ASSESSING THE UTILITY OF GROUND PENETRATING RADAR IN ARCHAEOLOGY ON THE NORTHWEST COAST: THE 'NEW WAVE', 'ALL SNELL', OR 'IT JUST HERTZ'?

by

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Abstract

This project investigates the application of ground penetrating radar (GPR), a remote sensing geophysical survey method, to the archaeological investigation of earthen architecture on the Northwest Coast of North America. The objective of this thesis is to assess the ability of GPR to detect and distinguish between architectural features within an earthen matrix, and to understand the limitations and uncertainties of the method in this and similar contexts. This thesis also assesses the ability of GPR to provide data that are able to contribute to broad anthropological questions of demographic change and socio-political complexity. GPR was used at *Welqámex* (DiRi-15), a Stó:lō-Coast Salish settlement near Hope, British Columbia, to collect nearly 1,000 m^2 of data over a minimum of 11 structures. GPR data were analysed with comparison to surface and subsurface data from *Welqámex*, including excavation data collected prior to and following GPR survey. The survey identified 157 anomalies that may be useful in guiding future excavations. Direct comparisons of GPR reflection profiles and amplitude slices with excavation stratigraphic profiles and plan views indicate that GPR is moderately successful in detecting *sqémél* floors, *s'iltexwáwtxw* floors, and pit features larger than 15 cm in diameter, but is not successful in detecting post and stake mold features larger than 15 cm in diameter, hearth features, and structure boundaries. The anomalies produced from these features, however, are not easily distinguished from one another or from other natural and archaeological features. The results suggest that while GPR is able to identify anomalies that may be useful in guiding archaeological excavation, it is at this time not an ideal method for addressing broader anthropological questions on its own.

Preface

This research project is affiliated with on-going archaeological investigations at the site of *Welqámex* (DiRi-15) under the direction of Dr. Anthony Graesch (Connecticut College; formerly UCLA and the Cotsen Institute of Archaeology) and Dr. David Schaepe (Stó:lō Research and Resource Management Centre). The project was conducted with the permission of Chawathil First Nation, under Stó:lō Heritage Investigation Permit #2010-46. Excavation data were made available for review and comparison by the project directors. Maps in this thesis were rendered from survey data collected by Sue Formosa, Anthony Graesch, David Schaepe, and field school students and volunteers (2003-2011).

The GPR equipment used for this project (a Sensors & Software PulseEKKO Pro) is owned by the University of British Columbia's Laboratory of Archaeology, and was acquired under a Teaching and Learning Enhancement Fund (TLEF) grant awarded in 2008/2009 to Andrew Martindale, Sue Rowley, Leona Sparrow, Hector Williams, and Steve Daniel.

This thesis heavily references the project permit report (Dojack 2012a) and a teaching guide to GPR for archaeologists (Dojack 2012b). For more detail on either the GPR at *Welqámex* or the use of GPR in archaeology, the reader is directed to these sources. The possible subterranean tunnel (see Chapter 4) was initially reported at the 2011 Society for American Archaeology Annual Meeting in Sacramento, California (Graesch et al. 2011).

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Acknowledgments

First and foremost, I'd like to thank my committee: Mike Blake (supervisor), Andrew Martindale, Anthony Graesch, and David Schaepe. I cannot envision a finer set of individuals to guide me along this journey, and I cannot thank them enough for the countless hours they've devoted (both individually and collectively) to discussing and commenting on all aspects of this project, from fieldwork to labwork, and from analysis to writing and editing. This thesis would not have been possible without their support, advice, and mentorship.

Mike Blake has been a constant source of support and encouragement from the moment I first set foot in UBC's Anthropology Department. I am especially grateful for the freedom he's given me to pursue this project and tackle some of its more difficult problems, and for his patience and willingness to help when I found those obstacles too difficult to overcome on my own. His comments, suggestions, and guidance have been invaluable to both this project and my growth as a scholar and an archaeologist.

Andrew Martindale introduced me to GPR at UBC, and provided me with the opportunity to advance my GPR knowledge and skills, through both an excellent seminar course on GPR in archaeology, and through applied experience at a number of projects in the Lower Mainland. My views on GPR in archaeology have grown out of numerous challenging and thought-provoking discussions with him on GPR theory and practice. I cannot thank him enough for these opportunities, for the time he dedicated to me, and for his willingness to share his knowledge and experience.

Anthony Graesch – what can I say? Aside from his support and encouragement (beginning well before this project came into existence) and his dedication to teaching (both as field school instructor and mentor), Anthony brought an incredible drive, commitment, and sense of humour to all aspects of this project, from leading the charge for more data collection to ferrying GPR equipment across the river (and sometimes leaving mutinous fieldworkers behind). I cannot thank him enough for all the knowledge he's shared, and for five summers of fieldwork that was so much fun it should have been criminal.

Dave Schaepe has also been supportive of my archaeological endeavours from before the start of this project, and has been an invaluable source of information on Stó:lō archaeology, ethnography, and history. I'm particularly grateful for his assistance in presenting the proposed project to the Chawathil Chief and Council and applying for a permit to carry out the work, and for the opportunity to continue archaeological work in Stó:lō traditional territory with the Stó:lō Research and Resource Management Centre.

This project could not have been conducted without the support of Chawathil First Nation, especially the past and present Chief and Council: current Chief Ruth Peters, Vice Chief Deanna John, and Councillors Peter John, Shane John, Bobbi Peters, Rose Peters, and Tim Peters; and former Chief Ron John and Councillor Monica Florence. Many thanks to all those who have shown an interest in GPR and archaeology at *Welqámex*, in particular Rose Peters, for helping to organize an information session to share what I've learned with the community, and Viola John, for her role in managing the Telte-Yet campground and making it a welcoming home base for the summers I've worked on the project.

A special thanks goes out to the field crews for the 2010-2011 archaeological investigations at *Welqámex*. These students, volunteers, lab directors, and research assistants helped push, pull, drag, and tow UBC's GPR a grand total of 19,279 m through an obstacle course of vine maples, fallen trees, stumps, archaeological features, and general unyielding terrain. Those hard-working students of the 2010 *Welqámex* field school are Joey Chang, Ta-Yi Chiang, Erica Dirks, Kim Eng, Sarah Folz, Katherine Kuprenas, Jacob Oppenheimer, Kyle Rasmusens, Adriana Rodriguez, Hilary Taylor, Eevee Valenzuela, Fionnagh Walker, and Crystal Wiens. Anna Antoniou and Jillian Levi also provided much needed field support that season (on top of their regular duties as lab directors), as did Autumn Cool and Kay Hullet, who generously volunteered their time to the *Welqámex* archaeological project (and some GPR survey) in 2010. The remainder of the field crew was made up of a very special group of research assistants from Chawathil First Nation. I'm honoured to have had the opportunity to work with Jordan Chapman, Sarah

Ewen, and Ciara John, all of whom eagerly put their minds and bodies to the task of GPR survey in 2010. Sarah returned to lend her hand again in 2011, along with Kelsey John. And no one would have survived without the great meals provided by our chef Christopher Bonora.

In addition to the field crew that directly helped in GPR data collection during the summers of 2010 and 2011, I need to thank past field school students, volunteers, research assistants, and others involved in archaeological investigations at *Welqámex*, some of whom I've had the opportunity to work with in the four summers I spent on Greenwood Island, and others who I've never met. This project would certainly have been much more difficult (if not entirely impossible) without the wealth of surface survey and excavation data they provided and that I used to verify my GPR survey results.

A very special thanks needs to go out to my unofficial 'technical support' team. These four individuals provided assistance with some of the most difficult aspects of this project that would have left me tearing my hair out if I'd had to conquer them on my own. Andrew Martindale and Steve Daniel got me off to a running start with GPR and continued to provide GPR-related advice and support (including shipping in a cable from Toronto when the one I was using failed early in my first field season). Mike Blake and Sue Formosa (the undisputed mapping goddess) helped me navigate the world of total station survey and ArcGIS mapping. I cannot thank them enough for their patience and willingness to help me as I struggled with topographic correction while juggling multiple mapping and geophysical analysis programs.

While not directly tied to this project, I feel the need to acknowledge those other groups and individuals who have given me the opportunity to gain more experience with GPR. Additional GPR projects that I have been involved and have helped to broaden my knowledge on the subject include surveys at St. Mungo (DgRr-2) with Musqueam First Nation and Andrew Martindale at UBC, at Dionisio Point (DgRv-3 and DgRv-6) with Penelakut First Nation and Colin Grier at Washington State University, and at other locations in the Lower Mainland with Musqueam First Nation, Skowkale First Nation, Kwantlen First Nation, and Matsqui First Nation. I'd also like to thank my uncle and aunt, Tom Grozier and Wendy Grozier, for allowing me to conduct controlled GPR experiments that involved burying all manner of materials (mostly bits of garbage) in their backyard.

My knowledge about GPR, archaeology, anthropology, and all things Coast Salish has been greatly expanded through discussions with numerous students and professors at UBC. I thank my fellow grad students, Steve Daniel, Peter Merchant, and Chris Arnett, for many thought-provoking and stimulating discussions both in class and in the field (and other less formal settings). Many thanks also to Bruce Miller, Zhichun Jing, Brian Chisholm, Mike Richards, Bill McKellin, and Shaylih Muehlmann, for introducing me to such a wide range of topics and encouraging me to pursue even more. I'd also like to thank UBC's Laboratory of Archaeology for allowing me the opportunity to use their GPR, and Patricia Ormerod, for helping to arrange for the GPR and other equipment I used in the field.

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1 Introduction

This thesis investigates the application of remote sensing ground penetrating radar (GPR) to the archaeological investigation of earthen architecture on the Northwest Coast of North America. The project employs GPR at the site of *Welqámex* (DiRi-15), a Late to Contact/Colonial period Stó:lō-Coast Salish settlement near the modern town of Hope in the Upper Fraser Valley of British Columbia.

The objectives of this project are broadly twofold. First, it aims to assess the applicability of the GPR method to the study of Northwest Coast household archaeology and, in particular, to assess the ability of GPR to detect and distinguish between architectural features within an earthen matrix, including house floors, midden deposits, postholes, benches, storage pits, and hearths; and to understand the method's limitations and uncertainties in this and similar contexts. Second, the project aims to assess the ability of GPR to provide data on the spatial layout and organization of Stó:lō-Coast Salish architecture, which can contribute to the analysis of socio-political complexity, changing economic relations, multiple building phases, and demographic changes, both at the site of *Welqámex* and in the broader Coast Salish culture area.

The greatest contribution of this project is likely to be methodological, in that it aims to develop GPR, a method that has had little exposure as of yet on the Northwest Coast, for the archaeological investigation of households. More broadly, the project can be seen as a test of the GPR method, the utility of which can be evaluated through direct comparisons to subsurface data. This project also has the potential to make significant archaeological contributions at *Welqámex*, and on the Northwest Coast in general, in the form of information on Northwest Coast architecture, which can be used to address broader anthropological questions of emerging socio-political complexity, changing economic relations, and spatial and social organization. In addition to its archaeological and methodological contributions, the anticipated future use of GPR in Stó:lō-Coast Salish territory can help archaeologists in this area to remain in compliance with the Stó:lō Heritage Policy (Stó:lō Nation 2003), which promotes protecting, preserving, and researching Stó:lō heritage and minimizing site impacts.

This thesis has five chapters: Chapter 1 provides background information on GPR theory, applications in archaeology, and Northwest Coast household archaeology; Chapter 2 describes data collected and methodology for analysis; Chapter 3 examines GPR detection thresholds through direct comparisons between GPR data and subsurface excavation data; Chapter 4 focuses on the ability of GPR to identify a range of specific architectural features present in Northwest Coast archaeological sites; and Chapter 5 provides a discussion on the applicability of GPR to Northwest Coast household archaeological research, and contributions of the project to Northwest Coast household archaeology in general, and the site of *Welqámex* in particular. Additional data pertaining to this thesis can be found in supplementary documents: the permit report produced from the project (Dojack 2012a), and a review paper on GPR theory, data collection, processing, and interpretation (Dojack 2012b).

1.1 Ground Penetrating Radar Theory

Ground Penetrating Radar (GPR) is a remote sensing geophysical prospection method that operates on the same principles as the radar equipment used in navigational systems.[1] Two antennae, the transmitter and the receiver, are located at the ground surface. The transmitter emits a pulse of electromagnetic (EM) radio waves into the ground. As these EM waves travel through the subsurface, their physical properties and direction of movement are altered as they encounter differences in subsurface materials. Any subsurface discontinuity can affect the EM wave, including voids, interfaces between different material types, and localized point sources. Material properties that strongly influence the EM wave form include water content, lithology, density, porosity, and electric/magnetic properties.

When EM waves encounter subsurface discontinuities, part of the EM wave is refracted (or bent) and continues to propagate until it is reflected or dissipated, and part of the wave is reflected back to the surface, where it is collected by the receiving antenna. Data are collected in traces, which represent the total wave form collected at a single surface location. Depth measurements are calculated based on two-way travel time (the

[1] For a comprehensive discussion of electromagnetic theory as it relates to GPR and the effects of subsurface materials on electromagnetic (EM) waves, refer to the review paper by Dojack (2012b), or see Annan (2009), Cassidy (2009b), Conyers (2004), and Leckebusch (2003).

time it takes for the EM wave to travel from the transmitter to a subsurface discontinuity, then back to the receiver) and the velocity of the EM wave through the subsurface. When travel time is converted to distance and the precise locations of traces are known, images can be produced that detail the shapes, sizes, and depths subsurface features.

