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## Challenges and Triumphs of Ground-Penetrating Radar for Studying the Archaeological Resources of Mormon Nauvoo

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Nauvoo, Illinois, sits astride a small promontory of land that appears to jut westward into the Mississippi River, reclaiming a formerly swampy area, locally known as “the flats.” The flats rise to about 30 feet (9 meters) above the river level, sloping gently upward to “the bluff,” from which point the prairie

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stretches eastward. The community was established as a gathering place for the Latter-day Saints (Mormons) in the aftermath of the “Mormon War” in Missouri, from which thousands fled, seeking refuge in western Illinois during the winter of 1838–1839. Numerous structures were erected, mainly over the flats, culminating in the construction of a magnificent limestone temple, which commanded a view of the river from the bluff.

The Nauvoo of today bears only faint resemblance to its historic counterpart. Visitors to Nauvoo today are presented with an open, park-like setting with broad manicured lawns and a few historic homes and public buildings—mostly brick—sparsely scattered across the flats. Little evidence remains of the “lively and animated” city that once inhabited the peninsula.<sup>1</sup> During the height of Mormon occupation in Nauvoo, the city grew at an exponential rate. Some contemporary observers report an enchanting city bravely perched on the western frontier, while others recount a desultory assortment of dilapidated houses. Despite these greatly varied aesthetic assessments, nineteenth century accounts, from visitors and immigrants alike, invariably comment on its expansive and rapid growth. In June 1840, Joseph Smith reported that approximately 250 “mostly block [log] houses, [and] a few frame” houses had been built and “many more” were then under construction.<sup>2</sup> By August 1843, the *Nauvoo Neighbor* reported, “buildings are being erected on every side, and many excellent brick houses have lately been finished. The low part of the town which in the spring was almost destitute of inhabitants, is now thickly studded with houses and swarming with children.”<sup>3</sup> One recent arrival, John Needham, described his first view of the city as he approached by river in 1843. “The city,” he said, “seemed to rise gradually from the sea, with houses much scattered, but over a great extent of ground.” Needham further described “many good brick houses, and others are frame-wood and log houses,” adding that “in a general way the houses have one good room below and a bedroom, some have more.”<sup>4</sup> Methodist minister Samuel A. Prior, in a letter printed in the *Times and Seasons*, described Nauvoo as “one of the most romantic places” he had visited in the West. Prior reported: “The buildings, though many of them were small and of wood, yet bore the marks of neatness which I have not seen equalled in this country. The far-spread plain at the bottom of the hill was dotted over with the habitations of men with such majestic profusion that I was almost willing to believe myself mistaken . . . Here and there arose a tall majestic brick house, speaking loudly of the genius and untiring labour of the inhabitants.”<sup>5</sup>

By 1846, as the main body of the Church was fleeing the city, an unnamed “eye-witness,” counting from the top of the temple, reported “two thousand houses in the city proper and in the suburbs five hundred more.” According to this account: “One-half of these were mere shanties built some of logs and

some of poles plastered over; others were framed. Of the remainder about twelve hundred were tolerably fit dwellings; six hundred of them at least were good brick or frame structures. The number of buildings made wholly of brick was about five hundred, a goodly proportion of them large and handsome.”<sup>6</sup>

Such descriptions of Mormon Nauvoo during its heyday contrast sadly with the account written by Latter-day Saint official Brigham H. Roberts following his 1885 visit to Nauvoo, almost forty years after the Mormons were forcefully exiled in 1846: “The whole place,” he wrote, “has a half-deserted, half-dilapidated appearance and seems to be withering under a blight, from which it cannot recover.”<sup>7</sup> Such disparate eye-witness descriptions indicate how the Latter-day Saints rapidly transformed a swamp into a major city—said to have rivaled Chicago in size with its estimated 12,000 inhabitants—that almost as rapidly faded into obscurity.<sup>8</sup>

Since the 1960s, the LDS Church has invested vast resources in the restoration of the city in an attempt to create a veritable “Williamsburg of the Midwest.” A significant part of this effort has involved extensive archaeological excavations that have uncovered the foundations of a number of original Mormon structures, several of which have since been reconstructed. More recent restoration-related activities in Nauvoo, however, have not considered the city’s vast subterranean archaeological resources prior to initiating construction, which has resulted in the disturbance of a number of the city’s historic sites.<sup>9</sup>

The overall layout of historic Nauvoo has been known for many years. Extant maps from the Mormon period (1840s) illustrate the city’s division into four-acre blocks. Tax and property records from the period, moreover, have shed light on the actual ownership of numerous Nauvoo lots and the various structures built throughout the city. What is lacking, however, is an understanding of where these structures were located within the specific city lots and what remains of the internal features of original Mormon sites that have long since disappeared from the landscape. Through the collaboration of the LDS Church History Department and the Department of Geological Sciences at Brigham Young University, we describe a strategy to fill this gap in the historical knowledge of Nauvoo.

Our study summarizes the results of a program to test the application of three-dimensional ground-penetrating radar (3D GPR) for locating and understanding the buried archaeological resources of the 1840s Mormon settlement of Nauvoo. This advanced, non-intrusive technology allows for the detection and visualization of foundations and related architectural features that survive beneath the surface of the earth today. A number of the city’s known historically-occupied lots have been surveyed with encouraging results. The information resulting from this project has the potential to

facilitate and guide future restoration projects in the historic city and ensure that development does not unintentionally disturb the buried resources of Nauvoo. It is not the purpose of this article to answer archaeological questions about the Mormon period of Nauvoo. Rather, we seek to describe the potential of 3D GPR for aiding future archaeological study using examples from our recent surveying efforts, including clear-cut cases as well as cases where the results are enigmatic and further study (e.g., excavation) is needed. If GPR exploration can answer questions about the archaeological resources lying buried in Nauvoo, we could use this technique to non-invasively guide our understanding of the dimensions, locations, and internal composition of historic Nauvoo structures that are no longer standing. These answers could, in turn, aid our understanding of the city's growth and decline, and shed some insight into the conditions under which the settlers lived.

### **Physical Description of the Nauvoo Study Site**

Nauvoo is located along the western edge of what geologists call the "Till Plains Section of the Central Lowland Province," where the rugged topography expressed as bluffs following the Mississippi River contrasts with the subdued, undissected terrain of ancient glacial deposits lying immediately to the east.<sup>10</sup> This area is mantled by glacial sediments (commonly known as "drift" or "till"), beneath which bedrock is deeply buried. Previous authors, writing from a civil engineering perspective, have described the surficial geology and soil composition for Nauvoo and the immediately surrounding area.<sup>11</sup> On the basis of coring observations, Rollins et al., constructed a soil profile that showed fine-grained sediments thinning from 16 feet (4.9 meters) at the foot of the Bluff to only 2 feet (0.6 meters) near the river's edge where limestone bedrock is exposed in places. Visitors to Nauvoo only need venture as far as the old quarry, from which the stone was extracted for the original Nauvoo Temple, to see how thin the top-soil can be; there the limestone bedrock is actually exposed at the ground surface. The soil overlying bedrock elsewhere in Nauvoo variably consists of a few feet of dark clay, silt, and occasionally some sandy deposits, as observed by borings made by Rollins et al., and encountered by our test pits at several sites (see results below). Such fine-grained materials (clay and silt) are expected for a swampy environment, whereas the sandy layers were likely deposited in higher-energy sedimentary environments, including streams that emptied into the main channel of what is now the Mississippi River. As pointed out by Rollins et al., some of the clay is likely the product of the weathering of the limestone bedrock. Because clay and the underlying limestone have low permeabilities, rainfall tends to infiltrate slowly, flowing horizontally as surface runoff.<sup>12</sup> Anyone engaged

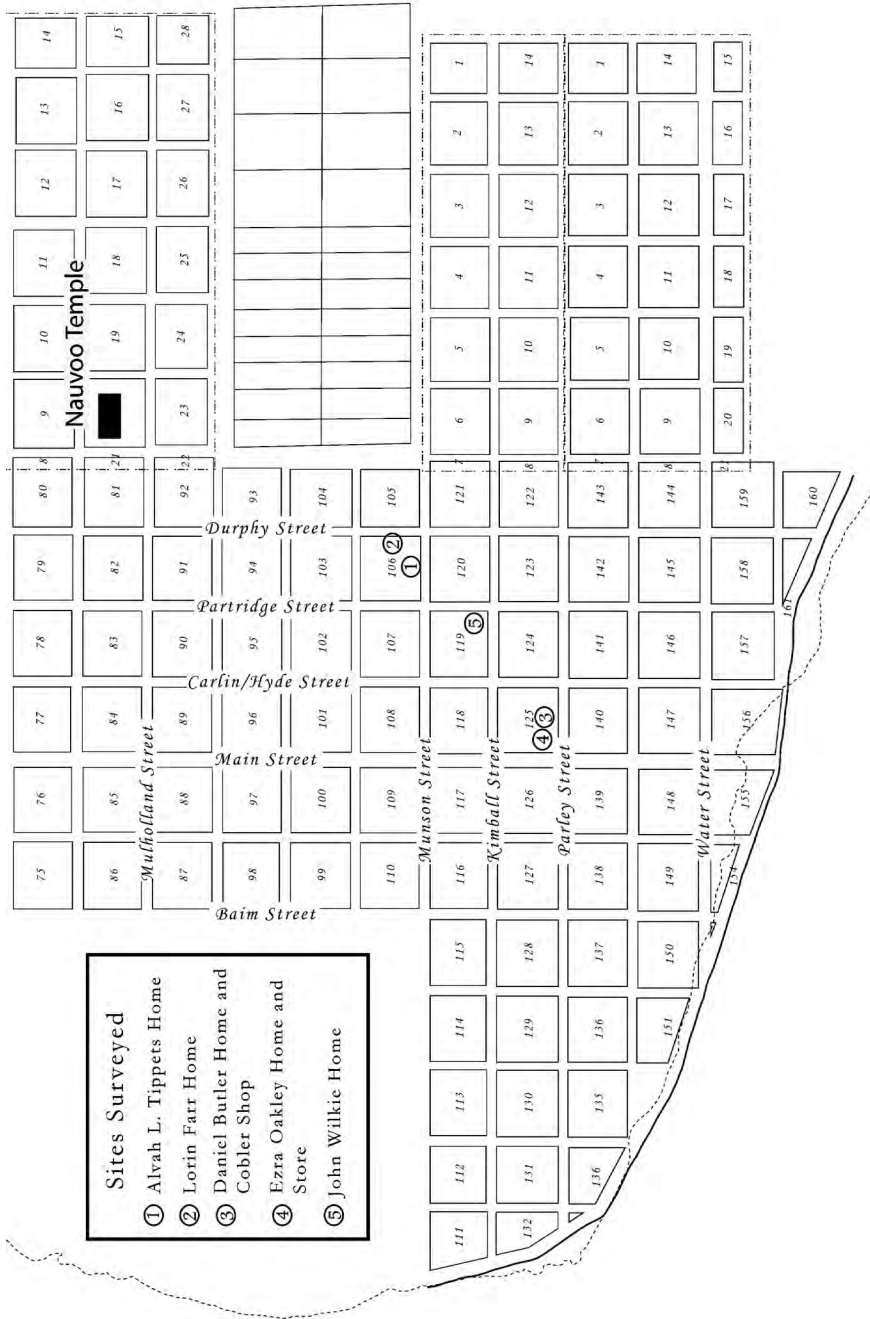


Figure 1. Contemporary map of Nauvoo showing the five GPR sites discussed in this report.

in digging for new building foundations in the flats of Nauvoo will likely discover that the water table can be very shallow.

