# A Soil-Based Methodology for Locating Buried Early Prehistoric Cultural Deposits in Draws on the High Plains of Eastern Colorado and Western Kansas

By

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# ABSTRACT

Based on the results of recent geomorphological and geoarchaeological investigations at the Kanorado locality in northwestern Kansas, it may be possible to target landforms with potential for buried Paleoindian cultural deposits using soil series that have been mapped by the USDA Natural Resource Conservation Service. Paleoindian artifacts were recovered from the buried cumulic A horizon of the Kanorado paleosol at the three sites that comprise the Kanorado locality. At Kanorado, the Goshen soil series is mapped as the surface soil over the majority of the locality. The co-occurrence of buried Paleoindian cultural deposits and the Goshen soil series at Kanorado suggests that similar co-occurrences may exist elsewhere in the Middle Beaver Creek Valley. Therefore, this study focused on alluvial landforms mapped with the Goshen surface soil in the Middle Beaver Creek Valley. Radiocarbon ages determined on soil organic matter (SOM) from study sites in the Middle Beaver Creek Valley provide a minimum age of landscape stability and concomitant soil formation. Using the radiocarbon ages determined on SOM, the potential for each study site to yield buried early prehistoric cultural components was determined.

Results of the study were positive, with 71 percent of the landforms examined having high potential to yield buried Paleoindian cultural deposits. The results suggest that the co-occurrence of the Goshen series and potential for Paleoindian cultural deposits is not a coincidence in the Middle Beaver Creek Valley. Therefore, investigations targeting the Goshen soil series have the potential to focus future research on areas with the greatest potential to yield Paleoindian cultural deposits. In addition, five of the seven alluvial landforms mapped with the Goshen soil series have potential to yield Archaic cultural components. Based on these results, alluvial landforms mapped with the Goshen soil series have potential to focus investigations on cultural deposits from the Pleistocene-Holocene transition through the middle Holocene. Within the Middle Beaver Creek Basin, archaeological investigations targeting the Goshen soil series can reduce survey size by as much as 96 percent, thus reducing field time and cost required to complete the archaeological surveys.

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# TABLE OF CONTENTS

# LIST OF FIGURES

FIGURE PAGE

# LIST OF TABLES

TABLE PAGE

# CHAPTER I

# INTRODUCTION

The antiquity of humans in North America was not accepted until prehistoric stone tools were found *in situ* with extinct Pleistocene fauna at sites such as 12 Mile Creek, Folsom, and Clovis (Hofman and Graham 1998; Albanese 2000; Holliday 2000a). To date, some of the earliest sites associated with human presence in the New World have been recorded on the High Plains.

A number of these sites, such as Clovis in New Mexico, Olsen-Chubbuck in Colorado, and Scottsbluff in Nebraska, have been found in the valleys of intermittent, low-order streams, or draws, that are common in the region (Howard 1935; Schultz and Eiseley 1935; Barbour and Schultz 1936; Howard 1936; Cotter 1937; Wheat 1972; Boldurian and Cotter 1999). Mandel et al. (2004) and Mandel (2006a, 2008) suggested that the waves of early and middle Holocene erosion that removed much of the Paleoindian archaeological record from small and intermediate-size streams (≤5th order) in the Central Plains did not reach the draws at the upper ends of drainage systems on the High Plains of eastern Colorado and western Kansas. Consequently, thick deposits of alluvium with multiple buried soils dating to the late Pleistocene and early Holocene are preserved in the valleys of the draws (Mandel 2008). The formation of the soils coincided with some of the earliest occupation of the region, and therefore, the soils have high potential for containing *in situ* Paleoindian cultural deposits. However, discovering the often ephemeral Paleoindian sites in such a vast area is a daunting task.

Traditional archaeological surveys of large regions are costly and require large research teams to complete in a timely manner. To reduce the financial and physical cost of large, region-wide surveys, archaeologists have increasingly relied on predictive modeling to target locations that are likely to yield cultural deposits (Kvamme 1990, 2006; Mandel 1992, 1995, 2006a). Such models often include a suite of independent variables derived from the location of known archaeological sites, such as elevation, slope, aspect, and distance from fresh water. These archaeological predictive models are most effective when they are based on a large number of archaeological sites; the more examples used to build the model, the stronger the predictive capability of the model. Unfortunately, conventional predictive models are difficult to apply in the search for Paleoindian sites on the High Plains because of the relative scarcity of recorded sites.

A number of studies (e.g., Artz 1985; Bettis 1992; Mandel 1992; Monger 1995; Stafford and Creasman 2002) have used soil geomorphology and NRCS soil survey data to develop archaeological predictive models without the use of site-derived data. The predictive models based on soil data use soil classification and taxonomy to estimate the relative age of surface soils, which in turn provides a minimum age for the associated landforms (Holliday 2004). The estimated ages then can be used to assign specific landforms with an archaeological potential, generally described as low, medium, or high. For example, moderately developed surface soils with argillic horizons have a higher potential to yield prehistoric cultural components than poorly developed soils formed in recent alluvium. Such estimated ages can even be used to predict locations on the landscape that have the potential for yielding archaeological components dating to specific cultural periods (e.g., Paleoindian, Archaic, Woodland); (Artz 1985, Stafford and Creasman 2002).

Although archaeological predictive models based on soil data are very useful when recorded site data are insufficient or incomplete, care must be taken when employing them in the field. Holliday (2004) cautioned that using NRCS soil survey data, especially specific soil series, as the basis for archaeological predictive models can be problematic because of variability in soil mapping strategies. The scale at which soil units are mapped often is too broad (minimum 1 ha or 2.4 ac) to characterize the complexities that can exist in relatively small areas (Holliday 2004). Likewise, the soil map units do not always represent the gradation from one soil to another, or the genetic relationship (i.e., catena) that exists in soil landscapes. In addition to mapping strategies, the experience and background of each soil scientist also may play a role in the variability of the soil data. For example, a soil scientist with a geomorphology or stratigraphy background may interpret a soil differently than one whose training is more strictly in pedology. Geomorphology and stratigraphy are focused more on soil landscapes, while pedology is focused on the soil as an individual unit (Holliday 2004).

Even with the variability that exists in the NRCS soil survey data, in regions like the central High Plains where very few Paleoindian sites have been recorded, archaeological predictive models that rely on NRCS soil data remain one of the best methods for focusing research on high probability locations. Many archaeological investigations that employ soil data-based predictive models depend on general soil classification and taxonomy instead of the mapped soil series. However, based on the results of recent geomorphological and geoarchaeological investigations at the Kanorado locality (sites 14SN101, 14SN105, and 14SN106) in northwestern Kansas (Mandel et al. 2004; Mandel et al. 2005), it may be feasible to predict the location of Paleoindian cultural deposits in the surrounding basin using an individual soil series to target areas of high potential.

The Kanorado locality is one of the few stratified Early Paleoindian site complexes in the central High Plains that has yielded both Folsom and Clovis-age artifacts from buried contexts. The three sites that comprise the locality are located along a 2 km stretch of Middle Beaver

Creek, a draw in Kit Carson County, Colorado and Sherman County, Kansas. Paleoindian artifacts were recovered from the buried cumulic A horizon of the Kanorado paleosol at all three sites.

At Kanorado, the Goshen soil series is mapped as the surface soil at sites 14SN101 and 14SN106. The Goshen soil series is a Pachic Argiustolls, and in Middle Beaver Creek is formed on terraces underlain with silty alluvium derived mainly from loess (Soil Survey 2006); (Appendix I). The surface soil at 14SN105 is mapped as the Bridgeport series, a Fluventic Haplustolls formed in calcareous alluvial sediments underlying floodplains and low terraces (Soil Survey 2006). Although the surface soil at 14SN105 is not mapped as the Goshen series, the cultural materials at 14SN105 were recovered from a buried soil formed in alluvium beneath a narrow (1-3 m wide) terrace remnant that is geomorphologically very similar to the alluvial terraces at sites 14SN101 and 14SN106. The terrace remnant at 14SN105 likely was not designated as a separate landform by the NRCS due to its size, and therefore, the surface soil was not mapped as the Goshen series as were the surface soils at 14SN101 and 14SN106. If a greater portion of the terrace remained intact, it is likely that the surface soil would have been mapped with the Goshen series as well.

The co-occurrence of the Kanorado paleosol and the Goshen soil series (or similar surface soil in the case of 14SN105) at the Kanorado locality suggests that it may not be a coincidence, and that similar co-occurrences may exist elsewhere in the Middle Beaver Creek Valley. Therefore, an archaeological investigation targeting alluvial terraces whose surface soil is mapped as the Goshen series has the potential to locate buried Paleoindian cultural components in a similar context to those at the Kanorado locality. To determine if the Goshen soil series can be used to target alluvial landforms with potential to yield Paleoindian cultural deposits, the landform sediment assemblages (LSAs) of a number of alluvial terraces mapped with the Goshen surface soil were examined in the basin. Localities both upstream and downstream from Kanorado were chosen to provide the broadest geographic sample of the Goshen soil series and the underlying soils and sediments. LSAs at each of the localities were described and, when possible, radiocarbon dated.

The results of this research have the potential to aid archaeologists as they continue to search for Paleoindian cultural deposits in Middle Beaver Creek Valley. Targeting the Goshen series will allow investigators to focus research on locations that have the highest potential to yield Paleoindian-age soils and sediments, and therefore, Paleoindian archaeological sites. As more sites are discovered and site-specific data become available, additional information may be added to this soil-based approach to strengthen its ability to predict the location of Paleoindian cultural deposits. The methodology employed herein also can be used as a template for similar investigations in other regions.

## Organization of the Thesis

This thesis is organized into six chapters. Chapter II provides an overview of the physical setting of the central High Plains. It includes descriptions of the geography, bedrock geology, climate, soils, and vegetation. In addition, Chapter II reviews aspects of the paleoclimate and paleoecology of the region. Chapter III focuses on the archaeological context of the region and the history of Paleoindian research on the High Plains. It also provides an overview of the soil geomorphology-based archaeological predictive models. Chapter IV describes the specific field and laboratory methods used in this study. Chapter V presents the results of field investigations and soils analyses. Chapter VI provides a summary of the results, and discusses the implications of the findings and their application to future research.

# CHAPTER II

# STUDY AREA

## Geographic Setting

The High Plains of Kansas and eastern Colorado is a subprovince of Fenneman's (1931) Great Plains physiographic province. The High Plains begin at the foothills of the Rocky Mountains in Colorado and extend as far east as Reno and Kingman counties in south-central Kansas (Figure 1). The eastern boundary of the High Plains is marked by the prominent scarp of the Cretaceous-age Fort Hays limestone. This scarp forms the border with the Smoky Hills region, and the scarp of the Neogene-age Ogallala Formation forms the border with the Great Bend and Red Hills regions (Frye and Leonard 1952; Frye et al. 1956).

The High Plains formed as a result of the erosion of the Rocky Mountains. During the Tertiary period the Rocky Mountains were forced upward by tectonic activity. As the mountains began to erode, large volumes of sediment were mobilized and carried eastward by streams and rivers. This sediment was deposited across an area that parallels the mountains for more than 1,288 km, from South Dakota southward to the Texas panhandle, and is almost 644 km wide in some places (Merriam 1961). The massive sediment load was deposited in a series of laterally overlapping valley fills that culminated in the complete overlapping of the remaining divides by the end of the Neogene (Frye et al. 1956; Merriam 1961). This immense alluvial plain consists of a relatively flat sheet of sand and gravel that gradually slopes eastward from the foothills of the Rocky Mountains in Colorado to the western edge of the Smoky Hills (Wilson 1984). The uneroded remnant of this plain is known as the Ogallala Formation and in Colorado and Kansas, the Ogallala deposits mainly date to the Miocene and Pliocene epochs, respectively (Merriam 1961; Diffendal 1984).

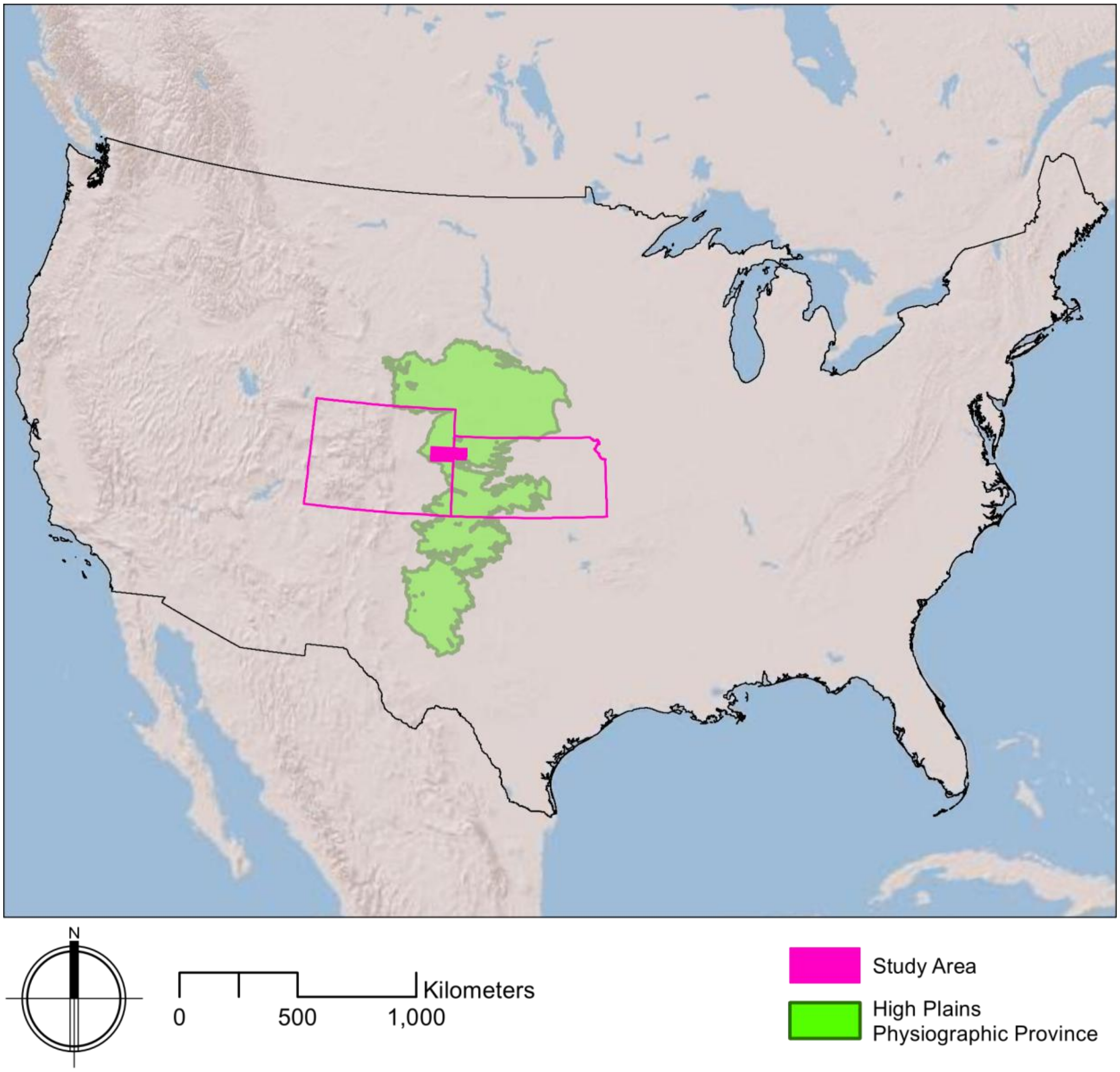

**Figure 1: Map of the United States showing the High Plains Physiographic Subprovince.**

The Ogallala Formation contains a number of petrocalcic (cemented caliche) horizons. The most distinct of these is the resistant "caprock" caliche (Reeves 1976). In the High Plains of Kansas the caprock marks the upper boundary of the Ogallala Formation and is typically several meters thick. The ability of the caprock to resist erosion preserves the plateau-like topography of the High Plains region (Mandel 2006b). The Ogallala Formation is often obscured by a mantle of Quaternary deposits and is generally exposed only in deeply dissected and eroded areas along the High Plains escarpment and in the valley walls of major streams and rivers. The Ogallala is the major aquifer for the High Plains and is the source of water for many springs in the region. These springs were likely reliable sources of fresh water for game and people during Holocene and late Pleistocene (Mandel 2006b).