1.2 Ground Penetrating Radar in Archaeology

Geophysical survey, including GPR, has become increasingly common in archaeological research since the early 1990s, and is currently being incorporated into projects worldwide (e.g., Conyers 2011; Goodman et al. 2007). Its surging popularity has been boosted by technological advancements that make data easier to collect, process, and analyse. GPR survey can cover large areas (as much as 2500 m^2 in a single day, as per Conyers 2004:12; see Ernenwein and Kvamme 2008 for 1.6 ha and 1.2 ha surveys), and when undertaken prior to excavation, can provide high-quality three-dimensional imagery of subsurface features useful in guiding further research, thereby maximizing efficiency while minimizing cost and site impact. Increasing interest in site preservation has also encouraged the pursuit of alternatives to excavation, which is inherently destructive by nature. GPR and other geophysical methods provide a means of conducting non-invasive, non-destructive research, the benefits of which include preserving the integrity of site deposits and providing opportunities to pursue research questions that are otherwise difficult or inappropriate to answer with traditional archaeological excavation methods.

While GPR is most frequently used as a prospection method to identify subsurface anomalies of interest and areas for further research (e.g., Bonomo et al. 2010; Creasman et al. 2010; Lasaponara et al. 2011; Yalçiner et al. 2009), recent shifts in geophysical archaeology have elevated GPR and other geophysical methods beyond their role as a supplement to more traditional archaeological excavation methods. Conyers and colleagues have encouraged archaeologists to integrate GPR with archaeological research design, and to develop theoretical perspectives, which can be used to address broader anthropological questions. For example, they use large-scale GPR surveys to examine the Chaco sphere of influence in the American Southwest and social differentiation and urban planning in Petra (Conyers 2010, 2011; Conyers and Leckebusch 2010). Barone et al. (2011) have followed suit, using GPR to examine the distribution of elite housing in suburban areas of Pompeii and theorize about suburban and economic growth. In general, however, GPR remains supplementary, with no concrete theoretical perspective guiding much GPR research, though attempts have been made to link GPR studies with landscape archaeology (Kvamme 2003) and persistent places (Thompson et al. 2011).

GPR has experienced considerable success in the American Southwest and Mediterranean regions (e.g., Conyers 2010; Negri and Leucci 2006, Piro et al. 2007), where stone architecture in a sand matrix makes for easily resolved target features. In these regions, it is not uncommon for GPR surveys to produce blueprint-like images of stone walls and building foundations, with individual rooms clearly visible (e.g., Gaffney et al. 2004; Neubauer et al. 2002; Piro et al. 2003). A wide range of architectural features have been detected by GPR in these environments, including structure walls, floors, and foundations of varying material types (e.g., Bini et al. 2010; Conyers 2009; Nuzzo et al. 2009). The feasibility of using GPR to identifying these and other archaeological features has been discussed by Conyers (2004) and Kvamme (2008).

In addition to its use in detecting architectural features, GPR has been regularly applied in both archaeological (e.g., Böniger and Tronicke 2010; Forte and Pipan 2008; Lorenzo and Arias 2005) and forensic (e.g., Conyers 2006; Doolittle and Bellantoni 2010; Ruffell et al. 2009) contexts to identify unmarked human burials. Some of this research has been undertaken by the University of British Columbia's Laboratory of Archaeology, where GPR has been used to identify unmarked burials in First Nations cemeteries in southwestern British Columbia (e.g., Martindale 2009, 2010, 2011; Martindale and Daniel 2008). Forensic applications in particular have yielded indispensible data from controlled experimental studies (e.g., Schultz 2008; Schultz et al. 2006; Schultz and Martin 2011), which are critical in furthering our understanding of the ability of GPR to detect subsurface features.

To date, the use of GPR on the Northwest Coast of North America has largely focused on applications involving the search for unmarked burials. This seems to be part of a global trend, whereby earthen and wooden architecture has been neglected by geophysically-minded archaeologists in favour of a stronger focus on the high resolution data provided by 'stone-in-sand' architecture. GPR studies of earthen architecture have been conducted successfully at sites in the United States, imaging such features as living surfaces, structure margins, post holes, and hearths (e.g., Arnold et al. 1997; Dalan et al. 2011; Kvamme 2008; Weaver 2006). Such studies suggest there is potential for the application of GPR at *Welqámex* and on the Northwest Coast.

Closer to this project's study area, GPR has been used at the Bridge River site (EeRl-4) in the Fraser Canyon (150 km north of *Welqámex*) to survey 200-1800 year old pit houses (Prentiss et al. 2008a, 2008b, 2009, 2010); however, these surveys were conducted in a climate considerably drier than encountered at *Welqámex*. GPR has also been used to survey house depressions in a shell matrix at the McNichol Creek site (GcTo-6) on the North Coast (800 km northwest of *Welqámex*) (Cross 1996), but again, these surveys were undertaken in a different environment than *Welqámex*, in this case, considerably wetter. GPR surveys of plank houses at Shingle Point (DgRv-2) in the Gulf Islands (150 km west of *Welqámex*) (Cross 1995; Matson 2003) are also difficult to compare, in that they were undertaken in a coastal shell midden context. Given the markedly different environmental conditions under which these surveys were conducted, it is difficult to use their findings for guidance in the current study.

1.3 Stó:lō-Coast Salish Architecture

Current knowledge regarding Stó:lō-Coast Salish architecture is derived from a combination of sources, including archaeological investigations, ethnographic accounts, and written and oral historical sources, both from the Coast Salish culture area and the broader Northwest Coast region. In general, sources agree on two basic 'types' of permanent dwellings: in-ground *sqémél* (pit houses) and on-ground *s'iltexwáwtxw* (plank houses)[2]; however, there is considerable variation within and between the two types (Barnett 1955:35-58; Lepofsky et al. 2009:616; Schaepe 2009; Smith 1947:265-266).

Sqémél, or pit houses, are circular to rectilinear semi-subterranean structures excavated into the ground. Using ethnographic data, Graesch (2006) suggests that they can be loosely divided into two broad types, distinguished generally by differences in roof construction. Type 1 *sqémél* featured a domed earthen roof constructed over a thin wooden shell, supported by vertical or angled poles at the perimeter of the structure and

[2] *Sqémél* and *s'iltexwáwtxw* are the Halq'eméylem words for pit house and plank house. Halq'eméylem is the upriver dialect of Halkomelem, the language traditionally spoken by the Stó:lō.

one or four posts near the centre. Type 2 *sqémél* featured a flat or angled solid roof constructed from poles, brush, or planks laid over a ridgeline pole supported by two or three poles across the midline of the structure. The ridgeline pole may not have been necessary in smaller structures, and the entire roof may have been covered with earth. In both structure types, there is variation in the number and locations of support posts, with some accounts suggesting no posts were placed directly in the structure floor. Floors and benches were generally shaped from the excavated soil, but were sometimes planked, and hearths were centrally located. Entrance was generally from a ladder in the roof or from a sloping gangway at the side, and subterranean tunnels connected to adjoining structures or for escape out the rear were also present. *Sqémél* varied greatly in size, with ethnographic accounts detailing structures ranging 4.5-10.7 m in diameter and 1.2-3.0 m in depth (Barnett 1944:265-268, 1955:49-55; Duff 1952:47; Schaepe et al. 2001:44-46; Smith 1947:257-258)

S'iltexwáwtxw, or plank houses, are on-ground wooden structures which, like *sqémél*, can be divided into two broad types by differences in roof construction, based on ethnographic accounts. Shed roof houses featured roofs with a single slope, the higher side at the water-facing front of the house, while gabled roof houses featured two sloping portions meeting at a central peak. The frame of both structure types featured rafter support posts up to 90 cm in diameter set into the ground at or near the structure perimeters and, in the case of especially wide houses and gabled roof houses, in the centre. Smaller poles filled the gaps between the large support posts, and were used for lashing wall planks. Entrances were located via doors at the middle or corner, at the front and rear or at each end in smaller structures, or at intervals along all four sides in larger structures. The structure perimeter was lined by 1-3 m wide raised plank benches on at least two sides. Floors were either earthen or planked, and were in some cases slightly excavated (Barnett 1955:35-38, 47; Duff 1952:47; Hill-Tout 1978:47; Lamb 2007:123; Schaepe et al. 2001:42-43; Smith 1947:264; Suttles 1991:212-214).

Unlike the more permanent *sqémél*, s*'iltexwáwtxw* (the shed roof type in particular) are recognized as highly fluid, and could be easily extended or contracted to accommodate varying numbers of occupants. This feature might account for the considerable regional variation in structure style noted by Barnett (1955) and Hill-Tout

(1978). Structures were either single-unit or multi-unit, and varied in size from 10-210 m in length and 3-10 m in height. Interior family-owned spaces were generally determined by the spacing between house posts and were divided by hanging reed mats or screens. Hearths were family-owned and were placed along the midline in smaller structures, or in rows along the walls in larger structures. In the case of single-unit structures, a single hearth was centrally located (Barnett 1955:35-58; Duff 1952:47-48; Hill-Tout 1978:47; Lamb 2007:119, 123; Schaepe et al. 2001:42-43; Suttles 1991:214-216).

Archaeological research in the Upper Fraser Valley has examined the change in household size and construction over the past 5,000 years, noting a general increase in size and shift from early partially sunken structures to the later ethnographically documented *sqémél* and s*'iltexwáwtxw* (Lepofsky et al. 2009:616-617; Schaepe 2009; Schaepe et al. 2001). A sample of these include early permanent houses of the Middle Period (5500-3000 BP) at the Maurer site (DhRk-8; Schaepe 1998; LeClair 1973, 1976) and *X̲á:ytem* (DgRn-23; Mason 1994, Ormerod 2002); Late Period (3000-200 BP) *sqémél* and/or s*'iltexwáwtxw* at *Qithyil* (DhRl-15 and DhRl-16; Lepofsky et al. 2000, Morrison 1997), *Sxwóxwiymelh* (DiRj-1; Hanson 1973; Lenert 2007), and *Welqámex* (DiRi-15; Graesch 2006; Graesch et al. 2011); and Colonial/Contact Period (ca 200 BP) *sqémél* at *Ts'qó:ls* (DiRi-1; Arnold 2006, Arnold and Schaepe 2004) and *Welqámex*. Information on Coast Salish architecture from these projects has also been supplemented with data from other regions, including the pit house villages of the interior (Hayden 1997, 2000; Prentiss et al. 2005, 2008b) and long houses from other parts of the Northwest Coast (Ames and Maschner 1999; Coupland and Banning 1996; Coupland et al. 2009; Matson et al. 2003; Matson and Coupland 1995; Sobel et al. 2006), in particular the well-preserved remains of Ozette (Mauger 1978, 1991). These studies provide a sample of the variation in the architecture that could be encountered at *Welqámex*.

1.4 *Welqámex* (DiRi-15)

Welqámex (DiRi-15) is a Stó:lō-Coast Salish settlement located on Greenwood Island (Chawathil IR 3) in the Fraser River, near the town of Hope, British Columbia (Figure 1.1). The site has been the subject of extensive past investigations (Graesch 2006, 2007, 2009; Graesch et al. 2010, 2011; Lepofsky et al. 2009; Schaepe 2009), which are ongoing under the direction of Anthony Graesch and David Schaepe. The site has been dated to the Late to Contact/Colonial periods (AD 1300 – 1894), and includes a minimum of 12 in-ground *sqémél* (pit houses) and five on-ground *s'iltexwáwtxw* (plank houses), all located in the residential area (Zone 1) of the site. The site also includes a cemetery (Zone 2) and borrow-pit area with possible defensive features (Zone 3).

