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Department of Defense Legacy Project for Integrating Military Training and Archaeological Site Integrity: A Data Analysis Approach

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Prepared for:

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1.0 INTRODUCTION

Versar, Inc. received funding in 2009 from the Department of Defense (DoD) Legacy Resource Management Program (#09-435) for the project entitled “Integrating Military Training and Archaeological Site Integrity: A Data Analysis Approach.” The U.S. Marine Corps was the project’s sponsor. This project seeks to identify methods to measure impacts of military training on archaeological resources with the goal of sustaining these activities while complying with cultural resource stewardship responsibilities.

The U.S. military is one of the largest federal landholders in the U.S. and must strive to maintain readiness and meet national security requirements while at the same time ensuring proper stewardship of its extensive environmental (Anderson and Ostler 2002:197; Bullard and McDonald 2008) and cultural resources. This can prove a delicate balancing act between what might appear at first glance to represent competing needs (Althoff and Thien 2005:159). Military land managers recognize, however, that proper stewardship of environmental resources ensures the long-term sustainability of military training facilities (Affleck 2005:7). Improper stewardship of environmental resources over an extended period can 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. 2005:208).

Concerns with maintaining sustainability of military training facilities have long focused on the interaction between military training vehicles and on soils (Affleck 2005; Garten and Ashwood 2004; Mulhearn 2001) and other aspects of the natural environment, particularly plant communities. 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).

While natural resources may recover if there is sufficient rest between training episodes, or may be restored through landscape modification and revegetation efforts (Anderson and Ostler 2002:198; Caldwell et al. 2006:457; Milchunas et al. 2000:525), archaeological resources cannot recover during rest periods and cannot be restored after they have been impacted by military training activities (CCPA 2007). Archaeological sites are often fragile and limited in quantity, and they are nonrenewable resources (Nickens 1991). Damage to archaeological sites is permanent and cumulative (CCPA 2007).

Archaeological sites are rarely considered in the literature devoted to the impacts of military training on environmental resources (Johnson and Campbell 2004:110; Zeidler 2004), and it is not readily evident how and to what extent military training might adversely impact a site’s physical integrity and eligibility to the NRHP. While some studies have focused on the vulnerability of archaeological sites to predictable impacts from vehicle traffic, the research has been primarily qualitative rather than quantitative in nature (e.g. Sampson 2007; Sowl and Poetter 2004).

The impact of training exercises on archaeological site significance is a potentially large and complex issue. Military training encompasses multiple types of activities that can directly or indirectly affect an archaeological site, including construction (bridges, earthworks, etc.), live

firing of guns and missiles, and maneuvers on foot and using a variety of vehicles (Canham and Chippindale 1988:59). The extent to which military training activities cause impacts to archaeological sites is not well understood, especially as related to archaeological site vulnerability and the potential loss of eligibility as a result of training activities. An archaeological site must retain sufficient integrity to convey its significance in order to remain eligible for the National Register of Historic Places (NRHP).

1.1 Purpose of Project

The potential range of impacts from military training activities on archaeological sites are quite broad and are related to a host of variables, including characteristics of the site itself, vehicle type(s), training regimen, soil properties, landform, and seasonality. How these variables intersect is different for each unique military training setting, but it is possible to develop broad parameters for understanding military training impacts and to discern what gaps exist in the available data for understanding how military training can affect archaeological resources.

This report focuses on the impacts caused by the movement of vehicles (tracked and wheeled) across military training landscapes. How military vehicles impact archaeological sites must be ascertained through a creative approach that integrates a number of different threads, including research on archaeological site formation processes and studies of terramechanics. Terramechanics researchers examine the complex interactions between moving vehicles (military and non-military) and the landscape—as detailed in Section 4. The major purpose of this project is to determine how the movement of military vehicles during training scenarios alters soil properties and the range of archaeological deposits potentially present within these soils.

1.2 Scope of Project

A basic question of this study is whether military training activities—alone or combined with other processes—may adversely affect the eligibility of a site by causing a loss of physical integrity (Anderson et al. 2005a:151). A starting point for answering this question is to determine a training facility’s land use history (Anderson et al. 2005a:152), which could reveal historic or ongoing natural damage that exceeds any actual or anticipated military training vehicle impacts. Addressing this question also involves quantifying military training impacts as related to potential damage to archaeological sites and determining whether there are acceptable thresholds for training below which a site’s physical integrity and eligibility are not compromised. Key to this study is the identification of archaeological site attributes that are most critical to understanding a site’s integrity and its vulnerability to factors that would affect its eligibility. The site attributes of greatest interest include depth of deposits, artifact and feature density, artifact size and fragility, feature dimensions, as well as the degree of stratification and spatial complexity of the site.

The study begins with a review of current literature on archaeological site integrity, especially as related to NRHP significance criteria and the assessment of significance from the perspective of the physical characteristics of an archaeological site. The eligibility of archaeological sites to the NRHP typically rests on Criterion (d); sites are eligible if they “have yielded, or may be likely to yield, information important in prehistory or history” (ACHP 2008). The information potential of archaeological sites is related to a variety of factors, notably significance within local or regional culture historical frameworks, and the degree to which a site retains physical integrity related to the human behaviors that originally created the site.

If a site lacks sufficient physical integrity, it may not be considered potentially eligible for listing on the NRHP even if it otherwise retains information important in prehistory or history. Sites that are already considered eligible for listing on the NRHP could lose this status if their physical integrity is compromised through direct or indirect actions, such as those related to military training activities or other natural or human processes. How much impact an archaeological site can sustain without losing its necessary integrity and how to measure the impact are considered as part of this literature review.

The impact of military vehicles on archaeological sites cannot be properly understood without an assessment of the wide variety of natural and human processes that can adversely impact the physical integrity of an archaeology site and threaten the site’s NRHP eligibility status. Specifically, it needs to be determined whether military vehicle impacts to archaeological sites in particular settings exceed levels of existing disturbances. The information potential of archaeological sites is related partly to the degree to which the archaeological record is transformed by natural and human-related influences, beginning with the human behaviors that created a site—including the original deposition of artifacts and the creation of features. The archaeological site formation processes literature is examined as part of this study, revealing concerns focused on impacts from human activities (e.g. plowing, erosion, vehicle impacts, trampling), animal activities (e.g. burrowing), and environmental forces (e.g. freeze/thaw cycles, sediment consolidation, root growth and tree falls).

The literature on the interaction between military vehicles and landscapes is fairly extensive, particularly as a subfield within terramechanics. Terramechanics researchers consider the ways in which military 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. Other military vehicle impacts that influence soil properties include increased erosion and changes to vegetation cover or groundwater and surface hydrology. As shown in the current study, integrating terramechanics research with the archaeological site formation processes literature is not a straightforward endeavor. Terramechanics studies are often either purely conceptual or narrowly focused on the impact of a single vehicle acting in a very specific and controlled environment.

A review of applicable studies on soil mechanics and soil deformation helps bridge the sometimes abstract terramechanics research with the observations made on archaeological site formation processes. For example, alterations to hydrology and soil chemistry in some

soils following compaction—perhaps from a military vehicle—can affect artifact preservation. Soil properties influence the ability of military vehicles to drive on the landscape, as well as the extent to which military vehicles cause soil deformation (notably rutting) and compaction. How archaeological sites are impacted by formation processes is also dependent on soil properties. Understanding soil mechanics and soil deformation may make it possible to determine whether ruts formed by military vehicles cause additional impacts to cultural components within a plowed field, or have no further impact to the cultural components. Given the wide variation in military training lands, the issue is ascertaining the most basic variables of soil mechanics—as well as landform characteristics—that one needs to gather to effectively assess the impacts of military vehicles on cultural deposits of varying types, densities, and depths—if such data exist.

The major challenge for this study is modeling when vehicle impacts from military training reach a threshold where the NRHP eligibility of an archaeological site is adversely affected. The review of site significance, archaeological site formation processes, terramechanics studies, and a consideration of geoarchaeological studies of soil mechanics and soil deformation indicate that a potentially large and complex set of variables could be incorporated into the modeling process. Careful selection of a subset of these variables is focused on the creation of a model grounded in real world conditions. The selected variables are related to: a site's cultural attributes; a site's locational/environmental attributes; and, military vehicle attributes. This report addresses whether such a model can be developed with existing data or whether new data must be collected in order to develop such a model.

2.0 ARCHAEOLOGICAL SITES AND SIGNIFICANCE

What makes a site significant? This is the basic question underlying the issue of determining the amount of training activity that an archaeological site can sustain while retaining its significance. More specifically, how do we define archaeological site significance? What are the qualities or attributes by which significance are measured? To what degree can those qualities be altered without compromising significance? Characterizing archaeological significance is not straightforward, and the concept is not easily or succinctly defined. Thomas King, who has conducted project review for the Advisory Council on Historic Preservation and has written extensively on the subject of site significance, has referred to it as an "uncomfortable but necessary" fact of historic preservation (King et al. 1977:95). At issue is the wide degree of latitude possible when assessing whether an individual archaeological site contains cultural deposits that are considered significant in terms of the NRHP.

2.1 Formal Definition

Site significance can be viewed from multiple perspectives, which makes characterizing the concept of significance in clear and distinct terms a difficult task (Briuer and Mathers 1996). Briuer and Mathers (1996:5) noted that: “[for] legal and historical reasons, the concept of significance has taken on a specific meaning and importance for U.S. archaeology and archaeologists.” The NRHP provides a formal definition widely employed by archaeologists, particularly those working within the framework of federal preservation laws:

The quality of significance in American history, architecture, archeology, engineering, and culture is present in districts, sites, buildings, structures, and objects that possess integrity of location, design, setting, materials, workmanship, feeling, and association and

- (a) that are associated with events that have made a significant contribution to the broad patterns of our history; or
- (b) that are associated with the lives of persons significant in our past; or
- (c) that embody the distinctive characteristics of a type, period, or method of construction, or that represent the work of a master, or that possess high artistic values, or that represent a significant and distinguishable entity whose components may lack individual distinction; or
- (d) that have yielded, or may be likely to yield, information important in prehistory or history (Little et al. 2000).

Currently, archaeological sites are most often assessed for significance under Criterion (d), the likelihood of yielding important information, especially for their demonstrated or future research potential.

An additional and important part of significance is the concept of physical integrity, or completeness. That is, a site must be sufficiently well-preserved—must retain sufficient integrity—to convey its significance. Again, according to NRHP guidelines:

Integrity of location, design, materials, and association are of primary importance [for sites being considered] under Criteria A and B. Design, materials, and workmanship are especially important under Criterion C. Under Criteria C and D, integrity of setting adds to the overall integrity of an individual site and ... district (Little et al. 2000).

While extensive, these definitions are nevertheless purposefully non-specific and therefore open to varying interpretations. Indeed, a substantial amount of critical literature regarding this potential for widely different interpretations has accumulated over the years. Little of the discourse, however, addresses ways to actually determine significance or to apply the NRHP criteria in practical terms. A complicating factor is that significance is locally situated, rendering it difficult to develop specific procedures for determining significance that can apply to all sites, irrespective of their locations within the U.S. Significance can therefore be viewed as dynamic and relative (Briuer and Mathers 1996:11).

2.2 A Brief History of Significance

Discussions of significance commonly begin with a phrase similar to: “the concept of significance has changed with time...” (Maslowski 1996:35). Indeed, historically the notion of what constitutes significance has evolved along with the legislative principles of architectural preservation. Modern federal legislation grew out of:

- the standards set by the National Resources Board in 1934, which required “first-rank” uniqueness at the national level for a resource to qualify as significant;
- standards set by the National Council for Historic Sites and Buildings in 1949, which added sites significant to state and local history to those of national importance; and,
- an expanded revision of the 1949 standards by the National Trust for Historic Preservation in 1956 (Tainter and Lucas 1983:709).

The current National Historic Preservation Act (NHPA; P.L. 89-665 as amended by P.L. 91-243, 93-54, 94-422, 94-458, and 96-515) was passed in 1966, establishing the National Register of Historic Places to list significant properties. The act was strengthened in 1971 by Executive Order 11593, *Protection and Enhancement of the Cultural Environment*, which extended the coverage to eligible sites, not just those actually listed. Eventually, the act was further extended to sites considered or recommended potentially eligible (King 1985:171), although to date the Secretary of Interior has not ruled on this additional change.

The National Register of Historic Places, 36 C.F.R. Part 60, established the now familiar eligibility criteria, (a) through (d) as enumerated above, by which sites are judged as demonstrating National Register significance. The earlier standards were explicitly geared toward architectural properties and the concerns of architectural preservation. Scientific importance, by which is meant research value rather than structural and associative characteristics, was not fully or explicitly integrated into the standards (Tainter and Lucas 1983:709). Yet archaeology and the potential for scientific research have become included by extension. This is an imperfect situation, as guidelines designed for standing structures are not readily translated to cultural remains that may exist largely at or below the ground surface.

NRHP criteria may be more realistically viewed as guidelines rather than as rigid standards, since applying the criteria is not necessarily a clear-cut or direct process. Most writing about significance tends to deal with theoretical rather than methodological aspects of this process. Missing are attempts to operationalize the criteria of significance, and to put the criteria into action. In an earlier Department of Defense Legacy project (Project 06-167), Cushman and Sebastian (2008:39-40) attempted this sort of operationalizing by developing a site significance model that they referred to as “rules for sorting archaeological sites within a database into provisional management categories.” They developed four categories of significance:

- Category 1 sites are those considered likely to contain “information that can contribute significantly to current research questions and theoretical issues”—e.g. significance as defined according to NRHP criteria;
- Category 2 sites have been subject to previous archaeological investigations and are seen as therefore having no current research potential; further studies “would be viewed as ‘redundant’ given current research questions and archaeological techniques.” Clearly, new research questions and/or archaeological techniques could shift Category 2 sites into Category 1.
- Category 3 sites have not been previously evaluated and “may contain substantial information about the past, but whose information potential cannot be tapped with current research approaches and archaeological methods.” Again, with new research approaches or archaeological procedures, these sites could be shifted into Category 1;
- Category 4 sites have “very high traditional cultural values” (Cushman and Sebastian 2008:39).

Yet, the model that resulted still focused on broader issues of research potential rather than on measurable site attributes that could be used to determine significance, and thus is not specifically relevant to the current study.

2.3 Research Contexts

Much of the commentary on archaeological site significance was published in the 1970s and 1980s. Writing as part of the early rise of self-consciousness in cultural resource management, Raab and Klinger (1977:631) noted that "...any fixed set of [significance] criteria that are broad enough to apply to many cases are also too nonspecific to provide a detailed rationale for assessment of significance in particular cases." Generally speaking, however, the characterization of significance has gone from a narrow focus on the rarity and distinctiveness of a particular site, the "first-rank uniqueness" of the 1934 standards, to a broader perspective encompassing research orientation and the place of a site in a larger context. With this viewpoint has come recognition of the importance regional research contexts play in assessing the potential of an archaeological site to speak to the past with respect to its immediate and wider surroundings: "The best approach to assessing archaeological significance is in relation to explicit, problem-oriented research designs...the identification of specific research questions on which the resources in question may be expected to inform" (Raab and Klinger 1977:632).

