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ORIGINAL ARTICLE

Geophysical Investigation of Mission San Francisco Solano, Sonoma, California

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Abstract Recent advances in mission archaeology advocate for studies beyond the mission church and quadrangle in order to better understand their spatial organizations and how they were embedded within the landscapes of indigenous populations. This raises the question of how to implement such studies in areas impacted for years by urban development, which has made it difficult to detect archaeological remains using standard pedestrian-survey methods. This article advocates for the use of geophysical survey as part of the mix of field strategies. Archaeologists undertook fieldwork at Mission San Francisco Solano in Sonoma, California, to assess the potential of employing geophysical-survey methods in contexts characterized by extensive post-mission reuse. The results indicate that ground-penetrating radar and resistivity surveys are capable of detecting earlier mission architectural remains that can be differentiated from the remains of post-mission urban development from the late 19th and early 20th centuries.

Extracto Avances recientes en la arqueología de misiones abogan por estudios más allá de la iglesia y del patio interior de la misión con el fin de comprender mejor sus organizaciones espaciales y cómo fueron incrustadas en los paisajes de las poblaciones indígenas. Esto plantea la cuestión de cómo implementar dichos estudios en áreas afectadas durante años por el desarrollo urbano, que ha dificultado detectar restos arqueológicos utilizando métodos estándar de estudios peatonales. El presente estudio aboga por el uso de estudios geofísicos como parte del mix de estrategias de campo. Los arqueólogos emprendieron trabajo de campo en la Misión San Francisco Solano en Sonoma (California) para evaluar el potencial de emplear métodos de estudio geofísicos en contextos caracterizados por una reutilización post-misión extensiva. Los resultados indican que el radar de penetración terrestre y los estudios de resistividad son capaces de detectar restos arquitectónicos de misiones anteriores que pueden ser diferenciados de los restos del desarrollo urbano post-misión de finales del siglo XIX y principios del siglo XX.

Resumé Les progrès récents en archéologie de mission défendent les études en dehors de l'église de la mission et du quadrilatère afin de mieux comprennent leur organisation spatiale et comment elle était intégrée dans les paysages des populations autochtones. Cela soulève la question de l'application de ces études dans les zones

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touchées pendant des années par le développement urbain, qui a rendu difficile la détection des vestiges archéologiques à l'aide de méthodes normalisées de sondages dans la rue. Cet article préconise l'utilisation d'un levé géophysique dans le cadre de la combinaison des stratégies de terrain. Les archéologues ont entrepris des travaux sur le terrain à la Mission San Francisco Solano, à Sonoma (Californie) pour évaluer la possibilité d'utilisation des méthodes de levés géophysiques dans des contextes caractérisés par une vaste réutilisation après la mission. Les résultats indiquent que les enquêtes de géoradar et les levés de résistivité sont capables de détecter des vestiges architecturaux de mission antérieurs, qui peuvent être différenciés des vestiges du développement urbain postérieur à la mission de la fin du 19e siècle et au début du 20e siècle.

Keywords Franciscan missions · ground-penetrating radar · Mexican period · colonialism · Northern California

Introduction

Mission San Francisco Solano was the last in the chain of 21 missions founded by the Franciscan order in Alta California from 1769 to 1823. It served as a Franciscan mission for a little over a decade (1823–1834). As with other California missions, archaeological research has focused on the central mission quadrangle containing two church sites, the *convento* (apartments for the friars), and other buildings. Yet, almost no systematic archaeological work has been done on the landscapes surrounding the mission church and quadrangle. Similar to many other California missions in urban settings, the area around the quadrangle has been extensively reused in post-mission times, initially as a Mexican pueblo and presidio from 1834 to 1846, and later as a thriving American town (post-1846). As such, Mission San Francisco Solano offers an ideal opportunity to evaluate survey methods designed to detect mission remains in contexts characterized by extensive post-mission reuse and occupation.

Mission Archaeology in California

Californians have long had a love affair with mission quadrangles—the focal compounds of the Franciscan enterprises that typically consisted of a church, *convento*, visitors' quarters, kitchens, storage rooms, and *monjerio* (dormitories for young girls, unmarried women) built around a central courtyard. Beginning in the late 1800s with the restoration of the churches and associated buildings and the creation of fanciful ornamental gardens, investigations of the material remains of many missions took place. Unfortunately, as detailed by Thomas (1991) and Kryder-Reid (2007, 2010, 2014), many of these reconstructions were based on romantic visions of the colonial past that resulted in rather fanciful renovations of the architectural design of the built landscape, although there were a few notable exceptions; e.g., Bennyhoff and Elsasser (1954), Treganza (1956), Deetz (1963), and Whitehead (1991). With the growing development of historical archaeology and the implementation of cultural resource management in the 1970s and 1980s, mission archaeology in California matured as it moved beyond its restoration roots to a sophisticated enterprise that considered Franciscan settlements as critical cornerstones of Spanish and later Mexican colonialism. Much of this research emphasized native entanglements with the missions and the attempts of the Franciscan friars to pacify thousands of California Indians and assimilate them to the Roman Catholic faith and Hispanic lifeways; e.g., Greenwood (1975, 1976), Hoover (1979, 1985, 1989, 2002), Costello (1989a, 1989b), Costello and Hornbeck (1989), Farnsworth (1989, 1992), Farris (1991, 1997), Johnson (1997), Allen (1998), Farris and Wheeler (1998), Mendoza (2002), and Peelo (2010, 2011).

Despite the flurry of innovative research on the diets, technology, workspaces, and residences of the colonial (e.g., friars, soldiers) and extensive Indian-neophyte populations, most archaeological investigations continued to focus on the mission quadrangles and a few well-documented nearby buildings, such as the *cuartel* (soldiers' quarters) and neophyte housing (Barker et al. 1995; Cannon 2003; Allen 2010:73–75; Panich 2014). Since most ethnohistorical accounts and period drawings of the missions also tend to spotlight the people and architecture associated with the mission quadrangles and nearby buildings, understanding of the broader spatial layout of most California missions remains rudimentary; see Allen (2010) and Schneider and Panich (2014).

The paucity of research on spaces beyond the mission quadrangles is unfortunate for two reasons. First, understanding of the mission enterprises is hampered because these outlying spaces contained the vital industrial sectors (e.g., tanning vats, kilns for ceramics and tiles, tallow- and soap-production areas, threshing floors, *matanza* floors) and agrarian infrastructure (e.g., stables, corrals, canals, gristmills, warehouses, granaries, fields, vineyards, orchards) that were the lifeblood of the missions. While some pioneering work has been undertaken at a limited number of outlying places at Missions La Purísima Concepcíon, San Antonio de Padua, San Luis Rey, Santa Inés, Santa Barbara, Santa Cruz, and Soledad (Deetz 1963; Hoover and Costello 1985; Dietz 1986; Farnsworth 1987; Costello 1989a; Whitehead 1991; Farris 1997; Allen and Felton 1998; Hoover 2002; Cohen-Williams 2005; Mendoza 2014), much remains to be done at all the California missions. Furthermore, the majority of the native people who lived and worked at the missions resided outside the quadrangle walls. While a few exemplary investigations of the adobe structures built for Indian neophytes have been completed (Deetz 1978; Hoover and Costello 1985; Farris 1991; Allen 1998; Panich 2014), the locations of many of these apartment complexes are not well documented. More importantly, only a handful of the traditional native structures in which neophytes lived during the construction of the adobe housing have been detected by archaeologists (Allen 2010). Typically built of wood and grass, these vernacular structures probably housed the majority of the neophyte population, given the chronic shortage of adobe housing space, which may have been reserved for longtime neophytes who had achieved some status in the mission hierarchies (Farris 1991; Farris and Johnson 1999; Allen 2010:85; Panich 2014).

Second, systematic investigations of spaces beyond the mission quadrangles may lead to fresh insights about native and colonial entanglements in colonial California. Rethinking missions as nodes within broader indigenous landscapes may offer a more holistic perspective for understanding how native peoples perceived, negotiated with, and survived the founding of these colonial settlements. Recent archaeological investigations are demonstrating that Indian neophytes residing in the missions were more closely linked to the resources of nearby habitats, their traditional homelands, and other gentile native populations in the outlying region than previously believed (Lightfoot 2014; Schneider and Panich 2014). Neophytes maintained connections well beyond the mission quadrangles through a variety of means—paseos (approved leaves of absence), fugitivism, and regional exchange ties with other native groups—from which they obtained foods, raw materials, craft goods, and ceremonial regalia from outlying lands (Lightfoot 2005:96–98; Panich 2010; Arkush 2011:71–84; Farris 2014; Mendoza 2014). The broader mission hinterlands also supported places of refuge where native people from diverse homelands and polities could regroup and maintain active communities in the face of Spanish and Mexican colonialism (Bernard 2008; Schneider 2010; Schneider et al. 2012; Bernard et al. 2014).

Rather than viewing the places beyond the quadrangles as fuzzy areas of secondary importance in mission scholarship, these spaces need to be re-envisioned as dynamic landscapes where neophytes worked at mission tasks, built their homes, hunted and gathered wild game and fruit, conducted secret ceremonies and illicit relationships, and where they interacted with people from outlying native communities. Lightfoot et al. (2009) generated a spatial model for reconsidering the investigation of colonial settlements as nodes on the indigenous landscape in which a series of places radiate out into the hinterland. The proximal zone (within earshot of the mission bell) would have included mission workplaces, neophyte quarters, and spaces for various other native practices. The more distant hinterlands would have encompassed *visitas* (mission stations), *asistencias* (ranchos with chapels), ranchos, various villages and sites of outlying Indian communities, and places of refuge for neophytes from the missions.

