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Site Interiography and Geophysical Scanning: Interpreting the Texture and Form of Archaeological Deposits with Ground-Penetrating Radar

Jun U. Sunseri[1] **· Scott Byram**[2]

Abstract The remarkable potential of geophysical scanning—to assess the internal variability of sites in new ways, to highlight important phenomena in the field, to exercise co-creation of interpretation and commitment to minimal destruction of community partners' resources, and to aid in the practice of due diligence in avoiding desecration of the sacred—continues to be underutilized in archaeology. While archaeological artifacts, features, and strata remain primary foci of archaeological geophysics, these phenomena are perceived quite differently in scans than in visual or tactile exposures. In turn, new registers of site exploration afforded by geophysical prospection may be constrained by the language of site excavation and visual observation, requiring adjustments in the ways of thinking about and describing what the instruments are measuring. The texture and form of site deposits as rendered in ground-penetrating radar scans can be examined in detail prior to making interpretations of cultural features or stratigraphy. Far more than simple "anomalies" demanding our attention for excavation, patterns in geophysical data can be the focus of extensive archaeological analysis prior to, in conjunction with, or independent from excavation.

Keywords Interiography · Ground-penetrating radar · Geophysics · Archaeological prospection

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Introduction

As new technologies move archaeology beyond its conventional emphasis on excavation, it is timely to spark conversations about larger connections to the ways we think through the supposed knowings which technologies such as magnetometry, resistivity, LiDAR, portable X-ray flourescence, photogrammetry, and others purport to provide within the realm of archaeological science. Few can fail to appreciate dimensions of site structure in situ and intact provided through geophysical instrument scanning. With techniques such as ground-penetrating radar (GPR), we are afforded chances to explore site histories with less emphasis on taking the site apart manually. Yes, GPR resolution has indeed improved enough to detect things to "think from" (Wylie 2002), even in some cases less than 10 cm in size. But we aim to consider here some issues and potentials of naming and knowing in the process of non-invasive prospecting. The goal is to maximize the interpretive spectra available to us through phenomena otherwise hidden by our traditional tool kits. If we can understand this tool of our trade, we certainly stand to reduce the impact of archaeology on sites that we want to preserve. But more importantly, it also allows us to expand our understanding of a site before and during excavation and informs our decisions about where and how to conduct sampling.

Despite the availability of subsurface geophysical scanning techniques for over a generation of new scholars of Americanist archaeology, techniques such as GPR are still incorporated into relatively few archaeological projects (Weymouth 1986). One particularly compounding factor might be that interpretation and discussion of subsurface scanning findings is considered esoteric, the language of specialists. For some, the potential of the technique to highlight important phenomena in the field, enhance opportunities to co-interpret phenomena while exercising commitments to minimal destruction of community partners' resources, and to help practice due diligence in avoiding the sacred is outweighed by an apparent opacity in application. However, it is also critical to recognize that interpretations afforded by geophysical instrumentation may also be constrained by the language of site excavation and visual observation itself. Never shying away from the bread and butter of our discipline, we suspect that most archaeologists would find the remarkable potential of subsurface scanning to assess the internal variability of sites to be compelling. Therefore, while archaeological artifacts, features, and strata can remain primary foci of subsurface scanning, these phenomena are perceived quite differently in scans than in visual exposures.

The rewards and challenges of deploying various GPR arrays effectively are as diverse as they are attractive, and geophysical prospection itself has long been advocated for archaeology (Linington 1963). Even with what we feel to be a warranted resurgence of GPR use, we feel it may be wise to learn from critiques of instrumentation not developed for, yet applied increasingly to archaeological investigation, such as those leveled at portable X-ray fluorescence (PXRF) studies (Killick and Goldberg 2009; Shackley 2010) or even familiar instruments and assemblages (Sunseri and Delage 2016). Precautions against archaeologists' rampant purchasing of and minimal training with instruments developed for other industries have at their core healthy skepticism of attempts to assume increased "science-ness" of analyses. In essence, just as it is true that anyone can pull the trigger of a portable X-ray fluorescence device, or schedule beam time on a scanning electron microscope, anyone can pull a ground-penetrating radar across a transect. In Fig. 1, it is possible that both field workers are making equal contributions to the use of the instrument. The larger worker is pulling it along a set transect line while his tiny assistant is using his body weight to ensure solid coupling of the antenna with the ground surface. Neither really contributes to "knowing" the site more than the other in just deploying the instrument. Without an interpretive framework to evaluate the real-time collection of data visualized on the instrument display, it could be argued that both have equally valid things to say about how the materiality of the site manifests in structure and function at the moment this photo was taken. Only later, in how each might differently review the reflection data, might one of them have something more to contribute. An archaeologist watching the instrument display as the transect is covered does have the potential to provide some useful information for the team. This aspect of GPR use is particularly demonstrative of the emergent nature of GPR interpretation in its revealing of site interiography via the ongoing visualization of signal returns on the instrument screen during this process. Later post-processing of the data collected may be even more powerfully interpretive.

With substantial time spent field-testing and refining approaches to GPR signal interpretation, archaeologists have joined geologists and hydrologists among the ranks of field scientists who might benefit from more critical perspectives on what should be expected from geophysical prospection. Many of us are influenced in our approach to archaeological GPR applications by the years of methodological development by Lawrence Conyers (2006, 2012, 2013, 2015, 2016) and Conyers and Goodman (1997). From both academic and cultural resource management perspectives, GPR practitioners following in his footsteps have developed deep frontline experiences with client and partner misapprehensions and time-critical concerns regarding deliverables from radar survey. Building on Conyer's foundation, we would like to consider how we communicate the data the instrument is actually receiving and how it is interpreted.

In particular, we emphasize that variability within subsurface deposits can and should be characterized prior to interpretation of potential cultural features or stratigraphic composition. Variables such as texture, form, composition, and conformation can be assessed from radar patterning prior to making statements about likely features or strata represented in the data. How we use language to qualitatively describe the

Fig. 1 Archaeological field crew deploying 900 mHz ground-penetrating radar survey rig at Mono Mills townsite, CA

emergent forms of visualized and interpreted data from a GPR survey is important. This language may be more nuanced and aligned with the theoretical reconsiderations of site interpretation that we advocate.

In honing our repertoire of descriptors for use with geophysical instruments, it may serve well to begin from first principles and be attentive to the relationship between technologically driven archaeology and more traditional approaches. For example, descriptive reflectivity, variable moisture, and density interfaces are often subtle but highly informative elements of site formation, but these are registers which are often lost in translation through archaeological object-oriented perspectives that emphasize durability, resilience, and visual characteristics. In the best of circumstances, this difference is a manifestation of our discipline's traditions of knowing—of unearthing, labeling, and positioning things we can see and touch.

The aforementioned differences are at the crux of interpreting the data returned as reflected energy in GPR survey. Like any of our practices, we bring tensions between the depth of archaeologists' underlying assumptions, the habitus of our work, and the implicit paradigms which condition the replication and reinvestment of our field traditions (Johnson 2006, p. 117). Applied to GPR, this ontological attitude is enframing in modes which challenge our intent to reveal and be receptive to the truly emergent contours of signals as they return to the instrument. The same attitudes magnify the dangers of misconstruing and misinterpreting what has been unconcealed (Heidegger 1977 (1954), p. 315) by geophysical mapping activities. This is because the sense we make of such signal returns are ultimately entangled with our past experiences. As an example, consider how many layers of abstraction are represented in a typical excavation profile drawing much less the reflections recorded by a geophysical instrument at the same transect (Fig. 2).