### **Archaeology in Nauvoo**

Archaeological studies in Nauvoo sponsored by the LDS Church commenced with the full-scale excavation of the Nauvoo Temple site in 1962, which exposed foundation walls as well as provided evidence of internal masonry partitions at the basement level of the building.<sup>13</sup> The success of the temple study was followed in 1965 by the initiation of excavations around the Brigham Young home on the flats, which uncovered features that were interpreted to be Brigham Young's cistern and well, in addition to sections of a brick pavement.<sup>14</sup> These excavations and others that followed contributed to the restoration of the Brigham Young home several years later.<sup>15</sup> The LDS Church's interest in the archaeological study of Nauvoo culminated during the late 1960s and early 1970s with the excavation of several sites on the flats, followed by a decline in the Church's archaeological study of Nauvoo.<sup>16</sup> During this same period, archaeological studies sponsored by the Reorganized Church of Jesus Christ of Latter Day Saints (now the Community of Christ) began to go forward on properties they owned on the flats, beginning with the excavation of the Mansion House stables in 1969, and including such notable sites as the Theodore Turley homesite, reportedly the first substantial home built by Latter-day Saints in Nauvoo.<sup>17</sup> These studies clearly established the presence of important buried architectural features—stone foundations, masonry or stone building partitions, cisterns and wells, and surviving pavements—that provide potential targets especially well suited for GPR investigation.

### **How GPR Works and What Makes a Good Target**

Locating buried archaeological remains, such as building foundations and interior structures, was one of the earliest uses of GPR.<sup>18</sup> Archaeological applications of GPR for understanding building sites broadly range from studies relevant to classical civilization in the ancient world,<sup>19</sup> to more arcane sites of relatively recent historical interest.<sup>20</sup> The technology has previously been utilized in archaeological applications at other LDS Church historic sites, including Kirtland, Ohio; Harmony (now Oakland), Pennsylvania; Far West, Missouri; the Mormon Handcart Historic Site near Martin's Cove, Wyoming; and the original Tabernacle site in Provo, Utah. In most instances, GPR imagery has proved valuable for assessing extant subsurface features and assisted in more efficient planning for excavations conducted at those sites.<sup>21</sup>

Three-dimensional (3D) GPR surveys move an antenna across the ground in a series of closely spaced lines (in our case, usually spaced 1 foot [0.3 meters]) running parallel and perpendicular to the expected orientation of possible buried structures, such as a buried foundation wall, so as to produce an orthogonal grid. The antenna both transmits and receives electromagnetic (EM) signals that reflect off, or are scattered by, dense or metallic objects and that are recorded by a specialized computer connected to the antenna. Antennas with various center frequencies may be used, depending on the depth and size of the target. For archaeological applications, a 400-MHz antenna, as employed by our study, is typical. Computer processing of the recordings generates a “volume” of radar reflectivity that can be sliced vertically or horizontally, producing cross-sections or subsurface maps, respectively, that reveal buried objects.

Because the reflected GPR signal arrives at the antenna over time (a typical recording time is 100 nanoseconds [ns]), the images must be converted to depth using an assumed or derived EM velocity for the soil overlying the target.<sup>22</sup> Stone or brick foundations, demolition rubble, and interior walls are examples of buried remnants that could reflect EM energy. Such materials have electrical properties (known as dielectric constant<sup>23</sup>) that contrast markedly with the surrounding soil. A buried limestone foundation, quarried from local bedrock, is composed mostly of calcium carbonate ( $\text{CaCO}_3$ ) and has a reflectivity that varies markedly from that of soil. This is largely because limestone has a lower porosity relative to soil. The speed of EM energy is much greater in air than in solid limestone.<sup>24</sup> This means that we expect a strong radar reflection from a foundation composed of limestone or other solid material (e.g., brick). A strong signal may also be a diffraction from a “scatterer,” which is expressed as an upward convex pattern (mathematically, a hyperbola) on a radar profile.<sup>25</sup>

The strength of any received signal also depends on absorption of energy by the medium through which the signal travels, as well as on the depth of the target. Water in the pore spaces of the soil (or stone) attenuates EM signals. Fine-grained materials (clay or silt) are also destructive to the signal. As reviewed above, the soils of Nauvoo, especially on the flats, are dominated in places by fine-grained sediments, which are frequently moist (or even water-logged). The presence of clays and wet conditions thus combine to make Nauvoo a challenging environment for GPR studies. Our results show that best performance of GPR is possible under dry conditions.<sup>26</sup>

## Results

In order to investigate the utility of GPR in Nauvoo, we conducted surveys over a range of differing archaeological targets related to the 1840s Mormon period: buried foundations, cisterns or wells, hidden pavements or floors, and concentrations of debris associated with the demolition of buildings. Sites on which both brick and frame structures once stood were surveyed. We began our process of selecting sites by consulting research based on tax records; lots that were associated with higher property tax values were deemed more likely to hold substantial buried archaeological remains (e.g., a stone foundation that once supported a brick structure). Here we present results from five known 1840s Mormon sites that demonstrate how varying targets can be imaged by 3D GPR: (1) the Alvah L. Tippetts home, (2) the Lorin Farr home, (3) the Daniel Butler home and cobbler shop, (4) the Ezra Oakley home and store, and (5) the John Wilkie home (Figure 1). The GPR surveys were conducted at different times of the year and under different soil moisture conditions. Our results show how, and under what conditions, such archaeological targets can be studied using GPR. Further, 3D computer visualization techniques were applied and deemed necessary in order to detect the subtle GPR anomalies that are typical of the archaeological resources in Nauvoo.

### *Alvah L. Tippetts House*

The Alvah L. Tippetts site, located along Munson Street just east of the Heber C. Kimball home (Figure 1), was chosen for our first radar test because previous archaeological testing had suggested where the foundation of a building was buried, lying beneath what is now a grassy lawn with no signs that a structure ever existed (Figure 2).<sup>27</sup> Limestone foundations and evidence of rubble-filled rooms had been reported from earlier test trenches. BYU archaeologist Dale Berge, who worked in Nauvoo in the 1970s and 1980s, reported that the Tippetts house, described in the *Nauvoo Independent* as an “old brick house, . . . an old Mormon landmark,” was demolished prior to the beginning of the twentieth century.<sup>28</sup>

Alvah L. Tippetts, the owner of the home on the west quarter of lot 4, block 106, first came in contact with the LDS Church in 1832 when Jared Carter was preaching the restored gospel in Lewis, New York. Shortly after his baptism, Tippetts was called to preside over the branch of the Church in Lewis. Tippetts appears to have remained in Lewis, presiding over the Church there during the troubles in Missouri in the 1830s. By 1842, however, he had relocated to Nauvoo, and on April 29 of that year, he purchased the property in block 106 from Randolph Alexander. While living in Nauvoo, Tippetts was called upon to sit on many important committees, including the committee seeking



