REVIEW AND EVALUATION OF

COMMON DEEP SUBSURFACE ARCHAEOLOGICAL INVESTIGATION METHODS

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Contents

Tables and Figures

Acronyms and Abbreviations

GPR	ground-penetrating radar
LiDAR	Light Detection and Ranging
MHz	megahertz
PAGDP	Port Angeles Graving Dock Project
SIR-10	Geophysical Survey Systems Incorporated Subsurface Interface Radar 10
WSDOT	Washington State Department of Transportation

Chapter 1
Introduction

The Washington State Department of Transportation (WSDOT) has commissioned a review and evaluation of commonly used approaches to deep archaeological investigations, as well as the development of a protocol for evaluating the strengths and weaknesses of these methods in the context of a specific project's goals. For the purposes of this study, deep archaeological investigations will be defined as subsurface archaeological investigations that exceed the depth that can be reasonably achieved by manually excavating shovel probes, test units, and/or auger probes, which tend to be able to reach depths ranging from 1 to 1.5 meters below the ground surface. In Washington State, deep archaeological investigations are usually performed using mechanical excavators and drill rigs, and geophysical survey methods are also occasionally used. Deep archaeological investigations are commonly used in environments where geomorphic processes and/or anthropogenic landscape alteration have created thick deposits of sediments that either bury or contain landforms or surfaces that have the potential to contain archaeological resources and create an environment where shallower, more traditional archaeological methods would be insufficient.

Dating as far back as the 1970s, archaeological studies have recognized that sea level rise, geomorphology, and anthropogenic landscape alteration affect the visibility, accessibility, and preservation of archaeological sites in the Pacific Northwest (Fladmark 1975; Hedlund 1976; Samuels 1991; Eldridge and Acheson 1992; Larson and Lewarch 1995; Moss and Erlandson 1998). Despite this knowledge, however, deep archaeological investigations were not performed frequently or systematically in Washington State for some time. However, attention to, and recognition of, deep archaeological investigations changed dramatically in Washington State after the Port Angeles Graving Dock Project (PAGDP). During the PAGDP, in 2003, a deeply buried Klallam village and cemetery was inadvertently discovered during construction. Eventual recognition of the scale of the discovery ultimately led to the termination of the PAGDP.

Since the PAGDP, WSDOT has diligently integrated deep archaeological investigations into archaeological studies for infrastructure projects (including, but not limited to, Miss and Hodges 2007; Sharp et al. 2009; Schneyder et al. 2010; Huber et al. 2010; Rinck and Kopperl 2010; Minor 2012; Elder and Cascella 2013; Elder and Cascella 2014; Punke 2015). The Washington State Department of Archaeology and Historic Preservation has been a strong advocate for the use of deep archaeological investigations for other major infrastructure projects across the state. These efforts have resulted in the discovery of several notable deeply buried archaeological sites (e.g., 45GH179—Schneyder et al. 2010; 45PI930—Sharp et al. 2009; 45PI1327—Stevenson et al. 2015), and have helped to limit the costs that would have otherwise been incurred had these resources been inadvertently discovered during construction.

Despite the emphasis on deep archaeological investigations in Washington State, formal guidance has yet to be developed by any agency in the region. Washington State is not alone in this, as this study has only identified one agency that has performed a deep archaeological testing study and developed guidance for deep archaeological investigations—the Minnesota Department of Transportation (Monaghan et al. 2006). However, it is important to note that there are key differences in the statewide geomorphology of Minnesota and Washington State, particularly relating to the thickness of archaeologically sensitive deposits as a result of sea level rise and catastrophic volcanism that warrant consideration. In the absence of established guidance, most deep archaeological investigation projects in Washington State have relied on a commonly used subset of methods, usually mechanical trenching and/or boring. The specific method, or methods, selected for a given project are often made by the lead investigator with the purpose of addressing project-specific research goals and equipment availability.

Without a clear guidance document, it is unknown whether the lead investigators, their clients, and agency reviewers have a shared understanding of the range of methods that is available and the relative strengths and weaknesses of those methods. Therefore, in order to ensure that all parties have the information necessary to make well-informed decisions about deep archaeological investigations, the goal of this study is to consider the range of deep archaeological investigation methods that are commonly used in Washington State, assess the relative strengths and weaknesses of those methods, and to establish a consistent framework for evaluating critical approaches to deep archaeological investigation methods in the context of a specific project's goals.

This document was written in order to satisfy Stipulation V.C. of *the Memorandum of Agreement—Alaskan Way Viaduct Replacement Program*, as amended in September 2015.

1.1 Report Organization

This study is organized into six chapters.

- **Chapter 1, Introduction.** This chapter summarizes the project background and document organization.
- **Chapter 2, Subsurface Investigation Technologies.** This chapter considers three classes of deep subsurface investigation technologies, including boring, mechanical excavation, and geophysical survey, and the way in which a sample is obtained, and summarizes overall strengths and weaknesses for each technology.
- **Chapter 3, Environmental Context.** This chapter briefly summarizes the environmental factors that are likely to result in the burial of archaeological resources in Washington State and the way that these factors may affect sample collection during subsurface investigations.
- **Chapter 4, Sampling.** This chapter considers the relationship between geologic environments, archaeological resource types, and sampling approaches, and how varying archaeological resource types may require differing approaches to archaeological sampling to increase the likelihood of their discovery.
- **Chapter 5, Case Studies.** This chapter presents eight case studies in which the subsurface investigation technologies described in Chapter 2 were used. These case studies consider the purpose, technology, field investigation approach, and findings, and review the extent to which the technology used successfully addressed the purpose of each study.
- **Chapter 6, A Framework for Selecting Deep Archaeological Investigation Methods.** This chapter provides a series of guidelines for evaluating the strengths and weaknesses of deep archaeological investigation methods in the context of a specific project's goals.

Chapter 2
Subsurface Investigation Technologies

This chapter describes three commonly used categories of technologies for performing deep subsurface investigations: boring, mechanical excavation, and geophysical survey. The following sections discuss the way in which a sample is obtained and the relative strengths and limitations of each technology.

2.1 Boring

For the purposes of this study, the term *boring* refers to the act of drilling a vertical circular hole into the earth to collect sediment samples. Although drill rigs are available in a wide range of configurations and use several methods to excavate a hole, this study focuses on two of the main mechanical components common to all rigs that work together to collect sediment samples and considers their ability to provide information applicable to this study. These components include the technology used to advance the sampling apparatus (hereafter referred to as a *sampler*) into the ground (hereafter referred to as *advancing technology*), and the sampler itself. It also briefly discusses some of the technologies that are used to increase the success of boring, as well as the three types of boring technologies are most commonly used for deep archaeological investigations: *rotosonic*, *geoprobe*, and *rotary* rigs (Figures 2-1, 2-2, and 2-3, respectively). These technologies are then discussed in relation to potential project conditions. In order to be consistent with the terminology used for drilling, all measurements discussed below use the English system.

Two of the most commonly used advancing technologies are direct percussion and rotosonic advancement. The former uses a combination of static force generated by the drill rig and the percussive force generated by an on-board mechanical hammer to advance a sampler into the ground. Direct percussion is the technology used to advance a sampler with geoprobes and rotary rigs (ASTM 2012, 2014). Rotosonic advancement uses a combination of the static force generated by the drill rig, drill pipe rotation, and high-frequency vibration to liquefy and displace sediments along the advancing edge of the sampler and along the drill pipe (ASTM 2010). This method of advancement also allows for horizontal drilling. Of the two advancing technologies, rotosonic tends to be able to advance in denser formations (Rinck et al. in press). In both cases, however, the force or vibration of the advancing sampler may be insufficient to advance into a particularly dense formation. Such instances are referred to as *refusal*. Table 2-1 briefly compares the attributes for each of these technologies, and these differences are discussed in greater detail below.

Figure 2-1. Example of a Medium-Sized Track-Mounted Rotosonic Rig with a Fully Extended Boom. The model in the photograph is a Geoprobe 8140 LS.

Figure 2-2. Example of a Medium-Sized Track-Mounted Geoprobe Rig (Rinck et al. in press). The model in the photograph is a Geoprobe 7730.

Figure 2-3. Example of a Medium-Sized Track-Mounted Rotary Rig with a Fully Extended Boom. The model in the photograph is a CME-850.

Table 2-1. Comparison of Key Attributes of Three Commonly Used Drilling Technologies (based on Rinck et al. in press)

	Rotosonic	Geoprobe	Rotary
Sampler advancement	Rotation and oscillation	Direct percussion	Direct percussion
Casing and drilling	Rotation and oscillation	Direct percussion	Hollow-stem auger
Sampler Type	Open- and closed-barrel	Open- and closed-barrel	Open- and closed-barrel
Max Depth	+	-	=
Max Sampler Diameter	+	-	=
Footprint Size	=	-	+
Excavation Speed	+	=	-
Mobilization Speed	+	+	-
Dense Substrate	+	-	=
Cost per day	+	-	=

+ greatest; = middle; - least

Although there are many types of samplers, this study focuses on samplers that produce undisturbed or minimally disturbed sediment samples—sediment samples that retain stratigraphy.

The types of sampling that can produce undisturbed sediment samples are *open-drive* samplers and *closed-drive* samplers. Open-drive samplers consist of open, thin-walled tubes that are advanced into a formation, rotated, and then extricated. Closed-drive samplers consist of a thin-walled sampling tube with an internal piston designed to prevent soil from entering the sampler until the appropriate depth has been reached. Once the appropriate depth has been reached, the piston retracts and allows for sediment to enter the sampler at a rate that is concomitant with the rate that the sampler is advanced into the ground. Upon completion, the closed-drive sampler is rotated and extricated (Ohio EPA 2005).

Many rotary rigs can be equipped with a series of standard open- and closed-drive samplers that range in length and diameter. One of the most commonly used open-drive samplers is a *split-spoon* sampler, which can be split lengthwise to expose a sediment sample (Figures 2-4 and 2-5). Split-spoon samplers may also be referred to as standard penetration test or modified California samplers, depending on their diameter, with modified California samplers being larger than standard penetration test samplers (ASTM 2011). In instances where formations comprise soft to medium-stiff fine sediments, a *Shelby tube*, which is a seamless, open-barrel sampler, may be used. The drawbacks of this sampler are that it risks being damaged in sandy and/or gravelly conditions and that sediment samples must be extruded from the sampler using specialized equipment (ASTM 2015a). In instances where formations are loose and non-cohesive (e.g., saturated silts and peat), a closed-drive piston or *Osterberg* sampler may be used (Figure 2-6). Like the Shelby tube, the piston sampler risks being damaged in sandy or gravelly conditions and sediment samples must be extruded using specialized equipment (ASTM 2015b). All of the samplers listed above typically range from 18 to 24 inches in length and from 1.5 to 4 inches in internal diameter, although longer and larger-diameters samplers are available.

Figure 2-4. Example of a 4-inch Diameter Split-Spoon Sampler, Split Lengthwise with Bisected Sample Exposed

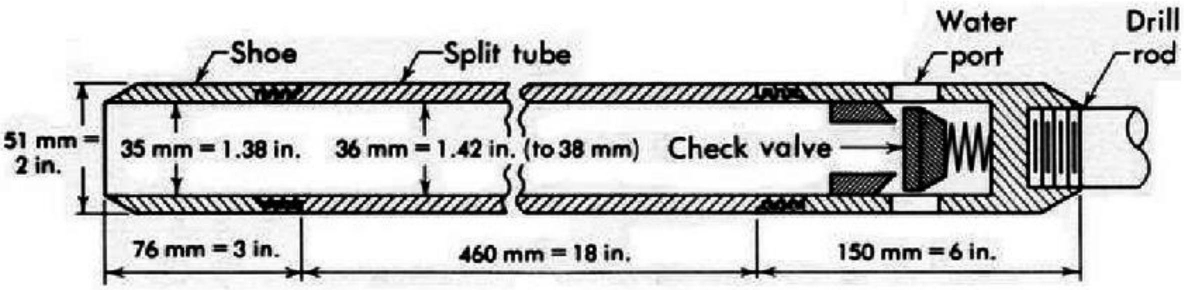

Figure 2-5. Example of a Common Split-Spoon Sampler (Sowers 1979)

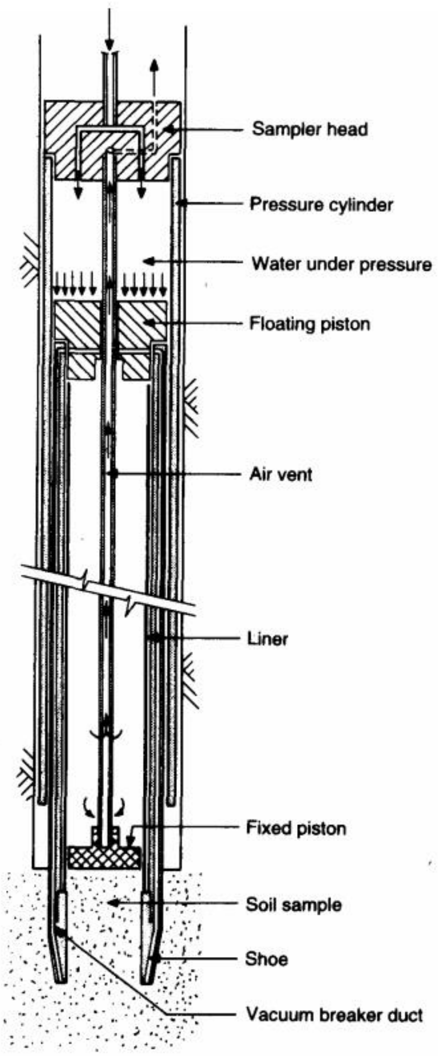

Figure 2-6. Example of an Osterberg Type Piston Sampler (Osterberg 1973)

Geoprobes can use variants of split-spoon and Shelby tube samplers, but may also use open *solid barrel* samplers, with which samples can be removed from the cutting edge or *shoe* of the sampler.

In order to obtain an undisturbed sample from a solid barrel sampler, a disposable solid plastic liner must be inserted into the sampler prior to advancement. The liner is then removed and can either be cut to expose the sample or the sample is extruded with specialized equipment (Figure 2-7). All of the samplers listed above may be modified into closed-drive samplers by adding a piston point that operates in the same fashion as the Osterberg sampler described above (Ohio EPA 2005). Unlike the Osterberg sampler, however, the piston point can be used in gravelly conditions and, if liners are used, sediment samples can be removed without specialized equipment. Depending on the equipment used, the maximum sample length that a geoprobe can collect ranges from 42 to 66 inches and the diameters range from 1 to 3 inches (Geoprobe 2016).

