



# **Department of Defense Legacy Resource Management**

Legacy Project # 10-435

## **Integrating Military Training and Archaeological Site Integrity: A Field Analysis Approach**

Brian Crane  
Dennis Knepper  
Christopher Bowen  
Bernard K. Means

Versar, Inc.

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*Prepared by:*

Brian Crane, Dennis Knepper, Christopher Bowen, Bernard K. Means  
Versar, Inc.  
6850 Versar Center  
Springfield, Virginia 22151

and

Trina Arpin  
Boston University

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## **Abstract**

Legacy Project #10-435, reported herein, was funded in FY 2010 by the Department of Defense Legacy Resource Management Program and was executed by Versar, Inc., of Springfield, Virginia. The U. S. Marine Corps was the project's sponsor. The purpose of the study was to identify factors useful for assessing potential damage to archaeological sites resulting from military vehicle training activities and determining acceptable thresholds for these activities. The report addresses whether a model of such a threshold can be developed with existing data or whether new data must be collected. The ultimate goal of the project was to assist DoD in sustaining critical military training while complying with cultural resource stewardship responsibilities.

The investigation consisted of field testing designed to measure the effects of military vehicle training in areas containing significant or potentially significant archaeological sites. The study focused on a single effect—soil compaction—examining physical evidence for compaction associated with vehicle ruts and the implications for artifact displacement and stratigraphic mixing drawn from that evidence. Soils were examined on a microscopic level in an analytical process referred to as soil micromorphology. The project contrasted with similar studies reported in the existing literature that have typically been confined to computer simulations or the effects of single vehicles under controlled test conditions. The current project was intended to test cumulative impacts on active training ranges and real archaeological sites.

Test excavations were conducted at locations on two active ranges: the Virginia Army National Guard installation at Maneuver Training Center Fort Pickett; and Marine Corps Base Quantico, Virginia. Both installations represent active military vehicle training centers and have large and diverse archaeological inventories. Appropriate archaeological sites were selected at the installations, and standard archaeological excavation and recording procedures were used to document sedimentary strata and natural and cultural inclusions in areas with visible rut disturbances of varying age and condition. Columns for micromorphological analysis were extracted at each location. The column samples were treated with resin, thin-sectioned, and examined microscopically in the laboratory. Soil porosity was observed in all of the samples examined, a finding interpreted as the result of natural causes, primarily biological activity. Evidence of surface disturbance associated with plowing was also identified. Little direct evidence of compaction was observed in the samples. In addition, differences between samples associated with visible ruts and those in control areas without visible disturbance were negligible. Based on these findings, recommendations for developing further studies were advanced.

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## Table of Contents

<b>Abstract.....</b>	<b>i</b>
<b>Table of Contents .....</b>	<b>iii</b>
<b>List of Figures.....</b>	<b>iv</b>
<b>List of Tables .....</b>	<b>v</b>
<b>1.0 INTRODUCTION.....</b>	<b>1</b>
1.1 Purpose of Project .....	1
1.2 Scope of Project .....	2
1.3 Field Testing Locations .....	2
<b>2.0 BACKGROUND .....</b>	<b>5</b>
2.1 Previous Study #09-435 .....	5
<b>3.0 RESEARCH ORIENTATION .....</b>	<b>7</b>
3.1 Defining the Problem: A Design for the Research.....	7
3.1.1 Landscape .....	7
3.1.2 Vehicle and Activity Type .....	9
3.1.3 Direct Effects of Vehicle Activity: Rut Formation.....	9
3.1.4 Indirect Effects of Vehicle Activity: Compaction .....	13
3.2 Current Approach.....	14
3.3 Site Selection Process.....	15
3.3.1 MTC-Fort Pickett. ....	15
3.3.2 MCB Quantico.....	22
3.4 Developing a Solution: Archaeological Methods .....	26
3.4.1 Field Methods .....	26
3.4.2 Laboratory Methods.....	27
<b>4.0 RESULTS (FIELD WORK) .....</b>	<b>31</b>
4.1 MTC-Fort Pickett.....	31
4.1.1 Previous Investigations at Site 44DW329 .....	31
4.1.2 Current Conditions.....	32
4.1.3 Test Unit Excavation.....	32
4.1.4 Micromorphology Results .....	40
4.2 MCB Quantico .....	42
4.2.1 Previous Investigations at Site 44PW957 .....	42
4.2.2 Current Conditions.....	42
4.2.3 Test Unit Excavation.....	44
4.2.4 Micromorphology Results .....	53
<b>5.0 DATA ANALYSIS .....</b>	<b>55</b>
5.1 Micromorphology.....	55
5.2 Assessment/Interpretation .....	55

5.2.1	Soil Compaction.....	55
5.2.2	Archaeological Significance .....	57
<b>6.0</b>	<b>CONCLUSIONS .....</b>	<b>59</b>
6.1	Summary .....	59
6.2	Recommendations .....	60
<b>7.0</b>	<b>REFERENCES CITED.....</b>	<b>62</b>

**Appendix A: Artifact Inventory**

**Appendix B: Micromorphology Data**

**Appendix C: Thin Section Images**

**List of Figures**

Figure 1-1.	Location of MTC-Fort Pickett and MCB Quantico. ....	3
Figure 3-1.	Rut Terminology .....	10
Figure 3-2.	Rut Measurements.....	11
Figure 3-3.	Locations of Sites Considered for the Current Study, MTC-Fort Pickett.....	21
Figure 3-4.	Locations of Sites Considered for the Current Study, MCB Quantico. ....	26
Figure 3-5.	Micromorphological Terminology.....	29
Figure 4-1.	MTC-Fort Pickett, Site 44DW329, General Setting and Location. ....	33
Figure 4-2.	MTC-Fort Pickett, Site 44DW329, View North Showing Current Site Conditions.....	34
Figure 4-3.	MTC-Fort Pickett, Site 44DW329, Test Unit Placement. ....	34
Figure 4-4.	MTC-Fort Pickett, Site 44DW329, Opening Photo-Documentation of Unit 1, View West.....	36
Figure 4-5.	MTC-Fort Pickett, Site 44DW329, West Profile Section of Unit 1. ....	36
Figure 4-6.	MTC-Fort Pickett, Site 44DW329, Unit 1 Excavated with Column Sampling in Progress, View West. ....	37
Figure 4-7.	MTC-Fort Pickett, Site 44DW329, Opening Photo-Documentation of Unit 2, View West.....	38
Figure 4-8.	MTC-Fort Pickett, Site 44DW329, West Profile Section of Unit 2. ....	38
Figure 4-9.	MTC-Fort Pickett, Site 44DW329, Unit 2 Excavated, prior to Column Sampling, View West. ....	39
Figure 4-10.	MTC-Fort Pickett, Site 44DW329, Savannah River Point Recovered from Surface near Unit 1. ....	40
Figure 4-11.	MCB Quantico, Site 44PW957, General Setting and Location. ....	43
Figure 4-12.	MCB Quantico, Site 44PW957, View North Showing Current Site Conditions.....	44
Figure 4-13.	MCB Quantico, Site 44PW957, Test Unit Placement. ....	45
Figure 4-14.	MCB Quantico, Site 44PW957, Opening Photo-Documentation of Unit 1, View North.....	46
Figure 4-15.	MCB Quantico, Site 44PW957, Unit 1 South Profile Section.....	47
Figure 4-16.	MCB Quantico, Site 44PW957, Unit 1 Excavated, View South. ....	47

Figure 4-17. MCB Quantico, Site 44PW957, Opening Photo-Documentation of Unit 2,  
View North..... 48

Figure 4-18. MCB Quantico, Site 44PW957, Unit 2 South Profile Section..... 49

Figure 4-19. MCB Quantico, Site 44PW957, Unit 2 Excavated, View South. .... 49

Figure 4-20. MCB Quantico, Site 44PW957, Opening Photo-Documentation of Unit 3,  
View North..... 51

Figure 4-21. MCB Quantico, Site 44PW957, Unit 3 South Profile Section..... 51

Figure 4-22. MCB Quantico, Site 44PW957, Unit 3 Excavated, View South. .... 52

**List of Tables**

Table 3-1. Sites Considered for the Current Study, MTC-Fort Pickett. .... 17

Table 3-2. Sites Considered for the Current Study, MCB Quantico. .... 23

Table 4-1. MTC-Fort Pickett, Artifacts Recovered from Site 44DW329..... 39

Table 4-2. MCB Quantico, Artifacts Recovered from Site 44PW957. .... 52

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## **1.0 INTRODUCTION**

Versar, Inc., received funding in 2010 from the Department of Defense (DoD) Legacy Resource Management Program for the project entitled “Integrating Military Training and Archaeological Site Integrity: A Field Analysis Approach.” (#10-435). The U. S. Marine Corps was the project’s sponsor. This project seeks to utilize data identified by a related Legacy Project, #09-435 (Integrating Military Training and Archaeological Site Integrity: A Data Analysis Approach) to measure evidence of military vehicle impacts on archaeological sites. The overall aim is to develop recommendations for sustaining military training activities while complying with cultural resource stewardship responsibilities, as mandated by federal regulation.

The U.S. military is one of the largest federal landholders in the United States and must strive to maintain readiness and meet national security requirements while at the same time ensuring proper stewardship of its extensive environmental and cultural resources (Anderson and Ostler 2002:197; Bullard and McDonald 2008). Meeting these sometimes competing needs can prove a delicate balancing act (Althoff and Thien 2005:159). Military land managers recognize, however, that proper stewardship of environmental resources, of which cultural resources may be considered a part, ensures the long-term sustainability of military training facilities (Affleck 2005:7). Improper stewardship of these resources over an extended period can, in contrast, result in degradation of lands used for training exercises and a loss of realism in the training experience, thus impeding military readiness (Anderson et al. 2005a:208).

A substantial body of research literature is devoted to the impacts of military training on environmental resources (Johnson and Campbell 2004:110; Zeidler 2004). Concerns have long focused on the interaction between military training vehicles and the natural environment, particularly soils and plant communities (Affleck 2005; Garten and Ashwood 2004; Mulhearn 2001). Plant communities help stabilize soils and, even if damaged through training, can potentially be restored—although not always to a pre-training ecosystem (Althoff and Thien 2005:174). Archaeological sites are as much a part of the physical environment as plant communities, yet they are rarely considered in any detail in this research literature (Johnson and Campbell 2004:110; Zeidler 2004). Thus, it is not readily evident how and to what extent military training might adversely affect the physical integrity of an archaeological site.

### **1.1 Purpose of Project**

The impact of training exercises on archaeological site significance is a potentially large and complex issue. Military training encompasses many forms of activity that can directly or indirectly affect an archaeological resource. Training may include construction (temporary bridges, earthworks, etc.), live firing of guns and missiles, and maneuvers on foot and using a variety of vehicles (Canham and Chippindale 1988:59). A basic question of this study concerns the effect of military vehicle impacts—alone or combined with other processes—on the eligibility of an archaeological site through the loss of physical integrity (Anderson et al. 2005a:151). Addressing this question involves quantifying military vehicle impacts and their

potential to damage archaeological sites, determining whether there are acceptable thresholds for such activity below which a site's physical integrity and eligibility are not compromised.

The ultimate aim of projects such as this is thus to assist DoD installations nationwide that conduct training exercises in the field in meeting their cultural resources management compliance requirements while maintaining mission-critical training activities. The current report seeks information that may assist DoD cultural resource managers with designing and executing programs that support training and testing exercises in areas containing potentially vulnerable archaeological resources.

## **1.2 Scope of Project**

The range of impacts from military training activities on archaeological sites is potentially extensive and is directly related to a host of variables, including the physical characteristics of the sites themselves, such as soil properties, landforms, and seasonality, as well as the types of vehicle involved and the training regimens undertaken. Precisely how these variables interact may be different for each unique military training setting, but it should be possible to develop broad parameters for understanding the impacts produced and to discern what information is available for understanding how the training activities can affect archaeological resources in a given situation.

This report focuses on a specific result of the movement of military vehicles (tracked or wheeled) across military training landscapes—soil compaction. The project measured the extent and degree of compaction from vehicle traffic under actual field conditions, and assessed the implications of this form of soil alteration on archaeological data contained in the soil. The major challenge for this study is modeling when vehicle impacts from military training reach a threshold at which the National Register of Historic Places (NRHP) eligibility of an archaeological site is adversely affected. The report addresses whether a model of such a threshold can be developed with existing data or whether new data must be collected. The experience of developing a practical field testing method has generated lessons learned that will aide in designing installation-specific approaches to the problem of archaeological site encroachment on training lands.

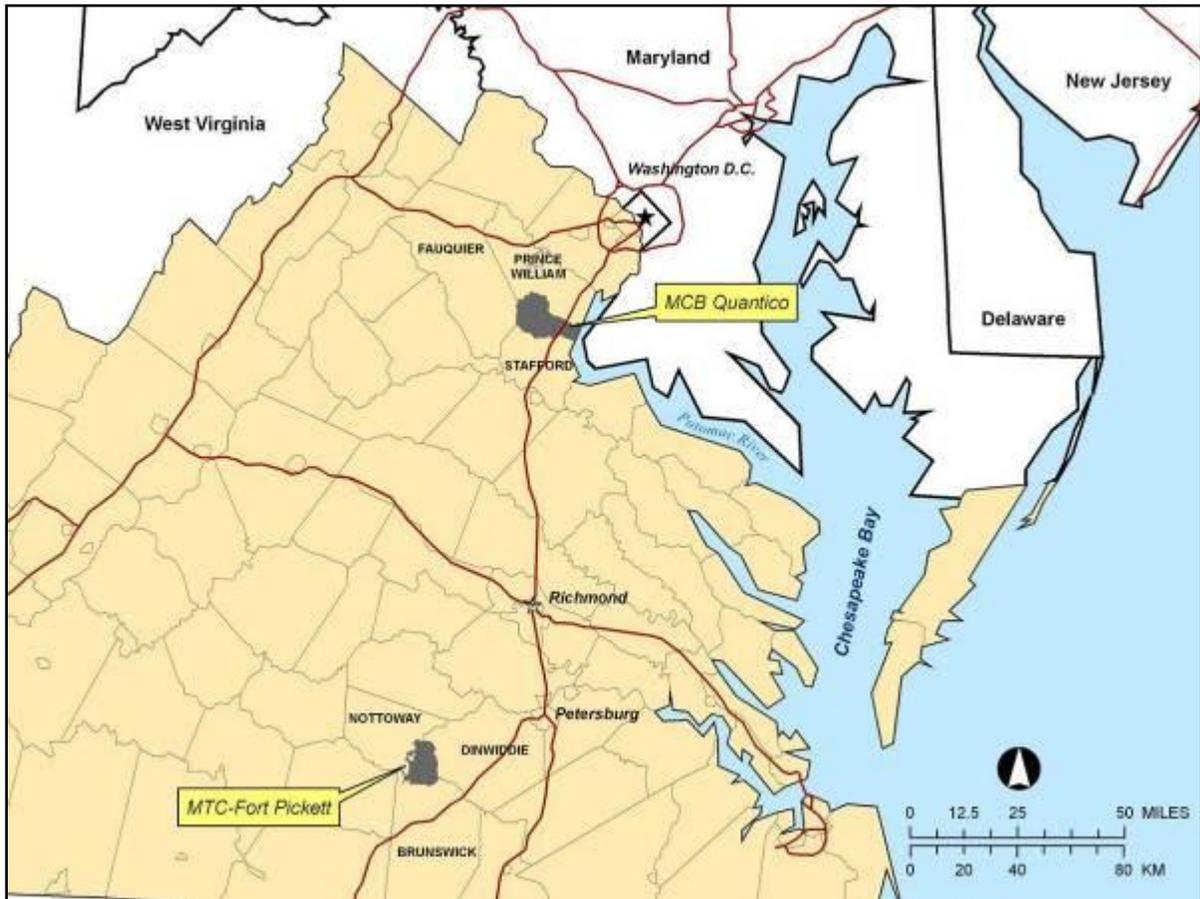
## **1.3 Field Testing Locations**

Field testing for this project was conducted at the Virginia Army National Guard (VAARNG) installation at Maneuver Training Center (MTC) Fort Pickett; and Marine Corps Base (MCB) Quantico, Virginia. These installations were chosen for their roles as active military vehicle training centers with large and diverse archaeological inventories. Both installations are located within Virginia's Piedmont physiographic province which is characterized by rolling topography and shallow clayey soils (Figure 1-1).

The 41,770-acre MTC-Fort Pickett is located approximately two miles east of Blackstone, Virginia, and 30 miles southwest of Petersburg, Virginia, within the counties of Brunswick, Dinwiddie, and Nottoway. The mission of MTC-Fort Pickett is to provide a training site capable of handling up to brigade size elements for live-fire and maneuver training of reserve and active components from all services. Headquarters for the VAARNG is stationed at MTC-Fort Pickett, as well as the Maneuver Area Training Equipment Site (MATES) for the

National Guard. This area of Virginia is relatively rural and MTC-Fort Pickett occupies thousands of acres formerly used for agriculture prior to the military installation's construction as Camp Pickett during World War II (VAARNG 2008).

MCB Quantico is located 30 miles southwest of Washington, D.C., within the counties of Prince William, Stafford, and Fauquier, Virginia. The primary mission of MCB Quantico is military education and training. The 62,295-acre installation consists of two parcels divided by Interstate 95, with "Mainside" to the east and "Guadalcanal" to the west of the highway (Huston and Downing 1994). The current project area is located in the Guadalcanal side of the base, which is largely undeveloped and used for live-fire training and troop and vehicle maneuvers.



**Figure 1-1. Location of MTC-Fort Pickett and MCB Quantico.**

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## **2.0 BACKGROUND**

### **2.1 Previous Study #09-435**

The current study follows recommendations outlined in Legacy Project #09-435, Department of Defense Legacy Project for Integrating Military Training and Archaeological Site Integrity: A Data Analysis Approach. The goal of the initial project was to identify practical methods for measuring the impacts of military vehicle training activities on archaeological resources on DoD installations, with the ultimate goal of sustaining these activities while complying with cultural resource stewardship responsibilities. The study assessed ways of modeling the thresholds at which vehicle impacts from military training may adversely affect the NRHP eligibility of an archaeological site, and whether a model of thresholds can be developed with existing data.

The investigation began with a wide-ranging review of existing literature. First was an examination of site significance and the assessment of site integrity, or the ability of a site to convey its significance. Next, archaeological site formation processes were summarized along with current understanding of the ways in which the archaeological record is both formed and transformed by human and natural agents in general. The extensive literature on the interaction between military vehicles and landscapes, particularly as presented in a field of research known as terramechanics, was then reviewed. Finally, geoarchaeological studies of soil mechanics and soil deformation were examined for relevant information to help bridge the gap between the sometimes abstract terramechanics research and observations made concerning archaeological site formation processes.

The investigation indicated that a potentially large and complex set of variables could be incorporated into a process that would model the effects of military vehicle training on archaeological sites. It further suggested that careful selection of a subset of these variables would allow generation of a model grounded in real-world conditions and would thus be of immediate use rather than providing only theoretical conclusions. Among the variables considered most appropriate were those related to: 1) the cultural attributes of a site; 2) the location and environmental attributes (soil properties in particular) of the site; and 3) the characteristics of the military vehicles involved in the training activities.

Recommendations for specific data types or formats were proposed:

- Major data categories that should be collected systematically include: artifact and feature density; the representativeness and redundancy of cultural deposits; the depths of deposits; and the spatial distributions of cultural materials.
- Soils data, including texture, horizonation, and other physical and chemical attributes, should be collected on a finer scale than are currently mapped in most USDA soil map units that typically exceed 10 acres in size. This information should be integrated with Light Detection and Ranging (LiDAR) data where possible to enhance topographic resolution.
- Experimental studies should be developed to link archaeological site formation processes with military vehicle impacts, particularly on actual training landscapes

as opposed to the analysis of hypothetical data or analyses of ruts created in controlled circumstances.

- Eligibility determinations should be conducted on sites that are currently categorized as potentially eligible to determine whether or not they actually retain sufficient integrity for NRHP eligibility and thus require protection from military vehicle impacts.

The most pertinent among these recommendations for the next phase of investigation involved examining soil properties on actual sites, collecting fine-scale data in real-world conditions. Emphasis was placed on one of the more obvious but incompletely understood effects of surface disturbance—soil compression or compaction. As noted in the 2009 project report, the full effects of soil compaction are not clearly defined in terms of influences on archaeologically sensitive deposits. It is known though, that compaction can have both obvious and unseen effects on archaeological deposits, effects that may range from displacing or breaking artifacts to altering drainage processes and, as a consequence, soil chemistry.

The recommendations of the initial study led to the development of a proposal to conduct the project reported herein: a project to document soil columns from training areas at selected installations in the Mid-Atlantic. The locations—MTC-Fort Pickett and MCB Quantico—included known, active vehicle training areas where recorded archaeological sites are present. Proposed field testing was to consist of the examination of soil profiles that have been under actual (as opposed to simulated) vehicle impacts within the training areas. Archaeologists would excavate narrow trenches across discrete areas of vehicle impacts (such as ruts or visible tracks). The purpose of the excavations would be to allow detailed analysis of available sedimentological and other field data related to the impacts of vehicle training on sediments and by implication on archaeological data contained in the sediments. Specific analytical procedures would include characterization of soil horizons, analysis of soil texture (particle size) and soil micromorphology to analyze sediments for evidence of the degree of compaction and mixing.

### **3.0 RESEARCH ORIENTATION**

An important part of developing this project was crafting a research design to guide the investigation. A research design examines what is known about an issue or problem, defines terms, and suggests directions for research and analysis. It thus provides critical background information to structure the investigation and insure its relevancy. More than a work plan, a research design provides the analytical context of the study, its reasoning and structure, the logic rather than logistics (DeVaus 2001).

#### **3.1 Defining the Problem: A Design for the Research**

The immediate goal of the project is to identify parameters of soil disturbance that might be useful in assessing the potential for archaeological site damage resulting from military vehicle training activities and determining acceptable thresholds for these activities. The type of information pertinent to the study falls under two main headings: landscape and military vehicle activity. The landscape grouping includes the properties of the natural sediments as well as the archaeological deposits contained within them; military vehicle activity includes the characteristics of the vehicles used, the type and intensity of activity that is conducted, and the effects these may have on the natural sediments and archaeological deposits.

The literature on the interaction between military vehicles and landscapes is fairly extensive, particularly as a subfield of a study referred to as terramechanics. Terramechanics is defined as “research, development, design, innovation, testing, application and utilization of off-road vehicles and soil working machinery, their sub-systems, and components” (ISTVS n.d.). Researchers in terramechanics consider the ways in which vehicles alter soil properties, notably through deformation and displacement of surface and shallow subsurface soil layers in the form of ruts, as well as the compaction of soil layers under vehicle loads.

##### **3.1.1 Landscape**

*Soil Properties.* Archaeological sites occur within a range of depositional contexts, the extremes of which can be characterized as surface/near-surface contexts and buried/stratified contexts. Surface or near-surface environments are highly susceptible to physical and chemical changes that may include erosion, burial, weathering, biological processes, and human activity. Buried or stratified environments may be better protected from all of these processes, which may act more slowly or indirectly on the deposits.

Critical factors in understanding the effects of near surface process on site integrity include soil texture, vegetation, slope, and climate. These factors do not operate independently of each other. Slope and soil texture are interrelated, for example, and can affect the potential for accelerated slope erosion and stability, both of which can greatly diminish archaeological site integrity. Soil compaction, deformation and displacement related to surface activity such as plowing or vehicle traffic are similarly affected by soil and sediment texture. Seasonality is an additional factor, influencing fluctuations in soil moisture and temperature (e.g. frozen versus thawing soils). Soil texture and moisture, as well as seasonality, can be used to determine a terrain’s bearing capacity and its ability to sustain surface disturbance.