House and Schiffer (1975) touched on this approach in the mid-1970s in one of the first regional cultural resource management studies, an analysis of archaeological sites in the Cache River Basin in Arkansas. They argued that "archeological resources acquire scientific or historical significance only as they relate to specific research questions in substantive, technical, methodological, and theoretical contexts" (House and Schiffer 1975:163). Sharrock and Grayson (1979:327) expanded the argument by asserting that the application of research designs focused on current issues alone is insufficient. Future problem-oriented situations need to be accommodated in the broader context of Criterion (d) – i.e., the *potential* "to yield information important in prehistory or history."

Raab and Klinger (1979:329) further expanded on this notion. They maintained that problem-oriented research must be broadly defined, so that "a wide spectrum of archaeological resources will be identified for preservation," and so that significance does not become tied to the research interests of specific individuals, specific times, or even specific places. Both representativeness and redundancy may figure into significance evaluations (Briuer and Mathers 1996:13), and this must be determined on a local or regional basis rather than on a national level. How to operationalize significance in these terms has proven elusive and problematic (Briuer and Mathers 1996:14).

It seems clear at least that these arguments are the impetus for the research contexts many state historic preservation officers (SHPOs) have been developed in recent years. Most well-reasoned recommendations of eligibility resulting from cultural resource management (CRM) studies are currently made with reference to the research contexts of the state encompassing the sites in question. Yet the open-endedness implied by "future problem-oriented situations" renders a practical assessment of significance and its specific characteristics difficult to attain.

Like significance, the concept of research contexts is expressly addressed in the National Register guidelines, where they are referred to as historic contexts. The definition of historic

contexts begins with a statement linking the two ideas: that is, a site's significance must be evaluated within its historic context. Further:

Historic contexts are those patterns or trends in history by which a specific occurrence, property, or site is understood and its meaning (and ultimately its significance) within history or prehistory is made clear. Historians, architectural historians, folklorists, archeologists, and anthropologists use different words to describe this phenomena [sic] such as trend, pattern, theme, or cultural affiliation, but ultimately the concept is the same.

The concept of historic context...it has been fundamental to the study of history since the 18th century...Its core premise is that resources, properties, or happenings in history do not occur in a vacuum but rather are part of larger trends or patterns.

In order to decide whether a property is significant within its historic context, the following five things must be determined:

- The facet of prehistory or history of the local area, State, or the nation that the property represents;
- Whether that facet of prehistory or history is significant;
- Whether it is a type of property that has relevance and importance in illustrating the historic context;
- How the property illustrates that history; and finally
- Whether the property possesses the physical features necessary to convey the aspect of prehistory or history with which it is associated. (NPS 1997:7)

Historic contexts thus form a background or framework within which archaeological resources gain fuller meaning, thereby providing a foundation for assessing their significance. As noted above, most archaeological sites are evaluated under NRHP Criterion (d), which emphasizes that site significance is based on whether they have, or are likely to have "information important in prehistory or history." The key word in this definition is "important," especially in relation to broader contextual issues:

Information is considered "important" when it is shown to have a significant bearing on a research design that addresses such areas as: 1) current data gaps or alternative theories that challenge existing ones or 2) priority areas identified under a State or Federal agency management plan (NPS 1997:21).

Discussions of historic contexts and problem-oriented research do not usually address significance determinations in practical terms. Rather they assume a theoretical perspective—the determination of site significance on a large scale, in terms of regional

contexts, regional research potential, and comprehensive research designs. Significance is not seen as a black-and-white issue, but one with room for interpretation based on the degree to which information from a site relates to regional research issues. Thus, no checklist has been developed for assessing archaeological site significance that applies to all sites across the nation regardless of their age, location, or cultural affiliation.

2.4 Physical Integrity

Despite the potential for ambiguity involved in determining archaeological site significance, the question of site significance has generally already been considered for archaeological sites within military training lands, either explicitly, for sites found eligible to the NRHP, or implicitly, for sites that have been placed in the “potentially eligible” category. Questions of the relevance of these sites within regional contexts have presumably been addressed or are assumed. Significance is thus implied, and the primary issue becomes one of physical integrity.

One of the assumptions underlying this perspective is that significance is inherent in a site. Significance is an immutable, intrinsic quality that is “present in a cultural property, rather than in the mind of the observer” (Tainter and Lucas 1983:712). This at first seems contrary to the relativistic perspective just reviewed, but in fact it is easily reconciled because it is only the historic contexts and research goals that are relative—the attributes used to define the integrity of a site remain inherent qualities.

An additional contrast is drawn between intrinsic qualities and physical qualities. Deeben et al. (1999:184) define physical quality as “the degree to which archaeological remains are still intact and in their original positions.” Physical qualities include integrity and degree of preservation, the distinction in this case being that integrity is the degree to which disturbance has taken place, while preservation is the degree to which the archaeological materials have survived. Intrinsic qualities on the other hand are seen as less concrete and more open to interpretation. In this view, intrinsic qualities include rarity (the relative scarcity of a site); research potential (the site as a source of knowledge of the past); group value (including archaeological context, in terms of sites known regionally, and geographical context, in terms of the preservation of original geographic context); and representativity (the degree to which a site is typical of a period or era) (Deeben et al. 1999:185).

In another approach, Glassow (1977:415) related integrity to the degree of preservation of archaeological resources. He expanded the definition of integrity to include “the completeness of the range of items that originally comprised a[n] ... assemblage ... or in the existence of disconformities in a stratigraphic sequence of deposits.” Glassow (1977:415) noted that this has long been at least intuitively recognized “given archaeologists’ predilection toward the excavation of unmolested sites...” It is a simpler matter to evaluate as significant a site with undisturbed cultural deposits than a site that has been extensively impacted by military training or other formation processes.

2.5 Physical Attributes of Significance

Physical integrity, then, brings the focus of the investigation to measurable characteristics that may be used to determine an archaeological site's significance. Along with more theoretical aspects of site significance, Cushman and Sebastian (2008) also discuss some specifics in terms of the physical attributes of archaeological sites:

Among these characteristics are: types, numbers, distributions, and densities of artifacts; overall site size; presence (though not absence) of temporal diagnostics; indications of structures or features; presence of ash, charcoal, or other evidence of burning; and indications of buried cultural materials. Other useful predictors of information potential are aspects of the site's setting and environment. Among these are: the geomorphic age of the surface on which the site is located; whether the site is in an erosional, stable, or depositional setting; and whether the site has been disturbed by natural or cultural forces (Cushman and Sebastian 2008:38).

These objective, material characteristics contribute to determinations of site significance. Alterations among these characteristics can result in changes in physical integrity that will diminish and eventually reverse or invalidate a site's significance.

The assessment of a site's physical integrity is necessarily conducted on a situational basis. Initially, site formation processes should be analyzed as part of this assessment. As detailed in the next section, considerations of site formation processes go beyond a description of a site's current conditions toward a recognition of how the site was formed: whether it is buried, how deeply, what kinds of disturbance are present, and so on. Soil mechanics and soil deformation should be analyzed to assess how the soils and sediments at a site operate as a system and how they can be expected to react to various levels of disturbance. Military training impacts can then be properly assessed in terms of how they influence a site's physical integrity and its significance. Thus, the material properties of an archaeological site are key to its physical integrity and thus to its significance.

3.0 ARCHAEOLOGICAL SITE FORMATION PROCESSES

Decades of research into archaeological site formation processes—including empirical and experimental studies—have revealed that archaeological sites are very dynamic entities. There was a growing recognition beginning in the late 1960s that the archaeological record was not a pristine and direct reflection of human activities, but rather that this record was influenced by subsequent human behaviors and various natural processes (Ascher 1968). Archaeologists working in the 1970s and 1980s expanded our understanding of archaeological site formation processes. These processes are often subdivided into those related to human actions and those related to natural phenomena, sometimes referred to as cultural transformations (c-transforms) or natural transformations (n-transforms), respectively (Schiffer 1983, 1987). Active research into site formation processes today typically is the province of geoarchaeologists or geomorphologists operating within the framework created by earlier archaeological studies (Butzer 2008). This review will consider archaeological site formation processes active on surface/near surface contexts versus deeper cultural deposits, particularly those most germane to military training impacts.

When analyzing a site, one must consider whether site formation processes were sufficient to obscure or distort the human activities that created the site—thus impacting the site’s information potential and its eligibility to the NRHP. The presence of human, animal or other natural activity does not necessarily mean that a site lacks information potential, only that one has to control for stratigraphic “noise” (Morin 2006). Some have even argued that a site might have eligibility because of the information it provides regarding formation processes (Peacock and Fant 2002).

Dunnell (1990) noted that, globally, the majority of the archaeological record is preserved on the surface or in shallow, subsurface deposits—largely within plowed agricultural fields. Although a variety of archaeological site formation processes can act on these deposits, it is now well established that even disturbed surface and shallow subsurface deposits can retain important information about archaeological sites—depending on the nature and extent of that disturbance (Cowan and Odell 1990; Dunnell 1990; Dunnell and Simek 1995; Schlanger and Orcutt 1986). Artifacts visible on the surface can provide clues to site function and size, as well as periods of occupation (Schlanger and Orcutt 1986). Shallow subsurface deposits may be reflected in the distribution of artifacts on the surface (Redman and Watson 1970), although surface collections of artifacts are typically biased toward larger objects (Baker 1978). Surface and shallow subsurface deposits are of particular concern here because, as will be addressed more fully in the next Section, the most extensive *visible* impacts following from the operation of military vehicles in training scenarios are evident on surface and immediate subsurface contexts.

One major goal of a site formation analysis is to ascertain the extent to which a site exhibits stratigraphic disturbances or movement of cultural objects from their original depositional location. Cross-mending of cultural objects within and between stratigraphic layers can help address this goal (Rowlett and Robbins 1982; Villa 1982). Bollong (1994), for instance, noted that cross-mending sherds can give clues to archaeological site formation processes and may even reveal stratigraphic associations that are otherwise obscured.

3.1 Erosion

One of the major formation processes influencing surface and near surface archaeological remains is erosion. Erosion is a major consequence of military vehicle training activities on the landscape. Left unchecked, surface erosion can make it difficult to identify sites or collect representative examples of the range of artifact types that exist at a site (MacDonald 1990). Natural or human activities can cause erosion, which is more prevalent on some landscapes than others, such as barren or moderate to steeply sloping landforms (Wainwright 1994). The movement of objects out of their original contexts can be facilitated by erosion, especially if they are large, heavy, and on a slope (Rick 1976).

Erosion resulting from modern human activities—such as tracks left behind by bulldozers used to uproot vegetation or as a consequence of plowing—is much greater today than was true of the past, partly due to the expansion of areas under cultivation or development (MacDonald 1990; Wilkinson 2005; Wilkinson et al. 2006). Some activities designed to conserve soil or promote even drainage—such as leveling a field or deep plowing to break a subsurface hardpan caused by shallow plowing—may destroy cultural deposits (MacDonald 1990:13). MacDonald (1990:13) notes that “Integrated rather than single purpose land management efforts are necessary to prevent this damage” to archaeological sites from attempts to minimize the effects of erosion.

Grazing animals are a major cause of erosion, as grazing can reduce vegetative cover and enhance erosion (MacDonald 1990). Military training lands may have multiple uses, including military vehicle traffic, grazing, cultivation, crop production, forestry, habitat protection and even recreation on the same or adjacent tracts (Boice 1996; Guretzky et al. 2006). Military vehicle traffic on such multi-use lands certainly would have to take grazing into consideration. Grazing and training need to be carefully scheduled at different times so that the results of these activities that might enhance erosion—such as soil compaction or vegetation damage—do not act in tandem (Guretzky et al. 2006).

3.2 Vehicle Impacts

Vehicle traffic has a major impact on archaeological sites. Recreational, off-road vehicle (ORV) use is a major contributor to erosion on archaeological sites—particularly in the western United States—and has parallels to the impacts caused by military training vehicles. Specific impacts from military vehicles will be considered later. ORVs can lead to loss of soils and the vegetation that helps bind soils, can create scars on the landscape up to 4.7 meters wide and 1.42 meters deep that promote further erosion, and can enhance visibility of archaeological remains—and thus their attractiveness to looters and collectors.

ORVs cause other damage to archaeological sites as well, such as degradation and deflation of cultural deposits within vehicle traffic patterns, including impacts to features and breaking or crushing of artifacts (BLM 2003:30; Sampson 2007; Sowl and Poetter 2004:12). 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). Degradation of the

landscape by individual ORVs, particularly through rut formation, can lead to broader damage as newer vehicle traffic avoids existing ruts; new ruts are created adjacent to older ruts, leading to wider and deeper damage to a site (BLM 2003:30).

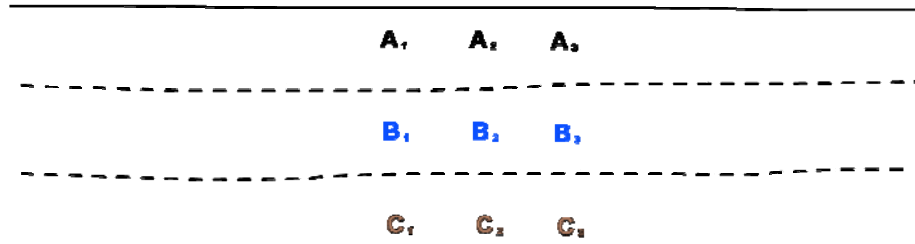
3.3 Plowzone Archaeology

A major focus of research into archaeological site formation processes of surface and near surface contexts has been related to the informational potential of cultural objects located in plowed fields (Carr 2008; Dunnell 1990; Fuller 1981; Hoffman 1982; Knoerl and Versaggi 1984; Lewarch and O'Brien 1981; Odell and Cowan 1987; Rieth 2008a, b; Roper 1976; Shott 1995; Versaggi and Hohman 2008:175). Military training lands often encompass former agricultural fields and understanding the archaeological research potential of the plowzone is important. A major issue is whether military training activities have an essentially neutral or an additive impact to the disruption caused by tillage equipment. In other words, do military training activities generate disruption of archaeological deposits greater than that caused by tillage equipment?

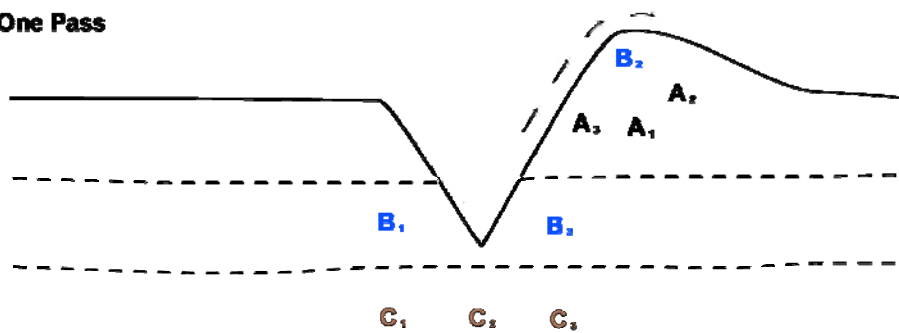
With modern tillage practices, regular plowing disrupts the upper 20 to 40 centimeters of an agricultural field, and can extend up to 75 centimeters below the surface through annual efforts to break up the subsurface hardpan created in part by compaction from the movement of a tractor across a field (Frink 1984; MacDonald 1990; Navazo and Diez 2008; Raper 2005). Plowing can truncate cultural features and both move and damage artifacts and ecofacts. Soil type can influence the extent to which cultural objects are damaged by plowing and how far they have moved. In clayey soils, artifacts can encounter enhanced static stresses and soil compacted ahead of a plow blade, which can break fragile artifacts. Artifacts in clayey soils may also aggregate and move farther under the influence of plowing than they would in non-clayey soils (Mallouff 1982).