Conyers writes that "Raw reflection data are *nothing more* [our emphasis] than a collection of many individual traces along two-dimensional transects … depending on the amount and intensity of energy reflection that occurred at buried interfaces" (Conyers 2006, p. 142). We might then interrogate the kinds of work that modes of enframing, or naming a sloping interface between relative dielectric permittivities as a pit floor reveals about the "domain of the correct, rather than the true" (Pickering and Guzik 2008, p. 8). And if such categories are fundamental to the justification of using these technologies, then the epistemological requirements of physically dismantling the

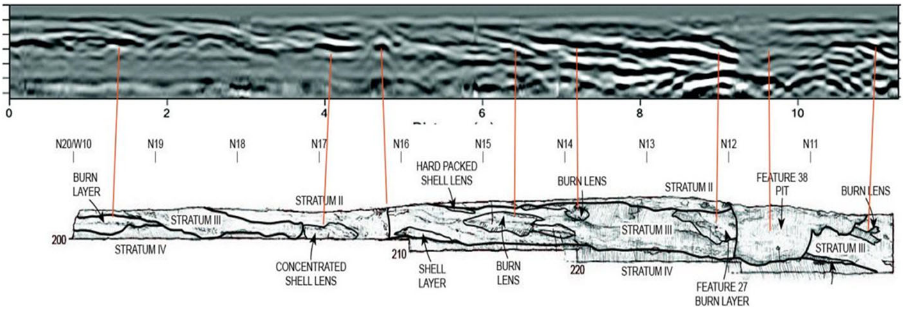

Fig. 2 Stege mound excavation profile matched with GPR transect profile in *grayscale*. The GPR transect preceded excavation. It shows more inclined microstrata than the excavation profile. The GPR data combined with the excavation provide a more detailed picture of shell mound structure than excavation data alone (Byram 2015; DeGeorgey 2015)

deposits actually risks cloaking the phenomena. Our trowels can obscure interfaces that Conyers describes as so subtle as to be "usually all but invisible to the human eye" (Conyers 2006, p. 140) but resolvable in GPR with careful amplitude analyses. Closer then, we tread toward transformation of "the image of thought" (Deleuze 1995 (1968), p. 135) in which we challenge how precisely the supposed principles—in this case, the geophysics of a given site—align with facts. Wylie's attention (2002, p. 166) to debates about how richly interpreted data can challenge and constrain what we claim about the past is important for how we consider the ways archaeologists perceive ground-penetrating radar scans when there is uncertainty about the subsurface phenomena being examined (*i.e.*, most of the time). For example, a set of GPR reflections may represent a clay floor or a rock-lined hearth, but that assessment only comes after multiple steps of analysis and in many cases, excavation of the area scanned with radar. Like everything in archaeology, interpreting radar scans is a process with a unique language to be developed as we understand more about those processes.

GPR Basics

Ground-penetrating radar data are generated by sending pulses of radar energy into the ground from a surface antenna at a specific time interval (Conyers 2013; Conyers and Goodman 1997). The energy reflected off of buried objects, features, or strata is measured as the waves return to a receiving antenna, often as it is moved along a transect, collecting reflection traces at intervals tallied with a calibrated survey wheel. The data are sampled and processed by a computer designed for this purpose, attached by cable 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 2013). The larger the contrast in electromagnetic properties (measured as relative dielectric permittivity or RDP) between two materials at an interface, the stronger the reflected signal. This determines the amplitude of the radar wave at a specific depth. Radar variation depends on sediment mineralogy, ground moisture, survey depth (radar time window), and site topography. Electrically conductive or highly magnetic materials including salt and some clays will attenuate the radar energy, resulting in little or no reflection in profile and less depth of data profiles. Dry sediments are generally more reflective than saturated sediments, resulting in deeper penetration and more detailed reflections when traces are combined to form a transect profile.

The GPR data we present were recorded using a Geophysical Survey Systems SIR-3000 instrument with either a 200-, 400-, or 900-MHz sending/receiving antenna array. Data were processed using open-source software for both profile viewing (GPR Viewer) and amplitude slice map generation using GPR Process, which was derived from MRI software (Conyers and Lucius 1996), gridded and plotted in Surfer 7.0. Amplitude slice maps are generated from multiple adjacent transects collected in a grid at fixed intervals. These maps represent varying depths or segments of the time window for radar travel.

Analysis of transect profiles is central to archaeological interpretation of GPR data. Often, a GPR transect profile will show a combination of point reflections and planar reflections. A point reflection occurs at a specific locus or point source, appearing in the profile as a hyperbola because the reflection is initially received from farther away as the antennae approaches the point source (Fig. 3). While over the locus, this distance is shortest, and it extends as the antenna moves past the locus. Planar reflections are more continuous, though these too may have partial hyperbolae at edges. Planar reflections may undulate, and they often show breaks or split into multiple planar reflections. Some of the variations in point and planar reflections are discussed elsewhere in this paper.

There are several steps to processing radar data for interpretation. For an individual transect profile, signal gains may be adjusted to compensate for diminishing signal return with depth. Continuous, horizontal background waves may be uniformly removed, though care must be taken to avoid removal of horizontal patterns that are not due to ambient radar energy. Filtering of high- and low-frequency radar energy may be adjusted. Determining depth through assessment of RDP value and hyperbola fitting may be useful, though RDP in one part of a site may be different from another, particularly when stratum constituents vary across the site. Migration may be used to visually reduce a hyperbola to its point source, but we have not used this step in the data presented here. In this paper, an approximate depth scale appears at the left axis of GPR transect profile images. Often, radar return time in nanoseconds is displayed on this axis instead of depth. Trace numbering can be shown instead of depth on the bottom axis, and sample number is often shown on the right axis of a transect profile.

Amplitude slice map variables include the depth range represented by the slice and interpolation of the data in both the X and Y directions within the gridded transects. Depending on the colors assigned to a portion of the gain-adjusted amplitude range (color scale), linear form, planar features, and concentrations of high- or low-amplitude reflection loci may be discerned in these maps. As with transect profiles, there is no "correct" output slice map for a given grid at a specified depth. Rather, these image

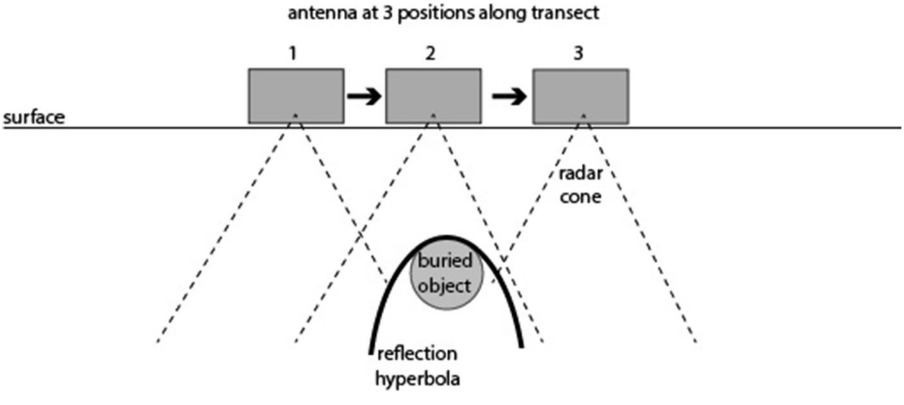

Fig. 3 As the GPR antenna array moves across the surface, the cone of radar energy emitted and received encounters a buried object at longer (*1*), shorter (*2*), and again longer (*3*) distances, as measured in nanoseconds. Therefore, the reflection image as processed from averaged wave traces in a transect profile appears as a hyperbola. Point reflection hyperbolae vary in size and shape depending on the depth of the object, its size, and the relative dielectric permittivity (RDP) of the sedimentary matrix. The survey wheel distance encoder is not shown in this diagram, but this is normally used to control radar trace frequency and spacing as data are recorded by the instrument

outputs are normally adjusted as the archaeologist relates individual transect profiles to patterns in the interpolated slice map data.

Language and Description in Encounters with Subsurface Phenomena

We advocate practical approaches to interpreting geophysical data, whether portrayed in profile diagrams, slice maps in plan, or three-dimensional diagrams. Each of these renderings of scanned data may resemble excavation exposures. Yet, a GPR transect profile compiled from scans may show different characteristics of the deposit in comparison with an excavation trench profile along the same transect. The GPR profile may depict less visually apparent or even invisible microstrata where these layers hold differing amounts of moisture or subtle bedding changes (Fig. 4). In comparison, the excavation profile may show color and sediment changes that are often informative but may be interpreted more meaningfully in light of the GPR scan patterns.