Reorientation of mission studies in reference to the broader indigenous hinterlands will require some rethinking about how mission archaeology is undertaken in California. Archaeologists will need to conduct systematic surveys of missions' proximal zones and outlying hinterlands. Clearly, this is not an easy task, given that many mission hinterlands have been significantly impacted by modern agrarian practices and by extensive urban development. Recent archaeological investigations, in an urban setting, of the proximal zone and nearby hinterland of Mission Santa Clara indicate that mission period archaeological remains can be found beneath parking lots, streets, landscaped areas, and buildings (Allen 2010:80–81; Panich 2014). While some of these remains may be deeply buried under historical fill, the findings from Mission Santa Clara indicate that intact features can be found with excellent archaeological contexts. Subsurface detection methods in these urban contexts will probably need to be highly diversified, with shovel testing, trenching, and broad-scale excavations all part of the solution, as implemented at Mission Santa Clara.

The authors advocate the consideration of geophysical survey as part of the mix of field strategies employed in the study of mission proximal zones and hinterlands, particularly in situations where church officials, agency managers, and/or descendant communities are leery of major impacts to archaeological remains during the initial detection phase of research. We outline our case study for Mission San Francisco Solano below.

Mission San Francisco Solano

Mission San Francisco Solano exemplifies the complex land-use histories and spotty early mission scholarship that characterize many California missions. Founded in 1823 under the newly established Mexican government, Mission San Francisco Solano developed rapidly over the following decade into a highly productive mission complex that housed about 1,000 Indian neophytes. They labored in a diverse range of economic activities, including weaving and the production of hides and tallow, soap, tiles, adobes, etc.; raising bountiful harvests of wheat and barley, and smaller crops of corn, peas, and beans; planting orchards and vineyards; and tending more than 3,500 cattle, 6,000 sheep and goats, 50 swine, and 900 horses and mares (Smilie 1975:37–38). Beginning with the secularization of the Franciscan missions, Mission San Francisco Solano experienced a rapid deterioration from 1834 to 1846 as it was transformed into a Mexican presidio and pueblo under the command of Mariano Guadalupe Vallejo. Many of the mission structures, particularly those outside the quadrangle, appear to have been robbed of adobe bricks, tiles, and other architectural elements that were incorporated into new buildings that became part of the pueblo of Sonoma (Smilie 1975:61). When the pueblo of Sonoma transitioned into an American town in the mid- to late 1800s, what remained of the mission structures in the quadrangle was altered significantly as they were incorporated into various commercial endeavors (e.g., hay depot, livestock barn, winery, saloon, and blacksmith shop), and some areas were used as refuse dumps (Bennyhoff and Elsasser 1954:1–11; Treganza 1956:1; Sonoma State Historic Park Association 1973:3).

By the time the California Historic Landmark League purchased the quadrangle in 1903 and later transferred that land to the State of California in 1906 to become, eventually, part of what is now the Sonoma State Historic Park, the remnant mission buildings were in terrible condition. Restoration of the chapel site (location of the original 1824 wooden chapel, replaced by an adobe chapel in 1840) and *convento*, designated as the "Priests' House," was done initially in 1903 and then more extensively in 1911–1913 after damage from the 1906 earthquake (Bennyhoff and Elsasser 1954:8–15). Unfortunately, the scholarship directing this restoration work appears to have been somewhat limited, and no archaeological research was involved. As Bennyhoff and Elsasser (1954:1) noted: "[T]his restoration was made from limited historical data with no attempt to expose earlier foundations or assess the archaeological potential of the Mission area." Treganza (1956:1) was blunt in his assessment:

> In 1911, when partial restoration was attempted, the nature and number of problems were not fully realized. Almost every earlier stage of reoccupation resulted in some form of structural alteration of the original Mission features. Restoration in part has proceeded on the basis of oral tradition, sometimes of third generation vintage or older.

Significant archaeological work did not take place until 1953 and 1954, when the California State Division of Beaches and Parks contracted with the University of California at Berkeley to undertake fieldwork after intact tile floors were detected outside the chapel site and Priests' House during landscaping and the construction of a drainage system in the central courtyard (Bennyhoff and Elsasser 1954:17). The resulting archaeological work undertaken by Bennyhoff and Elsasser (1954) and Treganza (1956) focused almost exclusively on the mission quadrangle. The excavations detected a diverse range of features that helped clarify the spatial structure of the quadrangle complex. As detailed in the above publications, the archaeologists located tile drains, tile walkways, remnants of adobe walls, possible adobe brick-making areas, the north half of the Priests' House (designated Building A), portions of the wall foundations of the original wooden chapel and later 1840 adobe chapel, an enigmatic structure (Building B) that appears to be a post-mission addition to the 1840 adobe chapel, a well in the central courtyard dating to the post-mission period, and conjectures about the

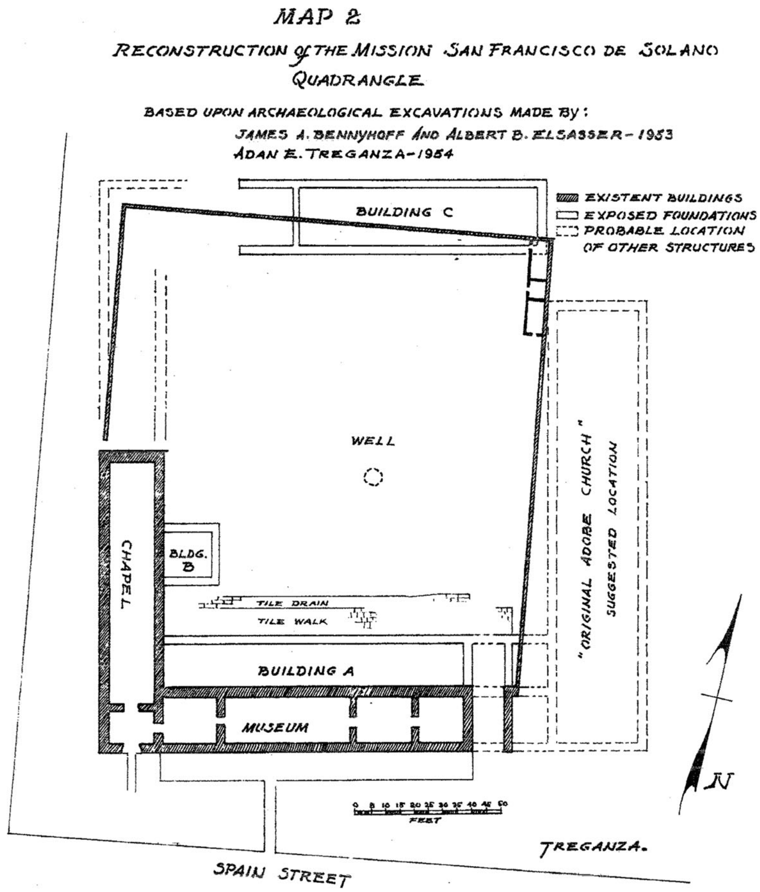


Fig. 1 Map of Mission San Francisco Solano Quadrangle showing the extant mission buildings, projected mission buildings, and archaeological features (Buildings A, B, and C; well; tile walk; etc.) (Treganza 1956:Map 2).

location of the adobe church built (ca. 1827–1832) along the east side of the quadrangle (Fig. 1).

Treganza (1956:8–10) also described the discovery of the buried foundation of a notable structure (Fig. 1, *Building C*) that appears to cover much of the north side of the quadrangle. Measuring 93 × 27 ft. along the outside walls, the foundation of Building C consisted of fieldstones (up to 5 in. in diameter) and broken pieces of roof tiles that were puddled into a matrix of adobe mud. Upon this foundation were found the remains of adobe bricks measuring 22–23 in. long, 1 in. wide, and 3 in. thick. The adobe walls were about 36–42 in. thick. The interior floor of the building appears to be covered by floor tiles measuring 10–13 in. on a side and 2 in. thick. Treganza (1956:8) speculated that Building C, located directly across from the Priests' House, may have served as "a dormitory for resident Indian neophytes."

While the vast majority of the archaeological work at Mission San Francisco Solano involved the investigation of the quadrangle buildings and central-courtyard features, Treganza (1956:12–13) reported that he initiated limited surface pedestrian survey outside the quadrangle complex in the hopes of finding the neophyte village and cemetery. He found no archaeological traces of either one. As a consequence of the archaeological work conducted in the 1950s (the primary excavations undertaken to date at the mission), researchers have a pretty good understanding of the spatial structure of the central core of Mission San Francisco Solano, but know little about the organization of the mission outside the quadrangle walls (see Treganza [1956:2]). The most detailed reconstruction of the broader mission complex has been undertaken by Smilie (1975:37–41) using available archival documents and historical paintings. Although the work is admirable for its depiction of the quadrangle and its hinterland, the specific location of most structures outside the central mission complex appears to be largely hypothetical, as there is no evidence that ground truthing took place, or that geospatial reference points exist.

Geophysical Survey at Mission San Francisco Solano

Ground-penetrating radar (GPR) and resistivity surveys were conducted in an open lot directly north of the extant quadrangle of Mission San Francisco Solano on 18 August 2012. The property is owned and administered by the California Department of Parks and Recreation. A grid system for undertaking the survey work was laid out in the north field area. The majority of the area was covered by the GPR, while a smaller overlapping slice was investigated with the electrical-resistivity instrument to compare with the GPR results. Archival review of the geophysical-survey area informs the results of the GPR and electrical-resistivity findings.