Because archaeologists often rely partly on surface distributions of cultural objects to interpret site size and site boundaries, the lateral (horizontal) movement of cultural objects in plowed fields has long been a major concern of archaeologists (Figure 3.1). The lateral movement of cultural objects in plowed fields is quite variable and can reach distances as great as 100 meters, although some studies suggest that the average horizontal displacement is approximately two meters (Navazo and Diez 2008; Odell and Cowan 1987; Roper 1976). Thus, cultural objects usually exhibit less horizontal displacement than many archaeologists had suspected. Farmers tend to plow in a consistent pattern, reversing direction in alternating seasons, and this can in turn move objects back and forth along the direction of plowing from their original location (Lewarch and O'Brien 1981). Even average movements of only two meters can lead to an expansion of site boundaries to twice the original size of a site, and overall site density exhibits a corresponding decrease (Navazo and Diez 2008; Odell and Cowan 1987).

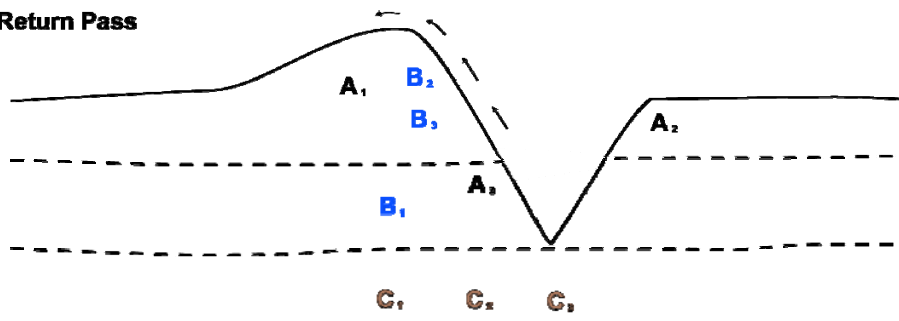
Original State



One Pass



Return Pass



Eventual State

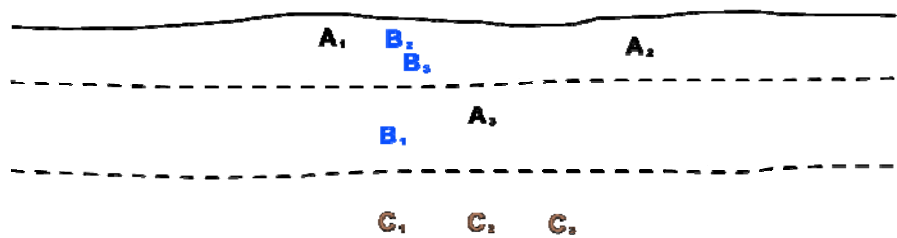


Figure 3.1: Schematic Illustration of the Effect of Plowing on Three Hypothetical Soil Layers. Letters represent individual artifacts; arrows indicate the general direction that soil is moved by the plow.

There is some debate about how to determine when or even if the horizontal dispersal of artifacts in a plowed field ever reaches an equilibrium—which might make it possible to more closely estimate original site size and site boundaries (Cowan and Odell 1990; Odell and Cowan 1987; Dunnell and Simek 1995). The size of fragile artifacts found within a plowzone may help address this question. Plowing can damage fragile objects, such as ceramic sherds or bone fragments, and these should eventually reach a stable size. If there are artifacts in the plowzone that exceed the stable size, they could indicate that equilibrium has not been reached, or, alternatively the artifacts are newly deposited or newly brought up from sub-plowzone contexts (Dunnell and Simek 1995). Interestingly, some studies have shown that size does not appear to be a factor in the lateral displacement of cultural objects (Cowan and Odell 1990).

Archaeologists are also interested in how objects move vertically within the plowzone. A basic question is whether the plowzone represents a homogenized deposit, with the vertical displacement of cultural objects being essentially random, or whether plowzone deposits are patterned, perhaps based on object size, age, or proximity to sub-plowzone deposits. Redman and Watson (1970) suggested that surface objects directly reflect shallow, subsurface remains and can guide exploration of cultural remains not visible on the surface. However, surface assemblages may contain no more than 10 percent of the material present within the plowzone (Navazo and Diez 2008), which is why some advocate repeated surface collections of plowed sites and “plowing, disking and a sufficient rain washing... between each collection” (Carr 2008:198; see also Shott 1995). Shott (1995:476) argued that the surface archaeological record is best viewed in terms of three characteristics: abundance (number of objects exposed); composition (number of items in various classes); and, distribution (arrangement of cultural objects across the surface).

Hoffman (1982) suggested that the lower part of the plowzone—the bottom five centimeters in his studies—more accurately predicts subplowzone deposits than the upper portions of the plowzone. Dunnell (1990) disputed the notion that there is a necessary connection between surface and subsurface deposits, but stressed that plowzone deposits nonetheless have considerable research potential in their own right. Some earlier studies seemed to show that vertical displacement of objects within the plowzone is essentially random (Frink 1984). More recent research indicates that smaller artifacts tend to be pushed downward but that the plowzone nonetheless retains the majority of very small artifacts that existed in these deposits before plowing (Navazo and Diez 2008).

For a variety of reasons, including visibility, surface collections of artifacts are biased toward larger artifacts and therefore do not reflect the range of materials located in shallow subsurface deposits (Baker 1978). The factors affecting the size of cultural objects recovered from the plowzone are difficult to decipher, because these are related to the movement of soil (and objects within the soil) by the plow, the movement of artifacts downward through the loosened soil deposits, and the fragmentation of cultural objects through the action of plowing. Lyman and O’Brien (1987) demonstrated that animal bones in the plowzone were much smaller than those from subplowzone deposits, and that animal bone size was directly related to bone fragmentation rather than the differential vertical movement of bone fragments based on size.

3.4 Trampling

Trampling by humans or animals is another well-studied archaeological site formation process that can lead to lateral and vertical displacement of cultural objects. Lateral displacement is not as well studied as the vertical movement of cultural objects, but it has been noted that trampling will displace larger objects laterally within the trafficked area, blurring horizontal patterns (Nielsen 1991). Early studies of vertical displacement as a result of trampling documented the dispersal of artifacts up to a meter deep and across two or more strata with no evidence reflected in soil profiles that the artifacts had moved (Gifford-Gonzales et al. 1984). Trampling may lead to size sorting of artifacts with larger artifacts higher in a profile than smaller fragments and some homogenization of upper layers (Blackham 2000; Gifford-Gonzales et al. 1984).

Artifacts may actually move up or down in response to trampling with substantial movement particularly evident in loose, sandy soil (Gifford-Gonzales et al. 1984). The migration of artifacts downward ceases when a compacted soil layer is reached (Nielsen 1991); this compacted layer may result from trampling or other factors (Weaver and Dale 1978)—such as the movement of military vehicles across the landscape (as discussed below). Trampling has also been studied as related to foot traffic from military training, creating significant compaction in the upper six centimeters of soil after two years of training (Whitecotton et al. 2000:697).

The presence of a compacted soil layer may result in what appears to represent a discrete and intact cultural layer or “living floor”—with objects potentially drawn from multiple, temporally discrete cultural events. Smaller objects can become imbedded in the compacted soil layer, furthering the illusion that these objects are part of a discrete cultural layer (Nielsen 1991). In addition to moving cultural objects within soil deposits, trampling can result in damages to the cultural objects that mirror cultural behaviors. Unmodified animal bones may become abraded, creating apparent cut marks, while chipped stone flakes can exhibit edge damage indistinguishable from deliberate retouch (Behrensmeyer et al. 1986; McBrearty et al. 1998). It is possible that any process that creates sufficient force to compact subsoil layers may mimic the manner in which trampling influences the archaeological record. Compaction of subsoil layers is a major focus of research regarding the impact of military vehicles on the landscape (see next section).

3.5 Artifact Fragility

Outside of plowzone and trampling studies, the literature on artifact fragility related to site formation processes appears to be very limited. Determining how the forces involved in soil compression directly interact with cultural objects would help interpret indirect impacts resulting from military training. Attempts to understand these and other factors affecting artifact breakage—including in a military training setting—have proven largely unsuccessful (Johnson and Campbell 2004). Mathewson (1989; cited in Bilsbarrow 2004; see also Thorne 1991) apparently determined that soil compression accelerates decay of animal bones, shell, plant remains, ceramics, features, and soil attributes, but has no effect on chipped stone and

groundstone objects. It was also suggested that metals are not affected directly by soil compression (Mathewson 1989; cited in Bilsbarrow 2004).

However, there exists some research—largely speculative—suggesting that buried archaeological remains are degrading faster today than during earlier periods as a result of alterations in soil chemistry resulting from construction, industrialization, and changes in agricultural practices (Kars 1998; Williams and Corfield 2002). Buried iron objects recovered from archaeological contexts, for example, are corroding more quickly today than they did in the past—even for objects of the same ancient age (Gerwin and Baumhauer 2000). Alterations to hydrology from human-related activities can lead to decreases in soil moisture and this may affect the preservation of cultural objects, particularly organic remains (Lillie and Smith 2007). Archaeologists working on American Indian village sites as part of the Meyersdale Bypass Project in Somerset County, Pennsylvania, in the mid-1990s noted far fewer human remains than expected compared to village sites excavated nearby in the 1930s and 1970s. It was speculated that modern agricultural practices—particularly chemical fertilization—might account for this discrepancy—because tillage practices otherwise had not altered much since the 1970s.

3.6 Natural Formation Processes

Archaeologists are not only interested in cultural impacts on the archaeological record, but also in the role natural processes play in site formation. The lateral and vertical movement of cultural objects as a result of natural processes has also been a subject of study over the last three decades (Balek 2002; Butzer 2008; Fowler et al. 2004; Johnson 1990; Wood and Johnson 1978). Investigations have shown that soil matrices and the cultural deposits within them are subject to numerous factors that could either accelerate or mitigate some impacts from military vehicle training. Wood and Johnson (1978:316-318) focused on various pedoturbation processes that move soil matter and the cultural objects within that matter, including, but not limited to: faunalturbation (animal activity, especially burrowing); floralturbation (plant activity, including root growth and tree falls); and cryoturbation (freezing and thawing).

Wood and Johnson (1978:369) noted that “Cultural materials... may sink into the soil, may be concentrated into layers at depth, may be reoriented within the soil, may be thrust to the surface, or may be moved horizontally on a plane or downslope.” Frost action, for example, has been documented as capable of displacing artifacts up to 20 centimeters a year in random directions, including upslope (Bowers et al. 1983). Freeze/thaw cycles can also lead to soil heaving, forcing objects to move upward (Butzer 2008). Pedoturbation processes may operate singly or together, either in an additive or subtractive fashion, and can lead to noncultural associations of artifacts (Wood and Johnson 1979:369). Thus, the depth of artifacts in non-feature contexts may not be related directly to cultural behaviors but instead to normal biological activities; essentially, artifact depth may correspond to the base of major biological activity (Balek 2002).

Scholars have long been concerned with the effect of animals on archaeological deposits, including early experimental studies and observations by Darwin (1881) on earthworm activity. Earthworms can dramatically mix the soil matrix and obscure soil horizons (Canti 2003; Stein 1983). Along with other small animals, earthworms can bury cultural deposits and can vertically displace artifacts up to 45 centimeters after only five years (Canti 2003; Fowler et al. 2004; Johnson 2002; Stein 1983; Van Nest 2002). Burrowing and tunneling by small animals can have a dramatic effect on the vertical movement of cultural objects. Wolf spiders, for example, can potentially displace objects to depths of 170 centimeters below the surface. However, this depth can be much shallower if compact sediments are encountered (Morin 2006).

Particular attention has been placed on the activities of burrowing animals, such as gophers and even armadillos (Araujo and Marcelino 2003; Erlandson 1984; Fowler et al. 2004; Johnson 1989; Pierce 1992). Gopher activity can blur the interfaces between discrete cultural deposits, and can move objects that are as large as 6.3 centimeters in maximum dimension to depths of 160 centimeters (Erlandson 1984; Johnson 1989; Pierce 1992). Burrowing behavior can cause size sorting of cultural objects, with artifacts increasing in size as depth increases (Blackham 2000). Bocek (1986) found that burrowing may lead to objects less than 2.5 centimeters being pushed closer to the surface and objects greater than 5 centimeters being pushed deeper, creating concentrations that might appear to represent discrete cultural layers. Distinct zones of artifacts greater than 6 centimeters in length, referred to as stone lines, may be created through burrowing behavior (Pierce 1992). In one case study, burrowing behavior created two stone lines, with the first and largest between 10 and 20 centimeters below the surface, and a second and smaller stone line below 50 centimeters (Erlandson 1984). Burrowing animals can also move artifacts great distances laterally; the average horizontal displacement caused by armadillos in one study was documented as 120 centimeters (Araujo and Marcelino 2003).

The final natural process to be considered here is sediment consolidation. Essentially, natural overburden loading can decrease sediment volume by reducing the void spaces in soil. Sediment consolidation may also displace artifacts downward up to 5.1 centimeters, possibly creating what appears at first glance to represent a living floor. This vertical displacement of artifacts does not appear to be related to metric attributes of artifacts (weight, area, volume, or size) and may be more pronounced in sediments with higher moisture content (Andrews 2006). It is possible, given the interaction between vehicles and the terrain discussed below, that military training vehicles would cause similar changes to cultural deposits, or add to those influences that already exist under natural conditions.

4.0 MILITARY VEHICLE IMPACTS ON TRAINING LANDSCAPES

The impacts that military vehicles have on cultural resources in training landscapes is clearly central to this study. Vehicle traffic at any frequency is viewed by some as always harmful to archaeological sites (Sampson 2007), although the point at which vehicle damage becomes sufficient to cause loss of site significance is an issue that is not well explored. Some vehicle damage can prove subtle and lead to loss of information potential from an archaeological site, which could affect determinations of eligibility. For example, vehicle traffic can 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). To better understand how military vehicles might affect cultural resources, it is important to examine existing research on the interaction between military vehicles and training landscapes.

4.1 Terramechanics and Military Vehicles

Terramechanics researchers focus on the interaction between the terrain and wheeled or tracked vehicles, especially on the ability of a section of terrain to support mobility (trafficability) (Muro 2004:ix, 1). Numerous environmental studies present analyses of direct and indirect impacts of military vehicles on the natural landscape. Military vehicle training can lead to reduced plant cover, compositional shifts in plant communities, large areas of exposed soil, and increased erosion, not to mention rutting (Quist et al. 2003). Impacts from military training may prove incremental rather than catastrophic (Carlson and Briuer 1986:1). A distinction can be made between studies focusing on training impacts that are readily evident to an observer either immediately or longer term (vegetation damage, erosion, rutting) and those not evident without specialized testing (e.g. soil compaction).