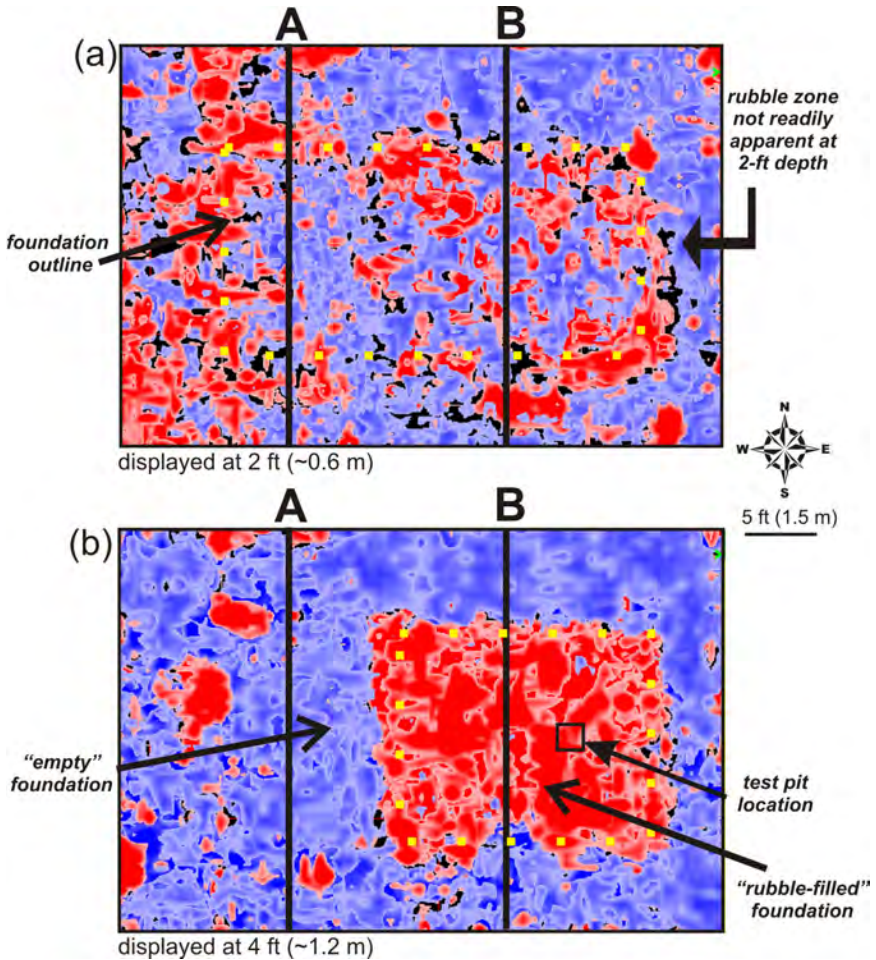


*close-up of 1-ft orthogonal grid*

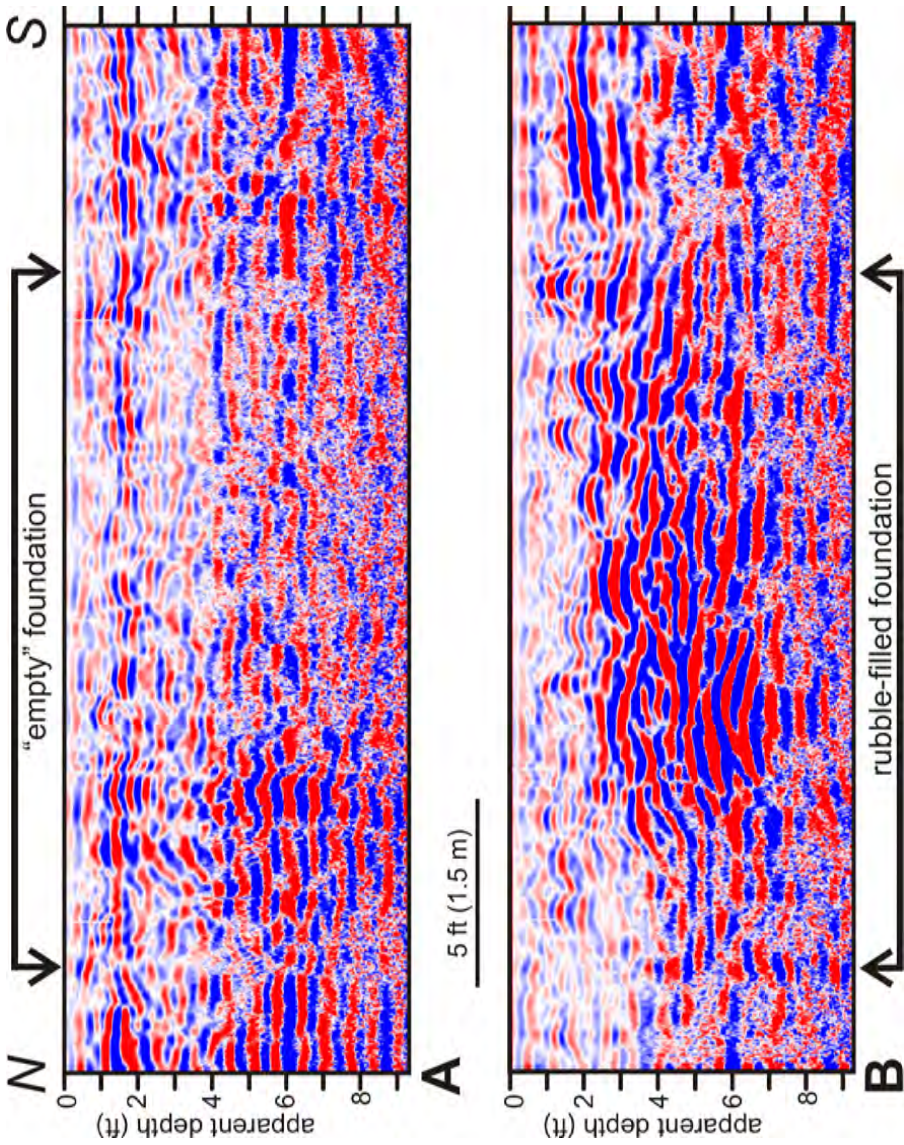
**Figure 2.** Photo looking south of the Tippets site being prepared for GPR survey, showing the 1-foot (0.3 meters) orthogonal grid typically used for the GPR surveys. Inset shows close-up of grid (survey lines drawn in black). Photograph by John H. McBride.

redress from the Missouri persecutions,<sup>29</sup> and as an agent of the Temple committee to collect tithes.<sup>30</sup> There is evidence to suggest that Tippets did not live in his Nauvoo home for very long. An affidavit sworn on June 20, 1844, lists him as living just south of Nauvoo in Warsaw, Illinois.<sup>31</sup> On October 24, 1847, at the age of thirty-eight, he passed away at Winter Quarters. Unfortunately, there is little documentary evidence to suggest what his Nauvoo home looked like, although historical documents referenced by Berge indicate that it was likely similar to the nearby Winslow Farr and Stillman Pond homes. Brick rubble found within the foundation during exploratory archaeological work indicates that it was likely a brick structure with a possible cellar that filled in with debris at the time the home was razed.<sup>32</sup>

The GPR survey was conducted in May 2009, after a moderate rain had fallen the previous week. For this and all sites studied, we created a survey area large enough that any anomalous pattern could be viewed in a context where archaeological features were absent. Horizontal depth slices through the volume were generated by arranging the data into a 3D grid and then interpolating the data over a narrow depth range. Volume rendering was also



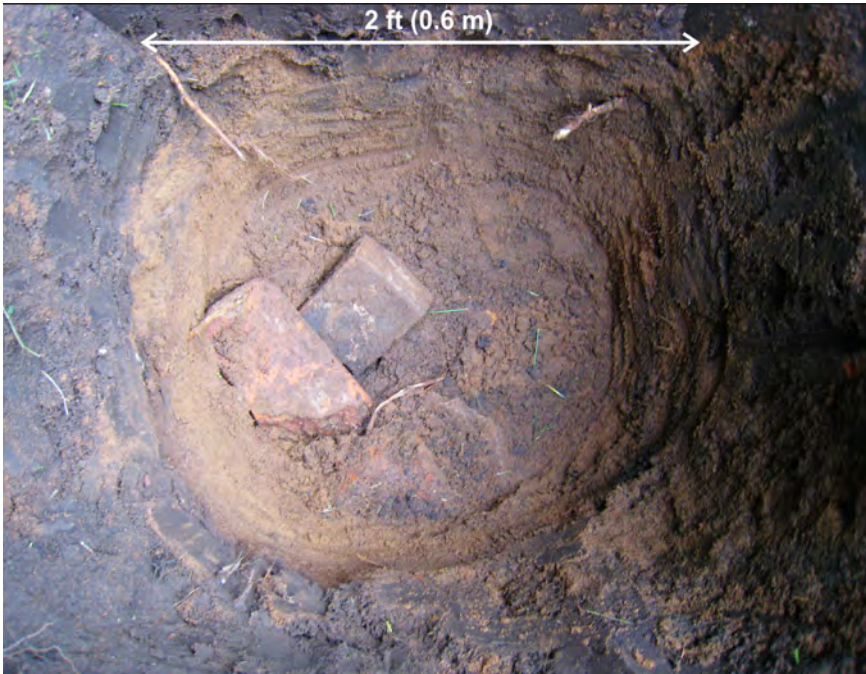
**Figure 3** (a) Volume-rendered depth “slice” (map) of 3D GPR data for Tippetts site at 2 feet (0.6 meters) depth (averaged over the vertical of range = 2.6 feet [0.8 meters]). This map shows the effect of the foundation wall, which is not evenly preserved in the ground. “A” and “B” indicate locations of cross-sections in Figures 4a and 4b, respectively. This image is processed as a volume rendering where high amplitudes are favored in the display. For this and subsequent radar images, red represents high reflectivity, and blue represent low reflectivity. All radar data have been converted from time to depth, assuming a dielectric constant of 8, unless otherwise noted. (b) Same as in Figure 3a, but at a depth of 4 feet (1.2 meters). This map shows the effect of a rubble-filled cellar within the foundation on the east side of the site.



**Figure 4.** Cross-sections (profile or vertical view) through the GPR volume shown in Figure 3 for the Tippets site. Profiles “A” and “B,” corresponding to profiles marked in Figure 3.

performed for this site by reducing the general gain of the volume so as to accentuate only the highest amplitudes.<sup>33</sup> Relatively shallow depth slices (horizontal maps) through the GPR volume show a rectangular outline, which is defined by patchy, discontinuous lines of moderate reflectivity (Figure 3a). We interpret this pattern to be remnant buried foundation walls. The patchy character likely represents a wall that is uneven and missing parts of its original stone. As we slice deeper into the site (i.e., produce horizontal maps from deeper intervals), a remarkably solid pattern of strong reflectivity appears within the eastern part of the buried structure (Figure 3b), precisely filling the foundation outline there. Vertical views (i.e., profiles or cross-sections) cutting through the eastern and western parts of the rectangular data volume (Figure 4), within the reflective and unreflective portions, respectively, show different patterns. The eastern profile shows pronounced reflectivity below about 2.5 feet (0.8 meters) consisting of strong scatterers (diffractions) down to about 7 feet (2.1 meters), whereas the western profile shows no internal reflective structure.

Our initial interpretation of this reflective versus non-reflective pattern was that the eastern part of the buried structure was filled with small objects (as evidenced by abundant diffractions), whereas the western part was devoid of any objects that could scatter the signal. Our guess was that the eastern half of the structure once had a cellar that is now filled with rubble (i.e., bricks and other building material or rubbish). To test this idea, we first augered test holes in the two areas. In the western area, we immediately encountered small fragments of red brick, but were able to easily penetrate to 4.5 feet (1.4 meters) without refusal; however, while augering in the eastern half (where reflectivity was high), we only managed to penetrate less than half that depth (2.1 feet [0.6 meters]) before being stopped by rigid material. We then dug a 2 x 2 feet (0.6 x 0.6 meters) pit over this hole, finding a 1-foot (0.3 meters) layer of dark, clayey soil underlain by lighter sandy soil. At 2 feet (0.6 meters) depth, red bricks, brickbats, and fist-sized limestone fragments appeared (Figure 5). These features confirmed our initial interpretation that the strong reflectivity in the eastern part of the structure was caused by building rubble used to fill only one side of the structure. Other objects recovered from the test pit included animal bones, metallic can pieces, small ceramic fragments, hand-forged and machine-cut nails, bits of charcoal, and miscellaneous metallic fragments. Such objects are consistent with an interpretation that the cellar area was used as a rubbish dump following the demolition of the house. An exploratory test trench excavated by Berge in 1970 led him to speculate the Tippets home had a cellar that had been filled in with destruction debris. Our survey and test excavations clarify the extent of the cellar by showing clear evidence of a cellar only in the east half of the structure.



**Figure 5.** Test pit (2 feet [0.6 meters] deep) within the eastern half of the Tippets site showing bricks (also metal and ceramic fragments) and charcoal (see Figure 3b for location). South is at the top in the picture. The artifacts from this pit furnish an explanation for the high reflectivity of this part of the site. Photograph by Benjamin C. Pykles.

The reflectivity patterns associated with foundation walls and the interior structure of the cellar are first-order features of the radar data; however, second-order features, whose interpretation is less straight forward, are also visible. For example, a rectangle of higher reflectivity, about 5 feet (1.5 meters) long and at a depth of about 2 feet (0.6 meters), appears just south of the foundation on the eastern side of the structure (Figure 3a). Looking at the deeper slice (Figure 3b), this anomaly defines a gap in the southern boundary. While a unique interpretation is not possible without excavation, possible explanations include a buried door stoop or bulkhead entrance to the cellar. Bulkhead entrances and door stoops composed of tooled limestone blocks are known from surviving structures, historic photographs, and archaeological excavations of 1840s Mormon homes in Nauvoo.<sup>34</sup>

We learn from studying this site that it is possible to achieve a high level of detail with GPR surveys in Nauvoo. One can see variations in reflectivity that relate to internal partitions and to the degree of rubble within a building's abandoned cellar hole. During demolition, it is probable that building material



**Figure 6.** View looking north of the excavated *Times and Seasons* building site at the northeast corner of Water and Bain Streets. Photograph by John H. McBride.