Figure 2-7. Example of a 2-inch-Diameter Sediment Sample Split Lengthwise in a Disposable Plastic Liner

Rotosonic rigs typically collect sediment samples using an open-drive sampler. The sampler consists of a thin-walled tube equipped with a shoe, similar in function to the solid barrel sampler that can be used with geoprobes. Once collected, a sample is extruded via oscillation into plastic sleeves (Figure 2-8), although some rotosonic rigs are equipped with samplers that can have solid plastic liners inserted into them. Depending on the equipment used, the maximum sample length that a rotosonic rig can collect ranges from 5 to 10 feet and the diameters range from 4 to 10 inches. If a casing is used, some rotosonic rigs can also use standard open-drive split-spoon, Shelby, and closed-drive Osterberg samplers (Ohio EPA 2005). Importantly, the maximum sample length is a function of the height of the drill rig tower, or *mast*. In order to collect longer sample intervals, a longer mast is needed.

Figure 2-8. Example of a 6-inch-Diameter Sediment Sample Extruded into a Plastic Liner from a Rotosonic Sampler Tube. Note the presence of buried soil and subsoil at the downhole end of the sample on the right-hand side of the screen. This buried soil was identified approximately 12 feet below the ground surface.

All of the open-drive samplers listed above are susceptible to a series of issues, including *heave*, *rodding*, and *refusal*. Heave occurs when sufficient pressure is generated within a formation to push sediments into a sampler at a rate that exceeds its rate of advancement. This will result in a *disturbed sample*, or a sample in which natural stratigraphy has been obscured. It may also require drillers to clean out the drill pipe to avoid further sample disturbance or the creation of false stratigraphy. Heave most commonly occurs in unconsolidated and saturated formations (i.e., loose, wet sand). Rodding, on the other hand, occurs when the friction within or along the advancing edge of the sampler is such that it pushes sediment out of the way as it advances. This can result in the collection of an incomplete stratigraphic sample or total sample loss. Rodding may occur if the sampler is plugged with wood or gravel obstructions, or in instances where dense formations overlie very loose formations. As discussed above, refusal occurs when the force or vibration of the advancing sampler cannot overcome the friction or compaction of a given formation. This can also result in the collection of an incomplete stratigraphic sample or total sample loss. Closed-drive samplers are susceptible to rodding and refusal, but heave is less common.

In instances where subsurface formations lack sufficient cohesiveness for a boring to remain open when a sampler is extruded, a dual tube sampling approach can be used to retrieve a soil sample using either of the advancing technologies described above. The dual-tube approach consists of a three-step process in which the sampler is advanced into an undisturbed formation, followed by the advancement of a larger-diameter tube (or casing) around the sampler to retain borehole integrity, followed by sample retrieval (ASTM 2010, 2012, 2014; Ohio EPA 2005). This process is repeated incrementally until the desired depth is reached. For geoprobes and rotosonic rigs, a casing is advanced using the same approach that is used to advance a sampler. The drawback of this approach, particularly for geoprobes, is that the larger surface area of the casing can result in increased friction and reduce the maximum depth that can be achieved (Ohio EPA 2005). On the other hand, rotary rigs use a rotating auger to advance a casing. The advantage of this approach is that, in many cases, the auger has the ability to advance through formations that may be impassible using direct percussion, allowing for the opportunity to try sampling at greater depths where conditions may be more conducive to sample collection.

Rotary rigs may also use a technique referred to as *mud rotary* to increase formation cohesiveness when collecting samples. This process consists of pumping a water and Bentonite clay mixture into the borehole to increase the cohesion of soft and unconsolidated sediments. All three drilling technologies may also use small metal or plastic screens, termed *catchers*, in the boot of a sampler in order to capture particularly soft and unconsolidated sediments (ASTM 2012).

While all three drilling technologies have the capacity to collect sediment samples, each have relative strengths and weaknesses to consider when proposing borings for deep archaeological investigations. Rotosonic rigs can collect the longest and largest-diameter sample increments, advance rapidly in a variety of formations and in formations that are difficult or impossible for geoprobes and rotary rigs, can excavate to greater depths than geoprobes, and are available in configurations that can work in limited access areas, such as areas with low-hanging power lines and tree limbs or within narrow corridors like rights-of-way along active roads. On the other hand, rotosonic rigs are substantially more expensive than other drilling technologies. Geoprobes can rapidly collect samples to depths of 10 feet below the ground surface depending on the machine configuration and nature of the substrate, can mobilize and demobilize very quickly, are available in the smallest limited access configurations of any of the drilling technologies, and are the least expensive of the drilling technologies discussed above. A particularly notable example of a very small limited access geoprobe configuration is a dolly-mounted machine (a Geoprobe 420M; Geoprobe 2016), which has a width of 36 inches and a maximum height of 94 inches while in use. The small size of this configuration, however, reduces the depth that can be achieved, and it is unlikely to be able to excavate to depths greater than 10 feet below the ground surface, even in favorable conditions. Geoprobes have limited capacity to advance in stiff formations, have limited capacity to advance to depths greater than 90 feet below the ground surface in favorable conditions (Hetzel et al. 2015), and only have the capacity to collect small-diameter samples—typically 2 inches or less. Rotary rigs have the ability to collect samples from great depths, can use a wide range of techniques and samplers to obtain sediment samples based on the nature of the formation, and are less expensive than rotosonic rigs. However, rotary rigs require the largest amount of work space of all of the drilling technologies described above (Rinck et al. in press). One additional consideration for rotary rigs is that, because these rigs can perform a wide range of sampling and testing applications beyond the collection of soil samples, they are the most commonly used rig for geotechnical and environmental applications. As a result, this may be the only rig available from smaller drilling companies or agencies that maintain their own fleet of drill rigs and is commonly the first rig option proposed by many companies.

Overall, the strengths of boring over other deep subsurface investigation technologies are that it enables an investigator to collect sediment samples that retain stratigraphy, can be used to access formations at depths that far exceed what can be accessed via trenching or remote sensing, can be used to investigate subsurface deposits with minimal disturbance to known archaeological deposits relative to trenching, and requires a smaller staging area for investigations than trenching. On the other hand, the limitations of boring are that even the largest-diameter sampler collects a miniscule sample compared to trenching. In addition, borings have the potential to result in limited, partial, or no recovery of samples, which can result in missed stratigraphy or failure to identify archaeological deposits.

2.2 Mechanical Excavation

For the purposes of this study, the phrase *mechanical excavation* is narrowly defined as excavations performed with a backhoe or excavator (Figure 2-9). In some instances, belly graders and skip loaders are also used for archaeological studies. However, they are typically used to clear large surface exposures rather than for deep subsurface investigations and are not included in this study.

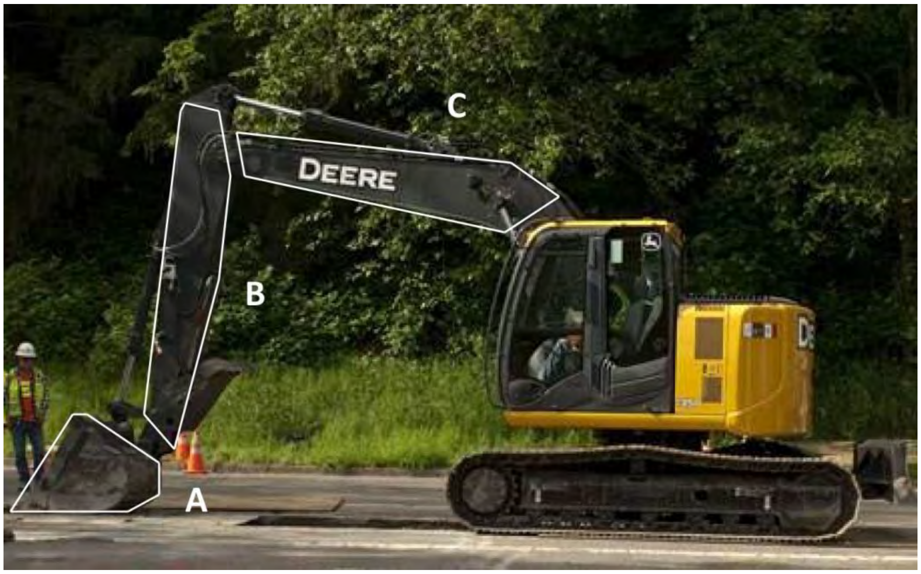

Figure 2-9. Example of a Small Excavator with Key Digging Components Identified. Area A is the bucket, Area B is the stick, and Area C is the main boom.

Although there is a wide range of manufacturers of backhoes and excavators, the overall technology used to excavate remains consistent between the various manufacturers. However, the specific digging components of the backhoe or excavator play a key role in determining the abilities of a given machine. Both backhoes and excavators use a two-part boom with a *bucket* to excavate sediments (Figure 2-9). The two-part boom consists of a *main boom*, which attaches to the body of the backhoe or excavator, and the *stick*, which attaches to the main boom at one end and the bucket at the other end. On some models of backhoes and excavators, both the main boom and stick can be changed out for longer or shorter components. If a longer main boom and/or stick are selected, the maximum reach of the backhoe or excavator is increased at the expense of the torque available to extricate obstructions or densely compacted sediments.

Buckets, too, can be changed out for wider or narrow components. Wider (or *large capacity*) buckets typically have a flat blade along their digging edge, whereas narrower (or *general purpose*) buckets tend to have metal teeth along their digging edge (Figures 2-10 and 2-11, respectively). The purpose of the metal teeth is to loosen densely compacted sediments and obstructions. Importantly, as the width of the bucket increases, the force that can be applied along the digging edge dissipates. As a result, wider buckets are typically only usable in loosely to moderately compacted sediments with few obstructions. Buckets come in a wide variety of sizes and configurations and typically range from 23 to 200 centimeters in width (Caterpillar 2016), although larger sizes are available. For all the component variations described above, the amount of power that can be generated by a given backhoe or excavator, as well as component options made available by specific manufacturers, will strongly influence the boom length and bucket sizes that can be used in a given environment. Table 2-2 describes the strengths and weaknesses of the various digging components described above.

Figure 2-10. Example of Excavations Performed with a Large-Capacity Bucket without Teeth

Figure 2-11. Example of Excavation Performed with a General Use Bucket with Teeth. Note that the general use bucket in this photograph is particularly large and attached to a large excavator.

Table 2-2. Strengths and Weaknesses of Backhoe and Excavator Digging Components

Digging Component	Strength	Weakness
Boom		
Longer	Greater reach	Lesser force
Shorter	Greater force	Lesser reach
Bucket		
Wider	Greater surface area exposure from a single lift, flat digging edge	Lesser force
Narrower	Greater force	Smaller surface area exposure from a single lift; may have teeth along digging edge
Teeth		
Absent	Smooth exposures, lesser disturbance to deposits below digging edge	May not be able excavate in compacted sediments or if obstructions are present
Present	Can excavate in compacted sediments and remove some types of obstructions	Fluted exposures, greater disturbance to deposits below digging edge

Mechanical excavation can be used to collect sediment samples and to create horizontal and vertical exposures for the purpose of documenting stratigraphy. The benefit of collecting sediment samples with a mechanical excavator is that a very large amount of sediment can be collected over a short period of time. The drawback, however, is that the process of sample collection is destructive, and the spatial relationships between any items recovered are obscured by the mixing that occurs as a result of the process of excavating. This can be somewhat mitigated by limiting the depth and/or horizontal extent that is excavated with each attempt to fill the bucket or *lift*. For example, with a skilled machine operator, one could limit each lift to around 2 inches in thickness.

Mechanical excavation is particularly well suited for documenting stratigraphy at shallow depths because of its ability to provide large, clean, and continuous exposures. As the depth of excavation increases, however, the logistical difficulty increases. For example, at depths greater than 1.3 meters, trench sidewalls must either be sloped or shoring must be used to prevent cave-ins (OSHA 2015). Sloping makes it difficult to document representative wall or floor exposures, while shoring typically warps or obscures wall exposures. Alternately, an investigator may collect measurements from outside of the test unit, but these data are likely to be lower-resolution than could be collected from within. An additional consideration, particularly along coasts and streams, is the depth of the water table. If left unmanaged, a shallow water table will obscure exposures and prevent entry into the test unit. This consideration can be managed with the use of dewatering pumps, but will result in increased costs and logistical complexity associated with water control.

Although mechanical excavation can generate large sediment samples and stratigraphic exposures, this technology has three key limitations. First, mechanical excavation technology requires a large footprint that is free of both above-ground and below-ground obstructions. This limitation is particularly notable in highly developed environments, where buried and overhead utilities are widespread. Second, the maximum depth that can be reasonably achieved with mechanical excavation is limited compared to drilling, with the maximum depth of excavation for most backhoes and excavators ranging from 3 to 10 meters below the ground surface. Additional methods, such as excavating a platform below the ground surface (or *benching*), can be used to increase the depth that can be reached with a mechanical excavator, but these methods require significant effort and result in a significantly larger area of ground disturbance. Third, a key drawback of the high rate of excavation that can be accomplished with this method is that it can increase the risk of damaging a resource or disturbing its context before it can be recognized by an archaeological observer. This drawback is particularly notable if the goal of a study is to determine the presence and/or integrity of buried archaeological deposits, but can be minimized by using protocols designed to reduce the depth of each lift and the rate of excavation.

2.3 Geophysical Sensing

For the purposes of this study, *geophysical sensing* refers to non-invasive methods of subsurface investigations. The phrase *non-invasive* refers to methods that do not result in subsurface ground disturbance. This section briefly describes how two commonly used methods—ground-penetrating radar (GPR) and magnetometry—function and their relative strengths and weaknesses in assessing/identifying deeply buried subsurface archaeological deposits. Other geophysical methods, such as magnetic resistivity and metal detection, are not discussed in this study, but are also commonly used to perform subsurface surveys. This section also discusses Light Detection and Ranging (LiDAR), a method that does not provide information about subsurface deposits but can be used to assess landform type as well as the nature and extent of previous anthropogenic landscape alteration based on high-resolution surface topography information.

