The Pocket Penetrometer

An Onsite Method for Discerning the Presence of Earthen House Floors and Other Trampled Surfaces

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Household archaeology is principally concerned with the study and interpretation of activities transpiring within and around residential dwellings. Pursuant to this goal, archaeologists are tasked with identifying the locations and boundaries of these dwellings in the material record. Although house-associated refuse is an important line of data in household-level investigations, the detection of house floors or living surfaces is often critical to addressing research questions centered on the organization of domestic space, interior house activities, and the diversity and elaboration of residential architecture. And yet—following abandonment, collapse, and transformation of

ABSTRACT

The identification of earthen house floors or living surfaces during archaeological field investigations can be hampered by the scale of excavation, variable fieldworker experiences, and any number of site formation processes. Furthermore, although time- and context-sensitive sampling protocols (e.g., those required of macrobotanical and microartifact data collection) rely on in-the-moment identifications of floors, strong empirical evidence for the presence of house floors often comes well after the field season has concluded. Pocket penetrometers—inexpensive instruments that measure the compaction strength of soil—can lend empirical support to decisions about sampling procedures during onsite investigations. In this study, we present findings from the analysis of 4,463 penetrometer readings recorded during the excavation of residential and non-residential architecture at Welqámex, a Stó:lō-Coast Salish settlement in southwestern British Columbia. We show how pocket penetrometer data reveal quantifiable differences in the compaction of floors and other cultural deposits. We argue that compaction measurements can provide an additional line of data (ratio scale) to affirm or challenge onsite interpretations of stratigraphy based on other tactile and observational data, particularly as such interpretations pertain to surfaces expected to have been exposed to recurrent foot traffic.

La identificación de pisos apisonados en casas o de suelos puede obstaculizarse durante las investigaciones arqueológicas por la escala de la excavación, por el grado de experiencia del trabajador en el campo y por cualesquiera de los procesos de formación del sitio. Además, aunque los protocolos de muestreo sensibles al tiempo y al contexto (por ejemplo, aquellos que se requieren en la colección de datos macro-botánicos y de micro-artefactos) dependen del momento en el que se identifiquen los pisos, mas la evidencia empírica contundente para determinar la presencia de pisos en casas, a menudo se presenta mucho tiempo después de haber concluido la temporada de campo. Los penetrómetros de bolsillo—instrumentos económicos que miden la fuerza de compactación del suelo—pueden proporcionar el soporte empírico para sustentar los procedimientos de muestreo durtante las investigaciones en el campo. En este estudio, presentamos los resultados del análisis de 4.463 lecturas realizadas con el penetrómetro y registradas durante la excavación de arquitectura residencial y no-residencial en Welqámex, un asentamiento Stó:lō-Coast Salish en el suroeste de Columbia Británica. Nosostros mostramos como los datos del penetrómetro de bolsillo revelan diferencias cuantificables en la compactación de los pisos y de otros depósitos culturales. Nosotros argumentamos que las medidas de compactación pueden proveer una serie adicional de datos (escala de rango) para afirmar u objetar las interpretaciones de la estratigrafía realizadas en el sitio basadas en otros datos tangibles o en datos observados, particularmente, cuando las interpretaciones correspondan a superficies en las que se asume estuvieron expuestas constantemente al tráfico peatonal.

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house-associated deposits—the identification and isolation of floors during stratigraphic excavation can be a challenging endeavor. This is a concern in as much as the identification of floor surfaces is critical to special context-sensitive sampling decisions, including surface scrapes for chemical analyses (e.g., Manzanilla and Barba 1990; Middleton and Price 1996; Sullivan and Kealhofer 2004; Terry et al. 2004; Wells et al. 2000), studies of microartifacts (e.g., Cessford 2003; Rosen 1989; Sherwood et al. 1995), and analyses of macrobotanical remains (e.g., Fritz et al. 2009; Hayden 1997; McCafferty 2008). For all of these analyses, sediment samples need to be recovered from stratigraphically comparable surfaces if patterned variation in microartifacts, macrobotanical specimens, or chemical signatures is to be inferentially linked to household behavior. To this end, excavators must be able to identify living surfaces when they are first exposed.

Floor identification can be especially challenging in regions where house floors were crafted from porous sediments but not plastered with fine clays or lime. In these regions, including much of North America, the appearance or co-appearance of certain features (e.g., hearths, post holes, storage pits) is often among the most reliable of indicators of a floor surface. Of course, the chances of exposing one or more floor features are that much higher when a large area is excavated. However, expansive excavation is costly, and archaeologists are increasingly reliant on small-scale subsurface investigation techniques. Such sampling methods can reduce the likelihood of revealing the requisite combination of features and macroscopically visible sediment attributes needed to identify floor surfaces before unwittingly removing them. This is especially true when excavation strategies make use of non-contiguous units, such as during investigations in which many dwellings are sampled with only one or two modest units (e.g., 1-x-1-m) per dwelling. In these circumstances, the identification of house floors during excavation is often a recursive process of using in-the-moment sensory data to test hypotheses concerning expected attributes of floor surfaces. Such descriptive attributes can include compacted sediments (and the audible ring of a trowel when lightly scraped across sediments), changes in the proportions of sediment constituents (particularly sand or clay), and changes in sediment color that can be attributed to cleaning and organic staining (e.g., charcoal-rich smears near open hearths). In our experiences, this process involves considerable dialogue among members of the field crew, and decisions are often reached through negotiation and consensus over a small ensemble of distinctly tactile but experientially mediated observations.

Strong empirical support for floor determinations may come only *after* the purported floor has been fully removed. For example, analysis of stratigraphic profiles sometimes reveals vertically and discretely bounded floor layers that went unrecognized during formal excavation. Even stronger empirical support is typically afforded by micromorphological analysis. A micromorphologist's attention to soil micro-structure, mineral and organic compounds, ground mass, and pedofeatures affords archaeologists a means of differentiating anthropogenic processes from other taphonomic processes and thus provides a basis for inferring cultural activities that are otherwise undetectable at the macroscopic level (MiJares and Lewis 2009; Walkington 2010). During house occupation, trampling and other compaction processes embed finer-sized sediments into floor strata, whereas larger and coarser materials are likely to have been periodically swept away (Davidson et al. 1992). Penetration resistance tests, as well as microscopic analyses of soil porosity and other attributes, can indicate the presence of a stratum formed from structural changes in sediments, such as frequent trampling (Banerjea et al. 2013; Bresson and Zambaux 1990).

However, although micromorphology is now commonly accepted as the "gold standard" for detecting floors, insights gained from micromorphological analyses are usually obtained only after the conclusion of a field season and thus long after the point at which another line of data is needed to guide time-sensitive decisions about sampling procedures (e.g., surface scrapes for macrobotanical remains). Here, we argue that detection of floors and living surfaces during formal excavation can be significantly aided by the use of a pocket penetrometer, an instrument that measures the compaction strength of sediments. Drawing on compaction data meticulously collected during the excavation of in-ground dwellings in southwestern British Columbia, we show how penetrometers afford an additional line of data for ascertaining the presence of house floors and other trampled surfaces and thus help to inform context-sensitive sampling decisions.