Depositional and pedological characteristics of a site are important because they provide the background of landform development and a context for describing the depositional integrity of archaeological deposits. Sedimentological characteristics are most useful in determining conditions of landform development, while soil formation (pedology) characteristics are most useful in determining conditions of post-depositional changes to a site and its associated landscape, both natural and cultural (Foss et al. 1995; Waters 1992). Important distinctions are made between sediments and soils: sediments consist of unweathered and unconsolidated deposits, whereas soils are pedogenically modified sediments (Ferring 1986, 1992; Hassan 1978). Soils develop in sediments through processes of weathering that include the transformation, translocation, and removal of both physical and chemical components (Birkeland 1984, Holliday 1990).

*Site Characteristics.* For an archaeological site to be considered significant, and thus to be legally protected from damage or disturbance, it must satisfy certain formal eligibility criteria as expressed in the National Register of Historic Places (NRHP). Sites typically qualify under NRHP Criterion D, which states that they “have yielded, or may be likely to yield, information important in prehistory or history.” A site that is regarded as significant is either *listed* on or, more commonly, is considered *eligible* for listing on the NRHP. However, meeting significance criteria alone is not sufficient: archaeological sites must retain sufficient integrity to convey their significance in order to be considered eligible and, as importantly in the current study, to remain eligible for the NRHP. The National Register recognizes seven aspects of integrity: location, design, setting, materials, workmanship, feeling, and association. While not all of these characteristics are relevant to archaeological sites, integrity of materials (the artifacts) and association (the relationship of those artifacts to each other and to site stratigraphy) are critical to archaeological significance.

One of these most important aspects in determining the significance of archaeological sites is thus the preservation of context, the physical relationships of items within the site. Archaeological materials, particularly artifacts or features, are themselves of limited value separate from their relationships with surrounding materials. For example, by itself an arrowhead may have aesthetic appeal—it may be colorful and nicely shaped—but it does not necessarily have intrinsic research value. The same arrowhead embedded in the shoulder blade of an individual found in a grave tells a much wider story about the past. Thus, archaeological context, where things are found, is as important in establishing significance as what the things are.

The extent to which military training activities cause impacts to archaeological sites is not well understood, especially as related to archaeological context and the potential loss of integrity. While natural resources may recover from damage if there is sufficient rest between training episodes, or may be restored through direct landscape modification and re-vegetation efforts (Anderson and Ostler 2002:198; Caldwell et al. 2006:457; Milchunas et al. 2000:525), archaeological resources cannot recover or be restored (CCPA 2007). Archaeological sites are often fragile and limited in quantity; they are non-renewable resources, and damage to them is cumulative and permanent (CCPA 2007; Nickens 1991).

The kinds of cultural remains present at an archaeological site must also be factored into considerations of site vulnerability to military vehicle impacts. A site whose physical integrity is closely related to surface distributions of fragile artifacts—such as glass vessels or bottles, or prehistoric or historic ceramics—may be considered more vulnerable to vehicle impacts than a site composed of more durable remains—such as chipped stone tools and debitage. Feature characteristics must also be integrated into assessments of site vulnerability. For example, broad and shallow features—which are present at many American Indian village sites in the eastern U.S.—are more likely to be disturbed by vehicle activity than narrow pit features that extend well below the ground surface. Likewise, structural remains that protrude above ground surface are more likely to be disturbed by military vehicles than structural remains that are flush with the ground or shallowly buried.

### 3.1.2 Military Vehicle Activity

*Vehicle and Activity Type.* Vehicle traffic of any sort can have a major impact on archaeological sites. More than a dozen major military vehicle types are actively in use at DoD installations across the country. The vehicles vary considerably in size, weight, and type of propulsion (tracks or wheels). An important variable is a vehicle's load, which takes into consideration both vehicle weight, the weight of its contents, and the way it contacts the ground surface. However, the most important variable may be whether the military vehicle is tracked or wheeled. Tracked and wheeled vehicles interact differently with the ground surface and thus may have different effects on cultural deposits on or under that surface. For example, when operating under the same conditions, wheeled vehicles tend to create deeper ruts than tracked vehicles, whereas tracked vehicles are more likely to cause greater lateral damage—especially when turning.

Recreational, off-road vehicle (ORV) use is a major contributor to erosion on archaeological sites—particularly in the western United States—and has direct parallels to the impacts caused by military training vehicles. Specific impacts from military vehicles will be considered later. ORVs can produce obvious damage to visible features or can break or crush artifacts (BLM 2003:30; Sampson 2007; Sowl and Poetter 2004:12). Vehicle traffic can lead to loss of soils and the vegetation that helps bind soils. As tires move through a site, they can cause horizontal and vertical displacement of softer soil and any artifacts or other cultural remains within that soil (BLM 2003:30). Vehicles can create scars on the landscape up to 4.7 meters wide and 1.42 meters deep that promote further erosion. Degradation of the landscape by individual ORVs, particularly through rut formation, can lead to broader damage, as newer vehicle traffic avoids existing ruts, creating new disturbances adjacent to the older ruts and leading to wider and deeper damage to the site (BLM 2003:30). And finally, erosion associated with rut creation can expose buried archaeological remains, leading to additional damage, direct (trampling) or indirect (weathering), as well as increasing their visibility and thus their attractiveness to looters and collectors.

*Direct Effects of Vehicle Activity: Rut Formation.* The most visible and perhaps most significant consequence of vehicle activity on open, unpaved ground surfaces is soil deformation and displacement in the form of rutting (Affleck 2005: ii). In formal terms, ruts are produced when the load represented by a vehicle is greater than the bearing capacity of the terrain, a quality that is particularly weak in soft or wet soils (Affleck 2005:ii; Hambleton

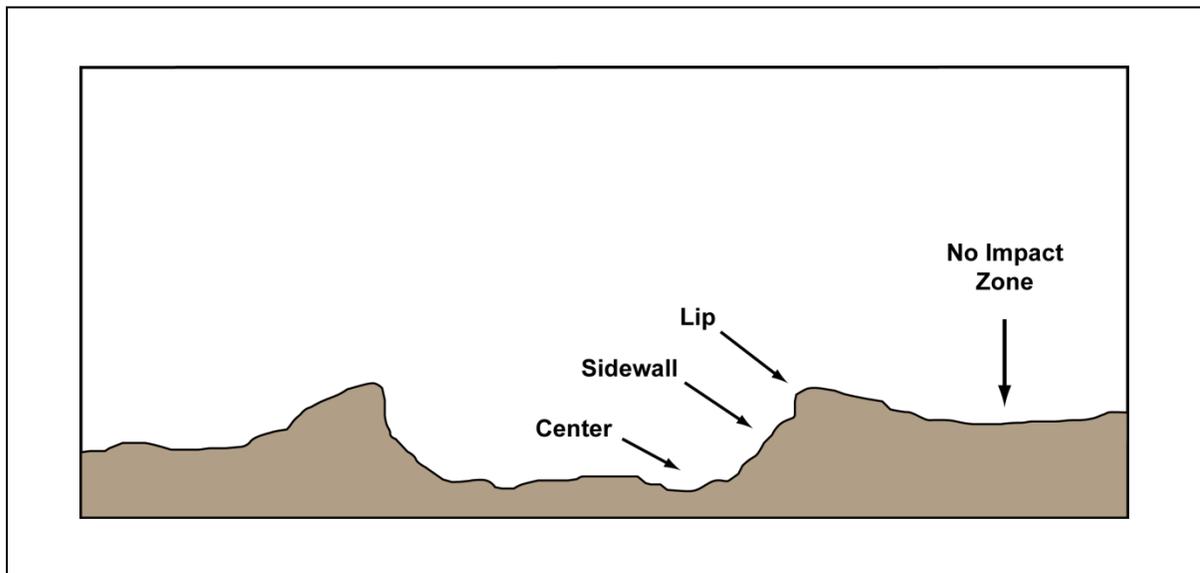
and Drescher 2008:201; Jones et al. 2005:246; Liu et al. 2009:49). Since archaeological sites often consist of cultural remains at or near ground surface, as outlined above, rut formation can have a direct impact on those remains.

Several researchers have developed general terms and measurements to provide quantitative data on the physical characteristics of ruts. The general characteristics, illustrated in Figures 3.1 and 3.2 are described as follows:

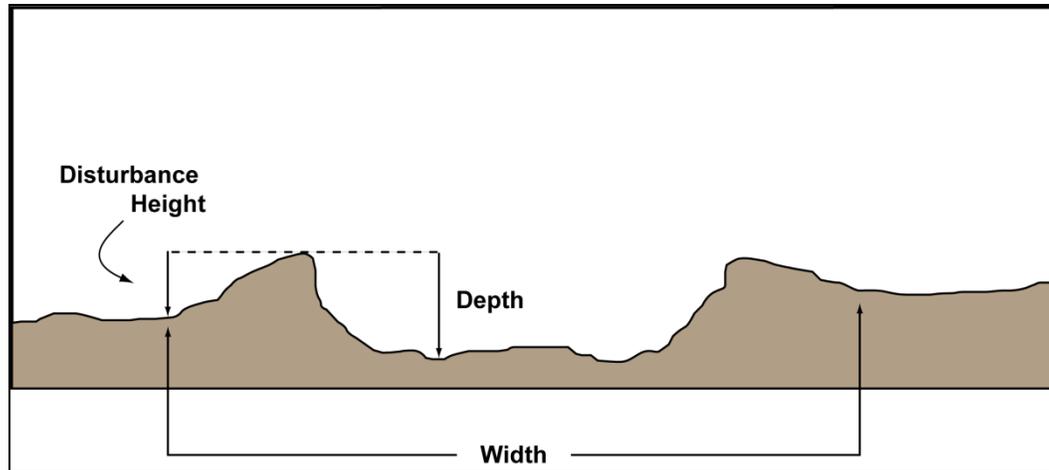
*Depth:* The vertical distance between the center of a track and undisturbed soil (the no impact zone) that is immediately adjacent (Affleck 2005:27; Liu et al. 2009:49). Depth has been used to subdivide ruts into *minor* (less than 7 cm), *moderate* (7-15 cm), and *severe* (greater than 15 cm) categories (Shoop et al. 2005:298).

*Disturbance Height:* The vertical distance from the top of the disturbed soil ridge (the lip in Figure 3.1), to the immediately adjacent undisturbed soil in the no impact zone. This variable may be measured for the inside and outside portions of the same track, and can be higher on the outside portion when the track is created by a turning vehicle (Althoff and Thien 2005:160; Halvorson et al. 2001:143).

*Width:* The measurement across the vehicle track representing the entire the width of the displaced soil and vegetation (Liu et al. 2009:49).



**Figure 3-1. Rut Terminology**  
(after Halvorson et al. 2001:41).



**Figure 3-2. Rut Measurements.**

Rut geometry is influenced by soil texture, soil moisture, topography, climatic conditions (precipitation and temperature), season, and, plant characteristics (Halvorson et al. 2003:2; Sullivan and Anderson 2000:27). Across varying landscapes, rut depth is usually significantly shallower if soils are dry as opposed to wet. In central Europe, only the heaviest military vehicles caused rutting greater than 2.54 cm in normal training conditions, while all tracked and wheeled vehicles exhibited depths greater than 2.54 cm for wet conditions. The heaviest tracked vehicles had ruts greater than 12.5 cm. Under the most severe training conditions in Germany, rut conditions for the heaviest vehicles can reach almost 5 cm for dry conditions and approximately 18 cm for wet conditions (Jones et al. 2005). In these cases, rut depth does not exceed the maximum thickness of the plow zone. Colder temperatures can lessen the impact of military training on wet soils. During the winter in Alaska, military training using Stryker vehicles results in no measurable ruts—and minimal vegetation disturbance (Affleck 2005:41,54 Shoop et al. 2005:300). It is only as the ground begins to thaw that ruts are created by Stryker training vehicles, and the depths of the ruts are related to the depth of the thaw (Affleck 2005:53).

The overall consensus among researchers has been the not too surprising conclusion that ruts tend to form more readily in moist soils, which are considered soft or weak. Additional findings appear somewhat less obvious, suggesting a degree of variation with depth. Intuitively it would seem that compaction would vary in inverse proportion, or decrease, with depth. But Halvorson et al. (2001) reported compaction to be greater with depth than at ground surface. In a study based on experimental areas at Yakima Training Center, Washington, these researchers looked specifically at changes in rut configuration caused by freeze-thaw over winter seasons, changes in surface characteristics of tank ruts and the effects on erosion. They measured saturated hydraulic conductivity (the amount of water infiltration into and through the soil); soil penetration resistance (measuring soil strength and density with a penetrometer); and soil bulk density (the weight of soil per unit volume). They noted that "...surface conditions will not resemble the compacted soil beneath it," and in particular that "...soil is less compacted...at the surface than deeper in the profile... [and] surface compaction does not persist" Halvorson et al. (2001:149).

In a later study, Halvorson (et al. 2003) looked at data from a single winter season. Some of their results were again predictable: bulk density increased within ruts in comparison with unrutted (uncompacted) soil, and the measure did not change quickly (through the single winter of their study). Soil penetration resistance was again found to be affected by moisture, in that greater resistance was recorded in moist soils. However, they observed that resistance, and by implication compaction, decreased “with age” especially near the surface, indicating that surface deposits may recover more quickly than buried sediments. The latter finding may be a function of increased potential for biological or other activity (such as freeze-thaw) in near-surface levels that may redistribute or loosen compacted sediments.

Observations regarding the relationship between soil moisture and compaction are mirrored in other studies. Adams (et al. 1982) studied soil compaction and its effects on the growth of desert annuals, documenting soil strength as measured with a soil penetrometer. They noted a significant difference in soil strength in wet soils after only a few passes by off-road vehicles, while in dry soils changes in soil strength were shallower and occurred only after many more vehicle passes. Jones (et al. 2005:250), in assessing vehicular rutting on terrains in Central Europe, also noted significant differences between wet and dry conditions. Little rutting occurred in dry conditions and only for the heaviest vehicles in the study. Conversely, all vehicles in the study produced ruts in wet conditions.

Affleck’s (2005) study of military vehicle impacts on the Alaskan landscape by the Stryker light armored vehicle represents the single best resource on rut formation and rut dimensions. Her study relied on experimental field tests, unlike several other studies in the terramechanics literature. Many terramechanics studies consist of analytical models that draw on vehicle parameters and landscape characteristics to derive rut dimensions—primarily depth—for particular regions and/or vehicle types (e.g. Jones et al. 2005; Shoop et al. 2005). The study by Li et al. (2007) represents one of the few cases where an analytical model was developed that was then subject to experimental field tests. Rut dimensions are available for five wheeled and eight tracked military vehicles.

In addition to vehicle load (weight), specific parameters affecting rut formation include track/wheel design, wheel diameter, footprint area of a tire/rack, and wheel slip (Affleck 2005:ii; Halvorson et al. 2003:2; Hambleton and Drescher 2009:45). Vehicle speed, driving pattern, and number of passes are also factors that may influence rut geometry (Halvorson et al. 2003:2; Sullivan and Anderson 2000:27). Rut width and depth increase when a vehicle turns, while rut depth is also related to speed for some vehicles (Affleck 2005:8; Li et al. 2007; Liu et al. 2009:51-54). Light armored vehicles (LAV) at Fort Lewis, Washington, for example, produced no ruts at low speeds but did at high speeds; at low speeds, it was concluded, LAVs may not have been able to generate sufficient force to overcome the resistive strength of vegetation (Liu et al. 2009:52-54). For straight paths, rut width corresponds closely to the width of the tire or track. Turning, especially if sharp, can produce a significantly deeper rut and a disturbed width almost four times the width of a track (Johnson and Campbell 2004:113).

The three variables in Figure 3.2 can be used directly to examine how archaeological sites are affected by military vehicle movement by comparing the horizontal and vertical dimensions

of the deposits with the disturbance measurements. However, rut depth may not indicate the total depth of vehicle impacts. For example, during rut formation the surface may “bounce back” so that the depth of the impact is deeper than the measured rut depth (Hambleton and Drescher 2009:36). In addition, soils or sediments may be compressed in regions below the observed depth of the rut.

*Indirect Effects of Vehicle Activity: Compaction.* Soil compaction results when vehicles traveling across the landscape reduce the volume of air in the soil, effectively pushing the mineral components together (Affleck 2005:4; Dregne 1983; Palazzo et al. 2005:178; Raper 2005:259; Sojka 1999; Stokowski and LaPointe 2000:3; Webb 1983:62). Compacted soils have a larger number of smaller pores, which enables them to retain greater amounts of water and results in increased soil density and strength (Adams et al. 1982:173; Belnap and Warren 2002:250; Iverson et al. 1981:915; Webb 1983).

Fine-textured soils typically tend to experience greater compaction from vehicular traffic than do coarse-textured soils (Althoff and Thien 2005:173; Dale et al. 2005:396; Raper 2005:259). Poorly sorted soils—such as loamy sands, sandy loams, or gravelly soils—are more vulnerable to soil compaction than sandy or clayey soils that are relatively uniform in texture and structure (Belnap and Warren 2002:250; Lei 2004:129; Milchunas et al. 2000:526; Ouren et al. 2007:6; Webb 1983:66-67, Webb 2002:293). Recently plowed soils have no inherent soil strength and can be compacted readily by vehicle traffic (Raper 2005:259). Wet or moist soils are more susceptible to compaction than soils with lower moisture contents (BLM 2003:3-4; Ouren et al. 2007:6; Raper 2005:270-276).

Compacted soil layers may not be present near the surface but rather exist deeper in a profile (Halvorson et al. 2001:149). Soil compaction has been recorded to depths greater than one meter. More typically, though, soil compaction resulting from vehicle traffic is evident between 5 and 30 centimeters in depth (Iverson et al. 1981:915; Prosser et al. 2000:668; Webb 1983:52, 2002:293). A thin, relatively loose layer often covers the more densely compacted layer (Webb 2002:293).

While compaction may be cumulative to some extent, it does not necessarily continue indefinitely. An upper limit is typically reached quite rapidly, often with the first vehicle pass (Iverson et al. 1981:915; Lei 2004:129). Once this threshold is reached, further compaction is limited. The actual limits of compaction are variable and related to soil texture. The persistence of soil compaction is determined by the depth at which it occurs, the shrink-swell potential of the soil, and climate. Typically, the greater the shrink-swell potential and number of wet/dry cycles, the lower is the duration of compaction at a particular depth. Freeze/thaw cycles also help decrease near-surface compaction. While not cumulative, if the activity that causes the compaction occurs regularly, then the natural “healing” processes discussed above will be less likely to occur, ultimately affecting soil moisture, runoff, and vegetation. For this reason, compaction on both agricultural and military training land is sometimes “repaired” by mechanical means (i.e., deep plowing). This indirect effect of compaction is typically more widespread than the rut formation causing compaction and can be more destructive to archaeological site integrity than the original vehicle activity.

Research from agricultural studies in Scandinavia has provided additional information. The investigations used a variety of analytical techniques including bulk density, resistivity, pore size distribution (Alaoui and Diserens 2011); bulk density, water retention, hydraulic conductivity (Arvidsson and Håkansson 1996; Arvidsson 2001); infiltration capacity, and compression tests (Berli et al. 2004); and compression tests and dye tracer experiments (Alakukku 1996). Alaoui and Diserens (2011), for example, reported a decrease in macropores at depths between 0.3 and 0.4 m, along with an increase in micropores and soil cracking between the surface and 0.1 m (following the use of heavy tracked equipment in golf course construction). Arvidsson's (2001) study of sugar beet fields and heavy tractors with inflatable tires noted reduced saturated hydraulic conductivity and increased bulk density at 0.5 m depth, increased effects following 2-4 years, possibly a result of age-hardening. Other studies tend to confirm compaction in the first 0.5 m of the soil column by heavy machinery (Alakukku 1996; Arvidsson and Håkansson 1996; deLeuw 2009).

Soil compaction often has important indirect effects on the soil profile. Compacted sediments may slow water infiltration, which can lead to changes in soil chemistry, organic-matter content, and hydrology, the latter affecting runoff and influencing erosion (Althoff et al. 2007:269; Belnap and Warren 2002:251; BLM 2003:3; Fuchs et al. 2003:343; Garten et al. 2003:172). Soil compaction can also lead to the collapse of animal burrows (Davenport and Switalski 2006), which might cause the downward movement of cultural objects in strata above the burrows.

The effects of compaction on archaeological deposits are unclear. The literature on aspects such as artifact fragility appears to be very limited. Attempts to understand factors affecting artifact breakage—including in a military training setting—have proven largely unsuccessful (Johnson and Campbell 2004). Mathewson (cited in Bilsbarrow 2004; see also Thorne 1991) reported that soil compression accelerates decay of animal bones, shell, plant remains, ceramics, features, and soil attributes, but has no direct effect on chipped stone and groundstone objects. Alterations to hydrology also reportedly lead to decreases in soil moisture that may affect the preservation of organic remains (Lillie and Smith 2007).

### **3.2 Current Approach**

The current project consisted of field testing designed to measure the effects of vehicle impacts resulting from training activities in areas containing significant or potentially significant archaeological sites. The study focused on a single effect of vehicle traffic—soil compaction. The analyses employed sought to identify physical evidence for compaction associated with vehicle ruts and, subsequently, to investigate the implications for artifact displacement and stratigraphic mixing drawn from that evidence. The detailed analytical process selected for the study was micromorphology, examining sediments from the sites at a microscopic level for evidence such as compression, cracking, unnatural particle alignment or sorting that might signal compaction. The project contrasted with similar studies reported in the existing literature that have usually been confined to the effects of single vehicles under controlled test conditions or in computer simulations. The current project was intended to test cumulative impacts on active training ranges and real archaeological sites.

Archaeological sites in active training areas were selected for the investigation at two installations participating in the study: a prehistoric site at MTC-Fort Pickett; and a historical site at MCB Quantico. Both sites had been previously recommended ineligible for NRHP listing and were chosen for the current study since the scope of the investigation did not allow for the type of comprehensive evaluation that would have been required for sites that were eligible or potentially eligible to the NRHP.

### **3.3 Site Selection Process**

The ultimate goal of the selection process was to select two sites, one from each installation that included one prehistoric and one historical site with subsurface deposits located in contrasting soil conditions with evidence of vehicle impacts. The site selection process began with a review of NRHP ineligible sites from MTC-Fort Pickett and MCB Quantico. Locations of NRHP ineligible sites were projected on aerial imagery in a GIS to identify which sites appeared to be in areas with vehicle related disturbance. GIS data were obtained from each installation with the assistance of the installation Cultural Resources Managers: Ms. Susan Smead (Virginia Department of Military Affairs [VADMA]) and Mr. John Haynes (MCB Quantico). The data included high resolution aerial imagery, infrastructure, hydrography, elevation contours, and site locations. Following this initial GIS analysis, a list of candidate sites was identified for each installation and previous site documentation was acquired from the Virginia Department of Historic Resources (VDHR) in the form of site forms from their online Data Sharing System (DSS) and survey reports from the VDHR archives in Richmond. Information regarding site components, artifact and feature contexts (i.e. surface or subsurface deposits), acreage, and site condition with particular attention paid to sites with documented vehicle impacts was gleaned from the site forms and survey reports. John Haynes provided additional site documentation and guidance on site selection at MCB Quantico. Soil data for each county within the study areas was downloaded via the Natural Resources Conservation Service's (NRCS) Web Soil Survey and added to the GIS to provide general soil conditions within the site areas.

Lastly, once the candidate site list was pared down based on existing documentation, reconnaissance field visits were made to each installation to assess logistics and the current conditions of the sites most likely to satisfy the study objectives. In most cases many years had passed since the site's initial recordation and site conditions had changed substantially (e.g., changes in ground cover and land use). In a few cases, there were conflicts among the existing site documentation, installation GIS, and conditions in the field and site boundaries could not be confidently reestablished.

