-east of Line 2.For Line 3, the first row of trees was located at 6.7 metres and the second row was passed at 13.7 metres.

All lines were surveyed using first the perpendicular orientation, then the inline orientation. The raw data for the two 200 MHz profiles for Line 2 are shown with topography added in Figure 4. The two 100 MHz profiles for Line 2 are shown with topography added in Figure 5. The 200 MHz profiles for Line 3 were shorter than the others, only 30 m.

All profiles were acquired in continuous profiling mode, with traces recorded every couple of seconds as the antennas were stepped along the tape measures laid out for accurate positioning. This is discussed further in the next section. In addition, topography along each line was determined by means of a theodolite survey.

Figure 3. Photographs of the Lime Walk GPR surveys viewed NW along the axis of the walk (A) and NE across the axis of the walk (B) towards the slope below the site of the house.

III. PROCESSING AND INTERPRETATION

A number of steps were involved in the data processing:

(1) First of all, the data were converted from Malå format to pulseEKKO format, because the later processing was carried out using pE software[1]. ReflexW (Sandmeier Software) was used for the conversion.

(2) The perpendicular and in-line profiles were compared to ensure that the sets of profiles contained the same number of traces for a given line length. Acquisition in the continuous mode caused us to occasionally lose or gain a trace, due to obstacles along the profile, e.g. long grass impeding the movement of antennas, etc. Thus extra traces were removed or missing traces corrected by adding blank traces, e.g. the in-line profile along the 200 MHz profile for Line 2 has had a blank trace added at 2.7 m (e.g., Figure 4B).

(3) After rectification of the profile traces, topography was added, as shown in Figures 4 and 5.

(4) The raw profiles contained diffractions that allowed us to determine the subsurface velocity, both by fitting the diffractions using the demo version of ReflexW, and by testing what velocities best collapsed those diffractions during migration. Velocities ranged from 60 to 75 m/μs; the majoity of values lay between 65 and 70 m/μs. The migration velocity was also tested using 60, 65, 70 and 75 m/μs to see which velocity collapsed the greatest number of diffractions with the fewest number of "smile" over-migration artifacts. Again, the vast majority of diffractions were collapsed using velocities of 65 to 70 m/μs.

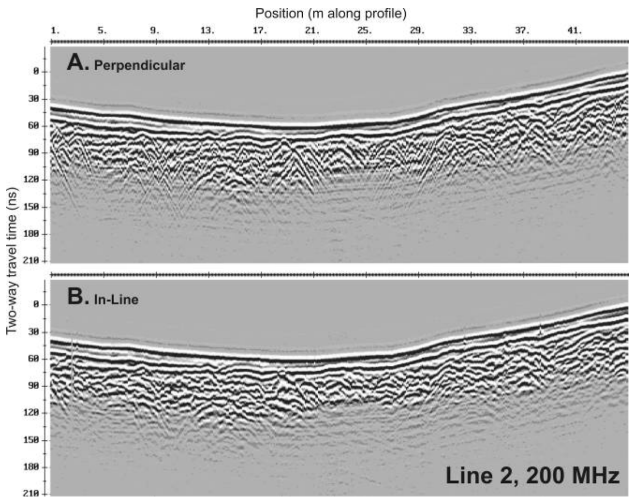

Figure 4. Raw 200 MHz profiles for Line 2, with topography included. Note the numerous diffractions in the profile with antennas oriented perpendicular to the line direction (A, top). The canal location can be seen most clearly in the in-line profile (B, bottom) approximately between positions 21 and 28 m.

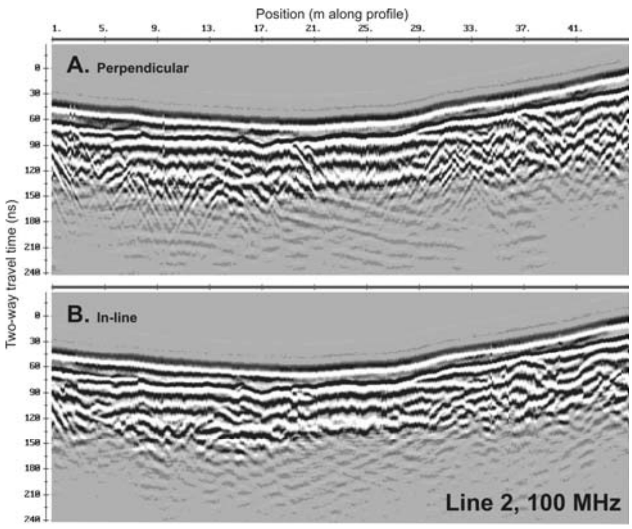

Figure 5. Raw 100 MHz profiles for Line 2, with topography included. The approximate location of the canal between about 21 and 29 m is now clearest in the perpendicular profile (A, top), although its position can also be inferred in the in-line profile (B, bottom). Note the longer time-scale (240 ns) reflecting the greater depth of penetration of the lower frequency signal.