POCKET PENETROMETERS

Pocket penetrometers are instruments for measuring soil compaction and are popularly used by glaciologists, geologists, agronomists, botanists, and various commercial engineers. Considerably smaller than other soil compaction testers, the pocket penetrometer is an inexpensive device designed to quantify surface penetration resistance, or the extent to which an area of soil can withstand pressure exerted downward at a right angle to the soil surface (Figure 1).[1] After resetting the indicating ring, the user grips the cylinder of the instrument and presses downward. As the soil surface resists penetration, the piston compresses a calibrated stainless steel spring, forcing the indicating ring to slide forward on the piston. At the point that the piston calibration mark sinks to the same level as the soil surface, the user stops exerting downward pressure and records the measure (tons/ft^2 or kg/cm^2) as indicated by the new location of the indicating ring against a piston-mounted scale (Figure 2). Given the simple design of the instrument, readings are best regarded as approximations of actual soil resistance, but accuracy to a half division or .125 tons/ft^2 (.122 kg/cm^2) is possible. For weak soils and sediments (e.g., uncompressed beach sand), an adapter (2.5

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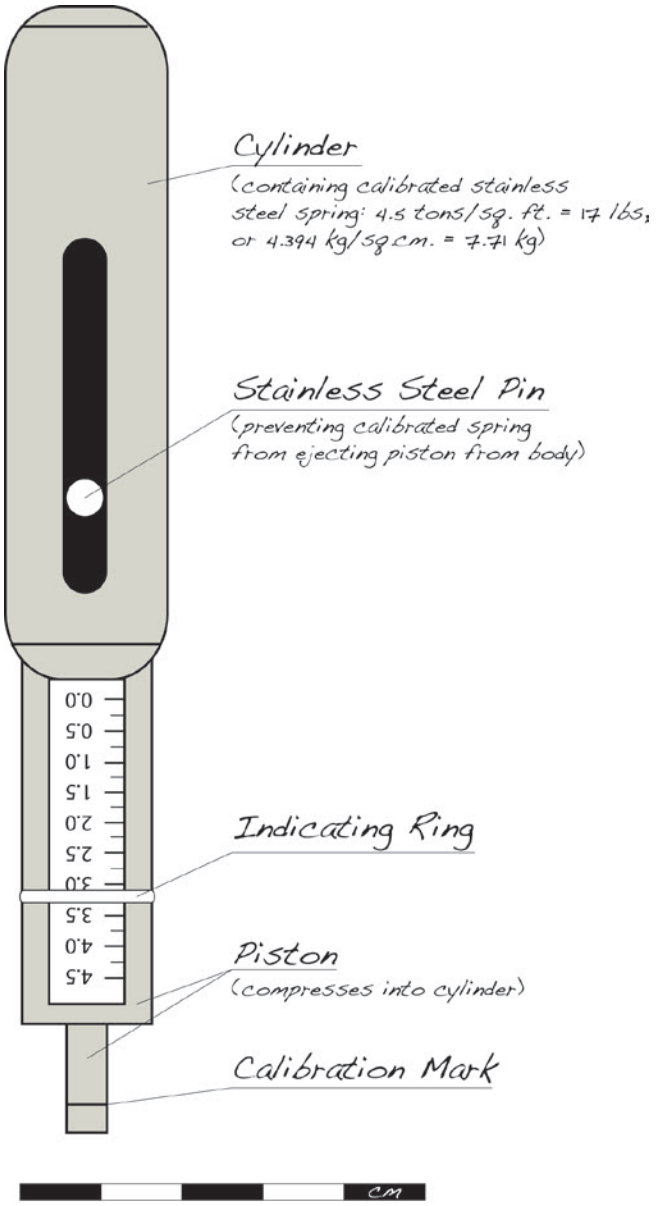


FIGURE 1. Annotated illustration of a pocket penetrometer.



FIGURE 2. Use of a pocket penetrometer during excavation.

cm diameter) can be attached to the end of the piston and all readings are multiplied by .0625.

Our decision to use the pocket penetrometer was based on the simple logic that earthen floors are subject to repeated trampling and thus should be more compacted than other types of archaeological deposits associated with Indigenous residential architecture (e.g., earthen roofs, decomposed wooden superstructures, middens) in southwestern British Columbia. We recognize that the type of substrate, the ways that floors are built, and the intensity and types of human activity are all variables that can individually and collectively affect the compaction of sediments. As such, an expectation of differentially compacted floors is by no means universally shared across cultural and geographic regions. That is, while experimental research has shown that recurrent and intensive foot traffic can differentially compact an earthen floor (e.g., Milek 2012), other studies suggest that trampling is not a monolithic process and may abrade and even loosen floor surfaces in certain sedimentary contexts (Gé et al. 1993; Gifford-Gonzalez et al. 1985; Miller et al. 2013). Furthermore, any number of natural formation processes can affect sediment compaction following house abandonment, not the least of which is bioturbation by roots and/or invertebrates (LaMotta and Schiffer 1999; Schiffer 1987).

Nevertheless, the moist, fine-grain sandy loams comprising house substrate in the upper Fraser Valley of southwestern British Columbia afford the construction of smooth, compacted floor surfaces without having to import other sediment. At the outset of excavation, we hypothesized that house floors or living surfaces would consistently yield higher resistance measures, assuming that taphonomic agents and other site formation processes had not greatly affected surfaces since the original compaction. In order to evaluate this hypothesis, we needed to depart from our typical method of assessing and recording compaction using only intuitive assessments and nominal data (e.g., "low," "moderate," or "high"). To this end, pocket penetrometers allowed compaction measures to be obtained in the field and to be compared within and across depositional contexts without having to second-guess the quality and congruence of subjective assessments recorded by the various members of excavation teams.

Elsewhere, compaction measurements collected with pocket penetrometers have been used to examine the presence of a putative cart path connecting two eighteenth-century plantations in rural Delaware (Burrow et al. 2014), to evaluate how the compaction of soils might affect burrowing behavior of armadillos in archaeological deposits (Araujo and Marcelino 2003), and to distinguish cultural from non-cultural soils in exploratory subsurface testing (Clayton et al. 1995). However, outside of geotechnical work that often occurs in tandem with Phase 1 and Phase 2 archaeological investigations, the affordances of pocket penetrometers have seldom been explored or realized in previous archaeological research. An important exception is a recent study of a modern Stó:lō-Coast Salish longhouse earthen floor in which pocket penetrometer measurements were collected along a sample transect that included interior perimeter sub-bench surfaces, walking and dancing spaces, and a central hearth (Schaepe et al. 2015). The resulting dataset reveals intra-house differences in compaction, with walking and dancing spaces notably more compacted than the hearth and areas under perimeter benches (Schaepe et al. 2015).

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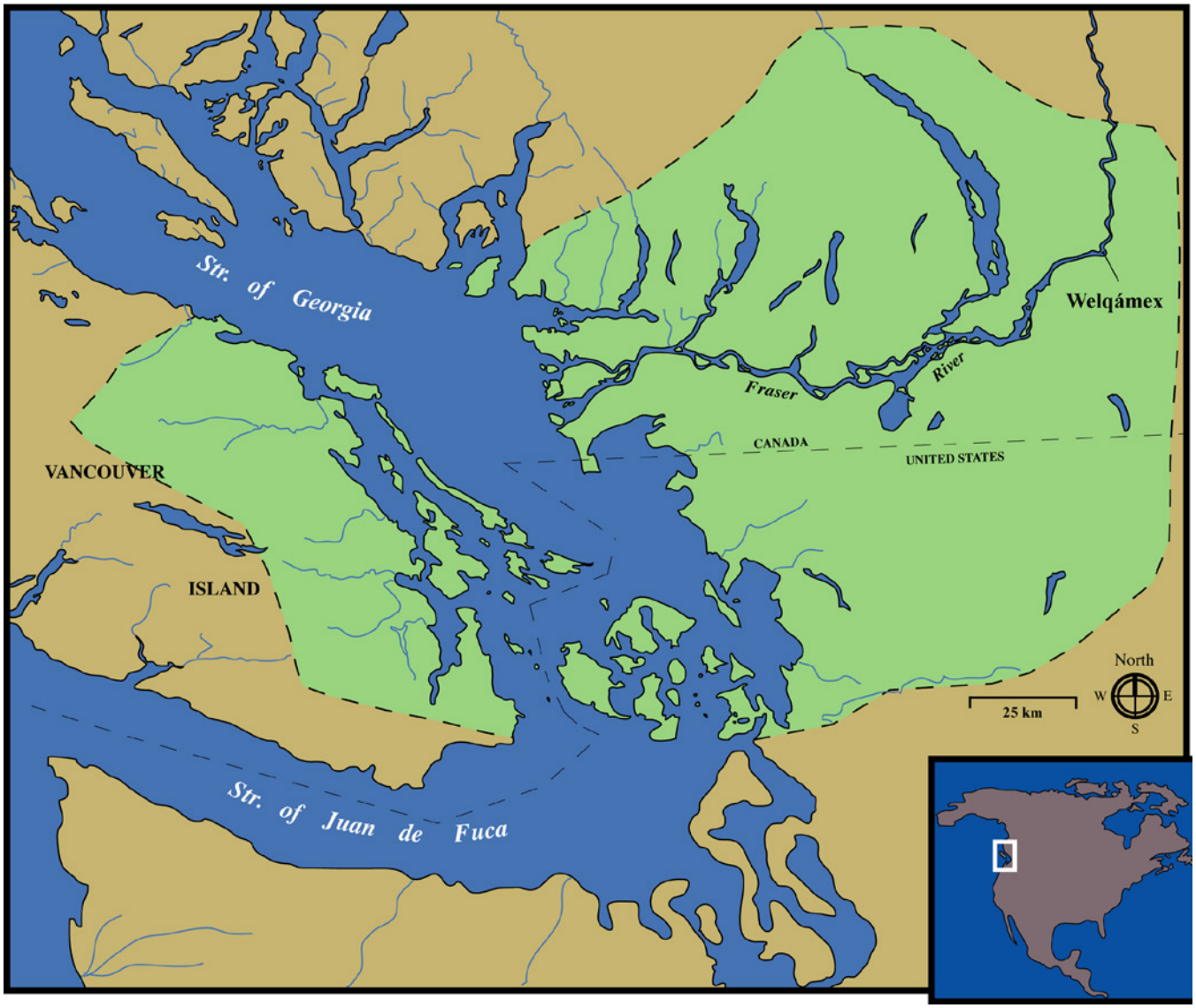