Archaeologists recognize that visual exposure of strata and features are not the sole means of examining site structure. Though weathering and wind sometimes show more of the varying textures once an interplay of layers has been exposed (*e.g.*, stone foundations in a sandy surface; an exposed cutbank weathered by wind), and the sound of a trowel tap or the push of a metal probe can indicate composition, for the most part, archaeologists have traditionally relied on visual inspection of in situ features and strata. Yet, compositional analysis has been primarily limited to exhumed samples and surface or trench wall exposures.

Limitations in interpreting scan results may be one reason that incorporation of scans of buried deposits still holds lower priority than site excavation, despite the vast potential offered by techniques such as GPR. Based on scans alone, we are able to examine reflective patterns relating to the properties of different materials in the site that make up the artifacts and sediments of the site's interior. One way to describe these

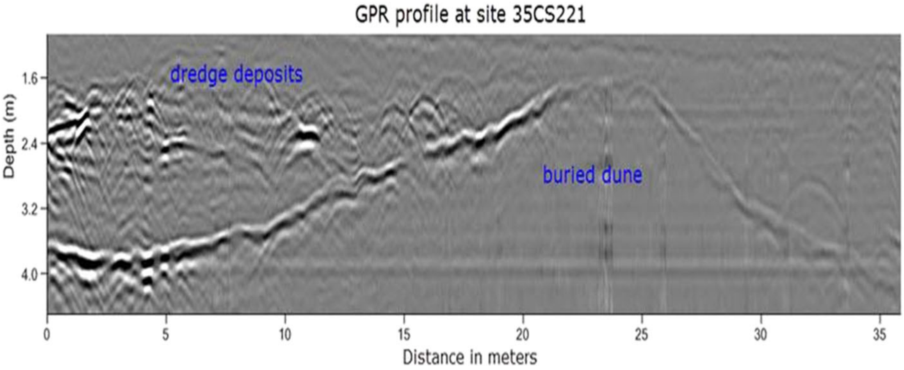

Fig. 4 GPR transect profile at coastal site showing two distinct horizons, one mound-shaped, capped by another with large inclusions. Both are largely sand. Excavation determined these to be dredged sand and wood fragments covering a buried sand dune. Generated with a 400-mHz medium frequency antenna; the dry sand allows unusually deep GPR readings (over 4 m). The surface of the buried dune includes a thin organic soil on its western face (left slope) that appears as an inclined planar lamina. The top of the dune has been truncated, and eastern (right) slope may be an erosional slip face, lacking the thin soil development which would produce a more pronounced laminar reflection. Depth is displayed at the left and has been confirmed through excavation (Byram 2014)

patterns is by iterating ways the scan patterns represent the internal texture and form of site deposits.

It is productive to discuss variation in a site's internal texture and form as suggested by patterns in radar reflections independent of, or prior to, interpretations about feature/artifact types or non-cultural sources of patterns in the scanned data. This is a critical concept in that textural variability must first be comprehended, including the shape and position of internal site constituents, before we can consider how the represented internal composition may include artifacts, features, strata, and non-cultural phenomena such as rodent burrowing and root growth. This variability is often implicitly considered in any interpretation of geophysical data, but there is a gaping need to clarify the framework on which our archaeological suppositions are based.

Working with such descriptive variables makes some accord with the gradient of knowing and claiming from which our discipline generates so much angst. Several ontological attitudes which pivot on preconceived mental templates are recognized among our social science colleagues (Pickering 1995), some of which archaeologists might recognize as our own traditions of encounter with site texture and form. We bring these mental templates to our measurements, along with sometimes dualist and detached underpinnings of meaning which deny us further emergences of understanding. Rather, encouraging linkage building between the invisible forms and textures that GPR returns evidence of and the ways we normally perceive them could result in more nuanced ways of dealing with the ongoing challenges we face with geophysical tools and their field applications. Through such frictions, we might extend and grade Pickering's (2008, p. 2) themes of knowing statically or dynamically into multiple interpretive repertoires for subsurface phenomena. We have an opportunity for discovery along not only radar's reflective planes but also what might be explored through other forms of subsurface investigation.

Another way to describe this aspect of archaeology is *interiography*, a term we propose for the characterization of internal site variability largely independent of visual exposure or excavation in the immediate area. Interiography is the process of assessing site interior variability from GPR scans or other subsurface scanning, along with other information from context such as local geological sequences or nearby stratigraphic or surface exposures (emergence). The term interiography has been used informally by interior design professionals and critics (Kernaghan 2009; Sherwood 1921) and more rarely in phenomenology (Clinger 2013), but no standard definition is available. These uses emphasize the documentation or in some cases the creative representation of interior spaces. Our use of interiography encompasses the many approaches to analysis of buried site stratigraphy, feature, and artifact distribution and composition, with an emphasis on techniques that do not disrupt the repose and interrelationship of site materials. The scope of interiography becomes more clear in light of the importance of texture and form when considered variables in site interiographic analysis.

The first steps in interpretation of GPR scans are to assess the texture and form of the focal site interior based on patterns in radar reflections. These may be displayed in transect profiles (Fig. 4), in amplitude slice map stacks (Fig. 5), or isolated in 3-D renderings of selected data. The second step is to consider variability in site composition that may be indicated by these patterns in site interior texture and form.

Refinement of archaeological GPR data interpretation is a process, beginning with texture assessment and followed by archaeological interpretation of this variability. The

Fig. 5 Cobble wall scanned with 200 mHz antenna appears clearly in amplitude slice map, but individual cobbles are not evident due to the low frequency of the antenna and the depth of the feature (1.5 m). Higher-frequency antennae were not suitable at this site due to the depth of the features in the deposit. Machado y Smith Adobe, Old Town San Diego State Park

benefits of this approach are numerous. By assessing site interior texture and the form of reflected site constituents rather than initially making interpretations of artifacts, features, and stratigraphy from geophysical scans, the GPR approach is more clearly explained and the potential for understanding interiographies otherwise invisible is amplified. If data about scanned site areas are also revealed by excavation, interpretations of textural patterning can be refined from multiple perspectives, both through manual encounters and with more nuanced expectations for interfaces. In some cases, the presence of rectilinear forms or other regularity of patterning may be identifiable as cultural phenomena using scans alone. But when exposures are present, such as excavation unit walls, strata can be traced, and features and artifact clusters delineated as we gather newer information about reflectivity parameters. In many cases, without other confirming observation, interiographic patterns may be our only information. Further, as in all forms of archaeological data, interpretations may be limited to how carefully we can register the various forms of information returned by the technique.

Texture in Archaeology and Geophysics

Textural perception of site composition can involve tactile, visual, chemical, or other types of direct sensing through excavation and direct sampling. Thanks to electromagnetic wave measuring instruments, our ability to access textural variability also encompasses sensing or recording through indirect means. This extends to aspects of immediately accessible data from a site and to those otherwise inaccessible, blurring the lines between our older traditions and newer techniques for contributions to understanding site structure. For example, laser scans record surfaces much like tactile or directly visible sensing and LiDAR does the same but can adjust for different kinds of vegetative cover and at greater distances. Both magnetometry and GPR provide images of subsurface interiors; magnetometry's output is two dimensional across a site, while GPR images are three dimensional, controlling for time of signal travel indicating depth in the deposit. Because it is the transitions between buried objects (*i.e.*, their buried surfaces) that are most clearly recorded in radar wave patterns (Conyers 2006:140), GPR scans provide information about the contours of the buried surfaces that are reflected. In this sense, texture can include aspects of the shape and distribution of large objects in an otherwise homogenous matrix—*e.g.*, the roughness of a buried paleosol surface or the distribution of distinct objects throughout a profile.

The use of texture as a variable in site compositional studies is not new. For example, in geology, internal compositional variation incorporates texture. Rock textures, like those of ceramic materials, consist of not only interstitial geometries and various angularities of inclusions but also homogeneities and/or diversity of matrix (Orton *et al.* 1993; Rice 1987). Just as geologists and ceramicists use petrography and geophysical scanning to look at the texture of their material constituent formations, archaeologists observe and measure the texture of artifacts and sediments in a site, their geometric aspects, and relationships among constituents or components.