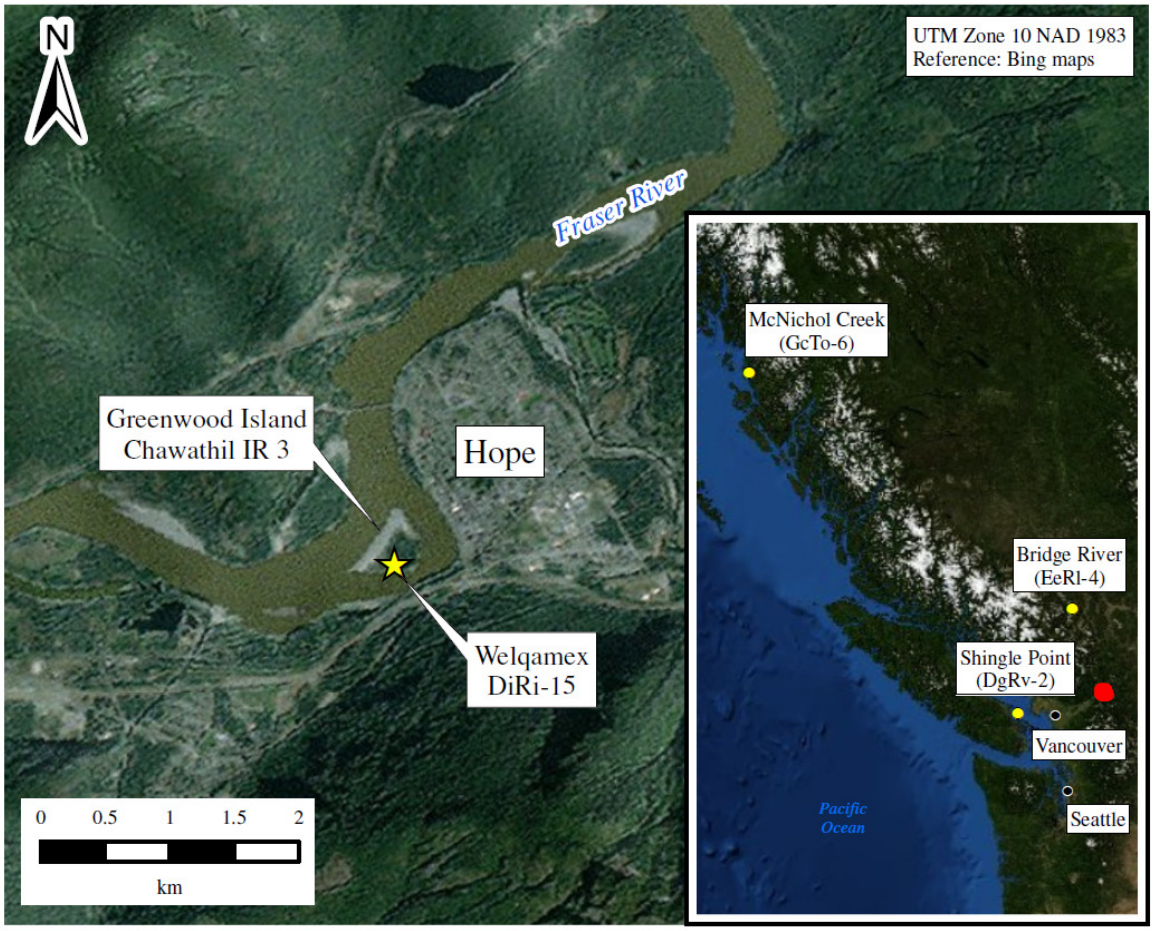

Figure 1.1 Map of Region showing *Welqámex* (DiRi-15)

The *sqémél* at the site consist of 'standard' circular *sqémél* structures and two unique rectilinear sunken *s'iltexwáwtxw* structures, with the largest measuring 16.25 m in length (Graesch 2006:71). *Sqémél* stratigraphy is generally characterised by organic and flood deposits in the upper 8-60 cm, overlying rim slump and roof deposits, with a compact floor or series of floors located directly above sterile deposits. Most Contact/Colonial period structures feature only a single floor, whereas Late period structures have a minimum of two floors, with as many as seven floors present in

Structure 7 (Graesch 2006; Graesch et al. 2011; Lepofsky et al. 2009). Multiple floors are separated by 2-3 cm of sand, and are not distinguishable near house perimeters (Graesch 2006:60). Topographic saddles located in the rims between Structure 1 and Structures 4 and 5 have been hypothesized as remnants of collapsed subterranean tunnels connecting these structures by Graesch (2006, 2007; Graesch et al. 2011; Lepfosky et al. 2009).

Less is known about the *s'iltexwáwtxw* at *Welqámex*. Investigations have focused on Structure 11, a *s'iltexwáwtxw* estimated to be 35-40 m in length, based primarily on surface survey data. Structure 11 stratigraphy is characterised by generally shallow organic deposits with little or no flood deposits, overlying discontinuous floors up to 15 cm in thickness (Graesch 2006:61). Structure 11 also partly overlies a second *s'iltexwáwtxw*, Structure 12 (Graesch 2006, Graesch et al. 2011). A wide range of architectural features have been identified in both *s'iltexwáwtxw* and *sqémél*, including series of compact floors, hearths, storage pits, postholes, stakes molds, and benches.

Welqámex was selected as an ideal site for testing the applicability of GPR to Northwest Coast household archaeology, based on the presence of at least three (and possibly more) types of major Stó:lō-Coast Salish architecture, coupled with extensive past investigations that provide a wealth of above-ground survey and subsurface excavation data for comparison with and verification of GPR data (but not so extensive as to render the results of a GPR survey irrelevant or significantly compromised). Concurrent field school investigations in 2010 also helped to minimize necessary ground-truthing to verify GPR anomalies, and planned future investigations will continue to provide data that can be used to further refine GPR interpretation on the Northwest Coast.

2 Data and Methodology

2.1 Ground Penetrating Radar Data

The methods utilized for GPR data collection, editing/processing, and visualization varied depending on survey location and goals. Only general methodology is presented below. For a full description of methodology employed for data collection, editing/processing, and visualization for individual GPR grids, refer to Dojack (2012a). For more information on GPR data processing, refer to a literature review by Dojack (2012b), or Annan (1999), Cassidy (2009a), and Conyers (2004:119-131).

2.1.1 Fieldwork: GPR Data Collection

Fieldwork for the project took place over approximately five weeks during the summers of 2010 (June 23-July 28) and 2011 (July 19-20). GPR data collection was undertaken in three phases: 1) a preliminary reconnaissance survey, 2) a ground-truthing experiment, and 3) a large-scale prospection survey. Data collection focused on three main areas across the site: 1) the locations of planned excavation units; 2) Zone 1 *sqémél*; and 3) Zone 1 *s'iltexwáwtxw* (Figure 2.1).

Preliminary reconnaissance survey was undertaken primarily to identify anomalies of interest that could be useful in placing excavation units for the ground-truthing experiment. The ground-truthing experiment focused on the five locations where excavation units were to be placed, following the preliminary reconnaissance GPR survey to identify anomalies of interest. These areas were largely selected to test previously unsampled structures at the site, including Structures 12 (*s'iltexwáwtxw*) and 13 (*sqémél*), and additional possible *s'iltexwáwtxw* features (Structures 15 and 16). Subsequent excavation of the surveyed areas provided data for direct comparison with GPR results.

Large-scale prospection surveys focused on two main areas: the *s'iltexwáwtxw* structures in the southern half of Zone 1, and the *sqémél* structures in the northern half of Zone 1. In the case of surveyed *sqémél*, GPR grids were generally placed bisecting the housepit feature through its centre, in order to capture both structure floors and central hearth features. In the case of surveyed *s'iltexwáwtxw*, GPR grids were placed over presumed structure footprints, with grids capturing probable exterior deposits, in order to aid in the identification of structure extents. Data collected in both areas can be compared with subsurface data from prior excavations at the site. Additional transects were collected in Zone 3 to act as control samples, as Zone 3 was considered to be the least modified portion of the site.

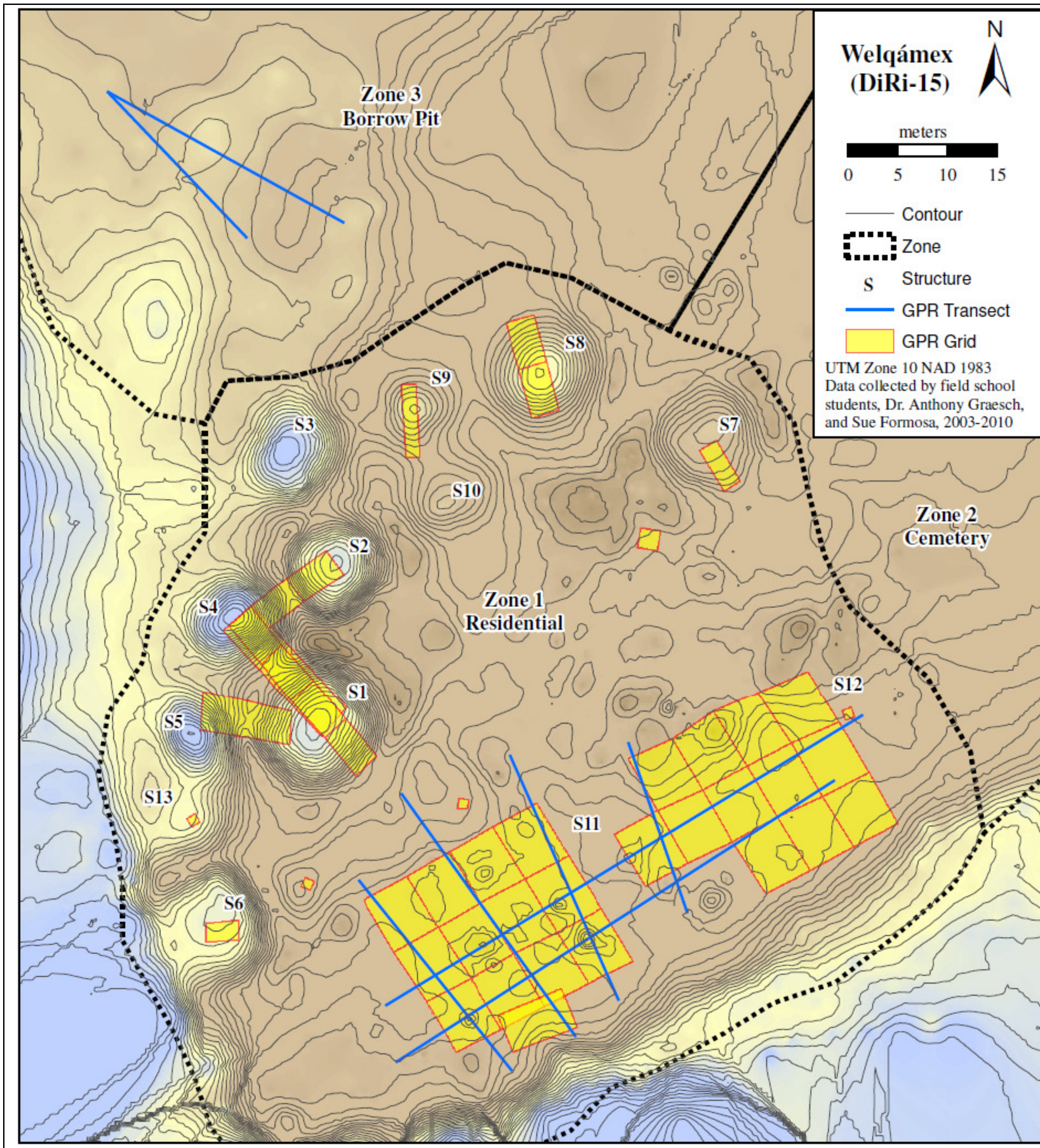

Figure 2.1 Map of *Welqámex* (DiRi-15) GPR Grids and Transects

Data were generally collected in grids (Figure 2.2). Local grid systems were set up over areas of the site selected for GPR survey. Grids were oriented with respect to architectural features, as determined from surface survey and subsurface excavation data. All grids were laid out with survey tape, and the corners were marked and later mapped with a Total Station. Transects were generally spaced 10 cm or 25 cm apart, and collected along both the x and y axes of each grid. A number of stand-alone transects were also collected across Zone 3 and the *s'iltexwáwtxw* in Zone 1. Protocols for data collection are similar to those used at UBC – LOA, as described in Daniel (n.d.).

Figure 2.2 Collecting GPR data at *Welqámex*: Sarah Ewen (left), and Crystal Wiens, Kim Eng, and Jordan Chapman (right)

Data were collected with UBC – MOA's PulseEKKO Pro GPR, from Sensors & Software. Data collection parameters varied depending on grid location and survey goals (for details about individual grids, see Dojack 2012a). In general, the survey employed 500 MHz antennae, providing depth imaging of up to 2.0 m. This was adequate for most areas of the site, where archaeological deposits are less than 1.0 m deep. Optimal data collection parameters were determined in part by an experiment conducted in the field prior to full-scale survey and alongside the ground-truthing experiment survey[3]. The experiment entailed the modification of specific parameters while keeping others constant

[3] The full results of the data collection experiment are discussed in Dojack (2012a).

(e.g., transect spacing, sampling interval, etc.) for the purpose of determining which parameters are best suited for GPR survey at *Welqámex*.

The following data collection parameters were determined in the data collection parameters experiment, and were generally used: 50 ns time window; 0.10 ns sampling interval; 500 points per trace; 0.02 m step size; and 4 stacks. A few grids over *sqémél* rim deposits were surveyed with 250 MHz antennae to achieve greater depths up to about 5.0 m. In general, data collection parameters for these grids include: 100 ns time window; 0.10 ns sampling interval; 1000 points per trace; 0.05 m step size; and 4 stacks.

2.1.2 Labwork: GPR Data Processing, Visualization, and Analysis

With the exception of work entailed in the ground-truthing experiment, most data editing, processing, and visualization took place in the lab. Data-editing and -processing steps varied depending on grid location and survey goals (for details about individual grids, see Dojack 2012a).

Data editing included, where necessary, line orientation, reverse, reposition, and merge, which was done in Sensors & Software's EKKO View Deluxe. Data were gridded in Sensors & Software's GFP Edit.

Data processing for reflection profiles was done in Sensors & Software's EKKO View Deluxe, and included the application of dewow, SEC gaining, bandpass filtering, background subtraction, rectify, depth conversion, and topographic correction. Data processing for amplitude slices was done in Sensors & Software's EKKO Mapper, and included dewow, background subtraction, attribute analysis (envelope), amplitude equalization, and depth conversion. Input parameters for processing of both reflection profiles and amplitude slices varied depending on grid location and survey goals (for details about individual grids, see Dojack 2012a).

Velocity analysis (necessary for depth conversion) was undertaken in the lab using hyperbola curve fitting. The velocity of the signal through the subsurface at *Welqámex* was found to range from 0.090-0.100 m/ns. These values were verified by comparison of GPR data with excavation profiles.