2.3.1 Ground-Penetrating Radar

GPR utilizes dielectric (non-conductive) electromagnetic waves in the radar frequency to identify subsurface materials and features. A GPR unit consists of an antenna, receiver, and monitor. The antenna transmits electromagnetic waves that penetrate the ground surface and are reflected back as they work through the substrate, to be intercepted and collected by the receiver. When these waves encounter an object or change in substrate, the velocity of the wave changes and the reflection is plotted as wave travel time and velocity (Conyers and Goodman 1997). The monitor then displays and records the encountered anomalies as incongruities with the surrounding pattern of wave reflection, calculating the depth from the time it takes waves to be reflected back and with a known velocity (Conyers and Goodman 1997).

The depth that can be investigated with GPR varies depending on the frequency of the electromagnetic waves used and the electromagnetic conductivity of the ground deposits, with frequencies ranging from 10 megahertz (MHz) to 1,000 MHz. In order to change electromagnetic wave frequency, the antennae must be switched out. Higher-frequency antennae are able to produce higher-resolution data, but at the cost of depth. Conversely, lower-frequency antennae will produce lower-resolution data, but will be able to penetrate to greater depths (Bjelajac et al. 1995; Conyers and Goodman 1997). While GPR can be used to investigate to depths of up to 50 meters, it is most commonly used in the 10 MHz to 500 MHz range, which typically has the capacity to investigate to a depth of 5 meters (Conyers and Goodman 1997; Conyers and Cameron 1998). GPR surveys are implemented using a grid pattern, which provides the greatest degree of horizontal and vertical control (Cross and Voss 1996).

GPR is particularly well suited for identifying abrupt changes in the volumetric water content of a substrate and can be used in locations covered by snow and ice. While GPR has been widely used to detect subsurface material, such as groundwater levels, existing utilities, and cultural features, it has some limitations. GPR is highly sensitive to highly conductive materials such as clay minerals and salt-saturated deposits, as well as poorly sorted (heterogeneous) deposits, like volcanic, colluvial, and some types of anthropogenic fill deposits. An increase in clay content may inhibit depth and resolution of reflection signals, whereas sandy soils allow for deeper penetration and greater resolution. If an area has a high concentration of clay, GPR may be effective for shallow investigations, but is less likely to be effective with depth. For GPR to be effective, a control study should be conducted to better understand the sediment as well as the results. Finally, the presence of groundwater can severely limit GPR penetration and resolution (Bjelajac et al. 1995; Cross and Voss 1996).

2.3.2 Magnetometry

There are several types of commonly used magnetometers (e.g., proton procession and cesium vapor magnetometers). Despite their differences, they share similar components and principles (Kvamme 2007). Magnetometry relies on the comparison of the strength of the local magnetic field to Earth's background magnetic field. With proton procession and cesium vapor magnetometers, two sensor heads are suspended across a horizontal boom. These sensors measure the local magnetic signature at a predetermined rate (Kvamme 2007). The measurements are recorded, transmitted to the instrumentation, and subsequently mapped using interpolation to a set grid system (Kvamme 2007; Rapp and Hill 2006).

Although iron-rich minerals (e.g., hematite, maghemite, and magnetite) and iron concretions are present in nature, this technology looks for positive or negative magnetic signatures that are anomalous relative to baseline. For example, midden appears to have an anomalously negative signature while ceramics and fire-affected rock appear to have an anomalously positive signature (Rapp and Hill 2006). Leaching from an item with an anomalously positive or negative signature may result in a recorded anomaly that is larger than the item in question (Monaghan et al. 2006), as will particularly large and deep items (Rapp and Hill 2006). Magnetic surveys are performed in a grid pattern, with magnetic points taken at set intervals. The spatial resolution of a magnetometry survey is largely dependent upon the spacing of the transect grids (Kvamme 2007). These point intervals can then be used to create a contour map of the subsurface area (Monaghan et al. 2006)

Magnetometry has a series of limitations that are worth considering. As stated above, anomalies in the magnetic field gradient could be caused by naturally high iron content in sediment deposits, and rock inclusions. Similarly, magnetometry is not effective where volcanic bedrock exists, or in urban settings near power lines or where modern construction has occurred. Magnetometry is not affected by changes in moisture content of soils and can work well across a variety of substrates. One of this method's greatest limitations is the depth at which it is effective. It is generally limited to a maximum depth of between 2 and 3 meters below the ground surface. In addition to this, estimating the vertical provenience of an item with this method can be imprecise (Kvamme 2007).

2.3.3 Light Detection and Ranging

LiDAR uses light in the form of pulsed radar to measure ranges or distances. The data returns produced by the recorded light pulses aggregate to produce a highly precise, three-dimensional point cloud of information about the shape of the Earth or surface characteristics of the object surveyed.

The typical LiDAR instrument consists of a laser, scanner, and specialized global positioning system receiver. These instruments are commonly installed on airplanes and helicopters, and data are collected during flights conducted over small to large areas. The data produced from a LiDAR survey have to be processed and classified to provide meaningful outputs for interpretation and use. LiDAR penetrates forest canopies and natural overgrowth, allows for canopy height to be mapped, and allows users to remove first return (or top canopy) information and produce a bare earth view of the surface being surveyed. Each return point in the point cloud has three-dimensional spatial coordinates that correspond to a particular coordinate point on the Earth's surface. The resulting outputs can be used to produce high-resolution digital elevation models, canopy models, engineering-quality building models, and contour maps. These data are then typically imported into geospatial software and engineering software for further analysis and use, which can include detailed stream and river geomorphic maps, detailed shoreline maps, emergency response use, commercial and public civil engineering design, and high-precision surface geology maps (Haugerud et al. 2003; NOAA 2012).

Currently in the Pacific Northwest, LiDAR is being shared publicly via the Puget Sound LiDAR Consortium. This is a group of public, government, and commercial agencies that has conducted LiDAR surveys across the Puget Sound and has assembled the raw and post-processed data for download by end users (PSLC 2016). Recent efforts have been made to automate landform analysis models using LiDAR data and imagery processing, which allows for improved resolution over traditional aerial imagery or low-resolution digital elevation models (Jones et al. 2007).

The key strengths of LiDAR are that it provides high-resolution surface data in both vegetated and unvegetated environments and can be used to quickly identify and define geomorphic landform types with the potential to contain deeply buried archaeological resources and evidence of anthropogenic alteration in areas that were previously unmapped or mapped using low-resolution data. The weaknesses of LiDAR are that it cannot penetrate the ground surface and that obtaining LiDAR data from a previously unsurveyed area can be costly.

Chapter 3
Environmental Context

The purpose of this chapter is to provide an overview of the environmental factors that may result in, or alter the rate of, burial of archaeological deposits. This section also considers how these factors may affect sample collection during subsurface investigations. Although this document does not include a detailed geologic history because of the size of the study area (i.e., Washington State), it is imperative that one be developed for a given project prior to subsurface investigations. Such information can help to define the range of environments that may be encountered, which can assist with the interpretation of sediment samples obtained during deep archaeological investigations, identifying and accounting for key logistical considerations associated with testing in various environments, and predicting the age and range of archaeological resource types that could be encountered.

Archaeological resources may become buried or destroyed when subject to environmental forces that result in landscape change; these forces are termed *geomorphic forces*. Geomorphic forces change the landscape in a variety of ways, most notably for the purposes of this study, through the deterioration and removal of landforms (*erosional*) or by the growth of landforms (*depositional*). This study primarily considers depositional forces because they have the potential to deeply bury archaeological resources. It also largely limits discussion of geomorphic forces to those that have influenced the landscape starting at the transition from the Pleistocene epoch to the Holocene epoch—the period for which there is documented evidence of human use of North America (Meltzer 2004; Erlandson et al. 2007). These forces include *aeolian* (also spelled as eolian), *alluvial*, *anthropogenic*, *colluvial*, and *volcanic*. Although Washington State was heavily altered by glacial forces prior to the Holocene epoch, the areas where glacial forces were active during the Holocene epoch represent a very small percentage of the landscape and almost exclusively in the alpine and subalpine zones. Therefore, limited discussion about glacial environments is provided. This study also considers other factors that do not necessarily directly result in the deposition of sediments, but rather influence which portions of the landscape are subject to varying types of geomorphic forces. These factors include tectonic movement and sea level change.

In order to illustrate how the various geomorphic environments described above are distributed across Washington State, soil data ranging from 1:12,000 to 1:63,360 in scale were obtained from the Natural Resources Conservation Service web soil survey (http://websoilsurvey.sc.egov.usda.gov/). Using the data attribute *Parent Material*, the 48 soil series that have been documented in Washington State were organized into seven units. These units represent primary geomorphic origin and include alluvial, anthropogenic, aeolian, colluvial, glacial, bedrock, and undefined. Of these, aeolian, alluvial, anthropogenic, colluvial, and volcanic are defined as having the potential to contain buried archaeological resources based on the discussion provided below. This dataset was expanded to include statewide 1:100,000 scale geologic map data in areas where no soil data coverage was available. This scale was selected because it was the finest resolution available with statewide coverage, although finer resolution maps are available for limited portions of Washington State. Because of thick vegetation and extensive bioturbation (i.e., plant- and animal-induced sediment mixing) across large portions of Washington State, subsurface investigations may still be needed in areas that are not defined as having the potential to contain buried archaeological resources to increase visibility. The areas defined in Figure 1 of Appendix A, however, are considered to have the greatest potential for deeply buried and intact archaeological deposits. Also, while this analysis can provide some preliminary insights into deeply buried site potential across Washington State, in-field verification is necessary given the large and varying scale of the data used.

3.1 Geomorphic Processes

3.1.1 Aeolian

The phrase *aeolian geomorphic process* refers to wind-induced transport and deposition of particles. When wind velocity exceeds the force of *entrainment*, or the force of gravity and friction that keeps particles at rest, it will result in the transport of sediments. In all but the most extreme cases, wind can lift and carry loose, fine-grained materials (i.e., fine sands and silts)—a state referred to as *suspension*. Coarser sands may be transported via bouncing movement along the ground surface—a state referred to as *saltation* (Waters 1992; Huckleberry 2001; Smalley and Smalley 1983). Deposition of wind-transported sediments occurs as the velocity of winds drop below the threshold needed to maintain particle movement or when topographic obstructions (e.g., valley walls, topographic lows, or vegetation) allow for sediment accumulation. Aeolian deposits typically show a high degree of sorting; typically exhibit a massive (i.e., exhibiting no visible structure), laminated, or cross-bedded structure; and most commonly comprise silt- to sand-sized particles (Huckleberry 2001; Smalley and Smalley 1983). Aeolian deposits are commonly found in dry areas with an abundance of loose, fine-grained sediment and limited vegetation. Such areas may include dry alluvial plains and fans, glacial outwash plains, and volcanic environments (Huckleberry 2001; Feibel 2001; Wells 2001).

Aeolian processes can erode and disturb archaeological deposits, as well as bury and preserve them (Feibel 2001; Rapp and Hill 2006; Waters 1992). Erosion and disturbance can occur through the selective removal of finer grains, which results in *deflation*—the process that can, over time, remove vertical stratigraphy of archaeological deposits (Nickling 1994). Intact archaeological deposits can be buried and preserved, especially if they are located in areas that are protected from the wind or on stable landforms. Although the thickness of aeolian deposits can vary widely, an illustrative example comes from the San Francisco area, in which archaeological deposits were identified below 3 to 4 meters of aeolian dune sands (i.e., Pastron and Walsh 1988).

Aeolian deposits are frequently fine-grained and relatively unconsolidated, although oxides and iron oxides are common and can result in moderate consolidation over time. The unconsolidated nature and shallow angle of repose of recent (late Pleistocene and Holocene aged) aeolian dune deposits is not always conducive to deep mechanical excavation because trench walls are likely to be unstable, which would result in rapid in-filling and disturbed stratigraphy. Given this limitation, borings may be a more appropriate technology for collecting sediment samples, particularly if a catcher is installed in the shoe of the sampler. However, careful consideration of false stratigraphy and sample disturbance should be taken into account, regardless of the method used. Aeolian deposits are ideal for geophysical sensing methods, such as GPR and magnetometry, because of the small size and homogeneity of the sediments that compose these deposits.

3.1.2 Alluvial

The phrase *alluvial geomorphic process* refers to the way in which water changes the landscape via the erosion, transport, and deposition of sediments. This term broadly refers to a range of distinct environments that have long been important to humans, including *fluvial* (riverine), *pluvial/lacustrine* (lake), and coastal environments (Huckleberry 2001; Gladfelter 2001; Ames and Maschner 1999; Waters 1992). While these environments have key differences in how the movement of water results in changes in the morphology of the landscape over time, this section briefly discusses each of these environments in the context of erosional and depositional processes.

Fluvial Environments

Fluvial environments are shaped via the gravity-induced downslope movement of water. This water tends to coalesce into river or stream channels. When water *discharge* (which measures water velocity combined with channel cross-section) in a given river or stream is great enough, it can erode and transport particles and move them downstream. Once discharge decreases to an extent that it can no longer sustain particle movement, the particles are deposited. Because discharge tends to be greatest (or highest energy) in the active river channel, the largest particles (i.e., gravels and coarse sands) in a fluvial environment are typically located within the active channel or relict channels. Over time, this results in the formation of imbricated (stacked) gravels and sands. Finer particles (i.e., silts and sands) are deposited in areas where discharge is relatively low along the channel (i.e., areas of slow-moving water) or during overbank flooding events where suspended sediments settle out in pools of standing water. Over time, repeated settlement results in the formation of loosely to moderately compacted planar laminations of sands and silts (Walker and Cant 1985; Waters 1992; Guccione 1993; Collinson 1996; Huckleberry 2001). Although deposition within a stream channel with a gravelly substrate is unlikely to preserve and bury archaeological deposits (Elder, Reed et al. 2015), overbank deposition typically occurs with low enough energy to preserve and bury archaeological deposits.