#### **3.3.1 MTC-Fort Pickett.**

The GIS data from MTC-Fort Pickett listed 242 sites as NRHP ineligible. Of these, 35 sites coincided with areas that showed vehicle activity in aerial imagery in the form of ruts and tracks. Table 3-1 lists the sites along with information obtained from previous documentation and GIS analysis as well as notes on the sites' suitability for the study. The group included 20 prehistoric sites, 10 multi-component sites, and five historical sites. Figure 3-3 shows the distribution of the sites across the installation. As indicated in the figure, sites in Areas E, D, and C were removed from consideration based solely on existing documentation that indicated conditions were not conducive to the proposed subsurface

sampling methods. This included sites with limited or no subsurface deposits, large widespread scatters of artifacts, or noted heavy disturbance not mission-related (e.g., recent logging or plowing). The sites within Area C consisted of six prehistoric lithic scatters with limited subsurface deposits and undetermined temporal affiliations; one low density historical artifact scatter; and one widespread (12-acre) multicomponent site. In addition, the area had been logged since the 2007 survey thus making it difficult to differentiate logging disturbance from military vehicle disturbance. The sites in Area D were reported to consist of mostly surface scatters of artifacts.

Reconnaissance field visits were scheduled for Areas A and B as they contained sites with buried deposits and appeared to be areas of frequent vehicle maneuvers. Versar personnel met with VADMA Cultural Resources Program Manager, Susan Smead on 23 February 2011 to discuss the scope of the study and gain access to the candidate site areas. Upon contacting Range Operations regarding access to the training areas it was learned that Area B was inaccessible for several months due to live-fire training. Area B contained two historical sites in particular, 44DW301 and 44DW302, which may have met the needs of the study. They both were reported to contain subsurface deposits and tracked vehicle impacts. However, the site area could not be visited due to ongoing mission needs. Field visits were then focused on Area A.

Area A contained a mix of 15 prehistoric, historical, and multi component sites in an area of approximately 570 acres. Individual site areas ranged from 0.1-to-24 acres. Most of the sites within this area exhibited either limited subsurface deposits, disturbance related to land clearing, widespread surface scatters, or indiscernible vehicle activity as compared to activity visible in aerial imagery. Two prehistoric sites, 44DW329 and 44DW229, appeared to be the best candidates. Ultimately, 44DW329 was chosen as it was reported to contain artifacts up to 60 cm below surface, had good field documentation so site boundaries and sampling locations could be reasonably identified, and recent vehicle activity was present within the site boundaries. Site 44DW229, while containing limited subsurface deposits, appeared to be a location of frequent vehicle activity based on review of aerial imagery, however, as viewed on the ground evidence of vehicle activity was difficult to identify. Based on the field visit and sample of sites available, 44DW329 was determined better suited to the goals of the study.

**Table 3-1. Sites Considered for the Current Study, MTC-Fort Pickett.**

<i>Site Number</i>	<i>Map Label</i>	<i>Component</i>	<i>Acres</i>	<i>Soil</i>	<i>Report/Site Form Notes</i>	<i>Study Suitability</i>	<i>Selection Notes</i>
44BR0084	C	Prehistoric / 19th/Early 20th century	12.0	sandy loam	Features noted; mostly surface deposits.	Low	Limited subsurface deposits. Large site, widespread artifact distribution.
44BR0085	C	Prehistoric /Late 18 <sup>th</sup> / Early 19th century	0.3	sandy loam	Subsurface deposits. Low artifact density.	Low	Limited subsurface deposits
44BR0182	C	Prehistoric	0.2	sandy loam	Low density, no temporal artifacts, lack of integrity due to plowing and soil deflation.	Low	Lack of integrity due to recent logging.
44BR0183	C	Prehistoric	1.7	sandy clay loam	Low density, no temporal artifacts, lack of integrity due to plowing and soil deflation.	Low	Low artifact density, no temporal artifacts, lack of integrity due to plowing and recent logging.
44BR0184	C	Prehistoric	2.5	sandy clay loam	Low density, no temporal artifacts, lack of integrity due to plowing and soil deflation.	Low	Low artifact density, no temporal artifacts, lack of integrity due to plowing and recent logging.
44BR0187	C	Prehistoric	1.3	sandy loam	Low density, no temporal artifacts, lack of integrity due to plowing and soil deflation.	Low	Low artifact density, no temporal artifacts, lack of integrity due to plowing and recent logging.
44BR0188	C	Woodland	0.7	sandy clay loam	Low density, no temporal artifacts, lack of integrity due to plowing and soil deflation.	Low	Low artifact density, no temporal artifacts, lack of integrity due to plowing and recent logging.
44BR0189	C	Prehistoric	1.7	sandy clay loam	Low density, no temporal artifacts, lack of integrity due to plowing and soil deflation.	Low	Low artifact density, no temporal artifacts, lack of integrity due to plowing and recent logging.
44DW0178	A	Early 20th century	0.1	sandy loam	Surface and Subsurface deposits. Bulldozing disturbance reported.	Low	Limited subsurface deposits. Area currently wooded.

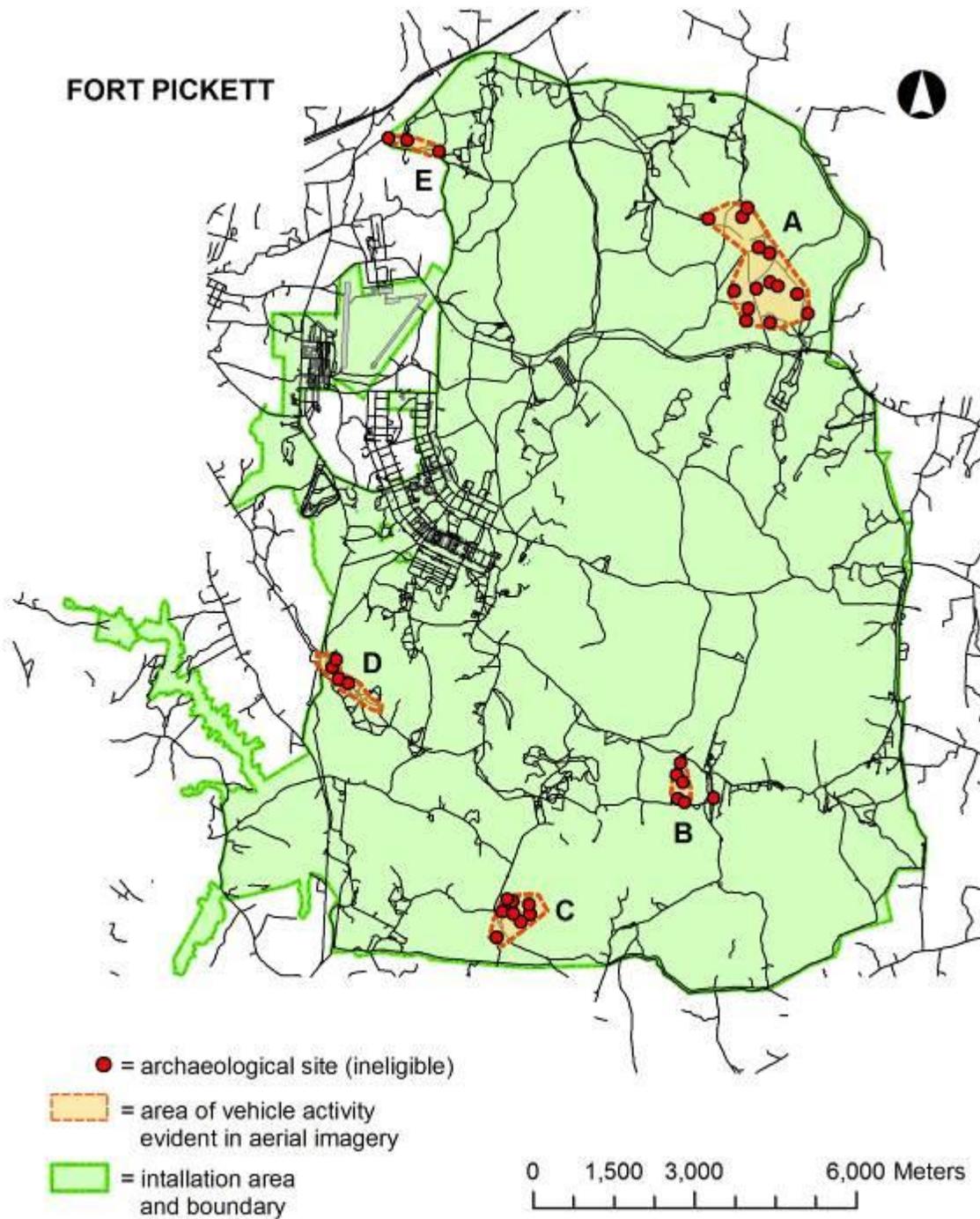
*Integrating Military Training and Archaeological Site Integrity:  
A Field Analysis Approach*

<i>Site Number</i>	<i>Map Label</i>	<i>Component</i>	<i>Acres</i>	<i>Soil</i>	<i>Report/Site Form Notes</i>	<i>Study Suitability</i>	<i>Selection Notes</i>
44DW0229	A	Middle Archaic/Middle-Late Woodland	0.2	sandy loam	Small, low artifact density. "Surface deposits with subsurface integrity" noted on form.	Low	Limited subsurface deposits. Vehicle activity difficult to identify on the ground.
44DW0230	A	Late 19th-Early 20th century	0.1	sandy loam	Subsurface deposits.	Low	Limited subsurface deposits.
44DW0231	A	Prehistoric/19th-Early 20th century	1.8	gravelly sandy loam	Site form states that site was destroyed by plowing. Subsurface deposits.	Low	Limited subsurface deposits.
44DW0296	A	19th/Early 20th century	0.2	gravelly sandy loam	Subsurface deposits. No features.	Low	Limited subsurface deposits.
44DW0297	A	Prehistoric/19th-Early 20th century	0.1	gravelly sandy loam	Low artifact density.	Low	Limited subsurface deposits.
44DW0301	B	Prehistoric/ Late 18th-20th	12.0	sandy loam	Tracked vehicle impacts noted. Surface features. Surface and subsurface artifacts.	High	Good candidate. No access -located in reserved/active training area.
44DW0302	B	Late 19th century	0.7	sandy loam	Tracked vehicle impacts noted. Surface features. Surface and subsurface artifacts.	High	Good candidate. No access -located in reserved/active training area.
44DW0303	B	Middle Archaic	0.5	sandy loam	Subsurface deposits. Low artifact density. Military training noted.	Low	Limited subsurface deposits. No access - located in reserved/active training area.
44DW0304	B	Prehistoric	0.3	sandy loam	Subsurface deposits. Low artifact density. Military training noted.	Low	Limited subsurface deposits. No access - located in reserved/active training area.
44DW0306	B	Prehistoric	0.08	sandy loam	Subsurface deposits. Low artifact density. Military training noted.	Low	Limited subsurface deposits. No access - located in reserved/active

<i>Site Number</i>	<i>Map Label</i>	<i>Component</i>	<i>Acres</i>	<i>Soil</i>	<i>Report/Site Form Notes</i>	<i>Study Suitability</i>	<i>Selection Notes</i>
							training area.
44DW0307	A	Middle Archaic	0.1	sandy loam	Subsurface deposits. Low artifact density. Military training noted.	Low	Limited subsurface deposits. No access - located in reserved/active training area.
44DW0312	A	Prehistoric/Late 19th	0.1	gravelly sandy loam	Subsurface deposits. Low artifact density. Military training noted.	Low	Limited subsurface deposits.
44DW0313	A	Middle Archaic/Late Woodland/Late 19th- Early 20th century	0.2	gravelly sandy loam	Subsurface deposits. Low artifact density. Military training noted.	Low	Limited subsurface deposits.
44DW0329	A	Early Archaic	1.1	sandy loam	Subsurface integrity noted. Surface and subsurface artifacts. Artifacts recovered from up to 60 cm below surface.	High	Site visit indicates recent vehicle activity within site boundaries. Relatively deep subsurface deposits
44DW0334	A	Prehistoric	0.5	sandy loam	Site form states completely destroyed. Low artifact density.	Low	Limited subsurface deposits.
44DW0335	A	Woodland	0.5	sandy loam	Site form states completely destroyed. Low artifact density.	Low	Limited subsurface deposits.
44DW0341	A	Late Archaic	0.3	sandy clay loam	Surface deposits only.	Low	No subsurface deposits.
44DW0342	A	Middle-Late Archaic	16.0	sandy loam	Appears that plowing impacted site significantly, heavy disturbance noted.	Low	Limited subsurface deposits.
44DW0351	A	Middle Archaic	24.0	gravelly sandy loam	Surface deposits only, low artifact density.	Low	No subsurface deposits.

*Integrating Military Training and Archaeological Site Integrity:  
A Field Analysis Approach*

<i>Site Number</i>	<i>Map Label</i>	<i>Component</i>	<i>Acres</i>	<i>Soil</i>	<i>Report/Site Form Notes</i>	<i>Study Suitability</i>	<i>Selection Notes</i>
44NT0099	E	Early 20th century	0.8	coarse sandy loam	Surface and Subsurface deposits.	Low	Heavy disturbance due to road construction and utility line r-o-w maintenance.
44NT0103	E	Prehistoric	0.02	coarse sandy loam	Surface deposits only, low artifact density.	Low	No subsurface deposits.
44NT0105	E	Archaic-Woodland/20th century	24.0	coarse sandy loam	Destruction of surface and subsurface deposits noted. Military training noted as agent of disturbance.	Low	Heavy disturbance due to recent plowing.
44NT0107	D	Late Archaic	2.0	coarse sandy loam	Lithic scatter. Mostly surface deposits.	Low	Limited to no subsurface deposits.
44NT0108	D	Late Archaic	0.07	coarse sandy loam	Lithic scatter. Mostly surface deposits.	Low	Limited to no subsurface deposits.
44NT0109	D	Late Archaic	1.1	coarse sandy loam	Lithic scatter. Mostly surface deposits.	Low	Limited to no subsurface deposits.
44NT0115	D	Prehistoric	1.1	coarse sandy loam	Lithic scatter. Surface deposits only.	Low	Limited to no subsurface deposits.



**Figure 3-3. Locations of Sites Considered for the Current Study, MTC-Fort Pickett.**

### 3.3.2 MCB Quantico

The site selection process at MCB Quantico varied somewhat from that employed at MTC-Fort Pickett. Since a prehistoric site with predominantly sandy loam soil had been selected at MTC-Fort Pickett, the preference at MCB Quantico was for selection of a historical site within clay loam or silty clay loam soils to provide contrasting conditions. In total, 36 sites were considered based on information obtained from previous documentation, GIS analysis, and recommendations made by the installation cultural resources manager (Table 3-2). The group included 17 historical sites, 14 prehistoric sites, and six multi-component sites. Figure 3-4 shows the distribution of the sites across the installation.

Thirty-two sites were removed from consideration based solely on existing documentation that indicated conditions were not conducive to the proposed subsurface sampling methods. This included sites with limited or no subsurface deposits; large sites consisting of widespread scatters of artifacts; sites with no vehicle activity noted in aerial imagery; or –sites with non-vehicle-related heavy disturbance (e.g., recent logging, plowing, or other earthmoving activities).

Field visits were made on 3 March 2011 to the four most promising sites (44ST209, 44PW899, 44PW957, and 44PW1550). The visits were made to assess vehicle impacts that were either previously documented or visible in aerial imagery: Site 44ST209 had vehicle ruts illustrated on site maps; sites 44PW899 and 44PW1550 had reported vehicle activity that was not evident on aerial imagery; and 44PW957 had multiple vehicle tracks visible in aerial imagery. The relevant parts of Sites 44ST209, 44PW899, and 44PW1550 were all located in wooded areas in which vehicle impacts consisted of two-track trails that could not be confidently associated with military vehicle training. Ultimately, historical site 44PW957 was chosen because previous documentation indicated the presence of subsurface deposits, the site was located on open ground, and there were clear signs of vehicle ruts on the surface at the time of the site visit and in aerial imagery. Additionally, the site was located on silty clay loam soil, contrasting with the soils at the site chosen at MTC-Fort Pickett.

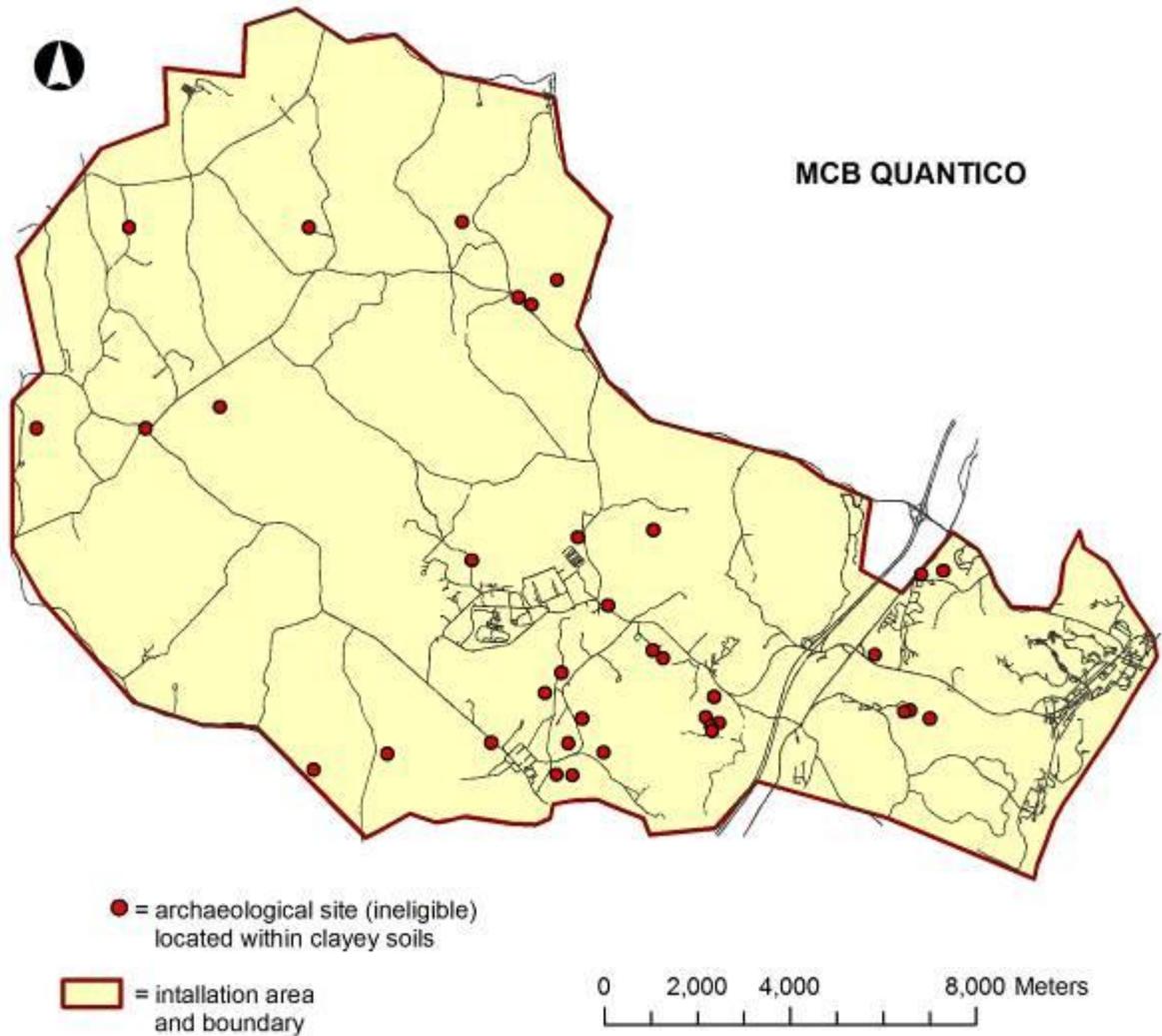
**Table 3-2. Sites Considered for the Current Study, MCB Quantico.**

<i>Site Number</i>	<i>Component</i>	<i>Acres</i>	<i>Soil</i>	<i>Report/Site Form Notes</i>	<i>Study Suitability</i>	<i>Selection Notes</i>
44FQ0155	Late 19th/Early 20th century	0.5	clay loam	Surface and subsurface deposits. Low artifact density.	Low	Limited subsurface deposits.
44PW0661	Prehistoric- unidentified/ 19th/20th century	1.5	loam	Tank trails present. No subsurface deposits	Low	No subsurface deposits.
44PW0899	Late 19th/Early 20th century	1.2	clay loam	Surface and subsurface deposits. Low artifact density. Vehicle impacts per cultural resources manager.	Low	Limited subsurface deposits. No vehicle activity evident during site visit. Site area is wooded.
44PW0951	19th century	0.1	clay loam	No subsurface deposits. Minimal disturbance noted.	Low	No subsurface deposits.
44PW0957	19th/20th century	1.3	silty clay loam	Plowing and clearing impacts reported. Ruts visible in aerial imagery. Surface and subsurface deposits.	High	Vehicle activity visible during field visit. Subsurface deposits to 20 cm in depth. Local soils are clayey.
44PW1002	Prehistoric	1.4	clay loam	Subsurface deposits, low artifact density.	Low	Limited subsurface deposits.
44PW1003	Prehistoric	1.0	clay loam	Subsurface deposits, low artifact density.	Low	Limited subsurface deposits.
44PW1400	Late 19th/Early 20th century	0.6	clay loam	Dwelling, surface features, military training impacts noted.	Low	Limited subsurface deposits.
44PW1414	19th century	1.9	clay loam	Cellar hole, surface and subsurface deposits.	Low	No vehicle activity evident.
44PW1550	Prehistoric / 19th/20th century	1.3	silt loam	Surface and subsurface deposits, surface feature, military training impacts noted. Recommended by cultural resources manager.	Low	No vehicle activity evident.
44PW1803	20th century	1.1	clay loam	Dwelling. Surface features. No subsurface testing conducted. Military training impacts noted.	Low	No vehicle activity evident.

*Integrating Military Training and Archaeological Site Integrity:  
A Field Analysis Approach*

<i>Site Number</i>	<i>Component</i>	<i>Acres</i>	<i>Soil</i>	<i>Report/Site Form Notes</i>	<i>Study Suitability</i>	<i>Selection Notes</i>
44ST0204	Prehistoric	0.5	fine sandy loam	Site map shows ruts; limited or no subsurface presence.	Low	Limited subsurface deposits.
44ST0209	Middle/Late Woodland	8.5	loam	Site map notes rut locations. Some depth/density to site deposits. Recommend by cultural resources manager.	Low	Large site. Site area is wooded. Difficult to distinguish military vehicle activity (if any) from logging trails.
44ST0218	Late-19th century	0.7	clay loam	Surface and subsurface deposits. Low artifact density.	Low	Limited subsurface deposits. No vehicle activity evident.
44ST0221	20th century	0.1	clay loam	Surface features. Surface and subsurface deposits. Low artifact density. Disturbance noted but not characterized.	Low	Limited subsurface deposits. No vehicle activity evident.
44ST0223	Prehistoric	0.1	clay loam	Subsurface deposits.	Low	No vehicle activity evident.
44ST0239	Prehistoric	0.2	clay loam	Subsurface deposits. Low artifact density.	Low	Limited subsurface deposits. No vehicle activity evident.
44ST0300	18th/19th/20th century	2.5	loam, silt loam	Push piles. No site map.	Low	Limited documentation. No vehicle activity evident.
44ST0366	Prehistoric	0.3	clay loam	Subsurface deposits (5 flakes). Heavy disturbance noted – deep vehicle ruts.	Low	Limited subsurface deposits.
44ST0797	Early 20th century	0.2	clay loam	Dwelling. Surface and subsurface deposits. Low artifact density.	Low	Limited subsurface deposits. No vehicle activity evident.
44ST0809	Prehistoric / Late-19th century	1.1	clay loam	Surface features. Surface and subsurface deposits.	Low	No vehicle activity evident.
44ST0868	Prehistoric	0.6	clay loam	Subsurface deposits. Low artifact density.	Low	Limited subsurface deposits. No vehicle activity evident.
44ST0869	Prehistoric	0.1	clay loam	Subsurface deposits. Low artifact density.	Low	Limited subsurface deposits. No vehicle activity evident.