Data were visualized as both reflection profiles and amplitude slices. Reflection profiles are constructed from sequentially aligned traces, and provide images in the vertical plane, analogous to stratigraphic profiles. Amplitude slices are constructed from grids of aligned reflection profiles, and provide images in the horizontal plane, analogous to plan views. Viewed in combination, reflection profiles and amplitude slices provide three-dimensional data of the subsurface. True three-dimensional images (isosurfaces along constant amplitude values) were produced for some areas of the site, but were not used in data analysis, as they were found to be ineffective.

Analysis of the data collected is based on examination of individual reflection profiles and amplitude slices. For data collected as part of the ground-truthing experiment, GPR survey results were compared directly with excavation data. For data collected as part of the large-scale prospection survey of Zone 1, individual reflection profiles and amplitude slices were examined for anomalous areas. Identified anomalies were numbered, mapped in ESRI ArcGIS, and recorded in a database, including information on location (GPR grid #; local x/y/z coordinates within the GPR grid; and global UTM coordinates), reflector type (planar, hyperbolic, semi-hyperbolic, or dipping), amplitude (high, moderate, or low), continuity (local and global), horizontality (horizontal, dipping, undulating, or point source), other descriptive notes (e.g., concavity, convexity, geometry, relation to other identified anomalies, etc.), and possible interpretations.

2.2 Surface Survey Data

Surface survey elevations and plans of *Welqámex* were used for topographic correction and to roughly identify structure boundaries, so that GPR grids could be placed to best capture architectural features. Topographic data were collected from 2003-2011 using a Total Station (e.g., Graesch 2006). Approximately 8,000 data points were collected, covering an area of roughly 15,000 m^2.

2.3 Subsurface Excavation Data

Two types of excavation data were available for comparison: data collected prior to GPR survey, and data collected following GPR survey. Subsurface excavation data are vital to the success of this project, as they can be used for comparison with and evaluation of GPR survey results and for verification of velocity values attained through hyperbola curve fitting, allowing accurate depth conversion. Data collected prior to GPR survey in particular are helpful because they provide information about archaeological deposits at the site, which can be used to select appropriate GPR data collection parameters and to orient GPR grids in order to best capture architectural features.

Previous excavations at *Welqámex*, from 2003-2009, sampled approximately 35 m^2 of the site, including ten *sqémél* and one *s'iltexwáwtxw* (Graesch 2006; Graesch et al. 2011). Excavation by trowel followed discrete stratigraphic layers and arbitrary 10 cm levels to retain vertical provenience.

Data from concurrent excavations conducted in 2010 alongside GPR survey include five 1-x-1 m excavation units, two 25-x-50 cm test units, and one 50-x-50 cm test unit. These data were collected as part of Graesch's and Schaepe's continued field investigations at the site. The five 1-x-1 m excavation units were placed with guidance from preliminary GPR reconnaissance survey, over GPR anomalies of interest. The two 25-x-50 cm test units were placed specifically to test a pair of anomalies identified in full-scale GPR survey. The 50-x-50 cm test unit was opened following discontinuation of excavation at one of the 1-x-1 m excavation units, and its placement was aided by data collected from the full-scale GPR survey. Excavation procedures for these units were the same as for previous excavations at *Welqámex* (Graesch 2006, 2009).

3 Direct Comparisons with Excavation Data

Before an analysis of specific architectural features could be undertaken, data first had to be acquired and analysed to establish detection thresholds of GPR at *Welqámex*, thereby providing a baseline of stratigraphic layers and architectural features that had potential for detection at the site. In order to establish this baseline, GPR data were directly compared with excavation data collected following GPR survey (undertaken during the 2010 field school). Eight areas were selected for excavation following GPR survey, and placement of these units was guided by the survey results. Five of these areas (Units 2010-1 through 2010-5) were roughly selected by Graesch and Schaepe to satisfy research goals for the broader *Welqámex* household archaeological research project, with GPR used to guide the exact placement of the excavation unit. The remaining three (Units 2010-6 through 2010-8) were selected to test specific anomalies identified in the site-wide reconnaissance GPR survey.

3.1 Excavation Unit 2010-1 (1 x 1 m)

Unit 2010-1 was placed in a depressed area identified as a potential *sqémél*, following a preliminary GPR survey that identified a strong planar reflection at 1.10 m dbs (roughly consistent with the depth of other *sqémél* floors at the site). Excavation confirmed the presence of a floor at 1.10 m dbs; however, a second floor was found at 1.20 m dbs that was not identified in GPR data (see Chapter 4 section 4.2). In addition to the two identified floors, excavation uncovered five post molds, one of which was 20 cm in diameter and the remaining four 10 cm or less in diameter. GPR survey was unable to detect anomalies that could be correlated with any of the five post molds in either profile or slice view.

3.2 Excavation Unit 2010-2 (1 x 1 m)

Unit 2010-2 was placed to test for the presence of a possible *s'iltexwáwtxw* located to the northwest of Structure 11. Preliminary GPR survey over the area was unable to identify any distinct anomalies to further guide placement of the excavation unit. Excavations revealed a minimum of 23 distinct stratigraphic layers, with extremely dense accumulations of fire-altered rock below 25 cm dbs (interpreted as possible midden deposits and/or a roasting feature) and one compacted, floor-like surface at 80 cm dbs. This unit was not excavated to a culturally sterile substrate, and the basal depth of cultural deposits in this area of the site has yet to be determined. GPR survey produced a series of strong planar and dipping anomalies in profile, most of which are not continuous, and cannot be strongly correlated with any of the specific layers identified in excavation (Figure 3.1). One reflector is located at approximately 80 cm dbs in some profiles; however, it is not sufficiently distinct to distinguish from the other reflectors, and cannot be said with confidence to represent the putative floor identified during excavation.

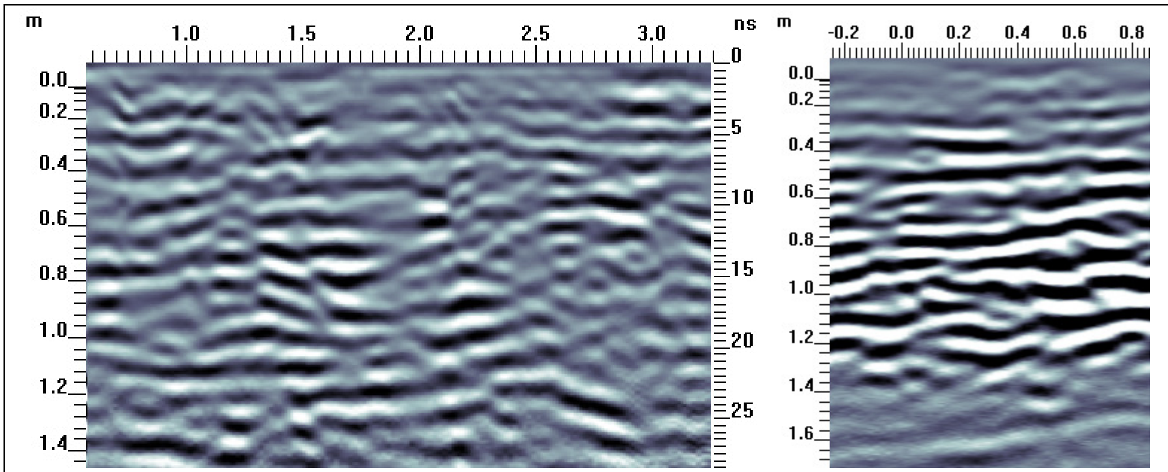

Figure 3.1 GPR profiles characteristics of FAR-rich midden/roasting pit deposits in Unit 2010-2, with possible living surface at 80 cm dbs

3.3 Excavation Unit 2010-3 (1 x 1 m)

Unit 2010-3 was placed to test for the presence of a possible *s'iltexwáwtxw* located to the north of the estimated boundary of Structure 11. Preliminary GPR survey over the area identified a strong planar reflection in profile and high amplitude anomaly in slice across the extent of the area at 50-55 cm dbs (Figure 3.2). Excavations revealed that the anomaly identified in GPR survey could be correlated with one of a minimum of three floors (located at 35 cm dbs, 50 cm dbs, and 55 cm dbs). Alternatively, the anomaly could be related to a highly compact pit-like feature located at 50 cm dbs. An additional four pits (located at 40 cm dbs and ranging from 15 cm to 40 cm in diameter) and nine stake molds (located at 45 cm dbs and generally less than 10 cm in diameter) could not be distinguished in the GPR survey results.

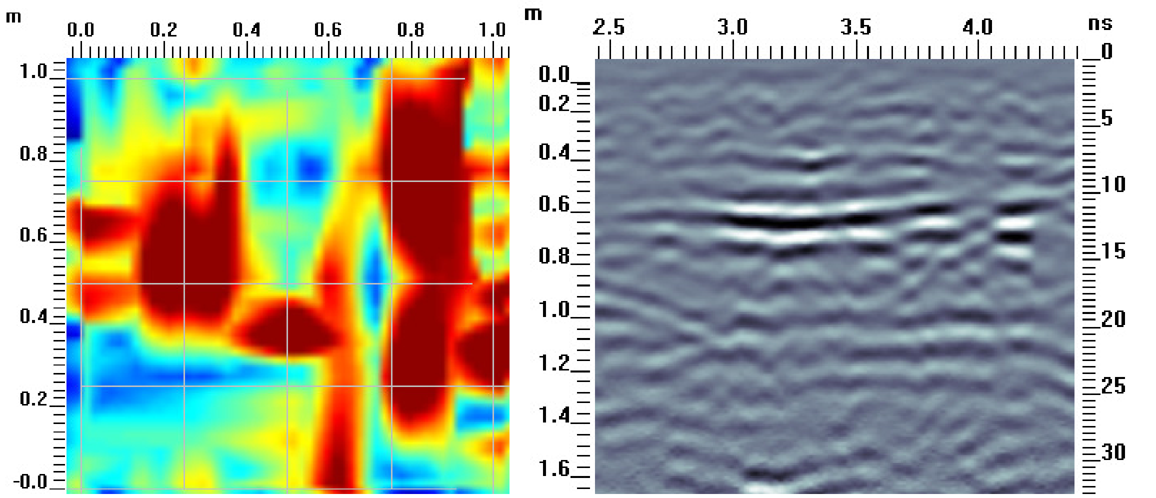

Figure 3.2 GPR profile (left) and slice (right) from Unit 2010-3, possibly related to a living surface or a high-compaction pit feature at 50-55 cm dbs

3.4 Excavation Unit 2010-4 (1 x 1 m)

Unit 2010-4 was placed to test for the presence of a possible *s'iltexwáwtxw* located to the rear of Structure 11. Preliminary GPR survey over the area identified four anomalies of interest: a pair of strong planar reflection across the extent of the area at 50-60 cm dbs and 80-100 cm dbs; a high-amplitude semi-circular planar anomaly (approximately 1.50 m in diameter) located at 70-100 cm dbs along the north boundary of the excavation unit; and one smaller high-amplitude anomaly located at 85-100 cm dbs in the southwest corner of the unit (Figure 3.3). Excavations revealed that the lower planar reflection and smaller southwest anomaly identified in GPR survey correlated with culturally sterile basal sand located below 80 cm dbs. The upper planar reflection correlates with the lower of two floors (located at 50-80 cm dbs; the upper floor is located at 25-55 cm dbs), as does the larger anomaly, which correlates with a particularly thick section of the lower floor at 80 cm dbs. Both floors are strongly sloping to a dip on the west wall, and this slope is visible in the GPR-identified floor. GPR was unable to distinguish four stake molds (less than 5 cm in diameter, located at 25-40 cm dbs), or a single cache pit (25 cm dbs, less than 10 cm of which was captured within the excavation unit). Slice images hint at a bench-like feature in the northwest corner at 10 cm dbs and adjacent depression in the southeast corner at 10-20 cm dbs (Figure 3.3).

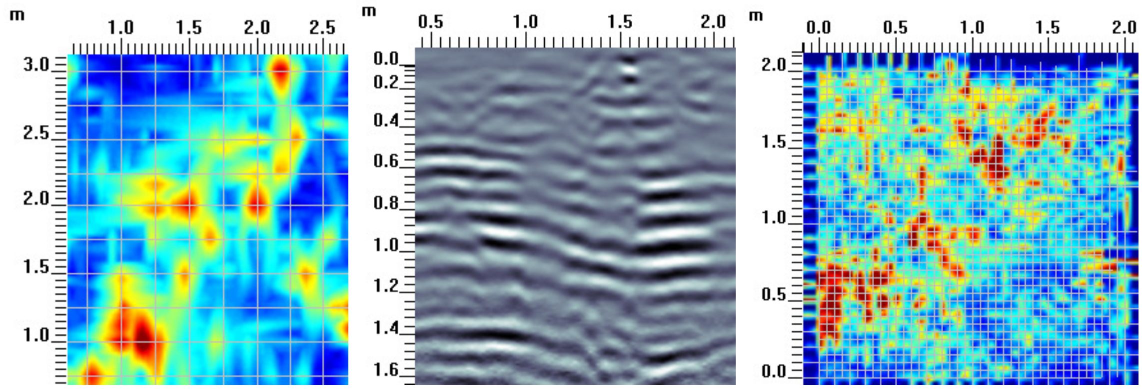

Figure 3.3 GPR slice showing high-amplitude anomalies and location of Unit 2010-4 (left), possible floors at 50 cm dbs and 80 cm dbs (middle), and possible bench feature in slice (right)

3.5 Excavation Unit 2010-5 (1 x 1 m)

Unit 2010-5 was placed specifically to test Structure 12, a *s'iltexwáwtxw* that had yet to be subsurface sampled. Preliminary GPR survey over the area was unable to identify any distinct anomalies to further guide placement of the excavation unit. Excavation revealed a floor at 10-20 cm dbs, several stake molds less than 10 cm in diameter, and a shallow burial beginning at 15-20 cm dbs (see Chapter 4 section 4.5). In addition, excavation uncovered three partial hearth/fire-affected earth features ranging in diameter from 5 cm to 30 cm. The GPR survey was unable to detect anomalies that could be correlated with the floor, stake molds, or any of the three hearth/fire-affected earth features in either profile or slice view.