Archival Research

The authors initiated an archival review of historical maps and photographs of Sonoma to evaluate the building history of the area, particularly that of the later 19th and 20th centuries. Archival sources can provide crucial information for undertaking any geophysical survey—not only do they provide a perspective on the kinds of anomalies that may be found in the study area, but they can also assist in the interpretation of geophysical results. The earliest known maps of Sonoma, including the 1850 map of town plots attributed to Jasper O'Farrell, the 1854 survey of the mission grounds by George Black, and the 1856 map of Lachryma Montis (property of General M. Vallejo), did not reveal any structures in the survey area. The latter depicted an agricultural field north of the mission quadrangle. A review of available maps produced by the Sanborn Map Company and other agencies for the town of Sonoma in the late 1800s and 1900s was also undertaken. The surveyors who created the earliest Sanborn maps (Sanborn Map Company 1888, 1891, 1897) did not extend their coverage north of the mission quadrangle. These maps show that the street fronting the southern boundary of the mission, designated as either Vallejo or Spain Street depending on the date of the map (it is now Spain Street), was a major thoroughfare with railroad tracks. Interestingly, 1st Street East, which runs along the east side of the plaza and intersects with Spain Street at the southwest corner of the mission, was blocked to the north by various buildings (including a bowling alley and storage facility) and extensive lumber piles. As the 1888 map of Sonoma (Fig. 2) shows, the only egress through this area was a narrow 12 ft. corridor that indicates that 1st Street East did not continue north of Spain Street at the time.

Maps produced in 1905, 1911, 1923, 1941, and 1953 expanded their coverage to include the study area. The 1905 map (Fig. 3) shows that 1st Street East now continued north past the mission quadrangle and survey area. Two dwellings bounded by fences and with sheds in the backyard were located north of the mission chapel. A large (50,000 gal.) water tank was located east of the houses. Several smaller structures were found between the dwellings, the water tank, and the mission quadrangle (Sanborn Map Company 1905). The 1911 map of the study area depicts no changes from the 1905 map (Sanborn Map Company 1911). The 1923 depiction (Fig. 4) illustrates several changes. The large tank had been removed. A fence now defined the boundaries of the mission quadrangle owned by the state, which encompassed the dwelling immediately north of the chapel. The 1911–1913 restorations of the chapel and

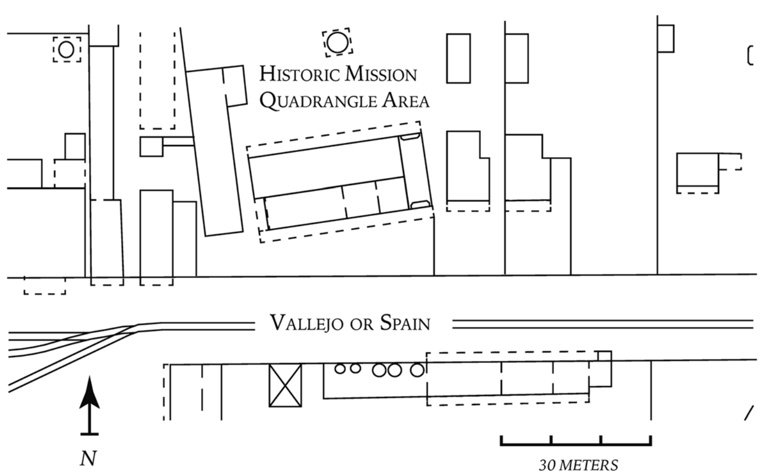
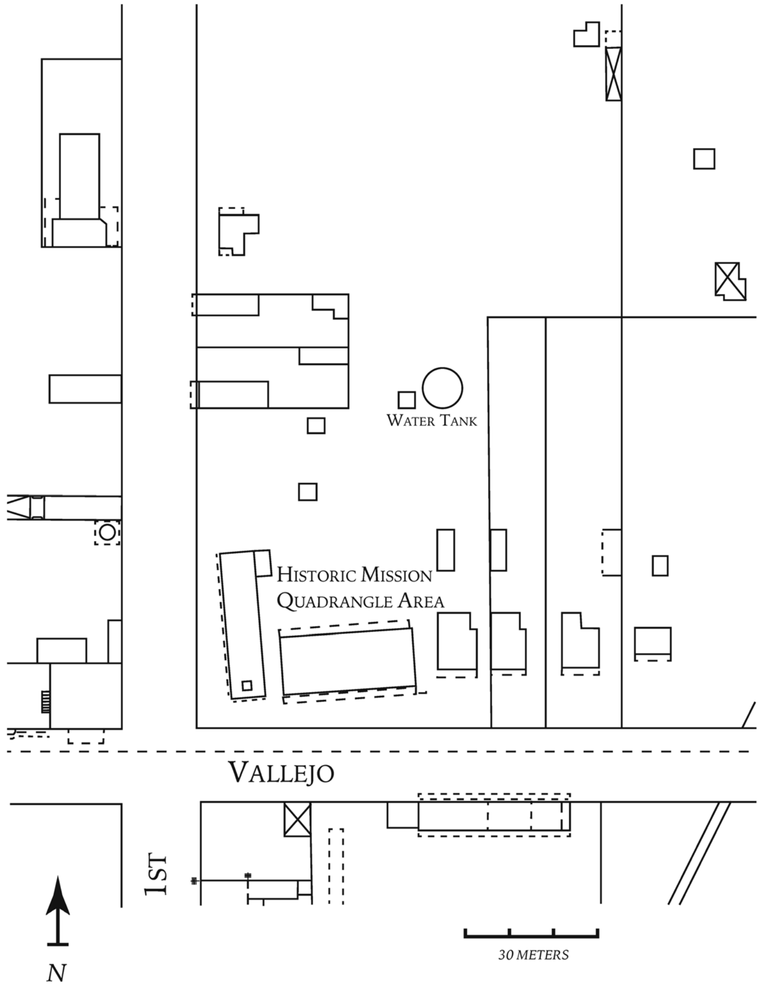


Fig. 2 1888 Sonoma map of the study area. (Map by Christopher Lowman, 2015; based on Sanborn Map Company [1888] and other available information.)

Fig. 3 1905 Sonoma map of the study area. (Map by Christopher Lowman, 2015; based on Sanborn Map Company [1905] and other available information.)



Priests' House are evident. Two small structures were found on state property between the mission quadrangle and the southernmost dwelling (Sanborn Map Company 1923). The 1941 map (Fig. 5) shows that the southern dwelling and two small structures within the fenced area of state park property had been removed (Sanborn Map Company 1941). The 1953 map of the study area (Fig. 6) demonstrates that all the buildings north of the mission quadrangle had been eliminated, creating the "vacant" lot that now exists along 1st Street East and Mission Terrace (Sanborn Map Company 1953).

GPR Methods

GPR data are generated by sending pulses of radar energy into the ground at a specific time interval from a surface antenna. The energy reflected off buried objects, features, or strata is detected as the waves return to a receiving antenna, which is moved along a transect, collecting reflection traces at measured intervals using a calibrated survey wheel. The data are sampled and processed by a CPU designed for this purpose, attached by cables to the receiving antenna. As radar energy passes through different subsurface materials, the velocity of the waves changes, depending on the physical and chemical properties of the material (Conyers 2004). The larger the contrast in electromagnetic properties between two materials at an interface, the stronger the reflected signal. Therefore, effective use of GPR data in archaeology depends on sediment mineralogy, ground moisture, depth, and topography. Electrically conductive or highly magnetic materials, including some clays, will quickly dissipate radar energy, resulting in little or no reflection in the trace profile and shallower

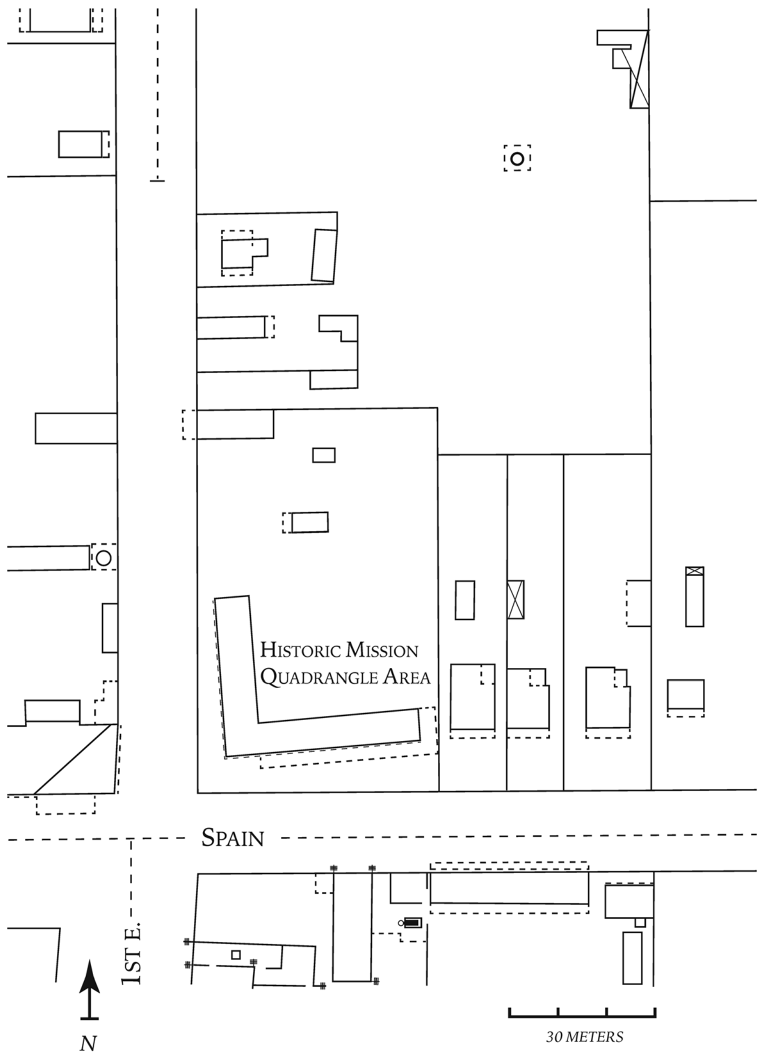


Fig. 4 1923 Sonoma map of the study area. (Map by Christopher Lowman, 2015; based on Sanborn Map Company [1923] and other available information.)

penetration. Dry sediments are generally more reflective than saturated sediments, resulting in deeper penetration and more detailed reflections.