<i>Site Number</i>	<i>Component</i>	<i>Acres</i>	<i>Soil</i>	<i>Report/Site Form Notes</i>	<i>Study Suitability</i>	<i>Selection Notes</i>
44ST0894	Prehistoric	0.1	clay loam	Subsurface deposits. Low artifact density.	Low	Limited subsurface deposits. No vehicle activity evident.
44ST0896	Prehistoric	0.0	clay loam	Subsurface deposits. Low artifact density.	Low	Limited subsurface deposits. No vehicle activity evident.
44ST0897	Prehistoric	0.2	clay loam	Subsurface deposits. Low artifact density.	Low	Limited subsurface deposits. No vehicle activity evident.
44ST0997	Historic	0.5	clay loam	Surface features/deposits. Logging disturbance noted.	Low	No military vehicle activity evident.
44ST1001	19th/Early 20th century	0.2	clay loam	Surface features. Surface and subsurface deposits. No visible surface disturbances noted.	Low	No vehicle activity evident.
44ST1002	20th century	0.6	clay loam	Surface features. Military training impacts noted.	Low	No vehicle activity evident.
44ST1006	Historic	1.3	clay loam	Dwelling. Disturbance from LZ construction noted.	Low	No vehicle activity evident.
44ST1027	Prehistoric	1.4	clay loam	Subsurface deposits. Low artifact density.	Low	Limited subsurface deposits. No vehicle activity evident.
44ST1030	Prehistoric / Late-18th / 19th century	4.3	clay loam	Surface features. Surface and subsurface deposits. Cemetery noted nearby.	Low	No vehicle activity evident. Large site area.
44ST1034	Prehistoric / 19th / Early 20th century	2.1	clay loam	Surface features. Surface and subsurface deposits.	Low	No vehicle activity evident. Logging disturbance.
44ST1036	Prehistoric / 19th/Early 20th century	0.8	clay loam	Surface features. Surface and subsurface deposits. Low artifact density.	Low	Limited subsurface deposits. No vehicle activity evident.
44ST1037	19th century	0.1	clay loam	Subsurface deposits. Low artifact density.	Low	Limited subsurface deposits. No vehicle activity evident.
44ST1039	Late Archaic	0.3	clay loam	Subsurface deposits, within pine stand.	Low	Limited subsurface deposits. No vehicle activity evident.



**Figure 3-4. Locations of Sites Considered for the Current Study, MCB Quantico.**

### **3.4 Developing a Solution: Archaeological Methods**

#### **3.4.1 Field Methods**

Prior to the start of fieldwork, Versar, Inc., drafted a health and safety plan. Potential hazards identified included vehicular traffic, slip/fall hazards, use of sharp tools, snakes, insects, and heat and/or cold stresses. Each member of the field team was required to read the health and safety plan and abide by its provisions. A copy of the plan was kept on site at all times.

### ***Archaeological Field Methods***

The field methods used for this study conformed to standard archaeological practices. Test units measuring 1-x-2 m and 1-x-1 m were excavated to expose profiles for soil column sampling and to characterize the archaeological deposits. Test units were placed in areas with visible vehicle ruts, areas with faint or weathered vehicle ruts, and areas with no visible vehicle activity, to provide a range of conditions for analysis. A total of 4 m<sup>2</sup> was excavated per site.

Excavated sediments were screened through quarter-inch mesh hardware cloth to ensure uniform recovery of cultural materials. The depths of all excavations were measured relative to adjacent ground surface. Test units were excavated in 10-cm (4-inch) arbitrary levels within natural stratigraphic breaks. Horizontal provenience information and stratigraphic profiles were recorded on standard forms, listing soil texture, color (using Munsell Soil Color Chart notation, 1994 Edition), and any natural or cultural inclusions present. Sections and plan views of the test units were drawn to scale and photographed. Artifacts from all proveniences were bagged in re-sealable polyethylene bags with complete provenience information recorded in indelible ink. Other field documentation included daily field notes and photographic documentation consisting of color digital images.

### ***Geoarchaeological Field Methods***

The purpose of geoarchaeological analysis at the sites was to look for evidence of soil compaction through detailed descriptions of the soils at a sedimentological level and through laboratory analysis of the sediments on a microscopic level. In the field, excavated profiles were examined and sediments were described using standard soil science terminology. The descriptions are summarized in the text of this report; full descriptions are included in a table in Appendix B. Samples of sediment were collected for lab analysis by cutting blocks measuring roughly 10-x-10 cm from exposed profiles using a knife and a trowel. The blocks were loosely wrapped in tissue paper then securely wrapped in packaging tape to keep the samples intact during transport to the laboratory at Boston University.

#### **3.4.2 Laboratory Methods**

##### ***Artifact Processing***

The archaeological investigations at the sites resulted in the recovery of artifacts. As required by federal law, the artifacts were processed and cataloged in accordance with the curation standards set forth in 36 CFR Part 79 and the Virginia Collections Management Standards (Virginia Department of Historic Resources [VDHR] 2009). At the conclusion of fieldwork, artifacts recovered from the field testing investigations were delivered to the Versar, Inc., laboratory in Springfield, Virginia, for processing, cataloging, and analysis.

The artifacts were cleaned in plain water and bagged in 4-mil polyethylene zip-lock bags according to provenience and material type. Consecutive bag numbers were assigned in the field for each provenience from which artifacts are recovered. Provenience information was written in indelible ink on the exterior of the artifact bags, and acid-free tags with the same information were placed within the bags. Artifacts were classified by general category (i.e., prehistoric or historical), followed by specific type (fire-cracked rock, debitage, nails, brick,

etc.), raw material type, function, and segment. Additional attributes were recorded where they contributed to the determination of the artifact function or temporal range.

The collections were labeled with the project name, site number, and the date of the fieldwork. Field notes and documentation were organized using archival materials, and digital image files were burned to a CD. The project records and the artifacts are stored in labeled, acid-free boxes. At the conclusion of the project, all artifacts and field records will be transferred to MTC-Fort Pickett and MCB Quantico for curation as required by 36 CFR 79.

#### ***Geoarchaeological/Micromorphological Processing***

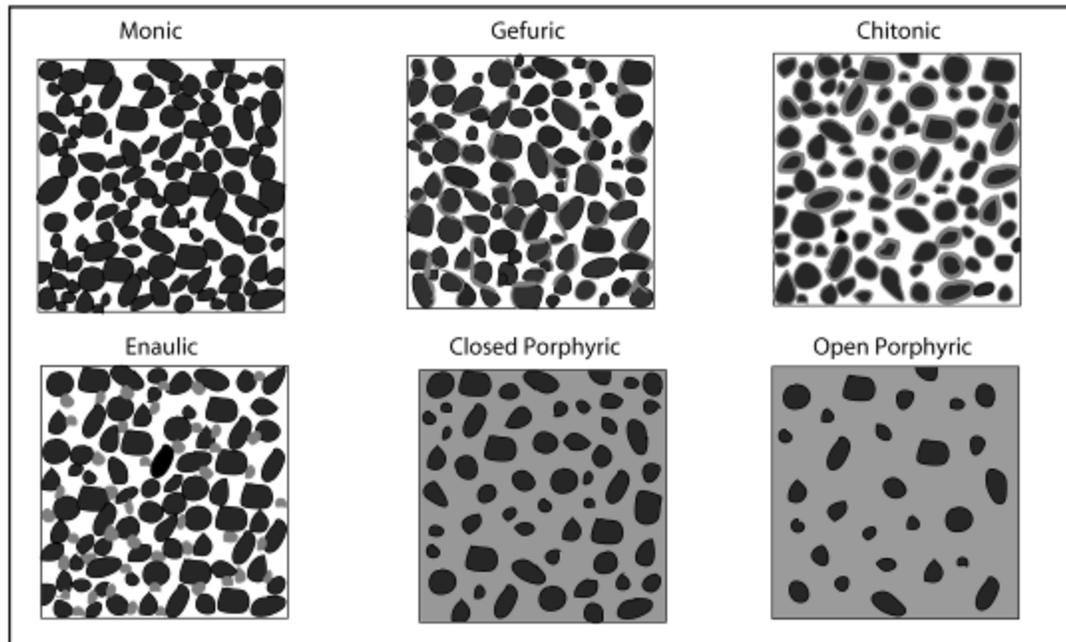
These samples were returned to the micromorphological laboratory at Boston University where they were impregnated with a mixture of liquid polyester resin and styrene in a ratio of 7:3. Methyl ethyl ketane peroxide was added as an accelerant to this mixture in a ratio of seven ml per liter. The addition of the accelerant reduces the curing time to approximately one week; without an accelerant the polyester resin would require several months to cure. When the resin in the samples had reached a gel-like consistency, the blocks were placed in an oven at 150° F overnight to finish hardening. The samples were then cut into 1–2 cm thick blocks on a rock saw. Samples selected for thin sectioning (15 total) were trimmed to a final size of 50-x-75 mm and shipped to Quality Thin Sections in Tucson, Arizona. Images of the sections are presented in Appendix C.

Micromorphology is an analytical technique developed in the soil sciences. It consists of the examination of thin-sectioned soil and sediment samples under a variety of magnifications (1–400x) and light conditions (including reflected, plane polarized, and cross polarized). The technique allows for the identification of the mineral (and often the organic) components present in the thin sections (Bullock et al. 1985, Courty et al 1989). The ability to identify these constituents is not unique to micromorphology; what is unique is the technique's ability to analyze the physical relationships between the constituents.

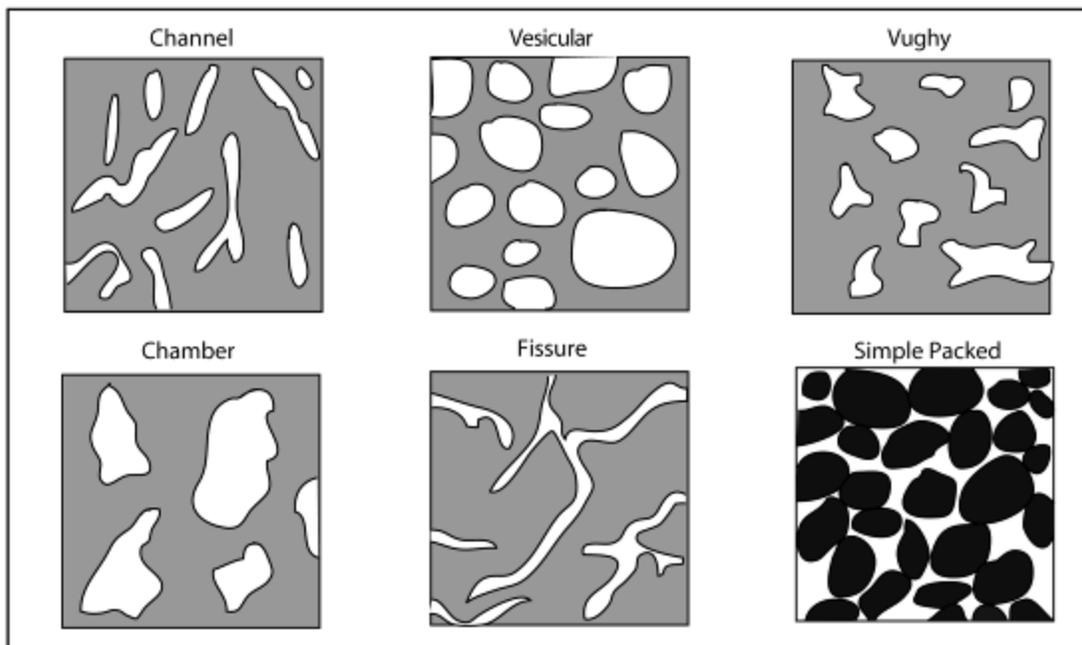
In technical analyses and descriptions the constituents can be divided into two size categories: the coarse fraction, grains that are sand sized or larger; and the fine fraction, the fine silt and clay sized particles. A third important component is the shape, number and distribution of space within the sediment or soil. These spaces are termed voids and the descriptive terms for the various shapes are depicted in Figure 3-5. The physical relationship between these elements is called the related distribution. The descriptions are important since the relationship between the coarse and fine fraction is often the result of the initial mechanism of sediment transport. They may therefore indicate whether the sediments have been subject to compaction.

The voids are important components of sediments and soils for a number of reasons. It is through the voids that air and water are transmitted, and it is within voids or along their edges that illuviated materials are deposited during pedogenesis, so that in many well developed soils, the voids have thick clay coatings. The shape of and distribution of spaces within the material can also be indicative of both transport processes and post-depositional activity. Closely spaced, irregularly shaped voids, called vughs, are typical of material that

has been bioturbated by roots. Cracks can form as a result of mechanical pressure (as noted above) or through drying or freeze/thaw cycles.



Schematic representation of related distribution types.



Schematic representation of void types.

**Figure 3-5. Micromorphological Terminology for Use in Assessing Soil Compaction.**

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## **4.0 RESULTS (FIELD WORK)**

MTC-Fort Pickett and MCB Quantico were selected as field testing locations due to their role as active military vehicle training centers and for their large and diverse archaeological inventories.

Two sites were selected for the current study: prehistoric site 44DW329 at MTC-Fort Pickett and historical site 44PW957 at MCB Quantico. The sites were chosen because they are located within active training areas utilized for military vehicle maneuvers and they contain subsurface archaeological deposits. Both sites had been previously determined not eligible for the NRHP due to a lack of research potential. NRHP-ineligible sites were chosen to avoid adverse effects on sites resulting from the current investigation—the scope of this study did not allow for a comprehensive re-evaluation of eligible or potentially eligible sites. A background summary of each site is presented below along with the results of field investigations.

### **4.1 MTC-Fort Pickett**

Fieldwork at MTC-Fort Pickett was conducted May 3 through May 6, 2011.

#### **4.1.1 Previous Investigations at Site 44DW329**

This section describes how the site was first located and what was found there. Site 44DW329 was first recorded as an Early Archaic lithic scatter in 2004 by the Conservation Management Institute (CMI), the in-house cultural resources management program at MTC-Fort Pickett (Brown and Boyko 2006). The site was documented during a 2004 archaeological survey conducted in advance of the establishment of a 34-acre fire and medical training area. The survey included surface inspection and systematic subsurface testing. Artifacts were recovered from surface contexts and 13 shovel tests that included:

- 2 quartzite Kirk projectile point fragments
- 1 quartz LeCroy projectile point
- 1 quartz biface
- 13 quartz flakes
- 4 quartzite flakes
- 1 chert flake
- 1 diabase flake
- 2 quartzite hammerstones

In addition, three historical artifacts also were recovered including: a button, a bottle glass fragment, and a fence staple.

CMI described the site's stratigraphy as follows:

Although some major disturbance was visible within the site boundary, [shovel test] profiles do not appear to be truncated. Typically, the organic layer was underlain by dark yellowish brown (10YR 3/4) sandy loam, that varied from 8 to 41 cm thick, with an average thickness of 21 cm. Below this was a yellowish brown (10YR 6/4) loamy sand, with a thickness between 11 and 30 cm, with an average thickness of 18 cm. Excavation usually terminated at a brownish yellow (10YR 6/8) sandy clay; this basal stratum was excavated into an average of 16 cm, varying from 11 to 20 cm.

CMI recommended the site as not eligible for inclusion on the NRHP stating:

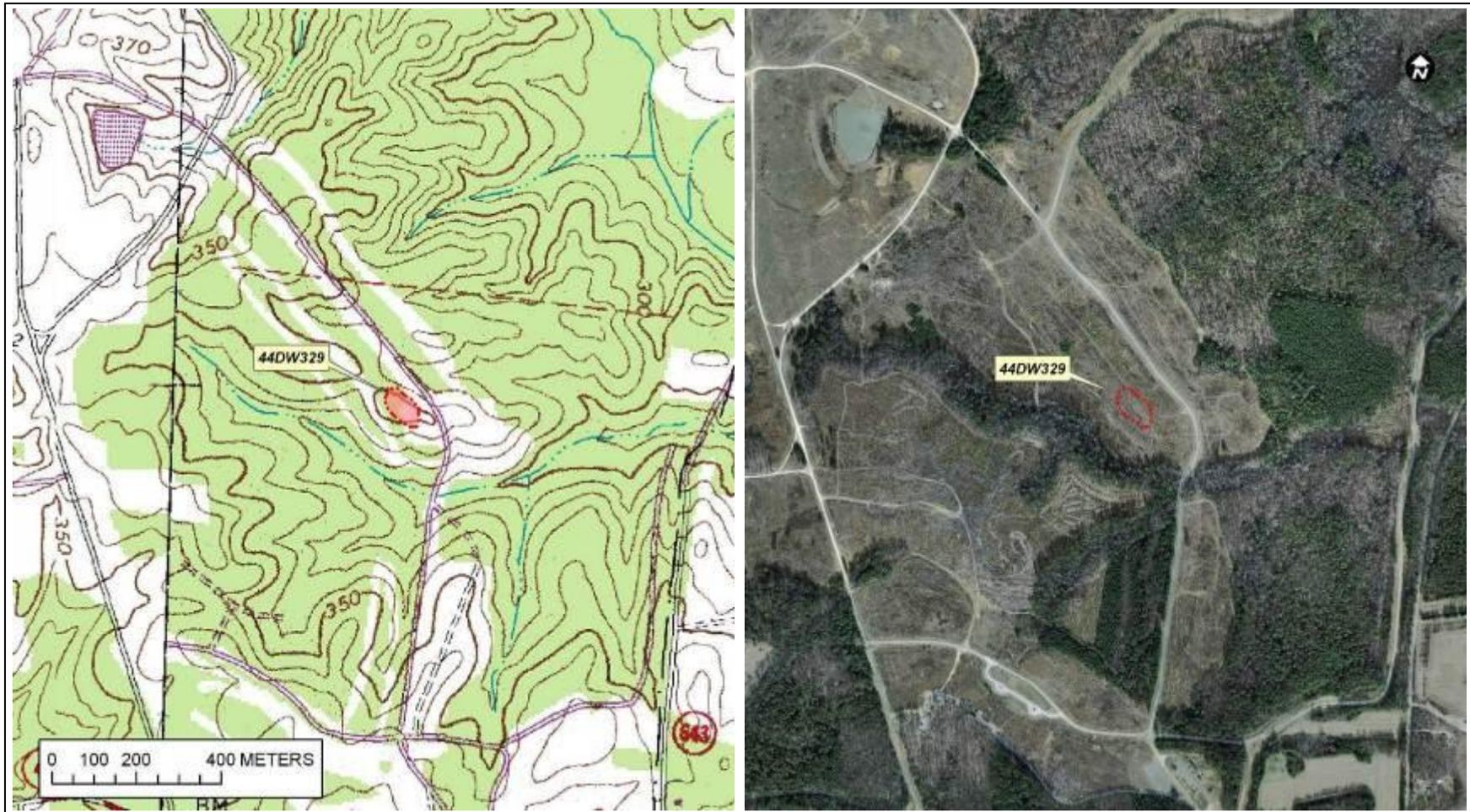
Neither the prehistoric or historic component of Site 44DW0329 is eligible for nomination to the National Register of Historic Places under Criterion A, C or D. Although three diagnostic projectile points were recovered, the small quantity of prehistoric artifacts recovered were not from undisturbed subsurface contexts such that the site can reasonably be expected to provide useful spatial and functional data contributing to a greater understanding of intra-site and intersite artifact patterning, and consequently, site function. The historic artifacts that are present and the majority of the prehistoric artifacts were recovered from the surface and plowzone, both highly disturbed contexts. No intact above ground or below ground features were documented. Natural and cultural transformations of this site are not minimal, and it cannot be linked to an important historic person or event. All the information this site has to offer has been realized at the survey level of effort. No further work is recommended at Site 44DW0329.

#### 4.1.2 Current Conditions

This section describes the site conditions at the time of the current investigation. Site 44DW329 is located near the terminus of a low, broad southeast-trending ridge at an elevation of approximately 99 m above mean sea level as illustrated by the left hand image in Figure 4-1. Recent aerial imagery, also shown in Figure 4-1, indicates the mix of open and wooded landcover present in the site vicinity during this study. The site area drains in an easterly direction via small intermittent tributaries to Butterwood Creek which ultimately flows to the Nottoway River. Soils in the area are described as Appling sandy loam (NRCS 2011). As reported by Brown and Boyko (2006), the site measures 4,770 m<sup>2</sup>. At the time of the current field investigations, the immediate site area was covered in a typical post-land-clearing, early-successional groundcover of brush, wildflowers, and grasses (Figure 4-2). Recent vehicle activity within the site boundaries was evident by the presence of several sets of wheeled-vehicle ruts. The ruts were devoid of vegetation and rut-depth ranged from 2-to-15 cm below ground surface, suggesting they were formed under wet conditions. Some pairs of ruts, representing a single vehicle, were distinguishable and measured 1.5 m between the rut center points.

#### 4.1.3 Test Unit Excavation

This section describes the results of the current investigation. Two 1-x-2 m test units were excavated within Site 44DW329 for this study (Figure 4-3). The purpose of the units was to characterize the sediment and archaeological deposits at the site and to provide soil columns for sampling in support of micromorphological analyses. Unit 1 was placed in the southern portion of the site where recent vehicle rutting was evident and Unit 2 was placed approximately 50 m north of Unit 1 in a portion of the site that exhibited no visible vehicle rutting on the ground surface.

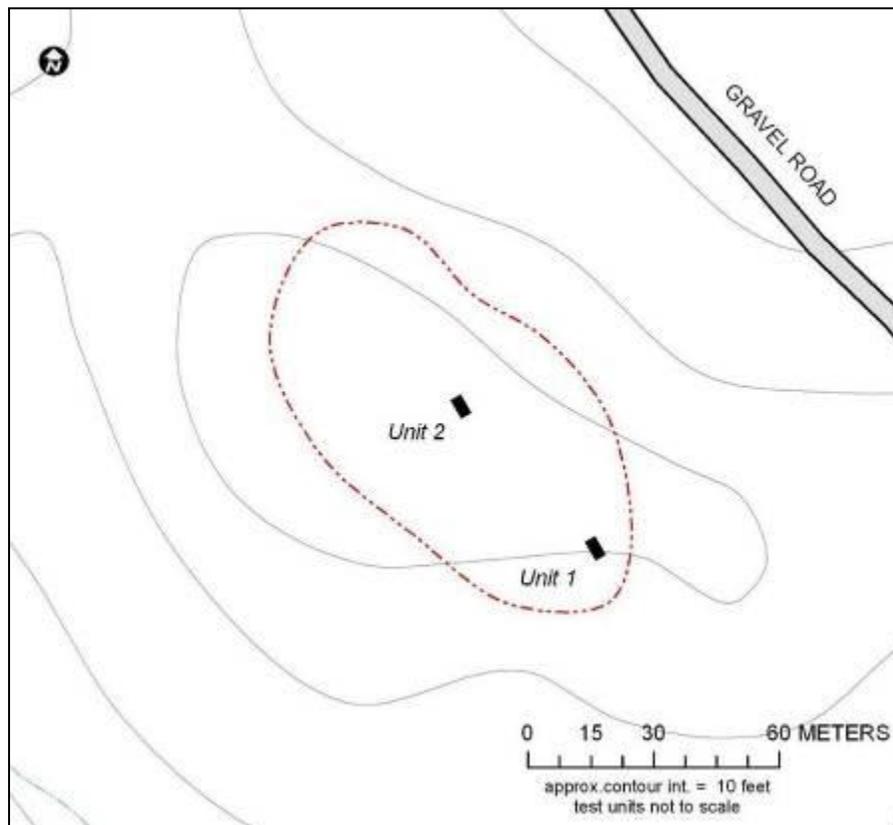


**Figure 4-1. MTC-Fort Pickett, Site 44DW329, General Setting and Location.**

[left image: USGS Blackstone East (1996) and Darvills (1989) quadrangles;  
right image: recent aerial imagery courtesy of MTC-Fort Pickett]



**Figure 4-2. MTC-Fort Pickett, Site 44DW329, View North  
Showing Current Site Conditions.**



**Figure 4-3. MTC-Fort Pickett, Site 44DW329, Test Unit Placement.**

*Unit 1 (1-x-2 m)*

Unit 1 was placed across a wheeled-vehicle rut that appeared relatively recent. The rut was situated in the southern half of the unit (Figure 4-4) to provide two soil column sample locations: one beneath the vehicle rut and one beyond the rut (Figures 4-4 and 4-5). Both column samples were taken from the west wall of the unit. As shown in Figure 4-5, excavation of the test unit exposed three strata: Stratum A, an organic-rich topsoil; Stratum B, a leached transition zone; and Stratum C, a clayey, culturally sterile subsoil. Geoarchaeological descriptions are summarized below (full descriptions included in Appendix A):

*Stratum A:* moderately compact, very sandy loam, 10YR 5/2 (grayish brown), with abundant rootlets and occasional dark mottles

*Stratum B* (two sub-units):

- 1) moderately compact, very sandy loam, 10YR 6/6 (brownish yellow), with occasional gravel and roots
- 2) compact sandy loam, 10YR 6/6 (brownish yellow), with occasional roots and worm casts

*Stratum C:* compact very slightly sandy loam, 10YR 5/6 (yellowish brown), platy to blocky structure, occasional roots and worm casts, abundant mottles (10R 4/6 [red])

All transitions were gradual.