Coastal Environments

The coast is broadly defined as the interface between the land and the sea, which includes areas both landward and seaward of the shoreline (Reading and Collinson 1996). This zone was of particular importance to the precontact peoples of the Pacific Northwest because it served both as an important resource base and an efficient means of transportation (Ames and Maschner 1999). For the purposes of this study, two types of nearshore coastal processes are considered: *tidal fluctuation* and *wave action*. Tidal fluctuation consists of the semi-diurnal (i.e., nearly twice per day) rise and fall of the tide, which results in the periodic exposure and inundation of the intertidal zone. Although the process of tidal fluctuation is typically neither strongly erosional nor depositional, over time and in environments where wave or fluvial processes have limited influence, tidal forces can both deposit suspended fine sediments—forming tidal flats—and erode drainage channels (Reading and Collinson 1996). Waves are generated either by wind or displacement (i.e., coseismic subsidence), and play a significant role in sorting and redistributing sediments along the shoreline (Downing 1983; Walker 1984; Reading and Collinson 1996). Wave action can result in horizontal erosion in instances where wave energy is rapidly transferred to erosion-susceptible shores, typically via a steep incline, or deposition of fine to coarse sediments where wave energy is dissipated to such an extent that particles suspended in the wave settle out. The former typically results in the formation of steep bluff-backed beaches, while the latter typically results in the formation of spits, cuspate forelands, and strandplains (Downing 1983; Shipmen 2008). Because these landforms are often unvegetated, they can serve as a sediment source for aeolian geomorphic processes, which can bury archaeological deposits located inland of the shoreline (i.e., Davis 2006; Milliken et al. 1999; Pastron and Walsh 1988). Although the areas in which both tidal fluctuation and wave action occur are not conducive to long-term habitation, when combined with tectonic movement and sea level change, these forces have the potential to bury precontact terrestrial habitations (i.e., Minor and Grant 1996). An illustrative example of the thickness of coastal deposits along the coast of Washington State is the north shore of Grays Harbor in the vicinity of Aberdeen and Hoquiam, where Holocene-aged tidal flat deposits ranged from 24 to 40 meters thick in some areas (Schneyder et al. 2010).

Lacustrine Environments

Wave action is the primary geomorphic force that affects the shoreline in lacustrine environments, although the scale of wave action is smaller than in coastal environments (Waters 1992). This is because *fetch*, or the distance over which wind can generate a wave, is smaller on a lake than on an open ocean or sea. Given this, lacustrine environments tend to accumulate fine sediments (i.e., clays, silts, and fine sands) or decomposing organic materials (*peat*) (Feibel 2001). Coarser sediments, such a gravels and boulders, can also accumulate in lake deposits and along shorelines via colluvial processes (Rapp and Hill 2006; Waters 1992). Depending upon variations in the rate of water input and output, lake levels may rise or fall over time. When this happens, archaeological deposits that were previously unaffected by alluvial forces may be eroded via wave action or buried when inundated (i.e., Waters 1983).

Testing Considerations

As indicated above, alluvial processes shape a wide range of environments and can deposit a wide range of sediment sizes. As a result, effectiveness of the various deep archaeological investigation technologies depends on the specific microenvironments that are being tested. For example, mechanical excavation would be suitable for most of the environments discussed in this section, but may be poorly suited for excavations in coarse sands and gravels that have the potential to infill faster than they can be excavated. Such environments would include relict channels in fluvial environments, as well as spits and cuspate forelands in coastal environments. Boring would also be suitable for most of the environments discussed above, but small-diameter borings may have poor sample recovery in particularly gravelly conditions, which would include relict channels in fluvial environments. Assuming the presence of a deep water table, geophysical technologies such as GPR and magnatometry would be well suited for the homogenous, fine-grained sediments usually associated with floodplains, but less well suited for heterogeneous and gravelly deposits associated with relict channels in fluvial environments, as well as spits and cuspate forelands in coastal environments. These technologies would also be poorly suited for tidal flat investigations because of the near-permanent presence of a shallow water table.

3.1.3 Anthropogenic

The phrase *anthropogenic geomorphic process* refers to human actions that result in the removal, transport, and deposition of sediments. Although humans have a long history of landscape modification in the Pacific Northwest (i.e., estuarine gardens—Deur 2005; prairie management—Storm and Shebitz 2006), the scale of anthropogenic landscape modification increased markedly during the post-contact period (Rozsa 2009). Although the specific activities that prompt anthropogenic landscape alteration can vary greatly, they can be generally divided into two functional types of activities: *cutting* and *filling*. Cutting is used to decrease the elevation and/or level the ground surface, or to remove sediments that are structurally unstable, while filling is used to level or raise the elevation of the ground surface and to provide structurally suitable materials for construction. Whereas cutting leaves no additive sedimentary indicator, the composition of fill materials is variable and dependent on its source of origin. The structure of fill materials is also variable, depending on the method used to fill an area. For example, hydraulic filling can form fine planar laminae of silts and fine sands, while massive intentional filling can form mixed deposits of silts, sands, gravels, and refuse (Schneyder et al. 2010; Schneyder et al. 2011; Elder and Cascella 2014).

Cutting can destroy or displace archaeological deposits, while filling can bury and preserve archaeological deposits (i.e., Schneyder et al. 2010; Elder and Cascella 2014; Elder, Cascella et al. 2014). Filling via refuse disposal may also result in the creation of archaeological deposits. Although the thickness of anthropogenic fill can be variable, fill deposits exceeding 7 meters thick have been observed along the developed shores of Washington State (i.e., Miss and Hodges 2007; Schneyder et al. 2010; Stevenson et al. 2015).

Like alluvial processes, anthropogenic processes can deposit a wide range of sediment sizes at various stages of consolidation. As a result, strengths and limitations of the various deep testing technologies depend on the specific development history of the area that is being tested. For example, mechanical excavation would be suitable for a wide range of sediment sizes and stages of consolidation, but would be poorly suited for fill materials composed of loose coarse sands and gravels. Boring would also be suitable for a wide range of sediment sizes, but would be less suitable in saturated, poorly consolidated, and fine-grained materials or in environments with abundant gravel and wood debris. Assuming the presence of a deep water table, geophysical technologies such as GPR and magnetometry would be suitable for fill materials composed of homogenous fine-grained materials, but poorly suited for heterogeneous materials with numerous large inclusions.

3.1.4 Colluvial

The phrase *colluvial geomorphic process* refers to gravity-induced downslope movement of sediments, a process also referred to as *mass wasting*. While mass wasting can be aided by other agents of erosion or triggering mechanisms (e.g., water, earthquakes), the primary agent is gravity. Mass wasting is commonly divided into five types of movement, ranging from rapid and catastrophic events to slow and gradual events—although a given mass wasting event may exhibit multiple types of movement. These movement types include falls, slides, slumps, creeps, and flows. Falls, slides, and slumps are typically rapid events; flows can be either rapid or gradual, and slumps and creeps are typically gradual events. The composition of colluvial sediments is varied and based on parent material and environmental setting. Colluvial deposits associated with slides and slumps are often poorly sorted; whereas falls, creeps, and flows may exhibit bedding that becomes thinner and finer as it extends away from the mass wasting event (Waters 1992).

Mass wasting is well-known it the Pacific Northwest for its ability to bury and preserve archaeological deposits (e.g.., Samuels 1991). However, if the mass wasting event occurs with enough force, it may disturb or displace downslope archaeological deposits. Although mass wasting events can vary significantly in scale, particularly large events can rapidly cause significant deposition. For example, the 2014 Oso mudslide, a particularly large and recent mass wasting event, deposited more than 15 meters of sediment at its thickest point and thinned to nearly equal to the pre-event ground surface along its distal edges (Keaton et al. 2014).

Colluvial processes can deposit a wide range of sediment sizes at various stages of consolidation. As a result, effectiveness of the various deep archaeological investigation technologies depends on the parent material and level of consolidation of the colluvial deposit. Mechanical excavation would be suitable for a wide range of sediment sizes and stages of consolidation, but may have difficulty accessing the sloped and/or hummocky terrain associated with many colluvial environments. Borings would suffer from the same access limitations, and may also be poorly suited for collecting samples from talus (i.e., rock debris) slopes associated with falls. If deposits are highly mixed with large gravels and wood debris, borings may also have limited recovery. Geophysical technologies such as GPR and magnetometry would be suitable in homogenous fine-grained deposits. However, colluvial deposits are often a heterogeneous mixture of sediments sizes and organic inclusions, which are not conditions that are best suited for using these technologies.

3.1.5 Volcanic

Although volcanoes move and deposit sediments in a variety of ways, this section focuses on the ways that volcanic geomorphic processes have the potential to result in widespread deposition. For the purposes of this study, two types of volcanic processes are considered: *pyroclastic transport* and *debris avalanches*. Pyroclastic transport carries particles via the rapid movement of hot gas expelled during an eruption. Sediments deposited by pyroclastic transport tend to comprise angular particles, with sizes ranging from greater than 64 millimeters closer to the eruptive source to less than 53 micrometers toward the distal edges of the pyroclastic cloud or *plume* (LaJoie 1984; Orton 1996). Debris avalanches, including mudflows (i.e., *lahars*), are commonly precipitated by earthquakes and/or eruptions and further catalyzed by gravity and water. Unlike pyroclastic transport, debris avalanches typically become confined to streams and valleys as they move downslope. Sediments deposited by debris avalanches also exhibit a wide range of sizes, and can have a mixed, massive, or laminated structure depending on water content (Orton 1996).

Both pyroclastic transport and debris avalanches have the potential to bury archaeological deposits, but debris avalanches—and the great force that they generate—also have the potential to disturb and displace archaeological deposits. Although there are numerous examples of archaeological sites underlying pyroclastic deposits (i.e., ash) in the Pacific Northwest, one particularly notable example of archaeological deposits being buried by debris avalanche deposits is located on the Enumclaw Plateau in Washington State. In this instance, an archaeological site (45KI5) was buried under a very shallow deposit, approximately 1 meter thick, of sediment associated with the Osceola mudflow, - which occurred approximately 5,700 years ago. In other areas, sediments associated with this mudflow are much thicker (Hedlund 1976; Dragovich et al. 1994). Although the rate of deposition associated with pyroclastic transport and debris avalanches varies greatly depending on distance from the eruption and volume of material displaced during the eruption, these events typically cause significant deposition. For example, the initial run-outs from the Osceola mudflow into the Duwamish and Puyallup embayments were up to 10 meters thick in some areas, and the pulse of sediment resulted in the rapid infilling of both embayments during the middle to late Holocene epoch (Dragovich et al. 1994). While the Osceola mudflow was particularly large, the observed thickness of these deposits is comparable to those observed during the eruption of Mount Saint Helens in May 1980 (Brantley and Myers 2000).

Like colluvial processes, volcanic processes can deposit a wide range of sediment sizes at various stages of consolidation. Similarly, effectiveness of the various deep archaeological investigation technologies depends again on the parent material and level of consolidation of the volcanic deposit. Both mechanical excavation and borings would be suitable for a wide range of sediment sizes and stages of consolidation, but borings may be poorly suited for collecting samples from debris avalanche deposits that are highly mixed with large gravels and wood debris. Geophysical technologies such as GPR and magnetometry may be suitable for thick ash deposits or lahar run-out deposits because of their fine texture and relatively homogenous composition, but would likely be unsuitable for the heterogeneous mixture of sediment sizes and organic inclusions that are likely to be associated with most debris avalanche deposits and pyroclastic deposits located near the source of the eruption.

3.2 Other Environmental Factors

3.2.1 Tectonic Movement

In the Pacific Northwest, tectonic movement (i.e., the movement of the Earth's plates) continues to cause long periods of gradual ground surface elevation change associated with plate warping, punctuated by rapid periods of elevation change associated with faulting. This is particularly apparent along the Cascadia subduction zone, which is the boundary along which the Pacific plate dives or *subducts* under the North American plate. The tectonic pressure generated by this subduction results in the slow upward movement of the ground surface along much of the outer coast of Washington State (Verdonck 2004), periodically broken by ruptures that result in several meters of downward movement or *subsidence* (Atwater 1987; Atwater et al. 1995). Rapid uplift and subsidence may also occur along the many intraplate faults that can be found in Washington State. A particularly notable example of intraplate faulting is an event that occurred around 1,300 years ago along the Seattle fault, in which one side of the fault underwent as much as 7 meters of uplift while the other side of the fault underwent up to 1 meter of subsidence (Bucknam et al. 1992). These events can result in previously surface-exposed archaeological deposits being lowered to an elevation where they could become subject to alluvial forces or raised to an elevation where they are no longer subject to such forces. These rapid events can also prompt tsunamis and landslides, which can further bury or destroy archaeological deposits.

3.2.2 Sea Level Change

Sea level change is considered at two scales: global (*eustatic*) and local (*isostatic*). Eustatic sea level change reflects global changes in total sea water volume while isostatic sea level measures sea level change relative to local tectonic factors (Jelgersma and Tooley 1995). For example, in areas that were previously covered by glaciers and where ground surfaces are in the process of rebounding, the rate of ground surface uplift may exceed the rate of eustatic sea level rise, which would mean that an area was experiencing isostatic sea level regression (i.e., falling). Sea level change is generally considered in terms of *transgression* (rising) and *regression* of the shoreline. When transgression occurs, sea level rises relative to the surrounding landscape. This results in the gradual inundation of nearshore terrestrial environments, exposing them to alluvial processes, which can bury and erode archaeological deposits (Wells 2001). During regression, previously inundated landforms emerge from the water and are either subject to new types of alluvial processes or are removed entirely from the influence of alluvial processes (Wells 2001). In some instances in areas where regression has occurred, archaeological deposits that were previously associated with shorelines may be located great distances from the current shoreline (Wells 2001).

Chapter 4
Sampling

This chapter builds on the content of Chapter 2, *Subsurface Investigation Technologies*, and Chapter 3, *Environmental Context*, to consider the relationship between archaeological resource types and sampling approaches. The purpose of this chapter is to illustrate how varying archaeological resource types may require differing approaches to sampling to increase the likelihood of their discovery. This chapter considers sampling as it relates to archaeological sites, rather than to individual artifacts and features.

4.1 Sampling Dimensions

A review of the Washington Information System for Architectural & Architectural Records database maintained by the Washington Department of Archaeology and Historic Preservation revealed that some of the most commonly documented precontact archaeological site types in Washington State—not including isolates, petroglyphs, or objects—include lithic materials (or lithic scatters/concentrations), camps, shell middens, and villages. The review also revealed that some of the most commonly documented historical archaeological site types—not including sites that primarily consist of structural remains (e.g., bridges, cabins, hydroelectric), isolates, or objects—include debris scatters, homesteads, and camps.