FIGURE 3. Location of Welqámex (DiRi-15) in traditional Stó:lō-Coast Salish territory (green), southwestern British Columbia. Map adapted from Graesch et al. 2014.

In this study, we show how a unique and large dataset comprising thousands of systematically collected pocket penetrometer readings reveals behaviorally significant variability in house-associated sediment compaction. We argue that use of pocket penetrometers during plan-view excavation can lend support to in-the-moment determinations of stratigraphic context and thus aid important sampling decisions. Below, we briefly characterize the archaeological record of residential architecture at Welqámex, a Stó:lō-Coast Salish settlement in the upper Fraser Valley of southwestern British Columbia. We then detail the methods by which we revealed and documented strata, including the recordation of sediment compaction using pocket penetrometers. Finally, we present and discuss pocket penetrometer data as they relate to our in-field interpretations of stratigraphy based on other observational and tactile data.

CASE STUDY: IN-GROUND DWELLINGS AT WELQÁMEX

Welqámex (DiRi-15) was an island-based, Stó:lō-Coast Salish settlement (Figure 3) occupied as early as A.D. 1300 and as recently as A.D. 1890 (Graesch 2006, 2007, 2009; Graesch et al. 2010, 2014). The settlement featured 12 in-ground architectural features, 10 of which were residential dwellings (or *sqémél*), as well as three or four on-ground structures (e.g., longhouses). In-ground residential dwellings were common to Stó:lō-Coast Salish settlements in the broader Fraser Valley region but particularly in the middle and upper valleys as well as the lower Fraser Canyon (Lepofsky et al. 2009; Schaepe 2009). At Welqámex, most in-ground residential dwellings featured wooden domed roofs partly supported by interior posts and constructed over large pre-excavated depressions. Roofs were often covered

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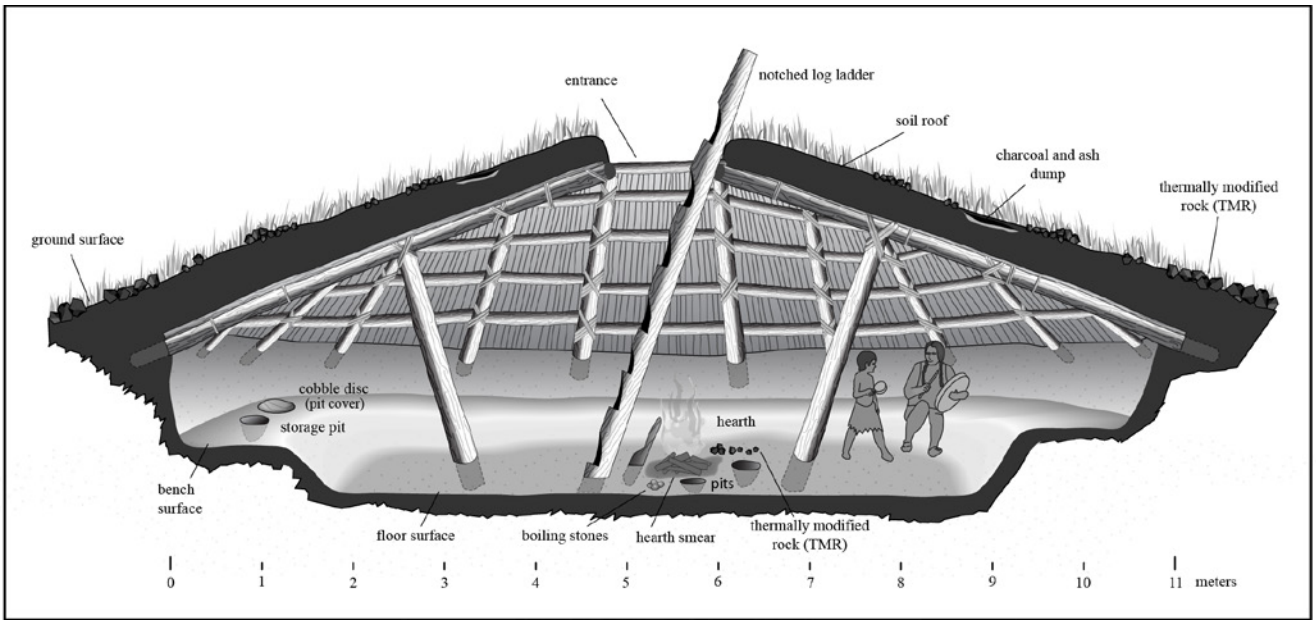


FIGURE 4. An example of in-ground residential Stó:lō-Coast Salish architecture at Welqámex. After Graesch 2007, and modeled on Schaepe et al. 2001.

with the sandy loam generated during the initial preparation of interior living spaces, and houses were typically entered via a notched log ladder that spanned the vertical space between the roof apex and an earthen floor (Figure 4). Benches were carved out of the interior substrate at the perimeter of the dwelling and spanned the partial or full circumference of the structure. There are no ethnographic data that speak to the use of woven or rush mats on floor surfaces, although these have been noted in residential architecture in regions to the south and west (e.g., Gunther 1927).

The archaeological record reflects important variation on the design attributes (e.g., shape, location of door, roof materials) of in-ground architecture in the Fraser Valley, in general, and at Welqámex, in particular (e.g., see Graesch 2006; Lepofsky et al. 2009; Springer and Lepofsky 2011), but all variants revealed through archaeological investigations have featured earthen floors/living surfaces constructed from the island substrate. We define *floors* as intentionally constructed or prepared surfaces on which interior activities (e.g., those typical of residential dwellings) transpired. New floors were sometimes constructed over old floors, as is evident in four in-ground dwellings featuring two or more floors and spanning the Late and Contact/Colonial periods at Welqámex. The other six of the 10 in-ground houses were constructed in the nineteenth century and feature only one obvious floor-building event prior to abandonment of the settlement.

Whereas sequences of floor construction are evident in the central interior spaces of some in-ground dwellings, archaeological deposits exposed at the periphery of interior living spaces do not always reflect the same sequence of building and rebuilding. In part, this is likely an outcome of differential organic staining attributable to the patterned location of food-preparation and hearth-related activities (see below). As such, we use the term *living surface* to analytically encapsulate all interior activity surfaces, including benches, regardless of whether stratigraphic data indicate episodic floor-construction events.

Perhaps owing to slow and deliberate abandonment, interior residential living surfaces at Welqámex rarely display tools or other artifacts. Furthermore, house floors are rarely level; most surfaces rise and fall across two or more meters of lateral space, thus complicating efforts to predict their three-dimensional location during stratigraphic excavation. As such, we were usually dependent on the co-presence of features, detectable changes in compaction, and organic staining to identify and document the presence of a house floor. In the absence of features and staining, perceptible and measurable changes in compaction were critical to the task of identifying living surfaces in the field. This is especially true of peripheral floor and bench surfaces, or areas furthest from hearths and likely used by house occupants for sleeping, socializing, storage, and various tool-making activities.