Two quartz flakes, detailed below, were recovered from Stratum A. No other artifacts or archaeological features were encountered.

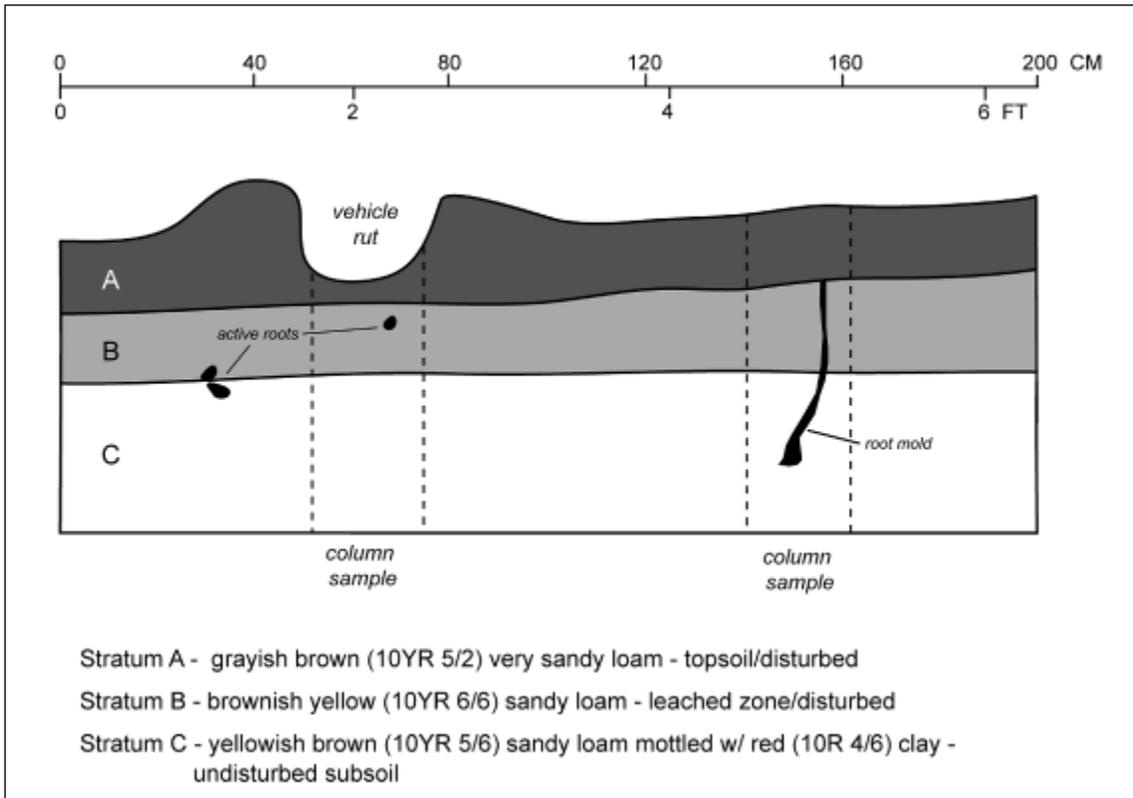
The rut in Unit 1 consisted of a straight-line feature that was recent and distinct, with almost perpendicular sidewalls present in some portions. The rut was the northern half of a pair separated by about 1 m (measured center-to-center). The rut bisected the test unit on a line paralleling the unit walls. Measurements taken in the west profile of Unit 1 were recorded as follows:

depth: 10 cm  
disturbance height: 17-18 cm  
width at base: 23 cm  
total width: 95 cm

The rut was less distinct in the opposite or east profile, where the depth of the feature was the same as to the west but the lip configuration was eroded, the disturbance height measuring approximately 8 cm. The total width in the east profile was 80 cm.



**Figure 4-4. MTC-Fort Pickett, Site 44DW329, Opening Photo-Documentation of Unit 1, View West.**



**Figure 4-5. MTC-Fort Pickett, Site 44DW329, West Profile Section of Unit 1.**



**Figure 4-6. MTC-Fort Pickett, Site 44DW329, Unit 1 Excavated with Column Sampling in Progress, View West.**

*Unit 2 (1-x-2 m)*

Unit 2 was placed in a portion of the site that did not exhibit obvious evidence of recent vehicle disturbance (Figure 4-7). Only one soil column sample was obtained from this unit due to subsurface disturbances encountered in the north half of the archaeological excavation (Figure 4-9).

As shown in Figures 4-8 and 4-9, excavation of Unit 2 exposed three strata similar to those documented in Unit 1: Stratum A, an organic-rich topsoil resulting from pre-military plowing and more recent grubbing and disking related to military land clearing practices (Ap horizon); Stratum B, a leached transitional layer (E horizon); and Stratum C, a culturally sterile subsoil with higher clay content and blocky structure characteristic of incipient soil development (B horizon).

Geoarchaeological descriptions are summarized below (full descriptions included in Appendix A):

*Stratum A:* moderately compact, very sandy loam, 10YR 4/2 (dark grayish brown), with occasional worm casts and dark mottles

*Stratum B* (two sub-units):

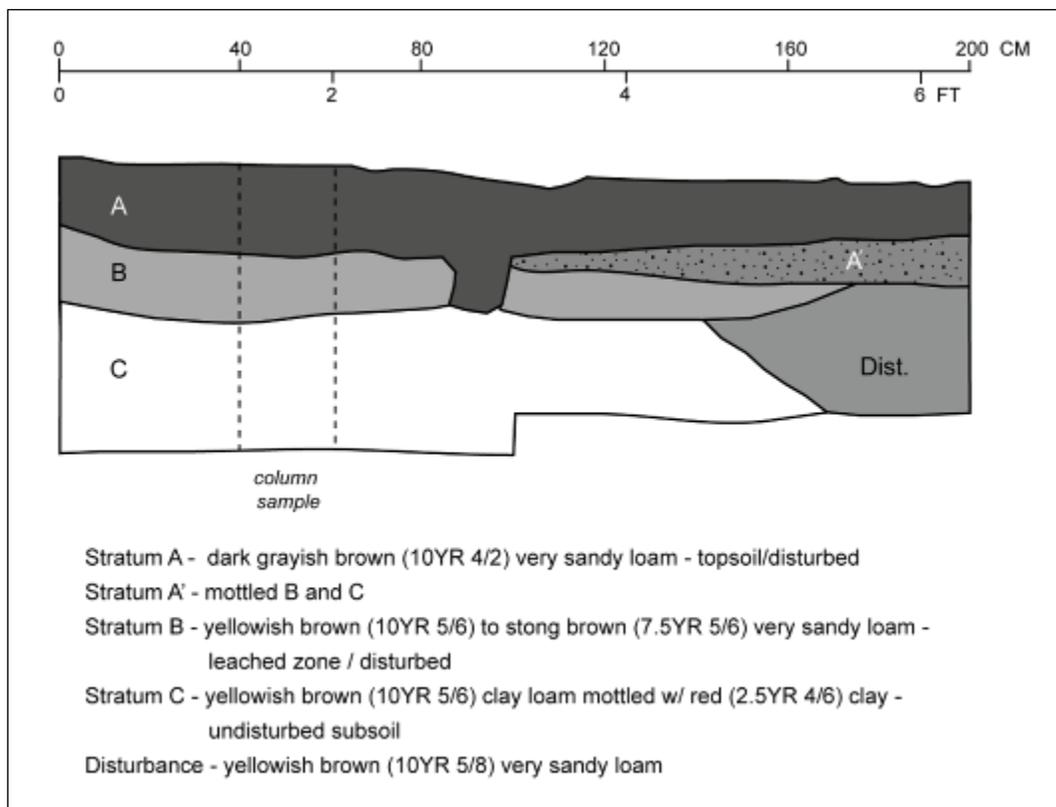
- 1) moderately compact, very sandy loam, 10YR 5/6 (yellowish brown), mottled with Stratum A sediment and with occasional worm casts and abundant roots
- 2) compact sandy loam, 7.5YR 5/6 (strong brown), with occasional roots and worm casts

*Stratum C:* compact clay loam, 10YR 5/6 (yellowish brown), subangular blocky structure, abundant mottles (2.5YR 4/6 [red])

A/B transitions are described as clear, all others gradual.



**Figure 4-7. MTC-Fort Pickett, Site 44DW329, Opening Photo-Documentation of Unit 2, View West.**



**Figure 4-8. MTC-Fort Pickett, Site 44DW329, West Profile Section of Unit 2.**



**Figure 4-9. MTC-Fort Pickett, Site 44DW329, Unit 2 Excavated, prior to Column Sampling, View West.**

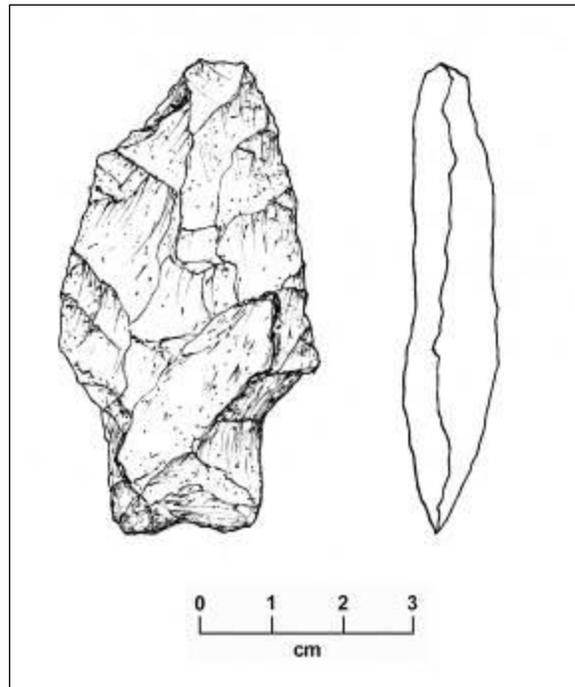
Two areas of disturbance were noted in the north half of the unit. Stratum A', located between Strata A and B, consisted of a mottling of Strata B and C and was underlain to the north by a large disturbance consisting of a darker silt loam with less clay content than the surrounding subsoil. Both anomalies may be the result of tree stump removal during an episode of land clearing operations. No artifacts, features, or intact deposits were encountered within Unit 2.

*Artifacts*

Three prehistoric artifacts were recovered from Site 44DW329 during the current study (Table 4-1). Two artifacts were recovered from Stratum A within Unit 1. The artifacts consisted of two small non-cortical quartz flake fragments. A third artifact, a quartzite Savannah River point, was recovered from the surface at 2.7 m west and 1 m south of Unit 1 (Figure 4-10). The point was exposed in the sidewall of the vehicle rut adjacent to the rut sectioned by Unit 1. Savannah River points date to the Late Archaic period (ca. 2500 BC to 1000 BC). A complete artifact inventory is presented in Appendix A.

**Table 4-1. MTC-Fort Pickett, Artifacts Recovered from Site 44DW329.**

<i>Provenience</i>	<i>Material</i>	<i>Morphology</i>	<i>Description</i>	<i>Bag#</i>
Surface	Quartzite	Point	Savannah River, 24.1 gm, L=62 mm, W=33mm, Th=11 mm	1
Unit 1-N Stratum A	Quartz	Flake	Non-cortical fragment, 0.2 gm	2
Unit 1-S Stratum A	Quartz	Flake	Non-cortical fragment, 0.3 gm	3



**Figure 4-10. MTC-Fort Pickett, Site 44DW329, Savannah River Point  
Recovered from Surface near Unit 1.**

#### 4.1.4 Micromorphology Results

Samples were collected from two units at the site. Two columns of samples were collected from Unit 1: S1-1, S1-5, and S1-6 were collected from the north end of the profile where there were no obvious indications of vehicle traffic and were intended to serve as control samples. Samples S1-2 through S1-4 were collected from the south end of the profile, directly underneath a tire track. Samples S2-1 through S1-3 were collected from Unit 2.

#### **Unit 1, North End**

##### *S1-1 (Stratum A)*

The coarse fraction of the sample consists of dense quartz silt and sand with occasional quartz gravel. The matrix consists of a silty clay that includes abundant organic matter. The voids consist primarily of intergrain packing voids and occasional vughs. The sediment has been considerably reworked by bioturbation and both fecal pellets and root fragments are present.

##### *S1-5 (Stratum B)*

The coarse fraction of the sample consists of quartz silt and sand in a dense matrix. The matrix contains both domains that are slightly siltier and resemble that seen in FTP-S1-1 and domains that are richer in clay and include vughs infilled with bedded limpid clay. The voids consist primarily of vughs; some have been infilled with limpid clay, and fissures. There are occasional root fragments and rare fecal pellets.

*S1-6 (Stratum B)*

The coarse fraction of the sample consists of quartz silt and sand in a dense clay-rich matrix as well as saprolite fragments that are decaying to clay. The voids consist primarily of vughs; some have been infilled with limpid clay, and fissures. There is no evidence of bioturbation.

**Unit 1, South End (under tire track)**

*S1-2 (Stratum A)*

The coarse fraction of the sample consists of quartz silt and sand in a matrix consisting of a silty clay that includes some organic matter, although this decreases towards the base of the thin section. The voids consist primarily of intergrain packing voids and vughs, some vughs have been infilled with layered limpid clay. These also increase towards the base of the thin section. Both fecal pellets and root fragments are present but they decrease towards the base of the thin section.

*S1-3 (Stratum B)*

The coarse fraction of the sample consists of quartz silt and sand in a dense clay-rich matrix along with saprolite grains that are weathering to clay. The matrix in some domains contains more organic matter and is more consistent with that seen in S1-1. The voids consist primarily of vughs; some have been infilled with limpid clay, and fissures. There are isolated domains of fecal pellets, indicating that bioturbation occurred in these zones.

*S1-4 (Stratum C)*

This was the deepest sample collected from the site. It consists mainly of a clay-rich matrix as well as large grains of decaying saprolite and quartz silt and sand. The voids consist of fissures and vughs; examples of both voids types are sometimes infilled with limpid clay.

**Unit 2**

*S2-1 (Stratum A)*

The coarse fraction of the sample consists of dense quartz silt and sand in a matrix consisting of a silty clay that includes organic matter. The voids consist primarily of intergrain packing voids and occasional vughs. The sediment has been reworked by bioturbation and both root fragments and occasional fecal pellets are present.

*S2-2 (Stratum B)*

The coarse fraction of the sample consists of quartz silt and sand in a dense clay-rich matrix and rare saprolite grains that are weathering to clay. The voids consist primarily of fissures and occasional vughs and channels; some have been infilled with limpid clay. There are rare isolated occurrences of fecal pellets, usually within channels, indicating that bioturbation occurred in these zones.

*S2-3 (Stratum C)*

The coarse fraction of the sample consists of fine quartz silt and occasional quartz sand in a dense iron-rich clay matrix. There are also occasional bands of saprolite decaying to clay. The void structure consists of occasional vughs and fissures, some of which are filled with limpid clay coatings.

## **4.2 MCB Quantico**

Fieldwork at MCB Quantico was conducted May 17 through May 20, 2011.

### **4.2.1 Previous Investigations at Site 44PW957**

This section describes how the site was first located and what was found there. Site 44PW957 was first recorded in 1994 during an archaeological inventory survey conducted by the William and Mary Center for Archaeological Research (WMCAR) (Jones et al. 1997). The site was identified through shovel testing at 20-m intervals. In total, 49 artifacts were recovered from 17 shovel tests. Artifacts were recovered from the top 20 cm of the soil profile. The artifacts were described as listed below:

- 1 quartz non cortical flake
- 1 whiteware pitcher spout
- 15 colorless bottle glass shards
- 1 solarized bottle glass shard
- 1 green bottle glass shard
- 17 windowpane glass shards
- 1 machine made brick
- 1 wrought nail
- 3 cut nails
- 2 wire nails
- 2 unidentified nail fragments
- 4 large dressed fieldstone specimens (not recovered)

WMCAR described the site's stratigraphy as follows:

Positive shovel tests at the site revealed a profile consisting of an A horizon yellowish red (5YR 4/6) silty clay loam mottled with dark red (2.5YR 4/6) clay extending to 17 cm below surface, over a B horizon of dark red (2.5YR 4/6) sterile clay subsoil.

Based on the recovered artifacts and archival research, the site was classified as the remnants of an early-20<sup>th</sup> century farmstead. WMCAR recommended the site as not eligible for inclusion on the NRHP stating:

Site 44PW957 is not considered eligible NRHP under Criterion D due to lack of research potential and integrity. The integrity of the site has been severely impacted by erosion, mechanical clearing of vegetation, and plowing. Therefore no further work is recommended.

### **4.2.2 Current Conditions**

This section describes the site conditions at the time of the current investigation. Site 44PW957 is located on the eastern aspect of a broad dissected terrace at an elevation of 76 m above mean sea level as illustrated by the left hand image in Figure 4-11. Aerial imagery from 2007, also shown in Figure 4-11, shows landcover in the site vicinity to be a mix of open and wooded areas similar to that observed during this study. The terrace forms a divide between Goslin Run to the west and Johns Branch to the east which both drain to the north into Cedar Run and ultimately the Potomac River via the Occoquan River. Soils in the area are described as Arcola silt loam (NRCS 2011). Site area was reported by Jones et al. (1997) as 9,590 m<sup>2</sup>. At the time of the current field investigations, ground cover in the immediate



**Figure 4-11. MCB Quantico, Site 44PW957, General Setting and Location.**  
[left image: USGS Somerville (1989); right image: 2007 aerial imagery courtesy of MCB Quantico]

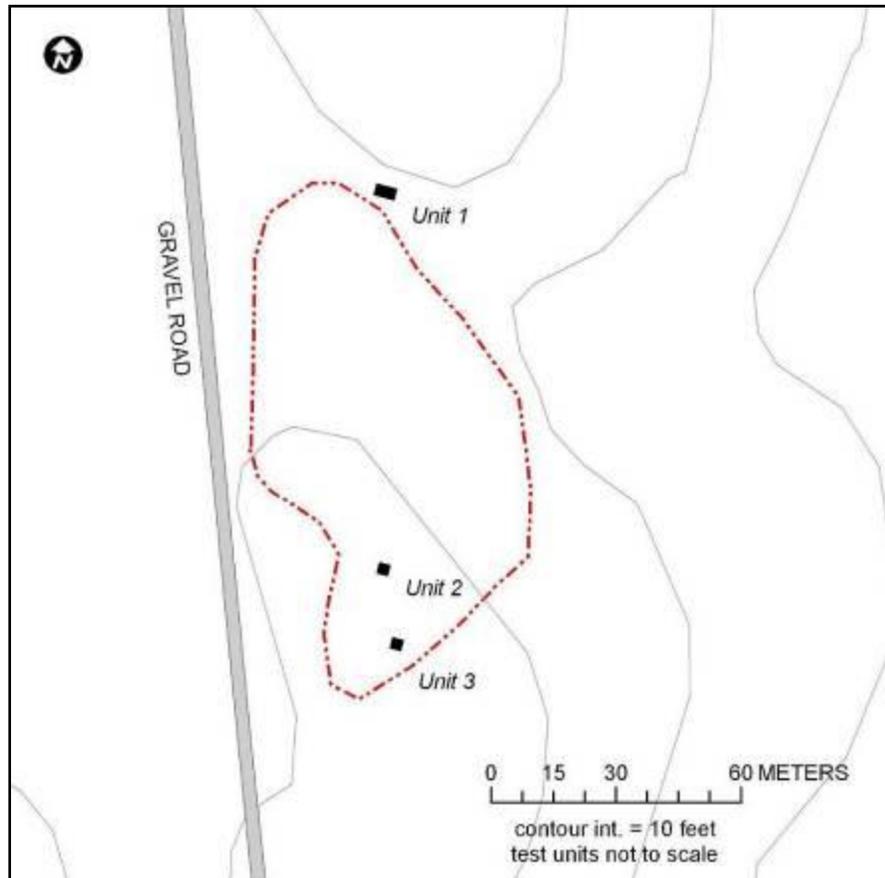
site area consisted of typical post-land clearing early-successional groundcover of saplings, brush, wildflowers, and grasses (Figure 4-12). In addition, domesticated ornamental plants including yucca, irises, and daffodils were present throughout the southern portion of the site. Vehicle activity in the site area, visible in the 2007 aerial imagery, was not as evident in the late spring overgrowth during the current study. In general, visible vehicle ruts were covered in vegetation, shallow, weathered, and sparse. Rut depth was 5-10 cm below ground surface. Rut pairs were difficult to distinguish but those that could be confidently related measured 1.5 m in width at the center points.



**Figure 4-12. MCB Quantico, Site 44PW957, View North  
Showing Current Site Conditions.**

#### 4.2.3 Test Unit Excavation

This section describes the site conditions at the time of the current investigation. Two 1-x-1 m and one 1-x-2 m test units were excavated within Site 44PW957 during this study (Figure 4-13). The purpose of the units was to characterize the sediment and archaeological deposits at the site and to provide soil columns for sampling in support of micromorphological analyses. Unit 1 was placed in the northern portion of the site where the most visible vehicle rutting was evident. The unit was placed just beyond the site boundary, as recorded in the installation GIS database, in order to sample the most recognizable portion of the rut. Unit 2 was placed approximately 90 m south of Unit 1 to sample a less discernible, more weathered rut and Unit 3 was placed in a portion of the site that exhibited no visible vehicle rutting on the ground surface. Unit 3 also was placed in an area with a dense groundcover of ornamental domestic plants.



**Figure 4-13. MCB Quantico, Site 44PW957, Test Unit Placement.**

*Unit 1 (1-x-2 m)*

The long axis of Unit 1 was placed perpendicular to a north-south running pair of weathered, yet discernible wheeled vehicle ruts. The easternmost rut of the pair was situated in the eastern half of the unit with the western half oriented to the west with the second rut paralleling the western edge of the unit (Figure 4-14). The wide, shallow morphology of the ruts along with the overgrowth of vegetation suggest a period of weathering exceeding one year. A single soil column sample was taken from beneath the easternmost rut along the southern profile section (Figure 4-15). No artifacts, features, or intact archaeological deposits were identified within Unit 1.