The surface of the High Plains region of Colorado and Kansas is mantled by Quaternary deposits consisting of alluvium, sand dunes, and loess (Johnson and Park 1996; Forman et al. 2001; Mandel 2006b). The late-Quaternary loess is 2-3 m thick across most of the region. However, in areas adjacent to major river valleys the loess typically is ≥ 5 m thick. Sand dunes are mainly concentrated immediately south of the Arkansas and Cimarron rivers in southwestern Kansas and in the Wray Dune Field in northeast Colorado. Dunes and sand sheets in these areas are 1-18 m thick (Forman et al. 2001).

Six major streams drain the High Plains of Colorado and Kansas: the South Platte, Republican, Solomon, Smoky Hill, Arkansas and Cimarron rivers. All of these rivers and their tributaries trend eastward. Today, many of the streams in the region are intermittent or completely dry, only carrying water after large rainfalls. This is especially true of the low-order (≤ 4th order) streams, including draws.

This study focused on Middle Beaver Creek, a draw located in northeastern Colorado and northwestern Kansas (Figure 2). Middle Beaver Creek drains approximately 82,218.0 ha of Kit Carson County, Colorado and Sherman County, Kansas. The total length of Middle Beaver Creek and all its tributaries is approximately 506.9 km. Today, Middle Beaver Creek is an intermittent stream, only carrying water after large rainfalls. It is a tributary of Beaver Creek, which forms at the confluence of Middle Beaver Creek and South

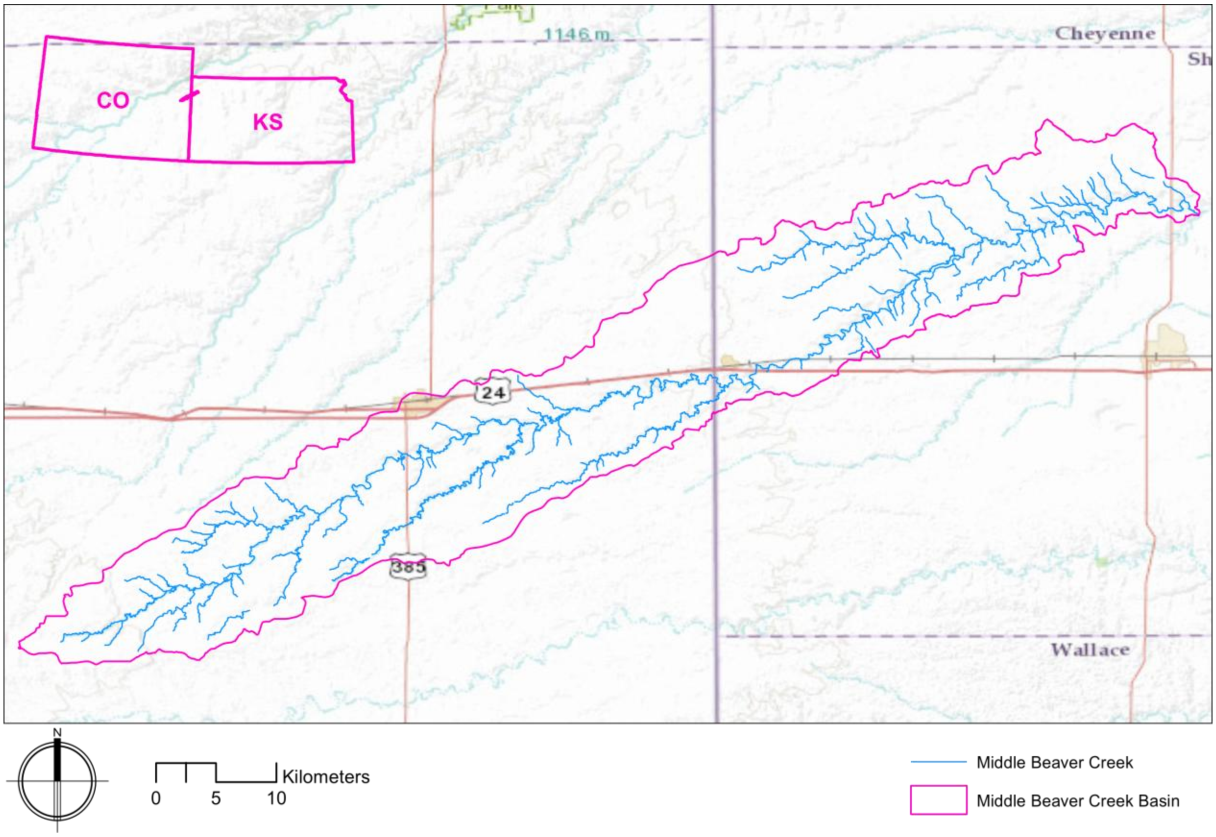

**Figure 2: Overview of the Middle Beaver Creek drainage basin**

Beaver Creek approximately 10.6 km (6.6 miles) north-northeast of Goodland, Kansas.

## <u>Bedrock Geology</u>

Within the High Plains of Colorado and Kansas, the Ogallala Formation overlies mostly Permian and Cretaceous bedrock. Cretaceous-age Niobrara chalk and Pierre shale mostly occur in the valley walls of deeply incised streams in the central High Plains. The Cretaceous Greenhorn limestone and Dakota Formation occur in the far southwestern portion of the region, and like the Niobrara chalk and Pierre shale are exposed in the valley walls of deeply incised streams. In the southwestern portion of the study area, a pocket of Jurassic-age bedrock composed of undifferentiated beds of red siltstone and buff, green, and white sandstone is exposed in the valley wall of the Cimarron River.

Several sources of lithic material are located in and around the study area. Two of the main lithic sources local to the High Plains, Smoky Hill silicified chalk and Dakota quartzite, occur in the Cretaceous bedrock (Stein 2006). Smoky Hill silicified chalk is common in the valley walls of the Smoky Hill and Saline rivers and their tributaries. In the southwestern portion of the study area, the Dakota quartzite occurs in the Dakota Formation in the valley walls of the Cimarron and Arkansas Rivers, as well as their larger tributaries. Outcrops of Day Creek silicified dolomite occur within the Big Basin Formation and Day Creek dolomite deposits at the base of the High Plains escarpment in the southeastern portion of the region. Another source of lithic material in close proximity to the study area is the Oligocene White River Group in northeastern Colorado. The White River Group is the source of Flattop chalcedony, which occurs in the Chadron Formation capstone in the South Platte River area (Hoard et al. 1993). Along with these primary deposits of lithic materials, cobbles of silicified sediment (quartzite), opaline chalcedony, chert, silicified wood, and basalt occur in the Ogallala Formation and were used by prehistoric peoples (Stein 2006).

## Soils

For the purposes of this study, a soil is defined as a natural three dimensional entity occurring at the earth's surface that is composed of mineral and organic matter (modified from Holliday 2004; Schaetzl and Anderson 2005). Soils are formed *in situ* in sediment and/or rock through the interaction of the climate, biota, topography, parent material, and time. Pedogenesis generally occurs during periods of landscape stability, when neither deposition nor erosion is intense enough to overtake soil formation (Birkland 1999; Mandel and Bettis 2001).

Soils are important to archaeological studies in a number of capacities (Holliday 2004). At the most basic level, soils are the medium in which most archaeological excavations occur. The study of soils and sediments can also help archaeologists understand past environments, how humans interacted with the landscape, and site taphonomy. The concept of landscape stability and pedogenesis are especially important to archaeological surveys and predictive models because the longer a surface remains stable, the greater the probability that it will be used by humans in some capacity (Hoyer 1980; Mandel and Bettis 2001; Mandel 2008).

Geomorphologic, pedologic, and physiographic information for much of the United States is available from the NRCS (Holliday 2004). NRCS soil scientists have surveyed nearly all of the surface soils in the country. The soils are classified and mapped as specific soil series on the basis of horizonation, color, texture, consistence, pH, amount of rock fragments, mineralogy, parent material, landscape position, and other properties (Soil Survey Staff 2006). Although soil survey data can be useful to archaeologists, the information provided for each location is not always accurate at a scale relevant to archaeological investigations. Consequently, caution must be employed when relying upon NRCS soil surveys.

For the purposes of my study, the NRCS soil series mapped in the Middle Beaver Creek Basin were separated into two categories: alluvial soil series and upland soil series (Table 1). Alluvial soils are soils formed in sediments deposited by flowing water. Nineteen alluvial soil series are mapped in the Middle Beaver Creek Basin (Soil Survey 2006). These soil series occur on a number of geomorphic surfaces, including flood plains, drainage ways, terraces, paleoterraces on tablelands, and alluvial fans. They include both fine- and coarse-textured soils.

**Table 1: Natural Resources Conservation Service (NRCS) soil series mapped in the Middle Beaver Creek drainage basin (Soil Survey 2006)**

| Soil Series | Geomorphic Surface | Parent Material | Taxonomic Classification |
|---|---|---|---|
| **Alluvial Soils** | | | |
| Bayard | alluvial fans | coarse-loamy alluvium | Coarse-loamy, mixed, superactive, mesic Torriorthentic Haplustolls |
| Beckton | terraces | clayey alluvium | Fine, smectitic, mesic Aridic Natrustolls |
| Bridgeport | floodplains | calcareous fine-silty alluvium | Fine-silty, mixed, superactive, mesic Fluventic Haplustolls |
| Concordia | floodplains | clayey alluvium | Fine, smectitic, mesic Typic Natrustalfs |
| Glenberg | flood plains | coarse-loamy alluvium | Coarse-loamy, mixed, superactive, calcareous, mesic Ustic Torrifluvents |
| Goshen | drainageways | fine-silty alluvium | Fine-silty, mixed, superactive, mesic Pachic Argiustolls |
| Haverson | floodplains | fine-loamy alluvium | Fine-loamy, mixed, superactive, calcareous, mesic Aridic Ustifluvents |
| Kitcarson | floodplains | coarse-loamy alluvium | Coarse-loamy, mixed, superactive, calcareous, mesic Oxyaquic Ustifluvents |
| Manzanst | drainageways | clayey alluvium | Fine, smectitic, mesic Aridic Haplustalfs |
| Nunn | terraces | clayey alluvium | Fine, smectitic, mesic Aridic Argiustolls |
| Oxyaquic Ustifluvents | floodplains | alluvium | Oxyaquic Ustifluvents |
| Paoli | terraces | coarse-loamy alluvium | Coarse-loamy, mixed, superactive, mesic Pachic Haplustolls |
| Rago | drainageways | clayey loess, calcareous | Fine, smectitic, mesic Pachic Argiustolls |
| Roxbury | floodplains | calcareous fine-silty alluvium | Fine-silty, mixed, superactive, mesic Cumulic Haplustolls |
| Sampson | drainageways | fine-loamy alluvium | Fine-loamy, mixed, superactive, mesic Pachic Argiustolls |
| Satanta | paleoterraces on tablelands | fine-loamy eolian deposits over fine-loamy alluvium | Fine-loamy, mixed, superactive, mesic Aridic Argiustolls |
| Satanta-Colby | paleoterraces on tablelands | fine-loamy eolian deposits over fine-loamy alluvium | Fine-loamy, mixed, superactive, mesic Aridic Argiustolls |
| Satanta-Sampson | paleoterraces on tablelands | fine-loamy eolian deposits over fine-loamy alluvium | Fine-loamy, mixed, superactive, mesic Aridic Argiustolls |
| Satanta-Ulmet | paleoterraces on tablelands | fine-loamy eolian deposits over fine-loamy alluvium | Fine-loamy, mixed, superactive, mesic Aridic Argiustolls |
| **Upland Soils** | | | |
| Ascalon | plains | fine-loamy eolian deposits | Fine-loamy, mixed, superactive, mesic Aridic Argiustolls |
| Bethune | plains | clayey loess over residuum weathered from sandstone, calcareous | Fine, smectitic, mesic Aridic Argiustolls |
| Canyon | hills | loamy residuum weathered from sandstone, calcareous | Loamy, mixed, superactive, calcareous, mesic, shallow Ustic Torriorthents |
| Colby | hillslopes on uplands | calcareous fine-silty loess | Fine-silty, mixed, superactive, calcareous, mesic Aridic Ustorthents |
| Eckley-Wages complex | hills | fine-loamy eolian deposits over sandy and gravelly | Fine-loamy over sandy or sandy-skeletal, mixed, superactive, mesic Aridic |

| | | | |
|---|---|---|---|
| | | alluvium | Argiustolls |
| Fort Collins | plains | fine-loamy eolian deposits over fine-loamy alluvium | Fine-loamy, mixed, superactive, mesic Aridic Haplustalfs |
| Haxtun | plains | fine-loamy eolian deposits | Fine-loamy, mixed, superactive, mesic Pachic Argiustolls |
| Iliff | plains | clayey loess over residuum weathered from sandstone, calcareous | Fine, smectitic, mesic Aridic Paleustolls |
| Julesburg | plains | coarse-loamy eolian deposits | Coarse-loamy, mixed, superactive, mesic Aridic Argiustolls |
| Keith | plains | fine-silty loess, calcareous | Fine-silty, mixed, superactive, mesic Aridic Argiustolls |
| Kimst | hillslopes on uplands | fine-loamy eolian deposits over fine-loamy alluvium | Fine-loamy, mixed, superactive, calcareous, mesic Aridic Ustorthents |
| Kuma-Keith | plains | calcareous fine-silty loess | Fine-silty, mixed, superactive, mesic Pachic Argiustolls |
| Manter | plains | coarse-loamy eolian deposits | Coarse-loamy, mixed, superactive, mesic Aridic Argiustolls |
| Midway-Razor | hills | clayey residuum weathered from shale, calcareous | Clayey, smectitic, calcareous, mesic, shallow Ustic Torriorthents |
| Norka | plains | fine-silty loess, calcareous | Fine-silty, mixed, superactive, mesic Aridic Argiustolls |
| Olnest | plains | fine-loamy eolian deposits over fine-loamy alluvium | Fine-loamy, mixed, superactive, mesic Aridic Haplustalfs |
| Otero | blowouts | coarse-loamy eolian deposits | Coarse-loamy, mixed, superactive, calcareous, mesic Aridic Ustorthents |
| Platner | plains | clayey alluvium | Fine, smectitic, mesic Aridic Paleustolls |
| Pleasant | depressions on uplands | clayey alluvium and/or eolian deposits | Fine, smectitic, mesic Torrertic Argiustolls |
| Richfield | plains | clayey loess, calcareous | Fine, smectitic, mesic Aridic Argiustolls |
| Stoneham | plains | fine-loamy eolian deposits over fine-loamy alluvium | Fine-loamy, mixed, superactive, mesic Aridic Haplustalfs |
| Ulmet | plains | clayey alluvium | Fine, smectitic, mesic Aridic Haplustalfs |
| Ulysses | plains | fine-silty loess, calcareous | Fine-silty, mixed, superactive, mesic Aridic Haplustolls |
| Valent | dunes | sandy eolian deposits | Mixed, mesic Ustic Torripsamments |
| Vona | hills | coarse-loamy eolian deposits | Coarse-loamy, mixed, superactive, mesic Aridic Haplustalfs |
| Wages | plains | fine-loamy eolian deposits over fine-loamy alluvium | Fine-loamy, mixed, superactive, mesic Aridic Argiustolls |
| Weld | interfluves | clayey loess, calcareous | Fine, smectitic, mesic Aridic Argiustolls |
| Wiley | plains | fine-silty loess, calcareous | Fine-silty, mixed, superactive, mesic Aridic Haplustalfs |

Alluvial soils tend to become finer grained with increasing distance from the active channel. The energy of flood water diminishes with distance from the channel, and therefore so does the water's ability to transport heavier, coarse particle. The silt- and clay-sized particles remain in suspension longer, and thus can be carried farther from the active channel. Although some coarse-grained alluvial soils occur close to active channels in the study area, the majority of the soils in the valley bottoms are fine-grained. Fourteen of 19 alluvial soils are described as fine, silty, or clayey. This pattern is attributable to the primary sediment source in the basin: the highly erodible loess mantle that covers much of the upland surface. The carbonate-rich, loess-derived alluvium also contributes to the calcareous nature of many of the alluvial soils that occur in the basin.