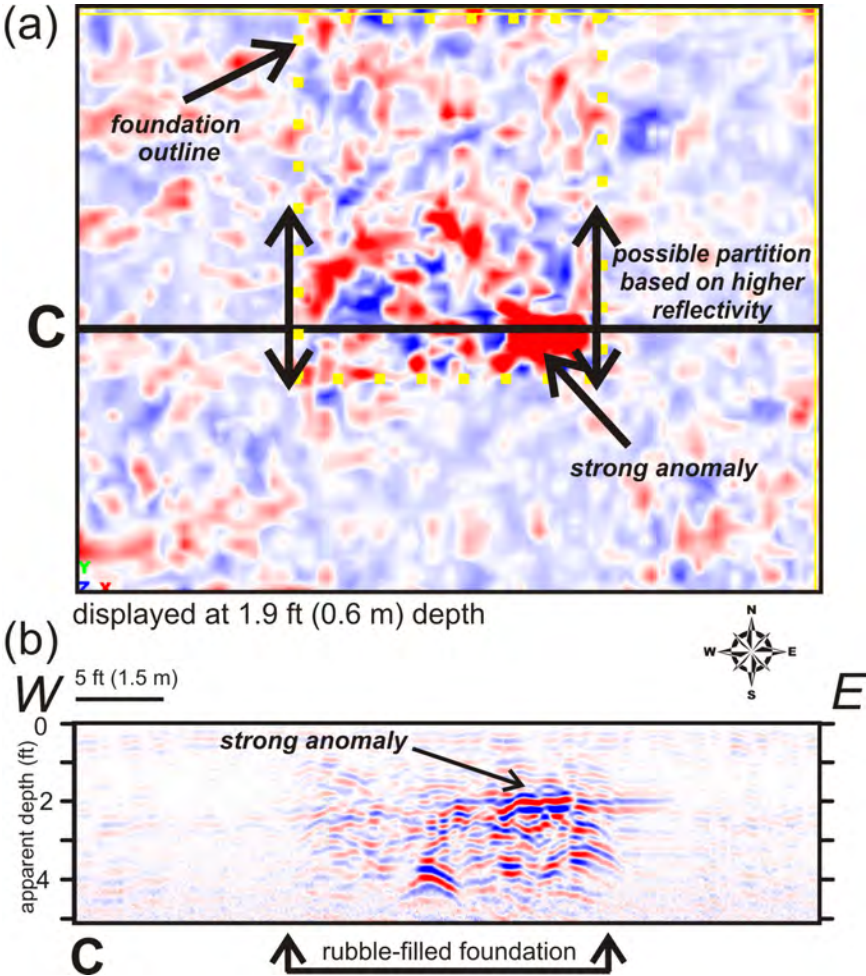
(bricks, portions of the stone foundation, glass, etc.) gets pushed into the interior, where it is then covered with soil laden with smaller debris. Such may account for the strong, but scattered and poorly coherent, reflectivity that appears within and actually defines the buried structure, even when a discrete foundation wall is not clearly defined. The effect of rubble defining the limits of a buried structure has also been noted by archaeologists working in Nauvoo. For example, Berge, in referring to the difficulty locating a buried wall at the Tippets site, states: “It was assumed that the wall ended where the rubble ended.”<sup>35</sup> No representation of the exposed Tippets site (either from excavation or an historic photograph) is available; however, the foundation exposed at the Community of Christ-owned *Times and Seasons* site, at the intersection of Water and Bain Streets (Figure 6), is possibly analogous to what underlies the Tippets site. As can be seen from Figure 6, the *Times and Seasons* site is divided into two sections, the one on the south being an open foundation (once a cellar), lined with stone and containing (or once containing) rubble, while the section to the north is a shallow stone foundation without a cellar.



**Figure 7.** Photograph of Lorin Farr’s home (misabeled) in Nauvoo, Illinois Used by permission, LDS Church History Library, PH 8466, box 2, item 116, all rights reserved.

### *Lorin Farr House*

The Lorin Farr house, located on block 106, lot 4 (Figure 7), was torn down after the turn of the twentieth century.<sup>36</sup> This site is located along the west side of what was originally Durphy Street (now State Highway 96). Lorin Farr, son of Winslow and Olive Farr, was a personal friend to the Prophet Joseph Smith. After joining the Church in 1834, the Farr family relocated from their home in Waterford, Vermont, to Kirtland, Ohio, in 1838 to be nearer the main body of the Saints. By that time, however, Church headquarters—and the Prophet—had relocated to northern Missouri. Lorin, in company with his brother Aaron, soon left his family and traveled to Caldwell County. After arriving in Missouri, Farr became a friend of the Smith family, a guest in their home, tutor to their children, and eventually accompanied the family through the persecutions of Missouri. While Joseph Smith was imprisoned in Liberty Jail, Farr carried letters between Smith and his wife. In 1839 he migrated to Nauvoo with the rest of the Church.<sup>37</sup> Soon after, Winslow Farr (Lorin’s father), his wife, and most of his children also relocated to Nauvoo. Winslow purchased a half-acre plot on the eastern half of lot 4, block 106 along Durphy Street in Nauvoo. The property was never officially subdivided and ownership was never transferred from father to son; however, it appears that Winslow allowed his son to build a home on a portion



**Figure 8.** (a) Depth "slice" (map) of 3D GPR data for Lorin Farr site at 1.9 feet (0.6 meters) depth (averaged over the vertical of range = 0.2 feet [0.06 meters]). "C" shows location of profile in Figure 8b. (b) Cross-section along line marked "C" through the GPR volume. Note the strong rectangular reflector (anomaly with arrow) located at the southeast corner of the main reflective zone (yellow outline). A dielectric constant of 12 was used for the Farr site, which increases the apparent vertical exaggeration, relative to a dielectric constant of 8 used elsewhere.



of the lot. John Farr, son of Lorin, wrote that his father built a “substantial” brick home “close to the Prophet’s home.”<sup>38</sup> During the time the Saints occupied Nauvoo, Lorin Farr served missions in Connecticut, Wisconsin, Illinois, and the “middle and eastern states.”<sup>39</sup> When he was not serving missions, Farr was a frequent laborer on the Nauvoo Temple.

Exactly when the Lorin Farr home was built is unclear; however, the Farr family were prolific in building activities in Nauvoo. In addition to the two homes on lot 4, block 106, Lorin and Winslow Farr built a “stone and adobe house” elsewhere during one of Lorin’s breaks between missions.<sup>40</sup> Lorin Farr married Nancy B. Chase on January 1, 1845, in a ceremony performed by Brigham Young. Shortly after, the young couple began making preparations to leave Nauvoo. According to Lorin’s son John, William Clayton penned a trail guide for those leaving the city while visiting Farr in his home.<sup>41</sup> After settling in Utah, Lorin Farr was called to settle in Ogden where he was made the first president of the Weber Stake. He was also the first mayor of Ogden, and served in that capacity for many years.

Because the area of the Farr home was swampy when the Mormons first arrived, a long canal was dug along the east side of Durphy Street, the remains of which can be seen today.<sup>42</sup> As part of an archaeological report on block 106, Berge states that the Lorin Farr house was relatively small and constructed of brick with a limestone foundation. A full-scale excavation of the site was not undertaken, but a preliminary set of exploratory trenches were dug in an attempt to understand the site’s archaeological resources.<sup>43</sup> Our GPR survey was designed to be identical to that for the Tippets site; it generated a series of horizontal depth slices (Figure 8a) and vertical views (Figure 8b).

The Farr site GPR survey had the advantage of being conducted under extremely dry conditions in September 2011, near the end of an extended drought. The results for the Farr site (Figures 8a and 8b) differ considerably from those of the Tippets site. First, the GPR depth maps for the Farr site show a discrete border, interpretable as buried foundation walls, surrounding a rectangular pattern of reflectivity that corresponds to the plan drawn by Berge.<sup>44</sup> Similar foundation walls are imaged for the Tippets house (Figure 8a). However, although divisions may be seen within the buried structure at the Farr site, as suggested by square or rectangular patches within the radar maps (Figure 8a), these are not nearly as well expressed as similar features seen in the maps for the Tippets site (Figure 3b).

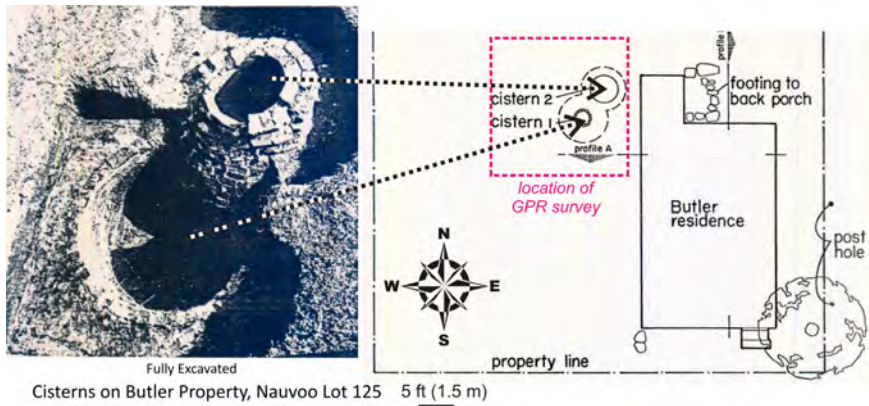
The most interesting result from the Farr site was the expression of a well-defined rectangle of strong reflectivity (Figure 8a) in the southeast corner of the survey area. The well-defined edges of the anomaly, combined with its perfectly flat expression on vertical profiles (Figure 8b), attests to a buried feature with a flat, smooth surface. After processing the 3D GPR data, we



**Figure 9.** Test pit, looking south (2 feet [0.6 meters] deep), at the southeast corner of the Lorin Farr house site, showing the brickwork that corresponds to the strong radar reflection shown in Figure 8. Photograph by Benjamin C. Pykles.

subsequently located the anomaly and dug a small 2 x 2 feet (0.6 x 0.6 meters) pit that revealed a section of remarkably smooth brickwork, rimmed on the west side of the pit by a short section of a curved brick wall, two bricks high (Figure 9). The same or a similar feature was described from preliminary archaeological explorations by Berge and was interpreted as a possible section of a fireplace.<sup>45</sup> Artifacts recovered from the soil above the brickwork included brick and limestone fragments, cut nails, glass, and fragments of earthenware ceramics, similar to what we found at the Tippets site.

The results of our surveying and excavation at the Farr site, when compared to our efforts at the Tippets site, demonstrate the variation in radar expression for two brick houses dating from the 1840s and demolished at roughly the same time (late nineteenth or early twentieth century). The Farr site also provides an example of how an unusual and historically interesting feature hidden beneath the soil can be mapped precisely without a full-scale excavation.



**Figure 10a.** (a) Left, photo of excavated cisterns west of Butler foundation (background in Figure 10b); right, map from prior archaeological study. Modified from Berge (1979). (b) Radar survey in progress for the Butler site, looking east (exposed foundations are in the background, enclosed within white picket fence). Photograph by Benjamin C. Pykles. (c) Depth “slice” (map) of 3D GPR data at 3.5 feet (1.1 meters) depth (averaged over the vertical of range = 0.2 feet [0.06 meters]). Radar map matches red dashed outline in Figure 10a. Three cross-sections (A, B, C) show expression of previously excavated and reburied cisterns west of the exposed foundation. Dashed arrows indicate diffractions caused by “scatterers” related to the edges of the cisterns.