Excavation of Unit 1 exposed three strata: Stratum A, an organic-rich topsoil resulting from pre-military plowing and more recent grubbing and disking related to military land clearing practices (Ap horizon); Stratum B, a leached transitional layer (E horizon); and Stratum C, a culturally sterile subsoil with higher clay content and blocky structure characteristic of incipient soil development (B horizon) (Figure 4-16).

Geoarchaeological descriptions are summarized below (full descriptions included in Appendix A):

*Integrating Military Training and Archaeological Site Integrity:  
A Field Analysis Approach*

- Stratum A:* moderately compact, slightly silty clay, 5YR 4/4 (reddish brown), with occasional granules (shale and quartzite), rare subangular gravel (quartzite), abundant rootlets and occasional worm casts
- Stratum B:* moderately compact, slightly silty clay, 5YR 4/6 (yellowish red), with abundant granules (mainly quartzite), occasional gravel, common roots and rare worm casts
- Stratum C:* moderately very slightly silty clay, 7.5YR 4/6 (strong brown), with abundant granules to gravel (decayed shale/siltstone), subangular blocky structure
- All transitions described as gradual.

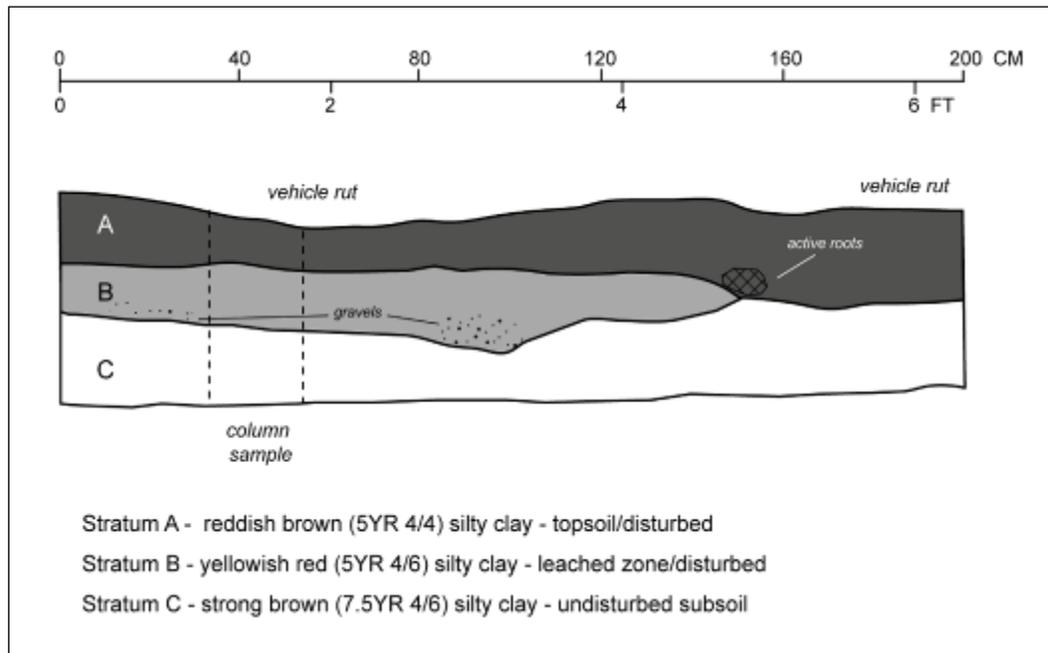
Stratum B was pinched-out in the western portion of the unit perhaps due to deep plowing/disking or other disturbance. No artifacts, features, or other intact archaeological deposits were encountered within Unit 1.



**Figure 4-14. MCB Quantico, Site 44PW957, Opening Photo-Documentation of Unit 1, View North.**

The rut in Unit 1 consisted of a straight-line feature that although recent, was less distinct than the rut in Unit 1 at MTC-Ft. Pickett. The lip had eroded level with the ground surface and was no longer evident; thus the disturbance height was zero. A second even less distinct rut paired with the first lay approximately 1.5 m to the west, partially within the west end of the unit. The ruts bisected the unit on a slight diagonal, on an angle approximating magnetic north. Measurements taken in the south profile of Unit 1 were recorded as follows:

depth: 7 cm  
disturbance height: 0 cm  
width at base: 35 cm  
total width: 120 cm



**Figure 4-15. MCB Quantico, Site 44PW957, Unit 1 South Profile Section.**



**Figure 4-16. MCB Quantico, Site 44PW957, Unit 1 Excavated, View South.**

In the opposite or north profile of the unit the rut was approximately the same depth and slightly wider, measuring 40 cm at the base and 135 cm in total width.

*Unit 2 (1-x-1 m)*

Unit 2 was located in an area of linear depressions (ruts) that suggested older, more weathered vehicle impacts. The unit was placed over a north/south trending rut centered on the lowest point of the depression (Figure 4-17). A single soil column sample was taken from the center of the south profile section (Figure 4-18).

Excavation of Unit 2 revealed two strata: Stratum A, an organic-rich topsoil resulting from pre-military plowing and more recent grubbing and disking related to military land clearing practices (Ap horizon) and Stratum B, a culturally sterile subsoil with higher clay content and blocky structure characteristic of incipient soil development (B horizon) (Figure 4-19).

Geoarchaeological descriptions are summarized below (full descriptions included in Appendix A):

*Stratum A:* compact, slightly silty clay, 5YR 4/4 (reddish brown), with occasional granules and fine gravel, abundant roots and occasional worm casts

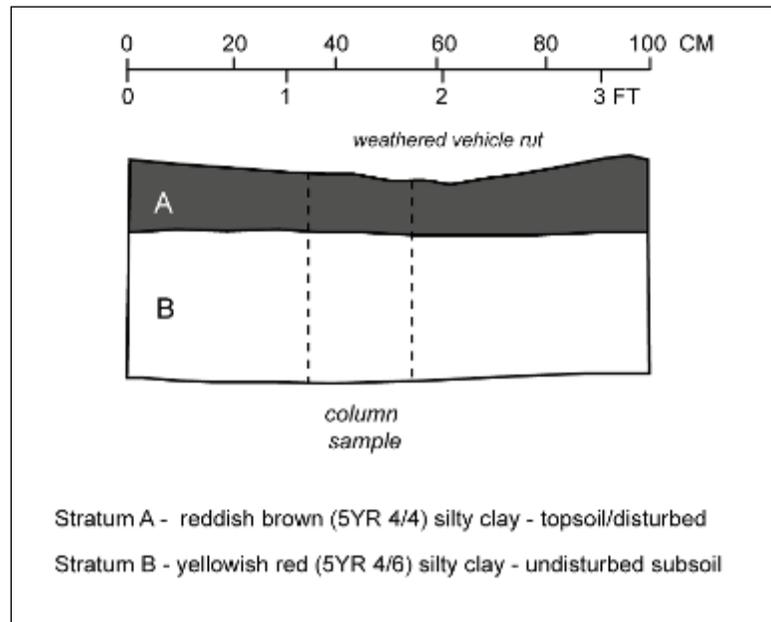
*Stratum B:* moderately compact, slightly silty clay, 5YR 4/6 (yellowish red), with abundant granules and gravel, occasional roots and worm casts, subangular blocky structure

A/B transition described as gradual.

The lack of a transitional layer and truncated subsoil may be a result of soil deflation as this unit is located near the top of a slight rise. Two historical artifacts (a white glass fragment and a sheet metal fragment) and a charcoal fragment were recovered from Stratum A. No features or intact archaeological deposits were encountered within Unit 2.



**Figure 4-17. MCB Quantico, Site 44PW957, Opening Photo-Documentation of Unit 2, View North.**



**Figure 4-18. MCB Quantico, Site 44PW957, Unit 2  
South Profile Section.**



**Figure 4-19. MCB Quantico, Site 44PW957, Unit 2 Excavated, View South.**

The rut in Unit 2 was wide and indistinct. A second, paired rut was assumed to have been present, but it was not immediately apparent at ground surface. Like the feature in Unit 1, the lip of the rut had eroded level with the ground surface, and thus the disturbance height was zero. Measurements taken in the south profile of Unit 2 were recorded as follows:

depth: 78 cm  
disturbance height: 0 cm  
width at base: 70 cm  
total width: 100+ cm

The west edge of the rut appeared to occur just beyond the edge of the 1-m<sup>2</sup> unit, and thus the total width is listed as 100+ cm. In the opposite or north profile of the unit, the rut was approximately the same dimensions as in the south profile.

*Unit 3 (1-x-1 m)*

This unit was placed in a level area of the landform in the southern portion of the site that exhibited no visible depressions, rutting or other features that would indicate vehicle activity (Figure 4-20). A single soil column sample was taken from center of the southern profile section (Figure 4-21).

Excavation of Unit 3 exposed a profile consisting of three strata: Stratum A, an organic-rich topsoil resulting from pre-military plowing and more recent grubbing and disking related to military land clearing practices (Ap horizon); Stratum B, a thin leached transitional layer (E horizon); and Stratum C, a culturally sterile subsoil with higher clay content and blocky structure characteristic of incipient soil development (B horizon) (Figure 4-24).

Geoarchaeological descriptions are summarized below (full descriptions included in Appendix A):

*Stratum A:* moderately compact, slightly silty clay, 7.5YR 3/4 (dark brown), with rare 7.5YR 4/6 (strong brown) mottles, occasional granules (shale and quartzite) and gravel (quartzite), abundant roots and occasional worm casts, subangular blocky structure

*Stratum B:* moderately compact, slightly silty clay, 7.5YR 4/6 (strong brown), with occasional granules and rare gravel, occasional roots and rare worm casts, subangular blocky structure

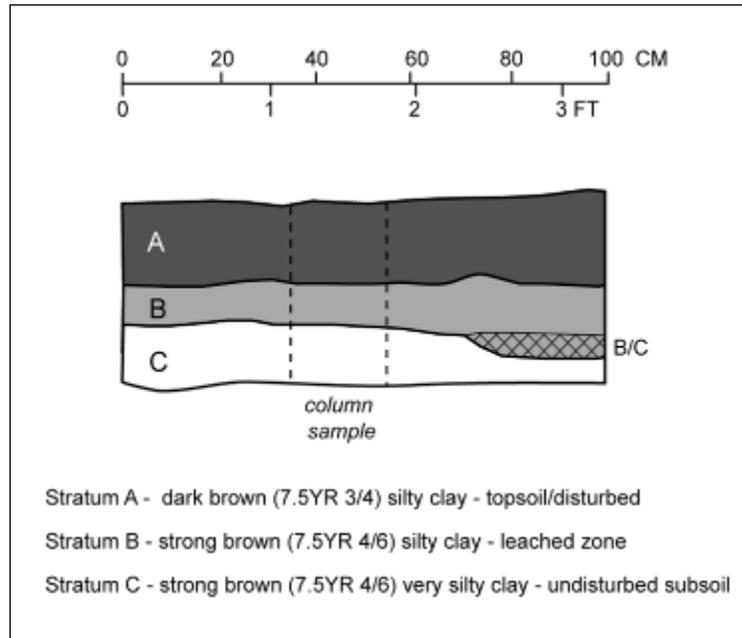
*Stratum C:* moderately compact, very slightly silty clay, 7.5YR 4/6 (strong brown), with occasional granules and rare roots, subangular blocky structure

All transitions described as gradual.

A small lens of mixed soils, likely representing a decayed root or infilled rodent borrow, was present in the southwestern corner of the unit. Twenty-four historical artifacts were recovered from Stratum A. No features or other intact archaeological deposits were encountered within Unit 3.



**Figure 4-20. MCB Quantico, Site 44PW957, Opening Photo-Documentation of Unit 3, View North.**



**Figure 4-21. MCB Quantico, Site 44PW957, Unit 3 South Profile Section.**



**Figure 4-22. MCB Quantico, Site 44PW957, Unit 3 Excavated, View South.**

*Artifacts*

In total, 27 historical artifacts were recovered from Units 2 and 3, excavated in the southern portion of Site 44PW957 (Table 4-2). The artifacts consisted primarily of domestic and architectural items consistent with the assemblage reported by Jones et al. (1997) and with the reported timeframe and site function of an early-20<sup>th</sup> century farmstead. All of the artifacts were contained within the disturbed uppermost stratum of the soil profiles documented within the units. A complete artifact inventory is presented in Appendix A.

**Table 4-2. MCB Quantico, Artifacts Recovered from Site 44PW957.**

<i>Provenience</i>	<i>Description</i>	<i>Count</i>
Unit 2, Str. A	white glass lid liner fragment	1
	Sheet metal fragment	1
	charcoal fragment	1
<i>unit total</i>		3
Unit 3, Str. A	yellow-glazed earthenware fragment	1
	white glass lid liner fragment	1
	clear glass, pharmaceutical bottle fragment	1
	clear glass, bottle fragment	2
	clear window glass fragment	2
	aqua window glass fragment	2
	brass bullet casing	2
	wire nail	9
	white sheet metal	2
	brick fragment	1
	plastic coated wire fragment	1
<i>unit total</i>		24

#### 4.2.4 Micromorphology Results

Samples were collected from each of the three test units at the site using methods described previously.

##### **Unit 1**

###### *S1-1 (Stratum A)*

The coarse fraction of the sample consists of fine quartz silt, occasional quartz sand and iron-rich grains in a matrix that is a mixture of iron-rich clay and fine-grained organic matter. The upper portion of the sample is noticeable denser than the lower portion. The lower portion of the sample has an overall slightly spongy texture with occasional vughs and rare fissures; the upper part of the sample also contains organic matter worked in to the matrix and has been biologically reworked into fine pellets. In the lower part of the sample, occasional vughs have been infilled with a limpid clay.

###### *S1-2A (Stratum B)*

The coarse fraction of the sample consists of fine quartz silt, occasional quartz sand and iron-rich grains in a dense iron-rich clay matrix. The sample has an overall slightly vughy texture with occasional vughs and fissures. Some vughs have been infilled with a limpid clay. There is also some evidence of bioturbation of the sediments in the form of root fragments and a passage feature filled with fecal pellets.

###### *S1-2B (Stratum B)*

The coarse fraction of the sample consists of fine quartz silt, occasional quartz sand, and abundant iron-rich grains in a dense iron-rich clay matrix. The sample has an overall spongy texture with occasional vughs and rare fissures. Some vughs have been infilled with a limpid clay. There is also slight evidence of bioturbation of the sediments in the form rare passage features filled with fecal pellets.

##### **Unit S2**

###### *S2-1 (Stratum A)*

The coarse fraction of the sample consists of fine quartz silt, occasional quartz sand, and iron-rich grains in a matrix that is a mixture of iron-rich clay and fine-grained organic matter. The sample has an overall slightly spongy texture but much of the matrix has been biologically reworked into fine pellets. The voids structure consists of occasional vughs. Occasionally vughs have been infilled with a very dusty clay. There is also some evidence of bioturbation of the sediments in the form of root fragments and a passage feature filled with fecal pellets.

###### *S2-3 (Stratum B)*

The coarse fraction of the sample consists of fine quartz silt, occasional quartz sand, and iron-rich grains in a matrix that is a mixture of iron-rich clay and fine grained organic matter. The sample has an overall very spongy texture, probably due mainly to biological reworking. The voids structure consists of frequent vughs. Unlike the overlying sample there is no evidence of bioturbation of the sediments in the form of root fragments and a passage feature filled with fecal pellets.

### **Unit S3**

#### *S3-2 (Stratum A)*

The coarse fraction of the sample consists of fine quartz silt, occasional quartz sand, and iron-rich grains in a matrix that is a mixture of iron-rich clay and fine-grained organic matter. The sample has an overall very spongy texture. The voids structure consists of abundant vughs. There is also some evidence of bioturbation of the sediments in the form of passage features filled with fecal pellets.

## **5.0 DATA ANALYSIS**

### **5.1 Micromorphology**

The analysis of the thin sections from the two sites indicated that the soil structure was consistent with what one would expect in the well-developed soils in these regions. The evidence for post-depositional activity within the profiles consisted of root fragments and fecal pellets (indicating bioturbation) present in Units 2 and 3 at Fort Pickett and Unit 2 at Quantico, and translocated clay (a typical soil formation feature) that has infilled vughs and fissures at both sites. The only other evidence of post-depositional activity noted at either site was silty-clay infillings in S2-1 at Quantico. These features are consistent with plowing or other surface disturbances.

Much of the porosity observed in the samples from both sites appears due to bioturbation. The porosity extended throughout the upper 50 cm of the profiles, the areas in which compaction has been noted in other studies. There were no noticeable differences between the control samples collected from the north end of Unit 1 at Fort Pickett and the samples from beneath visible ruts. Finally, other studies have noted that cracks form in soil in response to compaction; however, cracks were not noted in either the field or in the lab in the profiles studied here.

### **5.2 Assessment/Interpretation**

#### **5.2.1 Soil Compaction**

The findings of the thin section analysis indicated no obvious micromorphological evidence of soil compaction in the samples from the two sites. Soil particles were well-sorted and described as either open or closed porphyric, indicating the relative amounts of large particles with the fine matrix (Courty et al. 1989:74). Spaces referred to as fissures and vughs were present among the particles prompting a description of the samples as porous. Porosity is often attributed to biological activity (Courty et al. 1989:39), and it was so in this case. The porosity in the samples was described as uniform, not changing with depth, suggesting no variation in density or degree of compaction between the surface and underlying deposits. In many cases, translocated clays were present within the channels and vughs indicating that soil formation processes had begun.

Previously cited studies have suggested that while compacted soil layers may occur at depth in an impacted soil profile, evidence of compression may not be present near the surface (Halvorson et al. 2001:149). Soil compression has been recorded at depths greater than one meter, yet more typically compaction resulting from vehicle traffic is evident at depths between 5 and 30 cm (Iverson et al. 1981:915; Prosser et al. 2000:668; Webb 1983:52, 2002:293). A thin, relatively loose layer often covers the more densely compacted layer (Webb 2002:293). The samples from the current study were from depths ranging from <10 cm to 60 cm, the latter well into dense clay soil, and none exhibited definitive evidence of compaction at the micromorphological level of analysis.

Sediment texture has also been cited as a factor in the degree to which soil may be prone to compaction. Lei (2004), working in shrublands in southern Nevada, noted that poorly sorted

soils, particularly loamy sands or sandy loams with abundant gravel, were the most vulnerable to soil compaction. In contrast, soils with uniform particle sizes tended to be less liable to compaction. Hambleton and Drescher (2008), in research based on theoretical models, likewise reported that ruts were more likely to form in coarse-grained sediments such as sands as opposed to fine-grained sediments such as clays. In the current findings, sediments consisted of fine sediments including silt loams and silty clays. The particles were well-sorted to very well-sorted and, in accordance with Hambleton and Drescher's findings, showed little evidence of compaction.

In the end, little evidence was noted of direct effects from vehicle activity related to soil compaction. None of the signs typically associated with compaction—cracking, resorting of particles—appeared to have been present. Most of the evidence reported in the micromorphological samples was considered to have been related to biological activity such as root action, although there was also some evidence of mixing of sediments due to tillage. The absence of direct evidence of compaction may have been related to a combination of factors, including vehicle weights, soil consistency, or long-term and widespread activity and inadequately identified control areas.

Information was sought regarding the type of vehicles involved in the training activities at both sites, but in each case installation personnel were unable to provide detailed information. Therefore assumptions were made based on the size and configuration of the ruts, which suggested that the most recent traffic had consisted of wheeled vehicles that were not particularly heavy or massive and may have contributed to the absence of compaction. An additional factor may have been the natural consistency of the soil. With its relatively high silt content, the soil would have been compact prior to vehicle activity. This in combination with relatively light vehicles may have limited the amount of additional subsurface compaction. Still another factor may have been the length and intensity of use of the areas (again, detailed information was unavailable from the installations). Lei (2004) observed that the greatest effects of vehicle activity occurred during the first few passes, with changes decreasing with successive passes. He noted that both the proportional extent of impact and the statistical variability of soil compaction, such as bulk density, and percent of pore space, decreased with increasing numbers of passes. The entire area may thus have been compacted so that additional activity had little or no cumulative effect. In the current investigation, the absence of variation between disturbed and control areas noted could be an indication of an inability to recognize evidence of age differences in the profiles—all of the ground may have experienced impact from ongoing training, so that the effects are widespread and hard to differentiate historically. If the areas tested had been driven over successively, the minimal compaction effects allowed by relatively light vehicles on well-sorted, fine grained sediments may already have occurred so that the recently observed ruts produced little additional or cumulative effect. But the absence of other ruts in the vicinity argues against this.

While direct evidence of compaction was not identified at the micromorphological level, vehicular activity did affect the sediments at the surface. The effects were, however, largely horizontal, serving to spread material laterally. A correlated but minor vertical effect, similar to that resulting from plowing, was also noted: as sediments were pushed laterally out of

ruts, they were in effect turned over, bringing buried artifacts to the surface, as witnessed by the projectile point recovered from the top of a nearby rut crest or lip.

### 5.2.2 Archaeological Significance

Assessing the degree of physical change within the sediment profile is only the first step in determining the effect of vehicle activity on archaeological sites. The ultimate question concerns how these changes might affect archaeological significance. The important measure is the degree to which information potential may be lost as a result of the physical processes affecting depositional integrity and how that may alter previously made determinations of eligibility.

Compaction resulting from rut formation can be examined from the perspective of both surface and buried deposits, since the effects may be different depending on proximity to ground surface. Breakage of fragile artifacts at ground surface may occur, for example, although how much this might ultimately affect significance may be debatable unless the artifacts are crushed and cannot be refitted or reassembled, or unless the resulting fragments are scattered to the extent that their pre-disturbance contexts or associations are destroyed. Other potential considerations include the implications of a loss of near-surface stratigraphic separation (extreme compression or intermixing of thinly layered deposits), or of the spreading of deposits in the ridge and lip formed in a rut (which may be seen as a different form of compaction, pressing sediments and contents sideways). In the present case, for example, it appeared that vehicles tended to scatter artifacts that occurred in surface contexts. Such a process could destroy spatial associations, while repeated traffic could impede the ability to conduct geophysical prospecting by “clouding” sites with additional data or “noise” unrelated to the archaeological deposits of interest (Archaeo-physics 2009; Somers et al. 2004; Zeidler et al. 2004).

A considerable amount of archaeological literature has been generated on the subject of site significance—what it entails and how it is measured—as well as on the degree of physical or depositional integrity that is necessary to convey significance (a summary of the subject can be found in #09-435). The issue addressed in the current study is whether an NRHP-eligible site can retain the necessary integrity in the face of disturbance from military vehicle training. Vehicle traffic of any sort or frequency is viewed by some researchers and cultural resource specialists as harmful to archaeological sites, without qualification (Sampson 2007). That position notwithstanding, research developed in the earlier Legacy Project (#09-435 *Integrating Military Training and Archaeological Site Integrity: A Data Analysis Approach*) indicated that the point at which vehicle damage becomes sufficient to cause loss of site significance is an issue that in fact has not been well explored and is not yet clearly understood. Soil compaction is a directly measurable effect, and that effect is the focus of the current project and report. Yet, the results of the study indicate that the impact of soil compression on archaeological deposits is not easily calculated, and likewise, the implications for maintaining site integrity and eligibility are not readily gauged. In the course of this investigation we discussed the variety of subtle influences soil compaction may have beyond the simple notion of breaking artifacts—effects such as obscuring the separation of stratigraphic layers; affecting ground cover, which may lead to increases in erosion; altering drainage patterns, which may induce changes to geochemistry and artifact

preservation. When evidence of soil compression is itself subtle, as in the current analysis, the effects are even more difficult to judge, and at some point might be considered negligible. This may be good news, in that other forms of disturbance common on archaeological sites, such as stratigraphic mixing from plowing or other impacts, are usually easy to spot. That evidence of soil compaction in a location with obvious surface ruts is slight suggests that at least under some circumstances, potential vehicle impacts to archaeological sites may be manageable.