Twenty-six upland soil series have been mapped in the Middle Beaver Creek Basin. These soils series occur on a variety of geomorphic surfaces, including plains, hills, hillslopes on uplands, interfluves, dunes, blowouts, and depressions on uplands (playa basins). Eighteen of the 26 upland soil series in the Middle Beaver Creek Basin are formed in loess. The majority of the loess deposits in the region are the result of two major depositional episodes: one that occurred during the late Pleistocene, and another that occurred during the early to middle Holocene. The Peoria Loess, which is the most extensive eolian deposit in the region, aggraded between the last glacial maximum (LGM) and the end of the Pleistocene (~18,000-12,000 $^{14}$C yr B.P.); (Johnson and Park 1996; Muhs, Aleinikoff et al. 1999; Muhs, Swinehart et al. 1999). In addition to being the most extensive eolian deposit in the region, it is also the thickest, ranging from approximately 3 to 50 m thick. The Bignell Loess mantles the Peoria Loess and is the youngest eolian deposit recognized in the region. Aggradation of the Bignell Loess began around 10,000 $^{14}$C yr B.P, and in some places, continued into the late Holocene (Mason et al. 2002). The Bignell is not as widely distributed as the Peoria Loess and is generally <2 m thick.

Eight upland soils are formed in either clay-rich paludal deposits, sandy eolian deposits, residuum weathered from bedrock, or very old (Tertiary) alluvium. These soils comprise a small portion of the upland soils in the Middle Beaver Creek Basin and are associated with distinct geomorphic features such as playa basins, sand dunes, or bedrock outcrops.

## The Goshen Soil Series

This study focused on the Goshen soil series, a fine-silty, mixed, superactive, mesic Pachic Argiustolls formed in alluvium (Soil Survey Staff 2006); (Appendix I). The Goshen soil occurs throughout western Nebraska, Kansas, South Dakota, and eastern Wyoming and Colorado and is formed in silty alluvium derived mainly from loess. In the official series description, the Goshen series occurs on swales and narrow drainageways on uplands (Soil Survey 2006); (Appendix I); however, in Middle Beaver Creek the Goshen mainly occurs on T-1 or T-2 stream terraces. The Goshen series is mapped on approximately 3005 ha (7424 acres) of the Middle Beaver Creek Basin.

The Goshen series is comprised of a Mollic epipedon overlying a dark grayish brown to grayish brown argillic horizon with nearly continuous clay films on ped surfaces (Soil Survey Staff 2006). The series is described as having a moderately developed A-Bt profile, as defined by Holliday (2004). Based on the summaries of argillic horizon formation presented by Artz (1985), Bettis (1992), Birkeland (1999), and Holliday (2004), landforms whose surface soils are moderately developed, such as the Goshen series, have likely been stable for approximately 2,000-4,000 yr. This suggests the minimum age of the deposits in which the Goshen soil is formed is early-late Holocene to late-middle Holocene. Therefore, landforms whose surface soil is mapped as the Goshen series have a greater potential to yield buried archaeological components that predate the late Holocene (e.g., Archaic and Paleoindian). The potential of landforms in Middle Beaver Creek mapped with the Goshen series to yield Paleoindian

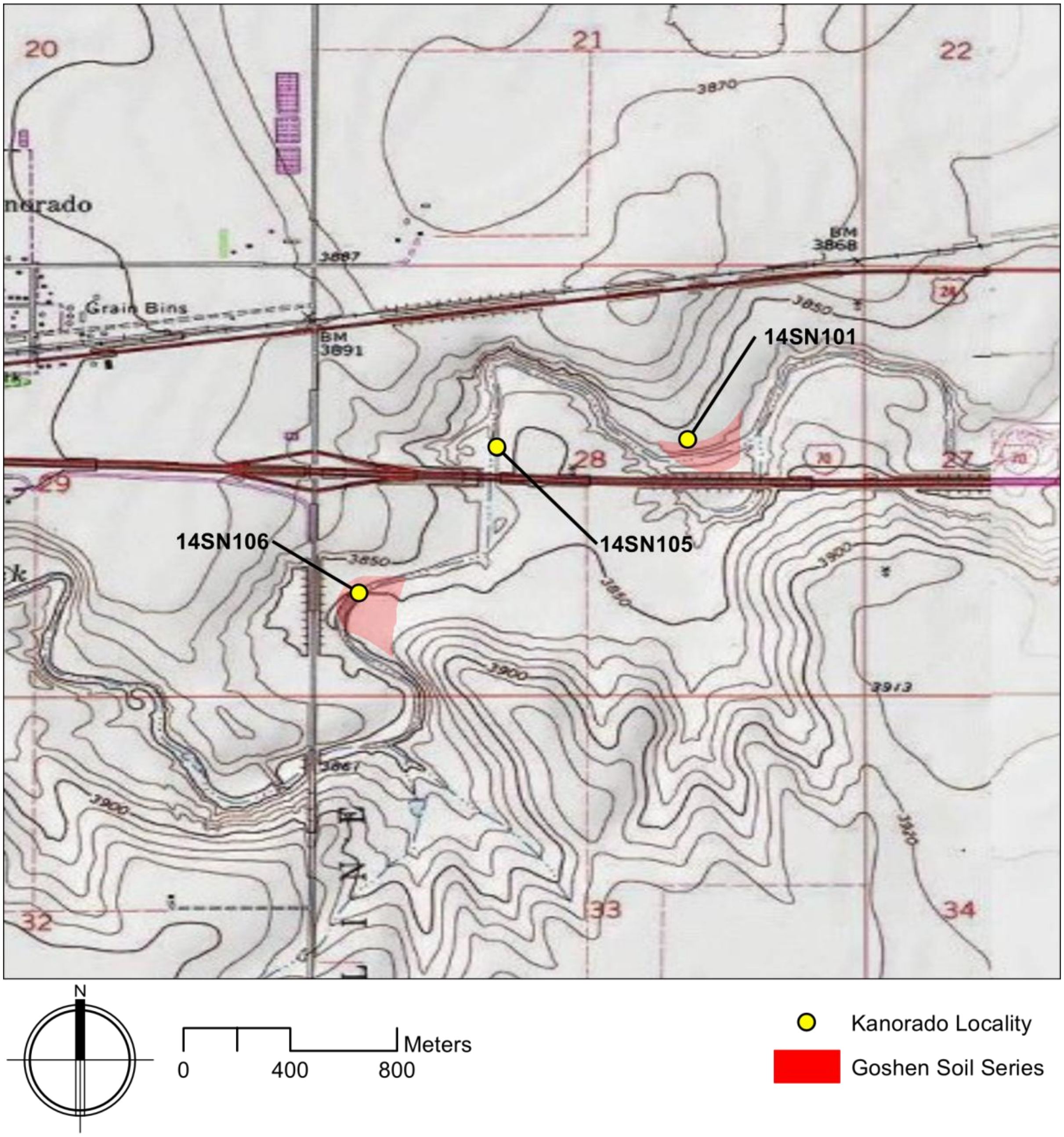

**Figure 3: Excerpt of USGS 7.5 minute quadrangle map showing the Kanorado locality with the Goshen soil series highlighted**

cultural components is evidenced at the Kanorado locality, where the Goshen series is mapped as the surface soil for the majority of the locality (Figure 3).

## Modern Climate

The central High Plains region has a continental climate characterized by a large annual temperature range. The average annual temperature at Goodland, KS is 10.7º C (51.3º F), and the average low and high temperatures are 2.9 º C (37.2 º F) and 18.6 º C (65.4º F), respectively (High Plains Regional Climate Center 2010). The average first freeze of the year generally occurs in early October, while the average last freeze of the year occurs in early May. The growing season averages 161 days (Prescott, Jr. 1953). A distinct east-to-west precipitation gradient occurs on the High Plains. In the study area, mean annual precipitation ranges from 46.1 cm (18.2 in) in Goodland, KS to 42.4 cm (16.7 in) in Burlington, CO (High Plains Regional Climate Center 2010). Much of the rainfall occurs as a result of frontal activity during late spring through early autumn (Mandel 2006b). During the spring and summer, Pacific and polar air masses converge with warm, moist maritime-tropical air from the Gulf of Mexico over the region. The collision of these air masses produces cyclonic storms, some with intensive rainfall.

The High Plains are subject to periodic droughts associated with the intensification of zonal airflow and anticyclonic, high-pressure systems in the upper atmosphere. Severe droughts, which have occurred in the region roughly every 20 years, appear to be linked to persistent cool sea surface temperatures associated with La Niña in the eastern tropical Pacific Ocean (Schubert et al. 2004a, b; Seager et al. 2005; Seager 2007). These severe droughts affect the composition of the grassland communities of the region and can severely reduce vegetative cover. According to Laird et al. (1996), Woodhouse and Overpeck (1998), Cook et al. (2004), Cook et al. (2007), and Miao et al. (2007), the Great Plains experienced episodes of "megadrought" during the Holocene. These droughts were more severe than any in modern times and may have lasted for hundreds of years, significantly impacting prehistoric people and the High Plains ecosystem (Meltzer 1999; Forman et al. 2001; Clark et al. 2002; Brown et al. 2005; Mandel 2008).

## Modern Vegetation

The High Plains region of eastern Colorado and western Kansas is short-grass prairie dominated by blue grama (*Bouteloua gacilis*) and buffalo grass (*Buchloe dactyloides*) (Küchler 1974). Along the eastern boundary of the High Plains, short-grass prairie grades into mixed-grass prairie dominated by big bluestem (*Andropogon gerardii*), little bluestem (*Andropogon scoparius*), and blue grama (*Bouteloua gracilis*). Other common plants in the study area include soapweed yucca (*Yucca glauca*) and twistspine pricklypear (*Opuntia macrorhiza*).

Riparian forests form narrow bands along the major streams throughout the High Plains. These woodlands, which become less dense from east to west across the region, are dominated by cottonwood (*Populus deltoides*), hackberry (*Celtis occidentalis*), willow (*Salix* sp.), and American elm (*Ulmus americana*).

## Paleoclimate

During the late Pleistocene and early Holocene, discussed here as the period between the last glacial maximum (LGM) and the end of the Pleistocene-Holocene transition; (~18,000-9,000 $^{14}$C yr B.P.), the environment of the central High Plains was quite different from the modern environment (Mandel 1987, 2006b; Martin and Martin 1987; COHMAP Members 1988; Johnson and Park 1996). This is due in large part to the Laurentide ice sheet that covered much of North America during the late Pleistocene. The massive ice sheet and the strong anticyclonic circulation associated with it, forced the summer jet stream to the south and split the flow of the winter jet stream. During the winter, one branch of the jet stream remained in the southern portion of the Northern Hemisphere while the other flowed along the northern ice sheet margin (COHMAP Members 1988). Circulation models show the glacial anticyclone and the jet stream's more southerly flow funneled cold, dry glacial air down across the Plains and pushed the storm track to the south. As a result, conditions over much of the midcontinent were cooler with less precipitation than today. The results of stable carbon isotope analysis (Forman et al. 1995; Johnson and Park 1996; Arbogast and Johnson 1998; Muhs, Aleinikoff et al. 1999; Muhs, Swinehart et al. 1999; Johnson and Willey 2000; Cordova et al. 2011) and geomorphological investigation (Forman et al. 1995; Muhs, Aleinikoff et al. 1999; Muhs, Swinehart et al. 1999; Forman et al. 2008; Mandel 2008) generally corroborate the condition simulated in the climate models. Even though the climate of the region was likely cooler with less precipitation than present, the Earth's increased distance from the sun and its decreased axial tilt decreased seasonality; summers and winters were significantly milder than they are today (Martin and Martin 1987; COHMAP Members 1988).

## Paleoecology

Due of decreased seasonality during the Wisconsin glacial episode, the central High Plains was home to diverse floral and faunal communities that have no modern analogs in North America. Studies of plant macrofossils, phytoliths, pollen, and stable carbon isotopes suggest that from the LGM to the beginning of the Pleistocene-Holocene transition (~11,000 $^{14}$C yr B.P.) the central High Plains was a spruce/aspen parkland intermixed with $C_3$ grasses (Mandel 1987; Wells and Stewart 1987; Fredlund 1995; Johnson and Park 1996; Fredlund and Tiezen 1997a, b; Arbogast and Johnson 1998; Muhs, Aleinikoff et al. 1999; Johnson and Willey 2000). The late-

Pleistocene faunal communities benefitted from the more equitable climate; both cold and warm-adapted species thrived throughout the region (Martin and Neuner 1978; Martin and Martin 1987). Martin and Hoffman (1987) grouped the late-Pleistocene High Plains fauna into the *Camelops* faunal province. It was in this faunal province that many of the well-known Pleistocene megafauna occurred, including American camel (*Camelops*), horse (*Equus*), imperial mammoth (*Mammuthus imperator*), and extinct bison (*Bison antiquus*). The region also was home to several large predators, including the short-faced bear (*Arctodus simus*) and the American lion (*Panthera atrox*).

During the Pleistocene-Holocene transition the central High Plains experienced dramatic environmental changes that affected the floral and faunal communities. As the Laurentide ice sheet began to retreat north, the glacial anticyclone weakened, allowing the jet stream to shift northward. Evidence of the Pleistocene-Holocene transition warming trend has been detected in stable carbon isotope records as a shift from $C_3$ plants (trees, shrubs and cool-season grasses) to warm season $C_4$ grasses in the central High Plains and surrounding regions (Forman et al. 1995; Johnson and Park 1996; Arbogast and Johnson 1998; Muhs, Aleinikoff et al. 1999; Muhs, Swinehart et al. 1999; Johnson and Willey 2000; Olson and Porter 2002; Nordt et al. 2007). Vegetative change was accompanied by the collapse of the late-Pleistocene faunal communities, with approximately two-thirds of the large mammals becoming extinct (Martin and Wright 1967; Martin and Klein 1984). Pleistocene extinction has been attributed to different factors, including environmental change and over hunting by humans. Flannery (1999), Grayson and Meltzer (2003), Barnosky et al. (2004), and Fiedel and Haynes (2004) have summarized the ongoing extinction debate.