An individual military vehicle’s impact on the landscape depends on the interaction between vehicle static properties (wheeled vs. tracked, weight, ground pressure), vehicle dynamic properties (velocity, acceleration, turning) and landscape conditions (soil texture and moisture, slope, vegetation type) (Anderson et al. 2005a:146; Li et al. 2007a:205). Tracked vehicles generally do not impact the soil as deeply as wheeled vehicles because a tracked vehicle’s weight is more uniformly distributed across its treads (Belnap and Warren 2002:250; FEMA 2008). The width of a tire or track has an obvious impact on surface attributes such as vegetation; the wider the track or tire, the lower the survivability of vegetation in the locations directly encountered by a vehicle (Hansen and Ostler 2005:201).

The type of vehicle movement during training has a major influence on the interaction between a vehicle and the landscape. Straight or smooth turns impact the landscape to a lesser degree, while sharp turns can cause considerable damage to surface and shallow subsurface deposits (Affleck 2005:ii; Althoff et al. 2007:278-279; Anderson et al. 2005a:146). Sharp turns disturb a larger width of soil and cause deeper ruts than smooth turns or straight movement (Dale et al. 2005:385). Tracked vehicles tend to skid and drag on turns and this may cause greater lateral displacement of soil than wheeled vehicles; a higher force is required for a tracked vehicle to turn (Affleck 2005:16, 46; Li et al. 2007b:398). The

skidding effect during a tracked vehicle's turn can crush or uproot vegetation, displace soil, and compact soil; these are three major consequences of military vehicle movements that are explored in greater detail below (Fuchs et al. 2003:343).

The damage caused by tracked vehicles during turning—and presumably wheeled vehicles as well—is cumulative (Althoff and Thien 2005:174). Although most terramechanics researchers examine how a single vehicle of a particular type interacts with the environment, military vehicles do not operate individually during training. The type and intensity of a training scenario will determine how many and what types of vehicles—each with different static properties—are involved (Anderson et al. 2005a:146-147). Military vehicle formations during training that consist of multiple columns—which may pass over an area more than once (Affleck 2005:8)—will cause greater damage than more laterally dispersed vehicles (Herl et al. 2005:363-364).

The spatial characteristics of training are definitely a factor that needs to be considered when assessing potential impacts to cultural resources. For example, a heavily mechanized infantry battalion can include 100 tracked vehicles and requires up to 13,800 hectares for a “defensive operation” and up to 24,800 hectares for a “move to contact” exercise (Demarais et al. 1999:387). The frequency of vehicles crossing an area may range from light to heavy, and the nature of vehicle crossings might be random or patterned. As training within a particular area intensifies, the amount of the area covered by vehicle tracks increases, as does the level of disturbance (Anderson et al. 2005b:221). The resulting ad hoc network of unimproved roads can prove a significant source of erosion (Ayers et al. 2005:232). Damage to the landscape may persist for decades, as evidenced by the remnants of World War II training maneuvers still visible today in the Mojave Desert (Belnap and Warren 2002; Bischoff 2000; Gilewitch 2004; Lathrop 1983:275; Prose et al. 1987).

Military vehicles operate on training landscapes distributed across a variety of environments and at different times of the year. Seasonality and landscape characteristics together can influence the degree to which wheeled or tracked military vehicles impact a given training facility (Affleck 2005; Anderson et al. 2005a). Soil moisture content, strength, and type influence how much the environment is affected by military vehicle traffic (Affleck 2005:ii, 6; Bacon et al. 2008:169; Department of the Army 1994). Military vehicles driven over wet soils tend to more adversely impact a landscape than vehicles driven over dry soils. For example, lighter vehicles at Fort Hood, Texas, left no visible traces of their passage during dry periods, but during wet periods severe damage was generated that lasted more than a year (Anderson et al. 2005b:215; see also Department of the Army 1994:7-27).

Johnson and Campbell (2004:121) assert that heavy military traffic during periods of wet conditions will severely damage artifacts within the upper meter of deposits—perhaps more—or at least affect the contexts of artifacts. Stickiness and the potential for vehicles to accumulate soil—and “pick up” artifacts—are higher in wet, fine-grained soils (Department of the Army 1994:7-1). Affleck (2005:ii, 1, 53-55) noted that, in Alaska, damage from military vehicles is greatest during the spring thaw season when the soil is saturated and weakened, leading to increased slippage and loss of traction, and resulting in severe rutting. During the winter, on the other hand, the ground is frozen and has greater strength, meaning

that disturbances caused by vehicle movement are minimal (Affleck 2005; Shoop et al. 2005:288).

4.2 Biological Communities and Military Vehicles

There exists a strong concern with the impact of military training vehicles on biological communities, especially vegetation, because a threshold can be reached beyond which the damage becomes too great for natural recovery of original plant communities (Althoff et al. 2007; Anderson et al. 2005; Demarais et al. 1999:386; Kade and Warren 2002; Lathrop 1983). With notable exceptions, the impact of military vehicle training on cultural landscapes is generally ignored in these studies. Unlike biological communities, cultural resources cannot recover “naturally” during rest periods if military training causes sufficient damage for an archaeological site to lose physical integrity, information potential, and eligibility to the NRHP. However, examining ecological damages resulting from military vehicle training is our best proxy for understanding the impacts of military vehicles on archaeological sites (Zeidler 2004:1). Although not specifically addressed in the archaeology or terramechanics literature, disruption of native ecosystems and other features of the landscape by military vehicle training can impede the archaeologist’s ability to collect data from off-site locations integral to examining past settlement-subsistence systems, in addition to directly impacting individual archaeological sites.

The emphasis in the terramechanics and ecological literature on the interaction between military vehicles and vegetation is unsurprising for two principal reasons. First, the physical integrity of any given landscape depends on the structure and health of its ecological communities. Plants reduce the degree to which rain impacts soils, decrease runoff by increasing surface roughness, and their roots help bind soils, decreasing erosion (Fuchs et al. 2003:346). Dense surface vegetation also minimizes the impact military vehicles have on natural—and cultural—landscapes. For example, areas with dense vegetation in Alaska show shallower ruts, and less soil displacement (Affleck 2005:55). Consequently, sufficient vegetation cover can mitigate damage to cultural remains located at or near the surface.

Second, many aspects of vegetation damage caused by the passage of military vehicles across the landscape are readily visible to even the casual observer. Military vehicles can shear, crush, and uproot plants (Affleck 2005:1; Althoff and Thien 2005:173; Huagen et al. 2003:84). Damaged vegetation can result in loosened soil surfaces and lead to increased erosion, particularly in areas that are left devoid of vegetation (Adams et al. 1982:167-168; Brooks and Lair 2005:7; Caldwell et al. 2006:457). Some fragile landscapes, such as deserts, can be disrupted for decades or even millennia following a single pass from a wheeled or tracked vehicle (Fuchs et al. 2003:343; Kade and Warren 2002:232; Lathrop 1983:275). Removal of desert vegetation creates bare ground that forms an impermeable soil crust (Fuchs et al. 2003:350). Disturbance of vertical vegetation (e.g. not just ground cover) can also prove problematic, as this can lead to increased wind erosion (Grantham et al. 2001). The greatest impact to plant communities usually happens in the first few passes (Yorks et al. 1997:121).

Other impacts to vegetation may be delayed and indirect and can affect vegetation growth, including the ability for plants to recover after training operations. Root systems might be damaged through training and compaction of soil can adversely alter water and nutrient cycling (Affleck 2005:1; Althoff and Thien 2005:173). Plant growth and revegetation are slow on compacted soils, partly because seedlings cannot penetrate compacted soils (Adams et al. 1982:167-168; Dale et al. 2005:196; Davenport and Switalski 2006:344; Lathrop 1983). These disturbances can lead to loss of wildlife habitat, disrupting faunal communities key to the health of an ecosystem, including earthworms and nematodes that live in the soil (Althoff et al. 2007; Althoff and Thien 2005:171-172; Demarais et al. 1999:385; Garten et al. 2003:172).

The native ecosystem can also be disrupted by the introduction of invasive plants carried into an area by tracked or wheeled vehicles (Althoff et al. 2007:269; Milchunas et al. 2000:525-526), resulting in conditions that may differ from a preferred training scenario. One major measure of military vehicle impacts on the landscape is *impact severity*, which is related to vegetation damage or removal and the amount of bare soil exposed in a vehicle's track. Impact severity is usually greatest when vehicles make a sharp turn at a high speed (Affleck 2005:9, 15-16, 55; Li et al. 2007a:214, 2007b:398).

4.3 Rut Formation and Military Vehicles

Vehicles moving across the landscape affect more than the stability, structure, and viability of plant and animal communities. Soil deformation and displacement, especially in the form of rutting, are significant and highly visible consequences of military vehicle training activities (Affleck 2005:ii) and can have a direct impact on archaeological sites. As outlined above, archaeological sites often consist of cultural remains at or near the surface, and the eligibility of a site to the NRHP is usually dependent at least partly on its physical integrity. Movement of vehicles across the landscape can disaggregate soil and decrease micro-topographic variation by smoothing slopes, with both processes leading to sediment loss (e.g. erosion) and decreased plant development (Affleck 2005:1; Brooks and Lair 2005:7; Diersing et al. 1988; Iverson et al. 1981:916; Sampson 2007). The amount of soil displaced as a result of vehicle movement increases in volume as the turning radius of a vehicle increases and also with the number of times a vehicle passes through a particular area (Affleck 2005:41-53). Additionally, moisture and soil type influence the amount of soil deformation generated from a vehicle's movement (Althoff and Thien 2005:174).

Affleck (2005:15) presented terminology useful for understanding the impact of wheeled or tracked vehicles on the landscape. Soil deformation consists of:

- Imprints:* soil and vegetation compressed in vehicle tracks;
- Scrapes:* soil and vegetation stripped away from vehicle tracks; and,
- Piles:* soil and vegetation displaced from vehicle tracks and piled on one or both sides of a track.

These can combine to form ruts, a topic of particular interest to terramechanics researchers. Damages caused by vehicle movements extend beyond the ruts themselves. Surface water flow is concentrated by ruts, depending on their orientation, slope, soils, and position on the landscape, and these ruts can increase erosion (Halvorson et al. 2001:143).

Ruts are formed when soil is compacted or displaced laterally and/or longitudinally (Liu et al. 2009:49). Essentially, ruts form when a vehicle's load is greater than a terrain's bearing capacity, which is particularly weak in soft soils (Affleck 2005:ii; Hambleton and Drescher 2008:201; Jones et al. 2005:246; Liu et al. 2009:49). In addition to vehicle load, vehicle 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 influence rut geometry (Halvorson et al. 2003:2; Sullivan and Anderson 2000:27). Rut width and depth increase when a vehicle turns and rut depth is also related to speed for some vehicles (Affleck 2005:8; Li et al. 2007b; 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, 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).

Quantitative data exist on the physical characteristics of ruts that reveal how military vehicle training can disturb an archaeological site (Figure 4.1). Ruts are measured in terms of:

Depth: the vertical distance between the bottom of a track and undisturbed soil immediately adjacent to the track (Affleck 2005:27; Liu et al. 2009:49). Depth may be used to subdivide ruts into minor (less than 7 centimeters), moderate (7-15 centimeters), and severe (greater than 15 centimeters) categories (Shoop et al. 2005:298).

Disturbance height: the vertical distance of the disturbed soil ridge, i.e. pile, relative to the undisturbed soil immediately adjacent to a track. This variable is measured for the inside and outside portions of the same track, and is 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 of the width of the displaced soil and vegetation impacted by a vehicle (Liu et al. 2009:49).

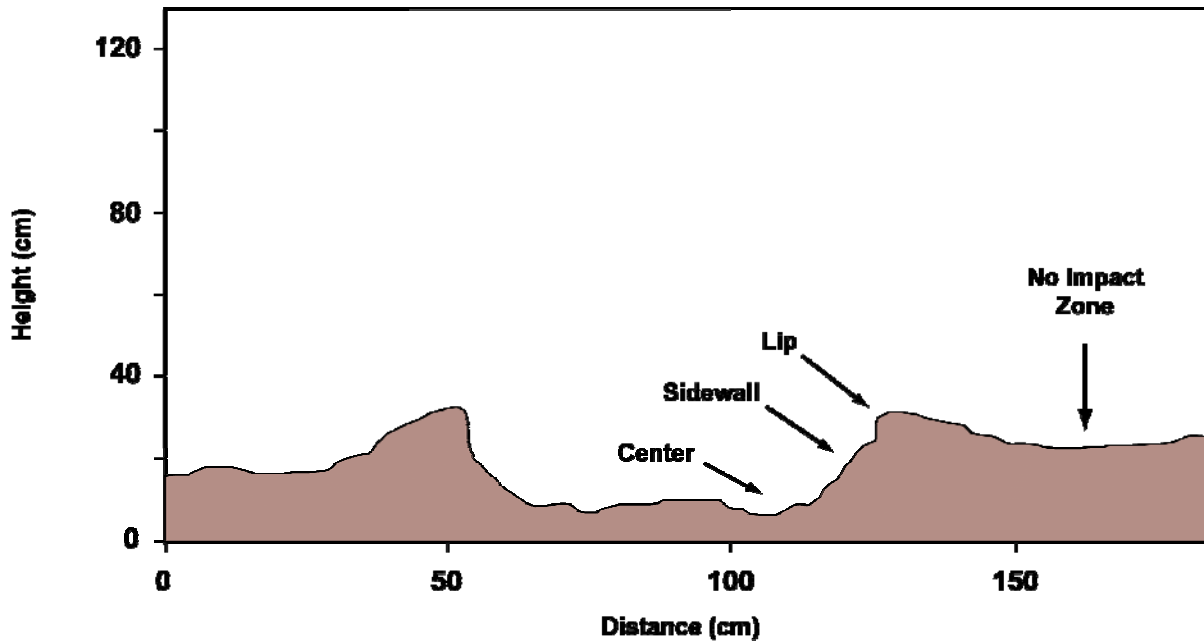


Figure 4.1: Schematic Illustration of a Hypothetical Rut.

These three variables can be extrapolated to examine how archaeological sites are affected by military vehicle movements. Measurements of rut depth can indicate to what extent surface and subsurface deposits have been impacted, and whether disturbance from a military vehicle exceeds that of other site formation processes, such as plowing.

Interestingly, rut depth may not indicate the total depth to which a vehicle has impacted a site. During rut formation, the surface “bounces” back so that the depth of direct impact from a vehicle is deeper than the measured rut depth (Hambleton and Drescher 2009:36). How much a site’s remains are displaced from their original contexts is reflected in the disturbance height measurement, although knowing the volume of the pile would be a stronger indicator. A clearer indication of how much a military vehicle disturbs an archaeological site would need to integrate measurements of rut depth, width, and disturbance height with the width of the track or tire that created the rut. Unfortunately, all three of the rut metric variables are not consistently measured by researchers, who usually focus on only one of the three dimensions of a rut.