At Mission San Francisco Solano, sediments are highly suitable for GPR survey and mapping. The topsoil is uniformly dry in the summer, but retains some moisture below 20–30 cm. There is no indication of compacted clay, except in adobe-wall feature elements. Natural cobble-sized rock does not appear to be common in the soil, so buried point reflections are more likely to indicate cultural objects, roots, or rodent cavities. Indications of root networks and rodent activity were limited in this largely open, grass-covered lot.

Small transect spacing and middle- to higher-range antenna frequencies are best for mapping near-surface archaeological sites. At Mission San Francisco Solano, both high-frequency (900 mhz) and medium-frequency (400 mhz) antennas were used in our survey. The authors collected data in two grids (Grids 1 and 2). We employed a Geophysical Survey Systems SIR-3000 instrument with a 400 mhz antenna to collect a total of 140 GPR profiles along a grid system with a transect interval of 50 cm. The 900 mhz antenna was used to collect data from 169 profiles at a 25 cm transect interval. Both used a survey-wheel configuration to record distance for tracking profile-trace location. Only 400 mhz data are examined in this paper, as the results of the 900 mhz survey appear to have been partially compromised by interference from frequent cell-phone and wireless-Internet use in the immediate vicinity of the instrument survey.

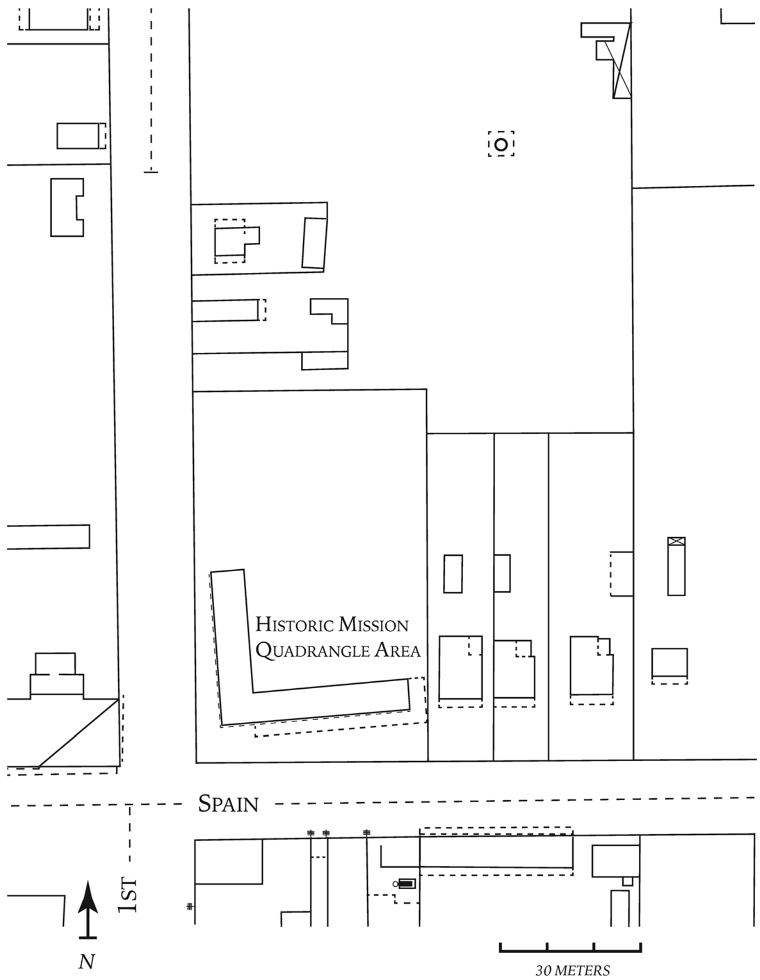


Fig. 5 1941 Sonoma map of the study area. (Map by Christopher Lowman, 2015; based on Sanborn Map Company [1941] and other available information.)

GPR data can be viewed in plan, profile, and 3-D renderings. In this paper we present plan (multiple transect) and profile (single transect) images. Profile images were generated with GPR Viewer software (2011 version 1.1.0 developed by Lawrence Conyers and Jeffery Lucius), which processes data to produce two-dimensional reflection profiles with standard GPR-data files. The processing steps include placing all reflection traces into a profile with grayscale color for positive and negative amplitude reflections; removal of continuous horizontal bands produced by background energy; and applying gains to compensate for amplitude reduction at depth. The depth scale at the left is approximated, based on sediment reflective properties (RDP) and previous feature-excavation measurements. The distance scale at the bottom axis is measured from the southern edge of Grid 1, which begins 1.5 m north of and parallel to the existing concrete wall. All transect profiles are viewed facing west.

Data were also processed for slice-map reflection amplitude topographic plots generated with GPR Process version 1.7.6 (developed in 2011 by Lawrence Conyers) and Surfer 7.0. These two programs grid the data and generate color-scale plan maps for specified depth ranges (slices) within the surveyed site area. The color scale, which incorporates gains and *xy* interpolations, is depicted in grayscale for the printed version of this article.

Normally, GPR findings are related to other sources of information about buried deposits at an archaeological site. Such data fusion can involve examination of historical maps, surface feature elements, excavation data, contextual geomorphology, and other geophysical remote-survey data. Often a site component can be depicted with increasing detail as GPR survey is repeated (perhaps with different antenna configurations or transect spacing, overlapping transect orientations, etc.), or other types of data are further explored in

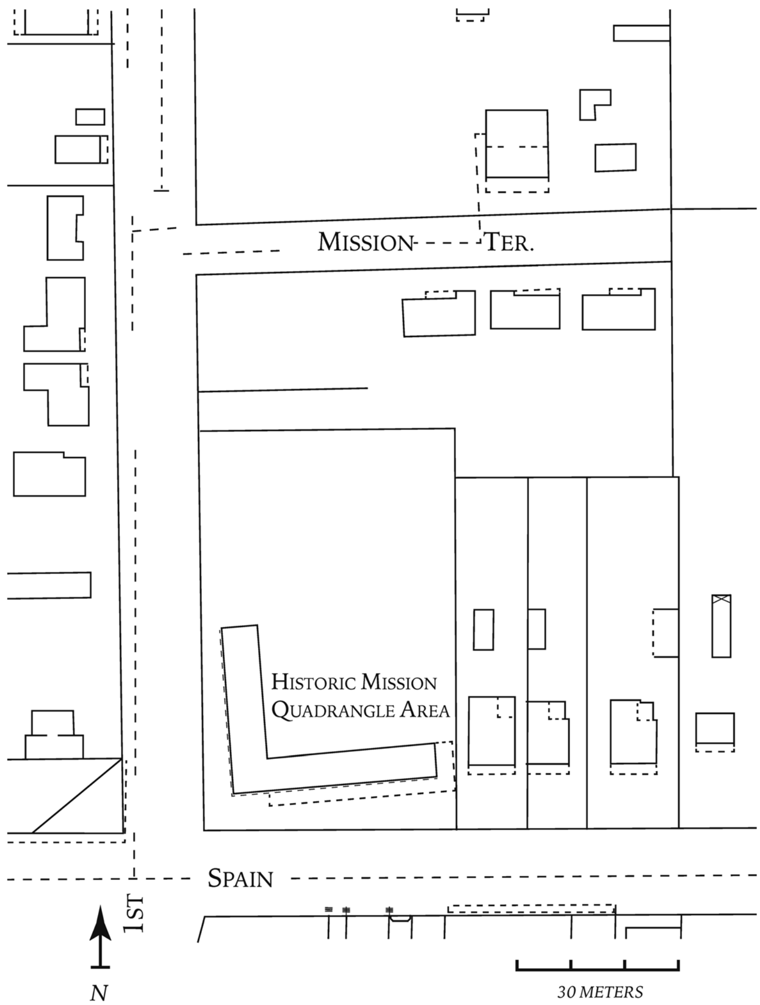


Fig. 6 1953 Sonoma map of the study area. (Map by Christopher Lowman, 2015; based on Sanborn Map Company [1953] and other available information.)

relation to GPR findings. A GPR survey map or profile set becomes part of a dynamic suite of site-interpretation tools that are enhanced as additional types of data become accessible.

GPR Findings

Mission adobes present some challenges to archaeological GPR-profile and -map interpretation (Conyers 2012a). Floor types vary, with tile floors being quite distinct and earthen floors less so. Collapsed roof tiles are difficult to distinguish from objects such as stone, pottery, or glass that may be present within fill areas. The walls themselves are often indistinct because they are constructed of clay bricks, often plastered with multiple iterations of earthen materials, the melting of which can attenuate the radar, resulting in no distinct reflection and even cloaking the reflections of architectural rubble that may be at the base of the wall (Conyers 2012b:193–194). Use of the area in the late 19th and early 20th centuries may also account for a portion of likely cultural features identified in GPR profiles. With these limitations in mind, some general interpretations of the Sonoma Mission GPR data are offered.