# CHAPTER III

# PREVIOUS RESEARCH

## Paleoindian Cultural Complexes

This study focuses on the Paleoindian cultural period, which spans the terminal Pleistocene and early Holocene, approximately 11,500 - 8,500 $^{14}$C B.P. (Hofman and Graham 1998; Holliday 2000b). The specific Paleoindian cultural periods of the High Plains are as follows: Clovis (11,500 - 10,900 $^{14}$C B.P.), Goshen (ca. 11,000 $^{14}$C B.P.), Folsom/Midland (10,900 - 10,200 $^{14}$C B.P.), Plano complex (Agate Basin, Plainview, Milnesands and Hell Gap); (10,500 - 9,500 $^{14}$C B.P.), Cody complex (Alberta, Scottsbluff, Eden, and Firstview); (10,200 - 8,800 $^{14}$C B.P.), Dalton (10,500 -9,200 $^{14}$C B.P.), and Allen (9,400 – 7,800 $^{14}$C B.P.) .

Archaeological evidence from a number of sites in North and South America suggest people were present in the Americas prior to ca. 11,500 $^{14}$C B.P. (Dillahey 1999; Dixon 1999). These sites are referred to as Pre-Clovis or Pre-Paleoindian. Sites in the Great Plains that have yielded possible Pre-Paleoindian materials include Selby and Dutton in northeastern Colorado (Stanford 1979), La Sena in southwestern Nebraska (Holen et al. 1990; May and Holen 1993: Holen 2006), Lovewell in north-central Kansas (Holen 2007), and Burnham in northwestern Oklahoma (Wyckoff et al. 2003). The antiquity of these sites has been disputed because of possible problems with dating, stratigraphic integrity, and/or identification of the artifacts (Hofman and Graham 1998). Additional research is necessary to determine the antiquity of humans in the New World. However, it is not within the scope of this study to affirm or refute a human presence in the Central Plains before Clovis time.

## Archaeological Background

Paleoindian research has a long history on the High Plains (Wormington 1957; Meltzer 1983; Hofman 1996; Holliday 1997; Mandel 2000, 2008; Holliday and Mandel 2006). During the late 19th and early 20th centuries, the recovery of stone tools in association with extinct Pleistocene fauna at sites like 12 Mile Creek, Folsom, and Clovis, confirmed the antiquity of humans in North America (Hofman and Graham 1998; Albanese 2000; Holliday 2000a). Since the first discoveries of early prehistoric cultural components on the High Plains, a number of buried, *in situ*, often stratified Paleoindian sites have been discovered in the region (Sellards 1952; Wormington 1957; Mandel 2000, 2008; Holliday and Mandel 2006). This is especially true on the Southern High Plains of Texas and New Mexico (Johnson 1991; Holliday 1997, 2000b), and the Northern High Plains of eastern Colorado and Wyoming (Frison 1991; Albanese 2000).

Many Paleoindian sites on the High Plains are in or adjacent to the valleys of low-order streams or draws that are common in the region (see Howard 1935; Schultz and Eiseley 1935; Barbour and Schultz 1936; Howard 1936; Cotter 1937; Bryan and Ray 1940; Wormington 1957; Wilmsen and Roberts Jr. 1978; Boldurian and Cotter 1999; Meltzer et al. 2002). These draws were attractive locations to the Paleoindians because they offered sources of fresh water, especially springs, and a number of plant resources that could be used for food and tools (Frison 1991; Mandel et al. 2004). Paleoindians also used the draws as natural traps when hunting large fauna (Frison 1991).

Although the Folsom site is generally accepted as the first recorded site containing artifacts in primary context with extinct Pleistocene fauna, another Paleoindian site, 12 Mile Creek in Kansas, predated the Folsom discovery by three decades and also contained cultural

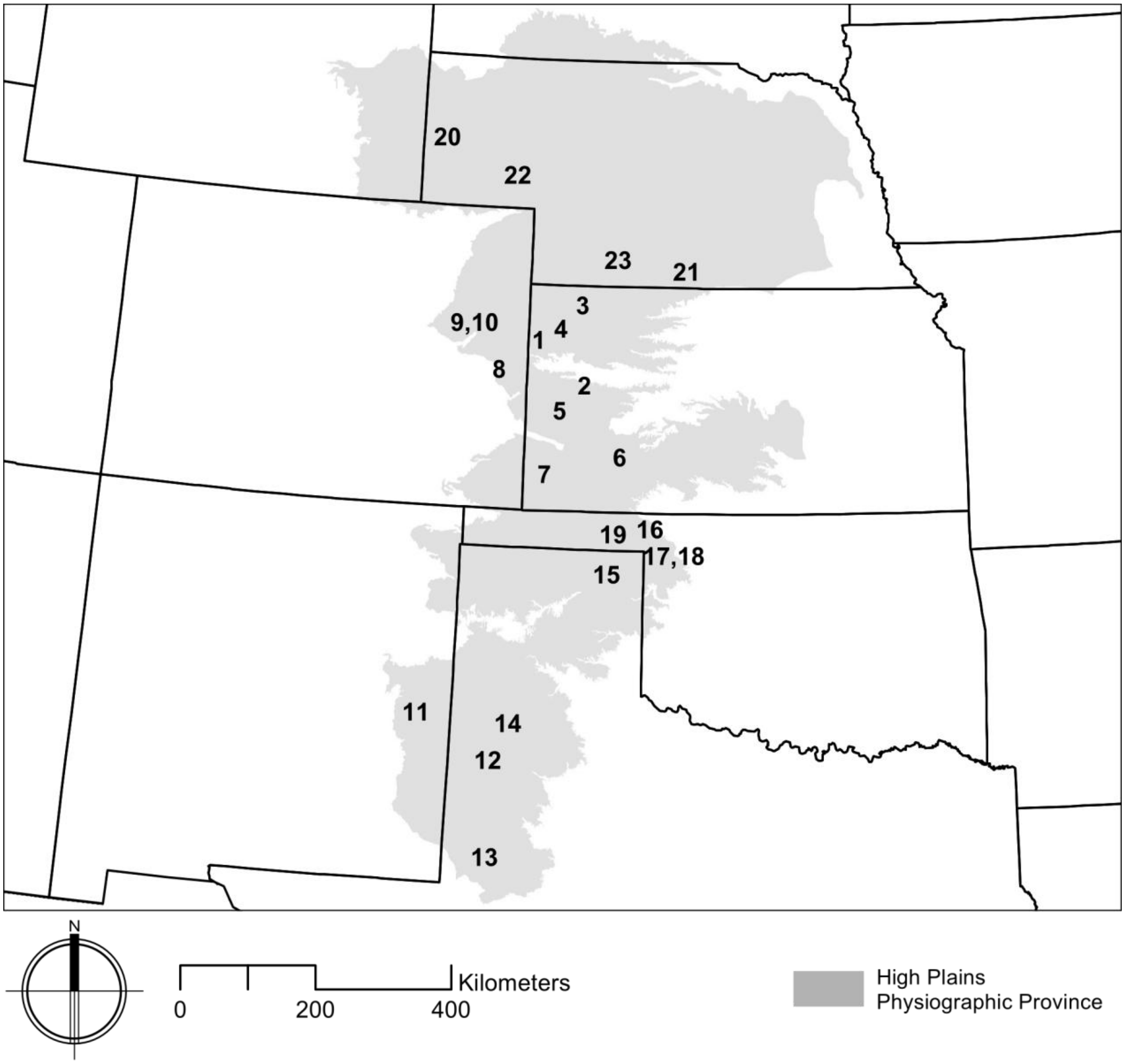

**Figure 4: Map of selected Paleoindian sites located along draws discussed in the text (Table 2)**

materials with the remains of Pleistocene fauna (Hofman and Graham 1998; Mandel2000b). The 12 Mile Creek site is located in Logan County, Kansas along 12 Mile Creek, a small stream in the Smoky Hill River basin (Figure 4 and Table 2). Like the Folsom site, 12 Mile Creek was discovered during paleontological excavations of a bison bonebed (Rogers and Martin 1984; Hill 1994). In 1895 excavators discovered a fluted projectile point in direct association with the bison bones. Samuel Williston, a geologist at the University of Kansas, was in charge of the excavations at 12 Mile Creek. Based on the field description of the bison skeletons, Williston concluded they were likely extinct Pleistocene forms. He immediately recognized the significance of the point's direct association with the bonebed (Mandel 2000b). Unfortunately, the point was subsequently lost or stolen, and the site was not accepted as evidence of a human presence in North America during the Pleistocene.

**Table 2: Selected Paleoindian sites located along draws discussed in the text**

| Map Number | Site Name | Site Number | Complex | Radiocarbon Ages | Reference |
|---|---|---|---|---|---|
| 1 | Kanorado Locality | 14SN101, 14SN105,14SN106 | Pre-Clovis?, Clovis, Folsom | 10,700± 200[a] | Mandel et al. 2004; Mandel et al. 2005 |
| 2 | 12 Mile Creek | 14LO1 | Clovis, Folsom | 10,400 ±220[a] | Williston 1902; Rogers and Martin 1984; Hill 1994 |
| 3 | Burntwood Creek | 14RW2 | Allen-Frederick | 8897 ± 75[a]<br>9,050 ± 25[a] | Hill et al. 1992; Russell and Hofman 2006; Murphy 2008; Hofman et al. 2010 |
| 4 | Laird | 14SN2 | Dalton | 8,495 ± 40 | Hofman and Blackmar 1997; Mandel et al. 2004 |
| 5 | Norton | 14SC6 | Cody, Allen-Frederick | 9,080 ± 60 | Hofman et al. 1995; Hofman et al. 2010 |
| 6 | Simshauser | 14KY102 | Folsom | pre 10,170 ± 70 | Mandel and Hofman 2006 |
| 7 | Winger | 14ST401 | Allen-Frederick | 9,080 ± 90 | Buckner 1970; Mandel and Hofman 2003 |
| 8 | Olsen-Chubbuck,CO | 5CH3 | Firstview | 9,390 ± 60[a] | Wheat 1972; Holliday et al. 1999 |
| 9 | Selby, CO | 5YM36 | Pre-Clovis? | 16,630 ± 320 | Stanford 1979 |
| 10 | Dutton, CO | 5YM36 | Pre-Clovis?, Clovis | 13,600 ± 485<br>11,710 ± 150 | Stanford 1979 |
| 11 | Clovis, NM | 29RV2 | Clovis, Folsom | 11,300 ± 235[a] | Howard 1935, 1936; Cotter 1937; Boldurian and Cotter 1999 |
| 12 | Lubbock Lake, TX | 41LU1 | Clovis, Folsom, Plainview | 10,081 ± 85[a] | Black 1974; Holliday et al. 1983, 1985, 1999; Johnson, 1976, 1983 |
| 13 | Midland, TX | 41MD1 | Midland, | 10,600 ± 1000 | Wendorf et al. 1955; |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
|  |  |  | Folsom |  | Wendorf and Krieger 1959; Holliday and Meltzer 1996 |
| 14 | Plainview, TX | 41HA1 | Plainview | 9,620 ± 83[a] | Sellards et al. 1947; Guffee 1979; Holliday et al. 1999 |
| 15 | Lipscomb,TX | 41LP1 | Folsom | 7250 ± 155<br>10,820 ± 150 | Hofman 1995; Hofman et al. 1989, 1991 |
| 16 | Burnham, OK | 34WO73 | Pre-Clovis? | 10,210 ± 270<br>46,200 ± 1,600 | Wyckoff et al. 2003 |
| 17 | Jake Bluff, OK | 34HP60 | Clovis | 10,765 ± 25[a] | Bement and Carter 2006 |
| 18 | Cooper, OK | 34HP45 | Folsom | 7,020 ± 120<br>8,880 ± 190<br>10,050 ± 210 | Bement 1999; Carter and Bement 2006 |
| 19 | Waugh, OK | 34HP42 | Folsom | 10,392 ± 86[a] | Hofman 1991, 1995; Hill and Hofman 1997; Hofman 2006 |
| 20 | Scottsbluff, NE | 25SF2 | Cody | 8,400<br>9,200 | Schultz and Eiseley 1935; Barbour and Schultz 1936; Holen 1995 |
| 21 | La Sena, NE | 25FT177 | Pre-Clovis? | 17,765 ± 425[a] | Holen et al. 1990; May and Holen 1993; Holen 2006 |
| 22 | Clary Ranch, NE | 25GD106 | Allen-Frederick | 9,040 ± 35 | Hill et al. 2001, 2002; Hill et al. 2008; May et al. 2008 |
| 23 | *Medicine Creek Sites, NE* |  |  |  |  |
|  | Allen | 25FT50 | Frontier | 8,595 ± 210[a]<br>10,461 ± 825[a] | Holder and Wike 1949 Bamforth 2002; Bamforth et al. 2005; May 2007 |
|  | Lime Creek | 25FT41 | Frontier | 9,470 ± 590[a] | Schultz and Frankforter 1948; Davis and Schultz 1952; Davis 1953; May 2007 |
|  | Red Smoke | 25FT42 | Allen-Frederick | 8,870 ± 130[a]<br>9,820 ± 80 | Schultz and Frankforter 1948; Davis and Schultz 1952; Davis 1953; Knudson 2002; May 2007 |

[a] Average of multiple radiocarbon dates

Like 12 Mile Creek, the Lipscomb site represents a Paleoindian bison kill that began as a paleontological excavation in a draw. The Lipscomb site is located along a tributary of Wolf Creek in the North Canadian River basin at the southern extent of the central High Plains in the northeastern Texas panhandle (Figure 4 and Table 2). In 1939, the first excavations at the site were conducted by C. Bertrand Schultz of the University of Nebraska State Museum (Barbour and Schultz 1941; Schultz 1943). Schultz's excavations were primarily focused on the extinct bison bone bed as a paleontological site; however the importance of Lipscomb as an early archaeological site was recognized with the discovery of Folsom artifacts in primary context with the bison remains (Hofman et al. 1989; Holliday 1997). Examination of the first reports on Lipscomb, further analysis of the collections, and ongoing excavations at the site have provided insight into Folsom adaptation in the region (Hillerud 1970; Todd et al. 1990; 1992; Hofman et al. 1991; Hofman 1995).

Another early find that was recognized as having stone tools in association with extinct fauna is the Clovis site (Howard 1935, 1936; Cotter 1937; Hester 1972; Boldurian and Cotter 1999). This site was discovered in Blackwater Draw in 1932 near the town of Clovis, New Mexico on the Southern High Plains (Figure 4 and Table 2). Stratified Clovis and Folsom artifacts were found in association with a mammoth and bison kill, respectively, and it became the type locality for the Clovis culture. Because both Clovis and Folsom projectile points were discovered in good stratigraphic context, the site also became the first location where the differences between the two fluted point types was documented (Sellards 1952; Holliday 2000a), as well as the type locality for the Clovis culture. In addition to Clovis and Folsom, a number of other Paleoindian sites in the southern High Plains of Texas are associated with draws, including

Lubbock Lake, Midland, and Mustang Springs (Hill and Meltzer 1987; Johnson and Holliday 1989; Holliday and Meltzer 1996; Holliday 2000a).

The Scottsbluff site is also a Paleoindian bison kill that began as a paleontological excavation in a draw. The Scottsbluff site, located along Spring Creek in the North Platte River basin in northwestern Nebraska, was discovered during the 1932 Morrill Paleontological Expedition (Schultz and Eiseley 1935; Barbour and Schultz 1936; Todd et al. 1990; Holen 1995); (Figure 4 and Table 2). It is one of the first documented associations of cultural materials with extinct Pleistocene fauna on the Northern High Plains (Worminton 1957; Albanese 2000), and is the type locality for the Scottsbluff projectile point. Several additional Late Paleoindian sites have been discovered along low-order streams or draws in the High Plains region of Nebraska, including the following Clary Ranch and the Medicine Creek sites: Allen, Lime Creek, and Red Smoke (Hill et al. 2001; Bamforth 2002; Knudson 2002; Hill et al. 2008; May et al. 2008).