Some of the archaeological site types listed above are located in very specific environments (i.e., shell middens along coasts, villages along rivers and coasts), while others can be found in a range of environments (e.g., precontact lithic materials and camps; historical debris scatters, homestead, and camps). Similarly, geomorphic forces like alluvial and colluvial deposition are limited to specific slopes and elevations, while other geomorphic forces like aeolian, anthropogenic, and volcanic deposition can occur nearly anywhere on the landscape. As a result, anticipating the range of archaeological site types in a given area would require both an understanding of the types of geomorphic forces that have deposited sediments in a given area and the range of archaeological site types that are commonly associated with these forces. For example, the breadth of archaeological site types that one would anticipate encountering in a coastal (alluvial) environment that has also been influenced by aeolian forces is likely to be greater than the range of archaeological site types that one would anticipate encountering in an upland environment that has been influenced by aeolian and volcanic forces. Both environments may have the potential to contain precontact lithic materials, camps, historical debris scatters, homesteads, and camps, but only the coastal environment is likely to contain shell middens, villages, and fish weirs. For historical archaeological sites, other lines of evidence, such as maps and documents, can be used to anticipate types and locations of archaeological sites.

The anticipated range of archaeological site types for a given area is an important consideration because the types and density of artifacts that compose the site will differ depending on resource type. For example, precontact intertidal fishing sites in Washington State often only comprise linear or v-shaped alignments of small wooden stakes (Elder et al. 2014), while shell middens commonly comprise contiguous deposits of shell and vertebrate faunal remains (Claassen 1998). Importantly, the physical dimensions of an archaeological site can affect one's ability to perceive them. Three dimensions in particular are discussed below: *item visibility*, *item dispersal*, and *resource size*.

Item Visibility: Commonly, artifact size and color are key factors that affect their visibility in that as artifacts become smaller or as they increasingly blend in with the surrounding area, they become more difficult to perceive. Shell middens, for example, are typically highly visible both because they usually contain a wide range of artifact sizes that are easily differentiated from the sediment that they are collected from and because they usually contain dark and greasy soil that is visibly distinct from the surrounding sediments. On the other hand, some lithic material sites can be comprised of very small pieces of debitage created from local materials, and can be very difficult to perceive without the aid of fine mesh. While this dimension does not necessarily affect the specific deep subsurface investigation method that one uses, it is an important overall methodological consideration when designing a deep subsurface archaeological investigation approach.

Item Dispersal: As the contents of an archaeological site become more dispersed, the site becomes more difficult to perceive if the excavated sample size remains constant (Schiffer et al. 1978; McManamon 1984; Bowden 2016). Some archaeological sites—like shell middens, precontact villages, and camps—may have clearly visible and continuous anthropogenic soils regardless of how dispersed their contents may be. Other sites—like precontact lithic materials, historic debris scatters, camps, and homesteads—may not have clearly visible anthropogenic soils and can range from having diffuse to concentrated contents. In instances where archaeological sites contain highly dispersed artifacts but do not have a clearly visible anthropogenic soil, an increase in the total sample size excavated—as measured by either total surface area or volume—would be needed to identify the archaeological site relative to sites that either contain tightly clustered artifacts or have a visible anthropogenic soil.

For comparative purposes, assuming that a mechanical excavator excavates a single 1.5-meter by 3-meter test unit and a drill rig excavates a single 20-centimeter diameter boring, the, the total excavated surface area of each would be 4.5 square meters and 0.13 square meter, respectively—a nearly 35x difference in total surface area. Although the dimensions presented above are arbitrary, they represent what would typically be considered a relatively small mechanically excavated test unit and a relatively large diameter boring. Geophysical sensing is a special case in that it is typically used to collect information on 100% of a sample area, but must be corroborated using some form of subsurface investigation method.

Resource Size: As the horizontal size of the anticipated site decreases, the likelihood of encountering it during subsurface investigations decreases if sample spacing remains constant (Schiffer et al. 1978; McManamon 1984). Some sites, like lithic materials and shell middens, can range from less than a few meters to tens of meters (or more) in size. In order to increase the potential of encountering small resources, the spacing between subsurface testing units must decrease. Alternately, or in conjunction with decreasing the spacing between subsurface testing units, increasing the total surface area investigated within each testing unit will also assist with increasing the potential for encountering small resources.

4.2 Summary

To increase the probability of perceiving archaeological sites, archaeologists must consider whether the sites that they are looking for are likely to be visible to the unaided eye, clustered or dispersed, and large or small, and then adjust their field methods to collect the sample dimensions that have the greatest potential to perceive these sites. With this in mind, Table 4-1 summarizes the anticipated physical dimensions of some of the most commonly documented archaeological site types in Washington State.

Table 4-1. Common Archaeological Site Type and their Anticipated Physical Dimensions

Resource Type	Item Visibility	Item Dispersal	Resource Size
Precontact			
Shell Midden	High	Low	Small to Large
Lithic Scatter	Low to High	Low to High	Small to Large
Camp	Low to High	Low to high	Small
Village	High	Medium to High	Large
Fish Weir	High	High	Large
Historical			
Debris Scatters	High	Low to High	Small to Large
Homestead	High	High	Large
Camp	High	High	Small

Based on the discussion presented in this section, mechanical excavation would be the preferred method if a study calls for the identification of archaeological sites in an environment where resources are likely to be small, composed of diffuse items, and/or require a relatively large sample size. Boring would be best suited for identifying landforms and large continuous deposits, considering the small sample size provided by each borehole and relatively slow rate of excavation. In some instances, boring may be the only viable option because of depth or access limitations. However, unless an extremely large level of effort is used (i.e., dozens of side-by-side borings), the potential for sample size and spacing-related missed resources is greater than if a mechanical excavator is used. Despite the fact that geophysical sensing has the capacity to collect information from 100% of a sample area relatively rapidly, it must be corroborated using subsurface investigation methods. Therefore, it is not appropriate as a stand-alone resource identification tool.

Chapter 5
Case Studies

This chapter presents eight case studies in which the subsurface investigation technologies described in Chapter 2 were used. Summaries of the purpose, technology, field investigation approach, findings, and a review of the extent to which the technology successfully addressed the purpose of each study are provided. This information, combined with the information presented in previous chapters, serves as a basis for the discussion presented in Chapter 6.

To obtain the case studies reviewed in this document, ICF International staff reviewed online archaeological publication repositories, consulted the Washington Information System for Architectural & Archaeological Records database, and performed outreach to archaeologists and geoarchaeologists from across the United States. The purpose of the outreach effort was to identify relevant articles and grey literature relating to deep archaeological investigation studies. Although not all of the references that were provided were used, the following individuals were contacted.

- John Pouley, Assistant State Archaeologist, Oregon State Historic Preservation Office
- Lance Lundquist, Archaeologist, U.S. Army Corps of Engineers, Seattle District Regulatory Branch
- Jim Abbott, PhD, Archaeologist, Texas Department of Transportation
- Brandy Rinck, Geoarchaeologist, SWCA Environmental Consultants
- Jack Meyer, Geoarchaeologist, Far Western Anthropological Research Group, Inc.
- Christina Rieth, PhD, State Archaeologist and Director, New York State Museum
- Brett Rushing, Office of Cultural Resources Studies, District 4, California Department of Transportation
- Bruce Koenen, Assistant State Archaeologist, Minnesota Office of the State Archaeologist
- Jessica Tudor, Associate State Archaeologist, California Office of Historic Preservation

5.1 Boring

Five case studies that used borings as a means for deep testing were selected for this study. The project-specific goals of these studies ranged from preliminary archaeological sensitivity analyses to archaeological inventory and evaluation to data recovery excavations. One of the case studies, the archaeological investigations for the Imperium and Westway expansion projects, also used mechanical excavation for the purposes of verifying the results of the borings.

5.1.1 Tacoma/Pierce County High-Occupancy Vehicle Program Archaeological Data Recovery, Tacoma, Washington, WSDOT (Elder and Sparks 2010)

Key Terms: *Sonicore Borings, Site Delineation, Data Recovery Excavations*

Purpose: A precontact archaeological resource (45PI930) was documented during an earlier cultural resources inventory for the project in a geoarchaeological test boring approximately 18 feet below the ground surface, or 5 feet below mean sea level. The resource was determined eligible for listing in the National Register of Historic Places and data recovery via rotosonic borings was selected as mitigation for project-related adverse effects. The boundaries of the resource had not previously been delineated. As a result, the goals of this study were to delineate the site boundary and to perform data recovery excavations in accordance with the project's Memorandum of Agreement. The project was within a filled area thought to be located on the pre-development Puyallup River delta and it was known from previous studies that a thin bed of organic delta top deposits underlain by a thick bed of sandy delta front deposits would be encountered below the fill. These same studies identified a thin layer of midden on top of the delta top deposits.

Technology/Method: This study used a rotosonic drill rig equipped with an 8-inch external diameter sampler tube to collect sediment samples. A total of 65 boreholes were excavated over a 5-day period. Boreholes were spaced at various intervals, ranging from 3 to 15 feet, depending on whether archaeological deposits were discovered in other boreholes nearby, and ranged from 21 to 30 feet in depth. The excavations resulted in the collection of 1,450 linear feet (or 44 cubic meters) of sediments. From this sample, a total of 107 sub-samples (totaling 56 linear feet and 0.54 cubic meter) were collected from 55 boreholes for further study. Sub-samples were selected for further analysis if they were located at the stratigraphic contact where 45PI930 was previously located (i.e., the target interface) or if archaeological deposits visible to the naked eye were identified. In 10 instances, sub-samples were not collected from boreholes because of sample loss at the contact of interest. All sub-samples were screened through nested 12-, 6-, 3-, and 1.5-millimeter mesh.

Findings: Nearly all of the boreholes contained approximately 5 feet of gravelly fill material, underlain by 5 feet of silty sand dredge materials, underlain by 5 to 6 feet of laminated native silts and peats, underlain by medium to coarse massive sands of unknown thickness. All archaeological deposits were identified at the interface between the native silts and peats and the underlying medium to coarse sands. Of the 55 sub-samples that were collected for further study, 23 contained artifacts. A total of 1,330 artifacts were recovered, including 36 pieces of lithic debitage, 58 pieces of fire-modified rock, and 1,239 pieces of burned and unburned bone. No archaeological features were identified, but this was anticipated because each boring provided a very limited horizontal sample size and it was nearly impossible to sample a contiguous line of borings, which would be necessary to obtain a horizontal sample large enough to recognize archaeological features.

Review of Methodology: Overall, the boring program successfully recovered deposits from the target interface in 55 out of 65 instances (85% of the time). In the 10 instances where target deposits were not fully collected, the conditions that led to sample loss appeared to be related to the presence of particularly soft and saturated sands that underlay the target interface. Despite the relatively high rate of recovery at the target interface, the boring program had two notable weaknesses in the context of data recovery excavations. First, the limited horizontal sample size and inability to collect a contiguous horizontal sample prevented the recognition of archaeological features. Second, there was a high degree of variability in the depth at which archaeological deposits were encountered. It is unclear whether this variability was a function of the natural topography of the pre-development ground surface, deformation of the pre-development ground surface caused by development activities, or sample compression due to water loss during data collection. Given these sample size and resolution limitations, and the relatively large amount of effort (i.e., 44 cubic meters excavated over 5 days) required to collect a small amount of archaeological data (0.54 cubic meter sampled, 1330 artifacts collected), borings appear to be poorly suited for data recovery excavations.

5.1.2 Archaeological Investigations for the Westway and Imperium Expansion Projects, Grays Harbor, Washington (Hetzel et al. 2015)

Key Terms: *Geoprobe, Boring, Mechanical Trenching, Archaeological Testing*

Purpose: The Washington Department of Archaeology & Historic Preservation requested that a deep archaeological investigation study be performed for a proposed industrial facility expansion project along the Aberdeen and Hoquiam waterfront. The pre-development shoreline is largely obscured by thick deposits of fill, and there is at least one documented instance in which filling has buried archaeological resources that would have been previously exposed at the ground surface (i.e., Schneyder et al. 2010).The goal of the study was to determine whether previously undocumented buried archaeological resources were present and to assess the potential for encountering buried archaeological resources in the event that none were identified during the survey. Because the project was located within a filled area seaward of the pre-development shoreline, it was anticipated that the project would encounter thick intertidal flat deposits below the fill. The project area was dredged for use as slip during the historic era and filled during the late twentieth century, so no buried historic archaeological resources were anticipated. However, it was considered possible that precontact resource collection features (i.e., fish weirs, basket traps) would be encountered in the intertidal flat deposits.

Technology/Method: This study used a Geoprobe 7730 rig with a 2-inch internal diameter sampler and a Deere 330 LC excavator equipped with a 42-inch flat-bladed bucket. A total of 14 borings and 9 trenches were excavated over a 4-day period. Boreholes and trenches were spaced at approximately 30-meter intervals across the outer margins of the project footprint. Borings ranged from 40 to 90 feet in depth, while trenches ranged from 10 to 25 feet in depth. All sediment samples collected during the borings were split, inspected, and then screened through 6-millimeter mesh. Sediments excavated during trenching were spread out and inspected using hand rakes.

Findings: All of the boreholes and trenches contained structural and undifferentiated fill. Although the precise depth of fill could not be determined in several instances, deposits definitely identified as fill ranged from 4 to 35 feet in thickness. In nine instances, all boreholes, the origin of the recovered deposits was ambiguous. In these instances, fill deposits comprised soils that had been dredged from a nearby tidal flat and hydraulically deposited within the study area. Because approval could not be obtained from the Port of Hoquiam to remove large expanses of asphalt for mechanical excavation in a portion of the project area, trenches could not be excavated in these locations to further sample the deposits in question. Intertidal flat deposits were definitively identified in 14 instances, with the upper interface of these deposits ranging from 14 feet to 35 feet below the ground surface. No archaeological deposits were identified during the study. However, because most of the project-related activities would occur within deposits clearly identified as fill, testing was curtailed at the interface between the fill deposits and intertidal flat deposits.

Review of Methodology: Overall, the deep archaeological investigation program accomplished the goals of the study. The combined results of the borings and mechanical trenches revealed that deposits that could be recognized as fill extended deeper than the anticipated depth of all but one of the proposed project-related ground-disturbing activities. Because of this, the potential for encountering buried archaeological resources was considered to be low for all but one of the proposed activities. One proposed activity—the driving of piles—retained the potential to encounter buried archaeological resources. However, the depth at which archaeologically sensitive deposits (i.e., tidal flats) would be encountered exceeded the maximum depth that could be accessed with a mechanical excavator in all but a few instances and the sample size provided by borings was considered to be too small to identify the types of spatially diffuse archaeological resources associated with tidal flats (i.e., fish weirs and traps).

