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Subsurface imaging a Viking-Age churchyard using GPR with TDR: Direct comparison to the archaeological record from an excavated site in northern Iceland

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ABSTRACT

The results of a ground-penetrating radar (GPR) survey over a Viking-Age Christian churchyard (ca. 1000–1100 CE) that was subsequently fully excavated are reported. During excavation, broadband time-domain reflectometry (TDR) measurements of apparent relative permittivity were made of various features which helped to constrain interpretations of the radar data. Although four probes of different lengths were used (0.1, 0.15, 0.2 and 0.3 m), the longest waveguide yielded effective frequencies that most closely matched the bandwidth of the radar data, which was collected using a 500 MHz antenna.

The excavation revealed 25 graves. Comparison of the radar data to the archaeological record indicated that all graves containing skeletal remains produced signatures from the bones, but only half of those were interpreted as such prior to excavation. The skeletons of three adults and two children as well as two pairs of isolated leg bones were identified beforehand, whereas five sets of remains (small child, infants and neonates) were noted only after reanalysis of the radar data following the excavation. Thirteen of the graves had been re-dug and their bones removed prior to 1100 CE presumably for interment to a nearby more recent churchyard. The only indication of burial pits in the radar profiles was a break in a sub-horizontal reflector that corresponded to a perforated in situ volcanic tephra sequence. Six of the 25 burial pits were identified prior to excavation, eight more after reanalysis, and 11 had no signature because of the absence of preserved tephra in their vicinity. The TDR measurements confirmed the general lack of contrast between backfill material within pits and soil surrounding pits. This study provides one of the best documented cases for comparison of radar data to the archaeological record for a fully excavated churchyard, and confirms the direct detection of skeletal remains by GPR.

1. Introduction

Ground-penetrating radar (GPR) is an important geophysical tool for shallow subsurface imaging. The method is based on detecting contrasts in the electromagnetic properties of relative permittivity (electric) and relative permeability (magnetic) in soil. The former is strongly correlated to water content while the latter varies insignificantly for most field conditions that are likely to be encountered. For archaeological and forensic applications, GPR has proved useful in detecting unmarked burials and clandestine graves (e.g., Bevan, 1991; Buck, 2003; Conyers, 2006; Schultz, 2007; Ruffell et al., 2009; Fiedler et al., 2009; Doolittle and Bellantoni, 2010; Damiata et al., 2013).

In general, the presence of a grave can be identified in radar profiles by several means including: (1) the perforation or truncation of natural stratigraphy due to digging of the burial pit (Bevan, 1991; Mellett, 1992; King et al., 1993; Conyers, 2006; Damiata et al., 2013); (2) the slumping of the ground surface (Conyers, 2006; Doolittle and Bellantoni, 2010) and associated lateral changes in velocity (Unterberger, 1992) due to differences in compaction and homogeneity between undisturbed and backfill deposits; and (3) the detection of a burial container such as a casket or coffin (Mellett, 1992; Unterberger, 1992; Dionne et al., 2010). Rarer still is reported the direct detection of skeletal remains (Mellett, 1992; Damiata et al., 2013).

In a previous paper, Damiata et al. (2013) presented a case study in which GPR was used to discover the Viking-Age Christian churchyard that is considered in the present work (Fig. 1). As reported in that paper, several sets of hyperbolas (diffractions) on contiguous radar profiles were identified and interpreted to be graves. A targeted excavation was performed over the most pronounced set revealing the presence of