FIELD METHODS

The preservation of stratified deposits among in-ground houses at *Welqámex* is quite exceptional, partly owing to only modest bioturbation and partly owing to the flood sediments that cap and protect cultural deposits in most house depressions. Our understanding of site stratigraphy as a whole is informed by data derived from the excavation of 42 1-x-1-m units in a variety of architectural features as well as other cultural and non-cultural contexts. Although many of the data recovery techniques applied during field investigations at *Welqámex* were unique to the region, we are careful to note that our methods are best regarded as conventional and not geoarchaeological in scope or design.

All in-ground architectural features were tested using one or more 1-x-1-m excavation units (Figure 5). Units were typically

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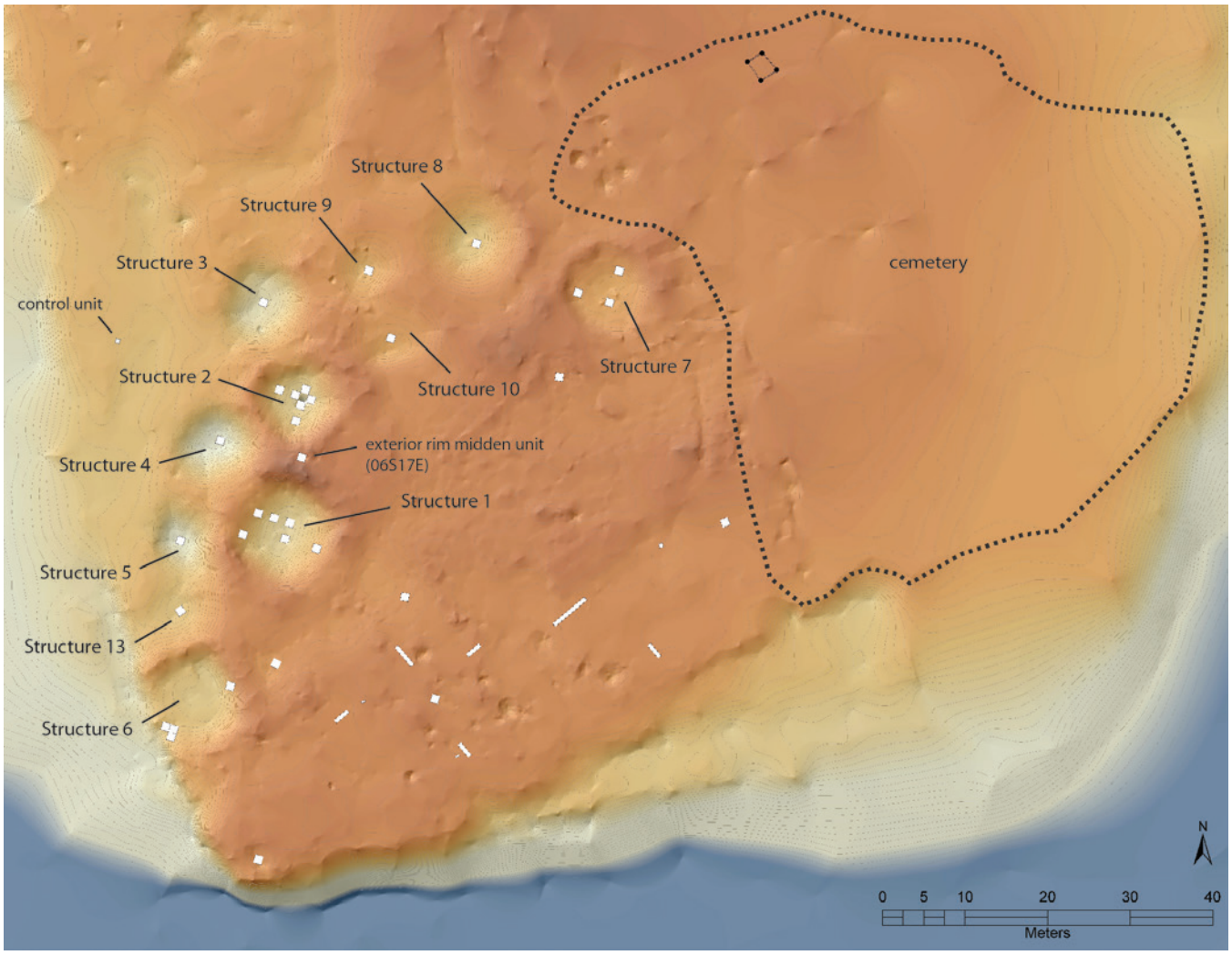


FIGURE 5. Location of in-ground residential structures and associated excavation units at Welqámex (DiRi-15). On-ground architectural features are not included in this analysis and are thus not labeled here.

located near the center of each dwelling so as to sample a combination of rim-slump, roof, and floor deposits, and all deposits were excavated with trowels and using a layer-and-level approach. Layers were defined as strata with macroscopically visible and unique combinations of attributes, including soil and sediment color, texture (i.e., sand, silt, or clay), compaction (as perceived by touch and sound), and contents (i.e., artifacts, ecofacts, wood charcoal, and thermally modified rock [TMR]). We excavated each layer in 5–10 cm arbitrary levels (or .05–.10 cm^3) so as to divide thick strata into smaller analytic units for purpose of examining the vertical organization of seemingly similar cultural deposits (Figure 6). Volumes of excavated deposits were meticulously measured and documented throughout. If a new layer was encountered during excavation, a level would be halted and closed, even if the predetermined volume of deposits (or depth below datum) had not been achieved. All excavated deposits were dry-sieved with 3.2-mm (1/8") mesh, and all screen residue was retained for full laboratory sorting to ensure the recovery of a representative sample of small artifacts and animal remains (Graesch 2009). Large TMR fragments were counted and weighed prior to discard in the field (Graesch et al. 2014).

The upper layers of house deposits at Welqámex comprise soils developed from organic decomposition of forest canopy and understory as well as wind-transported (i.e., saltation and suspension) sands from the nearby shoreline. These recent strata often overlay one or two lenses of fine silty loam that formed during massive floods on the Fraser River in 1948 and 1894, respectively. In residential architecture, removal of flood strata—the earliest of which postdates the abandonment and collapse of Welqámex dwellings—reveals a distinctly sandy loam containing numerous fragments of TMR, charcoal, animal bone, lithic byproducts, and other midden constituents once deposited on house roofs and rims. We were rarely able to distinguish roof materials from those of rim deposits that slumped back into architectural depressions during the collapse of the roof and supporting timbers; both deposits are similar in composition and likely mixed as a result of variable collapse-related formation processes. Regardless, roof/rim-slump layers overlay

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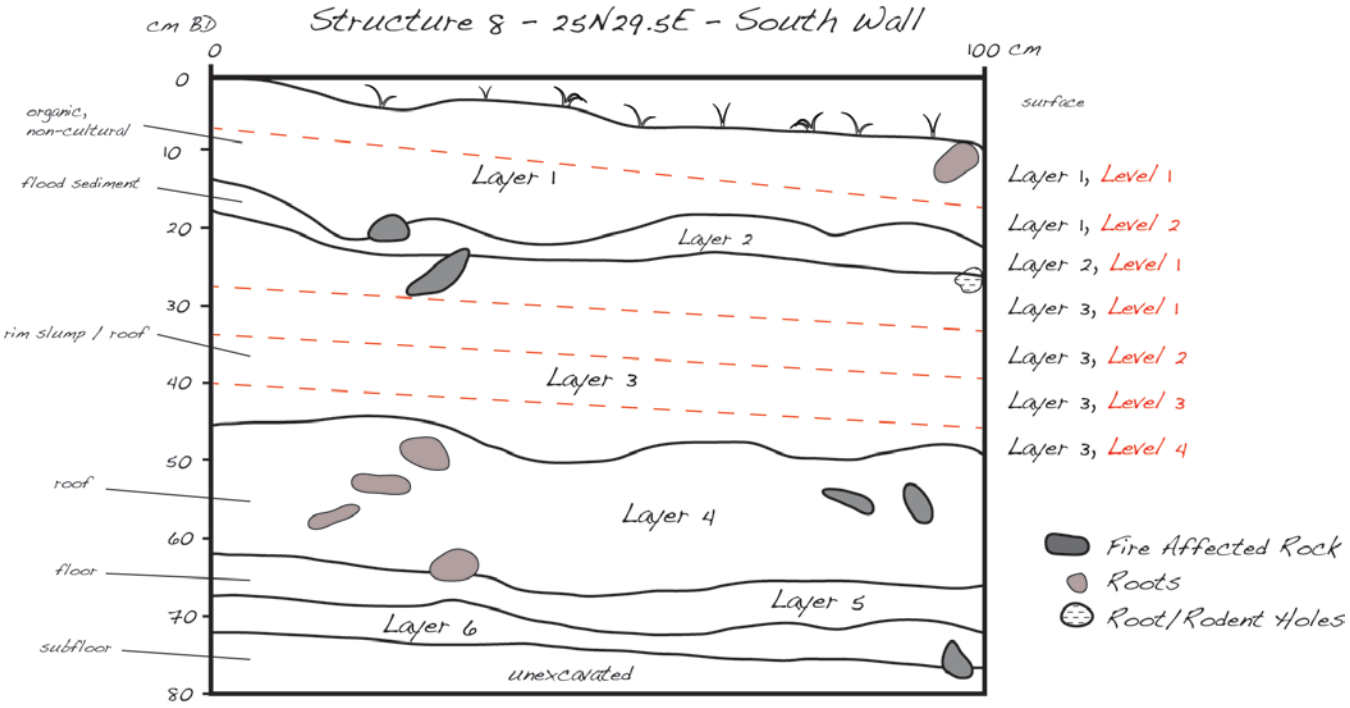