We can consider how this approach is similar to magnetic resonance imaging (MRI) scans in medical science, which examine internal physiological structures that may be characterized in terms of their texture and form. MRI tomography and image processing software has served as the basis for GPR slice map development (Fig. 5), and the techniques have much in common. Tomography most often focuses on reconstructing three-dimensional interiors of the anatomical regions from image slices. In addition, those images are to be interpreted with respect to comparative structures (plant, bone, tissue) in heavy reliance upon uniformitarian principles of anatomy. Although this is part of what GPR and other instruments, such as electrical resistivity tomography, take advantage of, such imaging does not encompass the entire approach to instrument scanning of site interiors nor do we have ready comparatives or known targets in most cases. Therefore, it is appropriate to use a broader term like interiography for the more expansive assessment of site composition based on GPR reflections, resistivity patterns, or other instrument scanning data. There is much work to do, some of it iterative, before any team can make conclusions about the composition of features and strata revealed through subsurface instrument scanning. Interiography also encompasses the process of assessing buried portions of features and strata from partial exposures, with or without instrument scanning.

Archaeology differs from physiology and many other fields in the degree to which scanned phenomena are often unpredictable. A medical professional examining MRI scans relies on uniformitarian principles of human anatomy to comparatively understand what internal physiological structures are represented in an image. In comparison, archaeologists rely upon uniformitarian principles of reflectivity throughout the sequence of signal return operations. However, the archaeologist may or may not have an idea of the types of artifacts and features likely to be present in buried portions of a site. Hence, there is a need for terminology that characterizes shape, consistency, and nature of GPR signal reflections without relying on initial interpretations about the features and dispersed constituents these textural patterns may represent.

Emergent Texture and Imbedded Texture

Whether buried by sediments, cloaked by vegetation, or submerged in water, archaeological site surfaces can be scanned with instruments that record topographic data in great detail. Some surface scanning techniques rely on storing optical detail much like visual perception, such as photogrammetry. Others may rely on concentrated light or lasers, or sound wave data, such as side-scan sonar used in the water column. For both laser and side-scan sonar, it is the site surface or *emergent texture* of the site that is scanned with instruments, rather than only visual properties being recorded, though there may be similarities. These scanning techniques render composition and conformity of objects and strata in media other than direct visual perception, as well as render textural variability in ways we can examine to assess site makeup.

In contrast to purely surface observation techniques (visual and instrument-based), techniques such as magnetometry, electromagnetic induction (conductivity and magnetic susceptibility), electrical resistivity, and in particular, GPR examine *imbedded texture***.** For GPR, this includes variation in interior site surfaces or interfaces that portrays both the composition and conformity of objects and strata. There is a long tradition of textural analysis of archaeological objects, from molecular composition to morphology to petrography (Orton *et al.* 1993; Rice 1987). As noted, to some degree, we use excavation profiles to investigate texture at the margins of intact deposits, yet most archaeological material remains imbedded well beyond visual exposures and exhumed samples. This is the realm of interiography, the focus of GPR and other imbedded texture scanning techniques. The methodological distinction between direct and indirect site observation is diagramed in Fig. 6.

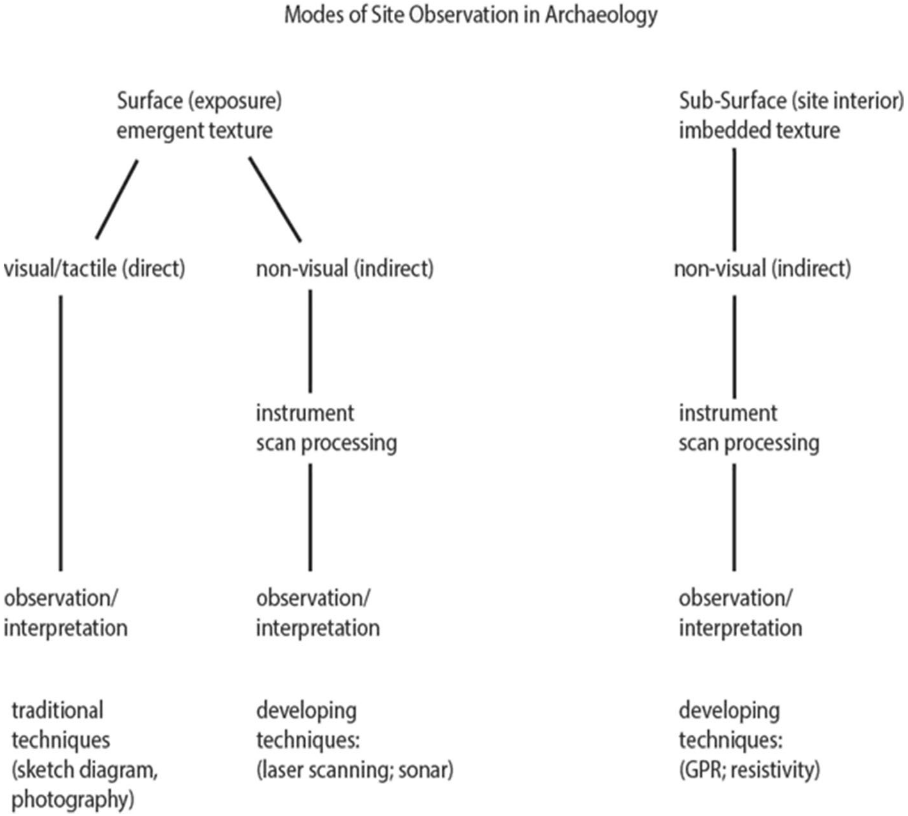

Fig. 6 Diagram of direct and indirect observation of archaeological phenomena, at earth surface in the atmosphere or water column, and in subsurface

Developing a lexicon of instrument-recorded subsurface textural variability allows us to discuss returned signal data without imposing the language of visual perception on nonvisual subsurface site texture. When emergent texture (*e.g.*, site surface features, topography) is recorded by lasers or infrared photos, resulting scans may be more recognizable or interpreted in ways comparable with direct visual perception. In contrast, subsurface GPR scans present a less-intuitive set of reflection patterns, not an obvious map of a feature such as a stone wall or buried aqueduct. Even with real-time profile imaging, the texture represented may or may not be interpreted as a particular type of feature because these renderings (Fig. 7) are even more distinct from direct observation than surface LiDAR or photogrammetry.

Interiography and Imbedded Site Texture

Composition and conformation are the most basic elements of interiographic site analysis. Composition is the material of an object or deposit, including its physical makeup and form (*e.g.*, limestone slab, obsidian biface, basalt mortar, adobe melt lens). Conformation, related to conformity in geology, is the interrelationship between the deposits that make up the site matrix, including sediments, feature fill, artifact accumulations, *etc.* Conformation and stratigraphy are closely related. Typically, the specific composition of an object is unclear from a GPR scan, but variability in composition (*e.g.*, sediment structure, moisture content) is what produces variation in scanned data as the differential return of radar signals because of variations in electromagnetic properties recorded by the instrument.

Radar scans show reflection magnitude variation indicative of electromagnetic properties (RDP) at buried interfaces (Conyers 2012, pp. 25–27). Moisture content is often a strong factor in RDP variation, and this varies between sediments and archaeological objects. Stratigraphic layering is often the most recognizable observation to be made from a set of GPR transects (Figs. 2 and 8). In some cases, subtle layers that are not easily observed during excavation are far more readily discernible in a GPR profile. In Fig. 8, a GPR profile of a shell mound is shown, recorded shortly before excavation. The inclined planar reflections in the GPR profile show more laminated strata than were visible after excavation, most likely because the soft, organic sediments were not visually distinct as the edges of digging tools merged these interfaces during unit-level excavation.