In contrast to many of the earliest discovered Paleoindian kill sites, excavations at the Olsen-Chubbck site were primarily conducted by trained archaeologists. The Olsen-Chubbuck site is located in the valley of a small tributary of Big Sandy Creek in the Arkansas River drainage in eastern Colorado (Figure 4 and Table 2). Olsen-Chubbuck was excavated by Joe Ben Wheat in the late 1950's and early 1960's and consists of a large bonebed comprised of extinct early Holocene bison and a number of Firstview complex artifacts (Wheat 1972). Through careful excavations, Wheat (1972) was able to not only determine the hunting strategies used by the Paleoindians at the site, but was also able to demonstrate how the bonebed and assoicated cultural materials were tied to Paleoindian subsistence and social systems.

Additional examples of Paleoindian sites in northwest Oklahoma are Cooper and Jake Bluff (Figure 4 and Table 2). Both sites are in the Beaver River drainage basin along the High Plains boundary. Excavations in 2002 produced Clovis projectile points in association with at least 15 *Bison antiquus* individuals, and a radiocarbon age of 10,750±40 yr B.P. was determined on bison bone (Bement and Carter 2006). This date falls near the end of the accepted Clovis period and may postdate mammoth extinction. Bement and Carter (2006) suggested that the Jake Bluff site represents a Clovis/Folsom transition where Paleoindian peoples were adapting to the changing ecosystem of the Pleistocene-Holocene transition.

In addition to the Jake Bluff site, a number of other Paleoindian sites have been recorded in the draws of the High Plains border region in northwest Oklahoma, including Cooper (Bement 1999); Waugh (Hill and Hofman 1997; Hofman 1991;2006), and Goff Creek (Ballenger 1999a, b); (Figure 4 and Table 2).

In western Kansas, there are a number of Late Paleoindian sites associated with draws, including Burntwood Creek (Hill et al. 1992; Russell and Hofman 2006; Hoffman 2010), Gardiner (Asher 2008; Hofman 2010), Laird (Hofman and Blackmar 1997; Mandel et al. 2004; Hofman 2010), Norton (Hofman et al. 1995; Hofman 2010), and Winger (Buckner 1970; Mandel and Hofman 2003) (Figure 4 and Table 2); however, few Early Paleoindian sites have been recorded in the region.

Although many of the Paleoindian sites recorded in the High Plains region are associated with low-order streams or draws, some researchers have suggested that Paleoindian settlement patterns may not be the only explanation for the disproportionate distribution. In their analysis of the distribution of Paleoindian sites in the state of Kansas, Brown and Logan (1987) discussed the likelihood of a survey bias. They suggested that an archaeological focus on stream valleys has inflated the number of Paleoindian sites in alluvial settings versus other geomorphic settings. Though a survey bias may be partially responsible for the greater number of recorded sites in and near alluvial setting, the importance of the streams, including draws, to Paleoindians cannot be disregarded.

### Geoarchaeological Background

Geoarchaeology has become an important aspect of archaeological research, and it has been especially useful when applied to Paleoindian research in the Central Plains. The application of geoscientific methods to archaeological investigations has facilitated a greater understanding of paleoenvironments and paleolandscapes at sites throughout the region. Geoarchaeological investigations also have examined patterns of site distribution and how geomorphic processes have played a major role in the preservation and removal of the archaeological record.

Bettis and Mandel (2002), Mandel et al. (2004), Blackmar and Hofman (2006), and Mandel (2006a, 2008) suggested that the archaeological record has been filtered by geomorphic processes throughout the Central Plains. Specifically, erosion, sedimentation, and soil formation has destroyed or altered the archaeological record or reduced its visibility in alluvial settings (Waters 1992; Brown 1997; Rapp and Hill 2006).

According to Mandel et al. (2004) and Mandel (2006a, 2008), waves of early and middle Holocene erosion associated with the Altithermal climactic episode removed much of the Paleoindian archaeological record from small to intermediate streams (≤6th order) in the Central Plains. However, the erosion did not reach the upper end of drainage systems on the High Plains of Kansas and eastern Colorado. Consequently, thick deposits of alluvium with multiple

Paleoindian-age buried soils are preserved in the valleys of draws. Hence, there is high potential for Paleoindian cultural deposits in the draws.

The Kanorado locality is a good example of the preservation of Paleoindian-age soils in draws on the central High Plains. As previously noted, Paleoindian cultural deposits at Kanorado occur in a buried cumulic soil in the T-1 terrace. The buried soil, referred to as the Kanorado paleosol, marks an episode of relative landscape stability during the late Pleistocene and early Holocene (Mandel et al. 2004; Mandel 2006a, 2008). Buried alluvial soils dating to the Pleistocene-Holocene transition have been documented elsewhere on the High Plains of Kansas, suggesting that the episode of landscape stability was widespread (Mandel 2006a, 2008).

The laterally extensive buried Paleoindian-age soils that occur in valley fills on the High Plains may contain a wealth of information about the Paleoindians that inhabited the region. However, discovering the often sparse material record in such a vast area is a daunting task. In several studies, researchers have successfully used published NRCS soil survey data to predict locations with high potential for archaeological deposits (e.g., Artz 1985; Bettis 1992; Mandel 1992; Monger 1995; Stafford and Creasman 2002).

Stafford and Creasman (2002) used published soil survey data to examine the distribution of Entisols, Inceptisols, and Mollisols in the lower Ohio River valley. They focused on the taxonomic classification of the three soil orders to determine the magnitude of soil development, from very weakly developed Entisols to better developed Inceptisols and Mollisols. The magnitude of soil development was then used to predict the age and distribution of late Holocene alluvium in the valley. Stafford and Creasman were then able to determine which soils were most likely to yield Woodland (~2,800 - 1,000 ybp), Late Prehistoric (~1,000 - 350 ybp), and Historic (350 ybp - present) period cultural deposits.

Artz (1985) also used degree of soil development in his study of the Late Archaic (~5,000 -2,000 ybp) in the Little Caney River valley of northeast Oklahoma. He determined that Late Archaic cultural deposits most likely would be associated with soils that have moderately developed Bt (argillic) horizons. In northeastern Oklahoma, argillic horizons typically 1,500-2,000 years of landscape stability to form, and therefore, soils that contain Bt horizons generally are older than soils that do not have Bt horizons. In the Little Caney River valley, the Mason soil series is the only alluvial soil with an argillic horizon. Therefore, Artz (1985) identified the Mason series as a target for locating Late Archaic sites. An archaeological survey of the Little Caney River valley verified his strategy; Late Archaic cultural deposits were only found in alluvial fills with the Mason series mapped on their surfaces.

Monger (1995) used soil geomorphic mapping to interpret the geomorphological context of known archaeological sites in the deserts of southern New Mexico and west Texas and to focus the efforts of archaeological surveys. He mapped the geomorphic surfaces throughout the Fort Bliss Military Installation to determine the age and evolution of the landscape. Relative age determinations were based on the magnitude of surface-soil development. During the investigation, Monger also identified episodes of Holocene erosion and deposition throughout the study area. Landform sediment assemblages were mapped according to their age, and the maps were used to predict the temporal pattern of the archaeological record. The maps also were used to determine where cultural deposits are likely to have good horizontal and vertical integrity. For example, upland surfaces that are ~250,000 to 400,000 years old are too old to contain deeply buried cultural deposits, but cultural deposits are likely to occur on or immediately below these surfaces. Monger stressed that these surfaces tend to be deflated and, therefore, are less likely to yield artifacts in their primary context.

Bettis (1992) and Bettis and Hajic (1995) used the magnitude of soil development as their primary component for predicting the age of alluvial landforms and predicting archaeological site location in the Upper Midwest. Specific characteristics of soils, including horizonation, rubification, and mottling, were used to estimate the relative age of alluvial soils and sediments. Bettis (1992) chose these easily observable criteria to aid archaeologists who may have only a modest knowledge of soils and geomorphology. The soil geomorphology-based model also was intended to guide the archaeological sampling of alluvial landscapes. For example, according to the model, early and middle Holocene deposits are likely to be buried below the depth of shallow shovel test excavations. Therefore, it is necessary to use deep mechanical excavation to sample the early and middle Holocene archaeological record in the alluvial fills.

Although soil surveys have been used elsewhere to predict the age of specific landforms and areas of high archaeological potential, the strategy has not been employed on the High Plains of eastern Colorado and western Kansas. Given the discovery of Early Paleoindian cultural deposits in a buried, laterally extensive, Paleoindian-age soil at Kanorado, there is potential for early cultural deposits in the draws of the central High Plains. An archaeological predictive model employing NRCS soil series to locate buried, early cultural deposits in draws has the potential to yield additional early prehistoric sites. Such discoveries would advance archaeologists' understanding of the peopling of the region and human adaptation to the changing environment throughout the Late Pleistocene and Early Holocene.

# CHAPTER IV

# RESEARCH METHODS

A geographic information system (GIS) basemap was prepared for the study area prior to fieldwork. The map included National Agriculture Imagery Program (NAIP) high resolution aerial photographs, hydrological datasets, and NRCS Soil Survey Geographic (SSURGO) data. All GIS data were downloaded from the Kansas Data Access and Support Center (DASC). The GIS basemap facilitated the selection of alluvial landforms adjacent to Middle Beaver Creek that have the Goshen series mapped as the surface soil. Six study sites were selected among these landforms during two separate reconnaissance trips to the Middle Beaver Creek Basin (Figure 5). Study sites were chosen based on a number of factors including accessibility, landowner permission, and location in the drainage network. Location in the drainage network was an especially important factor. Selecting landforms across the entirety of the Middle Beaver Creek Basin allowed for the broadest sample of the landscape sediment assemblages of the Goshen-mapped landforms. A geographically comprehensive sample provided the most accurate assessment of the co-occurrence of the Goshen series and the potential for Paleoindian cultural components.

A total of eight landform sediment assemblages were examined throughout the field investigations using a trailer-mounted Giddings hydraulic soil probe with a 2.5 inch bit. In addition to the six soil cores, soil profiles exposed in the bank of Middle Beaver Creek at two of the study sites were described and sampled. Soils and sediments were described using standard terminology and procedures presented by Schoeneberger et al. (2002) and Birkeland (1999). Soil and sediment color was determined using the Munsell color chart. Moist horizon colors are presented in the text; moist and dry horizon colors are presented in Appendix II.

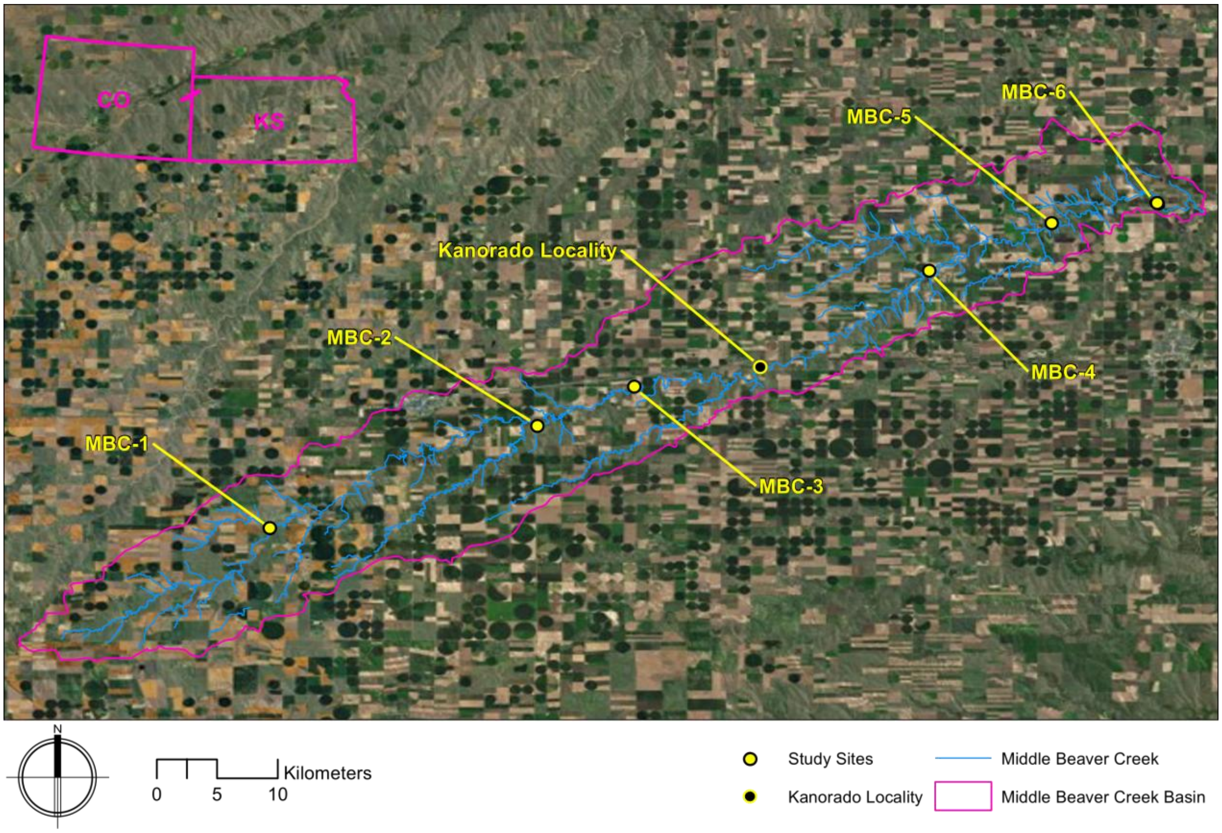

**Figure 5: Aerial photograph of Middle Beaver Creek Basin with locations of study sites and the Kanorado locality**

Relative degree of soil development at the six study sites was described using terms presented by Holliday (2004). Soils with A-C profiles (i.e., little or no evidence of pedogenesis or carbonate accumulation) were described as “very weakly developed.” Those soils with A-Bw profiles (i.e. evidence of minor subsoil alteration by pedogenesis and Stage I carbonate morphology) were described as “weakly developed,” and soils with A-Bt or A-Bt-Bk profiles (i.e. evidence of pedogenesis in the form of argillic horizons and Stage II carbonate morphology) were described as “moderately developed.” Holliday’s (2004) description includes “strongly developed” soils that exhibit increased thickness of diagnostic subsurface horizons, rubification of the subsoil, and Stage III or higher carbonate morphology; however, no strongly developed soils were encountered during this investigation. These qualitative designations provided a simple means to compare and correlate magnitude of soil development among the eight soil profiles.

Degree of soil development at each locality was calculated using a profile development index (PDI); (Harden 1982, Harden and Taylor 1983, modified in Birkland 1999). The PDI is a semi-quantitative method to define the degree of soil development of a soil profile. Field properties were quantified for each horizon of each locality profile, as well as each horizon at Kanorado Locality site 14SN101 (Mandel 2012 personal communication). Field property values were based on the degree of pedogenic development as compared to the quantified field properties of the uppermost C horizon, or parent material, in the soil profile. Horizon properties used in the PDI calculations were: color paling, melanization, texture, dry consistency, moist consistency, structure, clay films, and carbonate stage. Field property values were then normalized to a scale between 0 - 1 (no development - maximum development) by dividing by the maximum possible value for that property. Maximum property values used in this study were modified from Birkland (1999). Parent material was not encountered in Core 1-2 or Core 2, nor was the parent material described at site 14SN101. In these cases, parent material properties from the nearest locality were used as a proxy.