FIGURE 6. A profile schematic of the excavation strategy showing the division of non-cultural and cultural strata (layers) into arbitrary levels.

surfaces that typically feel more compact and often conform to our expectations of house floors.

Strata that we identified in the field as probable floors or living surfaces were typically compact to the touch and devoid of both artifacts and midden constituents. Indeed the upper surfaces of such strata usually constituted the plane of origin for specific features, including postholes, small pits, hearths, and hearth smears. When excavation units revealed hearths or hearth-adjacent surfaces, sediments were observed to be heavily stained with charcoal and presumably other carbon-rich materials. Interior living surfaces identified further away from hearths tended to be the same color as non-cultural substrate (2.5Y 4/3), although a thin lens of color-mottled sediment—likely the result of light staining from organic substances—was not uncommon. When exposed sediments were notably compacted *and* featured visible color mottling, we interpreted this as a likely encounter with a floor surface; this in-the-moment hypothesis was usually reinforced with the concurrent appearance of storage pits and postholes. Our macrobotanical and microartifact sampling procedures were then called into play. However, when no color mottling or features were evident, or when only a modest increase in sediment compaction was detected by trowel, our confidence in detecting the presence or location of house floors was greatly diminished.

During excavation of all strata—non-cultural and cultural layers alike—we typically recorded 20–25 penetrometer readings at the "opening" or beginning of each layer and level. Given that fragments of TMR, artifacts, faunal specimens, and worm-created cavities sometimes lay immediately below the exposed surface and thus may have affected any single penetrometer reading, we opted for more measurements rather than fewer. We divided 1-x-1-m units into four 50-x-50-cm quadrants and recorded four or five compaction measurements in each (Figure 7). In thicker strata, we regularly documented a minimum of 40 readings for every 10 cm of excavated deposit when excavating in 5-cm arbitrary levels, or 200 penetrometer readings in 50 cm of vertical excavation. Usually, however, we encountered many stratigraphic breaks in deposits associated with residential architecture; given that we started a new layer and level with each, the number of penetrometer readings in a single 1-x-1-m unit often exceeded 300 (range = 55 to 658). All sediments encountered were strong enough to withstand pocket penetrometer readings without requiring the attachment of an adapter to the penetrometer piston.

Our consideration of the analytic contributions of penetrometers is based on 4,463 compaction measurements recorded during the excavation of the 10 in-ground residential dwellings at Welqámex, one non-residential in-ground structure, a 1-x-1-m unit located in the rim midden between Structure 1 and Structure 2, and a single 50-x-50-cm excavation (or control) unit placed beyond all architectural features on the northern margin of the settlement. Subsurface investigations in dwellings typically entailed the use of non-contiguous excavation units, a method that can provide insights into the ways that different areas of the dwelling were used, but at the cost of making it more difficult to locate floors/living surfaces across space (see Figure 4). Below, we explore the extent to which sediment compaction as recorded with pocket penetrometers varies among deposits expected to have been differentially trampled. Our analysis relies on in-field classifications of stratigraphy as the basis for grouping pocket penetrometer readings into meaning-

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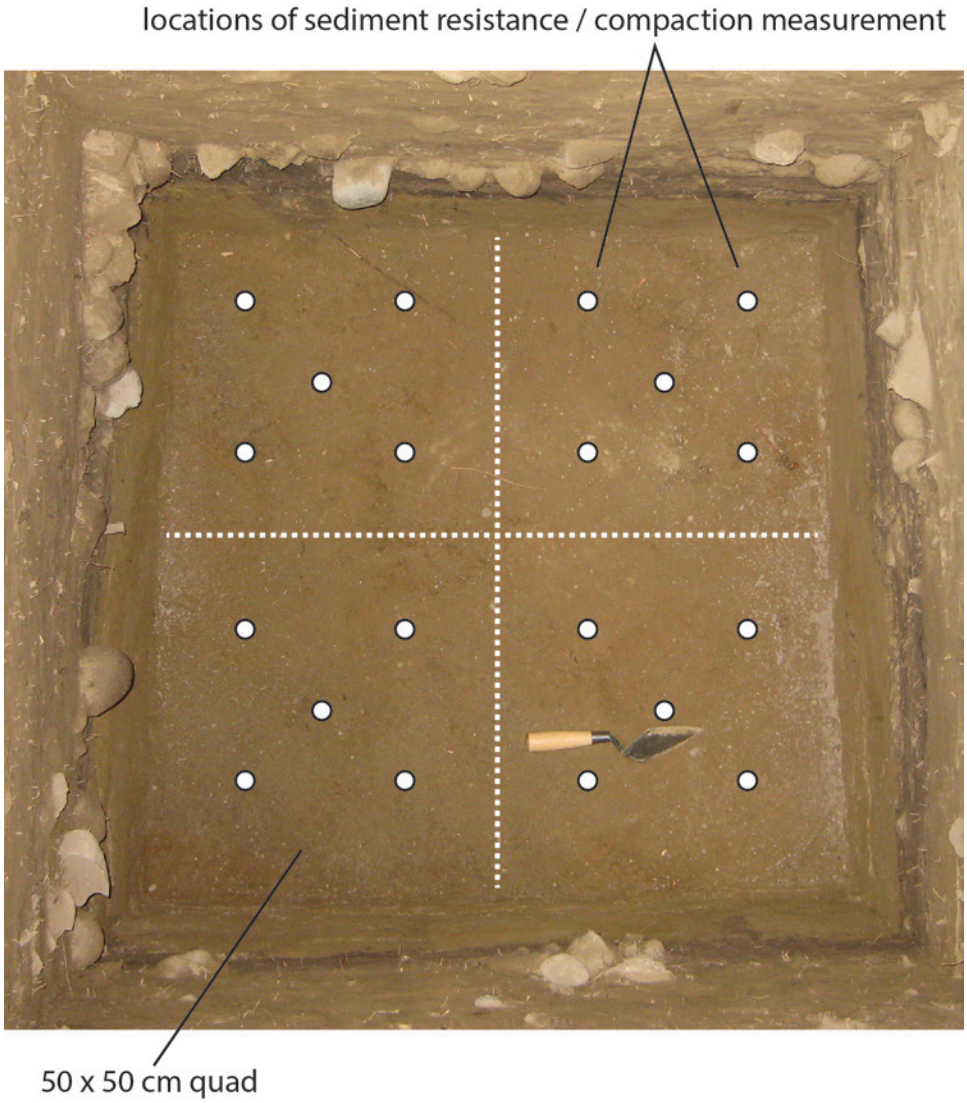


FIGURE 7. Typical locations of penetrometer measurements in a 1-x-1-m unit during plan excavation.

ful analytic units (e.g., cultural and non-cultural; midden, roof/rim slump, floor/living surface, features) for which distributions of compaction measurements can be compared.