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 centimeters in normal training conditions, while all tracked and wheeled vehicles exhibited depths greater than 2.54 centimeters for wet conditions. The heaviest tracked vehicles had ruts greater than 12.5 centimeters. Under the most severe training conditions in Germany, rut conditions for the heaviest vehicles can reach almost 5 centimeters for dry conditions and approximately 18 centimeters for wet conditions (Jones et al. 2005). In these cases, rut depth does not exceed the maximum thickness of the plowzone. 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).

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 training vehicles (e.g. Jones et al. 2005; Shoop et al. 2005). The study by Li et al. (2007b) 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. Vehicle parameters are summarized in Table 4.1 and available rut dimensions are presented in Table 4.2.

The high mobility multipurpose wheeled vehicle (HMMWV) is the lightest wheeled military vehicle with rut data, with ruts ranging in projected depth from 2.54 centimeters to as many as 25 centimeters (Jones et al. 2009; Shoop et al. 2009). Experimental research by Liu et al. (2009) near Yuma, Arizona, produced ruts ranging in depth from one to six centimeters. Unlike the studies that rely on analytical models, Liu et al. (2009) did not confine themselves to a consideration of rut depth, but also measured rut width. The HMMWV produced ruts ranging in width from 20 to 100 centimeters, with the widest (and deepest) ruts created when the vehicle's turning radius was less than 200 centimeters. The only other wheeled vehicle with rut width measurements is the Stryker. In spring thaw conditions, ruts were measured as wide as 174 centimeters and as deep as 38 centimeters (Affleck 2005). Arizona and Alaska represent relatively extreme and atypical environmental conditions within the U.S. but similar data involving direct measurements of field data are not widely available for other regions. The heaviest wheeled military vehicle with available rut data is the heavy expanded mobility tactical truck (HEMTT) with rut depth reaching up to 61 centimeters in wet soil during the spring in Wisconsin (Affleck 2005). Depths projected from an analytical model applied to wet and dry conditions in Germany and Jordan saw shallower depths ranging from 2.54 centimeters to greater than 12.7 centimeters (Jones et al. 2005).

The lightest tracked military vehicle with projected rut data is the small unit support vehicle (SUSV), with rut depths in Alaska estimated at up to almost 5 centimeters (Shoop et al. 2005). The M1A1 tank is the heaviest tracked military vehicle with measured rut depths at Fort Riley, Kansas, of more than 8 centimeters for a wet, silty clay loam and 12 centimeters for a dry, silty clay loam (Althoff and Thien 2005:168). Interestingly, in this case, the dry depth of the rut was greater than the wet depth of the rut—which seemingly contradicts most other statements on these data. Li et al. (2007b) measured M1A1 tank ruts ranging from 50 to 95 centimeters wide, with the widest ruts formed when the vehicle's turning radius was less than 400 centimeters. As one can see from Table 4.2, wheeled vehicles generally are capable of creating wider and deeper ruts than tracked vehicles.

Table 4.1: Military Vehicle Parameters.

Vehicle type	wheeled or tracked	Vehicle dimensions		total wt (kg)	wt (kg) per tire/track	contact pressure (kPa)	tire/track width (cm)	track length (cm)	Reference
		length (cm)	width (cm)						
Wheeled Vehicles									
HMMWV	wheeled	457	179	2608		123	31.8		Jones et al. 2005; Liu et al 2009; Shoop et al. 2005
M35A2 cargo truck	wheeled	683.3	243.8	6137					Olive-drab.com 2008
LAV (light armored vehicle) 25	wheeled	638	250	12546		126			Shoop et al. 2005
Stryker LAV	wheeled	698	230	13930		483	28.9		Affleck 2005:14, 18, 36, 38; Liu et al 2009
LAV Gen3	wheeled	692	265.4	17877		182	31		Affleck 2005:14
HEMTT (Heavy Expanded Mobility Tactical Truck)	wheeled	917	244	27386	3,423	121	40.6		Affleck 2005:14, 18, 36, 42
Tracked Vehicles									
M2 Light Tractor (1940s)	tracked	281.94	157.48	1021		39.23	20.3		Belnap and Warren 2002:249-250; War Department 1942:3
SUSV (small unit support vehicle)	tracked	689	185	3283	2399.5	13			Shoop et al. 2005
M113A1 armored personnel carrier	tracked	488	268.7	10614	6,164	51	38.1	276.9	Affleck 2005:14
M577A2 (armored personnel carrier)	tracked	485	269	11700			38	264	Li et al 2007b
M548 (tracked cargo carrier)	tracked	584	269	12800			38	277	Li et al 2007b
M2A1 fighting vehicle	tracked	533		22590					Jones et al. 2005
D7 bulldozer	tracked	693.4	365.8	22679					Olive-drab.com 2008
M3/M4 Sherman Tank (1940s)	tracked	533	259	32205		88.26	58.4	609.6	Belnap and Warren 2002:249-250; Bischoff 2000:47
M60A3	tracked	639.4	363.2	52617		76.5	71.1	434.3	Affleck 2005:14, 18, 36, 42
M1A2 (Abrams)	tracked	790	337.6	57154	31,751	94.14	64		Halvorson et al. 2001
M1A1	tracked	903	366	57200		98	63	455	Li et al 2007b

Table 4.2: Rut Data.

Vehicle type	Location	Passes	Terrain	Vegetation	Soil Type	Soil moisture general	Season/ date	Rut dimensions			Reference	Study type
								Depth (cm)	Width (cm)	Soil displacement x 10 ² (cm ³ /m)		
HMMWV	Yuma, Arizona	4 (spiral)		Colonial bentgrass	sand	8.9% by dry weight basis		1 to 6 (Liu et al.)/up to 25 (Shoop et al.)	20-100 cm		Liu et al 2009; Shoop et al. 2005)	Experimental field test (Liu et al. 2009) and Analytical model (Shoop et al. 2005)
HMMWV	Germany					dry		2.54			Jones et al. 2005	Analytical model
HMMWV	Germany					wet		2.54 to 7.62			Jones et al. 2005	Analytical model
HMMWV	Jordan					dry		2.54			Jones et al. 2005	Analytical model
HMMWV	Jordan					wet		2.54 to 5.08			Jones et al. 2005	Analytical model
M35A2	Germany					dry		2.54			Jones et al. 2005	Analytical model
M35A2	Germany					wet		2.54 to >12.7			Jones et al. 2005	Analytical model
M35A2	Jordan					dry		2.54			Jones et al. 2005	Analytical model
M35A2	Jordan					wet		2.54 to 10.16			Jones et al. 2005	Analytical model
LAV 25	Alaska										Shoop et al. 2005	Analytical model
Stryker LAV	Fort Lewis, Washington	10 (spiral)			sandy loam	37.1 % by dry weight basis		0 to 9	20 to ~140		Liu et al 2009	Experimental field test
Stryker LAV	Donnelly Training Area, Alaska: Arkansas Range	1 to 13	flat, non permafrost	grass/ short bushes	silty sand	wet soil	Spring	5 to 30	0 to 100	145 to 2393	Affleck 2005:14, 18, 36, 38, 64	Experimental field test
Stryker LAV	Donnelly Training Area, Alaska: Arkansas Range	1 to 13	flat, non permafrost	grass/ short bushes	silty sand	drier soil	Spring	0 to 11			Affleck 2005:14, 18, 36, 38	Experimental field test
Stryker LAV	Donnelly Training Area, Alaska: Eddy Drop Zone	13	flat, non permafrost	sparse vegetation	silty sand	deep thaw	Spring	10 to 38	0 to 174	474 to 1825	Affleck 2005:14, 18, 36, 38, 64	Experimental field test
Stryker LAV	Donnelly Training Area, Alaska: Eddy Drop Zone	1 to 8	flat, non permafrost	dense vegetation	silty sand	shallow thaw	Spring	0 to ~17			Affleck 2005:14, 18, 36, 38	Experimental field test
Stryker LAV	Donnelly Training Area, Alaska: Texas Range	1 spiral	gently sloping, permafrost	spagnum moss, sedge, shrub	peat, organics		Spring	0 to 12	0 to 30.4	0 to 613	Affleck 2005:14, 18, 36, 39, 64	Experimental field test
Stryker LAV	Alaska							up to 45			Shoop et al. 2005	Analytical model
LAV Gen3									0 to 40		Affleck 2005:14	Experimental field test
HEMTT	Fort McCoy, Wisconsin		gently sloping, seasonal frost	wooded trail	silty sand	wet soil	Spring	10 to 61			Affleck 2005:14, 18, 36, 42, 65	Experimental field test
HEMTT	Fort McCoy, Wisconsin		gently sloping, seasonal frost	wooded trail	poorly graded sand w. silt	dry soil	Spring	~10 to 35			Affleck 2005:14, 18, 36, 42	Experimental field test
HEMTT	Jordan					dry		2.54 to 5.08			Jones et al. 2005	Analytical model
HEMTT	Germany					dry		2.54			Jones et al. 2005	Analytical model
HEMTT	Germany					wet		2.54 to >12.7			Jones et al. 2005	Analytical model
HEMTT	Jordan					wet		2.54 to >12.7			Jones et al. 2005	Analytical model
Tracked Vehicles												
SUSV	Alaska							0 to < 5 cm			Shoop et al. 2005	Analytical model
M113A1							Summer		0 to ~95		Affleck 2005:14,51	Experimental field test

Table 4.2: Rut Data.

Vehicle type	Location	Passes	Terrain	Vegetation	Soil Type	Soil moisture general	Season/date	Rut dimensions			Reference	Study type
								Depth (cm)	Width (cm)	Soil displacement x 10 ² (cm ³ /m)		
M113A1	Grafton South State Military Reservation, North Dakota	37, 74	footslopes	grasslands	coarse loamy or coarse silty		August				Prosser et al. 2000	Experimental field test
M113A1	Germany					dry		2.54 to 10.16			Jones et al. 2005	Analytical model
M113A1	Germany					wet		2.54 to >12.7			Jones et al. 2005	Analytical model
M113A1	Jordan					dry		2.54 to 10.16			Jones et al. 2005	Analytical model
M113A1	Jordan					wet		2.54 to 10.16			Jones et al. 2005	Analytical model
M577A2	Fort Riley, KS								30 to ~60		Li et al 2007b	Analytical model & Experimental field test
M548	Camp Atterbury, Indiana								40 to 75		Li et al 2007b	Analytical model & Experimental field test
M2A1	Germany					dry		2.54 to >12.7			Jones et al. 2005	Analytical model
M2A1	Germany					wet		2.54 to >12.7			Jones et al. 2005	Analytical model
M2A1	Jordan					dry		2.54 to >12.7			Jones et al. 2005	Analytical model
M2A1	Jordan					wet		2.54 to >12.7			Jones et al. 2005	Analytical model
M60A3	Fort McCoy, Wisconsin	1 to 50	gently sloping, seasonal frost	wooded trail	silty sand	wet soil	Spring	10 to 61			Affleck 2005:14, 18, 36, 42, 65	Experimental field test
M60A3	Fort McCoy, Wisconsin	1 to 50	gently sloping, seasonal frost	wooded trail	poorly graded sand w. silt	dry soil	Spring	~15 to 20			Affleck 2005:14, 18, 36, 42	Experimental field test
M1A2	Yakima Training Center, Washington							2 to 15	64		Halvorson et al. 2001	Experimental field test
M1A2	Germany					dry		5.08 to >12.7			Jones et al. 2005	Analytical model
M1A2	Germany					wet		5.08 to >12.7			Jones et al. 2005	Analytical model
M1A2	Jordan					dry		5.08 to >12.7			Jones et al. 2005	Analytical model
M1A2	Jordan					wet		5.08 to >12.7			Jones et al. 2005	Analytical model
M1A1	Fort Riley, Kansas	5		grasslands	silty clay loam	wet soil	May	2+ to 8+			Affleck 2005:14; Althoff and Thien 2005:168	Experimental field test
M1A1	Fort Riley, Kansas	5		grasslands	silt loam	wet soil	August	0+ to 7			Affleck 2005:14; Althoff and Thien 2005:168	Experimental field test
M1A1	Fort Riley, Kansas	5		grasslands	silty clay loam	dry soil	May	4 to 12			Affleck 2005:14; Althoff and Thien 2005:168	Experimental field test
M1A1	Fort Riley, Kansas	5		grasslands	silt loam	dry soil	August	8 to 11			Affleck 2005:14; Althoff and Thien 2005:168	Experimental field test
M1A1								up to 45			Shoop et al. 2005	Analytical model
M1A1	Fort Riley, Kansas								50 to 95		Li et al 2007b	Analytical model & Experimental field test

Ruts formed by moving military vehicles would clearly impact surface and shallow subsurface cultural deposits. Mechanized military training is most often on flat and open terrain (Demarais et al. 1999), which, in many cases, represents formerly plowed fields. In a plowed field, except in extreme conditions such as during spring thaws in Alaska, a single wheeled or tracked military vehicle will generally not create a rut deeper than the reach of blades from modern tillage equipment used during normal plowing operations. Plowing truncates those portions of archaeological features that extend into the plowzone and vertically and laterally moves cultural objects—but not as far as one might expect, as shown in Section 3. Farmers using tillage equipment also generally follow set linear and parallel paths across a field that they change infrequently—if at all.

While ruts created under training circumstances may not exceed the reach of tillage equipment during normal operations, the manner in which ruts are formed indicates that even shallow ruts could generate a significant impact to cultural deposits that is not neutral relative to the damage cause by tillage equipment. The creation of a rut by a moving vehicle leads to the horizontal displacement of soil—and the re-deposition of cultural deposits within that soil—to either side of each tire or track. Subsequent passages by a military vehicle would not necessarily displace this soil back toward its original horizontal location. Efforts to restore the landscape by smoothing out and filling ruts could further disrupt the distribution of cultural objects that had been displaced when the ruts were originally formed.

Whether in a plowed or unplowed field, cultural objects displaced vertically in the piles formed by ruts would become more susceptible to damage by other passing vehicles due to their elevated position above the original ground surface. The vertical position of cultural remains within these piles might also be inverted, with older materials atop newer materials. Multiple moving military vehicles—each with different static properties—may or may not follow linear and parallel paths during training scenarios, and could result in considerable impact to surface and subsurface cultural deposits that might be displaced in an essentially random fashion. Impacts to cultural deposits would be more pronounced where the tracks of vehicles intersect and would be very severe when vehicles are turning—especially if the turning radius is relatively small. An M1A1 tank, for example, can potentially create a rut that measures 45 centimeters deep and 95 centimeters wide in cross-section during a narrow turn (Li et al. 2007b; Shoop et al. 2005). Erosion of rut piles and within the rut itself could lead to further impacts on cultural deposits long after training within a particular area had ceased. Multiple military vehicles of varying types moving across a landscape during active training operations likely would cause cumulative damage and generate deeper and wider ruts, but currently there exists insufficient information to determine the maximum amount of soil displaced vertically and horizontally by the formation of multiple ruts.