Thirteen of the borings were excavated to a depth of 40 feet below the ground surface and one was excavated to a depth of 90 feet below the ground surface. One of the 40-foot borings recovered approximately 62% of the total core that was sampled and the cause of sample loss was not clearly visible. In this instance, no casing was used to protect the contents of the boring because of rig operator error. In the remaining 40-foot borings, casing was used and sample recovery ranged from 87 to 100%. When sample loss occurred, it was primarily a result of cobble and woody debris getting lodged in the inlet of the sampling tube. To a depth of 45 feet, the 90-foot boring had a recovery rate of 100%—comparable to the shallow borings. Below 45 feet, the recovery rate declined to 50%. The cause of sample loss was not clearly apparent to the investigator. At a depth of 90 feet below the ground surface, fine-grained but stiff deposits were encountered and further boring was not possible.

In some instances, the data obtained from the boring program could not be used to differentiate between the fill and native tidal flat. In these instances, fill deposits comprised soils that had been dredged from a nearby tidal flat and hydraulically deposited within the study area and were visually indistinguishable from the undisturbed tidal flat based on sedimentary structure and composition alone. Where possible, mechanical trenching was used to collect a larger sample to look for sparsely distributed historic and modern items that were included in the dredged materials to differentiate between the native tidal flat and dredge spoils. In instances where mechanical trenching was used, the interface between the fill and tidal flat could be defined with a greater degree of precision. However, mechanical trenching could only reach a maximum depth of 25 feet below the ground surface without the assistance of shoring, and the resolution of vertical provenience for any item recovered during trenching was no better than approximately 1 foot. This resolution tended to decrease with depth.

5.1.3 Geotechnical and Archaeological Bore Monitoring for Tacoma Trestle Track and Signal Project, Pierce County, Washington (Stevenson et al. 2015)

Key Topics: *Rotary Drilling; Split-spoon and Osterberg Samplers; Archaeological Testing and Delineation*

Purpose: Sound Transit proposed to replace an existing single-rail trestle with a double-rail trestle in a portion of the City of Tacoma that was filled during the historic period. In order to determine whether deeply buried archaeological deposits were present, Sound Transit elected to have archaeologists monitor geotechnical borings and excavate and analyze geoarchaeological borings. During these investigations, buried archaeological deposits were encountered, and additional geoarchaeological borings were excavated to further characterize and delineate the deposits. The goal of the archaeological study was to determine whether previously undocumented buried archaeological resources were present and, if resources were identified, further characterize and delineate them. The study did not explicitly present expectations for depositional context and archaeological resource types, but the geoarchaeological information presented in the results of the study indicate that it is located within a filled area that is thought to have been the Puyallup River delta prior to historic development. Such an area would have the potential to contain resource collection features and artifacts.

Technology/Method: This study used 10-inch diameter by 24-inch-long split spoon and Osterberg samplers. A total of 17 borings, 4 geotechnical and 13 geoarchaeological, were excavated at no more than 100-foot horizontal intervals. Sediment samples were collected from geotechnical borings at 5-foot intervals (i.e., 24-inch sediment sample followed by 36 inches of drilling where no sample was collected) and were collected from geoarchaeological borings in 3-foot intervals (i.e., 24-inch sediment sample followed by 12 inches of drilling where no sample was collected). Borings ranged from 36 to 60 feet in depth, except in one instance where a boring was excavated to a depth of 90 feet but no sediment samples were collected at depths greater than 50 feet below the ground surface. All sediment samples collected from geoarchaeological borings were transported to a laboratory, extruded, characterized, and then screened. Sediments with visible organic strata were screened through 3-millimeter mesh and all other sediment was screened through 6-millimeter mesh.

Findings: Possible lithic artifacts were recovered from three borings, two of which were geotechnical and one of which was geoarchaeological. Cultural materials—including burned shell and fiber cordage—were identified in two geoarchaeological borings, and buried surfaces were identified in four geoarchaeological borings. In two instances, both of which were geoarchaeological borings, cultural materials or possible cultural materials were recovered from cuttings, which are sediments that are removed from a boring by way of an auger between sediment sample intervals. In order for cuttings to be brought to the surface, they are rotated upward along the outer *threadings* (i.e., the corkscrew-like blades along the outer surface) of the auger until they emerge from the borehole. This process, which has the potential to mix and integrate sediments from anywhere along the length of the borehole, does not allow for the establishment of vertical provenience. The cultural materials and possible cultural materials originated from a range of depths, but the cordage, burned shell, and a possible lithic artifact appeared to be associated with a buried surface observed in several borings. Based on the information obtained during the study, the location was given an archaeological site designation (45PI1327).

Review of Methodology: Overall, it is unclear whether the primary goal of the study—to identify previously undocumented buried archaeological resources—was accomplished. Based on the ambiguous origin of many the possible artifacts recovered during subsurface investigations, it appears that the technology used to perform the testing program introduced a degree of uncertainty to the study. This uncertainty was related to the fact that the mechanical process of collecting soil samples and drilling between soil sample depths had the potential to fracture gravels in a way that could be difficult to differentiate from precontact lithic reduction activities. In addition to this, in instances where possible artifacts were recovered from drill cuttings generated by the hollow stem auger, the amount of disturbance and displacement involved in extracting these items was such that their original depositional context was indeterminate upon their discovery. In the case of the possible lithic artifacts, this uncertainty was addressed with a detailed lithic analysis, which found that many of the items in question were likely to be of recent origin. Regardless, the lack of vertical provenance for sediments obtained from hollow stem auger cuttings appears to make this a poor method for the collection of archaeological data, particularly in settings where the auger must advance through anthropogenic fill, which increases the potential for the incorporation of more recent items into the cuttings.

The testing program resulted in the collection of 33% (or less) of the length of the geotechnical cores and around 83% of the length of the geoarchaeological cores. However, the higher recovery percentage for the geoarchaeological cores was partially accomplished because the cuttings that were extruded between soil sample depths were inspected and screened by an archaeologist. Although additional borings were excavated to further characterize and delineate archaeological deposits in three instances, the small size of the project footprint appears to have limited the number of borings that could be reasonably excavated to delineate the resource.

Finally, the investigators noted that while the exclusive use of an Osterberg sampler was originally proposed for the geoarchaeological borings, the sampler did not perform well when very densely compacted sediments, impediments, or particularly loosely compacted sediments were present. As a result, a combination of Osterberg and split-spoon samplers was used. The investigators also noted that the split-spoon sampler appeared to more consistently recover sediment samples, and sediment samples with fewer gaps, than the Osterberg sampler.

5.1.4 Archaeological Testing for the Alaskan Way Viaduct Replacement Project Tunnel Boring Machine Repair Shaft, Seattle, Washington (Elder and Cascella 2014)

Key Topics: *Rotary Drilling, Split-Spoon Sampler, Identification and Delineation*

Purpose: When the tunnel boring machine for the Alaskan Way Viaduct Replacement project was damaged, WSDOT developed a testing plan in consultation with the Washington Department of Archaeology & Historic Preservation and the affected tribes. The testing plan consisted of excavating geoarchaeological borings at systematic intervals in an area that encompassed the proposed location for a large shaft to access and repair the tunnel boring machine. The goals of the study included identifying and delineating any undisturbed native tidal flat deposits and/or any deposits associated with the archaeological resource Ballast Island (45KI1189), as well as identification of any previously undocumented archaeological resources. The project was located within a filled area seaward of the pre-development shoreline, and it was anticipated that the project would encounter gravelly beach deposits below the fill. The proposed shaft location was in the vicinity of several historic-era wharves and the above-referenced site 45KI1189, a man-made island built out of ships' ballast; it was anticipated that remnants of the island would be encountered. Other historic-era deposits and precontact deposits were not anticipated because the pre-development beach was thought to have been too high energy of an environment to allow for the preservation of archaeological deposits. However, a subsequent study did identify an intact historic-era pile of shell refuse on the pre-development beach surface (Elder, Cascella, et al. 2015)

Technology/Method: Geoarchaeological borings were excavated in a systematic grid pattern at 15-foot intervals in the vicinity of the proposed shaft location and at 66-foot intervals north of the proposed shaft location. Once deposits of interest were identified north of the proposed shaft location, additional borings were excavated between negative and positive borings to more precisely delineate the extent of the deposits. Prior to excavating borings, each of the proposed boring locations was vactor-excavated (i.e., excavated using pressurized water and a large truck-mounted industrial vacuum) to depths ranging from 6 to 10 feet below the ground surface to inspect for buried utilities. Geoarchaeological borings were continuously excavated using truck- and track-mounted CME-75 and CME-85 rotary drill rigs. Samples were advanced using a 140- or 300-pound autohammer and collected using 18- or 24-inch-long by 4-inch-diameter split-spoon sampler tubes.

Borings were terminated at a depth of 35 feet unless impassible conditions or glacial deposits were encountered at shallower depths. Sediment samples were analyzed and documented, and then sediments from 20 of the borings were screened through 6-millimeter mesh. In eight instances, only vactored holes were used to uncover and inspect deposits thought to be associated with the archaeological resource Ballast Island (45KI1189).

Findings: A total of 45 geoarchaeological borings and 8 holes that were only vactored were excavated. Archaeological deposits associated with the Ballast Island site were identified in 10 geoarchaeological borings and vactored holes north of the proposed shaft location. Within the proposed shaft location, fill deposits ranged from 18 to 27 feet thick and were underlain by intertidal beach deposits. No intertidal flat or previously undocumented archaeological resources were identified and the study revealed that the pre-development ground surface would have been located between 2 and 8 feet below mean sea level.

Review of Methodology: Following the completion of the survey and during shaft construction, archaeological monitors identified several concentrations of marine bivalve shells at an approximate depth of 18 feet below the ground surface within the area that was previously tested using geoarchaeological borings. Closer inspection revealed that the bivalve shells were located at the interface between historic fill and the underlying intertidal beach deposits, and primarily consisted of native oyster. Subsequent archaeological testing and historical documentary research revealed that the shell deposit was actually a series of refuse deposits associated with a restaurant and fish market that operated on a dock over the study area during the late nineteenth century. Following the archaeological testing, the researchers inferred that the shell deposit was not identified during geoarchaeological testing because of the fragile nature and platy structure of the shells combined with the use of relatively small-diameter samplers with soil-catcher screens, resulting in poor sample recovery when thick deposits of shell were encountered (Elder, Cascella, et al. 2015).

As a result of this discovery, while two of the goals of the study were accomplished (i.e., identify and delineate intertidal flat deposits and deposits associated with the archaeological resource Ballast Island), the third (i.e., identify previously undocumented archaeological resources) was not. Sample loss in unsuitable substrate and small sample size appeared to be key factors in this method's failure to identify archaeological deposits. Importantly, rotary drilling has been successfully used to identify deeply buried archaeological deposits on this project and elsewhere in Washington State, indicating that it can be used to determine whether archaeological deposits are present. However, factors like sample loss and heave introduce uncertainty and make it difficult to determine whether archaeological deposits are truly absent without using alternative methods for verification.

5.1.5 Buried Archaeological Site Assessment and Extended Phase I Subsurface Explorations for the Interstate 80 Integrated Corridor Mobility Project, California Department of Transportation District 04, Alameda and Contra Costa Counties, California (Meyer 2011)

Key Terms: *Geoprobe, Boring, Archaeological Assessment and Inventory*

Purpose: Alameda County Congestion Management Agency proposed road improvements and to install and operate equipment for an intelligent transportation system along Interstate 80 from the Bay Bridge Toll Plaza to the Carquinez Bridge. To determine whether deeply buried archaeological deposits were present, the Alameda County Congestion Management Agency, with the California Department of Transportation serving as the lead state and federal agency, elected to conduct a buried site sensitivity assessment. The assessment was then tested for accuracy and validity using geoarchaeological borings. The overarching goal of the study was to identify and examine areas with high potential to contain archaeological deposits for significant archaeological deposits. The project traversed multiple landforms, including floodplains, fans, hillslopes, and anthropogenically modified landforms. The study focused on landforms that were formed during the Holocene epoch and therefore had the potential to contain buried archaeological deposits. The study further focused on areas in the vicinity of previously documented archaeological sites, which primarily consisted of shell mounds (a synonym for shell midden).

Technology/Method: This study used a Geoprobe 6600 outfitted with a hydraulic coring device to recover continuous samples from 24 locations in the project area. The specific locations where geoarchaeological borings were proposed were in areas defined as having high to very high potential to contain buried archaeological deposits based on geologic research and review of previous archaeological studies in the project vicinity. Borings ranged from 17 to 43 feet in depth, were approximately 2 inches in diameter, and totaled 663 linear feet of sediment samples. All cores were stored in hard plastic liners and, if found, portions of buried soils were screened through 1.5-millimeter mesh to determine if archaeological materials were present. From the recovered sediment samples, 15 samples of organic materials, primarily from stratified alluvial sediments or formerly stable surfaces, were selected for radiometric dating via accelerator mass spectroscopy.

Findings: During testing, no buried archaeological materials were found and additional information on the geologic development of the project area was identified. Eight major stratigraphic units were found associated with the Pleistocene, Holocene, Historical, and Modern age groups. Using this information, the landscape history for the project area was reconstructed and the original buried site sensitivity assessment was corroborated and refined. For instance, Late Pleistocene Stratum III was stable and available for human use for the majority of the Holocene. As such, it was identified as the buried surface with the highest potential to contain archaeological materials. For this and similar strata, the investigation was able to restrict areas of high buried site potential to relatively narrow surface interfaces located at or near the contact between Late Pleistocene-aged alluvium and overlying tidal deposits, shore deposits, and historical or artificial fill deposits. The investigation concluded that it was highly unlikely that the project would adversely affect any large or substantial cultural resources and no further studies were recommended.

Review of Methodology: Overall, the primary goal of the study, which was to identify previously undocumented buried archaeological resources if they were present, was accomplished. No archaeological materials were identified and, although the authors acknowledged that there was a limited possibility that smaller or isolated archaeological resources may have gone undetected, they concluded that it was highly unlikely that any large or substantial cultural resources were present in areas identified as having high archaeological sensitivity. However, it should be noted that these conclusions were based on a field approach that used a total sample size of less than half of a square meter to characterize several hundred acres identified as having high sensitivity for buried archaeological resources. Although it is acknowledged that the small subsurface sample size collected for this study appears to have been a function of logistical factors (e.g., limited access, the need to access deposits at greater depths than could be achieved with a mechanical excavator), it is questionable whether enough subsurface information was collected to rule out the potential for encountering larger archaeological resources. Regardless, the approach used in this study was particularly useful as a means to identify, target, and corroborate spatially limited archaeologically sensitivity areas with limited level of effort, which was an important consideration given the limited scope and size of the overall project.