Spatial Pattern of GPR Anomalies in the Survey Area

Figure 7 depicts the two grids (Grids 1 and 2) employed in the GPR survey. A grid represents a set of parallel transects spaced at even intervals, e.g., 50 cm. A single transect corresponds to a single GPR profile, though only a portion of a profile may appear in an image shown below. Slice maps are plan diagrams generated from the data gathered along each transect and interpolated at a specific depth range. The 400 mhz antenna

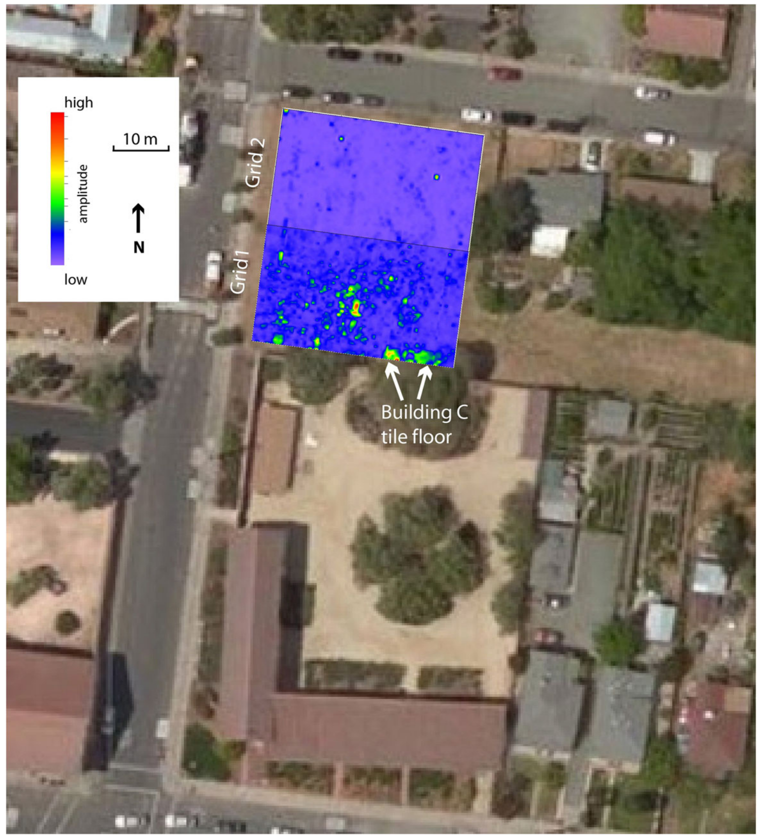


Fig. 7 Overlay of the shallow- or upper-slice maps for Grids 1 and 2 on modern aerial photo of the Sonoma Mission site area. Darker grayscale shades represent higher amplitude reflections associated with buried objects and features such as compacted surfaces, tile floors, stone, pottery, and glass. Lighter grayscale shades are low amplitude reflection areas indicating an absence of buried features. (Map by Scott Byram, 2015.)

used for this survey generated profiles and slice maps at depths from 10 cm to approximately 80 cm deep. Grid 1, the southernmost of the two GPR grids, showed numerous signs of buried features and concentrations of objects. Materials are present at depths ranging from near surface to over 50 cm, although precise depths will require field testing for confirmation. Grid 2 held fewer indications of buried surfaces or other potential architectural features, although scattered objects are also present in this portion of the parcel. The plan maps generated with slice-processing software and profile views show what appear to be cultural features, including the Building C tile floor and numerous objects, often in concentrations. Metal objects show distinct reflections, and these are present in buried areas of concentrated cultural activity, as well as in near-surface sediments. Some objects are likely from 20th-century refuse disposal and incidental discard, but metal and other objects associated with buried surfaces are more likely to be of the mission (1823–1834) or pueblo (1834–1846) eras.

Of particular interest are areas near the center of Grid 1, north of the western portion of Building C, where the remains of two or more possible structures appear to be present (Fig. 7). In addition to these buried floors or compacted surfaces, a rise to the north and a trench farther north within Grid 1 may be related activity areas. The profile and plan-map data indicate that numerous areas have the potential to hold buried cultural deposits at depths comparable to that of the tile floor in Building C. Deeper cultural features are limited to a small number of pits or trenches, possible adobe-foundation rubble, a sloping mound north of Building C, and the floors of excavation pits dating to the 1954 testing of the Building C area.

Slice Maps Depicting Radar Reflections in Grid 1

Figure 8 depicts two slice maps from Grid 1, upper and lower, with the relative amplitude color scale shown at the right. The map at the top is the shallower of two slice maps, with a depth estimated at 8–14 in. These maps include a meter scale along their south and west edges. The upper-slice map in Fig. 8 clearly shows a pronounced rectangular planar reflection where the tile floor of Building C was identified in 1954. This is in

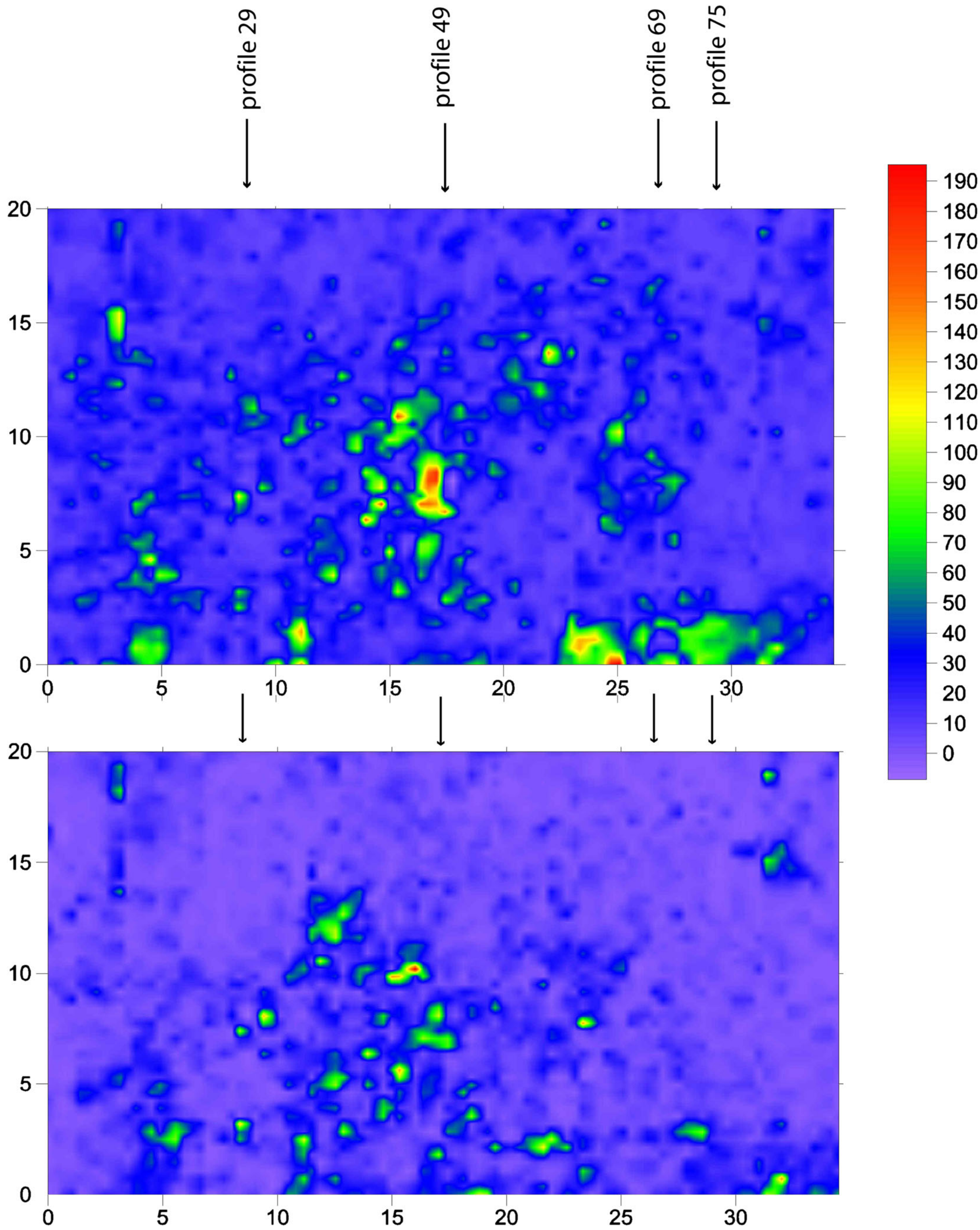


Fig. 8 GPR anomalies detected in two slice maps of Grid 1. The top map is the upper-slice and the lower is the deeper-slice map. Note the location of Profiles 75, 69, 49 and 29. (Map by Scott Byram, 2015.)

the southern edge of Grid 1, eastern quadrant. Another tile floor or compacted surface is suggested at this depth in the center of the slice map, where no excavation has taken place. The upper-slice map also shows a reflection of approximately 3 × 3 m located north of Building C that may be the remains of a small structure depicted on the 1905 and 1923 maps of the study area. The lower-slice map shows deeper reflections at roughly 12–20 in. Deeper reflections are indicative of pits, including the pits from the 1954 excavations along the southern edge of the slice map, and architectural rubble surrounding the tile-floor perimeter associated with adobe-wall foundations (Fig. 9). To the north, in the center of the slice map, the deeper reflections may represent pits, trenches, or architectural foundation rubble.

In comparison to Grid 1, Grid 2 (Fig. 7) shows limited patterning that may indicate features. Linear reflections in Grid 2 appear to relate to the structures and fence lines illustrated on the 1905, 1923, and 1941 maps (see discussion below). No potential tile floors or deeper, Mexican era (1823–1846) historical features are indicated for this grid, though more ephemeral or dispersed reflections could be from cultural material of that era.