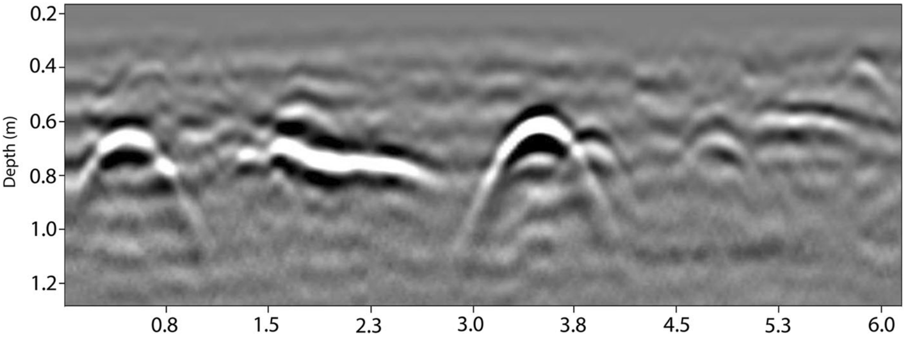

Fig. 7 At 60–80 cm depth, both spheroid and tabular structures are indicated in this GPR scan profile, an amalgam of hundreds of individual trace scans collected along a 6-m transect, Faculty Club lawn, UC Berkeley, CA

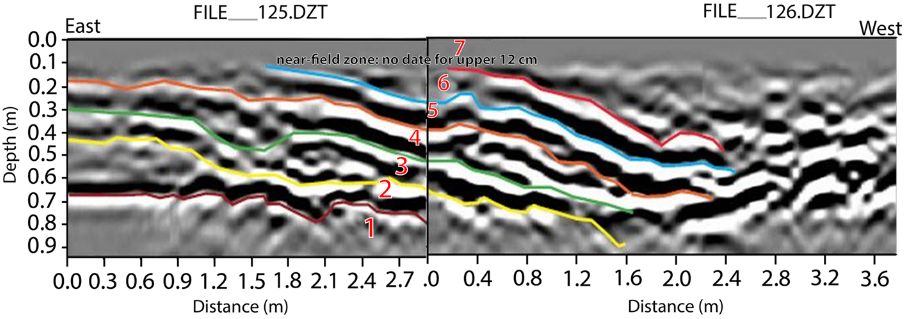

Fig. 8 Grayscale GPR scan profile of a shell mound; seven distinct strata are outlined in multiple colors in the combined scan set along adjacent transects (Byram 2015; DeGeorgey 2015)

In addition to stratigraphy, the size and shape of individual buried objects can often be inferred from GPR scans. In some cases, the composition that produced a given reflection locus is indicated, such as buried metal or void spaces in a deposit (Conyers 2006:136). The distinctive "multiple" reflection of metal or other highly reflective material is often evident. Reversed polarity in the wave trace at an interface may demonstrate that a void is present, such as a tunnel or sinkhole. As the positions of buried objects are plotted (manually from multiple profiles or in amplitude slice maps), feature form may become clear, as part of overall site structure. Before inferences about object size, feature composition and type can be made from a given scan or radar profile the data should first be described in terms of texture and its form, including size, shape, orientation, and distribution of distinct reflections.

Spatial analysis, feature studies (*e.g.*, architectural), site formation, and stratigraphic sequencing can each follow from thorough GPR characterization of a site. Emergent texture (*e.g.*, strata in trench walls, surface exposures of features) can be traced into the buried site interior. As scanning moves away from excavation areas and the information about stratigraphy or features becomes more reliant on scans and less on visual exposures, the variability is increasingly characterized in terms of texture and form in radar reflections.

Radar Profiles as Texture Scans: Terminology of GPR

Geophysicists have developed techniques and terminology for the portrayal of both surface topography (Bohnenstiehl *et al.* 2012) and deep subsurface structure (Nedimovic *et al.* 2009). Yet, the integration of this terminology with archaeological interiography is nascent and in need of more rigor. For the archaeologist, foci include artifact, feature, and stratum composition and conformation, and the variable for assessing this in scanned data is texture. In this context, texture is the shape, size, and position of the electromagnetic reflection properties that are initially characterized in the language of geophysics.

Examples of geophysical GPR terminology may include dense/diffuse, lamination, planar/point, clustering/aligned descriptors for signal reflections recorded by the instrument. However, a cluster of point reflections is not readily identified as a "cobble feature" and even less so a "cobble-lined hearth." The texture of a cluster of point reflections is their size, shape, and relative position. Thus, a set of four alignments of arced and acute point reflections on a planar surface, roughly a meter in width and 4 m long, positioned at right angles may be identified as having the form of a rectangular structure such as an adobe dwelling foundation (Fig. 9). Specifically, the texture indicates a 4 × 4-m rectilinear feature composed of objects sized at the resolution minimum of a particular antenna array, located at a horizon a specific number of nanoseconds of radar travel through the substrate. These are uniformitarian principles of reflectivity with which, as technical sophistication increases, will increasingly enable identification of more subtle features through scans of site interiors and comparative collections of similar reflections with which to base those tentative identifications. That said, even now there are many larger types of features that may be identified through interpretations of GPR data independent of excavation. Some geomorphic units, such as buried dunes and paleochannels are also recognizable with a high degree of confidence without excavation.

The relationship of an identified feature to nearby surface structures, its chronology and composition are all questions that may require additional investigation, but the likelihood of the presence of a structural feature can sometimes be assessed based on GPR data alone. This can then be related to other information such as former investigation maps, historic documents, aerial photographs, and depictions of the site (*e.g.*, Fig. 5). The conclusion can be made that site interiography using GPR and contextual information indicates that the foundation of a building may be present in the scanned portion of the site. The authors' contributions to a team (Byram *et al.* 2017), relating multiple lines of evidence to our GPR findings at a mission adobe site present but one example of this approach.

Stratigraphy is often indicated by the texture assessed from radar scans. The term stratum is useful during interpretation but usually not in the initial assessment of a radar profile. Textural assessment of scans may indicate the presence of a continuous lamina (planar reflection) at a given depth or at an incline. The term horizon is sometimes used to refer to a portion of the profile vertically bracketed by planar reflections above and below (Conyers 2012). A horizon may also be defined as a homogenous or heterogeneous layer that is relatively continuous across a profile (Fig. 8). Equating a horizon identified this way with a stratum usually requires other information about the stratum such as exposure by excavation or erosion.

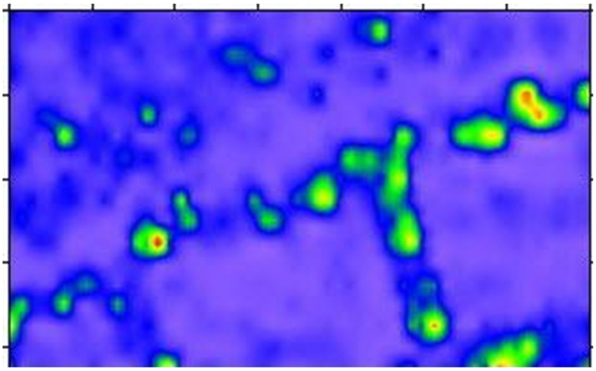

Fig. 9 Amplitude slice map of scans from eight parallel GPR transects, 7 m long, spaced 50 cm apart. The high amplitude green reflections in this map indicate a feature with a texture and form consistent with a building foundation. Previous excavations and historical records indicate these are sandstone blocks and corridor posts associated with former mission adobe buildings (Byram *et al.* 2017)

Assessing embedded textural variability in GPR data stands in contrast to what Conyers (2006, p. 134) has critiqued as “anomaly hunting” and by extension, a too widespread use of the term “anomaly” in GPR scan interpretations. Often, it seems that the term anomaly is used to denote a distinctive radar reflection set the researcher is paying attention to. While this may suffice in some circumstances, this is not an effective language for comprehensive archaeological analysis of site interiors. Some GPR specialists emphasize targets, particularly in utility assessment. This approach is very different from the archaeological interest in discovering the range of variability in a deposit.

In assessing GPR data, it is also critical to consider sources of scanned data variability not related to subsurface phenomena. GPR profile and slice map output will include disruptions due to data collection (uneven surfaces, unstable antenna deployment), air-wave reflections from walls or other objects on the site surface, and interference from other energy sources such as communication equipment or power transmission. Filtering out these non-textural sources of data is critical to interpretation of composition and conformation.