3.6 Excavation Unit 2010-6 (50 cm x 50 cm)

Unit 2010-6 was opened as an alternative subsurface test for Structure 12 after excavation was halted at Unit 2010-5. GPR survey had been completed over the area by this time, and the unit was placed over an identified high-amplitude anomaly at 30-50 cm dbs (Figure 3.4). Excavation revealed a likely floor at 20 cm dbs and a series of laminar living surfaces (minimum of five) from 25-40 cm dbs. In addition, excavation uncovered an in-filled pit covered with a large green stone from 25-45 cm dbs. The high-amplitude anomaly identified in the preliminary GPR survey correlates well with the identified stone-covered pit; however, none of the floors could be definitively identified in GPR profiles or slices.

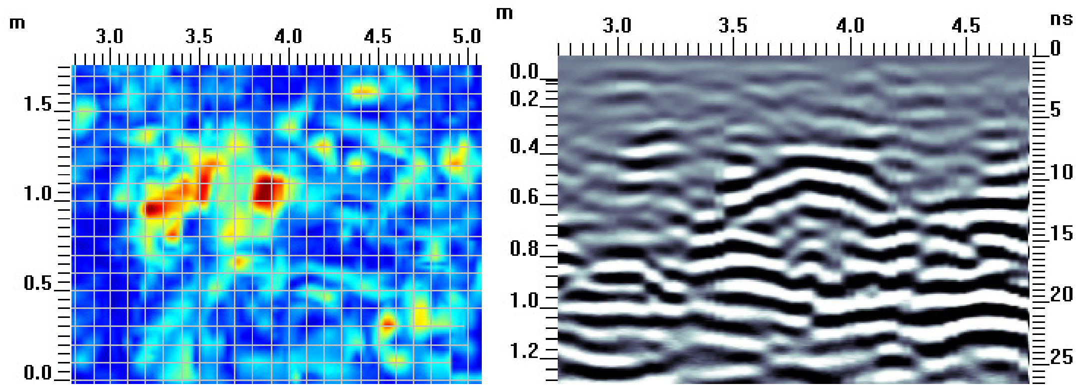

Figure 3.4 Unit 2010-6 high-amplitude hyperbolic anomaly ground-truthed as a stone-covered pit in slice (left) and profile (right)

3.7 Excavation Unit 2010-7 (50 cm x 25 cm)

Unit 2010-7 was opened to test a 4.5 m long high-amplitude linear hyperbolic anomaly identified at 20 cm dbs near the assumed western extent of Structure 11 (Figure 3.5). Excavation revealed the linear anomaly was the result of a tree root located at 20 cm dbs. In addition, excavation uncovered two possible floors at 15 cm dbs and 40 cm dbs, and a possible hearth/fire-affected earth feature at 35 cm dbs. The GPR survey was unable to detect the hearth/fire-affected earth feature or the upper floor, but a planar reflection located at 40 cm dbs correlates strongly with the identified lower floor.

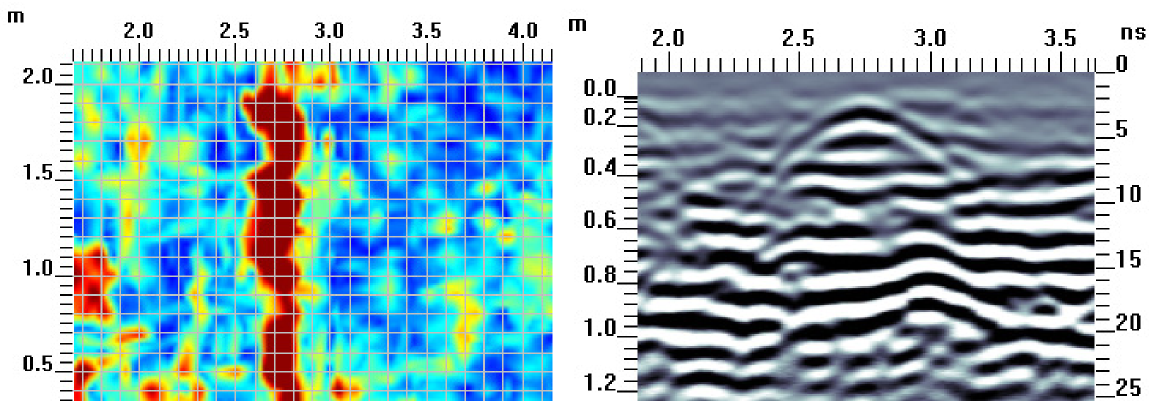

Figure 3.5 Unit 2010-7 linear anomaly ground-truthed as a root in slice (left) and profile (right)

3.8 Excavation Unit 2010-8 (50 cm x 25 cm)

Unit 2010-8 was opened in Structure 11 to test a low-amplitude anomaly believed to be a possible post hole (Figure 3.6), based on comparison to signals attained for post holes visible on the surface (see Chapter 4 section 4.4). Excavation revealed the presence of a possible pit feature starting at 15 cm dbs that correlates strongly with the identified anomaly. In addition, excavation uncovered a series of as many as five possible floors from 15 cm dbs to 35 cm dbs, none of which could be distinguished with confidence in GPR profiles or slices, though it is possible that a rough, discontinuous planar reflection located at 20 cm dbs could correlate with one of the known floors.

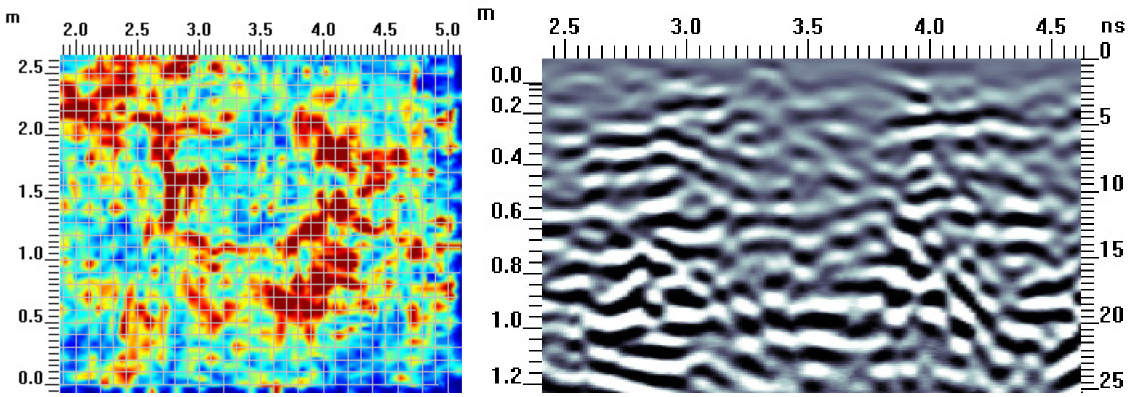

Figure 3.6 Unit 2010-8 possible pit feature in slice (left) and profile (right)

3.9 Summary

To assess the detection thresholds of GPR at *Welqámex*, an inventory of the number and type of features identified in excavation was compared with those detected by the GPR survey, via direct comparison to excavation data (Table 3.1). At first glance, the results are generally uninspiring: successes are seemingly limited to the detection of some floors and a few larger pit features.

Table 3.1 Comparison of features identified in excavation and GPR

Feature Type	# Identified in Excavation	# Identified in GPR Profiles/Slices	% GPR Success
Floor (*sqémél*)	2	1	50%
Floor (*s'iltexwáwtxw*)	20+	≤ 3	≤ 15%
Post/stake mold	23+	0	0%
Pit feature	8	≤ 3	≤ 38%
Hearth/fire-affected earth feature	4	0	0%

Detection of floors in *s'iltexwáwtxw* was hampered in part by shallow depths (with several floors located less than 20 cm dbs) and, in the case of multiple floors, extremely close spacing of less than 5 cm. Due to the detection limits of the 500 MHz antennae used for the surveys in these areas, anomalies close to the surface and closely spaced interfaces, such as those encountered in the *s'iltexwáwtxw*, are unlikely to be resolved.

Likewise, the 500 MHz antennae used for the survey are unlikely to resolve small objects, which explains the inability to successfully identify stake/post molds and pit features less than 15 cm in diameter. Indeed, the 500 MHz antennae selected for survey in the *s'iltexwáwtxw* may be one of the key limiting factors in detection and positive identification of smaller, near-surface, and/or closely spaced features. It may have been beneficial to conduct GPR survey at the site with 1000 MHz antennae, which would have been more likely to capture smaller, shallower, and more closely spaced features. Using 1000 MHz antennae, however, would have compromised depth of deposits resolved, as depth of EM wave penetration is conversely related to horizontal and vertical resolution.

While the success rates improved for larger features, many of these features were not detected, possibly due to insufficient contrast with surrounding deposits. In particular, GPR was not able to detect hearths/fire-affected earth features, despite the presence of large features that otherwise had strong potential for detection by GPR.

The results of the GPR survey are more promising when Table 3.1 is restructured to compare the number of features detected by GPR to the number of features encountered archaeologically that can be *expected* to be detected (Table 3.2). Features expected to be detected include those that are larger than 15 cm in diameter, located more than 20 cm dbs, and, with reference to floors, spaced more than 15 cm apart. For the purposes of these calculations, all floors spaced less than 15 cm apart have been counted as a single floor.

Table 3.2 Comparison of GPR-identified features and excavation features expected to be identified

Feature Type	# Identified in Excavation	# Identified in GPR Profiles/Slices	% GPR Success
Floor (*sqémél*)	1	1	100%
Floor (*s'iltexwáwtxw*)	8	≤ 3	≤ 38%
Post/stake mold (>15 cm diameter)	1	0	0%
Pit feature (>15 cm diameter)	5	≤ 3	≤ 43%
Hearth/fire-affected earth feature	3	0	0%

Regardless of the success of GPR in detecting floors and larger pit features, it should be noted that each of these feature types do not produce a single distinct anomaly that can directed correlated solely with that feature type and with no other feature type or other cultural or natural feature. That is, all GPR signals fall under one of two basic categories, planar reflections and hyperbolic reflections, both of which can be produced by a wide range of both archaeological and natural features that may be easily distinguished in subsurface testing, but are represented by the same signal type in GPR data. As was discovered in this exercise, it is difficult to interpret GPR anomalies without prior knowledge of deposits at a site or, in some cases, without direct comparison to excavation data, such as stratigraphic profiles.

4 Identifying Specific Architectural Features

One of the primary objectives of the project was to assess the ability of GPR to detect and distinguish between different architectural features at *Welqámex*, such as house floors and post holes, and to identify those features which GPR is most successful in resolving in this and similar contexts. For this part of the project, a large-scale prospection survey was undertaken, covering nearly 1,000 m^2 and providing over 19 km of GPR reflection profiles. The survey captured at least 11 structures, including nine *sqémél* and at least two *s'iltexwáwtxw*. Data were examined with an emphasis on identifying *sqémél* floors, *s'iltexwáwtxw* floors and boundaries, and post holes. The survey also tested a hypothesis regarding two subterranean tunnels connecting Structure 1 with Structures 4 and 5.

4.1 Control Samples

Two stand-alone transects were collected over Zone 3 to act as control samples of undisturbed stratigraphy at the site. Zone 3 was selected because it likely represents the least anthropogenically altered area of the site. This assumption is based on surface topography and a single subsurface test in Zone 3 by Graesch (personal communication) that identified no archaeological deposits. GPR survey over this area produced reflection profiles with no significant reflectors that could not be correlated with tree root disturbance (Figure 4.1). A moderate-amplitude planar reflection is visible in the upper 30 cm in some parts of the reflection profile, but it is not believed to be of archaeological significance, based on the results of the single subsurface test in the area, and is likely related to organic and/or flood deposits that are also present in other areas of the site.

4.2 *Sqémél* Floors

GPR survey at *Welqámex* sampled nine of the eleven identified *sqémél* at the site (Structures 1-2, 4-9, and 13). Data were collected over all nine tested *sqémél* with a 500 MHz antenna, and additional samples were taken over three *sqémél* (Structures 1, 2, and 4) with a 250 MHz antenna. The survey sought to identify house floors and other interior architectural features. House floors are expected to be more compact than surrounding deposits and therefore more reflective to EM waves, so they are expected to be visible in GPR reflection profiles as roughly horizontal planar reflections.