## **6.0 CONCLUSIONS**

The impact that military vehicles have on significant or NRHP-eligible cultural resources located in training landscapes is the central issue of this study. The investigation examined one particular result of vehicular traffic: soil or sediment compaction associated with the creation of vehicle ruts. Compaction was measured at previously documented archaeological sites occurring in active training ranges in areas with visible surface disturbance. Controlling the many variables that may potentially affect site disturbance was an admittedly difficult task. For example, soil properties will clearly vary with the type and location of land form and geographic setting within which a particular site occurs, and these properties will affect the way in which sediments react to compaction. Similarly, variables such as moisture content and previous disturbance may influence the degree and form of compaction that a soil column may sustain. But the effort in the current study was to document compaction in a particular setting within a real-world situation as a starting point to understanding the results of this kind of activity on archaeological deposits in general.

### **6.1 Summary**

Test excavations were conducted at locations on two active ranges. Samples were taken below visible rut disturbances of varying age and condition. Standard archaeological excavation procedures were used in the excavations, recording sedimentary strata and natural and cultural inclusions. Columns for micromorphology were taken from each archaeological excavation. The samples were treated with resin, thin-sectioned, examined microscopically. Little direct evidence of compaction was observed in the samples. The study documented evidence of disturbance from biological agents, in the form of roots and rootlet fragments, and fecal pellets from small animals, along with evidence of soil formation in the form of translocation of clay deposits in voids. Soil porosity was observed in all of the samples examined and was considered to have been the result of biological activity, and there was minor evidence of surface disturbance associated with plowing. Little difference was noted between samples associated with visible ruts and those in control areas without visible disturbance.

That no evidence for significant vehicle disturbance was found below the surface echoes other studies that have shown that vehicle rut depths may not necessarily extend deeper than typical plowzones. This holds out the possibility that certain kinds of military vehicle training under certain soil conditions may not necessarily adversely affect archaeological site integrity. In order to make use of these results, the extent of testing may need to go beyond that attempted here, with a broader range of studies in a variety of conditions conducted to establish details regarding the type of training activity and soil. It may also be necessary to adjust some of the field methods used to record and evaluate archaeological sites at the Phase I and II levels. Analysis of the field results in this study provides the basis for some specific recommendations along these lines.

## 6.2 Recommendations

Legacy Project 09-435 explored the literature on soil deformation and site impacts to arrive at specific recommendations for future action. The present Legacy project took on the recommendation for actual field testing of vehicle impacts. Table 6-1 lists the recommendations from Legacy Project 09-435, and describes lessons learned about each from the present study.

**Table 6-1. Legacy Project lessons Learned.**

<b>Legacy Project # 09-435 Recommendations</b>	<b>Lessons Learned</b>
Site data needed include: <ul style="list-style-type: none"> <li>• artifact and feature density;</li> <li>• representativeness and redundancy of cultural deposits;</li> <li>• depth of deposits; and,</li> <li>• spatial distribution of cultural materials.</li> </ul>	These data are essential for estimating site vulnerabilities, but are rare from Phase I studies, and not always recorded for evaluation studies.
Develop experimental studies to link archaeological site formation processes with military vehicle impacts.	This study developed an experimental field approach, but found that the question is complex and that there is a wide variety of variables involved. A series of studies will be necessary in order to account for all of them.
Determine whether soil compaction from the movement of military vehicles is sufficient to break artifacts and damage cultural features.	The study limited itself to ineligible sites for ethical reasons. Though the evaluation reports suggested some possibility of cultural deposits, field investigation showed that artifact density was low at the tested sites, and the study found no features. We need controlled impact data from sites with more information potential, such as features and a wider variety of artifact types.
Complete installation eligibility determinations.	Efforts to identify candidate sites showed that Phase I survey results don't have enough information to make risk assessments.
Soils data, including texture, horizonation, and other physical and chemical attributes, should be collected on a much finer scale than current USDA soil map units that each exceed 10 acres and size.	Soil strength data under varying moisture conditions are particularly important.
Study soil compaction and rut formation on actual training landscapes as opposed to controlled circumstances.	Data collected from this study show that some vehicle impacts may be slight. However, there are many variables that affect soil compaction and deformation. Real world studies have potential, but soil conditions and vehicle particulars at time of impact need to be known. Also data from a wide variety of contexts are needed to confirm this.

A CRM on an installation with active training areas for which archaeological sites are considered an encroachment can take the following steps to assess how vulnerable their sites may be to mechanized training.

1. Identify soil types present on archaeological sites at issue;
2. Measure depth of impact from vehicles used in training on those soils in areas where sites are absent in wet and dry conditions, with multiple passes, and at different speeds;
3. Determine whether depth of potential impact is less than the extent of any previous disturbance (such as from plowing) documented at the sites;
4. If potential impact is less than previously documented impact, consult with SHPO to determine whether a Memorandum of Agreement (MOA) is possible for training in the vicinity of the sites.

Note that assessments of the impact of vehicles on soil should include depth of any ruts, and depth of soil compaction as shown by micromorphological study. Some archaeological testing on sites that may be impacted may be necessary to determine the depth of any previous disturbance. For installations with relatively few archaeological sites encroaching on mechanized training areas, conventional NRHP evaluation and mitigation may be more cost effective. In discussing an MOA with a SHPO, it may be necessary to include protection measures for sites in the training area, such as periodic monitoring for site condition. Other possible treatments for addressing sites in training areas could include site hardening methods such as burial, or creating barriers around the site.

Based on the results of the current study the following recommendations are presented.

- Incorporate micromorphology/soil compaction studies into NRHP evaluations of sites within vehicle maneuver areas to provide a better baseline for determining the types of sediments and various conditions wherein soil compaction is liable to occur;
- conduct similar actualization studies in different settings with different soil conditions to increase understanding of the range of impacts that may be expected;
- include detailed information regarding vehicle types involved in specific disturbances as well as speed and number of passes;
- conduct similar studies before and after training activity focused on specifically documented vehicle types; and
- combine soil micromorphological analysis in a more comprehensive study with other techniques such as bulk density, resistivity, and hydraulic conductivity.

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**Appendix A**  
**Artifact Inventory**

*Integrating Military Training and Archaeological Site Integrity:  
A Field Analysis Approach*

Artifact Inventory, Sites 44PW957 (MCB Quantio) and 44DW329 (MTC-Fort Pickett)													
Legacy Project #10-435													
SITE	UNIT	STRATUM	COUNT	GROUP	MORHPOLGY	CLASS	MATERIAL	FUNCTION	SEGMENT	COLOR	NOTES	BAG #	ART.#
44PW957	2	A	1	DOMESTIC		FOOD STORAGE	GLASS	FRUIT JAR	LIDLINER	WHITE	1869+ (TOULOUSE 1969:350)	1	1
44PW957	2	A	1	UNIDENTIFIED		HARDWARE	FERROUS ALLOY	SHEETMETAL	FRAG			1	2
44PW957	2	A	1	FLORAL		UNIDENTIFIED	CHARCOAL		FRAG			1	3
44PW957	3	A	1	DOMESTIC		CONTAINER	REFINED EARTHENWARE	HOLLOWWARE	BODY	WHITE-BODIED	YELLOW GLAZED, EMBOSSED LEAF AND TENDRIL, LIKELY PLANTER OR FLOWER POT, MCCOY-LIKE (FIRST HALF OF 20TH CENTURY STYLE)	2	1
44PW957	3	A	1	DOMESTIC		FOOD STORAGE	GLASS	FRUIT JAR	LIDLINER	WHITE	EMBOSSSED "[MASO]N JAR.", 1869+ (TOULOUSE 1969:350)	2	2
44PW957	3	A	1	MEDICAL		BOTTLE	GLASS	PHARMACEUTICAL	BODY	AQUA	EMBOSSSED "GRE..." ON RECESSED PANEL (LATE 19TH/EARLY 20TH C)	2	3
44PW957	3	A	2	DOMESTIC		BOTTLE	GLASS		BODY	CLEAR		2	4
44PW957	3	A	2	ARCHITECTURAL		CONSTRUCTION MATERIAL	GLASS	WINDOW		AQUA		2	5
44PW957	3	A	2	ARCHITECTURAL		CONSTRUCTION MATERIAL	GLASS	WINDOW		CLEAR		2	6
44PW957	3	A	1	ARMS		AMMUNITION	BRASS	BULLET CASING	WHOLE		CENTER-FIRED, BULLET BLANK (CRIMPED NOSE), STAMPED "L C / 7 6", LAKE CITY ORDNANCE PLANT, MO, 1976 (WHITE AND MUNHALL 1977:102)	2	7
44PW957	3	A	1	ARMS		AMMUNITION	BRASS	BULLET CASING	BODY		CENTER-FIRED, NOSE MISSING, STAMPED "F A 51", FRANKFORD ARSENAL, 1951 (WHITE AND MUNHALL 1977:74)	2	8
44PW957	3	A	9	ARCHITECTURAL		HARDWARE	FERROUS ALLOY	WIRE NAIL			GENERALLY 1880s+ (ADAMS 2002:66)	2	9
44PW957	3	A	2	UNIDENTIFIED		UNIDENTIFIED	WHITE METAL	SHEETMETAL			THIN, <1" FRAGS	2	10
44PW957	3	A	1	ARCHITECTURAL		CONSTRUCTION MATERIAL	BRICK		FRAGMENT		BURNT	2	11
44PW957	3	A	1	UNIDENTIFIED		UNIDENTIFIED	PLASTIC		WHOLE	ORANGE	PLASTIC COASTED WIRE COIL	2	12
44DW329	SURFACE	SURFACE	1	PREHISTORIC	POINT		QUARTZITE		WHOLE		Savannah River, 24.1 grams, L=62, W=33, Th=11 mm	1	1
44DW329	1	A	1	PREHISTORIC	FLAKE		QUARTZ		FRAGMENT		Non-cortical fragment, 0.3 grams	2	1
44DW329	1	A	1	PREHISTORIC	FLAKE		QUARTZ		FRAGMENT		Non-cortical fragment, 0.2 grams	3	1

## **Appendix B**

### **Micromorphology Data**

*Integrating Military Training and Archaeological Site Integrity:  
A Field Analysis Approach*



*Integrating Military Training and Archaeological Site Integrity:  
A Field Analysis Approach*

Site/Trench	Soil Unit	Samples	Description
<b>MTC Fort Pickett (44PW0957)</b>			
FP Trench 1	1	S1-1 and S1-2	Moderately compact very sandy loam, moist but dries quickly. 10YR 5/2 (grayish brown). Crumb structure. Abundant rootlets. Occasional dark mottles (>5 cm; 10YR2/1 [black]), mostly at base of unit. Gradual transition to Unit 2.
FP Trench 1	2	S1-1, S1-2, S1-5	Moderately compact very sandy loam, moist. Occasional sub-angular to subrounded gravel (>1 cm). 10YR 6/6 (brownish yellow). Crumb structure. Rare dark mottles (>0.5 cm) at top of unit. Occasional roots. Gradual transition to Unit 3.
FP Trench 1	3	S1-3 and S1-5	Compact sandy loam. Moist. Noticeably more clay-rich. 10YR 6/6 (brownish yellow). Slightly platy structure. Occasional roots. Occasional worm casts. Slightly developed ped coatings. Gradual transition to Unit 4.
FP Trench 1	4	S1-4 and S1-6	Compact very slightly sandy loam. Moist. Noticeably more clay-rich. 10YR 5/6 (yellowish brown). Platy to blocky structure. Occasional roots. Occasional worm casts. Slightly developed ped coatings that increase with depth. Abundant mottles (10R 4/6 [red]).
FP Trench 2	1	S2-1	Moderately compact very sandy loam, very moist. 10YR 4/2 (dark grayish brown). Occasional worm casts. Occasional very dark mottles (10YR 2/1 [black]) near base of unit. Granular structure. Clear transition to Unit 2.
FP Trench 2	2	S2-1 and S2-2	Moderately compact sandy loam, very moist. 10YR 5/6 (yellowish brown). Granular structure. Occasional worm casts. Common inclusions of Unit 1 sediment (0.5-2 cm). Abundant roots. Gradual transition to Unit 3.
FP Trench 2	3	S2-2 and S2-3	Moderately compact sandy loam. Very moist. Noticeably more clay-rich. 7.5YR 5/6 (strong brown). Subangular blocky structure. Occasional roots. Occasional worm casts. Gradual transition to Unit 4.
FP Trench 2	4	S2-3	Compact very clay loam. Very moist. 10YR 5/6 (yellowish brown). Subangular blocky structure. Occasional roots. Occasional worm casts. Slightly developed ped coatings. Abundant mottles (2.5YR 4/6 [red]).
<b>MCB Quantico (DW329)</b>			
MCBQ Trench1	1	1-1	Moderately compact, slightly silty clay with occasional granules (shale and quartzite) and rare subangular gravel (quartzite). Very moist. 5YR 4/4. Abundant roots. Occasional worm casts. Subangular blocky structure. Gradual transition to Unit 2.
MCBQ Trench1	2	1-1 and 1-2	Moderately compact, slightly silty clay with abundant granules (mainly quartzite) and occasional gravel. Very moist 5YR 4/6. Common roots. Rare worm casts. Slightly developed ped coatings. Subangular blocky structure. Gradual transition to Unit 3.

*Integrating Military Training and Archaeological Site Integrity:  
A Field Analysis Approach*

Site/Trench	Soil Unit	Samples	Description
MCBQ Trench1	3	1-2	Moderately compact, very slightly silty clay with abundant granules to gravel decayed shale/siltstone. Moist 7.5YR 4/6 Subangular blocky structure. Slightly developed ped coatings. Gradual transition to Unit 3
MCBQ Trench 2	1	2-1	Compact, slightly silty clay with occasional granules and fine gravel. Very moist. Much redder than unit 1 in other trenches. 5YR 4/4 Abundant roots. Some worm casts. Slightly crumbly structure. Gradual transition to Unit 2
MCBQ Trench 2	2	2-1 and 2-2	Moderately compact, slightly silty clay with abundant granules – gravel inclusions (skews to gravel and concentration increases with depth). Very moist 5YR 4/6 Occasional roots. Occasional worm casts. Slightly developed ped coatings. Subangular blocky structure.
MCBQ Trench 3	1	3-1	Moderately compact, slightly silty clay with occasional granules (shale and quartzite) and gravel (quartzite). Very moist. 7.5YR 3/4 Abundant roots. Occasional worm casts. Rare orange mottles 4/6). Subangular blocky structure. Gradual transition to Unit 2
MCBQ Trench 3	2	3-2	Moderately compact, slightly silty clay with occasional granules (less common than in Unit 1) and rare gravel. Very moist 7.5YR 4/6 Occasional roots. rare worm casts. Slightly developed ped coatings. Subangular blocky structure. Gradual transition to Unit 3
MCBQ Trench 3	3	3-2	Moderately compact, very slightly silty clay with occasional granules (fewer and smaller than in Unit 2). Very moist 7.5YR 4/6 Rare roots. Subangular blocky structure. Gradual transition to Unit 3