4.3 Soil Compaction and Military Vehicles

Ruts are a highly visible consequence of military vehicle training activities and can be readily measured to estimate potential damage to surface and shallow subsurface cultural deposits. However, not all damage caused by military vehicle movements produces visible evidence on the landscape. Military vehicles can cause significant soil compaction even if there are no

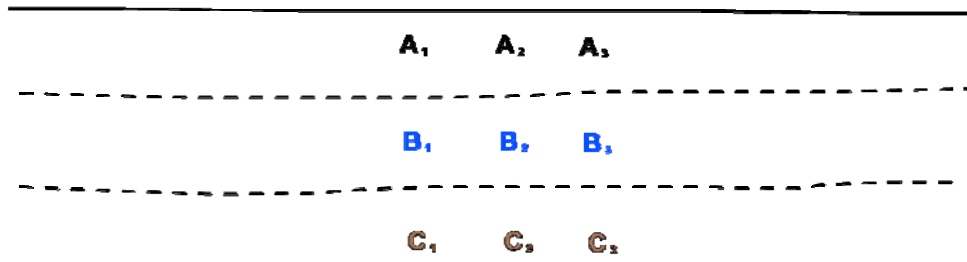
other obvious traces of military training activities (Raper 2005:262). Soil compaction results when vehicles—as they travel across the landscape—reduce the volume of air in the soil, pushing the mineral components together (Affleck 2005:4; Dregne 1983; Palazzo et al. 2005:178; Raper 2005:259; Sojka 1999; 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). Soil compaction slows water infiltration, and this can lead to changes in soil chemistry, organic content, and hydrology, as well as increased runoff and 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.

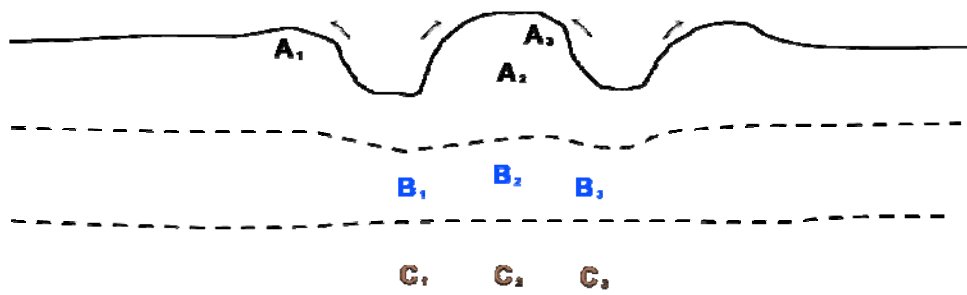
Compacted soil layers may not be present near the surface but rather exist deeper in a profile (Halvorson et al. 2001:149). Soil compaction has been recorded to depths greater than one meter, although more typically soil compaction resulting from vehicle traffic is evident between 5 and 30 centimeters 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). Fine-textured soils typically see greater compaction from vehicular traffic than 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 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; Dale et al. 2007:6; Ouren et al. 2007:6; Raper 2005:270-276).

The degree of soil compaction created by the movement of military vehicles is related to a vehicle's mass and weight; soil compaction increases as a vehicle's load increases. Increased frequency of vehicle traffic over a given area by vehicles carrying smaller loads can lead to a similar degree of soil compaction (Adams et al. 1982:167; Raper 2005:259) (Figure 4.2). Soil compaction is influenced by other vehicle static properties, including tire/track geometry and pressure distribution at the ground surface (Webb 1983:62). Narrow, well-inflated tires can cause significant soil compaction, as well as deep ruts (Raper 2005). Vehicle dynamic properties—notably speed—can influence soil compaction. Slower vehicles tend to cause more compaction than faster vehicles, although faster vehicles typically cause greater surface disruption (e.g. ruts) (Belnap and Warren 2002:250; Webb 1983:63). However, soil moisture has a greater influence on soil compaction than vehicle static or dynamic properties (Webb 1983:63).

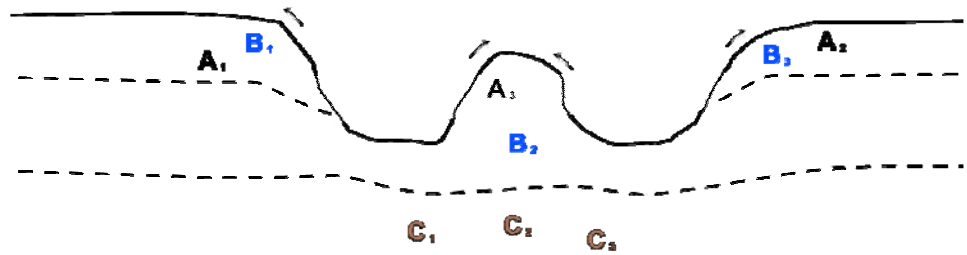
Original State



One Pass



Multiple Passes



Eventual State

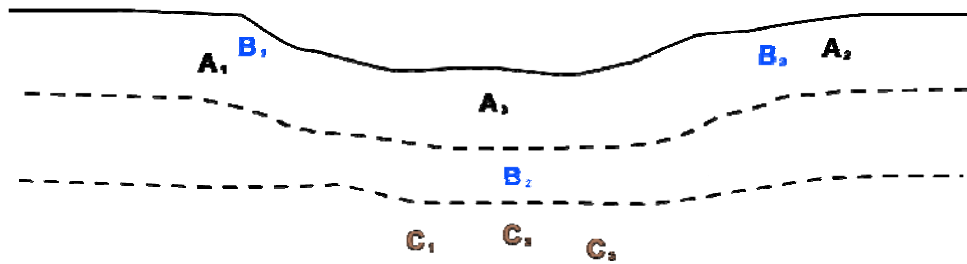


Figure 4.2: Schematic Illustration of Three Hypothetical Soil Layers Affected by Rut Formation and Soil Compaction. Letters represent individual artifacts.

The first passes of a vehicle generally cause the greatest degree of soil compaction, with additional soil compaction decreasing logarithmically as the number of passes increases (Iverson et al. 1981:915; Lei 2004:129). This situation arises because soils can reach close to their maximum compaction after the first few passes of a vehicle, depending on vehicle type and size, as well as soil characteristics (Lei 2004:129). The greatest recorded increase in soil strength is for the tracked M113A1 armored personnel carrier operating in North Dakota which caused significant compaction in levels between 0 and 15 centimeters, and 30 to 60 centimeters, but not between 15 and 30 centimeters (Table 4.3) (Prosser et al. 2000:668).

Soil compaction by military vehicles can persist for decades even in areas not subjected to subsequent traffic (Althoff et al. 2007:278; Belnap and Warren 2002:245-249; Gilewitch 2004:251-255). Gilewitch (2004:251-255) documented compacted soils to 20 centimeters in depth within tracks left behind by World War II military vehicle training maneuvers in the deserts of western Arizona. Compaction caused by tanks travelling across the landscape may be responsible for pushing desert pavement downward to between 2 and 4 centimeters below the surface (Belnap and Warren 2002:250), in a process analogous to trampling. In other studies, significant soil compaction has been recorded for depths greater than 50 centimeters below the surface for military vehicles with heavy axle loads (Prosser et al. 2000:668). The data for soil compaction from wheeled military vehicles are limited, but Adams et al. (1982) have recorded increased soil strength depth for a Ford Bronco and a Yamaha motorcycle, with the greatest depth at 25 centimeters for a Ford Bronco operating on wet loamy sand/coarse sand (Table 4.3).

Table 4.3: Soil Compaction Data.

Vehicle type	Location	Terrain	Vegetation	Soil Type	Soil moisture general	Mean bulk density (g/cm ³)	Increased Soil Strength depth (cm)	Month	Reference
Military Transportation									
M2 Light Tractor	Mojave Desert, California	desert	shrubs	sandy loam	dry soil		5 & 10 cm	April	Belnap and Warren 2002:249-250
M113A1	Grafton South State Military Reservation, North Dakota	footslopes	grasslands	coarse loamy or coarse silty			0 to 15, 30 to 60	August and September	Prosser et al. 2000
D7 bulldozer	Fort Benning, Georgia		secondary growth pine forests			Treatment: 1.44 ± 0.026 ; control: 1.28 ± 0.058 (Dale et al. 2005); Treatment: 1.32 ± 0.05 ; control: 1.13 ± 0.03 (Garten and Ashwood 2004)	significant only in 0-10 cm		Dale et al 2005; Garten and Ashwood 2004
M3/M4 Sherman Tank	Mojave Desert, CA	desert	shrubs	sandy loam	dry soil		5 & 10 cm		Belnap and Warren 2002:249-250
M1A2	Yakima Training Center, Washington		grasslands	loess	wet soil	in rut: 1.4; adjacent to rut: 1.1	10 to 22.5	December	Halvorson et al. 2001, 2003
M1A1	Fort Riley, KS	level and gently sloping uplands	grasslands	silty clay loam	wet soil	~1.17		May	Althoff and Thien 2005:168
M1A1	Fort Riley, KS	level and gently sloping uplands	grasslands	silt loam	wet soil	~1.13		August	Althoff and Thien 2005:168
M1A1	Fort Riley, KS	level and gently sloping uplands	grasslands	silty clay loam	dry soil	~1.13		May	Althoff and Thien 2005:168
M1A1	Fort Riley, KS	level and gently sloping uplands	grasslands	silt loam	dry soil	~1.05		August	Althoff and Thien 2005:168

Table 4.3: Soil Compaction Data.

Vehicle type	Location	Terrain	Vegetation	Soil Type	Soil moisture general	Mean bulk density (g/cm ³)	Increased Soil Strength depth (cm)	Month	Reference
Non-military Transportation									
Ford Bronco	Mojave Desert, CA	desert	shrubs	loamy sand/ coarse sand	wet soil		25	August	Adams et al. 1982
Ford Bronco	Mojave Desert, CA	desert	shrubs	loamy sand/ coarse sand	dry soil		15	August	Adams et al. 1982
Yahmaha motorcycle	Mojave Desert, CA	desert	shrubs	loamy sand/ coarse sand	wet soil		20	January	Adams et al. 1982
Yahmaha motorcycle	Mojave Desert, CA	desert	shrubs	loamy sand/ coarse sand	dry soil		10	January	Adams et al. 1982

5.0 SOIL MECHANICS AND SOIL DEFORMATION

Military training exercises carried out on an archaeological site clearly will have an impact on site integrity. The extent and amount of impact, how much actual effect such exercises have on critical site information, and how to measure that impact, however, is less well understood. Sites exist as an integral part of the landscape in which they developed. Thus, site and landscape development goes hand in hand and each carries important data related to human settlement systems. Moreover, the specific landform on which sites are situated also existed prior to human occupation, and the site and associated landscape continued to change long after the site was abandoned through deposition, erosion, weathering, biological processes, etc. Distinguishing changes in the relationships between artifacts, features, and landscape wrought by post-occupation alterations from those of the original contexts is vital. These relationships were discussed in Sections 3 and 4 above, particularly in relationship to what makes a site significant, the factors that destroy significance, and the impact of military vehicles moving across training landscapes.

Site formation processes include artifacts destroyed through pedogenesis, features disturbed by burrowing animals or tree roots, and soil processes that alter the geochemistry of features or displaced artifacts. Erosion can realign artifact relationships or sedimentation can bury site horizons. Although most site formation processes are deleterious to site integrity, a few, such as alluviation, may act to preserve and protect the site from further degradation. Regardless, in order to recognize and otherwise deal with the alteration or destruction processes that may act on an archaeological site during military training exercises, the natural processes that are part of archaeological site formation during occupation, as well as the overall changes that occurred after site abandonment, must be understood. These can best be addressed through the concepts of archaeological content and the contextual relationship of the content within the site. From this standpoint, activities that represent destructive processes to archaeological site integrity within a military training area are those that act to destroy or dramatically alter either the content (e.g., artifacts, bone, etc.) and/or the contexts of that material culture (e.g., features or spatial relationship between artifacts, etc). While some discussion was given in Section 3 to the site formation process, further presentation is warranted here, especially in how these processes relate to landscape, pedology, and site formation processes.

5.1 The Importance of Context and Content at Archaeological Sites

One of these most important elements marking the scientific value and historical significance of archaeological sites is the preservation of context. Archaeological materials, particularly artifacts or features, are themselves of very limited value divorced of their site-landscape contexts and relationships. The record of occupation at a site itself also exists within the context of the surrounding landscape. The preservation of site features and landscape relationships are critical measures of the scientific value of the site because they ultimately provide the specific environmental context for the site. Context and the preservation of the relationships among artifacts and features at a site as well as how they relate to a site's landscape are critically important measures of the scientific value and NRHP eligibility for an archaeological site. These aspects were discussed above in terms of the criteria for determining NRHP eligibility. From a practical standpoint, the examination of site context focuses on the three-dimensional

distributions of both natural and cultural components within a site's landform, including site sediments, soils and archaeological additions. Much of our understanding of site context and landscape relationships is underpinned by the recognition that the site landform itself is of a different age and scale than the site. Both share a similar developmental history, although at the very least the site landform is older than, or its initial formation predates, human occupation. Additionally, changes in the landscape that are attributable to human occupation (both cultural and natural) are primarily within the surface and near-surface horizons and contexts. Importantly, this near-surface environment is also the most susceptible part of the landform to natural and human disturbances, including those related to military training exercises, and, consequently, also occupies the most detrimental landscape position for the preservation of cultural and natural contexts within the site.

Although the relationship between contents and contexts of an archaeological site and the natural landscape components are critical, the actual site and associated cultural materials are also important because they provide the record of cultural use of the landscape. Examination of site content includes the identification and characterization of cultural additions to the archaeological site. These data always carry information regardless of site formation processes, although the degree of usefulness of this information changes with the relative amount of alterations to their context. The archaeological site should be considered an integral part of the landform, with cultural effects noted as anomalous contributions to the non-cultural landscape, which means that the developmental history of both are intimately linked. These cultural components within the landform included obvious lithic and ceramic artifacts (or anomalous stone and stone-like additions of sediment), physical disconformities within the sediment and soil record (primarily noted as matrix-type features such as basins), and chemical anomalies attributable to archaeological additions.

5.2 Sediments and Soils in Relation to Archaeological Context and Content

Depositional and pedological characteristics of a site are important because they provide the background of landform development and can also provide a measure of archaeological integrity. 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 associated landscape, both natural and cultural (Foss et al. 1995; Waters 1992). Important distinctions exist between sediments and soils: soils are pedogenically modified sediments; sediments include unweathered and unconsolidated deposits and are not soils, even when derived from former eroded soils (Ferring 1986, 1992; Hassan 1978). Soils develop in sediments through processes of weathering (transformation, translocation, and removal of both physical and chemical components), and additions of new physical and chemical components (both geo- and biochemical), through infusions of new sediment, organic matter, precipitation, and atmospheric gasses (Birkeland 1984, Holliday 1990).

The relative preservation of sedimentological and pedological characteristics is strongly influenced by the length of time that a particular strata forms the contemporary ground surface. An actively aggrading landform environment favors preservation of sediment characteristics

(including archaeological sediments). A relatively stable environment (with little net accumulation of sediment) favors increased pedogenic weathering and an increase in accumulation of anthropogenic debris, sometimes in a midden-like deposit. An actively degrading (or eroding) environment may include truncation of surfaces, selective erosion and displacement of both natural and archeological sediments, and a general deflation of the stratigraphic record. These often result in a surface “lag” of archaeological material and destruction of all but deep features.