The texture of site deposits as indicated by radar point reflections is described in terms of constituents (objects, moisture pockets, voids, cavities) while more continuous planar radar reflections might be understood as layers or transitions between layers. These buried phenomena are indicated by the characteristics of the GPR reflections generated by the instrument scans, and they range from small nodes to expansive horizon boundaries. Each can be discerned through examination of both transect profiles and amplitude slice maps, and both of these renderings are normally needed for comprehensive analysis. Three-dimensional renderings of scanned data can also be useful for analysis of site interiography, though the opacity of a selected isomorphic rendering may cloak important variability. Despite these caveats, three-dimensional renderings can be valuable for public interpretation and other untrained eyes for whom the image might draw attention to visualized differences in signal returns (Sturm and Crown 2015).

Textural description includes assessment of the relative size of constituent objects reflecting differentially from surrounding matrices, stratigraphic position, and the interfaces of buried strata. Textural variability is often indicative of buried objects, cultural or other depositional features, and buried surfaces. This is because internal site texture consists of interfaces between materials of varying composition and electromagnetic properties (RDP values), including moisture retention and other properties of sediments and inclusions. The following categories are useful descriptors for analysis of GPR scan data at the point where texture is being assessed for its information about site composition. Table 1 introduces some of the textural language that might describe

Table 1 Terms for variability in GPR transect profiles (excludes interference, errors)

Size	Geophysical	Textural element	Possible Interpretations
Small	Narrow/acute Point reflection hyperbola	Nodular inclusion	Cobbles, artifacts, bioturbation
Medium	Wide/obtuse Point reflection hyperbola	Block or spheroid	Boulder, slab, segment of weathered floor, concrete footing
Wide	Small planar Reflection	Tabular/lamina	Stone pavement, tile floor, lenses of clay, shell or gravel; oxidized area
Expansive	Layer	Horizon break	Stratum, stratigraphic transition

subsurface reflections. Terms suitable for archaeological interpretation are described below.

Nodular/Nodal and Spheroid Inclusions

While antenna frequency is a factor in hyberbola size and object recognition, at medium frequency (600–300 MHz), nodular inclusions appear as point reflections with acute hyperbolas (Fig. 10). Point reflections that are more broad and expansive indicate phenomena that are spheroid or block-shaped or elongated but roughly parallel to transect direction. Point reflections are the most common type of reflection in many GPR profiles. They have a wide range of origins, some cultural but many related to biotic activity or site geology. Linear animal burrows, buried logs, or elongate artifacts often intersect with a transect as point reflections, as do the filled cavities of decomposed roots. In some cases, sediment replacement results in a material or moisture change (interface) that produces the point reflection. Thus, the term "object" may not always be appropriate for these smaller loci of reflection; voids and areas of high-moisture pooling may not be objects. We prefer to use the term "node" for smaller point reflections, and spheroid or block for broader reflections that are not wide enough in the context of site scale and instrument resolution to be termed tabular. Inclusion as used here is borrowed from geology, where mineral inclusions may be mineral or organic, solid liquid (moisture pocket), or gas (void space).

Often, a layer of bioturbation is indicated by numerous nodular phenomena at a given depth (Fig. 11), creating a porous stratum that may or may not be indicated on the surface by burrowing or exposed roots.

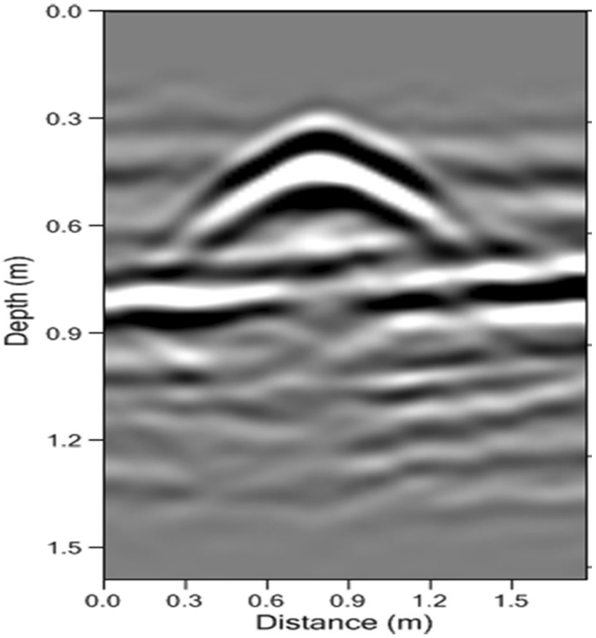

Fig. 10 Portion of transect profile in sand dune deposit showing an acute point reflection where the antennae crossed a horizontal iron rod from a salvaged Gold Rush era shipwreck

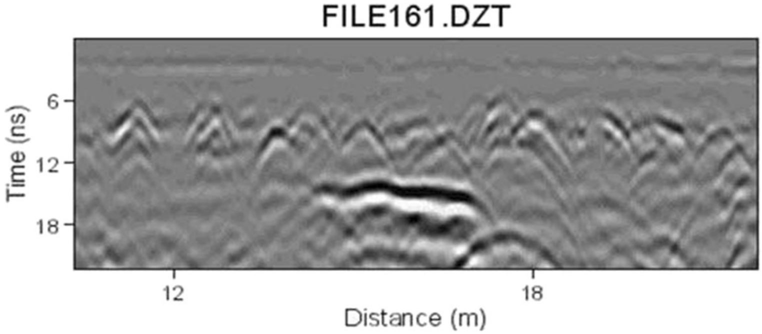

Fig. 11 Tseriadun (house pit clay floor) planar reflection at depth beneath a horizon of nodular clustering from rodent burrows

Spheroids are arc shaped in profile and round or subrounded in plan; blocks are more angular in profile and plan. Large spheroids (Fig. 12) may be boulders or the tops of dome-shaped earthen features such as mounds or embankments. Large spheroids can appear as wavy horizon boundaries, but they are often evident where they cross horizontal planar reflections (Fig. 16). A deposit containing large spheroids has one of the more distinctive textures identifiable through GPR survey. Due to the limited range of specific GPR antennae, it may be only the upper portion of a large spheroid that is recognizable in a transect profile.

Descriptive textural categories are not discrete, and categorization depends on the scale of the site or the range and precision of the instrument being used. For example, a laminar convexity resembling a mound crest in a high-frequency (900 MHz) scan may be recognized as the top of a spheroid more like a large boulder in a medium- or low-frequency (400–200 MHz) GPR scan.

Elongate, Tubular, and Linear

Individual GPR profiles are often insufficient for distinguishing narrow, linear-shaped phenomena. In two dimensions, the radar reflection difference between a linear object (*e.g.*, buried log, PVC pipe) and a planar or tabular feature (*e.g.*, buried surface, house floor) may not be evident from single transect scan set. But when multiple transects are

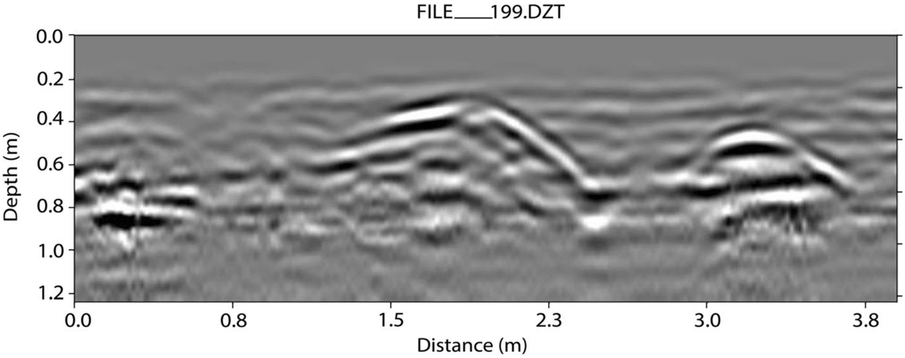

Fig. 12 Wo Feature, Pa Site, Oahu, Hawaii (Byram and Gill 2016)

combined in a grid and processed through interpolation, elongate phenomena may be discerned. With standard amplitude slice maps, elongate structures that are inclined within a deposit may be difficult to identify, as their reflections cross both slices and profiles. If a set of collapsed stone columns is present in a site at varying depths, one approach to studying these may be to use multiple transect/grid orientations and/or antennae of different frequencies (Fig. 13) over the same area, each rotated a fixed amount so that the narrow, inclined objects can each be shown in profile. While roots and rodent burrows are some of the most common elongate phenomena, it is rarely necessary to trace these individually. More often, these elongates represent a disruptive noise that ideally can be distinguished from cultural deposit variability.