[1] pulseEKKO software was used because that was the software available for processing after the data acquisition was complete.

(5) The two profiles for the perpendicular and in-line antenna orientations were merged, either as the last step after migration, or the penultimate step immediately prior to migration. We ensured that: (i) all profiles had the correct number of traces, and were all correctly aligned using distinctive subsurface events along each profile to guide spatial alignment; and (ii) the profiles along a given line had the same "time zero", i.e. had the same air wave arrival time, so that identical events occurred at the same two-way travel time. Thus profiles for a given line were properly aligned in space and time, thereby minimising errors due to misalignment.

IV. RESULTS AND DISCUSSION

We cannot present all of the results, and so will instead focus on the 200 MHz results for two lines, 1 and 2. 100 MHz data were acquired only for one profile along Line 2, and Line 3 was only 30 m long, rather than 45 m as for the other profiles. The raw results for Line 2 are shown in Figure 4. The Line 1 raw data are similar, but with less topography.

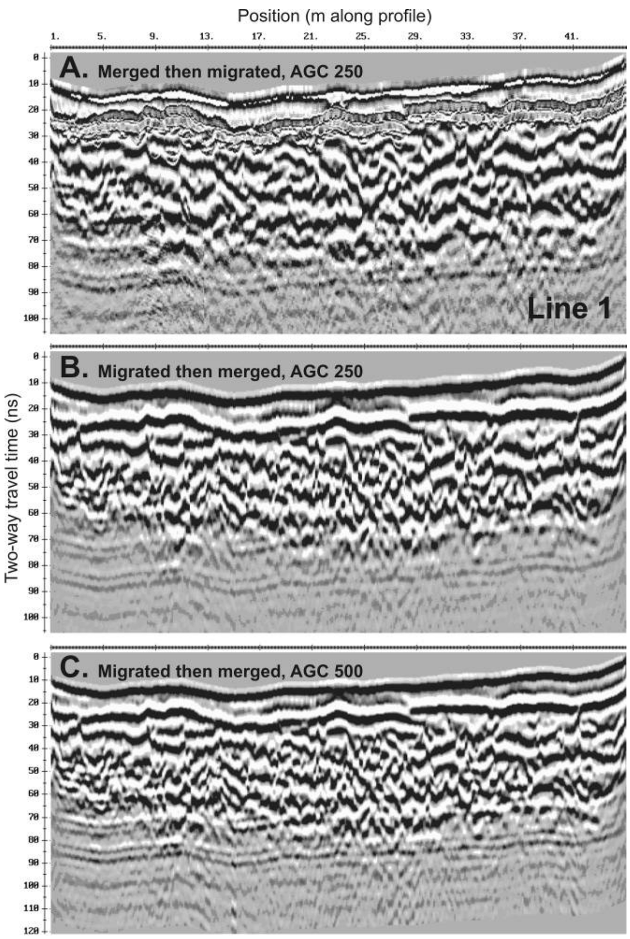

Figure 6. Processed 200 MHz profiles for Line 1. When the data are merged then migrated (A, top), the resulting profile is noisier than the one which is migrated then merged (B, middle). In addition, the deeper reflectors in A appear to be stronger, even when the AGC gain factor is doubled (C, bottom). Conversely, the shallower reflectors are clearer in B and C.

The results for Line 1, shown in Figure 6, used a migration velocity of 70 m/μs. The merged-then-migrated profile (Figure 6A) appears to be noisier than the profile that is migrated then merged (Figure 6B), and the deeper reflection events (below about 60 – 80 ns) are stronger, even when the migrated-then-merged AGC gain factor is twice as large (Figure 6C) as for the merged-then-migrated profile. The migrated-then-merged profiles also appear to have more residual scattering artifacts, despite the fact that diffractions are, in general, collapsed using a migration velocity of 70 m/μs. Diffractions that remain are air wave events from trees adjacent to the survey lines.

Conversely, shallow subsurface reflection events (upper 40 – 50 ns) are clearer in the migrated-then-merged profiles (Figures 6B and 6C).

The results are similar for Line 2 (Figure 7). The deeper reflection events (below about 60 ns) are stronger. This is especially noticeable below two-way travel times of 80 – 100 ns.