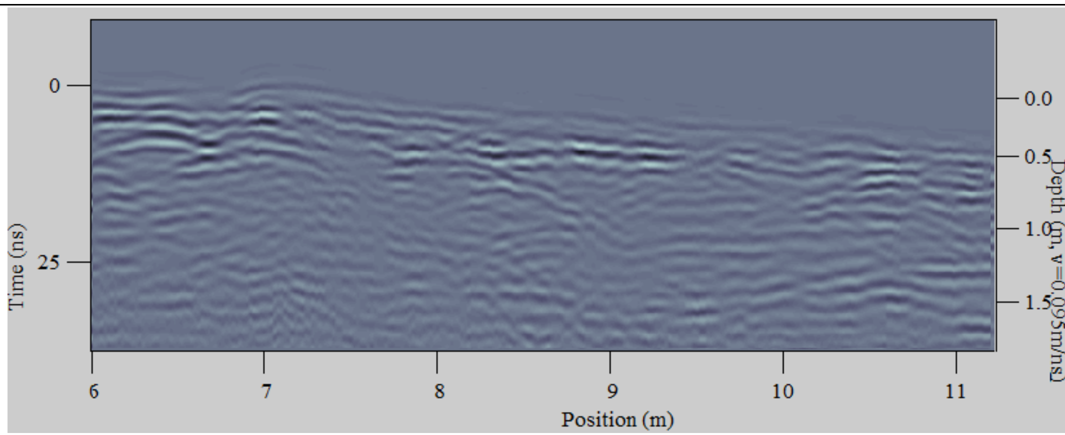

Figure 4.1 Control sample from Zone 3

House floors were identified as planar reflections in eight of the nine *sqémél* surveyed (Structures 1-2, 5-9, and 13), for a success rate of 89%. In all cases (including data collected with both 500 MHz and 250 MHz antenna), the floor was imaged in reflection profiles as a horizontal to sub-horizontal, moderate- to high-amplitude planar reflection (Figure 4.2). The interpretation of this anomaly was verified by comparison to excavation stratigraphic profiles. Floors encountered are generally continuous, with few signs of internal anomalies that could be correlated with internal architectural features. The majority of the internal anomalies identified could be easily correlated with disturbances from previously backfilled excavation units.

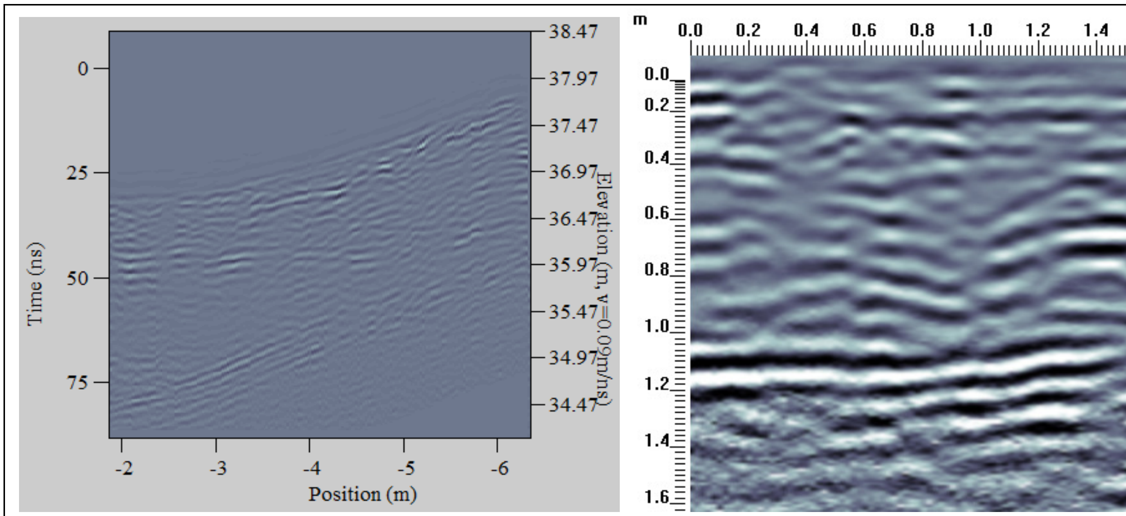

Figure 4.2 *Sqémél* floors from Structure 2 (left) and Structure 13 (right)

The success of GPR in identifying *sqémél* floor deposits is perhaps best demonstrated by a blind test conducted over Structure 13. The area was identified as a possible *sqémél* based on surface contours; however, no subsurface examinations were conducted to prior to GPR survey to verify this hypothesis. An area approximately 15 m^2 was surveyed near the centre of the structure, and a planar reflection was identified at a depth of 1.10 m. Subsequent excavation of the area (see Chapter 3 Section 3.1.1) verified the presence of a floor at a depth of 1.10 m.

Structure 4 is the only *sqémél* where floor deposits could not be easily distinguished in reflection profiles. One floor is documented in excavation data, occurring at around 70 cm dbs near the centre of the structure. A number of factors may have influenced the ability of GPR to resolve the floor in this structure. A large cottonwood is present near the centre of the structure, and the house floor may be affected by root disturbance. Structure 4 is topographically different than other *sqémél* tested in that it is bowl-shaped with steep rims. Other *sqémél* tested at the site are either shallower (e.g., Structure 9) or are more basin-shaped, with a nearly horizontal central pit surrounded by steep rims (e.g., Structure 6). The floor in Structure 4 may not have been resolved if the topography was such that the EM signal was reflected away from the receiving antenna and not collected. It is also possible that taphonomic effects may be a factor, or the chemical and/or physical properties of the floor in this structure may not be sufficiently distinct from surrounding deposits to produce a signal; however, excavation data suggest this structure is comparable to the other structures tested, based on overall floor compaction. In addition, it is apparent that 'ring-down' from the transition between flood and roof/rim slump deposits may obscure any signal collected from the Structure 4 floor.

GPR was unable to resolve multiple floors within individual structures. Of the nine *sqémél* sampled, three (Structures 1, 7, and 13) have more than one floor. In most cases, multiple floors within single structures are spaced less than 5 cm apart (Graesch 2006:60). This is below the minimum resolvable vertical distance for both 500 MHz and 250 MHz antenna, and the inability to detect multiple house floors is therefore a methodological as opposed to interpretive limitation. It seems unlikely that this issue could be resolved by increasing antenna frequency (and thereby decreasing minimum resolvable vertical distance), as this would also decrease the depth from which data could be collected. Given the general depth of *sqémél* floors at *Welqámex* (0.40-1.10 m), increasing the antenna frequency could mean risking the ability to resolve any floors, let alone multiple floors. Lower floors in structures with multiple floors may also be obscured by 'ring-down' from the uppermost floor.

4.3 *S'iltexwáwtxw* Floors and Boundaries

GPR survey of *s'iltexwáwtxw* at *Welqámex* focused on two large structures (Structures 11 and 12) in the southern half of the site. The primary goal of the survey over this area was to identify house floors and structure boundaries, as well as other interior architectural features. As with *sqémél* floors, *s'iltexwáwtxw* floors are more compact than surrounding deposits and are therefore more reflective to EM waves. They are expected to be visible in reflection profiles as roughly horizontal planar reflections. Structure boundaries are expected to be defined based on the extents of identified house floors.

The results of the *s'iltexwáwtxw* survey are less positive than the results of the *sqémél* survey. As expected, the survey imaged visible planar reflections in reflection profiles that correspond with archaeological deposits, including house floors. Similar planar reflections are not present in the control samples taken in Zone 3; however, GPR was unable to distinguish between house floors and other archaeological (or geological) strata. In some reflection profiles collected over the *s'iltexwáwtxw*, as many as four distinct planar reflections were identified (Figure 4.3); only two of these are expected to represent house floors, based on comparisons with subsurface excavation data.

Further, the identified planar reflections in the area of the *s'iltexwáwtxw* are not continuous, unlike the floors identified in GPR surveys of *sqémél*. This observation is supported by excavation data, which shows that floors and other archaeological deposits in Structures 11 and 12 are varying and discontinuous, and generally less compact or distinct than those in pit houses at the site. The variation in *s'iltexwáwtxw* floors may be related to the general shifting uses (both spatial and temporal) of *s'iltexwáwtxw*, as noted in ethnographic literature (e.g., Jewitt 1849), which would produce less distinct floors with lower compaction.

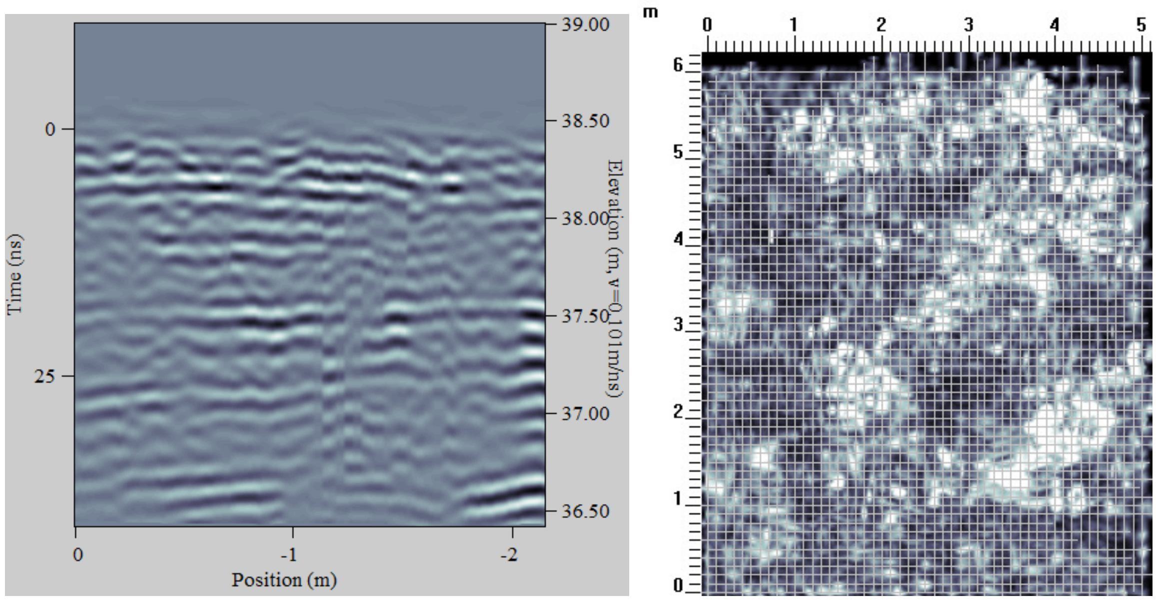

Figure 4.3 *S'iltexwáwtxw* floor in profile (left) and possible structure corner (right)

The differential use and preservation of *s'iltexwáwtxw* may also explain the inability of GPR to successfully define the boundaries of either Structure 11 or 12. Shifting use of the *s'iltexwáwtxw* may be expressed in shifting and undefined boundaries, which are not easily resolved by GPR survey. The most promising area for identifying the boundaries of Structure 11 was in the southwest corner of the survey area. A 5 m x 6 m GPR grid was collected near the presumed southwest corner of Structure 11, based on the presence of a large surface depression interpreted as a corner post. Depth slices produced from the GPR survey show a possible right-angle corner adjacent to and just outside of the apparent corner post, as defined by higher-amplitude reflections to the inside of the structure (Figure 4.3). This possible structure border falls where expected, based on interpolations of interior/exterior transitions in excavation units to the north and east (in adjacent GPR grids); however, this border cannot be traced in depth slices or reflection profiles into adjacent GPR grids.

In addition to the effects of inconsistent use, the ability of GPR to resolve *s'iltexwáwtxw* boundaries may also be influenced by the difference (or lack thereof) in activity inside as compared to outside the structure. The internal deposits of the *s'iltexwáwtxw* were expected to be more compact, and therefore more reflective, than external deposits, based on the assumption that high activity areas inside the *s'iltexwáwtxw* would be more compact than low activity areas outside the structure. The

GPR survey, however, shows little distinction between internal and external deposits in the area of the *s'iltexwáwtxw*, as interpreted from relative levels of high-amplitude reflections. This may suggest activity levels inside the *s'iltexwáwtxw* are comparable to those immediately outside the structure boundaries. The implications of this observation are discussed in more detail in Chapter 5.

4.4 Post Holes

The survey over the *s'iltexwáwtxw* also provided the opportunity to assess the ability of GPR to resolve other architectural features, such as post holes. GPR grids captured at least four probable post holes in the area of Structure 11, as interpreted from surface survey. The probable post holes are at least 50 cm in diameter and 50 cm in depth, and are arranged in a linear pattern along the front (river-facing side) of Structure 11. All four post holes displayed the same signal in GPR reflection profiles, where they appear as clear breaks in the surrounding stratigraphy, with few low-amplitude internal features (Figure 4.4). In depth slices, all four post holes are imaged as roughly circular, homogenous low-amplitude anomalies extending to depths of at least 0.40 m (Figure 4.4). Based on this signal type, a further eight possible post holes were identified in the survey area. Seven of these remain to be ground-truthed, but a small test unit was placed over one of the possible post holes identified a possible pit feature that correlates strongly with the identified anomaly (see Chapter 3 section 3.8).