### *Daniel Butler Jr. Home and Cobbler Shop*

The Daniel Butler Jr. site is located on block 125, lot 3 east of Main Street, on the north side of Parley Street (Figure 1). On December 18, 1843, Butler purchased the eastern third of this lot in the Nauvoo plat.<sup>46</sup> He appears to have been a merchant and a member of the Church from Massachusetts, who for a time rented and operated Joseph Smith’s Red Brick Store with his partner P. B. Lewis. Some evidence indicates that Butler may have operated a cobbler shop and dry goods or general store from his property on Parley Street.<sup>47</sup> Other evidence indicates that Butler, along with his partner Lewis, accompanied Addison Pratt on the first leg of his journey to the Pacific Islands. Neither Butler nor Lewis completed the journey, although Lewis apparently paid for the passage of Pratt and his three companions to Tahiti. Butler, on the other hand, appears to have left the Church when the group stopped in New Bedford, Massachusetts, Butler’s hometown.<sup>48</sup> In July 1845, an advertisement in the *Nauvoo Neighbor* announced that Butler’s home and “one third of a lot on Parley Street east of Main near Mr. Oakley’s” was for sale. The home, as advertised, was 20 x 30 feet (6.1 x 9.1 meters) and two stories high.<sup>49</sup> The property eventually sold for \$200 to William Jones in May 1846.<sup>50</sup>



Figure 10b. Daniel Butler Jr. home site.

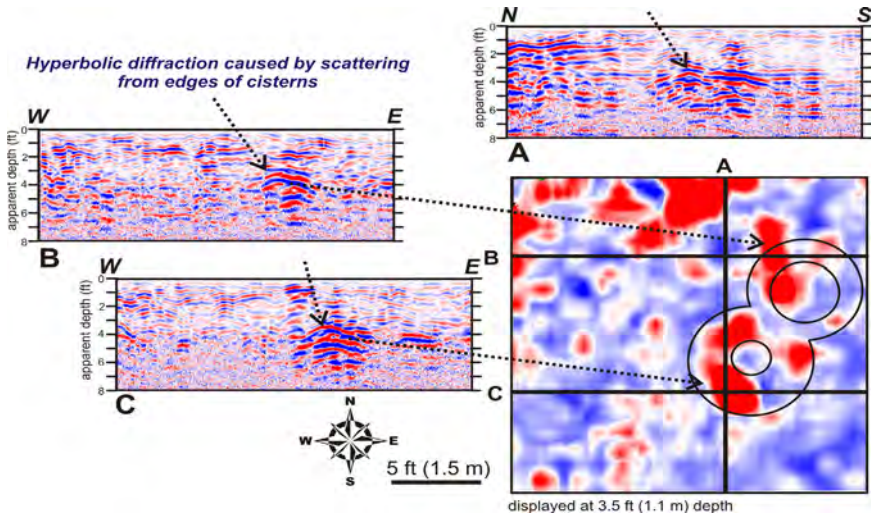


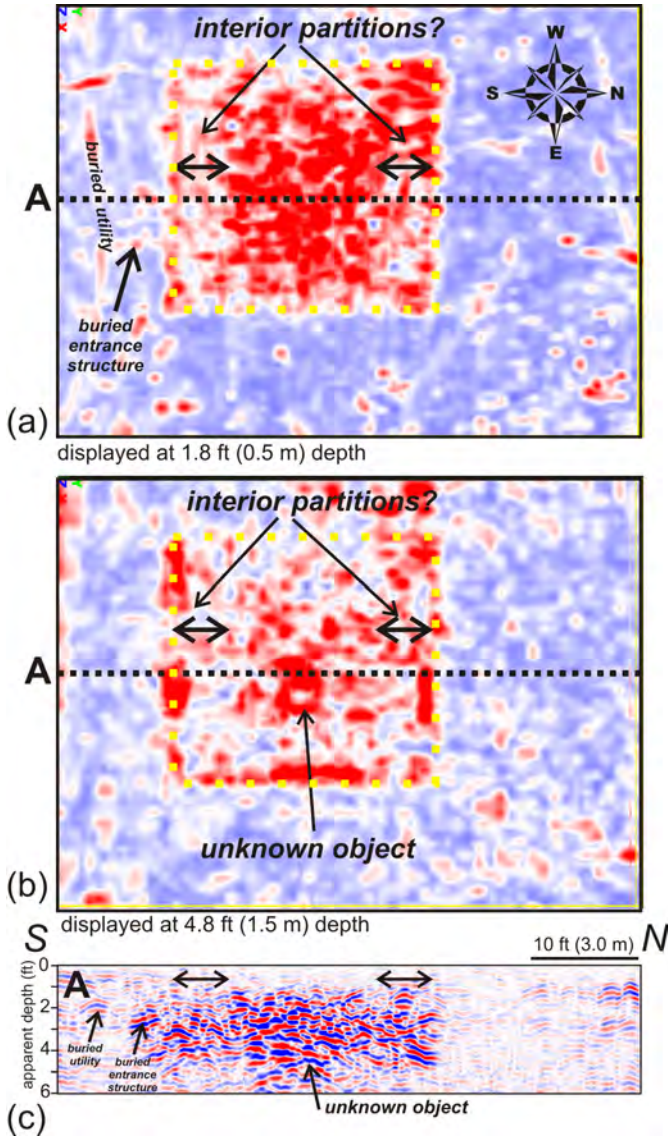
Figure 10c. GPR cross-sections and maps of the Daniel Butler Jr. homesite.

According to local tradition, Butler's home on Parley Street survived until the 1940s, when a kerosene stove exploded inside, burning it down.<sup>51</sup>

Following its destruction, the Butler property remained undisturbed until archaeological excavations commenced in the 1970s. By this time, the limestone foundations had been invaded by wild vegetation, which had to be cleared prior to starting excavations. While excavating the site, archaeologists uncovered two buried cisterns located west of the northwest corner of the main structure (Figure 10a). The two cisterns are superimposed, the northern and most recent one being constructed within and partially destroying the other. The northern cistern was a maximum of 6.3 feet wide (1.9 m) and extends to a total depth of 6.8 feet (2.1 meters). The older southern cistern was 5.82 feet (1.77 meters) wide with a total depth of 4.21 feet (1.28 meters). Although both cisterns had basically the same shape and construction material (brick and cement or heavy mortar), the southern one had been partially dismantled to a deeper level, exposing the vertical edges (Figure 10a), while the northern cistern was buried less deeply. Following the archaeological study, the cisterns were reburied. The foundations of the main structure remain exposed today as part of an exhibit of an early Nauvoo structure (Figures 10a and 10b).<sup>52</sup>

The GPR survey for the Butler site (Figure 10b) was conducted the day after the Tippets site survey, so the ground was still moist. To test the ability of GPR to detect complex 3D structures like buried cisterns, we conducted a survey immediately west of the main structure, using Berge's map as a guide (Figure 10a).<sup>53</sup> From the standpoint of radar imaging, a roughly spherical or cylindrical object made of brick or stone that is either hollow or filled with soil (and thus having a contrast in dielectric constant) is expected to present a complex target. "Slicing" the 3D radar volume in Figure 10c at a depth of 3.5 feet (1.1 meters) and superimposing the outline of the two cisterns shows two areas of high reflectivity that correspond to the remains of the buried cisterns. Vertical slices through the 3D volume (Figure 10c) show strong, isolated diffractions at depths indicated by Berge for the upper parts of the buried cisterns.<sup>54</sup> Further, the southern cistern (Figure 10a) shows more prominent scattering than does the northern one. Diffractions from the southern cistern arrive from a slightly greater depth. The above observations are consistent with a pair of buried objects, one of which (southern) is deeper and has sharper edges (because it had been partially dismantled).

This exercise of surveying a known but complex target demonstrates how GPR can detect and map buried cisterns or geometrically similar 3D objects. Although test excavation, guided by radar, is required to verify a cistern (or other) interpretation, explanations of anomalies such as these can also be constrained by spatial context, as most cisterns are expected to be located near a corner of a house.



**Figure 11.** (a) Depth “slice” (map) of 3D GPR data for Ezra Oakley site at 1.8 feet (0.5 meters) depth (averaged over the vertical of range = 0.3 feet [0.09 meters]). (b) Same as above but for 4.8 feet (1.5 meters) depth. Double arrows indicate possible partitions within the buried structure. Dashed line labeled “A” is cross-section. (c) Vertically exaggerated cross-section with features identified in maps noted. Note that the maps are oriented with north to the right so that features on the profile view (c) can be compared with the maps. Parley Street is located to the south.

### *Ezra Oakley Site*

The Ezra Oakley site is located on block 125, lot 3 immediately west of the Butler site (Figure 1). Like the foregoing study areas, the Oakley site was chosen for GPR survey because it had been referenced and marked during earlier archaeological investigations.<sup>55</sup> And like the other Nauvoo sites we have studied, no remnant of a structure was visible at ground level, other than a ghostly outline of dead grass brought on by severe drought. Several decades ago, Berge noted a similar effect during “a long dry spell.”<sup>56</sup>

Before joining the Church in 1841, Ezra Oakley, a veteran of the War of 1812, had made a modest living as a merchant in his native Brooklyn, New York. After arriving in Nauvoo in 1843, he purchased from Joseph Smith a third-acre plot in the eastern half of lot 3, block 125 in Nauvoo.<sup>57</sup> On this property, Oakley built a two-story home and store. His general store also served as the office of the Nauvoo Tannery.<sup>58</sup> He was a successful merchant and member of several professional guilds in Nauvoo. In fact, he was so successful that his store became, quite literally, a landmark in the city. Advertisements in the *Nauvoo Neighbor* frequently referred to the subscriber’s location relative to “Mr. Oakley’s Store.” Oakley sold the property to William Allen on April 15, 1846, shortly before he and his family departed the city and headed west. Oakley’s daughter, Mary Ann, became the fourth wife of LDS Apostle and future Church President John Taylor. As a result, the Oakley family traveled west as members of the John Taylor Company. It is not known when the Oakley home and store was later demolished.

Although some rain had fallen during and prior to the survey in October 2011, drought conditions prevailed and the ground remained relatively dry. Of all the sites discussed thus far, the Oakley site was the highest quality for radar, with considerable detail in the maps and cross-sections. Shallow depth slices (0.67 feet [0.2 meters]) (Figure 11a) reveal a more clearly defined outline than the Tippets and Farr sites. This outline is interpreted as a foundation wall, recognizable as diffractions on vertical views through the volume (Figure 11a). Along the southern part of the roughly square outline, a subdivision with a rectangular shape (long dimension parallel to Parley Street) can be defined that may represent an individual room or masonry partition. Near the southeastern corner of the structure a small rectangular feature appears on depth slices just outside the main outline, which could be interpreted as a small stoop or cellar entrance (Figure 11a). Looking deeper within the main structure, one can see a roughly square area of concentrated high reflectivity, as well as a clearer definition of the foundation walls (Figure

11b). Reflectivity for the main structure dissipates at a depth of about 4.6 feet (1.1 meters).

A shallow test pit (2 x 4 feet [0.6 x 1.2 meters]) was dug within the approximate center of the southern half of the structure to a depth of 14 inches (0.36 meters). A heavy concentration of artifacts was encountered immediately beneath the sod, much more so than in the other sites discussed above. Artifacts were varied and included many sizes of cut and wire nails, earthenware fragments, glazed brick pieces, glass, wire, charcoal, and coal, all of which indicate that the structure's cellar hole had been used as a trash dump for some time after the building was destroyed. Deeper excavation was not undertaken at this time.