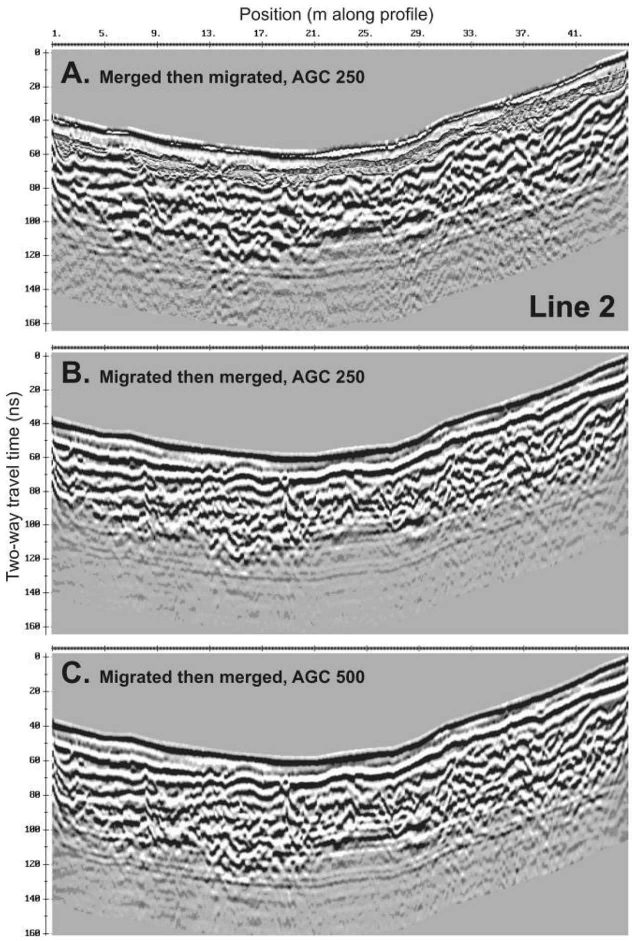

Figure 7. Processed 200 MHz profiles for Line 2. The results are similar to those for Line 1 (Figure 6, opposite).

Note events at positions 5 – 9, 13 – 17 and 29 – 37 m. The shallower reflection events are also clearer in the migrated-then-merged profiles for Line 2 (Figures 7B and 7C), just as we see for Line 1.

Finally, the canal is not readily apparent in Line 1, which may not have crossed the end of the buried canal, but we do see it in Line 2, between positions 21 and about 27 m along the survey line. The canal proper is indicated by the strong layering at those locations, with the absence of other reflections or scattering. The layering may be due to the presence of more fine-grained sediments. There also appear to be banks or canal sides, labeled “1” at 19 m and “2” at 31 m in Figure 8, which suggests a canal width of about 12 m. However, the right-hand bank, “2” (as viewed looking north, or into the GPR profiles), may be obscured by diffraction residuals arising from the trees nearby (labeled “T” in Figure 8).

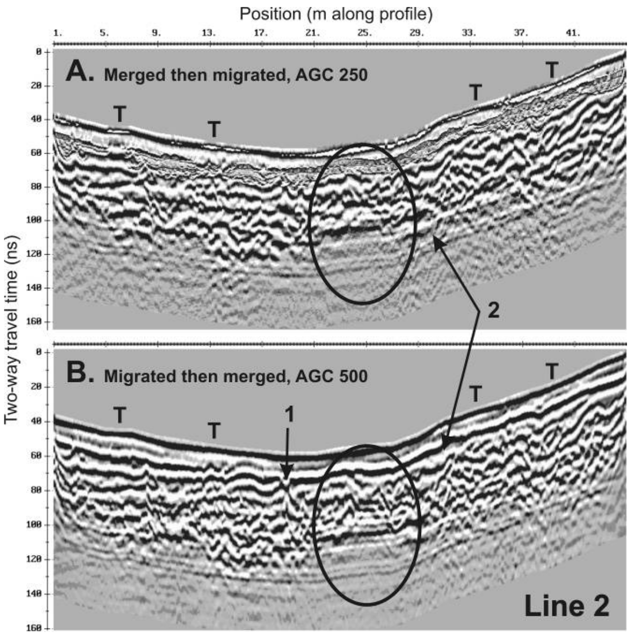

Figure 8. Interpreted profiles for Line 2, showing the canal (marked by the oval) and the layering within the canal, and what are possibly the sloping sides of the canal (labeled “1” and “2”). The trees (labelled “T”) are at 6.7, 13.3, 33.3 and 39.9 m. See text for discussion.

V. CONCLUSIONS

A suite of radar profiles were acquired at an archaeological site, Castle Ward, in County Down, Northern Ireland, for the purpose of locating a canal dating from the 17th century. The profiles were acquired using two polarisations: one was perpendicular to the survey line direction, and the other was parallel. We systematically tested the expectation (the hypothesis) that the final profiles should be the same, regardless of whether the two polarisations were first merged and then migrated, or migrated and then merged.

Our results show that the final profiles differ. It appears that migrating first, then merging, yields a clearer image of the shallower subsurface (the upper part of the profile image), whereas merging then migrating yields a clearer image of the deeper parts of the profiles. The same features are readily apparent in both profiles; there is no net loss of information nor any difference in interpretation in either case. Nonetheless, the interpretation is aided by processing using both orders – migrating then merging and merging then migrating – so that all relevant features are clearly identified, particularly the canal that was of interest.

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