5.2 Mechanical Excavation

A single case study that exclusively used mechanical excavation as a means for deep testing was selected for this study. The goal of this study was to characterize the relationship between archaeological sites and geology.

5.2.1 Alluvial Geology and Archaeological Potential of the Texas Southern High Plains (Stafford 1981)

Key Topics: *Mechanical Excavation, Manual Excavation, Archaeological Inventory and Testing*

Purpose: Geological, archaeological, and paleontological excavations were carried out to investigate the Llano Estacado region of northwest Texas, a region known to have significant potential to contain paleontological and archaeological deposits. The purpose of the study was to explore and characterize the association between archaeological sites and ancient alluvial depositional environments. Based on previous studies in the project vicinity, it was expected that the study would identify archaeological sites associated with specific geomorphic and topographic features, such as river channels, lakes, marshes, and associated terrestrial landforms.

Technology/Method: Mechanical excavations were undertaken at three locales: Lubbock Lake (103 trenches in a 110-acre area), the Yellowhouse Draw vicinity (23 trenches along 65 linear kilometers), and the Blackwater Draw (3 trenches along 100 linear kilometers). Previously excavated borings were used at one additional locale: the Running Water Draw. Modern quarries in the vicinity of the Running Water Draw and Blackwater Draw were also used as stratigraphic exposure. Trenches ranged from 50 to 300 meters in length and were 6 to 10 meters in depth. All stratigraphic exposures were inspected and profiled. This information was compared against the geologic context of known archaeological sites in the region to determine the types of depositional environments with which various archaeological site types were associated.

Findings: Mechanical excavations identified five distinct stratigraphic units across the study area. Stratum 1 was identified in the Blackwater Draw and Yellowhouse Draw, and contained late Pleistocene-aged faunal materials, and the uppermost member of the stratum was deposited contemporaneously with the Clovis period. At the time of the study, one Clovis-like projectile point had been identified in Stratum 1 deposits. Stratum 2 also contained late Pleistocene-aged faunal materials and was observed at all four locales. Based on the results of previous archaeological studies, this stratum contained archaeological deposits thought to be associated with the Folsom period. Stratum 3 contained the fewest vertebrate fossils of all of the stratigraphic units and was observed at all four locales. Only two definite lithic artifacts were observed in the stratum during previous archaeological studies. Stratum 4 contained few vertebrate fossil remains and was also identified at all four locales. Previous archaeological studies identified Archaic-aged archaeological deposits in the upper third of the stratum. Stratum 5 contained archaeological deposits associated with large bison kills and temporary camps, as well as late nineteenth century artifacts, and was located at all four locales.

Review of Methodology: Overall, the study accomplished its goal to identify the alluvial stratigraphy and geomorphologic history of the Llano Estacado and associate this stratigraphy with previously documented archaeological deposits. Mechanical trenching proved to be an exceptional method for linking stratigraphic sequences across long distances and for developing a detailed understanding of how the regional landscape changed over time. Through this analysis, the investigators were able to develop predictive models relating to the age, function, and stratigraphic association of archaeological resources in the Llano Estacado region. Importantly, however, this study required a significant level of effort to successfully accomplish its goal, a level of effort that may not be feasible for all but the largest of projects.

5.3 Geophysical Sensing

Two case studies that used geophysical sensing as a means for deep testing were selected for this study. These studies were selected because they used the two primary subsurface geophysical methods that were discussed in Chapter 2, *Subsurface Investigation Technologies.* In both instances, the goals of the studies were to identify subsurface archaeological deposits that were either known to be present or anticipated to be present, and manual excavations were used to verify any archaeological findings.

5.3.1 Ground Penetrating Radar Survey: Results from Four Sites in California (Bjelajac et al. 1995)

Key Terms: *Ground Penetrating Radar, Metal Detection, Archaeological Testing*

Purpose: The authors have used GPR on several investigations and, in this article, consider the feasibility of using GPR survey as part of archaeological investigations. They reference investigations that occurred at two historic and two prehistoric archaeological sites in California where GPR was used to identify targets that may correspond to subsurface archaeological deposits. The investigations were varied and presented a range of field conditions and subjects for the use of this technology. One of the four sites was then subsequently tested with manual excavation to provide further insights into the capabilities of the GPR. The four sites were located in varying geomorphic environments, and it was anticipated that these environments would differentially influence the GPR's ability to perceive archaeological deposits.

Technology/Method: This study used a Geophysical Survey Systems Incorporated Subsurface Interface Radar 10 (SIR-10) System that was equipped with an array of antennas ranging from 100 MHz to 900 MHz. A common 12-volt car battery was used to power the SIR-10 System and field data were digitally recorded using RADAN III software. Transect spacing ranged from 1 to 12 meters wide, and GPR penetration ranged from 0.8 to 9.1 meters deep. At one of the sites investigated, GPR was supplemented with metal detection, while at a second site GPR testing was followed by the manual excavation of seven 1-meter by 1-meter test units and one 1-meter by 2-meter test unit.

Findings: Three of the investigations were conducted in different landscapes and appeared to demonstrate the successful use of GPR. At the Sunol Valley investigation, GPR was conducted in an agricultural field and was able to both identify several reflections and confirm, due to the presence of a known culvert, that GPR reached depths of 0.8 meter. At the Palace of the Legion of Honor investigation in San Francisco, GPR was conducted in the courtyard and 20 interments were identified with radar penetration to a depth of 9.1 meters below the ground surface. At the historic Martinez Cemetery, GPR was conducted in the 131-year old, still-functioning cemetery. These efforts were supplemented with metal detection and appeared to identify graves in areas previously thought to contain no interment. No excavations were conducted to confirm these findings, but rather a map was produced for cemetery staff to avoid these reflections during renovations and landscape work.

A fourth investigation used GPR and then subsequently tested several locations based on these findings. This investigation, conducted at SOL-356 in Green Valley, California, included 1,120 linear meters of GPR profile data and identified numerous reflections. Three of these reflections were chosen due to their location, likely near project components, while a fourth was chosen due to its large size. Two reflections contained no cultural materials, one reflection contained a large bowl mortar in an ash lens, and the fourth, largest reflection contained a pithouse floor with hearth, post holes, and several artifacts including beads, an ornament/pendant, and an obsidian projectile point.

Review of Methodology: The studies discussed demonstrated, in ideal conditions, that GPR investigations can be used to characterize soils, locate subsurface features, and identify and map areas to be avoided without using invasive methods. However, not all GPR reflections necessarily correlate to subsurface cultural features, and separating the signature of subsurface cultural features from other potential features, such as utilities, natural rock outcroppings, and so forth, is challenging even for experienced users. This is further complicated by drastically different GPR signatures for distinct subsurface cultural features. For example, at the Martinez Cemetery site, reflections thought to be interments differed so drastically from one another that attributing one standard reflection signature to human interments could not be made. Consequently, investigators could not go to a site with an unknown context to identify human interments based on the results of the GPR studies at the Martinez Cemetery or other similar archaeological sites. Therefore, while this method can help to rapidly identify and delineate deeply buried subsurface features, it also appears to require some form of subsurface excavation to calibrate for reflections and to corroborate findings. As a result, because no subsurface excavations were performed at the Martinez Cemetery site—recognizing the sensitivities associated with performing excavations at such a site—it is unclear whether GPR succeeded in identifying human interments in this instance.

5.3.2 Magnetometer Prospecting in Historical Archaeology: Evaluating Survey Options at a 19th Century Rancho Site in California (Silliman et al. 2000)

Key Topics: *Magnetometry, Proton Procession Magnetometer, Alkali Vapor Magnetometer, Gradiometer Archaeological Prospection/Delineation*.

Purpose: The authors, in collaboration with California State Parks Archaeologists and historians, developed the research project to investigate the lives of Native American laborers at Petaluma Adobe Historic Park, located northeast of Petaluma, California. The survey project was designed to supplement earlier surveys of the park and relocate previously identified adobe/cobble foundations and activity areas once associated with the Native American laborers, but had since been lost. In order to identify subsurface deposits, a pedestrian survey and three different magnetometry methods were employed. The study occurred within a known historic-period ranch that had been subject to minimal deposition since it was in use, but the specific depositional environment was not described in the study. The researchers anticipated that historic-period archaeological deposits associated with ranching would be located in shallowly buried contexts across the study area.

Technology/Method: Three distinct magnetometry instruments were used. One was a Geometrics 858 alkali-vapor (cesium) gradiometer with sensors set 0.75 meter apart, and the vertical sensor at 1.2 meters above the ground surface. Measurements were taken every 0.05 meter. The second survey instrument was a geometrics 858 alkali-vapor (cesium) magnetometer, with sensors set 0.85 meter apart and 1.2 meters above the ground surface, with measurements taken every 0.1 meter. The third survey instrument was a geometrics 856AX proton precession gradiometer, with sensors set 0.85 meter apart and ranging from 0.70 to 1.55 meters above the ground surface. Measurements were taken every meter. All data were collected and interpolated using Golden Software's SURFER 6.0 program. Each instrument used a 1-meter grid system, oriented east to west, to survey a 400-square-meter section of the park.

Findings: All three of the instruments identified two areas of concentrated refuse and midden deposits and a shallowly buried (less than 1.3 meters below the ground surface) linear anomaly in the study area. Later excavations of the linear anomaly identified it as a natural alluvial cobble feature and not an adobe or cobble foundation. As the primary goal of the project was to assess the effectiveness of the three different survey instruments and geophysical survey methods, the authors found that both of the cesium gradiometers outperformed the proton precession magnetometer in both efficiency and data quality, but that the gradiometer set 0.75 meter apart and 1.2 meters above the ground surface had the strongest performance.

Review of Methodology: The study succeeded in demonstrating that differing magnetometry instruments can result in notable differences in survey resolution and performance, but that all three appeared to be suitable for locating shallowly buried subsurface anomalies. For example, while the alkali-vapor gradiometers appeared to perform with the best resolution and were able to collect data at a significantly faster rate, all three instruments were able to identify the same subsurface anomalies in ideal conditions. However, as with GPR, hand excavations were still necessary to determine the depth and nature of the identified anomalies.

5.4 Summary

All of the case studies described above help to illustrate important considerations relating to research design development and sampling methods for deep archaeological investigations. The five case studies that used borings to conduct deep archaeological investigations explore both the range of applications and limitations associated with this method. For example, the data recovery excavations performed in support of the Tacoma/Pierce County Program were successful at reliably recovering archaeological deposits from depths that would have otherwise been logistically challenging to access. However, the use of borings required extensive effort to recover a very small sample, and the method could not collect the sample dimensions necessary to assess whether archaeological features were present. Both of these limitations are notable when developing investigations intended to produce detailed data about the range and spatial distribution of artifacts and features across an archaeological site. The investigations for both the Tacoma Trestle and Alaskan Way Viaduct projects are important reminders that borings carry the risk of sample contamination and loss, and that the possibility for both should be carefully considered when interpreting data and crafting recommendations. Both the Interstate 80 Integrated Corridor and Westway/Imperium Expansion projects demonstrate what appears to be an ideal application of borings—to generally characterize the archaeological sensitivity of deeply buried deposits with limited investigations. This application emphasizes the strengths that borings provide (i.e., collecting undisturbed sediment samples from great depths), while minimizing the impact of their weaknesses (i.e., small sample size, risk of sample loss).

Both of the case studies (one of which, Westway/Imperium Expansion, was presented in the boring section) that used mechanical excavation relied on the strengths of this method, rapidly collecting large sediment samples and providing broad subsurface exposures, to address their research goals. Both studies, however, were also performed in areas with extensive undeveloped space. As a result, neither study illustrates a key weakness of mechanical trenching—that it requires a large amount of space, which may not be available in highly developed settings. The Westway/Imperium Expansion project also demonstrates another weakness of mechanical trenching: depending on the equipment used, it can only be used to explore deeply buried sediments to depths of around 8 meters below the ground surface. In the instance of the Westway/Imperium Expansion case study, this depth was not adequate to advance below fill deposits.

Both of the remote sensing case studies illustrate the strength of the most commonly used remote sensing methods, which is to help focus and refine archaeological investigations while using data that can be collected without extensive subsurface investigations. However, both case studies also demonstrated that the success of these methods can be highly variable depending on local conditions. The GPR study, for example, revealed that subsurface reflections associated with a single resource type (interments) at a single archaeological site were drastically different from one another and that one would not necessarily be able to go to an area with an unknown context and differentiate archaeological resources from natural or recent anthropogenic reflections. Overall, the level of ambiguity associated with the findings presented in these case studies indicates that these remote-sensing technologies should be used to contribute to focusing and refining deep subsurface investigations in instances where the environmental conditions are conducive for their use, but not necessarily to serve as stand-alone deep subsurface investigation methods.

Chapter 6
A Framework for Selecting Deep Archaeological Investigation Methods

This chapter provides a framework for evaluating deep archaeological investigation methods in the context of a specific study's goals. Ideally, the method, or methods, selected to perform deep subsurface investigations would be optimally suited to address a given research goal or set of research goals. Unfortunately, each method comes with its own set of logistical constraints that affects its ability to access deeply buried deposits, as well as the size and characteristics of the sample that can be collected, in unfavorable conditions (Table 6-1). As a result, in many instances, selecting the most appropriate method becomes a balance between a method's ability to overcome logistically unfavorable conditions and its ability to provide information that sufficiently addresses a study's research goals. An additional key consideration is whether the method provides sufficient actionable data to warrant the financial cost of performing the investigation (i.e., Bartoy 2011).

Table 6-1 presents the strengths and weaknesses of the deep subsurface investigation methods considered in this study through seven attributes. Each attribute is briefly defined below.

Maximum Depth: This attribute describes the depth below ground surface that can be accessed with a given subsurface investigation method.

Above-Ground Space Requirements: This attribute describes the size of the work area needed to perform subsurface investigations with a given method.

Stratigraphic Resolution: This attribute describes the level of stratigraphic resolution that can be observed with a given method. The level of resolution tends to decrease with depth for trenching because the bottom of very deep trenches typically cannot be accessed and would need to be observed from afar. Geophysical investigations do not produce sediment samples and therefore this attribute is not applicable.

Sample Size: This attribute describes the relative size of the sediment sample that is collected in a single test unit with a given method. Geophysical investigations do not produce sediment samples and therefore this attribute is not applicable.