The Oakley site is a good example of how GPR maps can delineate the edges of a vanished building. This site also shows reflectivity variations in the interior of the main structure (e.g., area of reduced reflectivity parallel to Parley Street) and on the exterior of the structure (e.g., stoop or entrance facing Parley Street) that can guide an archaeological strategy for an excavation, or for simply non-invasively interpreting a site.

### *John Wilkie Site*

The John Wilkie site is block 119, lot 4, immediately east of Historic Nauvoo's brickyard demonstration area on the north side of Kimball Street, between Hyde and Partridge Streets (Figure 1).<sup>59</sup> The site is covered by a flat, well-tended lawn, which at the time of the survey, in early June 2012, was green and somewhat moist from recent rainfall. However, during a previous inspection of the site during a drought in September 2011, rectilinear outlines of dead grass could be seen (Figure 12b).

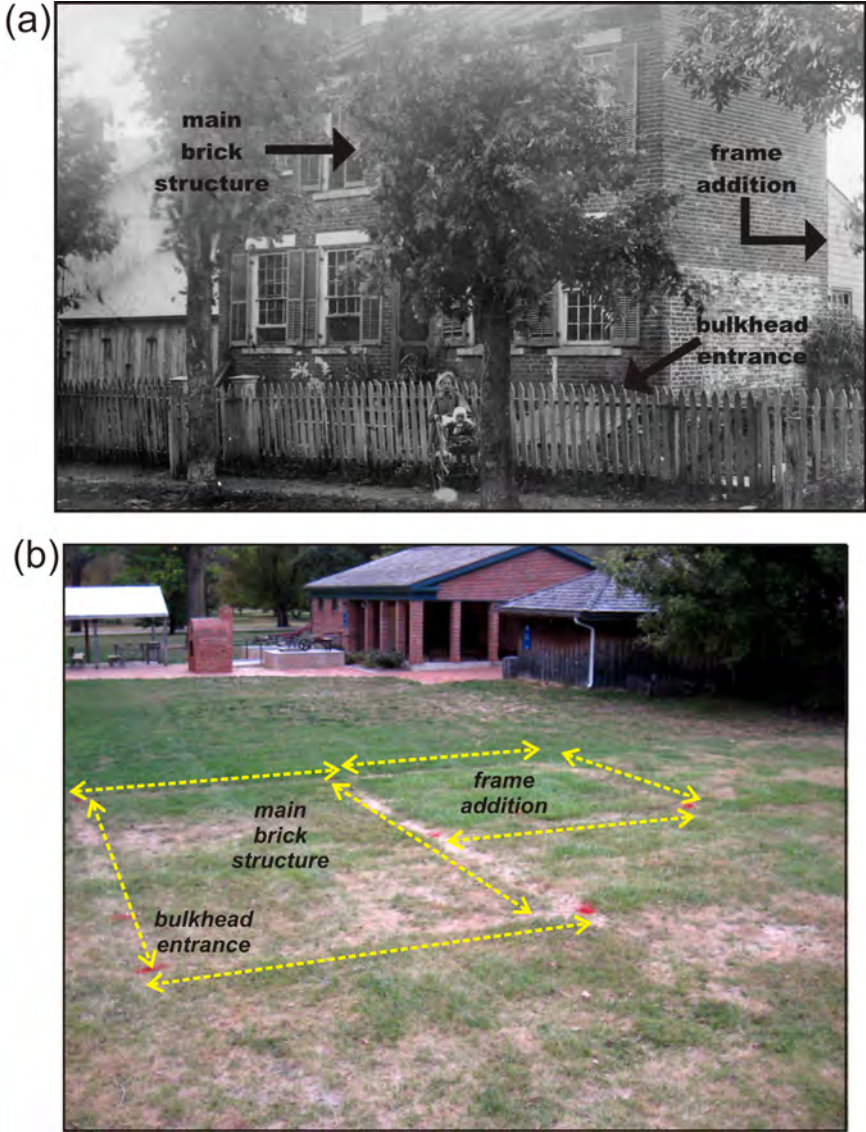
John Wilkie and his wife Catherine suffered through the persecution of the Saints in Missouri. When the Church moved to Nauvoo, the Wilkies followed, continuing in their intent to be with the main body of the Saints. When Joseph Smith announced his desire to purchase the steamboat *Des Moines* from Robert E. Lee, Wilkie was among the first to support the ill-fated venture. After the steamboat, renamed *Nauvoo*, ran aground and sank, Joseph Smith owed over \$73,000 in outstanding debts, \$2,700 of which he owed to Wilkie.<sup>60</sup> The situation was so dire that Smith was forced to declare bankruptcy, leaving many, including Wilkie, unable to recoup their funds. Wilkie understandably struggled as a result of this situation. Despite his personal loss, however, he continued to live among the Saints at Nauvoo. In 1843, he purchased a two-story brick home from two enterprising citizens, William E. Horner and Abraham Hoover, who appear to have built the home with the intention of selling it for a profit. Despite remaining in the city, Wilkie



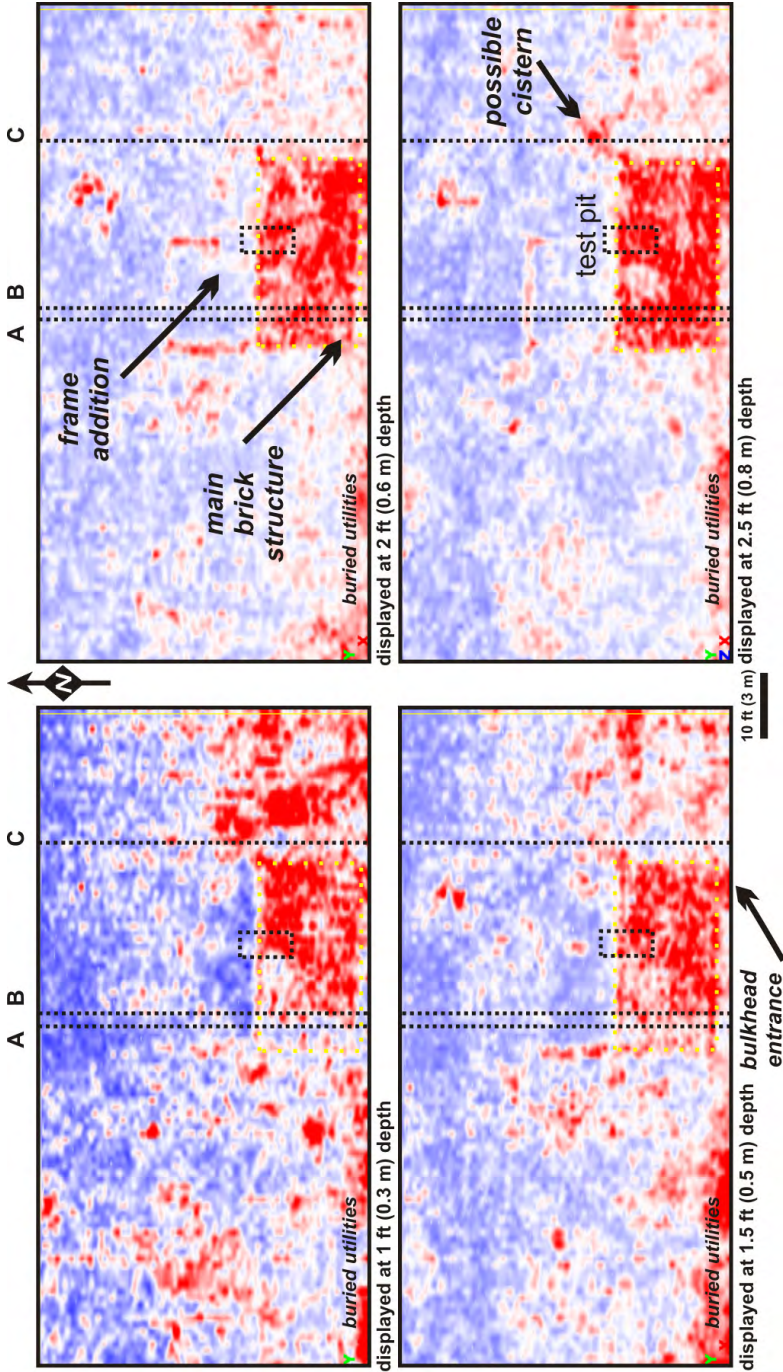
continued to struggle with the principles of the gospel, particularly tithing. In March 1844, he requested a personal audience with the Prophet. During the meeting, which took place in Wilkie's home, Smith explained the importance of a consecrated life and blessed the home. At the conclusion of the meeting, Wilkie gave \$300 in gold and silver coin to the Prophet to support the construction of the Nauvoo Temple.<sup>61</sup> The source of Wilkie's substantial financial assets is not known. After Smith was killed, the Wilkies remained in Nauvoo, choosing not to follow Brigham Young to the West. Wilkie's wife, Catherine, was later recorded among the adherents to the teaching of James J. Strang.

The Wilkie site was one of the higher quality GPR sites surveyed and showed the greatest detail. Our interpretation of the results is guided by a historic photograph (Figure 12a), taken at an angle oblique to Kimball Street, allowing for independent verification of important details of the structure. This site showcases how GPR can distinguish features by displaying radar maps over a range of depths. At a depth of 1 foot (0.3 meters) (Figure 13), a rectangle of patchy reflectivity appears, with its long dimension almost exactly parallel to Kimball Street. A distinct north-south line of reflectivity appears about in the middle, which defines a subtle change in the intensity of the reflectivity from west to east, the eastern half being slightly more reflective. This partitioning of the rectangle into two squares may be related to the symmetrical division of the brick home's front facade, as seen in the historic photograph (Figure 12a). Other areas of rectilinear reflectivity are also visible at this depth, such as a distinct area a short distance east of the main rectangle.