A total of eleven bulk soil samples were collected among the eight soil profiles for radiocarbon dating to determine numerical ages for the alluvial landforms mapped with the Goshen soil series. Radiocarbon dating soil organic matter (SOM) can be problematic (Birkeland 1999, Martin and Johnson 1995, Holliday 2004); however, under the right conditions and with appropriate caution in sampling and interpretation, radiocarbon dating SOM can help establish the broad outlines of a soil chronology (Holliday 2004:179). Radiocarbon ages determined on SOM represent an apparent mean residence time (AMRT) for the soil and are always younger than the time when pedogenesis began (Holliday 2004:179). Radiocarbon ages determined on SOM from surface soils only provide a minimum age for the end of deposition of the soil's parent material. Buried soils are often completely cut off from soil forming factors and additions of new organic carbon. Barring illuviation of younger organic carbon from the surface soil, radiocarbon ages determined on SOM from the top of buried soils can provide a minimum age for the inception of pedogenesis and a maximum age for its burial (Birkeland 1999). Radiocarbon dating SOM has proven reliable in a number of studies in the Central Plains (e.g., May and Holen 1985, 1993; Mandel 1994, 2008).

Soil samples were submitted to the Illinois Geological Survey's Isotope Geochemistry Laboratory for accelerator mass spectrometer (AMS) $^{14}C$ dating. Samples were pretreated to remove rootlets and carbonate. Numerical ages were determined for the total decalcified soil organic matter using the liquid scintillation method. All radiocarbon ages were $\delta^{13}C$ corrected. Uncalibrated radiocarbon years before present (B.P.) in the text, and in uncalibrated and calibrated years (cal B.P.) in Table 3.

The potential for each locality to yield Paleoindian was mostly based on the radiocarbon chronology. Localities where radiocarbon ages determined on SOM fell within the Pleistocene-Holocene transition or early Holocene, or approximately 12,000 – 7,000 B.P. $^{14}C$ yr B.P., were categorized as having high potential to yield Paleoindian cultural deposits. Although most of the early Holocene post-dates the Paleoindian cultural period, radiocarbon ages determined on SOM provide only a minimum age for the period of soil development. Hence buried and surface soils with SOM that yielded radiocarbon ages ranging between ca. 9,000 and 7,000 B.P. may contain Paleoindian cultural deposits. Those localities where SOM yielded radiocarbon ages between ca.

7,000 and 6,000 B.P. and radiocarbon ages <6,000 B.P. were categorized as having low potential and no potential, respectively.

Table 3. Radiocarbon ages determined on SOM from study sites in the Middle Beaver Creek Valley.

| Study Site | Profile Designation | Sample Depth (cm) | Horizon | $\delta^{13}C$ (‰) | $^{14}C$ Age (B.P.) | Cal Age[b] (B.P.) | Median Cal Age (B.P.) | Lab. No. |
|---|---|---|---|---|---|---|---|---|
| MBC-1 | Core 1-1 | 150-160 | Btk3 | -15.5 | 7,440±25 | 8,191 – 8,336 | 8,262 | ISGS-A1393 |
|  | Core 1-2 | 208-218 | Akb2 | -15.6 | 9,815±25 | 11,201 – 11,248 | 11,227 | ISGS-A1398 |
| MBC-2 | Core 2 | 203-218 | Btk2b | -16.9 | 9,200±25 | 10,254 – 10,483 | 10,347 | ISGS-A1400 |
| MBC-4 | Core 4 | 62-72 | Ab1 | -15.4 | 4,370±20 | 4,863 – 5,029 | 4,923 | ISGS-A1399 |
|  |  | 182-192 | ABkb2 | -16.0 | 6,445±20 | 7,322 – 7,423 | 7,369 | ISGS-A1396 |
| MBC-5 | Cutbank 5 | 104-114 | Atkb1 | -15.4 | 6,085±20 | 6,891 – 7,002 | 6,948 | ISGS-A1354 |
|  |  | 223-233 | Ak1b2 | -16.7 | 10,005±30 | 11,311 – 11,697 | 11,478 | ISGS-A1352 |
|  |  | 239-249 | Ak2b2 | -17.5 | 10,450±35 | 12,138 – 12,552 | 12,394 | ISGS-A1351 |
| MBC-6 | Core 6-1 | 71-83 | ACb | -15.4 | 1,595±15 | 1,416 – 1,529 | 1,462 | ISGS-A1395 |
|  | Cutbank 6-2 | 100-110 | Akb | -16.6 | 7,490±25 | 8,206 – 8,379 | 8,332 | ISGS-A1355 |
|  |  | 130-140 | Akb | -17.2 | 8,295±30 | 9,142 – 9,428 | 9,321 | ISGS-A1353 |

[b] Calibration to calendar years was performed with CALIB 5.0 (Stuiver and Reimer, 1993) using calibration dataset intcal09.14c (Reimer et al., 2009).

# CHAPTER V

# RESULTS

This chapter presents the results of the investigations. The geographic locations, geomorphic settings, and soil profiles are described for each locality. Next, the radiocarbon chronology is presented. Finally, the potential for each locality to yield Paleoindian cultural deposits is discussed. The implications of these results for predicting locations with potential for Paleoindian-age cultural deposits in the study area are discussed in Chapter VI.

## MBC-1

MBC-1 is located approximately 14.0 km southwest of the city of Burlington in Kit Carson County, CO. The locality is situated at the confluence of Sand Creek, a tributary of Middle Beaver Creek, and a small, unnamed tributary of Sand Creek (Figure 6). In this portion of the basin, Sand Creek is a third-order stream and drains approximately 13,060 ha.

The valley floor of Sand Creek is approximately 340 m wide at MBC-1. At this locality, two landforms comprise the valley floor: T-1 and T-2. The low, broad, paired T-1 terrace is approximately 1-2 m above the channel floor of Sand Creek. Its surface ranges from approximately 200 m wide upstream of MBC-1, to 430 m wide downstream from the nearby confluence of Sand Creek and its unnamed tributary. The T-1 extends to the T-2 terrace west of Sand Creek and to the valley wall east of the creek. The Goshen soil series is mapped on the T-1 surface.

The T-2 surface is separated from the T-1 surface by a gently sloping 1 m-high scarp. The T-2 surface is approximately 140 m wide and extends from the T-1 to the valley wall. The Rago soil series is mapped on the T-2 surface.

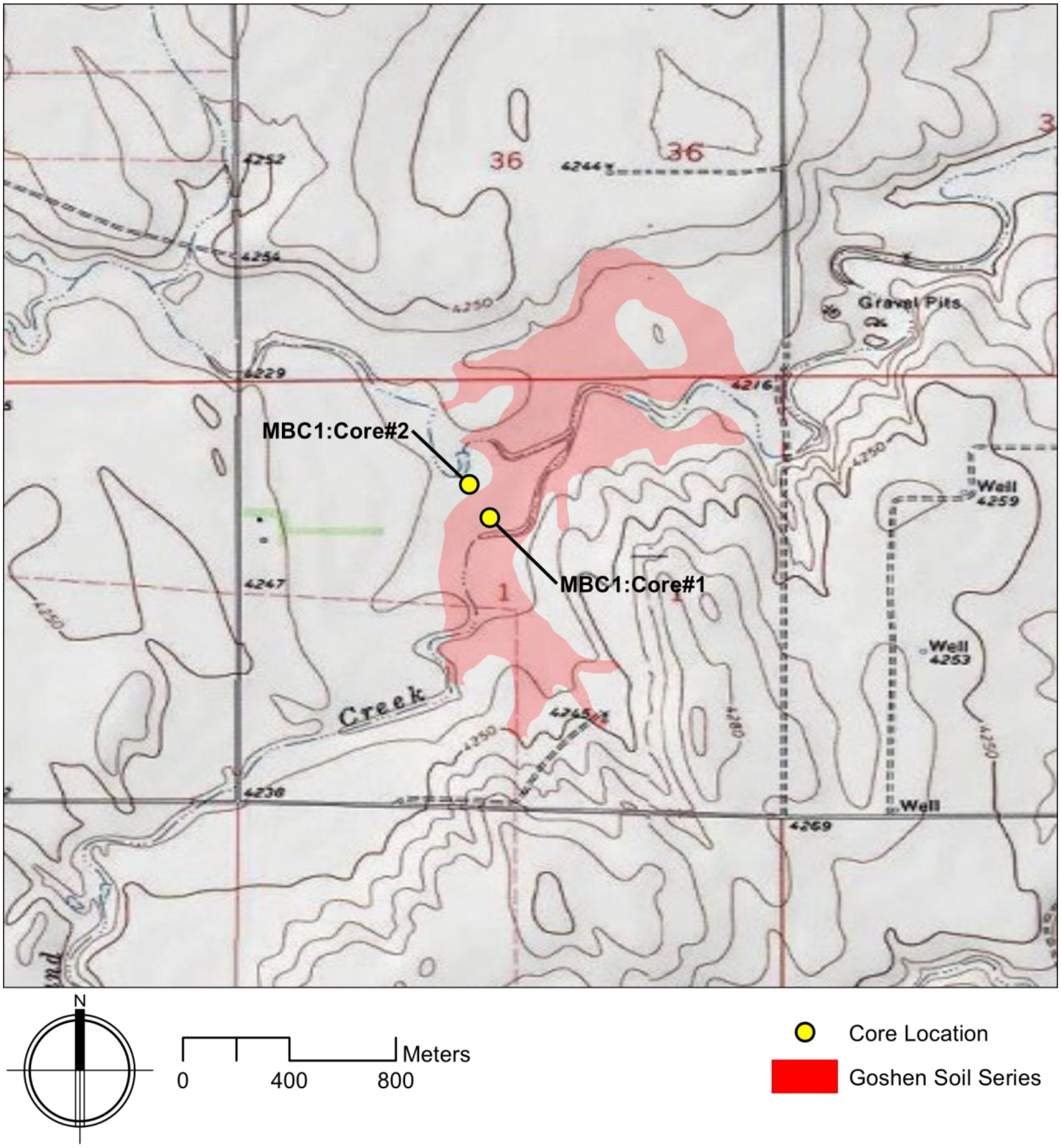

**Figure 6: Excerpt of USGS 7.5 minute Burlington 3 NW and Burlington 3 NE quadrangle maps showing locality MBC-1 with the Goshen soil series highlighted.**

Core 1-1 was taken on the T-1 terrace, approximately 50 m west of Sand Creek. A moderately expressed surface soil with an A-Bt-Btk profile is developed in the T-1 fill and extends to a depth of at least 220 cm below surface (cmbs); (Figure 7). There are many, distinct to prominent argillans and clay bridging in the Bt horizons and stage II carbonate morphology in the Btk horizons (Table 5 in Appendix II). The matrix of the soil is very dark grayish brown (10YR 3/2) to brown (10YR 5/3) and the texture ranges from fine sandy loam to silty clay loam. The A horizon exhibits weak prismatic structure, suggesting the soil may previously have been buried, overprinted by soil formation and subsequently exposed by erosion (see Holliday 2004). The PDI calculated for Core 1-1 is 72.84 (Table 13 in Appendix III).

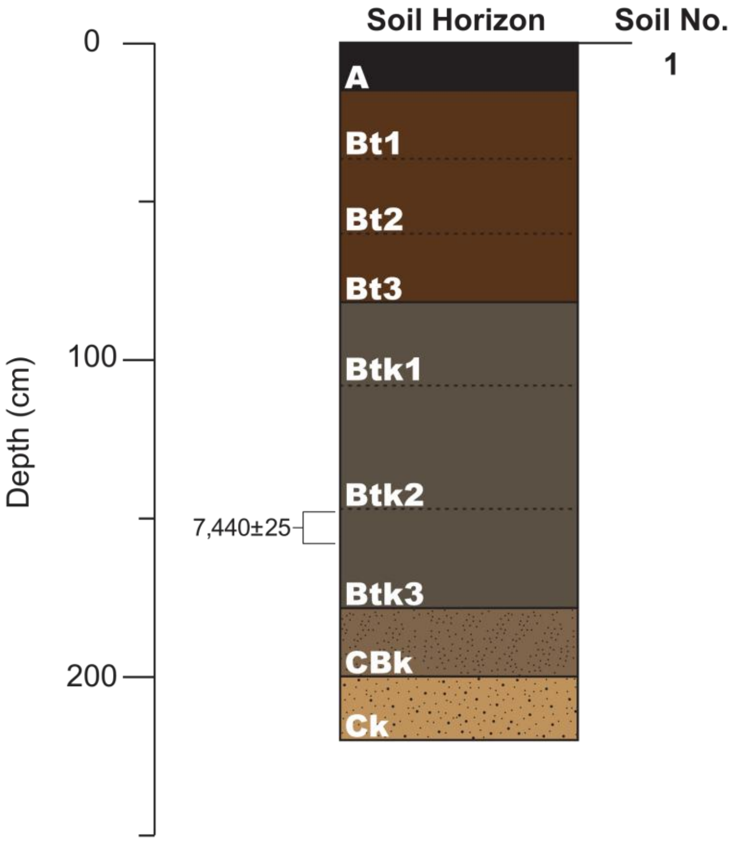

Figure 7: Core 1-1 soil profile with radiocarbon chronology

A radiocarbon age of 7,440±25 B.P. was determined on SOM from the upper 10 cm (150-160 cmbs) of the Btk3 horizon (Table 3). Radiocarbon ages determined on SOM from subsurface horizons can better approximate the onset of pedogenesis, as the oldest carbon in a soil often is stored deep in the profile where it was transported through years of illuviation (see Holliday 2004:181). Based on the radiocarbon age, aggradation ceased and the T-1 surface stabilized by at least ca. 7,500 B.P. Hence, the T-1 surface appears to have been stable during the early Holocene and therefore the underlying alluvial fill has high potential to yield Paleoindian and Early Archaic cultural deposits.

A core also was taken on the T-2 terrace, approximately 140 m northwest of Core 1-1. As was noted above, the T-2 surface is mapped as the Rago series. Hence, Core 1-2 provided a sample of alluvial landform in the upper Middle Beaver Creek Valley not mapped with the Goshen series. At least three soils are developed in the T-2 fill (Figure 8). The surface soil (Soil 1) extends to 181 cmbs and has a moderately developed A-Bt-Btk-Bk profile with common, distinct argillans in the Bt and Btk horizons and stage I+ carbonate morphology in the Btk and Bk horizons (Table 6 in Appendix II). The matrix of Soil 1 is very dark grayish brown (10YR 3/2) to brown (10YR 5/2) and the texture ranges from sandy loam to silty clay.

The uppermost buried soil (Soil 2) is at a depth of 181-208 cm below the T-2 surface. Soil 2 is represented by a truncated, moderately developed Btk horizon. The matrix of the Btkb1 horizon is brown (10YR 4/3) sandy clay loam with few, faint argillans, and stage I+ carbonate morphology.