GPR Profiles

Figure 8 shows the locations and specific orientations of four profiles from Grid 1 (Profiles 75, 69, 49, 29). An examination of these four profiles provides more detail on the size, depth, and location of the anomalies detected in Grid 1. Some features or concentrations are more distinct in profile images than in slice maps. These four profiles run from north to south, thus corresponding to the scale shown on the west edge of the grid-slice maps in Fig. 8.

Profile 75: The tile floor of Building C appears clearly in Fig. 10 as a higher amplitude planar reflection in the middle of the profile depth range at the left (south edge of profile, which faces west). The upper 15 cm is the near field zone, where the antenna was coupled with the ground, and no data were collected. Note that the depth scale may be exaggerated by 20% or so, based on comparisons with Treganza's (1956) observed tile-floor depth. Several mostly shallow objects (or roots or rodent burrows) are visible to the right as small chevron-shaped hyperbolas. The vertical repetition of these hyperbolas is due to reflected energy between the object and the receiving antenna, resulting in the exaggerated vertical dimension of the object. No other floor features or buried surfaces are indicated in the eastern portion of Grid 1 outside Building C. Deeper hyperbolas beneath the planar tile-floor reflection at 3 m north may be architectural rubble used as the foundation of wall construction (also evident on the lower Grid 1 slice map, Fig. 9). On the deeper-slice map (Figs. 8, 9), the general extent of this material is wider than that of the tile floor itself, corresponding to wall rubble on Treganza's excavation map.

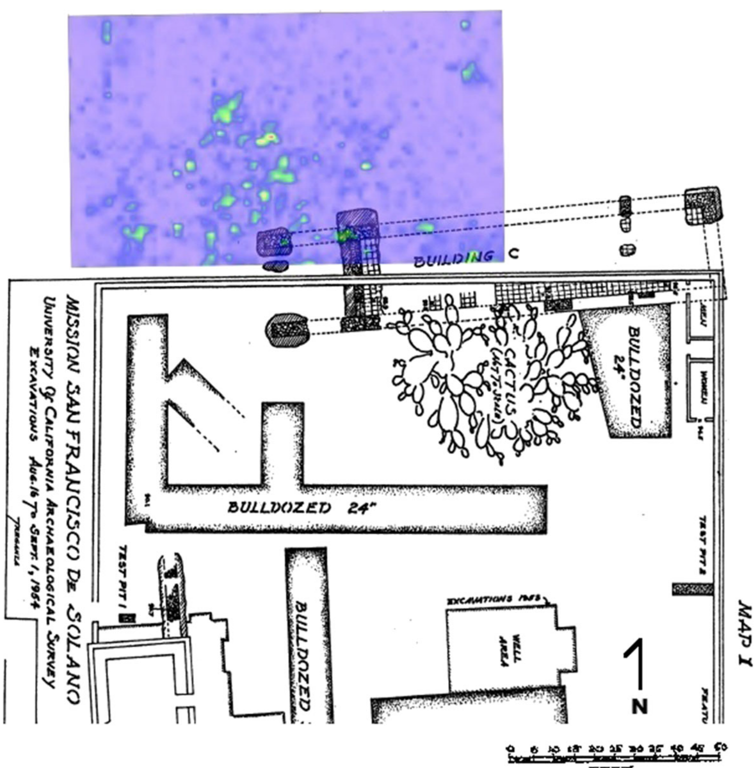


Fig. 9 The lower- or deep-slice map of Grid 1 is shown in transparency overlay on the northern portion of the 1956 excavation map (Treganza 1956:Map 1). High amplitude reflections are visible at what would be the base of the north adobe wall in Building C, in 1954 excavation areas, and in several locations north and west of Building C. (Map by Scott Byram, 2015.)

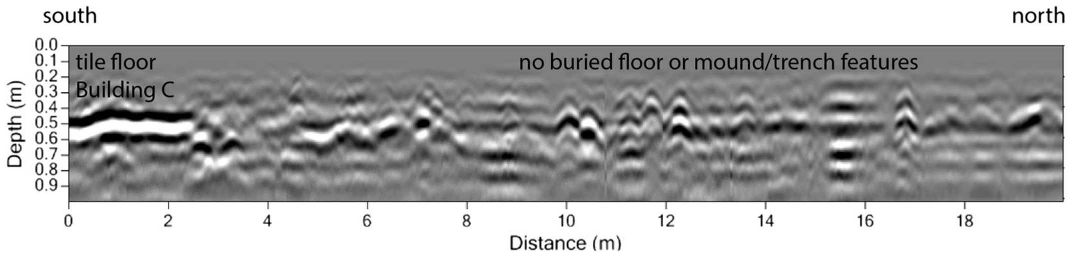


Fig. 10 Profile 75 from south to north (*left* to *right*). (Profile by Scott Byram, 2015.)

Profile 69: The tile floor depicted in the southern edge of Fig. 11 has a gap in the middle that corresponds to the pit appearing in the upper Grid 1 slice map. Rubble is evident below the northern edge of the tile floor (at 2 m on distance scale). An oblique stratum (possible small mound or adobe melt) slopes up from the base of rubble to a surface from 7 to 10 m north, then descends for 2 m. This low mound corresponds to the location of a small structure depicted on the 1905 and 1923 maps of the study area. The buried surface slopes up again, continuing north as the surface of a shallow mound that ends at 19 m north, in what may be a trench. This pattern of buried surface in the center of the profile, next to a rise and then a descent (moving northward), is repeated in several of the profiles in the center east of Grid 1. Distinct objects are more numerous in association with the buried surface than with the mound, which suggests the low rise to the north is not a refuse midden. It may be an architectural feature, such as collapsed or melted adobe wall, or associated with agriculture, such as raised soil for composting and planting. It may also correspond to the early 20th-century fence line and the buildings running east–west on the 1905, 1923, and 1941 maps. This area slopes downward to the north, to the modern Mission Terrace Street. The northern mound begins near Profile 45 and continues intermittently 18 m eastward to the vicinity of Profile 72.

Profile 49: In Fig. 12, no tile floor is evident at the far left (southern edge) of Profile 49, as this is west of the tiled portion of Building C. Instead, the base of the 1954 excavations is evident at depth, corresponding to a pit shown on Treganza's 1956 map. To the north, from 5 to 10 m on the profile transect, a buried surface resembling the tile floor is evident, with apparent rubble beneath (or tile edges) and numerous objects on its surface. A less distinct buried surface extends to the north, descending into a trench at approximately 17 m (distinguished from a pit by its presence in profiles to the east and west). The northern east–west trench feature may relate to the early 20th-century house depicted on the historical study-area maps (see below).

Profile 29: In the western portion of Grid 1, including Profile 29 (Fig. 13), no likely tile floor or distinct buried surface is evident in profiles, but numerous objects are concentrated from 5 to 9 m north, roughly in line with the buried surfaces seen in profiles to the east. The low rise or mound is distinct in this profile, beginning in a pit or trench at 10 m, rising to 14 m, and gradually descending to 18 m before leveling off. The northern east–west mound is not as continuous in profiles in the western third of Grid 1, and this may or may not be a related feature. This anomaly may be associated with the early 20th-century structure represented on the historical study-area maps.

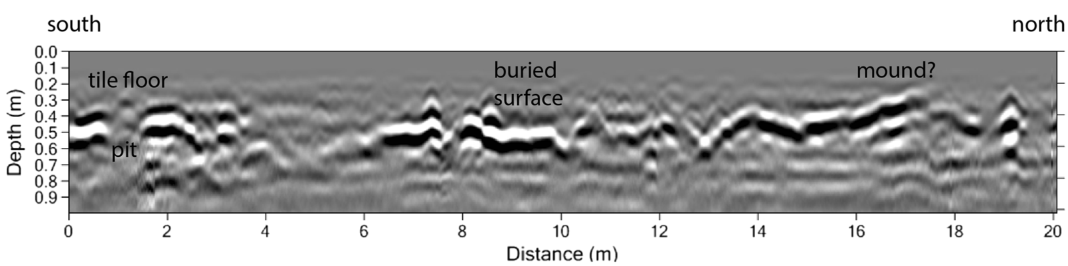


Fig. 11 Profile 69 from south to north (*left* to *right*). (Profile by Scott Byram, 2015.)

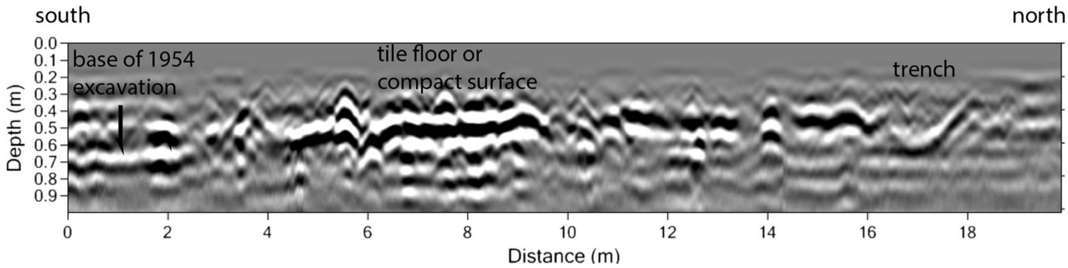


Fig. 12 Profile 49 from south to north (*left* to *right*). (Profile by Scott Byram, 2015.)

Resistivity Survey

To compare results of GPR and resistivity survey at Sonoma Mission, a single north–south resistivity profile was collected in the southeastern portion of Grid 1 (Fig. 14). The authors conducted the resistivity survey using an AGI Ministing resistivity meter and Swift multi-electrode system with a 28-lead electrode cable. Stainless-steel electrodes were spaced at 50 cm intervals (13.5 m total survey line length), hammered to a depth of ca. 10–15 cm, and moistened at the base to reduce contact resistance. Field crews collected each reading at least twice to measure repeat error. We collected a total of 204 data points along the survey line, representing subsurface resistivity values at ca. 25–105 cm in depth. A mixed array of dipole–dipole and gradient electrode configurations was used. Resistivity data was inverted with AGI EarthImager 2D software. We set default surface-inversion settings using the following alterations: mesh divisions per matrix cell=8, maximum RMS error=2.0%, number of CG iterations=12, maximum resistivity=200 ohm-m.