Concavities and Convexities

Concavities and convexities are areas of pronounced curvature in otherwise planar features or horizon breaks (*i.e.*, pronounced, non-hyperbolic wave). An undulating horizon break in profile may be interpreted as a series of pits or parallel ridges when perpendicular, overlapping transects are collected. In a grid, undulations may be shown to be an uneven texture at a horizon break with no parallel divisions, a scenario more likely of cultural origin or produced by root mounding, windfall, or other processes. A concavity holding a cluster of nodes or small spheroids associated with an otherwise smooth, level horizon break may be a rock-lined hearth, but we cannot label it as such in a report without excavation data or other support for this interpretation. Instead, we characterize the texture and form of the buried feature and discuss possible interpretations of the focal scanned area in the report.

Blocky, Segmented, Semi-planar, and Tabular

While planar horizon breaks are often quite distinctive, segmented planar breaks or tabular phenomena may sometimes indicate a buried surface that is porous and heavily bioturbated (Fig. 14) or otherwise decomposed. In other instances, blocky texture is just that, explained by the presence of buried blocks, such as the large subrounded cobbles in Fig. 15. Tabular phenomena on a plane or incline may appear as a set of nodes (point

Fig. 13 The authors simultaneously scanning with 400 and 900 mHz antennae, Mission Santa Clara, CA

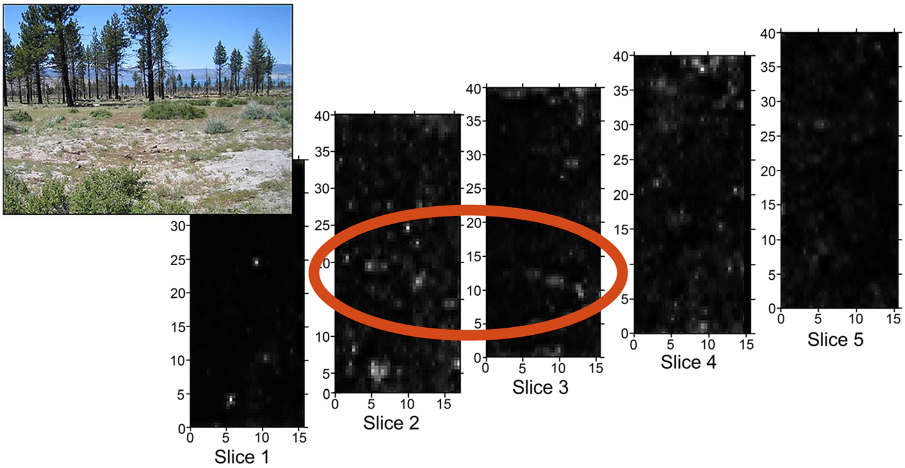

Fig. 14 Plan view slices at multiple depths showing light wooden architecture and extramural activity areas, both obscured by bioturbation at or near level of earthen floors at Mono Mills Townsite, CA

source reflections), or they may merge as a single planar reflection, depending on their spacing and the frequency of the antenna used.

Spatial Groupings

While individual objective phenomena such as spheroids or lamina can be described in terms of their size, position, orientation, and such, frequently, we are concerned with the spatial groupings of multiple nodes, lamina, *etc.* and spatial context. These groupings include sets of reflections indicative of features and bracketed layers within a deposit that may represent a stratigraphic unit. Here too, simplicity should prevail in the interim data description phase of site interiography. Thus, the terms cluster and

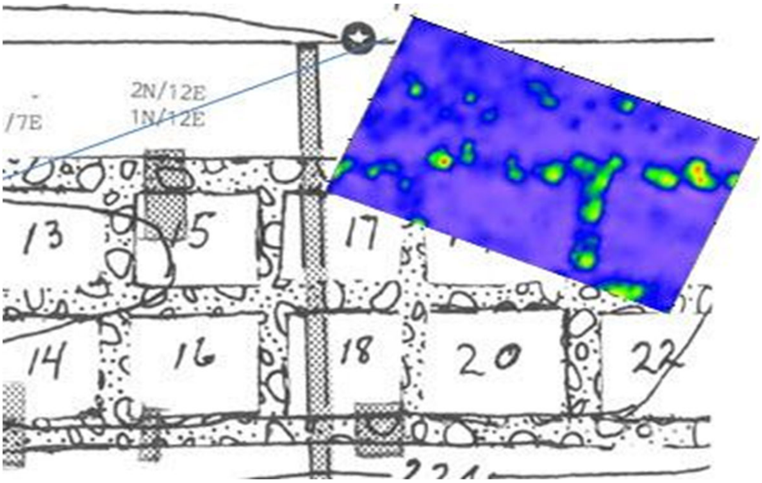

Fig. 15 San Juan Bautista Taix Lot where GPR confirms hypothesized portions of sandstone blocks of mission adobe based on previous limited excavation (Farris 2015)

concentration are useful for higher-density groupings of nodes, spheroids, or blocks. In amplitude slice maps (plan view), a block or spheroid concentration that is linear can be termed an alignment. A tabular area of blocks and spheroids (such as a weathered and fragmented earthen floor feature) may be termed a bed during the textural description phase. Horizon breaks are one of the most common patterns in GPR profile data. They may be less evident in slice maps, particularly if they are sloped (see Fig. 16 Mono Mills horizons).

Vertically sorted clusters of nodules and elongates appearing across large areas within a horizon and that appear in both profile and plan maps may be termed a mosaic. A mosaic may be produced in a bioturbation layer of dendritic root paths and rodent burrows. Artifact concentrations may also be identified as a mosaic. There is overlap between mosaics and beds, but generally, there is a planar element to a bed, which forms a buried surface of limited area, while the nodes and elongates in a mosaic are dispersed enough that they do not clearly represent a buried surface. A mosaic is generally not associated with a horizon break or other discrete lamina aside from the ground surface, and a bed may consist of larger objects than the nodes and elongates that make up a mosaic. If bioturbation is the source of a mosaic, then it is created by intrusion into a deposit. Bioturbation can also create a bed, as in the case of the artificial "Millingstone Horizon" in coastal California sites (see also Fig. 11). In such a bed, a layer of large groundstone artifacts occurs where an extensive rodent disturbance has lowered larger objects within the deposit (Bocek 1986).

Planar reflections appear in profile as continuous horizontal or inclined scan patterns. In plan, they may be less evident, particularly if inclined, and may appear as linear features in amplitude slice maps at the location where the surface-parallel slice plane intersects the inclined, buried lamina. Lamina vary at archaeological sites in terms of their thickness, orientation, area, smoothness, as well as their inclusions and associations. As data are gleaned from multiple transects, continuous lamina may be found to vertically bracket a portion of site deposits (the site surface often representing one horizontal boundary). In some cases, such less discernible phenomena are the exact loci we are looking to describe for their less-sharp distinctions, for example, clay and sand house floors contained in large and dense coastal middens (Arnold *et al.* 1997). These bracketed layers of varying thickness are horizons or sometimes inferred to be previously identified strata. Following Conyers (2012), we prefer to use the term horizon during GPR scan analysis, reserving the

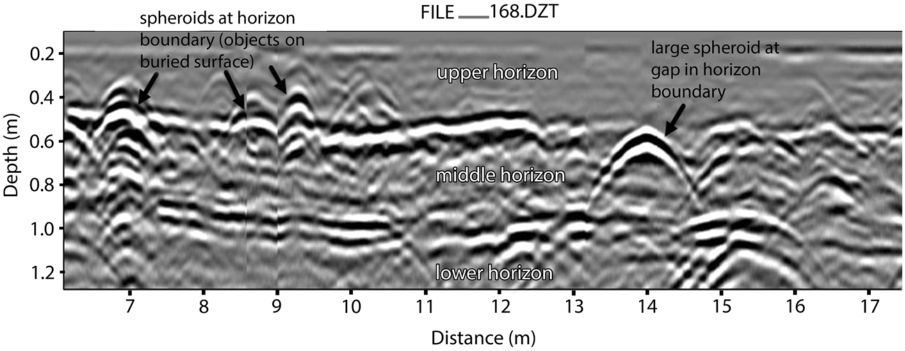

Fig. 16 Signal returns from deposits adjacent to and deeper than Chinese workers' cabin foundation stones in which filled barrel was recovered at Mono Mills Townsite, CA

term stratum for assessment based on exposures. Known strata can, however, be traced across a site from the point of excavation walls or erosional exposures with GPR transects. In some deposits such as shell mounds, high-density lamina may be stacked tightly with few evident inclusions (Fig. 10), while in others the horizons may be deep, containing large features (Fig. 16). Large spheroids or blocks may cross horizons, indicating that a horizon was formed while the larger object was present (*e.g.*, a standing boulder) or that the latter was placed in a pit at a later time.