RESULTS

Figure 8 shows that layers identified as cultural deposits reflect, on average, higher and more variable compaction measures than those recorded in non-cultural layers ($t = 2.797$, $p = .005$). Within the non-cultural deposits, compaction measures taken during the excavation of discrete layers of flood sediment tend to be higher than those documented in the organic loam that caps all of the in-ground architecture at Welqámex ($t = -4.119$, $p = .000$). These data meet our expectations; when excavated, flood sediments were perceived to be more consolidated and otherwise more difficult to remove by trowel. Our analysis did reveal, however, that organic loam and flood sediments yielded more outliers than observed in the aggregate set of compaction measurements recorded in cultural layers. We suspect that this reflects (1) greater variability in soil characteristics owing to minor mixing of flood sediments and overlaying loam by earthworms and (2) differential drying of some loam owing to greater aeration as a result of bioturbation. Although the comparative dataset is much smaller ($n = 34$), compaction measurements taken during the excavation of our "offsite" control unit reflect significantly less consolidated soils than the combined organic loam and flood deposits recorded in house depressions ($t = 3.786$, $p = .000$).

For cultural strata in dwelling interiors, we found that compaction readings for rim-slump/roof deposits ($n = 2181$) are, on average, significantly lower than those recorded for layers classified as floors/living surfaces ($n = 784$; $t = -36.014$, $p = .000$) and subfloors ($n = 253$; $t = -23.978$, $p = .000$). Not surprisingly, compaction measures recorded in features ($n = 80$) are virtually identical to rim-slump/roof deposits. These data are congruent with our in-field experiences. That is, features encountered dur-

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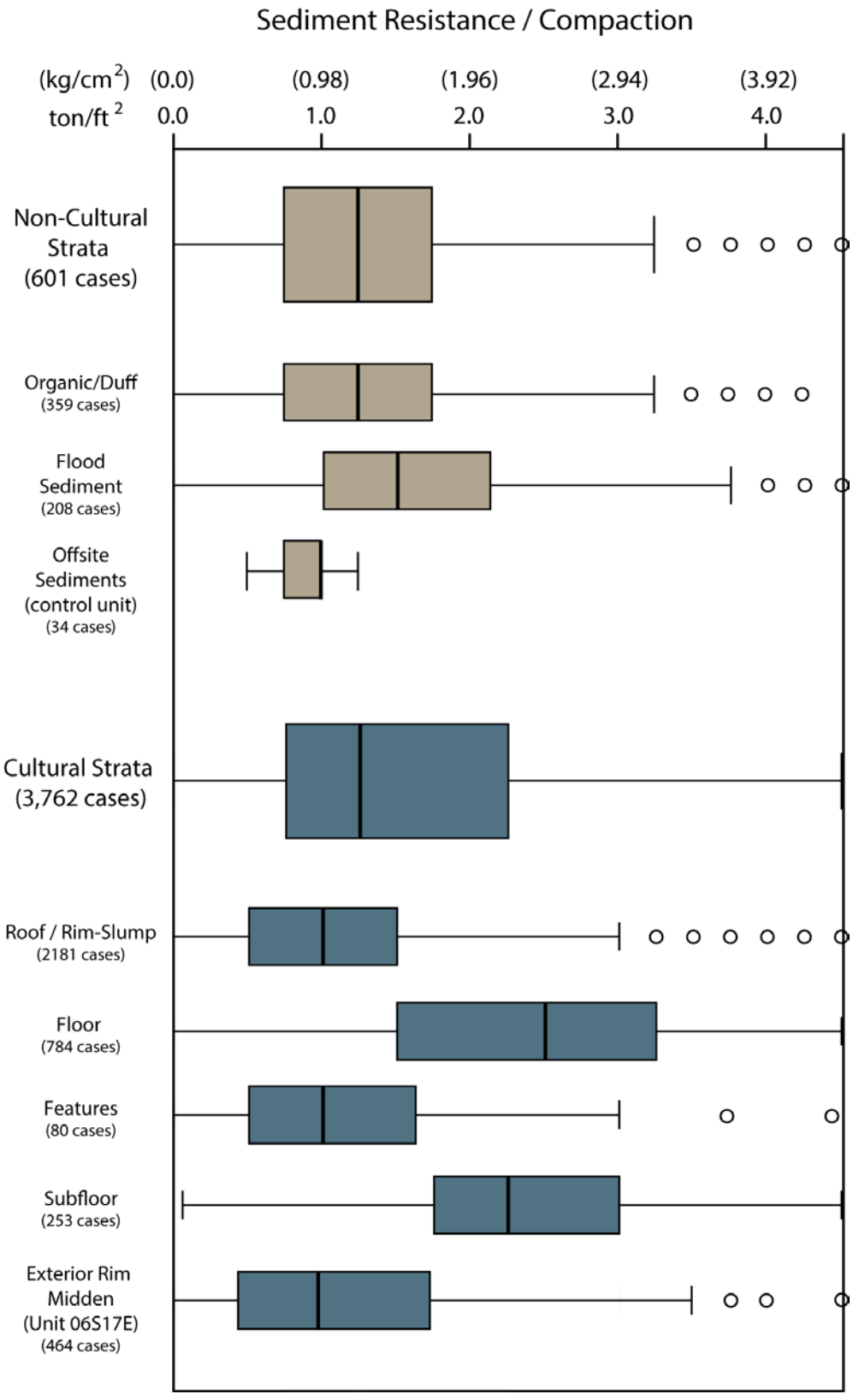


FIGURE 8. Distribution of compaction measures for categories and subcategories of strata at Welqámex.

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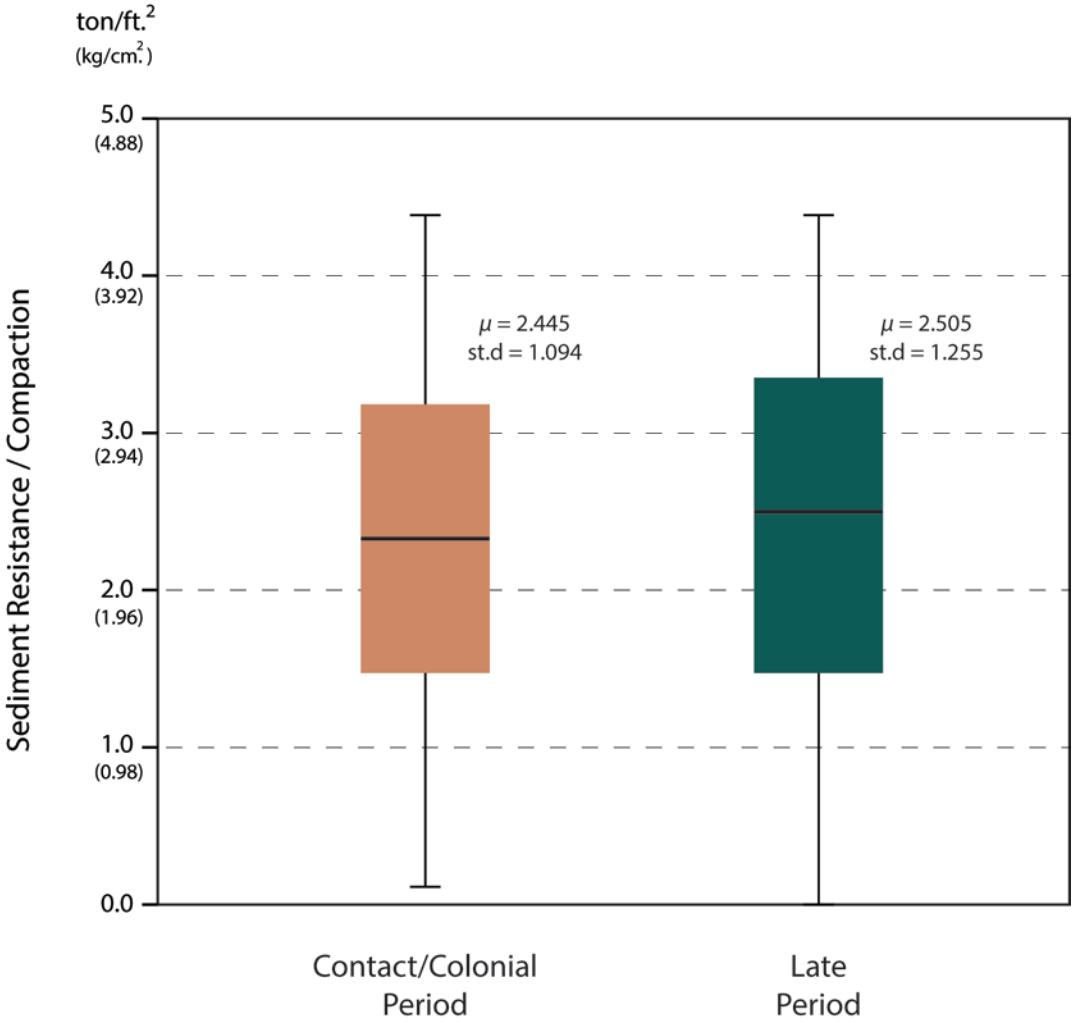