Risk of Sample Loss: This attribute describes the potential for a sediment sample to be partially or fully lost with a given method. Geophysical investigations do not produce sediment samples and therefore this attribute is not applicable.

Performance in Heterogeneous Deposits: This attribute describes how each method performs in sediments with a wide range of sediment particle sizes and inclusions.

Cost Per Day: This attribute describes the relative amount that each method would cost to conduct per day.

Table 6-1. Relative Evaluation of Deep Subsurface Investigation Methods

	Trenching	Boring*	Geophysical
Maximum Depth	-	+	-
Above-Ground Space Requirements	+	=	-
Stratigraphic Resolution	+ but decreases with depth	+	NA
Sample Size	+	-	NA
Risk of Sample Loss	-	+	NA
Performance in Heterogeneous Deposits	+	=	-
Cost Per Day	-	+	-

+ greatest, = intermediate, - least, NA not applicable

*A detailed breakdown of the strengths and weaknesses of various boring technologies is provided in Chapter 2.

Given the wide range of study goals and logistical considerations that could influence method selection, this study outlines a process for critically evaluating various methods in the context of each study's circumstances. To do this, three types of considerations are discussed below—*goals*, *logistics*, and *value*—in the recommended order in which they should be considered.

6.1 Goals

The goal, or goals, of a study defines the sample size, spacing, and stratigraphic resolution that are required to adequately address a study's archaeological needs. Often, as a study progresses from assessing archaeological sensitivity through inventorying archaeological resources to evaluating any archaeological resources that are identified, sample size and stratigraphic resolution must increase while sample spacing must decrease. For example, if a study's goals are to assess whether archaeologically sensitive deposits are present and to define their depth, this may only require small samples collected from a limited number of widely spaced subsurface testing units. Alternately, if it is known that an area has the potential to contain archaeological deposits, non-invasive techniques may be all that are needed to identify locations with increased archaeological sensitivity. On the opposite side of the spectrum, if a study's goals are to evaluate the contents and integrity of an archaeological resource, it is likely that larger samples with a high degree of stratigraphic resolution will be needed from a spatially limited area. Importantly, a study may have a single goal (e.g., evaluate a resource) or multiple goals (e.g., inventory and evaluate resources) that may require different sample sizes, spacing, and stratigraphic resolution—the latter of which may be best addressed with multiple methods. With this in mind, the following questions are designed to help identify a study's sample size, spacing, and stratigraphic resolution needs.

Questions

- What is the purpose of the study (e.g., assessment, inventory, evaluation)?
- Is the study being performed for multiple purposes?
- What has archaeological, ethnographic, and historic documentary research revealed about the presence, contents, and size of possible resources?

6.2 Logistics

Each of the deep archaeological investigation methods described in this document have strengths and limitations that affect how deep they can reasonably excavate, the size of the area that they disturb, the amount of above-ground space they require to operate, their performance in heterogeneous deposits, and the risk of sample loss. When these strengths and limitations are considered against goals of a study, it is possible that a method that would otherwise be optimally suited for a study would be unsuitable because of a combination of environmental and method-specific logistical constraints. For example, if the goal of a study is to investigate for the presence of deeply buried archaeological deposits, then the rapid and large subsurface sample provided by a mechanical excavator or the ability to rapidly identify and target subsurface anomalies and reflections provided by geophysical methods would seem like optimal approaches. However, if it is likely that archaeological deposits will be located greater than 10 meters below the ground surface or under a layer of heterogeneous and saturated sediments, neither method may be able to adequately address the study's goal. With this in mind, the following questions are designed to help characterize and account for the likely logistical constraints for a given study.

Questions

- If the study is for cultural resources compliance, what is the anticipated depth of ground disturbance? What is the maximum anticipated depth of archaeologically sensitive deposits?
- How large is the work area? Are there any overhead or underground utilities? How tightly spaced are the utilities?
- Are sediment sizes anticipated to be largely homogenous or heterogeneous? Are large cobbles, wood debris, and other large items anticipated?
- Does the risk of occasional partial or full sample loss substantively undermine the goal of the study?

6.3 Value

After deciding upon a method, or set of methods, that has the capacity to address research goals and overcome logistical constraints, it is important to reflect on the nature and quality of the data that will be obtained and consider whether the data retain sufficient value to move forward with the study. While this section considers the term *value* to mean the research benefit of a given method versus its cost, it is recognized that some cultural resources may retain a benefit or importance that extends beyond what can be provided through research. Research value can be of particular importance to agencies, which are not only tasked with the stewardship of cultural resources, but also with the responsible use of the public's money. For the purposes of this study, value will be defined as three attributes: the extent to which the method can achieve a study's goal, the cost of doing the work, and the risk in the event that the goal is not accomplished. By following the considerations outlined in this section, the former (i.e., extent to which a method can achieve a study's goal) should be established by the time one begins to consider value. In this case, *risk* refers to the risk of encountering significant unanticipated discoveries during construction that require large amounts of time and money to mitigate (i.e., Bartoy 2011). Importantly, in some instances, this risk can be offset through procedure (i.e., establishing contractually obligated pauses in construction at archaeologically sensitive depths) during construction, as demonstrated by WSDOT on the State Route 99 North Access Connection Study (i.e., Valentino 2015).

One of the more common and difficult-to-weigh value considerations is when a method has the capacity to collect the necessary sample size, spacing, and stratigraphic resolution needed to accomplish a study goal, but doing so would involve great costs. In such instances, the key consideration would be whether the risk of not performing the study, or performing a study of lesser resolution, would be significant enough to warrant the cost. On one side of the risk gradient, if background research and/or a preliminary inventory reveal elevated potential for encountering deeply buried and particularly significant resources (e.g., precontact village sites), the cost may be warranted considering that an unanticipated discovery is likely to be complex, to have unavoidable impacts, and be costly. Toward the middle of the risk gradient, if background research and/or a preliminary inventory revealed some degree of potential for encountering deeply buried significant resources or identifying deeply buried resources of questionable significance, then there may be better value in identifying alternative approaches to performing investigations. Some examples of alternative approaches could be to develop a detailed unanticipated discovery protocol and have monitors present during construction-related activities at archaeologically sensitive depths or to establish contract-mandated pauses in construction at archaeologically sensitive depths. Finally, if there is limited risk of encountering deeply buried and significant resources, the cost may not be warranted. With this in mind, the following questions are designed to help characterize whether a method provides value for a study.

Questions:

- Can you characterize the risk of encountering significant archaeological resources?
- Is there an opportunity for procedural alternatives (e.g., protocols established in contracts and agreement documents) to deep investigation methods during construction?
- How much would the method cost to perform? Would it be more cost effective and equally risk averse to implement procedural alternatives?

6.4 Conclusions

This study discussed key considerations related to the methods, depositional environments, and sampling for deep subsurface archaeological investigations; presented case studies that assessed the strengths and weaknesses of various deep subsurface archaeological investigation approaches in action; and presented a framework for assessing whether a research design will address the goals of a study. Combined, these considerations can help researchers develop well-defined research designs with a clear understanding of the critical factors associated with the methods that are selected. In order to do this effectively, the following steps are recommended.

1. **Understand the study area and research goals:** Identify the goal or goals of a study, including whether it would need to be able to provide sufficient data to evaluate a resource without having to go back and perform additional studies. Perform background research to define landscape history using both geologic and historical documentation. Use this information to generate expectations about the sequence, types, and depths of sediments that could be encountered, as well as the anticipated range of archaeological site types.

2. **Understand the degree to which the selected method or methods will achieve the study's research goals.** Consider the study's goals in the context of the anticipated sequence, types, and depths of sediment types, and anticipated range of archaeological site types. Consider whether using multiple methods would increase level of resolution or reduce the risk of data loss (hereafter referred to as *reliability*). Identify the method or methods that would have the greatest potential to provide the data level of resolution, sample size, and reliability needed to adequately address the study's goals. Identify any logistical constraints that could limit the method's ability to collect data with the necessary level of resolution, sample size, and/or reliability, if applicable. Evaluate whether other variations of the same method (e.g., rotosonic versus rotary borings) or other methods could be employed to greater effect given these logistical constraints. Consider whether the data obtained from alternative methods would be justified if they provide lesser level of resolution, sample size, and reliability, and/or require greater costs.
3. **Clearly document the reasons for selecting a study's research design and acknowledge any limitations and/or data gaps in the study's results summary.** Describe the critical factors that were used to identify the method, or methods, used. Acknowledge and document any level of resolution, sample size, and/or reliability issues associated with the research design that could affect the outcome of the study. Document any additional imitations or data gaps that may have been identified while performing the study. Acknowledge any remaining degree of uncertainty in the study's conclusions and recommendations and describe how this uncertainty could manifest itself in future studies or if a ground-disturbing project were to commence in the study area vicinity.

Ultimately, the goal of building a research design should be to ensure that the investigator and reviewer are critically informed in a transparent way about the adequacy of the research design's ability meet the study's goals and its limitations. Doing so can help to reduce the risk of unanticipated discoveries and provide a clear understanding of a study's limitations, and can help all parties to better assess the value of the study.

Chapter 7
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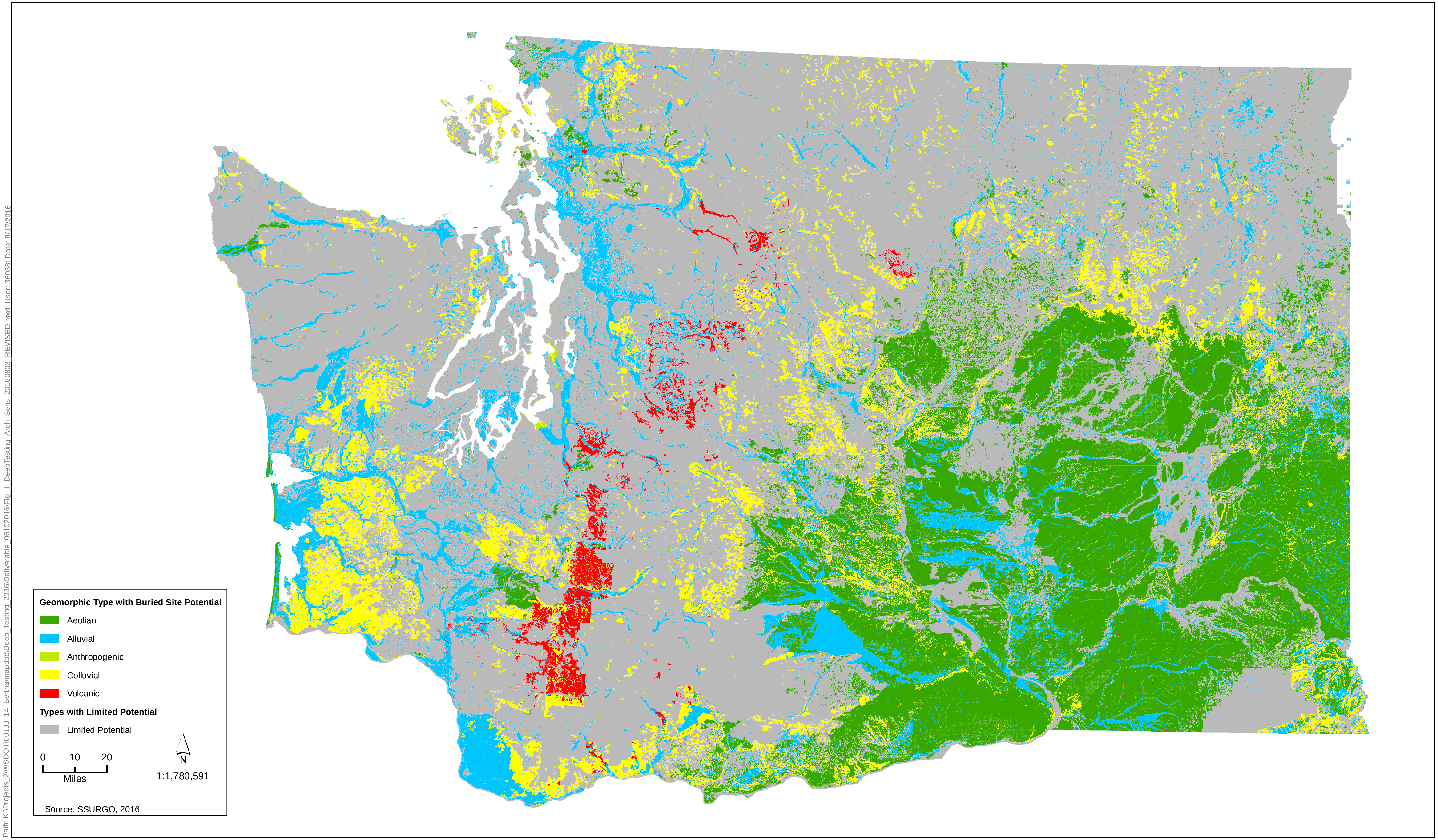
Appendix A

Buried Site Sensitivity Model



Source: SSURGO, 2016.

Path: K:\Projects_2\WSDOT\00133_14_Bertha\mapdoc\Deep_Testing_2016\Deliverable_06102016\Fig_1_DeepTesting_Arch_Sens_20160803_REVISED.mxd; User: 36038; Date: 8/17/2016

Figure 1.
Buried Site Sensitivity Model

BURIED SITE SENSITIVITY MODEL LIMITATIONS AND CONSIDERATIONS

- The scale of the soil data that was used for this analysis ranged from 1:12,000 to 1:63,360. In instances where no soil data was available, 1:100,000 scale geologic map data obtained from the Washington Department of Natural Resources was used. Therefore, the precision of the model may vary by county and in areas where no soil data was available.

- This model did not consider whether soil scientists from different counties classified soil type consistently.

- No attempt was made to differentiate Holocene-aged aeolian and alluvial deposits from Pleistocene-aged deposits of the same origin using the soil data. This is likely to have resulted in the area defined has being sensitive for buried archaeological deposits being larger than the actual area that is sensitive for buried archaeological deposits, particularly in the southeastern portion of the state.

- For the purposes of this study, slopewash was considered to be a colluvial in origin.

- In some instances, not enough information was available to differentiate Holocene-aged volcanic deposits from older deposits.

- There were a large amount of soil units with no associated data in Okanogan County. Upon closer inspection it was determined that these areas are located on exposed bedrock outcrops with minimal soil deposition. As a result, these null values were classified as having limited potential to contain buried archaeological resources.