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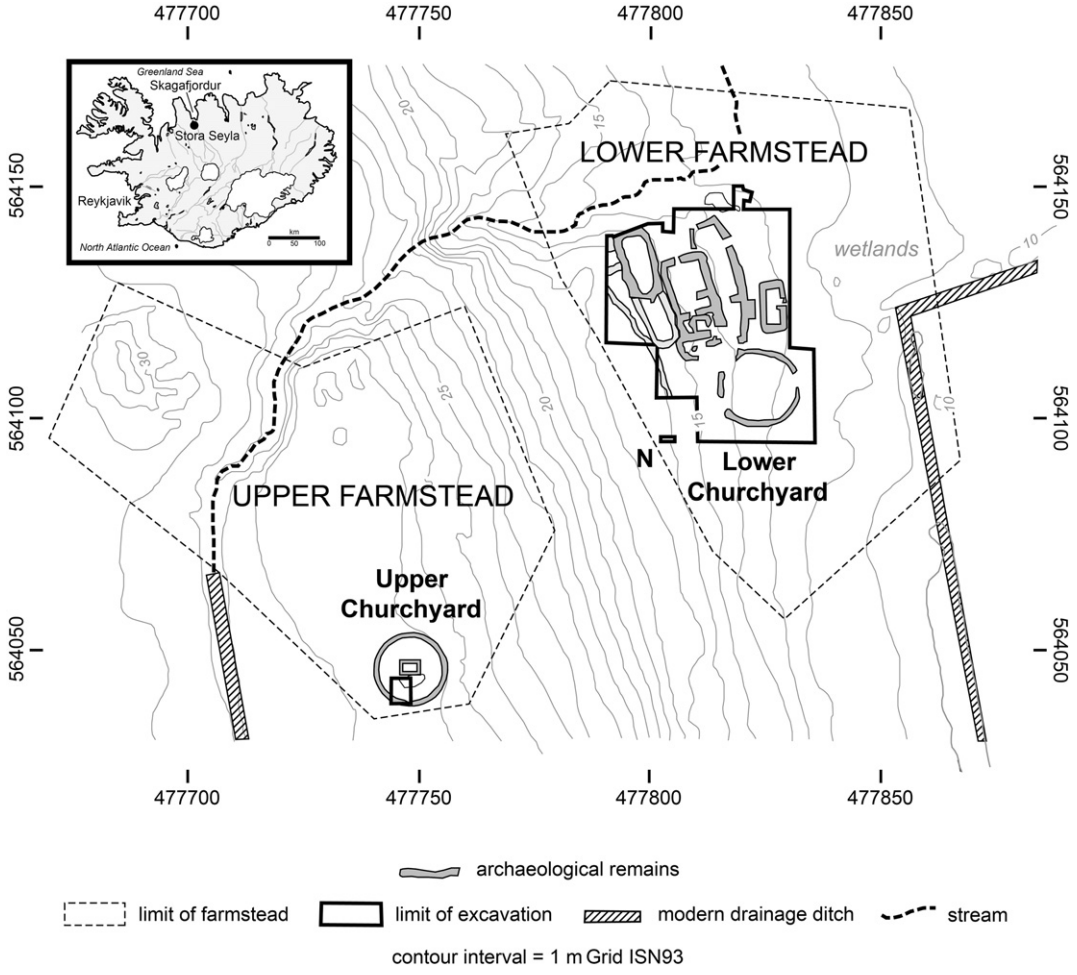

Fig. 1. Index map showing the locations of Skagafjörður and the Stóra-Seyla farm in northern Iceland. The archaeological remains of the upper Medieval churchyard are partially exposed at the ground surface but there were no visible signs of the lower Viking-Age churchyard. "N" denotes location of trench used for TDR vertical profiling as discussed in text (modified after Damiata et al., 2013).

a well-preserved adult skeleton. Comparison of the radar profiles to the archaeological record indicated that various long bones of the skeleton were directly detected. The only indication of the burial pit in the profiles was the break in a sub-horizontal reflector that corresponded to a perforation of a relatively thick, prehistoric, volcanic tephra sequence.

Subsequently, the churchyard has been fully excavated and the radar data reanalyzed. During the course of excavation, time-domain reflectometry (TDR) measurements of apparent relative permittivity were made on various features in and around the churchyard. The TDR measurements were used to help constrain interpretations of the radar data. TDR is commonly used in the soil sciences to indirectly measure the moisture content of soils (Topp et al., 1980; Topp et al., 1982; Jones et al., 2002; Pettinelli et al., 2002; Robinson et al., 2003). Its use in archaeological studies has been limited—Leckebusch (2000) employed TDR to estimate radar velocities under a concrete floor in a Medieval Swiss choir; Verdonck et al. (2009) made measurements on Bronze-Age burial mounds in Belgium to estimate radar velocity for migrating data; and Pettinelli et al. (2012) used it to estimate the relative permittivity and signal attenuation of radar waves for different volcanic units that cover the ruins at Pompeii.

The present study represents an extension of the preliminary work that was reported by Damiata et al. (2013) for a single grave, and provides a rare opportunity to directly evaluate the diffractions and reflections arising from various buried features of a Viking-Age Christian churchyard. This study is one of best documented cases for detecting in situ skeletons and partial remains by GPR surveying and is unique in that interpretations are both constrained by TDR measurements and verified through excavation. Note that this paper does not deal with 11th century mortuary practices nor with burial customs in this part of Iceland which are subjects to be reported upon elsewhere (Zoëga and Bolender, in review).

2. Methods and instrumentation

The present study was conducted as part of the Skagafjörður Archaeological Settlement Survey (SASS) in collaboration with the Skagafjörður Church Project (SCP). SASS was initiated in 2001 and has intensively investigated twenty-one present-day farms in the Langholt region of Skagafjörður (Steinberg, 2003; Bolender et al., 2008; Bolender et al., 2011; Damiata et al., 2013; Bolender, 2015; Steinberg et al., 2016). Over the course of several field seasons, a protocol was developed to investigate a given farm in order to: identify the presence of Viking-Age farmsteads, estimate their extent, determine their establishment date, locate individual structures and features that comprise a farmstead, and understand the function of some of the structures. The SCP was initiated in 2007 with the aim of establishing the frequency of spatial and temporal distribution of early Christian cemeteries as well as to examine developments in burial practices and religious architecture (Zoëga and Sigurðarson, 2010; Sigurðardóttir, 2012; Zoëga, 2014; Zoëga, 2015).

The SASS protocol involves systematic hand coring, reconnaissance geophysical surveying, test excavation, targeted geophysical surveying, and traditional excavation. Using this protocol, the Viking-Age churchyard at the lower site on the present-day Stóra-Seyla farm was discovered in 2009. Based on tephrochronology, the churchyard was in