## **Appendix C**

### **Thin Section Images**



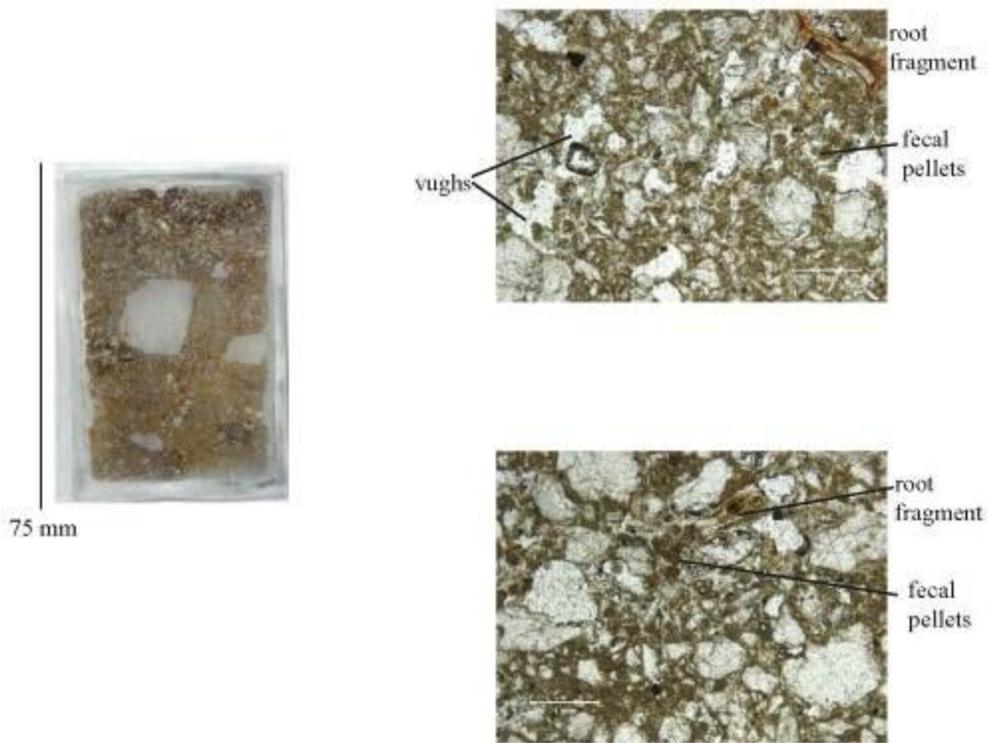


Figure 2

FTP-S1-1

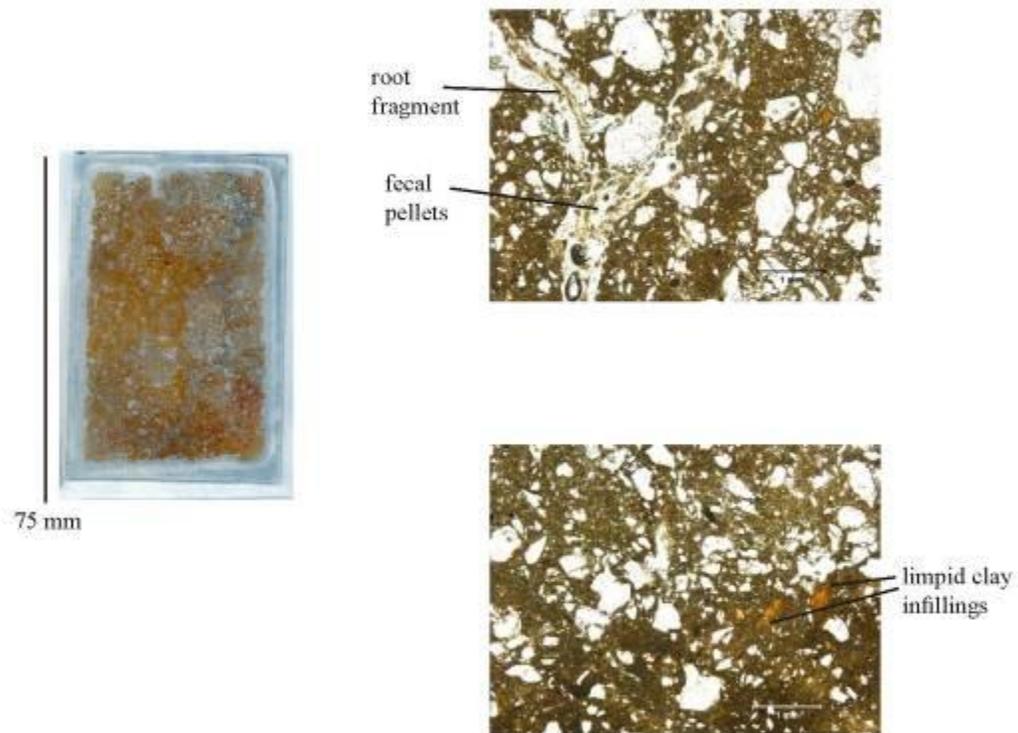


Figure 3

FTP-S1-5

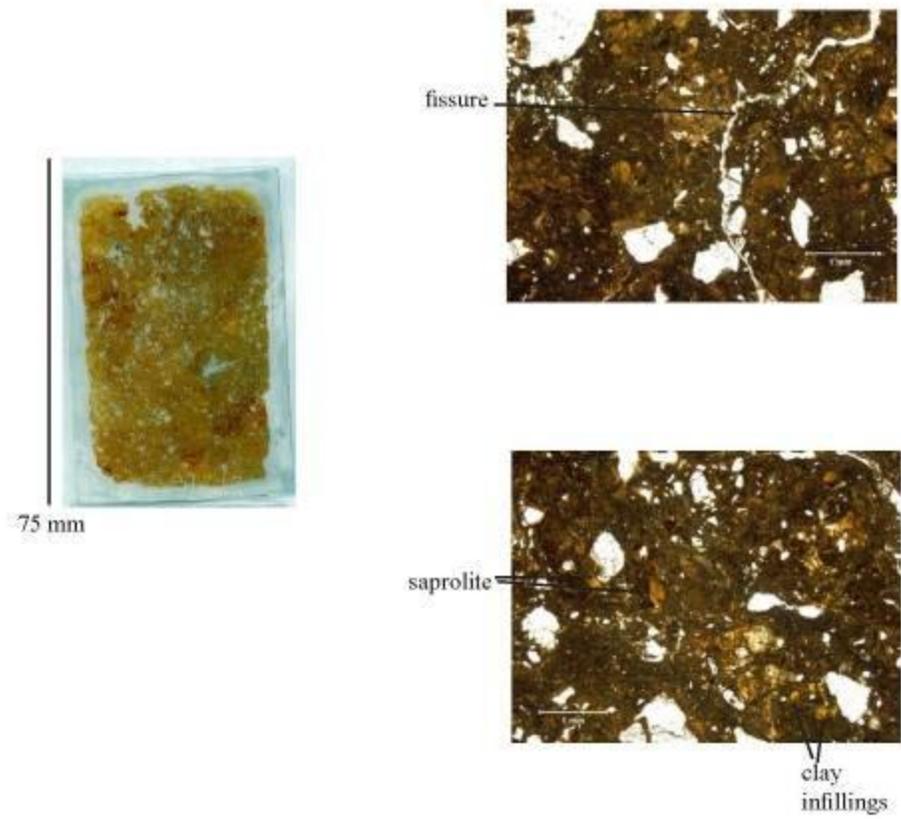


Figure 4

FTP-S1-6

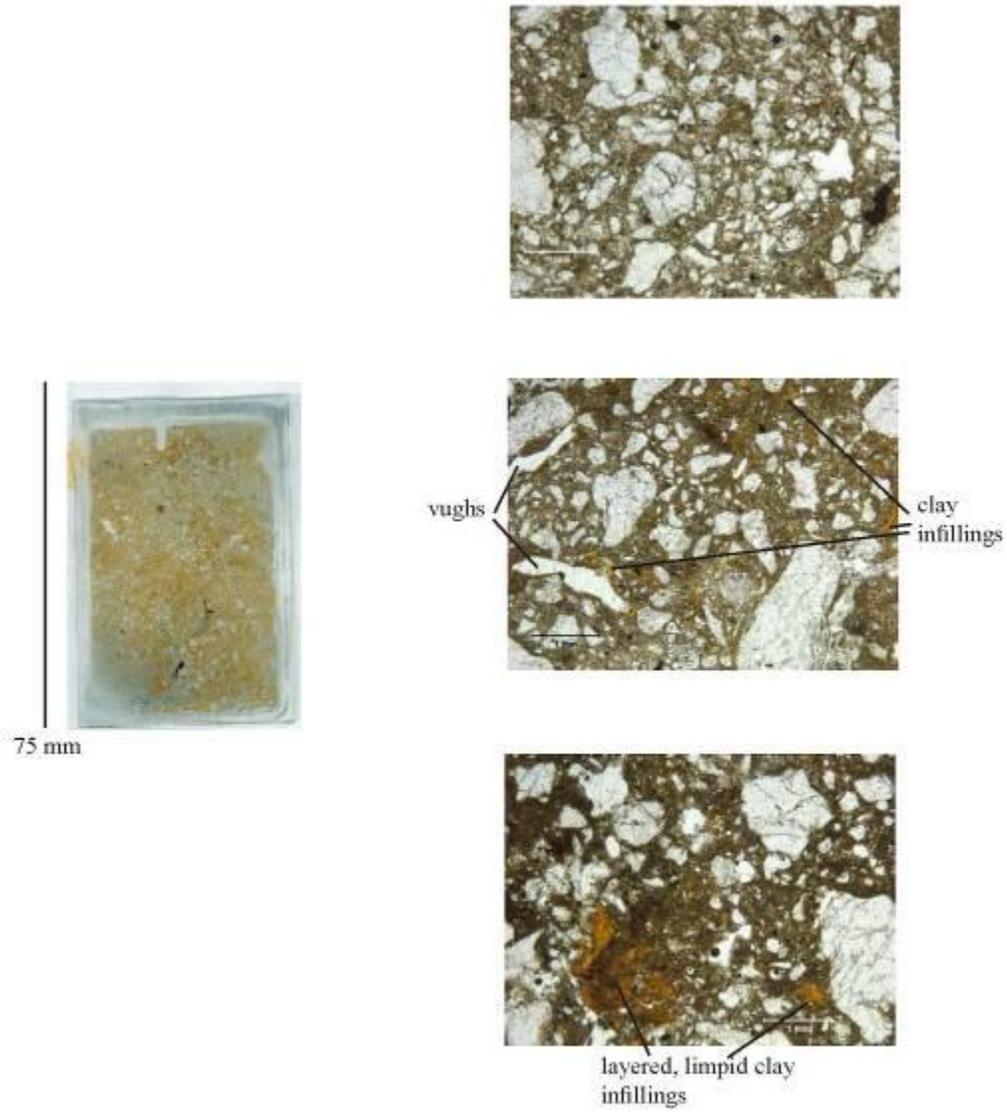


Figure 5

FTP-S1-2

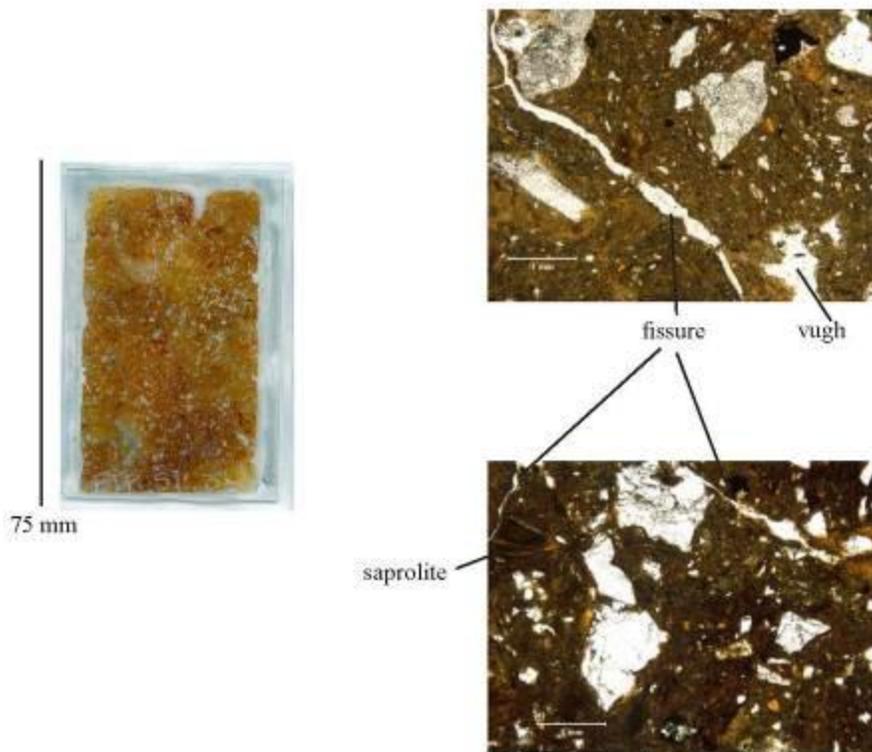


Figure 6

FTP-S1-3

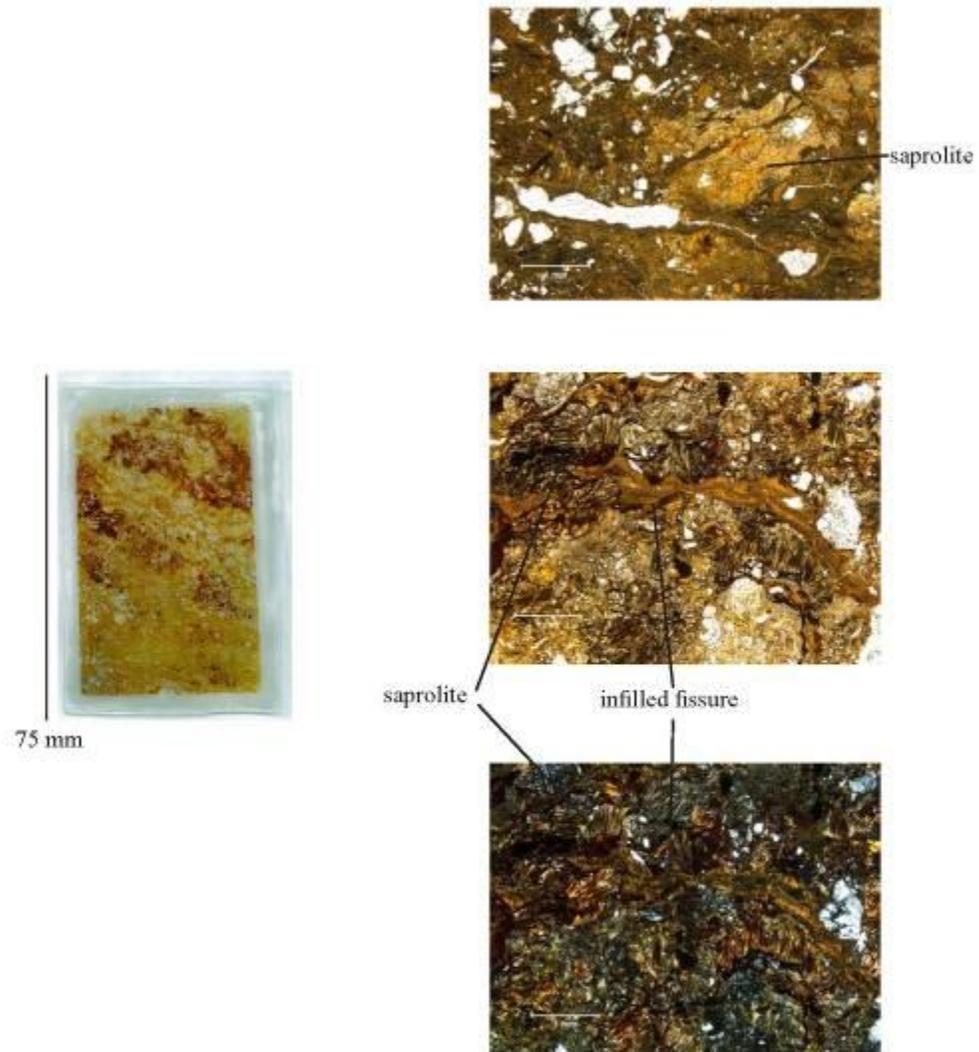


Figure 7

FTP-S1-4

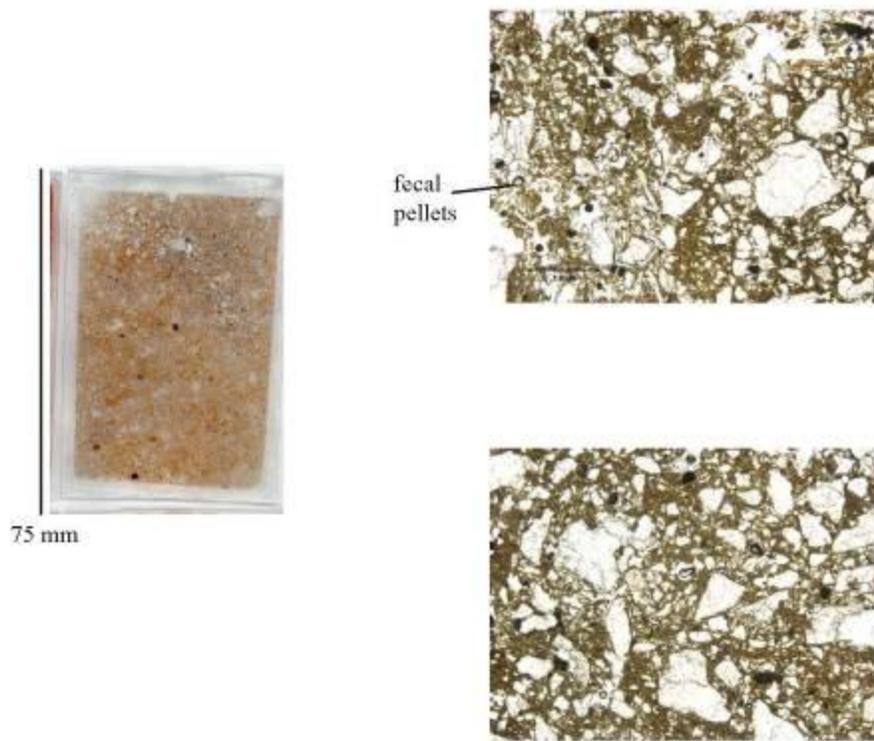


Figure 8

FTP-S2-1

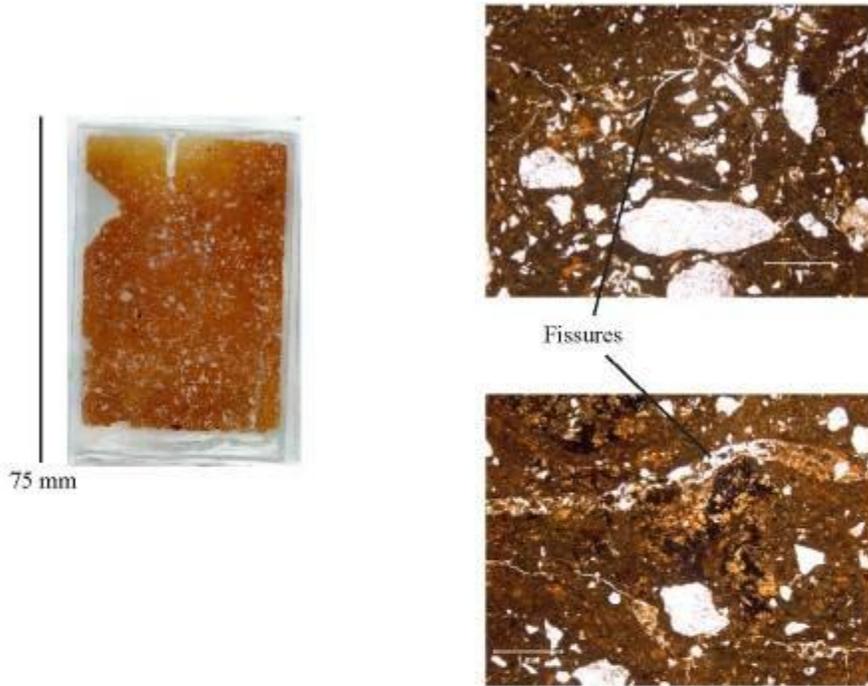


Figure 9

FTP-S2-2

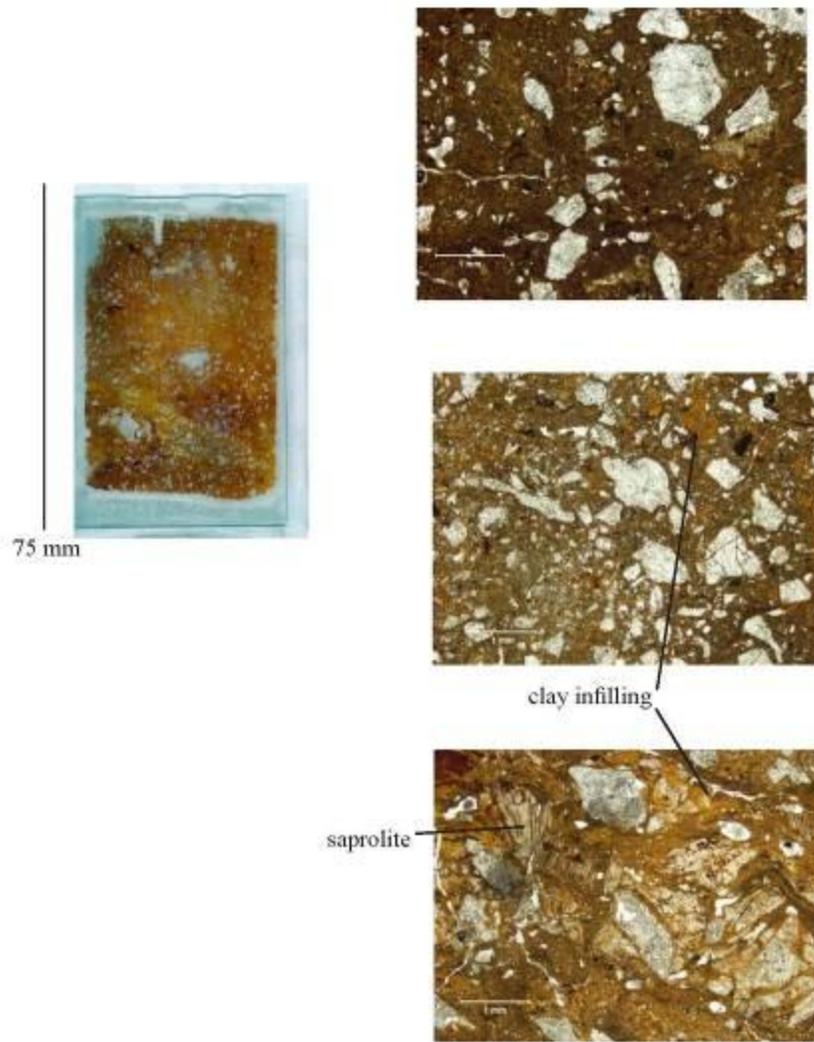


Figure 10

FTP-S2-3

*Integrating Military Training and Archaeological Site Integrity:  
A Field Analysis Approach*

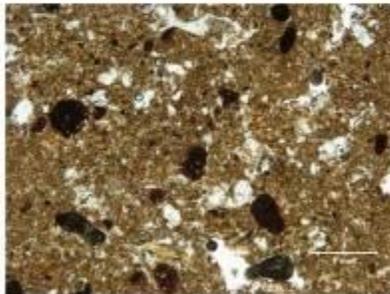
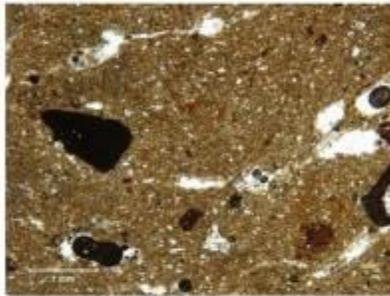


Figure 11

QTC-S1-1

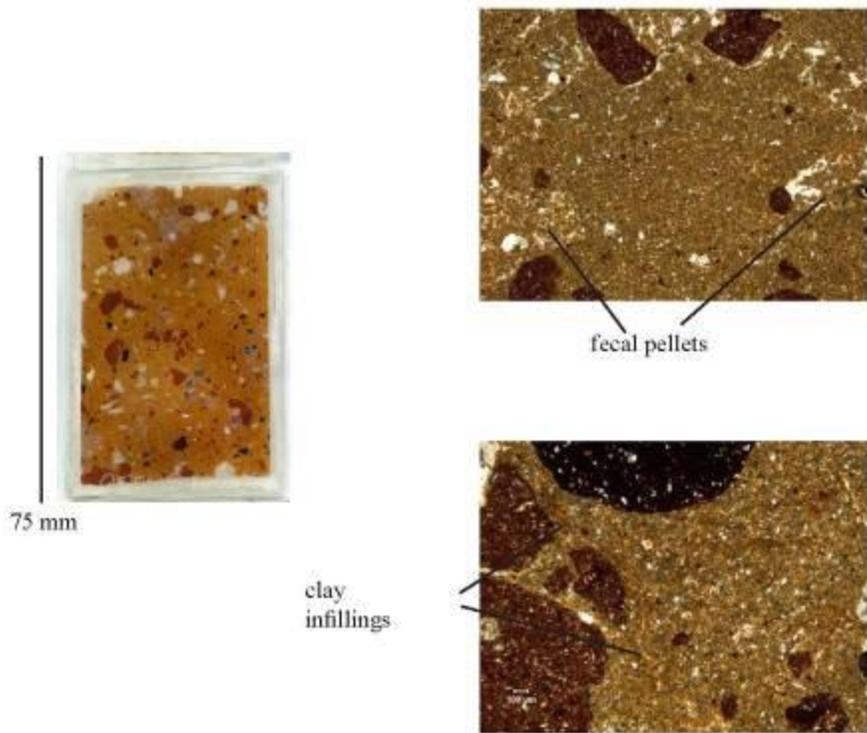


Figure 12

QTC-S1-2

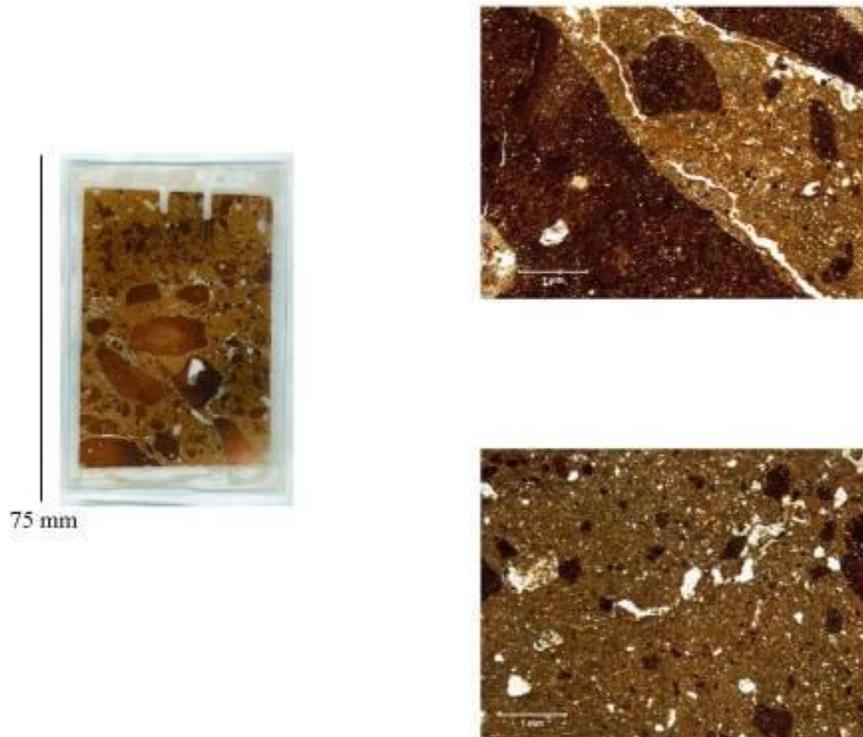


Figure 13

QTC-S1-2B

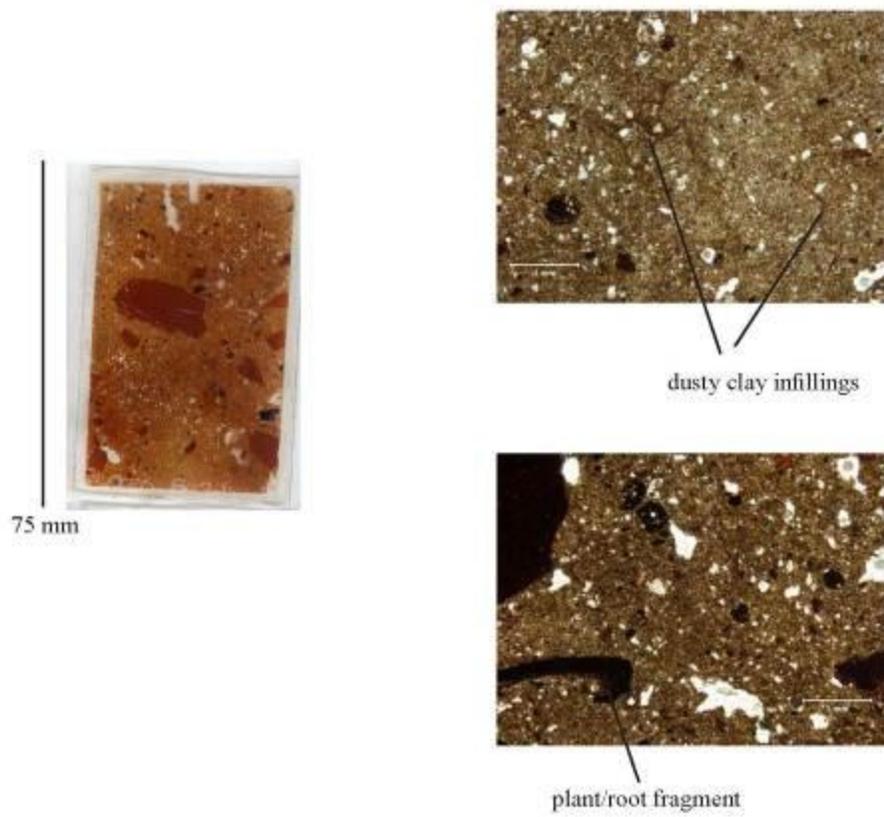


Figure 14

QTC-S2-1



Figure 15

QTC-S2-3

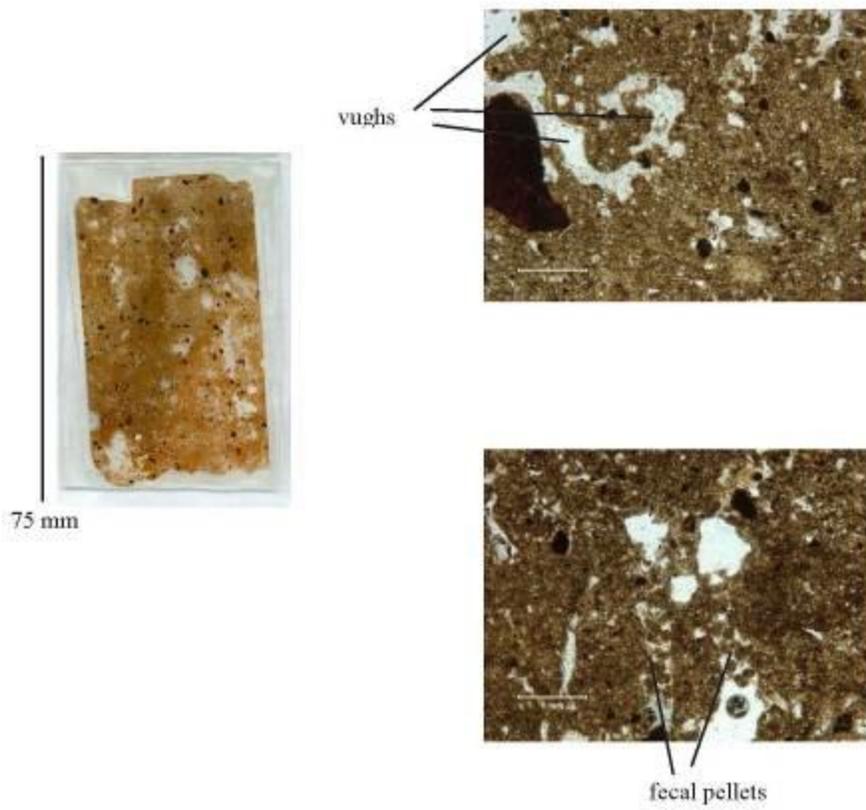


Figure 16

QTC-S3-2