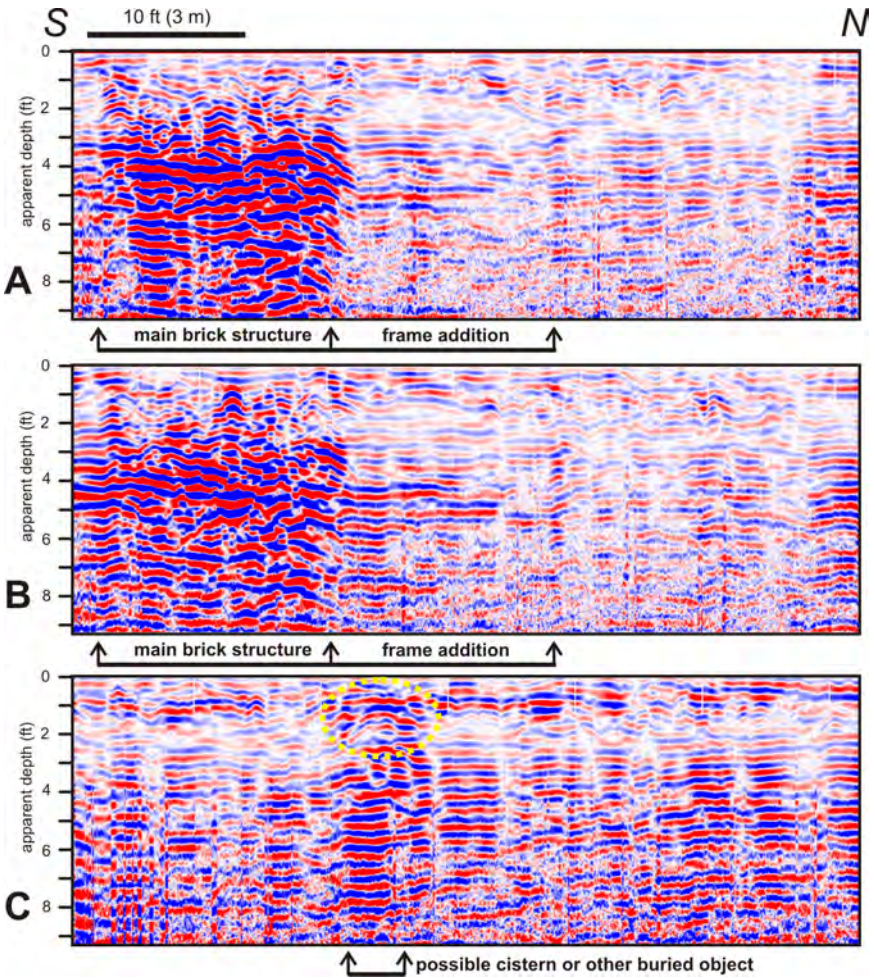
A slightly deeper radar map at 1.5 feet (0.46 meters) (Figure 13) reveals a distinct outline enclosing the rectangular zone of high reflectivity, which we interpret as a stone foundation. By analogy with the Tippets and Oakley sites, we interpret the strong reflectivity enclosed within the distinct outline to represent rubble and/or rubbish in the cellar hole of the main brick structure. At this depth, one can now also see a thick band of reflectivity extending north from the west boundary of the main structure for about 12 feet (3.7 meters). On depth maps from 2.0 and 2.5 feet (0.6–0.8 meters) (Figure 13), additional lines of distinct reflectivity north of the main brick structure suggest an approximately square feature, but with no pronounced internal reflectivity like that seen in the main brick structure (Figure 13). This square outline is interpreted to represent the frame addition to the rear of the home, a corner of which appears in the historic photograph (Figure 12a). As expected, north-south cross-sections that span the area of the main brick structure and the frame addition in the rear (profiles A and B, Figure 14a) show a strong pattern of reflectivity for the former area and a non-reflective pattern for the latter.



**Figure 12.** (a) Historical photograph of the John Wilkie home looking northwest, taken from Kimball Street. Sections of the house identified in the modern photo (Figure 12b) and the radar maps (Figure 13) are noted. Photograph courtesy Utah State Historical Society. Used by permission. (b) View of area where the John Wilkie home once stood (east of the brickyard demonstration area) looking approximately west, September 2011. Dashed yellow lines show rectangular areas identified from dead grass patterns (due to prolonged drought) and interpreted areas of the house shown in Figure 12a. Photograph by John H. McBride.



**Figure 13.** Four depth “slices” (maps) for depths shown (averaged over the vertical of range = 0.5 feet [0.15 meters]). Labeled dashed lines show locations of profiles (A, B, C) in Figure 14. Black dashed rectangle is test pit location and yellow dashed rectangle is interpreted location of main brick structure. Other interpreted features are noted.



**Figure 14.** Three GPR cross-sections (vertically exaggerated) through the radar volume for the Wilkie site. Profiles A and B show the stark change from high to low reflectivity between the area of the main brick structure and the frame addition, respectively. Profile C shows a prominent diffraction pattern similar to that expressed by the buried cisterns at the Butler site (Figure 10c).



**Figure 15.** Photograph looking north of shallow test pit that exposed the foundation stones for the Wilkie site (see Figure 13 for location). Photograph by Benjamin C. Pykles.

With increasing depth, the reflectivity within the main structure becomes stronger, but also more variable. A patch of reduced reflectivity appears along the northern border of the west half of the main structure. At 2.5 feet (0.8 meters), a small circular concentration appears just off the northeastern corner of the main structure. We suggest that this represents a possible buried cistern, positioned with respect to the main structure to collect rainwater. This possible cistern shows a diffraction pattern similar to that observed for the confirmed cistern expression on radar images from the Butler site, discussed above (cf. Figures 10c and 14b). A distinct rectangle of high reflectivity is appended to the southeast corner. We interpret this small feature to be the footprint of the bulkhead entrance to the cellar beneath the main brick structure, as seen in the historic photograph (Figure 12a).

The day after we conducted the radar survey and examined the processed radar results, an exploratory test pit was dug (Figure 15) over the boundary between the two varyingly reflective halves of the main structure. The pit revealed a thick limestone foundation with smaller pieces of rock on either side. The foundation corresponds with the north-south line of reflectivity dividing the two halves seen on the GPR depth map. Due to time constraints

in the field, additional test pits were not completed to verify the interpretation of other features on the radar depth maps (e.g., the possible cistern).

## **Discussion and Conclusions**

The five archaeological sites we surveyed demonstrate the diversity of GPR targets that are likely to be associated with Mormon Nauvoo. Our results give specific examples of how GPR surveys can pinpoint features of particular interest and minimize disturbance of an archaeological site or make a major excavation more efficient. The maps and cross-sections derived from GPR reveal some of the architectural elements and related features that an archaeologist can expect to find in the course of an excavation in Nauvoo.

The Tippets site shows how GPR can delineate distinctly different areas expressed by the strength of signal scattering, in this case an area of high scattering juxtaposed with an area of no scattering. The strong variation in radar scattering was verified, through test excavation, to be directly related to bricks and other rubble that had been placed in one section of the structure, but not in the other. This variation effectively divides the interior of the buried foundation into two partitions or rooms, the eastern section having a cellar. Knowledge about the buried partitioning of the building, and about the solid material (in this case, bricks and rubble) within the partitions, would be valuable to archaeologists intending to excavate this site, and reveals more important details about the structure's design. In some parts of the Tippets site, foundation walls are not well preserved, but may be inferred by the lateral cessation in reflectivity related to interior rubble. Other Nauvoo sites we studied (e.g., Lorin Farr site) also showed this effect. In contrast, the Wilkie site shows well-preserved foundation walls expressed as a distinct outline of reflectivity that encloses a highly scattering rectangular area, which was also confirmed by test excavations.

The Farr site provides a case where the main footprint of the structure is defined by a rectangular patch of weakly scattered radar signal, but also includes a small, discrete, rectangular area of enhanced reflectivity that was confirmed by test excavations to be a neatly intact section of smooth brickwork. The exceptionally strong reflectivity of this target, together with its rectangular outline, suggest to an archaeologist that something with a flat surface lies buried within the overall structure and deserves further study or strategic excavation.

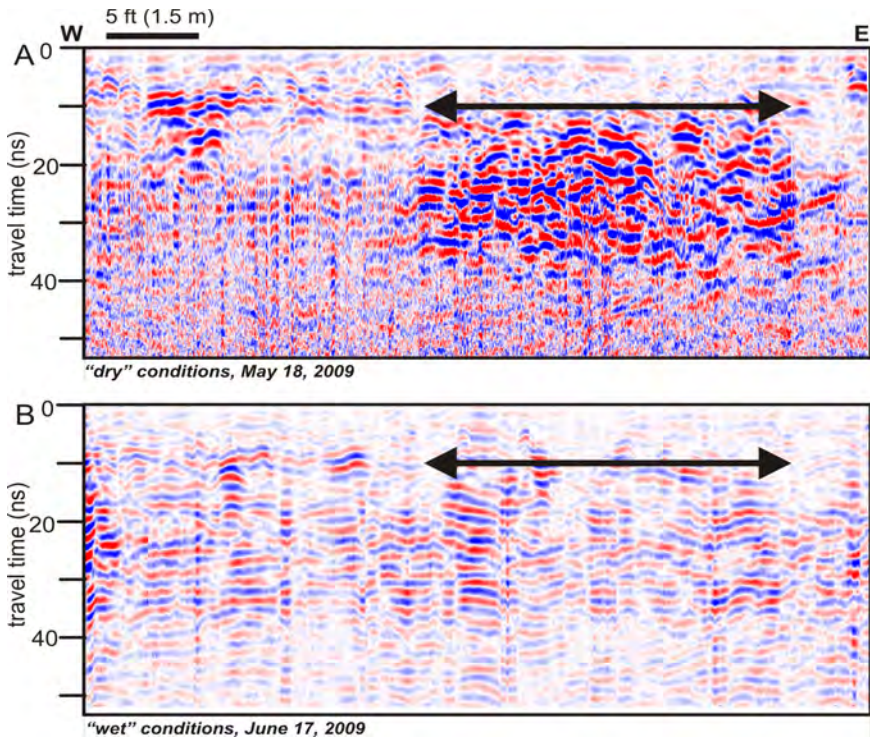
The Oakley site provides a good example of GPR's capabilities under ideal conditions (in this case, extremely dry soil and reduced vegetation). The GPR maps for this site allow the archaeologist not only to see a high degree of scattering, indicating interior rubble (like that seen at the Tip-

pets site), but also the exact location of discrete foundation walls at deeper levels. The quality of the image is such that subtle interior partitioning is visible, as well as the remains of a front step or bulkhead entrance.

A three-dimensional (3D) target (i.e., a feature that does not merely follow one or two directions, like a wall or area of buried brickwork) is considerably more difficult to image with GPR, especially if it is small compared to the signal wavelength. The most common 3D archaeological targets expected for buried 1840s buildings in Nauvoo include privies, wells, and cisterns. The GPR survey adjacent to the excavated Butler foundation indicates that buried cisterns can be detected; however, due to their complex shape and small size, they are expressed mainly as a concentration of strong scatterers with an overall circular outline in map view. Understanding what kind of pattern to expect for such a feature enables the archaeologist to deduce the possible presence of such delicate, complex structures prior to commencing an excavation.

The Wilkie site shows the most detail of all those surveyed for this project, including a set of foundation walls expressed on the radar maps as distinct rectilinear features. These walls enclose varying intensities of the radar signal, which likely represent variations in the amount of rubble-filled space beneath the main brick part of the building (located to the south, facing the street) and a frame addition (attached to the rear of the main brick structure on its northwestern corner). This site also gives us the best example of how GPR can reveal a small buried structure attached to the main building, in this case a bulkhead entrance into a cellar, as seen in a historic photograph. Several other features appeared on the radar maps, features that need to be explored with strategically placed test pits in order to verify their meaning (e.g., a possible cistern, like those at the Butler site).

Last, to demonstrate the critical importance of dry conditions for successful GPR imaging, we collected single profiles across the Tippetts site before and after a significant rainfall (May and June 2009, respectively). Figure 16 shows the before and after profile that cuts through the center of the site. The results speak for themselves. The intense radar scattering that so clearly delineates the separate partition shown in Figure 16 is difficult or impossible to see after the rain. The increase in electrical conductivity caused by the infiltrated rainwater and the presence of clays, has dramatically attenuated the radar signal. Thus, it is essential to conduct GPR surveys under dry soil conditions.