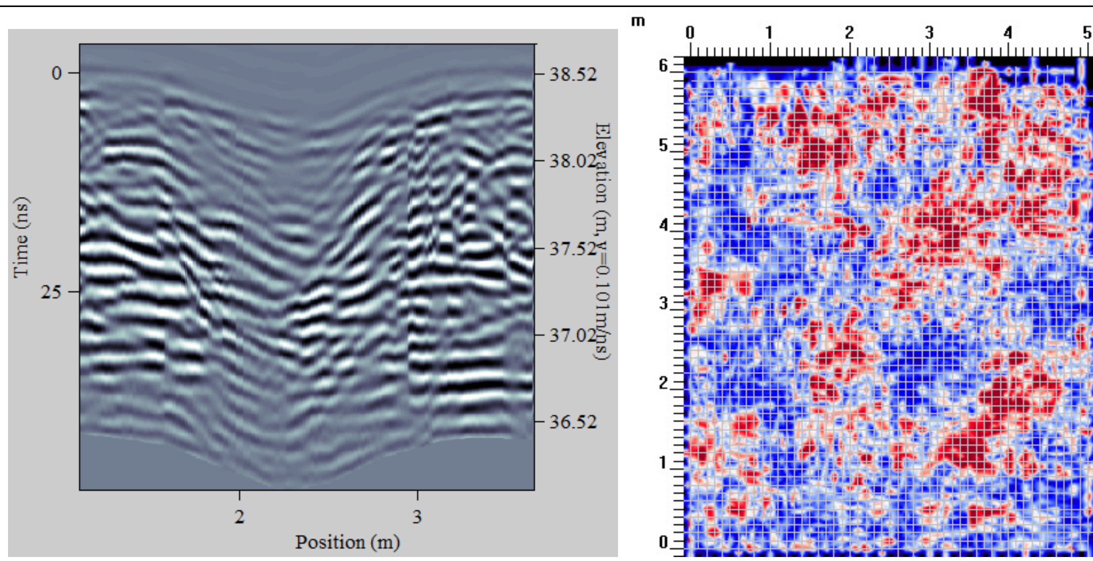

Figure 4.4 Post hole in profile (left) and slice (right)

In addition to the GPR grids collected over the *s'iltexwáwtxw*, six stand-alone transects were collected across the length and width of the *s'iltexwáwtxw* area, passing over five post holes. Based on the signal collected over post holes in GPR grids as described above, only one of the five post holes sampled by a single transect was clearly distinguishable, a success rate of only 20%. These results suggest that gridded GPR data (and in particular the depth slices produced from such data) is superior to single transects in identifying post holes. The resolution of the four post holes noted above in GPR grids was likely aided by closely spaced (10 cm) transects. For this and similar contexts, it is apparent that GPR survey is most likely to be successful in identifying spatially-restricted architectural features when conducted in grids, which can produce plan view depth slices, as opposed to stand-alone transects.

4.5 Unexpected Burial

One of the failures of the GPR survey at *Welqámex* was its inability to detect a human burial encountered in one of the ground-truthing experiment excavations. The location for the survey was selected in order to test Structure 12, located at the eastern extents of Zone 1 and near the cemetery in Zone 2. A preliminary 4-x-4 m reconnaissance survey in the area found no features of interest or of concern. The location of excavation unit 2010-5 was then selected based on the presence of a unique type of vegetation in one part of the reconnaissance survey area. The formal ground-truthing experiment GPR grid covered the 1-x-1 m area of the excavation unit, and as with the reconnaissance survey, did not detect any anomalies of interest or concern. During excavation, human remains were encountered at a depth of 30 cm, and excavation was discontinued.

As noted in Chapter 1, GPR has been used with success in detecting burials in other contexts, including GPR surveys by the author in archaeological and historic cemetery contexts. A number of factors may have contributed to the inability to detect this burial. The burial was shallow, with the remains encountered at a depth of 30 cm. The burial pit itself is not expected to be deeper than 40 cm (note however that this was not tested, as excavation was discontinued). The 500 MHz antenna used for this survey is not the ideal frequency for imaging such shallow features, and it is possible that horizontal banding in the upper 30 cm due to interference between the two GPR antennae may have obscured the burial. The burial was also in poor condition, with only a few elements remaining. Given its advanced state of decomposition, and the fact that the site was occupied as late as the early 1900s, the burial is likely at least 100 years old. The ability of GPR to detect burials decreases significantly over time (c.f. Schultz et al. 2006; Schultz 2008). In addition, deposits inside the burial pit may not have provided a strong enough contrast to be resolved by the EM signal, despite the fact that archaeologically these deposits would be described as strongly contrasting, based on characteristics such as colour and compaction.

4.6 Possible Subterranean Tunnel

GPR was also used to test a hypothesis by Graesch (2006:47, 2007:601; Graesch et al. 2011; Lepofsky et al. 2009:612) as to the existence of subterranean tunnels connecting Structure 1 with Structures 4 and 5. The hypothesis is based on the presence of topographic saddles in the rim deposits between these *sqémél*, which suggest the possible collapse of a passageway within the rims connecting the *sqémél*. To test the subterranean tunnel hypothesis, GPR grids were placed over the rims between Structure 1 and Structures 4 and 5. Control samples were collected over 'normal' rim deposits adjacent these grids, as well as between Structures 2 and 4, and over the rim opposite the possible subterranean tunnel in Structure 1.

The initial testing took place in the summer of 2010 using 250 MHz antennae. The survey over the 'normal' rim deposits between Structures 2 and 4, and adjacent topographic saddles between Structures 1 and 4, produced no significant reflectors within the rim deposits, which are generally homogenous and undisturbed (Figure 4.5). By contrast, the survey over the topographic saddles between Structures 1 and 4 produced a series of high-amplitude anomalies located within the rim deposits, extending from around 0.80 m to the depth of floor deposits in Structure 1 (Figure 4.5). The lowest in the series of anomalies may be continuous with floor deposits from Structure 1. Because floors were not identified in GPR profiles from Structure 4, it is uncertain as to whether or not this anomaly is continuous with Structure 4 floor deposits. The anomalies suggest a highly-disturbed area within the house rims that cannot be accounted for by nearby tree root disturbance, and may be the result of a possible collapse of a subterranean tunnel. The results of this survey were first reported by Graesch et al. (2011).

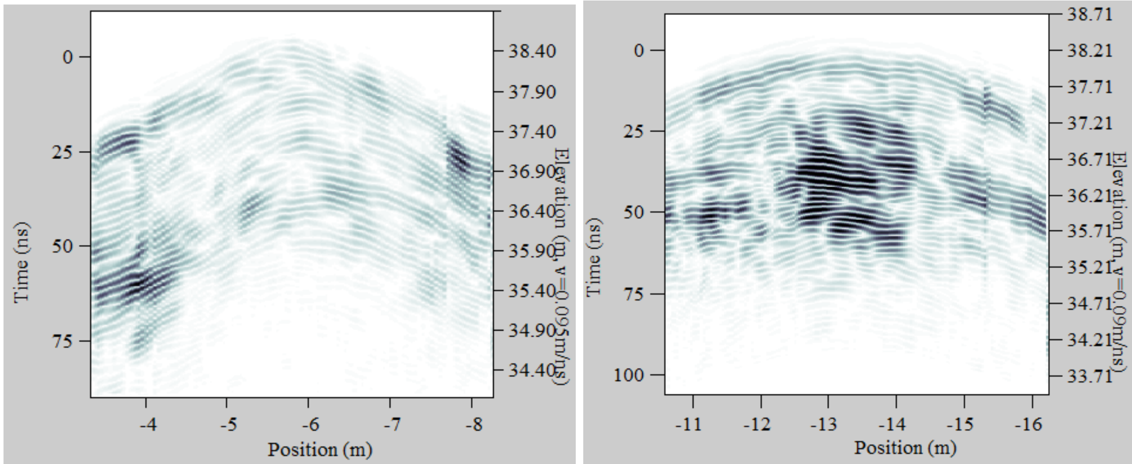

Figure 4.5 Normal rim deposits between Structures 2 and 4 (left) and topographic saddle between Structures 1 and 4 (right)

Additional testing took place in the summer of 2011, using 500 MHz antennae over the rims between Structure 1 and Structures 4 and 5. This later survey confirmed the results of the initial survey over topographic saddles between Structures 1 and 4, producing a comparable high-amplitude anomaly within the rim between these structures that may be continuous with floor deposits in Structure 1. The survey over rim deposits between Structures 1 and 5 is not so definitive, and produced a weaker, poorly-defined anomaly within the rim, which may be related to root disturbance from a nearby tree. While the GPR survey provides strong evidence for a large disturbance within the rims between Structures 1 and 4, it cannot provide the same support for the hypothesis of a subterranean tunnel joining Structures 1 and 5.

5 Discussion

Kvamme (2003:452) wrote that “archaeo-geophysicists are frequently guilty of presenting only their “best” results.” I think it safe to say that I have largely avoided this particular fault in this thesis. In order to address one of the primary research questions of this project (“to assess the ability of GPR to detect and distinguish between architectural features”), it is necessary to present both the successes and failures.

At *Welqámex*, GPR was very good at detecting *sqémél* floors, providing accurate results for 8 out of 9 (or 89%) *sqémél* tested, and successfully predicting the depth of floors encountered in an assumed *sqémél* prior to its excavation. It was also able to detect *s’iltexwáwtxw* floors at a rate of ≤38% for those floors expected to be detected, but could not distinguish between those and other stratigraphic layers, and could not identify structure boundaries. It could detect those large (>50 cm diameter) post holes that were clearly visible on the ground surface, but not smaller or less visible post holes or post/stake molds. While pit features larger than 15 cm in diameter were detected at a ≤43% success rate, none of the hearths/fire-affected earth features identified in excavation and expected to be detected by GPR could be distinguished in GPR profiles or slices. While targeted excavation of identified GPR anomalies produced in two cases pit features, ground-truthing of a third linear anomaly produced nothing more than a tree root. Most unfortunate of all, GPR was unable to detect an unmarked burial in a planned excavation unit, and as a result that burial was disturbed by subsurface testing.

When presented with such mixed results, the only option is to use them to further our understanding of the subject at hand. In the case of the undetected burial, this led to considerable questioning of the variability of target features, both as they are presented to us through excavation and as they appear in remote sensing images. In contrast, the excavation of the root highlighted the limited variability of GPR anomaly types which can be produced, and to which a wide range of interpretations can be given (see also Porsani et al. 2010:1147).

5.1 Uncertainty and Limitations

The uncertainty of any interpretation is limited by two factors: the quality of the GPR signal received (as determined by the characteristics of the propagated signal and its interaction with the subsurface – more broadly, the methodological limitations), and the quality of the comparative data by which the meaning of the signal is deduced (based on verified cases or the general principles of GPR – the interpretive limitations). Discussions of uncertainty with regards to the use of GPR in archaeology have been largely restricted to the methodological realm (e.g., Conyers 2004:170-171; Kvamme 2008:77; Neubauer et al. 2002:136). In this respect I am also guilty, as one of the primary research questions was methodological: "to assess the ability of GPR to detect and distinguish between architectural features." The methodological aspect of this question (the ability to detect) has already been discussed in the previous section.

Fortunately, however, the research question also forces discussion of the interpretive aspect of uncertainty, through a discussion of the ability to "distinguish between" features. As noted by Kvamme (2003:452), what archaeologists often get from geophysical surveys is "numerous anomalies, but uncertainty about what they represent" – an inability to confidently "distinguish between." This was certainly the case with my own project, and has forced considerable thought regarding how to best address interpretive uncertainty. Ideally, interpretive uncertainty would be quantified, and would be based on controlled experiments and direct comparison between GPR survey data and excavation results.

In practice, quantification of uncertainty is difficult. It must include a full assessment of all four ranges of possibility – true positives, false positives, true negatives, and false negatives. My own analysis only incorporates data for two of these four categories (true positives and false negatives). Sample size is also an issue. Then there is the problem of variability, both in the context in which the survey is undertaken and in the features themselves. Using Coast Salish architecture as a case study, it is clear that a single 'type' of feature (e.g., a *sqémél*) is more accurately portrayed as a spectrum, with a wide range of variation within and between types (see Chapter 1, section 1.3). Similarly, contextual variability can be between different contexts (or different sites) and within the same context (for example, surveys conducted on a dry day as compared to those conducted on a raining day where the substrate is waterlogged). And of course there is also the problem of inter- and intra-observer error that must be addressed for the quantification scheme to be deemed acceptable.

With these many roadblocks in the way of developing reliable quantifications of uncertainty, there must be an alternative means of addressing uncertainty. This can be done by providing qualifiers that clearly indicate uncertainty (e.g., an anomaly identified not as a "house floor" but as a "possible or probable house floor"), and providing alternative interpretations of the signal. When reporting survey results, it is also advisable to provide a discussion of the uncertainties and limitations of the GPR method, perhaps in the form of a disclaimer. These options should be preferable to providing substandard quantification schemes. Here I must address the quantified values presented in this thesis, and I must stress that these are not meant to be taken as predictive values, but rather a representation of comparison with excavation data. In this survey, at this site, 89% of *sqémél* tested were positively identified via the presence of a floor. This number is not meant to be predictive, and it cannot be assumed that this number will hold steady for GPR surveys at other archaeological sites.

5.2 Insights from the *Welqámex* survey

Given the shortcomings of the GPR method in its ability to detect and distinguish between architectural features, it is difficult in this context to address the second research question of this project, regarding the production of relevant spatial data for the analysis of broader anthropological questions at *Welqámex* and in the larger Coast Salish culture area. GPR was unable to detect on-ground structure boundaries, let alone distinguish between multiple building phases among in- and on-ground structures, and therefore in this case it is not a suitable tool to address demographic changes. Detecting internal boundaries was met with equal difficulty, indicating that GPR, in this context, is likewise unsuitable for addressing questions of social organization based on internal house organization and features.