FIGURE 9. Distribution of compaction measures by time period at Welqámex.

ing excavation—most of which are small, hearth-adjacent pits occurring on and below living surfaces—often consist of loosely consolidated sediments containing high densities of TMR. For all intents and purposes, the contents of interior pits are seemingly identical to rim slump/roof layers. This similarity may partly be explained by rim and roof contents, much of which is everyday household trash, being deposited into open pits during post-abandonment biodegradation of the superstructure and the subsequent collapse of overlaying midden.

Pocket penetrometers also revealed that strata classified as floors or living surfaces are notably more compressed than exterior rim middens (n = 564; t = 22.104, p = .000). Figure 8 shows that the distribution of resistance measurements in rim midden deposits is most similar to that recorded for roof/rim slump deposits. Both categories comprise strata that are the accretive residue of daily household discard, as well as isolated discard-related depositional events (e.g., a hearth cleanout). The midden that accumulates on and mixes with roof sediments that form on the exterior of house rims is much thicker and consists of numerous clearly definable strata (Figure 8). These distinctions likely reflect more frequent transformations to roof deposits, such as mixing of midden and original roof-insulating sediment during roof repairs. However, exterior rim middens also contain significantly higher densities of TMR per excavated volume of deposits when compared to most house roofs. This difference may reflect intentional discard of heavier and larger volumes of trash at the edges of Welqámex dwellings, rather than on top. Indeed, we documented 3,934 fragments (56.82 kg) of TMR in mesh ≥ 6.4 mm (1/4") during the excavation of 1.3 m^3 of midden in unit 06S17E alone; a dozen or so outliers in the distribution of compaction readings likely reflect subsurface rocks affecting individual resistance measures (see Figure 8). Regardless, neither depositional context is expected to be associated with frequent or heavy trampling, and data gathered with the pocket penetrometer support these expectations.

We hypothesized that the duration for which each dwelling was occupied would affect compaction; residential structures occupied for longer periods are expected to feature floor surfaces that are more compacted than dwellings occupied for shorter periods. We currently lack the data to fully evaluate this idea, but our data

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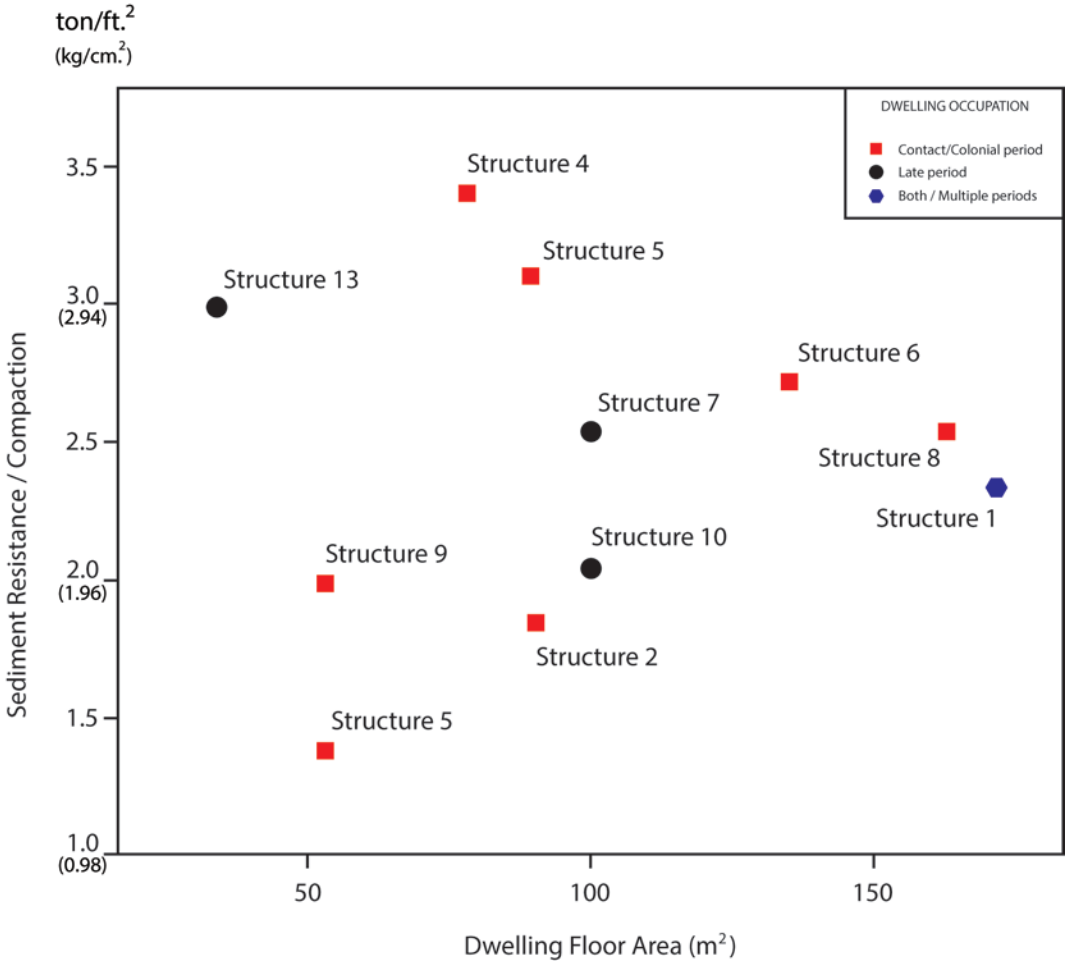


FIGURE 10. Mean compaction measure by dwelling size at Welqámex.

do suggest that the processes by which floors become compacted in older structures (ca. A.D. 1300) are seemingly no different than the processes accounting for floor compaction in recent dwellings (ca. A.D. 1860; Figure 9). That is, average compaction and standard deviation of measurements recorded in Contact/Colonial period dwellings (n = 7; 453 compaction readings) are remarkably similar to those documented in Late period structures (n = 4; 331 compaction readings). As such, we see no evidence for changes in the ways that floors/living surfaces were compacted or the extent to which floor compaction was transformed over the history of residential dwelling use, abandonment, and collapse at Welqámex. This finding is intriguing and worthy of further exploration if only for the fact that it suggests that post-collapse natural transformations that might variably affect artifact patterning among dwellings or over time (e.g., see LaMotta and Schiffer 1999; Schiffer 1987) may be minimal.

Although our sampled excavation area for any individual dwelling is small, we also could not find any apparent relationship between house size (as a proxy for household size) and the extent to which floors were compressed (Figure 10). For example, smaller dwellings—Structures 5, 9, and 13—might be expected to feature floors that are more or less compacted than larger structures, depending on assumptions about the ratio of occupants to regularly used floor space. Our findings, however, indicate that average floor compaction is highly variable among the smallest of residential structures at Welqámex, with Structure 5 featuring the lowest mean compaction measure and Structure 13 (the absolute smallest house) featuring one of the highest.