Geochemical analyses may indicate characteristics of a constituent sediment, as well as changes to original sediments due to both pedogenic and cultural influences. Geochemical characteristics are often relied upon to provide indices of cultural modifications to archeological sites (Ahler 1973; Entwistle 1999; Middleton and Price 1996; Proudfoot 1976; Sjöberg 1976; Stein 1992; Woods 1977). Beyond the base-level characteristics of the original sediment, chemical input is generally enhanced from the breakdown of introduced organic matter, much of which occurs naturally in a near-surface environment through the presence of a resident biotic community. Anthropogenic influences can intensify the additions of selective organic substances to a landscape, or discrete locations therein (such as hearths, storage basins, trash middens and burials).

The introduction of plant and animal foodstuffs and waste, organic artifacts, building materials and wood ash can modify soil acidity and result in increased soil organic matter content. Organic matter weathers into its constituent elements. Most notably, these include phosphorus, potassium, magnesium, calcium, strontium and barium. At archeological sites, phosphorus enrichment is intensified by accumulation of animal material (*i.e.*, bone, waste) (Monaghan and Schaetzl 1996). The amount and distribution of phosphorus and chemically similar elements (such as barium, calcium and strontium) are deemed particularly important because of their association with bone and teeth (Burton and Price 1990, Fricke et al. 1995). Molluscs, particularly from a marine source, are high in calcium and strontium (Burton and Price 1999). Similarly, as wood, ash, charcoal or other organic debris decay, they routinely leave some of their principal elements such as potassium, calcium, and magnesium as residuals in the soil (Kolb et al. 1990).

Each of these chemical elements, however, also interacts in the soil-weathering and plant-nutrient environment differently. Some are very mobile while others are relatively conservative. In particular, because of their chemical characteristics potassium, calcium, and magnesium are extremely mobile and may quickly leach, recycled from a near-surface environment or accumulate as parts of authogenic clays or oxides in subsurface soil B-horizons. In contrast, some phosphorus compounds are relatively conservative and less readily transported. Additionally these elements are very reactive and easily adsorbed onto mineral surfaces. They are also readily absorbed into the inter-lattice of expandable clay minerals and can often be associated with soil B-horizons. Thus, the background quantities of these elements, as well as their place in the soil environment, must be considered when examining landscape development.

5.3 Geoarchaeological Perspectives on Site Formation

From the standpoint of the preservation of cultural contexts, the near-surface environment is highly susceptible to physical and chemical changes that may include erosion, burial, weathering and biologic processes. The preservation of detailed contexts within the archaeological record is directly related to near-surface mean residence time of the archaeological stratum within the landform (Monaghan and Lovis 2005). Longer residence times in a near-surface context not only allow for more intense soil formation but also for the development of a thicker, more artifact-rich, and more easily recognized archaeological deposit. The downside of these circumstances is that the longer a deposit lies at the ground surface, more natural and human agents can act to disturb artifact and feature contexts. Conversely, rapid and deep burial generally preserves contexts because artifacts and features are isolated from direct surface disturbance and because they become stratigraphically separate from later occupation. Stratigraphic relationships that may be discerned within such settings can include indicators of the changing record of landform and site history, especially pertaining to processes of formation and preservation.

At the most simple level, archaeological sites form by the interrelationship between the rates and character of sediment deposition (i.e., naturally deposited mineral and organic material) and that of archaeological material (i.e., artifacts and features) (Monaghan and Lovis 2005; Monaghan et al. 2006). When the depositional rates of archaeological materials far exceeds the rate of natural sediment deposition, cultural debris accumulates on the contemporary ground surface and within near-surface features. Several centuries (or more) of occupations are often included in these surface/shallow subsurface sites and as a consequence can be thoroughly mixed by natural processes and by the continual reoccupation of the site.

When the rates of sediment deposition far exceed that of cultural deposition, on the other hand, a series of discrete, discontinuous, and often short-term archaeological occupation horizons form. The cultural horizons or strata are typically relatively thin, discontinuous, and separated by culturally sterile sediment. In effect, these circumstances form more clearly stratified sites. Such sites are relatively poor in artifacts compared to the surface/shallow subsurface sites but rich in context preservation because they were rapidly buried and removed from the deleterious effects of the near-surface pedogenic environment.

These two end member site types, shallow/subsurface mixed sites and stratified sites, form because of processes related to specific landforms on which a site develops. The stratified site requires that sediment rapidly accrete on the landscape, which is most commonly associated with alluvial landforms, but may also occur as a result of colluvial or eolian processes. The surface/shallow subsurface mixed site, conversely, is most commonly related to a non-depositional landform, such as an upland terrain or a high, rarely flooded terrace. However, it could occur on any landform as long as minimal deposition occurs during occupation. Further, cultural processes such as post-hole and pit digging continually mix the subsurface resulting in a thick deposit with no particular temporal order of the cultural materials located within the deposit. Given enough time, most of the earlier phases of the archaeological deposits are more or less mixed; many features may be commonly destroyed as more recent occupations continue to use a site's landscape. The thickness of this mixing zone relates mainly to cultural processes, for example, how deeply pits or post molds are dug.

Sediment accumulation causes the landform surface (and mixing zone) to rise. As the surface rises because of sediment additions, older buried components ultimately become isolated from the mixing zone because surface disturbances no longer penetrate deep enough to involve these components. Through time, this creates a thick, crudely stratified accreting mixing-zone deposit. The amount of integrity of cultural deposits and their context varies depending of the rate of sediment accretion, the depth of cultural turbation, and the length and intensity of cultural activity at the site.

5.4 Site Formation Processes and Integrity of Archaeological Deposits

Through time, natural formation processes continue to act on all archaeological sites. The closer the site occupation horizon is to the ground surface and the longer it lies in this pedogenic environment, the more deleterious these processes are to artifacts, sites and landscapes. Thus, no archaeological site maintains its content, contexts and relationships to the overall landscape in its original, unaltered state. The main point presented above is that the more rapidly and deeper a site is buried, which essentially removes it from near surface site formation processes, the less biological, cultural, and weathering processes act to disturb it and the more likely the original contextual relationship will be preserved.

Two significant, long-recognized biomantle processes are bioturbation and cultural turbation processes (Johnson 1989, 1990, 1992; Johnson and Balek 1991; Johnson and Watson-Stegner 1990). The later process is integral to the formation of the mixing-zone deposits described above, but also has several other important consequences. Typically, the biomantle process is considered from the perspective of natural, biological mechanisms and focuses on bioturbation activities. In essence, biomantle processes act to bury artifact horizons through a natural process whereby artifacts are introduced into the subsurface long after site abandonment by on-going soil mixing processes. This process was discussed previously in Section 3, particularly in relationship to gopher burrows.

From an archaeological perspective, the biomantle process has important implications for site integrity and must be considered when assessing the security and integrity of original site artifact and feature contexts. Site burial through biomantle processes has mixed cultural and stratigraphic contexts through natural processes and as such the all important relationship between site content and context, as well as that of site-landscape, has been altered. Although they can mimic in situ stratified sites, biomantle sites are actually disturbed and lack contextual integrity. Distinguishing such a site from a truly stratified context is important for assessing the potential for the site to provide information relevant to our understanding of the past and, in turn, its NRHP eligibility.

Biomantle site burial involves recycling of subsurface sediment upward mainly by worms and insects, but also by larger mammals such as gophers. As these organisms burrow and displace soil to the surface from deeper in the profile they progressively lower the surface soil horizon with its associated cultural material and effectively bury it by placing the subsoil on the ground surface (Johnson 1990, 1992). In addition, voids created by animal burrows or large roots may

fill in via gravity and sheet-washing with near-surface sediments including archaeological debris (Johnson and Balek 1991; Johnson and Watson-Stegner 1990).

As noted above, cultural turbation processes also can apparently bury subsurface artifacts as well (Monaghan and Hayes 2001; Monaghan and Lovis 2005). Instead of a post-depositional/post-occupational process implied by bioturbation, the cultural turbation mechanism maintains that artifacts become buried through cultural processes including deposition while a site is still occupied. Essentially, artifacts that appear to lie buried in the subsurface of the site actually mark the base of cultural features whose expression in the soil profile is so thoroughly disrupted by cultural and natural soil formation processes or so old and ephemeral that they can no longer be discerned. This is particularly common in well-drained, sandy soils. Unlike bioturbation, however, the associated subsurface artifacts are actually in place and were buried by cultural processes that are integral to the site itself (i.e., pit feature construction). The older the cultural features or the more intensive the weathering process (i.e., rapid leaching and oxidation in excessively well-drained sand), the less clear such features will be in a soil profile. Additionally, through time, feature construction often will displace older artifacts and, therefore, mask or confuse cultural stratigraphy.

5.5 Archaeological Site Integrity and Soils within a Military Training Context

The previous discussions highlight the fact that archaeological sites are never completely pristine. Their alteration is part of site formation processes and occurs at all sites. Furthermore, site formation processes begin to act on archaeological sites as soon as the first artifact is deposited and continue through the present, which is to say during occupation as well as after abandonment (Johnson 1989, 1992; Kolb et al. 1990). Site formation processes include natural processes, such as bioturbation and pedogenesis, as well as cultural processes, such as pit digging, shelter construction and post-occupation alteration through later use of the site landscape (Johnson 1989, 1992; Monaghan and Hayes 1998, 2001, 2002). The latter may include other human activity, such as plowing, urbanization, or military training. The intensity and amount of alteration these processes have on cultural deposits is largely dependent on the amount of time a site lies within near surface contexts (Monaghan and Lovis 2006).

The effects of site formation processes are cumulative; the longer a site is on or near the contemporary ground surface (i.e., within the surface pedogenic environment) the more these processes act to disrupt the original, purely cultural contexts and relationships among artifacts, sites and landscapes (Monaghan and Hayes 1998, 2001; Monaghan and Lovis 2005). Conversely, through rapid and deep burial within a landform, the original contextual relationships within a site will be more likely preserved because in deeply buried contexts fewer biological, cultural, and weathering processes can disturb the site (Ferring 1986; Holiday 1990; Monaghan and Lovis 2005). The identification of the near surface processes that act on sites is critical when designing mitigation plans or in enumerating the factors in training exercises that act on archaeological sites.

Far more archaeological sites are damaged or destroyed by human actions than through these natural processes (Wood and Johnson 1978). Within the United States, the most destructive of

these human processes are associated first (temporally) with the introduction of European agricultural practices (e.g., plowing) that homogenized the upper-most portions of many sites and then (later) by urbanization processes that often resulted in the total destruction of many other sites (Medford 1972; Williams and Corfield 2002). Military training and the construction and maintenance of associated infrastructure are also sources of site destruction (Carlson and Briuer 1986; Richardson and Hargrave 1998), although probably not nearly to the extent of agricultural impacts.

The most critical factors in understanding the effects of near surface process on site integrity include soil texture, vegetation, slope, and climate. These factors are actually not independent of each other. Slope and soil texture are also interrelated and greatly affect the potential for accelerated slope erosion and stability, both of which can greatly diminish site integrity. Soil compaction, deformation and displacement related to vehicular traffic on archeological site integrity are major concerns, as discussed in Section 4. These factors are especially affected by soil and sediment texture.

The persistence of soil compaction is determined by the depth at which it occurs, the shrink-swell potential of the soil, and the 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. Soil compaction can probably best be modeled as a temporary fragipan soil horizon that will affect soil moisture, vegetation, and runoff. Compaction is not cumulative but rather has an upper limit that is typically rapidly reached. Once reached, then essentially no further compaction, or related impacts to archaeological sites occurs. The actual compaction limits are variable and related to soil texture. While not cumulative, if the activity that causes the compaction occurs regularly, then the natural “healing” processes discussed above will not occur, which will ultimately affect soil moisture, runoff, and vegetation. For this reason, compaction on both agricultural and military training land is often “repaired” by mechanical means (i.e., deep plowing). As noted below, this indirect effect of compaction is what is actually most destructive to archaeological site integrity.

Compaction seems to be a particular concern in most evaluations of military training impacts to sites, but like an emphasis on such factors as rut depth and height, this emphasis is related partly to that fact that it can be measured than that compaction itself is necessarily a significant factor affecting site integrity. The concern with compaction, rut depth/height and other quantitative aspects of vehicular traffic begs several questions. For example, even if soil compaction is significantly greater than natural conditions, does that necessarily mean that it significantly affects site integrity? Are the forces involved great enough to break artifacts, dislodge them from their contexts, or damage features? Moreover, do broken artifact themselves actually significantly alter archeological site integrity or significantly degrade the NRHP eligibility of a site? Ultimately, the real concern with compaction, rutting, and other sediment/soil deformation is whether their occurrence significantly affects site integrity, not whether it occurs, the size of ruts, etc. The indirect effects of compaction and other soil deformations may be more significant than the direct effects, as discussed in Section 4.

In general, soil displacement issues, including rutting and compaction, are probably less significant as direct and immediate impacts than as indirect and longer-term effects. For

example, although compaction may on occasion break artifacts, which in the case of decorated historic and prehistoric ceramics may be significant, of greater concern is the typical remedy for fixing compaction – deep plowing. Deep plowing is quite destructive to archaeological sites because it can displace artifacts and destroy features up to 1.5 meters in depth, which is a far larger than the direct impact of compaction on archaeological sites. Similarly, revegetation of slopes often involves augering 0.6 to 0.9 meter deep holes for trees or plowing deep ruts into hill slopes to act as furrows for tree and shrub plantings. Rutting, if repaired at all, is typically addressed through disc plowing to remove the ruts, which itself is not particularly destructive to the site (at least no more so than associated agricultural practices), but does increase any horizontal displacement of artifacts and will also tend to further break more delicate artifacts.

6.0 MODELING MILITARY VEHICLES IMPACTS

How military vehicle training impacts archaeological sites is difficult to model with precision, because of the complex sets of variables involved. The primary issue is what variables should be selected so that the modeling process can be reduced to a manageable level without creating a model that is so general that it is too divorced from real world conditions. Relevant to the modeling process are three major sets of variables related to: a site's cultural attributes; a site's locational/environmental attributes; and, military vehicle attributes.

In terms of variables related to a site's cultural attributes, knowing the depths of cultural deposits is probably the most critical variable for understanding how military vehicle training of varying intensities will impact an archaeological site. The horizontal distribution of cultural resources and the nature of those resources are crucial site attributes as well. The redundancy and representativeness of artifacts and features, and whether these cultural resources are sparsely or densely distributed, are important attributes for assessing how spatially extensive training can become before it begins to impact site integrity.

The basic goal of the modeling process is to determine how vulnerable an archaeological site might be to various types of training at varying intensities. Cultural affiliation(s), age(s) of occupation, function(s), and integration of the site within regional subsistence-settlement systems are integral to determining a site's eligibility but are of lesser importance to this modeling process. Cultural affiliation and age can indicate the likelihood that a particular site will have cultural elements that are highly susceptible to impacts from military vehicle training, such as cultures known for constructing extensive earthworks or dwellings with an extensive surface/near surface or above-ground component. With rare exceptions, a site's eligibility—however it is determined—will be threatened if its physical integrity is overly compromised by military vehicle training. The major variables of interest include:

- depth of deposits
- artifact and feature density
- artifact size and fragility
- feature dimensions
- the degree of stratification
- spatial complexity

Unfortunately, some or all of these variables may be absent from site records or, if present, may not always be recorded with sufficient resolution to be incorporated into the modeling process.