Measured apparent resistivity in the survey line ranged from 6.9 to 153.0 ohm-m, indicating relatively fine-grained soils/sediments retaining moisture below the topsoil. Repeat error was below 1.0% for all readings. During inversion, data converged to a solution with less than 1.5% RMS error in four iterations, and no data were discarded. These measures indicate a relatively clean dataset that can be interpreted with a high degree of confidence. Figure 15 presents the inverted resistivity section. The section shows a typical transition from high resistivity values in drier, near-surface soils, to lower values in moister soils at greater than ca. 30 cm depth. Small anomalies at less than ca. 20 cm in depth are artifacts of the inversion process.

To the left (south) of the 3.5 m mark along the survey line *x* axis, as shown in Fig. 15, there is a region of consistently high resistivity (ca. 100–200 ohm-m) from near the ground surface down to a depth of ca. 70 cm. This area corresponds to the projected extent of Building C in the survey area as indicated by Treganza (1956) (Fig. 14). The resistivity profile indicates a "step" in the Building C section, with higher resistivity values reaching a depth of ca. 50 cm from 3.0 to 4.0 m along the *x* axis, and a depth of 70 cm left (south) of 3.0 m. This could indicate the transition between the building wall foundation and floor area. Treganza (1956:9) indicates that the adobe-wall foundations of Building C were ca. 1.0 m wide and constructed of fieldstones and broken roof tiles in an adobe matrix. This is consistent with the width of the "step" feature indicated in Fig. 15. Intriguingly, high resistivity values in the probable floor area of Building C are deeper than those in the probable wall foundation area. Since it is likely that adobe-wall foundations would have been deeper than the building's floor surface, a reverse of the observed configuration would be expected, with higher resistivity values at greater depths in the foundation area and at lesser depths in the floor area. Photographs of the exposed Building C

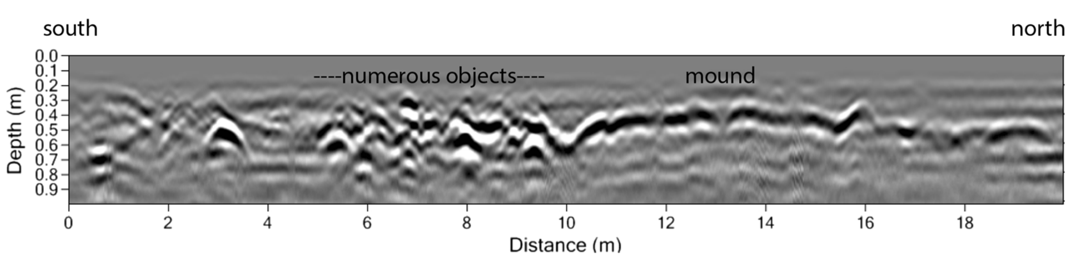


Fig. 13 Profile 29 from south to north (*left* to *right*). (Profile by Scott Byram, 2015.)

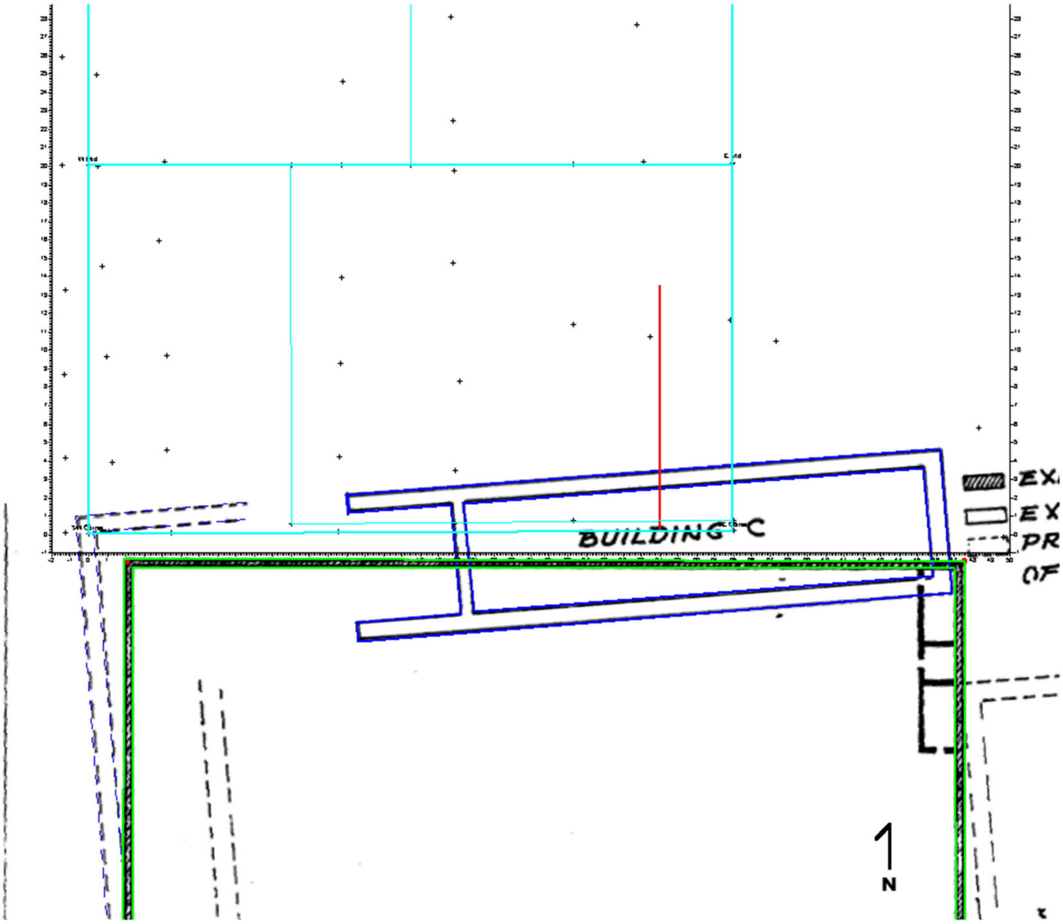


Fig. 14 Location of Resistivity Profile in Grid 1 overlaid on Treganza's (1956:Map 2) map of Building C. (Map overlay by Scott Byram, 2015.)

tile floor in Treganza (1956:plates 4b, 4c) suggest the depth of the floor is ca. 25–40 cm, shallower than the transition in resistivity values indicated in Fig. 15. High resistivity values at depths greater than ca. 50 cm in the Building C floor area could indicate either (1) disturbance of subfloor deposits during building construction, for example to improve drainage beneath the structure, or (2) substantial alteration of local subsurface drainage patterns (i.e., poorer water penetration in this area) caused by the construction of the tile floor or the collapse of Building C adobe walls (i.e., forming a poorly draining silt "cap" over the floor area). Higher overall soil-resistivity values at depths greater than ca. 30 cm in the northern portion of the resistivity section from ca. 10

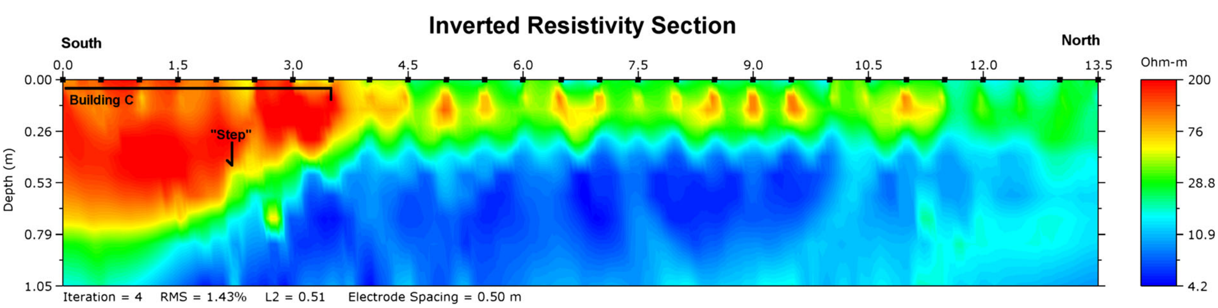


Fig. 15 Inverted resistivity section showing ohm-m readings from ground surface to a depth of about 1 m. (Profile by Scott Byram, 2015.)

to 13.5 m could indicate that soils there are drier due to greater distance from the contemporary mission wall, which provides more shade to soils in the southern portion of the resistivity survey line.

Discussion

The GPR and resistivity surveys of the area north of the San Francisco Solano mission quadrangle revealed numerous buried anomalies. Some of these anomalies, particularly in Grid 2, appear to be associated with later historical activities. The review of the available maps of Sonoma indicates that structures existed north of the mission quadrangle between 1905 and 1953. The construction dates of these buildings are not known. The two dwellings in the survey area appear to be built in alignment with 1st Street East, which was probably not a functioning street until after 1897, as indicated in the early Sanborn maps. It is probable that these structures were built some time between 1897 and 1905. In any event, there is little likelihood that they date to mission (1823–1834) or pueblo (1834–1846) times given their location on 1st Street East. In evaluating whether these later structures may have produced geophysical signals in the survey area, we superimposed information from the 1905 and 1923 maps on Grid 1 and 2 of the survey area. As illustrated in Figs. 16 and 17, the northern trench and low mound features that appear to run east–west, based on GPR profiles in Grid 2, are likely associated with the building and fence line shown on the 1905, 1923, and 1941 maps. Additionally, the low mound, shown north of Building C in GPR profiles and the upper-slice map from Grid 1, appears to be associated with the small structure appearing at this location on the 1905 and 1923 maps. Grid 2 does not clearly show the walls of the shed that appears on these maps, but it may have been a surficial structure. The linear feature along the western edges of GPR Grids 1 and 2 may be a utility trench or walkway associated with the street frontage of this early 20th-century component.