DISCUSSION

Data gathered with pocket penetrometers at Welqámex reveal quantifiable differences between the compaction of floors/living surfaces and other cultural deposits, including house roof, rim slump, features, and exterior rim midden. On average, surfaces identified as house floors during excavation consistently returned higher resistance measures (μ = 2.5 kg/cm^2), whereas most other depositional contexts were notably less compacted ($\mu \leq$ 1.5 kg/cm^2). Overall, these findings suggest that pocket penetrometers have analytic utility in the identification of depositional contexts in which sediments are expected to have been compacted as a result of recurrent trampling, such as that common to house floors, exterior activity areas, and frequently traveled pathways.

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It is important to note that decisions to systematically record compaction data at Welqámex were intrinsically linked to decision-making processes concerning the documentation of a new layer or a new level during onsite, plan-view investigations. That is, if perceptible changes in the macroscopic and tactile attributes of exposed deposits compelled assignment of a new layer, we pulled out a fresh field form and initiated a set of penetrometer measurements on the newly exposed unit surface. In other words, datasets presented in this analysis are interdependent and, as such, we cannot assess the extent to which penetrometer readings alone can indicate the presence or absence of floor deposits or other trampled surfaces. Despite this analytic limitation, we think it unlikely that field archaeologists would be using pocket penetrometer readings as the sole basis for determining the locations of floors. Rather, compelling interpretations of stratigraphy are typically based on multiple lines of observational and tactile data, and penetrometer readings can help support or challenge in-field hypotheses addressing the cultural significance of particular strata.

Another limitation of our study (that also stems from the interdependence of data) concerns our inability to parse the overlapping distributions of compaction readings across stratigraphic contexts. Although mean resistance measurements for floor deposits are, on average, significantly higher than those recorded for roof/rim-slump deposits, the lowest quartile of the former's distribution overlaps with as much as 75 percent of the latter's (see Figure 8). In some cases, low resistance readings for house floors may reflect subsurface cavities created by earthworms, pockets of loose sediment near floor-embedded objects, or the erroneous measurement of floor-associated features (e.g., a posthole). Similarly, high resistance measures in roof/rim-slump deposits may have resulted from penetrometer readings on sediments immediately overlaying TMR fragments or other objects. In still other cases, penetrometer readings may have been unwittingly recorded and grouped when a combination of partly exposed floor deposits and overlaying basal roof/rim-slump deposits were simultaneously exposed. Some of the lower floor compaction readings may reflect the contact or interface of floor and roof layers, or even perhaps the difference between the uppermost accretive surface and lower, more compacted layers of the floor proper. There are still other possible explanations, not the least of which concern possible formation processes (e.g., floor cleaning and abrasion) that challenge our assumption of differential, trampling-induced compaction. Regardless, the overlapping distributions indicate interpretive ambiguity of pocket penetrometer readings at least some of the time.

Nevertheless, given the patterned differences in compaction that are evident in Figure 8, we argue that the methodological value of the pocket penetrometer may be especially realized in circumstances where multiple diagnostic markers of floors—features, organic staining, artifacts—are absent, such as on the interior peripheries of residential dwellings. Chances of encountering these markers are greatly reduced when archaeologists excavate only modest samples. Similarly, residential living surfaces are not always topographically level or flat, a fact that oftentimes compounds the challenge of locating floors across the space of dwelling interiors. In all of these cases, resistance data gathered with pocket penetrometers can help guide sampling protocol reserved for floors/living surfaces, such as bulk sediment recovery for microartifact and macrobotanical analyses. We also predict that, in circumstances where bioturbation and other transformations have obfuscated a macroscopically observable depositional history, the diligent documentation of penetrometer readings in accordance with a high-resolution sampling strategy (e.g., every 5 cm of vertical excavation) would reveal behaviorally significant changes in compaction and allow field archaeologists to hone in on floors and other trampled surfaces.

This same affordance may be extendable to the investigation of patterned uses of floor spaces, such as in the longhouses of the Pacific Northwest and the American Northeast. Holding other taphonomic variables equal, differential floor compaction might be expected in dwellings where "paths" were frequently used to navigate between social spaces otherwise divided by mat partitions and other architectural elements. Systematic collection of sediment compaction measurements may help elucidate patterned uses of these structures and thus aid in the inferential reconstruction of social and political behaviors at the household level.

CONCLUSION AND RECOMMENDATIONS

In general, archaeologists in the twenty-first century are excavating less while doing more with excavated deposits. While massive open-air excavations of residential architecture afford the most opportunities to expose floor surfaces, small-scale excavation strategies are more widely applied and suited to budgets that often now include costs for macrobotanical, microartifact, chemical, and micromorphological analyses. The likelihood that field archaeologists are able to identify surfaces targeted for focused, context-sensitive sampling is greatly reduced when the placement of modest excavation units fails to reveal floor-associated features, sediment staining, and other diagnostic markers of floor surfaces. This is particularly true on the interior peripheries of domestic architecture, where archaeologists may be confined to subsurface investigations as a means of avoiding burials.

In and of themselves, pocket penetrometers cannot tell the field archaeologist whether a floor surface has been exposed; there is no single measurement that indicates "floor," and the compaction levels expected of floor surfaces will vary across sites and regions owing to varying formation processes and sediment composition. Rather, these instruments afford the collection of an additional dataset that can be evaluated in tandem with other observational and tactile data for purposes of determining whether a surface exhibits the compaction expected of a floor and thus is a better candidate for context-sensitive sampling. In some ways, pocket penetrometer data reinforced interpretations at Welqámex that were already compellingly supported by other datasets. However, we found pocket penetrometers to be especially useful when excavating in the interior margins of residential dwellings and where floor surfaces were very clean and rarely exhibited features. That is, in circumstances where we were challenged in the task of identifying floors in non-contiguous excavation units and for the purpose of scraping sediment samples for macrobotanical and microartifact analyses, pocket penetrometer data proved to be critical for making strata deter-

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minations. As such, we recommend the incorporation of the pocket penetrometer into the repertoire of basic archaeological field tools and data-recording protocol, especially in circumstances where application of special sampling protocol requires field investigators to expose, but not remove, floor surfaces.

Importantly, our findings are derived from and inherently limited by conventional archaeological methods and some degree of data interdependence. Future research addressing the analytic utility of pocket penetrometers should incorporate a combination of geoarchaeological and experimental archaeological data recovery techniques. For example, a micromorphological study of column samples from Welqámex houses would offer an independent dataset for assessing the extent to which pocket penetrometers can detect the appearance of floor surfaces. Similarly, greater attention to standardized documentation of sediment properties, such as strength, plasticity, and stickiness (e.g., see Hodgson 1978), may result in even more comparable pocket penetrometer measurements. Coupled with a research design in which, for example, an earthen floor is experimentally constructed and trampled, geoarchaeological research will likely demonstrate the fullest potential as well as key limitations in applying pocket penetrometers to archaeological investigations.

Lastly, we recognize that the ways that archaeologists document house floors vary widely by region and are as much shaped by historically situated traditions of "doing" archaeology as they are by the scope and goals of the research being conducted. Whereas some attributes of floor surfaces are codified in a way that facilitates intra- and inter-site comparisons (e.g., sediment color determinations using Munsell charts), others are documented using relative and subjective coding schemes. This tends to be true for sediment compaction, a tactile attribute that is often characterized in terms such as "low," "moderate," and "high" or variations thereof. Nevertheless, the comparability of such scales ultimately hinges on fieldworker training and experience. Indeed, identification of floors is often an exercise in recursive, in-the-moment applications of inductive and deductive logic, much of which is rooted in wisdom accumulated over multiple seasons of archaeological fieldwork. Pocket penetrometers can aid field workers by providing quantifiable measures of compaction in place of subjective assessments. In turn, this approach can greatly aid non-participating archaeologists by providing a means for evaluating and calibrating qualitative assessments of sediment compaction and thus reducing some of the guesswork often involved in interpreting field notes.

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Data Availability Statement

Compaction measurements documented with pocket penetrometers during subsurface investigations of in-ground architecture at Welqámex are on file and accessible in the Stó:lō Nation Library and Archives, searchable online at http://stolonation.pastperfect-online.com/37241cgi/mweb.exe?request=ks. Digital and physical materials for this project are housed in a file with the same name as the publication and also searchable by author(s), publisher, and key words.

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NOTE

1. In 2014, pocket penetrometers retailed for approximately $50–60 USD. We purchased ours for about the same cost from Forestry Suppliers (forestry-suppliers.com) in 2008.

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