The top of the lowermost buried soil (Soil 3) is at a depth of 208 cmbs. The soil is at least 88 cm thick. Soil 3 has a moderately developed Ak-Btk profile with few, faint argillans in the Btkb2 horizon. Stage I+ and stage I carbonate morphology occur in the Akb2 and Btkb2 horizons, respectively. The more advanced carbonate morphology in the Akb2 horizon versus

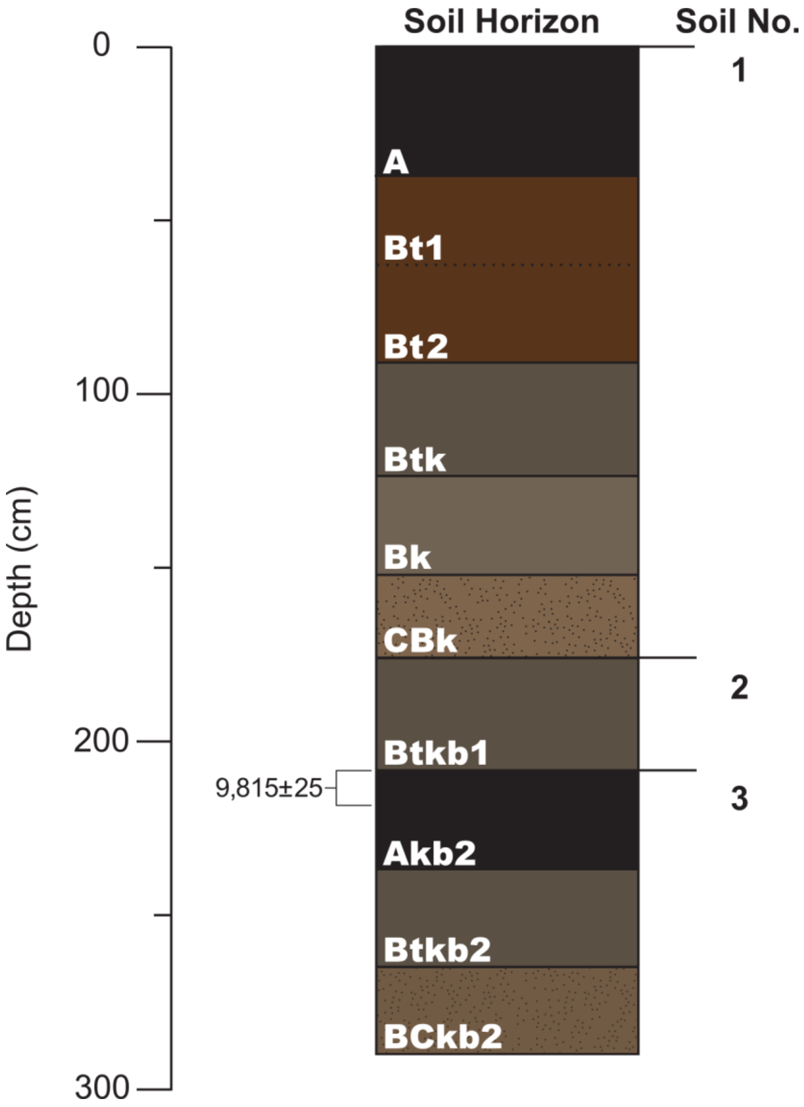

**Figure 8: Core 1-2 soil profile with radiocarbon chronology**

the Btkb2 horizon is indicative of overprinting by calcium carbonate ($CaCO_3$) translocated from Soil 2. The matrix of Soil 3 is dark grayish brown (10YR 4/2) to brown (10YR 4/3) and the texture ranges from sandy loam to sandy clay loam. The PDI calculated for Core 1-2 is 53.14 (Table 14 in Appendix III).

A radiocarbon age of 9,815±25 B.P. was determined on SOM from the upper 10 cm of the Akb2 horizon of Soil 3 (Table 3). Based on the radiocarbon age, the formation of Soil 3 was interrupted by alluviation soon after ca. 9,800 B.P. The degree of soil development in Soil 3 suggests it was stable at least 1,000 – 2,000 years prior to burial. Therefore, Soil 3 was stable during the Pleistocene-Holocene transition and has high potential to yield *in situ* Paleoindian cultural deposits.

### MBC-2

MBC-2 is located approximately 1.5 km east of the confluence of Middle Beaver Creek and Sand Creek in Kit Carson County, CO, or approximately 8.0 km east/southeast of Burlington, CO (Figure 9). At MBC-2, Middle Beaver Creek is a third-order stream and drains approximately 31,650 ha.

The valley floor of Middle Beaver Creek is approximately 570 m wide at MBC-2. At this locality, a broad, paired T-1 terrace extends to the valley wall and merges with alluvial/colluvial fans in some places along footslopes. The T-1 surface is approximately 1-2 m above the channel floor of Middle Beaver Creek. The Goshen soil series is mapped as the surface soil across the entire valley floor.

Core 2 was taken on the T-1 surface inside a large meander bend of Middle Beaver Creek. The coring location is approximately 70 m west of the creek. At least two soils are developed in the T-1 fill (Figure 10). The surface soil (Soil 1) is 50 cm thick and has a weakly developed A-AB profile (Table 7 in Appendix II). The matrix of Soil 1 is very dark gray (10YR 3/1) to dark gray (10YR 5/2) silty loam.

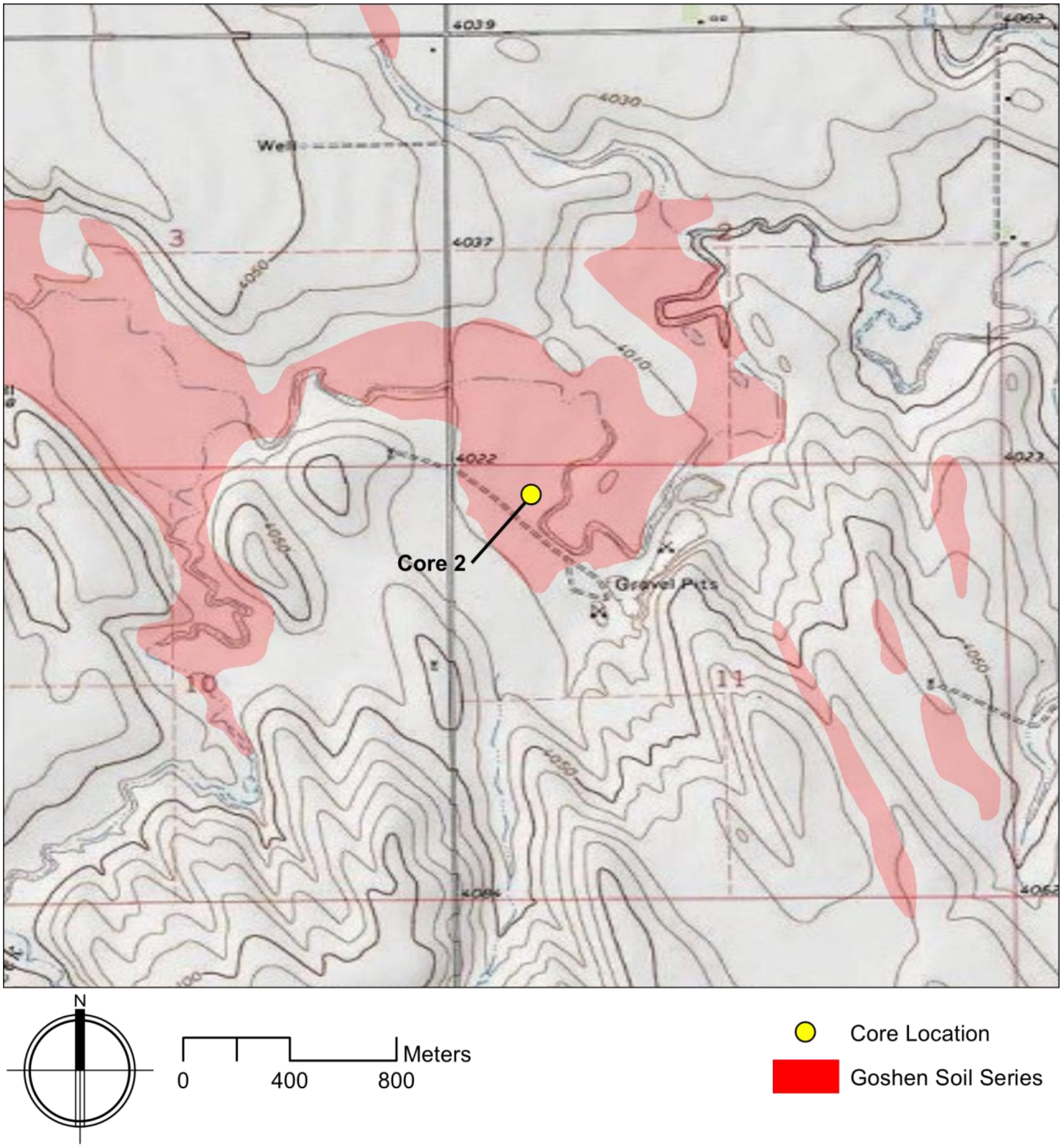

**Figure 9: Excerpt of USGS 7.5 minute Peconic quadrangle map showing locality MBC-2 with the Goshen soil series highlighted**

A buried soil (Soil 2) occurs at a depth of 50-224 cmbs. Soil 2 has a moderately developed A-Bt-Btk profile with many, distinct argillans in the Btb and Btkb horizons and stage II carbonate morphology in the Btkb horizon. The matrix of Soil 2 is very dark gray (10YR 3/1) to dark gray

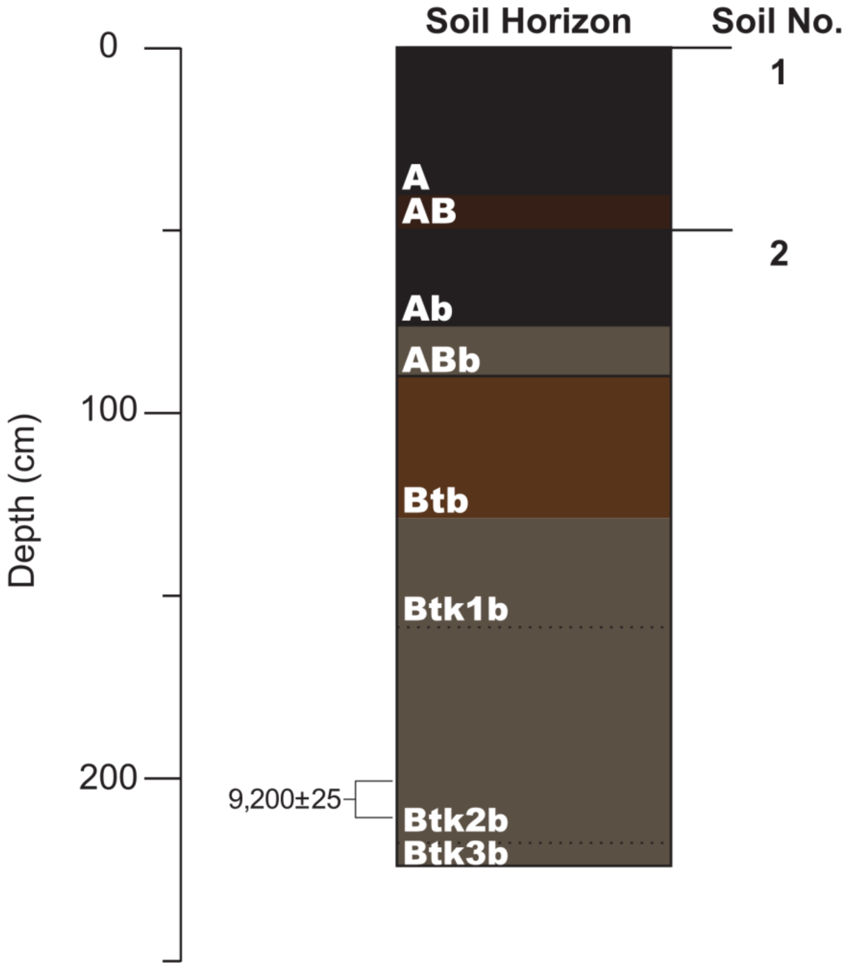

**Figure 10: Core 2 soil profile with radiocarbon chronology**

(10YR 5/2) and the texture ranges from silty clay loam to silty clay. The PDI calculated for Core 2 is 69.07 (Table 15 in Appendix III).

A radiocarbon age of 9,200±25 B.P. was determined on SOM from the lower 10 cm (208-218 cmbs) of the Btk2b horizon (Table 3). Based on the radiocarbon age, pedogenesis was underway by at least ca. 9,200 B.P. Hence, there is high potential for Paleoindian cultural

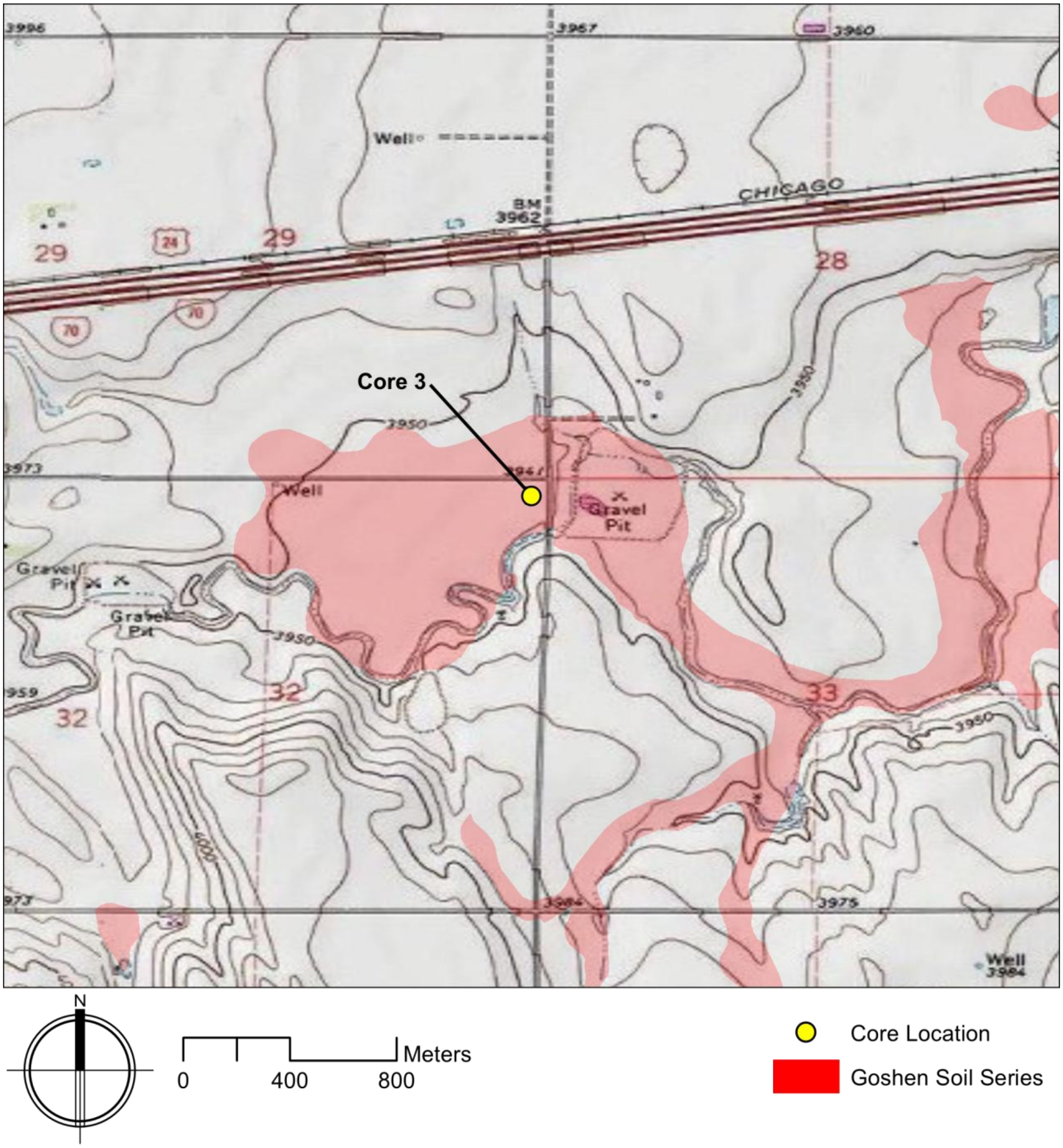

**Figure 11: Excerpt of USGS 7.5 minute Peconic and Kanorado quadrangle map showing locality MBC-3 with the Goshen soil series highlighted**

deposits in Soil 2. The degree of soil development in Soil 2 suggests it was stable at least 1,000 - 2,000 years after the onset of pedogenesis. Therefore, Soil 2 also has potential to yield Early Archaic cultural deposits.