Significantly, the majority of the GPR anomalies found in Grid 1 do not appear to be associated with the early 20th-century structures, but exhibit strong similarities to those found in the vicinity of Building C. Here, along the southern edge of Grid 1, the geophysical survey generated profile reflections and plan-map amplitude patterns that reflect building

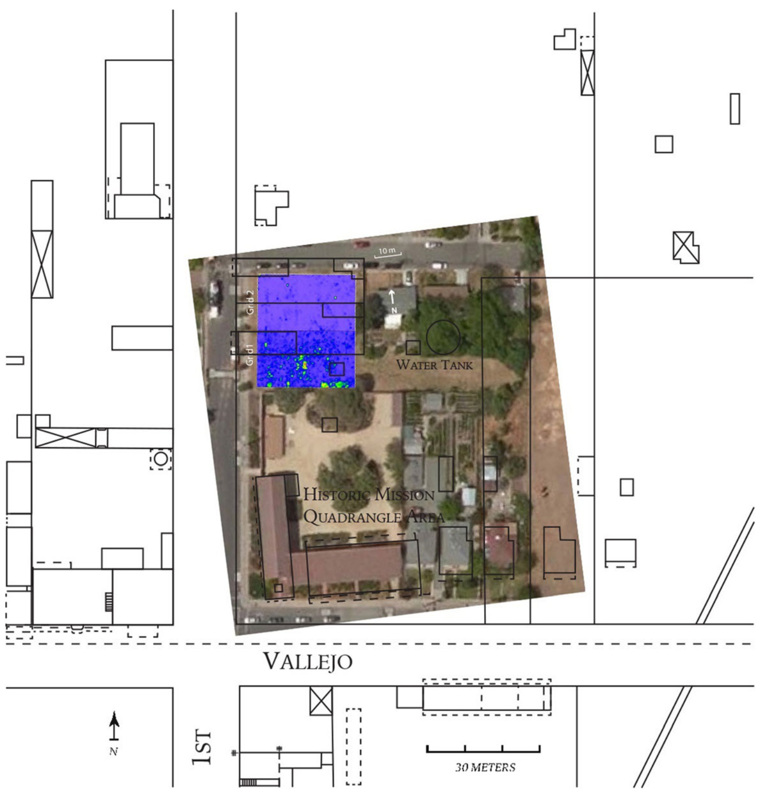


Fig. 16 1905 study area map superimposed on the survey area showing GPR anomalies in Grids 1 and 2. (Geophysical map by Scott Byram, 2015.)

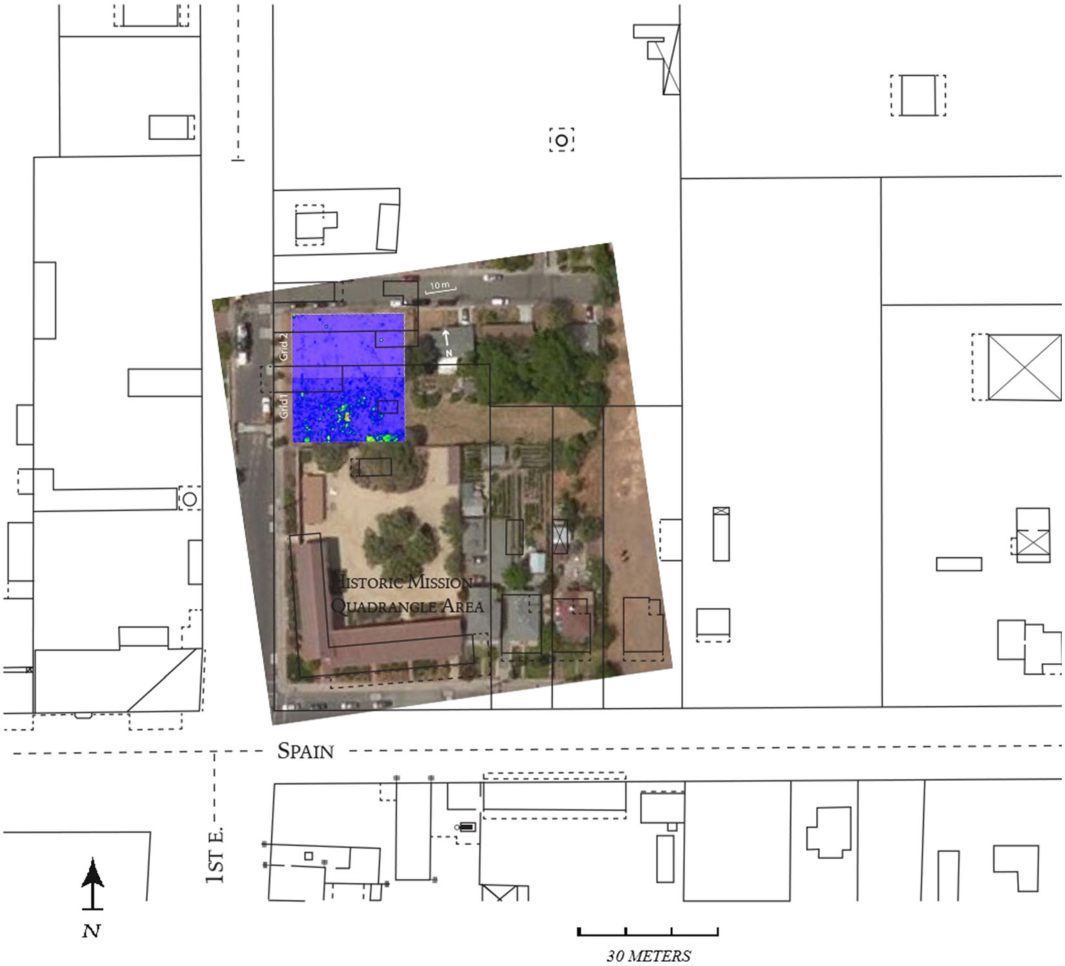


Fig. 17 1923 study area map superimposed on the survey area showing GPR anomalies in Grid 1 and 2. (Geophysical map by Scott Byram, 2015.)

foundations, adobe rubble, tile floors, and 1950s excavation pits. Figure 9 overlays the lower-slice GPR map on Treganza's (1956) map of Building C. It is significant that both the GPR and resistivity surveys picked up strong signals of the wall foundation, adobe walls, and tile floor of the buried structure. The GPR survey also detected similar kinds of anomalies in Grid 1 north of Building C, but south of the structures depicted on the 20th-century maps of the study area (Fig. 9). Although these GPR signals are not found on a scale comparable to Building C, similarities to this building in the profile reflections and plan-map amplitude patterns suggest these anomalies may be depicting one or more smaller adobe structures roughly in the center of Grid 1. Other more ephemeral architectural features may also be present, and there appear to be concentrations of artifacts, such as roof tile or discarded pottery and stones, north of Building C. Metal is most abundant near the surface, which is consistent with post-mission use of the area for refuse disposal and vehicle storage. Low mound and shallow trench features may relate to former walls or agricultural modifications of the landform associated with this potential structure and other nearby cultural features. What is creating these GPR signals will not be known precisely until further field testing is undertaken.

Conclusion

Recent advances in mission archaeology are encouraging more integrated studies of the central quadrangles with their proximal zones and hinterlands to better understand the spatial structure of these extensive enterprises and how these colonial institutions were embedded within broader indigenous landscapes. Yet, archaeological investigations of the proximal zones and outlying areas of California missions are in their infancy. The authors advocate that geophysical survey should be part of the mix of archaeological methods employed in the study of spaces beyond the mission quadrangles. In combination with surface pedestrian survey, shovel probes, and more extensive excavations, geophysical survey may provide crucial information for detecting buried archaeological remains, particularly when combined with other types of data, such as excavation findings and archival records.

The geophysical investigation of Mission San Francisco Solano demonstrates that ground-penetrating radar and resistivity can be employed in an urban context that has been built up during the late 19th and 20th centuries. In Grid 1, the GPR and resistivity surveys worked well in detecting the foundations, adobe walls, and tile floors of a previously known mission structure (Building C). The geophysical investigation provides support for Treganza's (1956) assessment about the size and configuration of the buried structure based on his subsurface testing. The GPR survey also detected a series of intriguing anomalies north of Building C. Some of these anomalies appear to be associated with buildings and features found in the study area from 1905 to 1953. The GPR signals for these more recent remains are less pronounced and quite distinctive from those found at Building C. Other geophysical anomalies detected in the area between Building C and the 20th-century structures exhibit profile reflections and plan-map amplitude patterns that may reflect adobe architecture (rock foundations, adobe rubble, tile floors), artifact concentrations, and strata suggesting land modification for structures or agriculture. It is interesting that the spatial distribution of these buried cultural remains appears to diminish with distance from the main quadrangle. An important finding of this study is that geophysical signals associated with the later 19th- and 20th-century housing development can be distinguished from those of earlier cultural remains (e.g., Building C), which may be crucial for future survey work in the built-up hinterlands of California missions. Whether the distinctive anomalies detected in the southern area of Grid 1 may be associated with mission (1823–1834) and/or pueblo (1834–1846) structures remains to be evaluated with further field testing. Geophysical survey methods, in combination with relevant archival information, can be a critical tool in identifying potential areas that may contain mission period archaeological remains in the proximal zones of mission quadrangles.

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