Radar scans sometimes reveal deposits that are very heterogeneous due to sediment fracture from moisture change, other matrix structure formation, and rock decomposition. These deposits are often the most challenging for examining GPR data for cultural features. In some of these cases though, large cultural phenomena may be sufficiently homogenous to appear distinct from the surrounding matrix. Textural variation that may indicate these broad patterns in a deposit includes smooth vs. noisy and continuous vs. segmented. We also use the terms erratic, noisy, rough, and speckled to characterize heterogeneous texture of deposits that appear post-depositionally disrupted. In some cases, an abundance of nodes may make up a homogenous stratum, as with dense gravel or pebble layers. Point reflections the size of gravel or pebbles will be more clearly indicated in profiles from a high-frequency antenna (900 mHz or more) sufficient for revealing small locus reflections this size. In higher-frequency GPR data, a layer of sand above a gravel stratum appears as an upper homogenous, smooth horizon overlying a horizon consisting entirely of overlapping small nodal reflections.

An example of describing a site's interiography based on GPR data without using terminology more appropriate to visual observation or the tracing of known features might appear as follows:

> "At least two horizons are present, separated by a continuous inclined break ascending westward. The upper horizon exhibits signal returns which are relatively homogenous, with scattered nodular inclusions.[1] The lower stratum reflects more variably, with clusters of large spheroids (20–40 cm in size, depending on antenna resolution) as well as elongate forms and numerous smaller nodes. One apparent discontinuous tabular bed of large blocks and smaller nodes may be a single lamina[2] that is partially decomposed. The heterogeneous lower horizon appears to hold a mix of spheroids, blocks, and interrupted lamina and may be a high-density stratum, but at this time, its origin as cultural has not been established. The base of the horizon is indicated by a continuous, level surface with two pronounced concavities,[3] one containing spheroid objects."

As instrument capability and processing techniques improve, the range of variation in textural description will likely expand the need for refined and standard terminology. Even now, there is likely to be considerable variability in the terms used to describe texture at sites with very different composition. Yet whatever the array of descriptors the archaeologist uses in assessing data from geophysical scans, the discipline will

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[1] Possibly rocks, roots, or krotovina

[2] For example, slab, tile floor or a pavement

[3] Possible pit features

benefit from efforts to characterize these data in detail and with consistency prior to and during the assessment of cultural features and strata.

Conclusion

Ultimately, replicable and quantifiable analysis of site interiography depends on accurate recovery and processing of the geophysical scanning data. Interpretation of that data as a process of evaluation of texture variables requires incorporation of shape, dimensions, relative position, and other elements of composition and conformity. When an object is scanned by radar in buried context, its texture is obviously not as defined and concrete as that of an emergent or excavated object. Because radar waves are much lower in frequency than optic waves, transitions between materials, or buried surfaces, are often not as abrupt in scans as they are when exposed visually through excavation. Yet, GPR scanning offers a powerful tool for sensing the interior of archaeological sites, particularly subtle texture shifts indicative of stratigraphic layers, and its resolution continues to increase as the technique evolves. Fully exploring and communicating the intricacy of intact site interiors requires articulating and expanding the descriptive language of texture and matrix composition beyond that of a visual perception.

Though we are not focusing on application here as much as data interpretation, this discussion informs the kind of partnerships that engaged scholars are building with descendant communities. The emergent forms of interpretation represented by shared languages of description built around our GPR use are complementary to priorities oriented to preservation of cultural resources and collaboration in the narrative building process of an archaeological partnership. Several of the sites showcased by our figures exemplify the fact that this is no mere academic exercise in renaming buried phenomena in that they come from collaborative archaeological projects. Research design and fieldwork in these projects were co-crafted with community stakeholders, but the language of our co-discovery using non-invasive methods became a powerful means of redistributing benefit and authority. Figures 14 and 16 are examples of how some of our first material perspectives on supposedly segregated barrios became mutually intelligible spaces to explore discussions about the residual traces of communities who built alliances across racial and class divides in a company town (Sunseri 2015). As the profiles emerged during a transect, the development of effective communication to share ideas about the different interfaces represented by the signal returns shifted from prognostication to sharing of stories on how deposits are formed and reformed by people and their families. As a result, crucial loci of basketry innovations related to a petition for federal recognition were understood only through discovery provided by this kind of close and adaptable communication between community and academic partners.

Developing terminology with less emphasis on initial interpretation can make the analysis process less esoteric as well as less likely that the archaeologist rather than the community partner gets to determine what is a “likely feature” of a “likely type” and, by extension, which possible features get managed and which are left out of planning. There is power in changing the dynamic of this process and ultimately that of archaeologists being the arbiters of what might be encountered via geophysical approaches. Time and again, we have realized not only cost and time savings from this approach but also in many cases, demonstrably more enthusiasm regarding the respectful engagement with community partners' mandates regarding minimal site disturbance. When compared with one community partner's perspective on shovel test pits he observed as part of other projects' methodological toolkits, we recognize that common practice may not often be aligned with witnessing of multiple small holes dug all over a sacred place.

Returning to the notion that an archaeological team might perceive GPR-rendered site structure with more nuance than that which may be observed by an excavator, we are again forced to reconsider how precisely our pre-supposed principles—in this case the uniformitarian principles of reflectivity—align with facts of a given site. As with the use of all instruments which take information unavailable to human senses and reconfigure or visualize it in ways that fit within specific orientations of human perception, scanning techniques likely have a long way to go before they can portray interiographies which outperform the information recovered through excavation (Conyers and Cameron 1998). The details of small artifacts from different angles or determination of an object's material constituency are things we can do through excavation and other laboratory analyses. Yet, already techniques such as GPR can often provide different kinds of stratigraphic detail than can be seen in some excavated exposures. Archaeology as a discipline is only recently coming around to a widespread recognition of the need to integrate these scanning techniques before or during an excavation. This is a change from previous eras of use when practitioners often dismissed the utility of geophysics for regular inclusion in research design. We argue that linking the potential for GPR's substantial interpretive power with research design lies in the ability to provide additional perspectives on evidence via site structure. More broadly, geophysical prospection has continued to interest archaeologists, as evidenced by journals like Archaeological Prospecting and has begun to more often find a place in the research agendas (Gaffney and Gater 2006; Oswin 2009; Witten 2006). Few archaeologists have done more than Lawrence Conyers (2015, 2016) to amplify archaeological site interpretive processes through integrating near-surface geophysical prospecting techniques.

For decades, we have chosen to disrupt stratigraphic subtleties in our quest for artifacts we might hold in our hand or specimens to be examined microscopically. We emphasize recovery of resilient materials that can be handled and chemical or micro-sampling of less resilient matter. Yet, there is an untold complexity in articulated strata and their constituents. In a sense, archaeology is like quantum physics; it is nearly impossible to observe a buried assemblage through excavation without altering it, often immeasurably. Sampling will always be part of archaeological analysis, but comprehensive study of the expanse of features and strata in a site need not require disruption of large portions of a deposit. As scanning techniques improve over time, our field will move more toward interiography and away from large-scale dismantling of sites, increasingly recovering resilient *ideas* of texture and form, along with archaeological objects. One day, perhaps not far from now, the repose and conformation of an archaeological object will be regarded much as the original provenience of excavated objects is regarded today. The integrity of context and conformity will be key linkages between preservation and site interpretation.

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