While GPR was unable to provide information on the spatial patterning of specific architectural features, the overall spatial patterning of identified anomalies may be of some significance, in particular with respect to those anomalies detected in the large *s'iltexwáwtxw* (Structures 11 and 12). A total of 121 anomalies were detected in the entire area surveyed over the two structures. Of these, 93 (77%) are located in the western half of the survey area, whereas only 28 (23%) are located in the eastern half (Figure 5.1). The western half of the survey area is characterised by more complex and heterogeneous deposits, while the eastern half is considerably more homogenous. Furthermore, the deposits in the eastern half are far less continuous, with few distinct stratigraphic layers cutting across multiple survey grids, as compared to the western half, which is comprised of at least four distinct stratigraphic layers which can be traced across multiple survey grids. It is unclear at this time if this observation is a reflection of an actual spatial transition (possibly between Structures 11 and 12), but it is worth noting that it falls in line with observations by Graesch et al. (2011) that found exchange objects more highly concentrated at the western end of Structure 11.

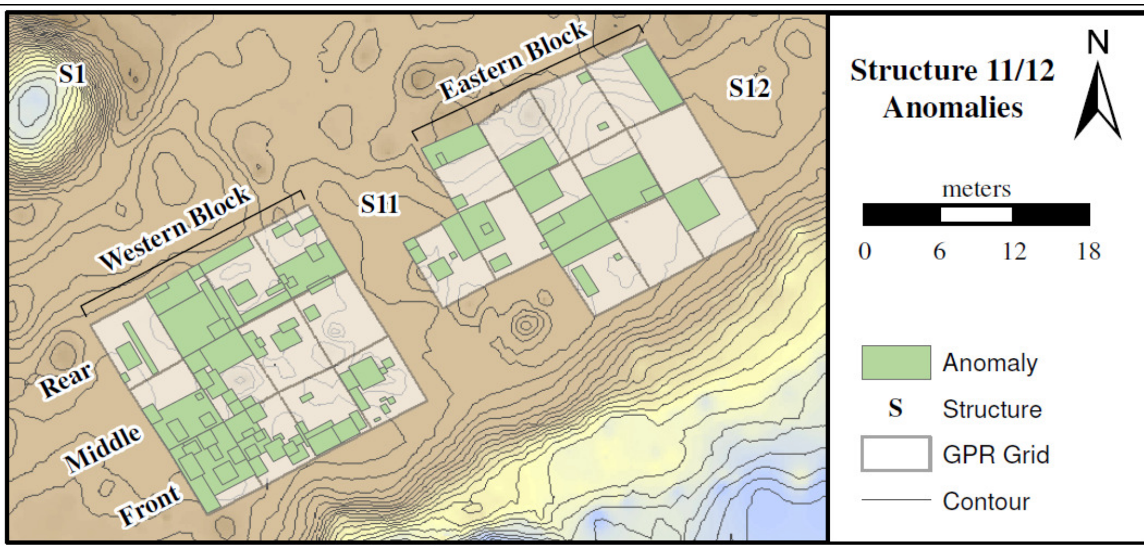

Figure 5.1 Map of anomalies in Structures 11 and 12

Within the western half of the survey area, another spatial pattern in frequency of anomalies is noted. The survey grids collected in the front (river-facing) third of the house appear more complex and heterogeneous than those in the middle and rear of the house. Of the total 93 anomalies identified in the western half of the survey area, 43 (46%) are located in the front third, as compared to 24 (26%) and 26 (28%) in the middle and rear thirds, respectively (Figure 5.1). Again, it is unclear if this observation represents a true spatial transition, but excavation data collected from this area appears to indicate that exchange objects are more highly concentrated near the front of Structure 11. Exchange objects at *Welqámex* include a wide range of materials that were not available to the Stó:lō prior to European contact, including iron metals, which are highly conductive and strongly affect GPR readings.

5.3 Implications for Stó:lō-Coast Salish Architecture

The GPR survey findings at Structures 11 and 12 are also the focal point for insights about Stólō-Coast Salish architecture. In particular, one of the more puzzling results (the inability to detect structure boundaries) has lent itself to thoughts about how we discuss 'floors' and our assumptions about living surfaces in general, and in particular as seen from a geophysical standpoint.

The floor of the *s'iltexwáwtxw* is compact from repeated foot traffic; we know this from excavation data collected at the site. In contrast, the area around the interior perimeter of the structure would not have been subject to the same degree of traffic, due to the presence of benches, and logic suggests it should be comparably less compact. The same is assumed for the exterior of the structure. By this logic, the internal area of a structure should be easily approximated by examining changes in relative compaction across a surface, with more compact surfaces located within the structure, and less compact surfaces outside. This transition should have been captured by the survey conducted over Structures 11 and 12, regardless of the location and/or presence of benches with relation to the surface post holes and subsurface excavation data used to estimate the structure extents. But no distinct transition was detected.

The inability to detect structure boundaries might be explained away through our general understanding of *s'iltexwáwtxw*. As previously noted, Coast Salish *s'iltexwáwtxw* are highly fluid structures, whose boundaries could be easily readjusted to accommodate expanding or contracting populations (Hill-Tout 1978:47; Schaepe et al. 2001:42; Suttles 1991:216). This variability (and implied variability in site formation processes) may account for the inability of GPR to detect the boundaries of such structures that are likewise "notoriously difficult to excavate" (Lepofsky et al. 2009:621). Non-continuous and shifting use may have resulted in a relative difference between internal and external surface compaction (or between compaction of surfaces that may have been internal at one point in time and external at another) that is not sufficient for GPR to detect.

An alternative would be to rethink how we conceptualize structure floors or living surfaces, in particular as they are seen from a geophysical perspective. Archaeologists expect compact surfaces revealed within the bounds of other architectural features (e.g., walls) are correlated with a structure floor, the outcome of some combination of floor construction and subsequent foot traffic; however, surface compaction can result from other human activities, and all compacted surfaces are not exclusively floors. Ground levelling and terracing, which are suspected to have occurred at *Welqámex* based on the presence of material borrowing areas in Sector 3, could also produce compact surfaces. Other such compact human-made structures include trails and pathways, which GPR has the proven ability to detect (e.g., Weissling 2011). Indeed, any surface which has been trodden upon repeatedly will become compact, and if we admit that the household is not a contained unit of human activity, that people live outside it as well as inside, it should only be natural to find compact surfaces extending beyond the boundaries of these structures. That being said, unless it can be confirmed through excavation that anomalies interpreted as possible structure 'floors' (or, perhaps more accurately, surfaces compacted by cultural activities), were actually used as floors, GPR is unable to distinguish between these and other features that produce planar reflections, and we return full circle to where we started – with the uncertainty and limitations of the GPR method.

5.4 Conclusions

The conclusion, then, based on these survey results, is that GPR may not be ideal for theory-driven archaeological work in similar contexts to those encountered at *Welqámex*. While it can detect a number of architectural features, including house floors, post holes, and pit features, it is difficult to distinguish between these and other cultural and natural subsurface features. For this reason, GPR may be of little benefit to targeted archaeological investigations when used on its own, in this location and at this time.

GPR can, however, become a useful prospection tool in contexts similar to those encountered at *Welqámex*, so long as those using it are aware of and willing to accept the method's limitations. Subsurface investigations at *Welqámex* are on-going, and will continue to provide useful data for further refining GPR interpretation in this and similar contexts, beyond the completion of this thesis. The data collected from GPR survey at *Welqámex* will be used to guide future excavations at the site. These future investigations include specific ground-truthing of GPR anomalies (of which this project produced 157 of interest), in particular the anomaly detected beneath the rim between Structures 1 and 4, interpreted as a possible subterranean tunnel. In turn, the excavation data collected from future investigations at the site can be used for direct comparisons with GPR data, providing the opportunity to further assess and refine the interpretability of GPR data on the Northwest Coast. Options for future research include testing higher resolution (1000 MHz) antennae and supplementing GPR data with other geophysical methods, a practice which has become increasingly common but was outside the scope of this project. In such a rapidly changing field, new technological advances in collecting, manipulating, and displaying GPR data may one day accurately reveal the underlying structures we seek.

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Appendix A: Glossary of GPR Terms

Ground Penetrating Radar (GPR) theory, data collection, processing, and interpretation is a broad topic, and an in-depth discussion is outside the scope of this thesis. For a more information on GPR theory and the terms mentioned below and throughout the text, the reader is directed to an online teaching guide on GPR theory, data collection, processing, and interpretation for archaeologists (Dojack 2012b). There are many excellent sources for further information on GPR, including Annan (1999, 2009), Cassidy (2009a, 2009b), Conyers (2004), and Leckebusch (2003).

Amplitude – describes the peak-to-peak 'height' of the EM wave, which changes as the EM wave passes through different materials (see Dojack 2012b:18). For this project, **high** (large amplitude, or great contrast), **low** (small amplitude, or low contrast), and **moderate** were used as relative terms to describe the signal strength of a given anomaly (or to provide a relative description of its degree of contrast with surrounding deposits).

Amplitude equalization – a data processing method used to boost amplitude signal strength in amplitude slices (see Dojack 2012b:36).

Amplitude slice – a two dimensional image constructed from grids of aligned reflection profiles, and providing images in the horizontal plane (analogous to plan views) (see Dojack 2012b:16).

Anomaly – a distinct feature in GPR data.

Attribute analysis (envelope) – attribute analysis is a data processing method used to inform on relationships expressed in the data using components of the data. Envelope is a type of attribute analysis used to emphasize the true resolution of the data, simplify the data, and evaluate signal strength and reflectivity by calculating the absolute value of each wavelet (see Dojack 2012b:51-52).

Background subtraction – a data processing method used to remove horizontal banding caused by system noise, electromagnetic interference, and surface reflections (see Dojack 2012b:44).

Bandpass filtering – a data processing method used to remove high and low frequency noise (see Dojack 2012b:39).

Continuity – describes the state of connectedness of an anomaly. For this project, **local** continuity was used to refer to the continuity of the primary signal within the anomaly, whereas **global** continuity was used to refer to the continuity of the anomaly with surrounding deposits.

Depth conversion – any method used to convert two-way travel time measurements to depth measurements.

Dewow – a data processing method used to remove low-frequency 'wow' caused by signal saturation, coupling effects, or instrumentation limitations (see Dojack 2012b:38).

Frequency – a data collection parameter that specifies the number of EM wavelengths repeating per unit time, and therefore the EM wavelength (see Dojack 2012b:11-12).

Horizontality – describes the degree to which an anomaly is horizontal. For this project, anomalies were described as **horizontal** (parallel to the plane of the earth), **dipping** (any non-horizontal anomaly with a constant angle), **undulating** (an anomaly with varying orientation with respect to the plane of the earth), or **point source** (too spatially restricted to be described in terms of horizontality).

Hyperbola curve fitting – a method used to estimate the velocity of the EM wave through the ground by fitting a curve to a hyperbolic reflection produced where the object was crossed at a right angle (see Dojack 2012b:17).

Points per trace – a data collection parameter that specifies the number of radar pulses needed to construct a trace (see Dojack 2012b:12-13).

Rectify – a data processing method used to calculate the absolute value of each point in a trace (see Dojack 2012b:54).

Reflection profile – a two dimensional image constructed from sequentially aligned traces, and providing images in the vertical plane (analogous to stratigraphic profiles) (see Dojack 2012b:15).

Reflector Type – describes the patterning of GPR data, which fall under two general types: **planar** reflections, which are horizontal or sub-horizontal lines in reflection profiles that are produced at transitions between deposits and/or features; and **hyperbolic** reflections, which are hyperbolic (or inverted v-shaped) arches in reflection profiles that are produced from distinct, spatially restricted, non-planar features (see Dojack 2012b:18). For this project, descriptive terms also included **dipping** reflections, which were defined as planar reflections at greater than 'sub-horizontal' angles, and **semi-hyperbolic** reflections, which were defined as those very strongly dipping reflections that otherwise had the characteristics of a hyperbolic reflection, but may have been missing one 'arm' of the hyperbola.

Ring-down – multiple stacked reflections in a reflection profile resulting from multiple EM wave reflections between a highly-reflective object and the surface (see Dojack 2012b:6).

Sampling interval – a data collection parameter that specifies the amount of time between data points collected for each recorded trace (see Dojack 2012b:12).

Stacks (stacking) – a data collection parameter used to specify the number of successive traces collected to produce a composite trace (see Dojack 2012b:13).

SEC gaining – a data processing method used to boost amplitude signal strength and enhance low-amplitude reflections by applying an exponential gain (see Dojack 2012b:33).

Step size – a data collection parameter that specifies the distance interval that separates individual traces (see Dojack 2012b:13).

Time window – a data collection parameter that specifies the amount of time for which the receiving antenna will record two-way travel time data (see Dojack 2012b:12).

Topographic correction – any method used to account for and express changes in surface topography in reflection profiles.

Trace – the total waveform of a series of EM waves collected from one surface location (see Dojack 2012b:15).

Transect spacing – a data collection parameter that specifies the distance between adjacent survey transects (see Dojack 2012b:13).

Two-way travel time – the time it takes for the EM wave to travel from the transmitter to a subsurface discontinuity, then back to the receiver (see Dojack 2012b:15).