Data resolution is also an issue for a site's locational and environmental attributes. USGS topographic maps are helpful for determining the broad parameters of some critical variables, such as slope—which can indicate whether military training might result in an enhanced chance for unacceptable erosion at or near a site. However, micro-topographical variation is important to consider as well, because USGS topographic maps may not indicate slope variation at the resolution relevant to an individual archaeological site. Fortunately, many military training lands have their micro-topographical variation mapped using LiDAR (Light Detection and Ranging). LiDAR-generated maps can help determine slope variation on the individual site level.

More problematic is the mapping of soils data, because the formation of ruts is heavily influenced by soil type, texture, and moisture. USDA soil maps are simply too imprecise to accurately assess variation in soils data across many archaeological sites because their smallest map unit is typically no less than 10 acres. Soil units that are smaller in size than this are usually not differentiated within individual map units. Finer-grained soils data are necessary for determining how military vehicle training might impact archaeological sites, and this should be recorded when an archaeological site is evaluated. Seasonality is also a factor that needs to be considered when assessing potential impacts, especially with regards to 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 military vehicle training. From this perspective, sites should be visited seasonally and specific types of data should be collected, such as soil moisture, nature of vegetation, and biological activities.

There are over a dozen major military vehicle types actively in operation, and these vary considerably in size, weight, and whether they are tracked or wheeled. In terms of military vehicle attributes, an important variable is a vehicle's load, which takes into consideration both vehicle weight and contact with 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 surface and shallow subsurface cultural deposits. When operating under the same conditions, wheeled vehicles are more likely to create deeper ruts than tracked vehicles, whereas tracked vehicles are more likely to cause greater lateral damage—especially when turning. Ideally, the type of training should be taken into consideration, as this will indicate the number, types, and movement patterns of the military vehicles involved in a given training scenario. However, at this stage, there appears to be insufficient information to model the impact of multiple vehicles with varying vehicle parameters on a single archaeological site. This latter task will have to wait until specific data are gathered regarding the impact of military vehicles on cultural deposits.

This study assumes that archaeological sites within areas subject to military training have been recorded and mapped under Section 106 or Section 110 of the National Historic Preservation Act, or other applicable laws or regulations. Until formal eligibility determinations are made, each recorded archaeological site must be viewed as at least potentially eligible to the NRHP. Potentially eligible sites must therefore be treated as if they contain physical integrity that could be adversely impacted by military vehicle movement on training lands, which in turn could result in a loss of eligibility.

Physical integrity, as noted above, depends on the nature and depth of cultural deposits—specifically the horizontal and vertical distribution of artifacts, features, and other cultural remains. Unprotected surface scatters of artifacts, for example, are especially susceptible to military vehicle impacts. This is particularly an issue in western desert training lands, where eligible cultural remains are commonly confined to surface or near surface contexts. Military training is frequently geographically extensive, and, not surprisingly, sites with a higher density of cultural remains at or near the surface—e.g. numerous features and artifacts within close proximity to one another—are more likely to be impacted by military vehicles than lower density sites.

Paradoxically, sites with a lower density of cultural remains are more likely to have their eligibility status threatened by military training than higher density archaeological sites. Lower density sites typically lack the redundancy and representativeness of feature and artifact classes present at higher density sites. These types of sites are also more likely to contain single occupations and, thus, contain very significant data related to specific cultural activities. Any impact to a feature or artifact cluster at a low density site would generally constitute a proportionally greater impact to the site's physical integrity—and eligibility—than would be true for a high density site. Thus, the vulnerability of an archaeological site to military vehicle impacts is related partly to the site's density—as well as the redundancy and representativeness of its cultural remains.

The kinds of cultural remains present at a site must also be factored into considerations of a site's 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—is more vulnerable to vehicle impacts than a site comprised of more durable remains—such as chipped stone tools and debitage. Feature characteristics must also be integrated into assessments of a site's vulnerability. For example, broad and shallow features—which are present at many American Indian village sites in the eastern U.S.—will have a greater proportion of their cultural deposits impacted if struck by a military vehicle than narrower and deeper pits. Additionally, structural remains that protrude above the ground's surface are more likely to be directly impacted by military vehicles than structural remains flush with the ground or even shallowly buried.

The vertical dimension of cultural deposits obviously is a critical element that must be considered when assessing military vehicle impacts. Based on a consideration of site formation processes and documented types of military vehicle impacts, this study considers the depths of cultural deposits in terms of four categories:

Surface deposits: include all cultural remains that exist at and above the ground's surface, including those remains whose primary manifestations may extend below the ground's surface. Some sites—particularly in the western U.S.—may consist solely of eligible or potentially eligible cultural remains located on the ground's surface.

Shallow subsurface deposits: include all cultural remains that exist just below the ground's surface and that extend to the maximum depth of direct impact from vehicle movement, i.e. the maximum depth of ruts formed by tracked or wheeled vehicles. At many sites, the maximum depth of ruts formed by tracked or wheeled vehicles will overlap with the plowzone. Significant or potentially significant sites in some areas—notably in the eastern U.S.—commonly are comprised of cultural remains present largely in shallow subsurface deposits.

Buried deposits:

include all cultural remains below the maximum depth of direct impact from vehicle movement, but within the maximum depth of indirect impact, i.e. the maximum depth of soil compaction caused by vehicle movement.

Deeply buried deposits:

include all cultural remains below the maximum depth of direct vehicle impacts (rutting) and indirect vehicle impacts (soil compaction). These deposits are still potentially subject to catastrophic damage resulting from direct or indirect vehicle impacts, such as accelerated erosion that might expose otherwise deeply buried deposits.

All four categories of cultural deposits depths may be present at an individual archaeological site, and could be differentially impacted by military training (Figure 6.1).

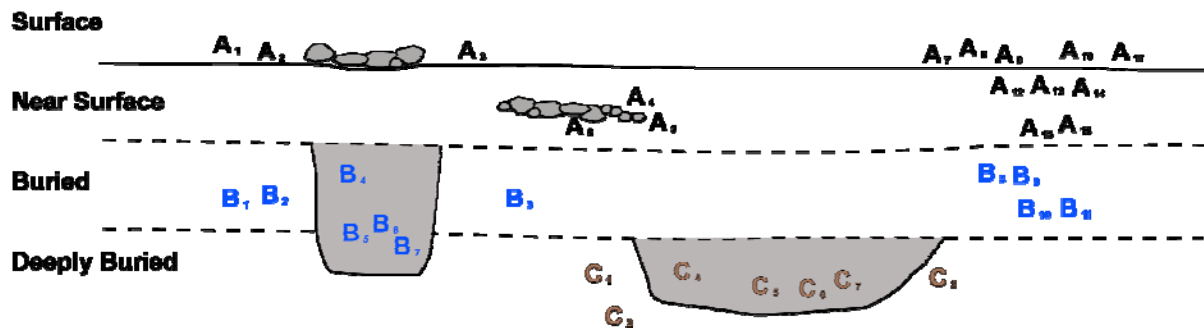


Figure 6.1: Schematic Illustration of the Four Hypothetical Site Categories. Letters represent individual artifacts.

The greatest immediate military training threat to surface and shallow subsurface cultural deposits is clearly related to rut formation resulting from the movement of tracked or wheeled vehicles. Soil compaction caused by tracked or wheeled vehicles is expected to have a comparatively minor direct impact on cultural deposits. The displacement of cultural remains through rutting has a more immediate impact on a site's physical integrity than potential breakage of artifacts as a result of soil compaction. However, soil compaction and rutting sometimes have an inter-related effect on cultural deposits; soil compaction could accelerate ponding, for example, which in turn could cause increased rutting.

Because of uncertainties, ambiguities, and incompleteness in the various data sets, it is not currently possible to quantify the major variables discussed above and examine their interrelationships through multivariate statistical procedures or other quantitative techniques. Regional variation in site attributes (e.g. sites with cultural deposits primarily on the surface versus those largely present in the plowzone) and environmental parameters (e.g. deserts versus forests) add complexity to the modeling process and the development of guidelines applicable to military training facilities irrespective of their location within the nation.

In an effort to operationalize this model, site data were examined from Marine Corps Base Quantico (MCBQ), Quantico, Virginia, Marine Corps Base Camp Pendleton (MCBCP),

Oceanside, California, and Marine Air Ground Task Force Training Command (MAGTF), Twentynine Palms, California. It quickly became clear that sufficiently detailed data on the nature and density of cultural remains and local environmental variation simply was unavailable for most sites. To operationalize the model in the most broadly applicable terms, additional data would need to be gathered so that sites could be subdivided into at least three major categories based on their cultural attributes: those consisting of only portable cultural objects; those with broad and shallow features; and, those with narrow and deep features. Portable cultural objects consist of artifacts (items made or modified by people) and ecofacts (bone, shell, antler, or other organic remains found on sites, but not modified). Features include pits, as well as structural remains, such as hearths, walls, and check dams. Sites could then be ranked in terms of their vulnerability using these categories and also the depth of cultural remains. A hypothetical ranking system has been developed, with the most vulnerable site ranked as 1 and the least vulnerable site ranked as 12 (see Table 6.1). Once sufficient site data is collected, these ranked sites can be analyzed through nonparametric statistics, particularly those approaches that draw on graphical displays of results.

This hypothetical ranking system will need to be integrated with environmental variables unique to each site location, including seasonality, soil types, soil moisture, and micro-topographic variation. These environmental variables are not integrated into the site vulnerability ranking system presented here as we currently lack sufficient and consistent data from enough locations to enable expansion of the model in this direction. We can argue, however, that a site with a Vulnerability Ranking of 1 would, for example, be at greater risk if local soil conditions were moist as opposed to dry, if sediments were fine-grained as opposed to coarse-grained, if the site occurred on a sloping grade as opposed to a flat surface, or in a bare and exposed area as opposed to a vegetated area. The complexity of the analysis will obviously vary with the number of attributes, both cultural and environmental, that are incorporated in the model.

Integrating the widest appropriate range of potential attributes will provide a more complex and richly textured ranking system and is proposed as part of the next stage of the modeling process. This process should be accompanied by the collection of relevant field data through practical investigations of the effects of vehicle training in real-world situations: that is, by archaeologically examining and analyzing the results of vehicular activity in active training areas.

Table 6.1: Site Vulnerability Rankings Drawn from Site Category and Depth of Cultural Remains.

Vulnerability Rank	Site Category	Depth	
← least vulnerable most vulnerable →	1	portable cultural objects only (artifacts and ecofacts)	Surface
	2	features, broad and shallow	Surface
	3	features, narrow and deep	Surface
	4	portable cultural objects only (artifacts and ecofacts)	shallow subsurface
	5	features, broad and shallow	shallow subsurface
	6	features, narrow and deep	shallow subsurface
	7	portable cultural objects only (artifacts and ecofacts)	Buried
	8	features, broad and shallow	Buried
	9	features, narrow and deep	Buried
	10	portable cultural objects only (artifacts and ecofacts)	deeply buried
	11	features, broad and shallow	deeply buried
	12	features, narrow and deep	deeply buried

7.0 RECOMMENDATIONS

Military training occurs within a great variety of landscapes and climates. These areas range from coastal to upland settings in temperate and subtropical zones as well as desert, semiarid prairie and arctic regions. Because sites exist as an integral part of the landscape in which they developed, a focus on the site within its landscape is critical. Distinguishing changes in the relationships between artifacts, features, and landscape affected by military training exercises is vital, particularly in relationship to what makes a site significant and the factors that can alter significance. It is imperative that a clear understanding is reached regarding the specific ways in which military vehicle training can impact archaeological sites.

Several recommendations for specific kinds of new data or for specific formats of that data can be made based on existing information reviewed in this report:

- Data gathered from sites on military training lands must be expanded so that they can be integrated with extant studies of how military vehicles impact training lands. Major data categories needed to model the impacts of military vehicles on cultural deposits include: artifact and feature density; representativeness and redundancy of cultural deposits; depth of deposits; and, spatial distribution of cultural materials.
- Experimental studies should be developed to link archaeological site formation processes with military vehicle impacts.
- Studies should be conducted to determine whether soil compaction from the movement of military vehicles is sufficient to break artifacts of varying degrees of fragility and/or damage cultural features.
- Eligibility determinations should be conducted on sites that are currently categorized as potentially eligible so that it can be determined whether or not they retain sufficient integrity such that they need to be protected from military vehicle impacts.
- 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. These data should be integrated with LiDAR information.
- Soil compaction and rut formation should be studied on actual training landscapes as opposed to studies of soil compaction drawn from hypothetical data or analyses of ruts created in controlled circumstances.

A critical and immediate need is to examine military training landscapes from an archaeological perspective. As stated in Section 4, active military training operations have a direct, visible, and long lasting impact on the landscape in terms of soil compaction and rut formation. Currently, there exists insufficient information to determine the maximum amount of soil displaced vertically and horizontally by the formation of multiple ruts. Thus, a crucial gap in our data for assessing the impacts of military vehicles on surface and shallow subsurface deposits is a lack of measurements on ruts formed during real world training scenarios by multiple vehicles and over

an extended period of time. Although useful, the data gathered from experimental field tests largely focus on single vehicles operating in controlled conditions. Historical data on rut dimensions could be gathered from the traces of Patton's World II-era training activities still visible in the Mojave Desert. Past measurements of these vehicle tracks have focused on soil compaction and not rut dimensions (Belnap and Warren 2002:249-250). Additional measurements of rut dimensions need also to be more comprehensive, and not emphasize one dimension at the expense of other dimensions. Depth measurements are more consistently reported, but to understand the impacts of military vehicles on archaeological sites, data on rut width also need to be consistently gathered. Knowing the length of military tracks and not simply the dimensions of ruts in cross-section would also aid with understanding the impacts of military vehicles have on cultural deposits.

Archaeological field testing would therefore consist of the examination of soil profiles that have been under actual (as opposed to simulated) vehicle impacts within training areas. Archaeologists could excavate narrow trenches across discrete areas of vehicle impacts (such as ruts or tracks), each trench measuring approximately two meters in length, one meter in width, and one meter in depth. 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. Specific analytical procedures would include examination of profiles with a soil penetrometer; analysis of soil texture (particle size) and standard soil chemistry to characterize soil horizons; and soil micromorphology to analyze mineral grain alignment for evidence of the degree of compaction and mixing present. Such a study would both contrast with and complement ongoing Strategic Environmental Research and Development Program (SERDP) projects focused on the magnetic signature of site impacts (SI-1697: Physical and Geophysical Measurement of Replicated Military Training Impacts to Archaeological Sites) and the vertical stratification of soil horizon interfaces (SI-1698: Identifying Military Impacts of Archeological Deposits Based on Differences in Soil Organic Carbon and Chemical Elements in Soil Horizon Interfaces).

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