**Figure 16.** (a) GPR profile over the Tippets site collected under relatively dry (but not drought) conditions. Note the prominent scattering within the eastern half of the profile as shown by double arrow (cf. Figure 3). (b) GPR profile collected over approximately the same path about one month later after considerable rain had fallen. Note the lack of reflectivity where there previously had been, along double arrow.

## Summary

Ground-penetrating radar (GPR) has been tested over a three-year period (2009–2012) in old Nauvoo at more than twenty sites owned by The Church of Jesus Christ of Latter-day Saints and by the Community of Christ. Most of these sites date from the 1840s Mormon period. Several of these were surveyed to produce 3D images of the upper few feet of the subsurface, the results of which are presented herein. Interpretation of the 3D GPR images was guided by test pits, shallow auger holes, prior archaeological excavations, historical photographs, and contextual information gleaned from historical documents such as newspaper articles or ads. The results of the GPR testing demonstrate the ability to detect and map buried foundation walls, interior partitions, cisterns, small features attached to the main building (e.g., a bulkhead entrance or small stoop), and zones of rub-



ble or other unknown material within a building foundation. The remains of some buried structures produce intense internal reflectivity (“scattering”), in some places with only a weak expression of the foundation walls. In other cases, internal scattering is less well expressed. The degree of internal scattering appears to be related to whether or not the structure had a cellar and to the history of the structure following abandonment (e.g., after abandonment, the cellar, if there was one, was either filled with rubble or rubbish, or only filled with soil). The tests conclusively confirm the applicability of GPR for learning about the archaeological resources of Nauvoo, while indicating the limitations imposed by varying soil moisture and clay content. Further, our results suggest a means by which large areas of the flats of historic Mormon Nauvoo could be non-invasively assessed for archaeological resources. Such an assessment could allow both churches to inventory their properties prior to any planned development or further archaeological excavations.

### Acknowledgements

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18. Lawrence B. Conyers, "Ground-Penetrating Radar for Archaeology," in *Geophysical Methods for Archaeology*, (Walnut Creek, CA: AltaMira Press, 2004), 149–59.
19. See Salvatore Piro, Dean Goodman, and Yukio Nishimura, "The Study and Characterization of Emperor Traiano's Villa (Altopiani di Arcinazzo, Roma) Using High-Resolution Integrated Geophysical Surveys," *Archaeological Prospection* 10, no. 1 (2003): 1–25; Sergio Leucci and Giovanni Negri, "Geophysical Investigation of the Temple of Apollo (Heirapolis, Turkey)," *Journal of Archaeological Science* 33, no. 11 (2006): 1505–13.
20. Lewis E. Hunter, Allan J. Delaney, and Daniel E. Lawson, "Investigation of the Roosevelt Road Transmitter Site, Fort Richardson, Alaska, Using Ground-Penetrating Radar," U. S. Army Corps of Engineers Cold Regions Research & Engineering Laboratory, Report 99–4, 1999; Abbas M. Abbas, Hiroyuki Kamei, Amer Helal, Magdy A. Atya, and Fathy A. Shaaban, "Contribution of Geophysics to Outlining the Foundation Structure of the Islamic Museum, Cairo, Egypt," *Archaeological Prospection* 12, no. 3 (2005): 167–76; Jean-Phillippe Boudreault, Jean-Sébastien Dubé, Michael Chouteau, Thierry Winiarski, Éric Hardy, "Geophysical Characterization of Contaminated Urban Fills," *Engineering Geology* 116 (2010): 196–206; John H. McBride, Benjamin C. Pykles, Emily Utt, and R. William Keach II, "Rediscovering Provo's First Tabernacle with Ground-Penetrating Radar," *BYU Studies Quarterly* 51, no. 2 (2012): 61–77.
21. See McBride, et al., "Rediscovering Provo's First Tabernacle with Ground-Penetrating Radar," 61–77.
22. See Conyers, "Ground-Penetrating Radar for Archaeology," 149–59; A. P. Annan, "Electromagnetic Principles of Ground-Penetrating Radar," in *Ground Penetrating Radar: Theory and Applications*, H. H. Jol, ed., (Amsterdam: Elsevier Science, 2009), 4–40.
23. John Milsom, *Field Geophysics*, 3rd ed. (New York: Wiley, 2003); and Annan, "Electromagnetic Principles of Ground-Penetrating Radar," 61–77.
24. Annan, "Electromagnetic Principles of Ground-Penetrating Radar," 61–77.
25. Diffractions indicate an object that is relatively small, with respect to the wavelength, such as a building stone or brick. A diffraction may also emanate from a sharp edge, such as the border of a buried brick pavement. Because the wavelength for our antenna when applied to the soils found in Nauvoo is expected to be about 1 foot (0.3 m), objects with a longest dimension much less than 1 foot are expressed as a scatterer of radar signal. For this study, a general dielectric constant of 8 was usually found to be close to optimum in order to match objects of a known depth with the depth-converted radar image. However, changing soil and moisture conditions among sites and during different survey dates (our study spans three years) means that the depth conversion can vary in accuracy.
26. See Milsom, *Field Geophysics*; and Conyers, "Ground-Penetrating Radar for Archaeology," 149–59.
27. Dale L. Berge, "Preliminary Archaeological Explorations at the Lorin Farr, Alvah H. Tippetts, and Stillman Pond Sites, Block 106, Lot 4, Nauvoo, Illinois" ([Nauvoo, IL]: Nauvoo Restoration, Inc., 1971), 7–8.
28. *Ibid.*, 1
29. *Nauvoo Neighbor*, June 12, 1844.
30. *Ibid.*, October 29, 1945.
31. *Millennial Star*, 26:245.
32. Berge, "Preliminary Archaeological Explorations at the Lorin Farr, Alvah H. Tippetts, and Stillman Pond Sites," 7–9.
33. B. J. Kadlec, H. M. Tufo, and G. A. Dorn, "Knowledge-assisted visualization and segmentation of geologic features" *IEEE (Institute of Electrical and Electronics*

*Engineers*) *Computer Graphics and Applications* 31, no. 1 (2010): 30–39.

34. Dale L. Berge, *Archaeology of the Daniel Butler, Jr. Property, Nauvoo, Illinois* (Salt Lake City, UT: Nauvoo Restoration, Inc., 1979), 16.

35. Berge, “Preliminary Archaeological Explorations at the Lorin Farr, Alvah H. Tippetts, and Stillman Pond Sites,” 7.

36. David J. Farr, “Lorin Farr Freind of the Prophet,” *The Religious Educator* 8, no. 1 (2007): 60–88; Berge, “Preliminary Archaeological Explorations at the Lorin Farr, Alvah H. Tippetts, and Stillman Pond Sites,” 1.

37. Earl T. Pardoe, *Lorin Farr, Pioneer* (Provo, UT: Brigham Young University Press, 1953); John Farr, *My Yesterdays* (Salt Lake City: Granite Publishing, 1957); Amy J. Oaks Long, David J. Farr, and Susan Easton Black, *Lorin Farr: Mormon Statesman* (Orem, UT: Millennial Press, 2007).

38. Farr, *My Yesterdays*, 8. According to our survey of the home site, the structure’s foundation measured approximately 17 x 23 feet (5.2 x 7 meters) and all extant photographs indicate that the building was constructed in the federal revival style common in Nauvoo.

39. Pardoe, *Lorin Farr, Pioneer*, 74.

40. *Ibid.*, 70.

41. Farr, *My Yesterdays*, 8–9. This account is second-hand and was written over one hundred years after the fact. As such, it may be inaccurate in the specifics.

42. Berge, “Preliminary Archaeological Explorations at the Lorin Farr, Alvah H. Tippetts, and Stillman Pond Sites,” 5; Rollins et al., “Transforming Swampland into Nauvoo, the City Beautiful,” 131–32.

43. Berge, “Preliminary Archaeological Explorations at the Lorin Farr, Alvah H. Tippetts, and Stillman Pond Sites,” 5.

44. *Ibid.*, 6.

45. *Ibid.*, 5.

46. Hancock County, Deed Records, Book M, 1843.

47. Melinda Evans Jeffress, “Mapping Historic Nauvoo,” *BYU Studies* 32, nos. 1–2 (1991): 269–75.

48. In a letter from Addison Pratt to Brigham Young, Pratt recorded that Daniel Butler had “denied the faith” and returned to New Bedford. See Addison Pratt, “News from Our Mission in the Pacific,” *The Latter-day Saints’ Millennial Star* 7, no. 1 (January 1, 1846): 14. Butler did eventually return to Nauvoo and was counted among the early members of the Reorganized Church of Jesus Christ of Latter Day Saints.

49. *Nauvoo Neighbor*, July 14, 1845.

50. Hancock County, Deed Records, Book O, 1846.

51. Berge, *Archaeology of the Daniel Butler, Jr. Property*, 4.

52. *Ibid.*, 6–28.

53. *Ibid.*, 10.

54. *Ibid.*, 21–23.

55. Dale L. Berge, “Annual Report for the 1970 Fiscal Year,” Nauvoo Restoration, Inc., corporate files, box 161, fld 4, LDS Church History Library, Salt Lake City, Utah, 4.

56. *Ibid.*

57. The property transaction for this sale listed the exact dimensions of the property as follows: “commencing 6 rods East from the South West corner of said lot [lot 3, block 125] and running thence East two rods [33 feet], thence north eleven rods [181.5 feet], thence West two rods [33 feet], thence South Eleven rods [181.5 feet] to the place of beginning.” Hancock County, Deed Records, Book N, 1846, 253–54.

58. *Nauvoo Neighbor*, January 29, 1845.

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59. When the primary city plat of Nauvoo was first registered with the Hancock County surveyor in 1839, the street just east of Main was named “Carlin Street,” in honor of then Illinois Governor Thomas Carlin, who had been friendly to the Saints and later signed the city charter into law. Later, in 1842, Carlin fell out of favor with the Saints after he signed the extradition warrants compelling Joseph Smith to return to Missouri to stand trial for the attempted assassination of former Missouri Governor Lilburn W. Boggs. As a result, the city council renamed the street “Hyde” (in honor of Orson Hyde) in 1843. See James L. Kimball Jr., “The Nauvoo Charter: A Reinterpretation,” *Journal of the Illinois State Historical Society* 54 (Spring 1971), 66–78; Andrew H. Hedges and Alex D. Smith, “Joseph Smith, John C. Bennett, and the Extradition Attempt, 1842,” in *Joseph Smith, the Prophet and Seer*, Richard Neitzel Holzapfel and Kent P. Jackson, eds. (Provo, UT: Religious Studies Center, Brigham Young University; Salt Lake City, UT: Deseret Book, 2010), 437–66; Myrtle Stevens Hyde, *Orson Hyde: The Olive Branch of Israel* (Phoenix: Agreka Books, 2000), 162.

60. Dallin H. Oaks and Joseph I. Bentley, “Joseph Smith and Legal Process: In the Wake of the Steamboat Nauvoo,” *Brigham Young University Law Review* 3 (1976):735–82.

61. *History of the Church*, 7:264–65.