### MBC-3

Locality MBC-3 is approximately 14.0 km east/northeast of Burlington, CO in Kit Carson County (Figure 11). This locality is approximately 8.0 km west/northwest of the Kanorado locality. At MBC-3, Middle Beaver Creek is a third-order stream and drains approximately 36,480 ha.

The valley floor of Middle Beaver Creek is approximately 590 m wide at MBC-3 and consists of a broad T-1 terrace that extends north from the channel to the valley wall. The T-1 surface is approximately 1-2 m above the channel floor of Middle Beaver Creek. The Goshen soil series is mapped across the entire valley floor.

Core 3 was taken on the T-1 terrace, approximately 105 m north of Middle Beaver Creek. A moderately developed surface soil is developed in the T-1 fill and extends to a depth of at least 351 cmbs (Figure 12). The soil has an A-Bt-Btk profile with many prominent argillans in the Bt horizon and stage II carbonate morphology in the Btk horizon (Table 8 in Appendix II). The matrix of the soil is very dark gray (10YR2/2) to light grayish brown (10YR6/2) and the texture ranges from sand to silty clay. The PDI calculated for Core 3 is 41.59 (Table 16 in Appendix III).

A soil sample was not collected for radiocarbon dating at Locality MBC-3. However, temporal information was inferred from Core 1-1 at MBC-1 located approximately 26 km downstream from MBC-3. The T-1 fill at both MBC-1 and MBC-3 has a moderately developed surface soil with an A-Bt-Btk profile and stage II carbonate morphology. Also, the argillic horizons at both localities have many argillans. The similarities of MBC-1 and MBC-3 suggest that both soils formed around the same time; hence, aggradation of the T-1 fill at MBC-3 probably ceased at least by ca. 7,400 B.P., the radiocarbon age determined on SOM from

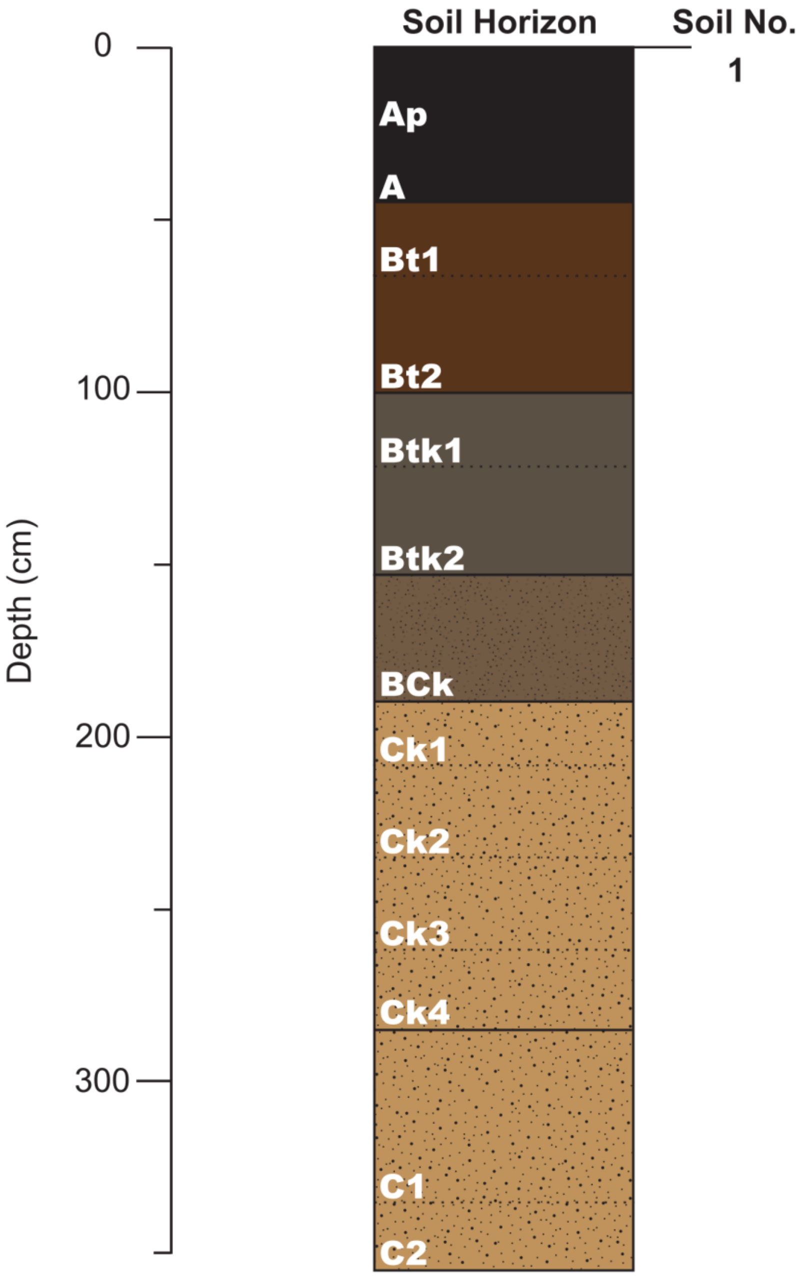

**Figure 12: Core 3 soil profile**

the Btk3 horizon of the surface soil at MBC-1. Hence, the T-1 surface appears to have been stable during the early Holocene. Hence the T-1 fill has high potential to yield Paleoindian and early Archaic cultural deposits.

### MBC-4

Locality MBC-4 is approximately 17.0 km west/northwest of Goodland, KS in Sherman County, KS (Figure 13). This locality is approximately 14.0 km northeast of the Kanorado locality. At MBC-4, Middle Beaver Creek is a third-order stream and drains approximately 56,390 ha.

At MBC-4, the valley floor of Middle Beaver Creek is approximately 710 m wide at MBC-4 and consists of two landforms: T-1 and T-2. The T-1 terrace is approximately 65 m wide and 1-2 m above the channel floor of Middle Beaver Creek. The Bridgeport soil series is mapped on the T-1 surface.

A gently sloping 1 m-high scarp separates the T-1 and T-2 surfaces. The T-2 surface is approximately 517 m wide and extends to the valley wall. The Goshen soil series is mapped on the T-2 surface.

Core 4 was taken on the T-2 terrace, approximately 70 m south of Middle Beaver Creek. At least three soils are developed in the T-2 fill at this locality (Figure 14). The surface soil (Soil 1) extends to 62 cmbs and has a weakly developed A-Bw profile (Table 9 in Appendix II). The matrix of Soil 1 is very dark gray (10YR3/1) and the texture ranges from sandy loam to silty clay loam.

The uppermost buried soil (Soil 2) is at a depth of 62-182 cm below the T-2 surface. Soil 2 has a moderately developed A-Btk-Bk profile with common, distinct argillans in the Btkb1 horizon and stage II carbonate morphology in the Bkb1 horizon. The matrix of Soil 2 is dark gray (10YR 4/1) to brown (10YR 5/3) and the texture ranges from sandy loam to silty clay.

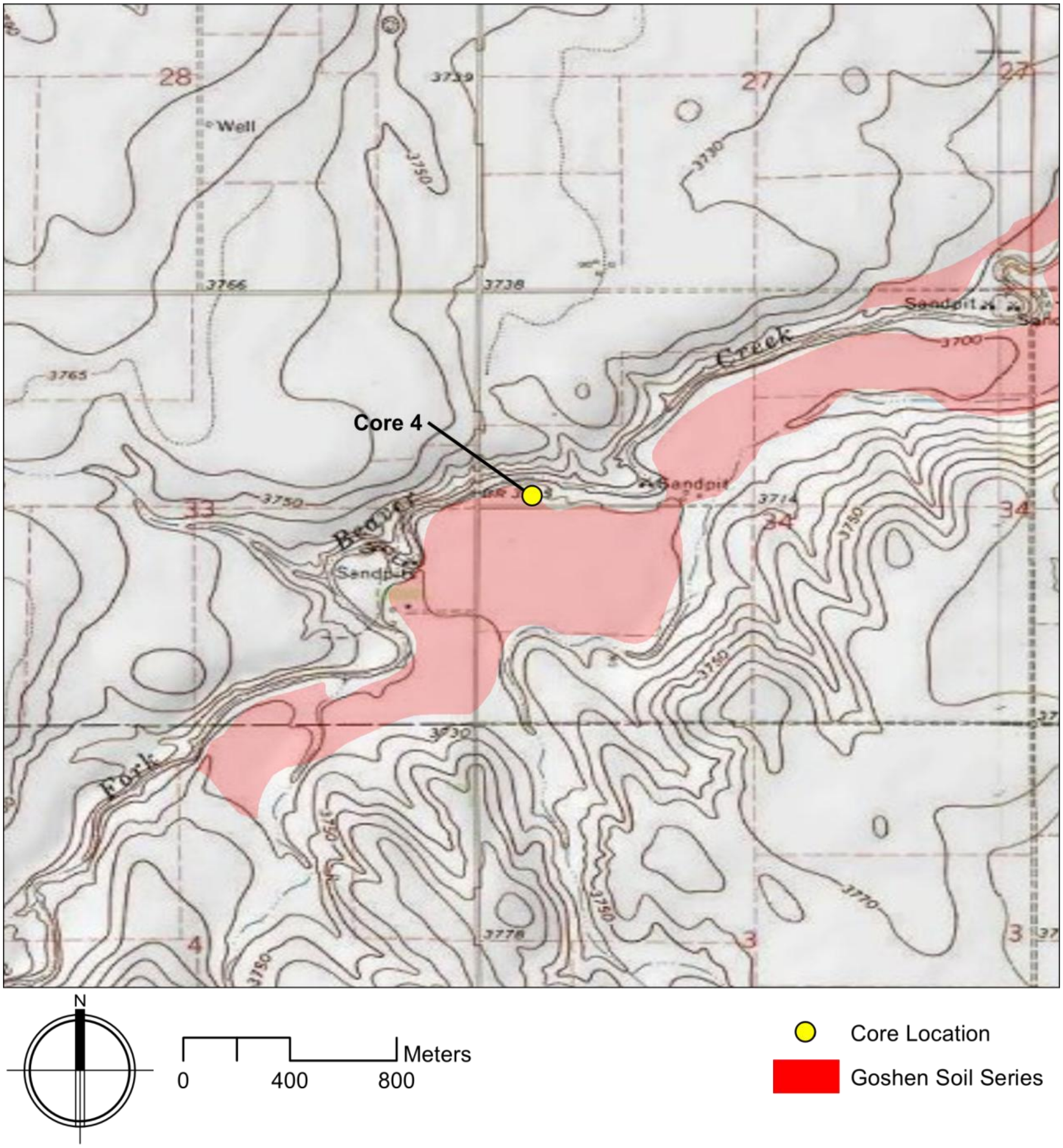

**Figure 13: Excerpt of USGS 7.5 minute Ruleton NW quadrangle map showing locality MBC-4 with the Goshen soil series highlighted**

The top of the lowermost buried soil (Soil 3) is at a depth of 182 cmbs and this soil is at least 99 cm thick. Soil 3 has a weakly developed ABk-BCk profile with stage I carbonate morphology in the ABkb2 and BCkb2 horizons. The matrix of Soil 3 is dark grayish brown

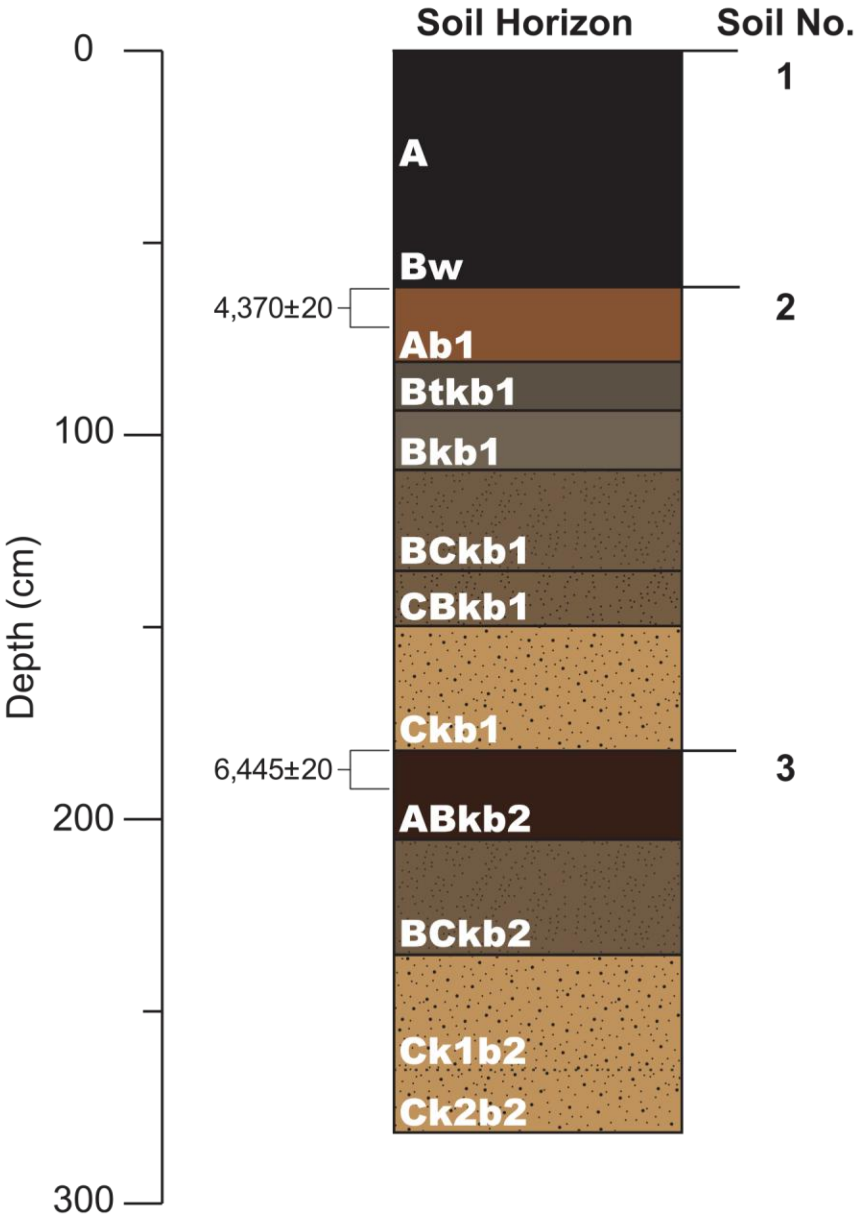

**Figure 14: Core 4 soil profile with radiocarbon chronology**

(10YR 4/2) to yellowish brown (10YR 5/4) and the texture ranges from silty loam to silty clay loam. The abrupt upper boundary of the ABkb2 horizon and the presence of sandy loam immediately above Soil 3, coupled with the absence of an A horizon, suggest that the soil was truncated by floodwaters prior to burial. The PDI calculated for Core 4 is 29.23 (Table 17 in Appendix III).

SOM from the upper 10 cm of the ABkb2 horizon of Soil 3 yielded a radiocarbon age of 6,445±20 B.P. (Table 3). Based on this age, Soil 3 began to form before ca. 6,450 B.P. The episode of landscape stability that produced Soil 3 was brief, given the weak soil development. Landscape stability was interrupted by an erosional event that truncated Soil 3, and alluviation occurred soon after ca. 6,450 B.P. SOM from the upper 10 cm of the Ab1 horizon of Soil 2 yielded a radiocarbon age of 4,370±20 B.P. Based on this age and the age determined on SOM from the upper 10 cm of Soil 3, Soil 2 developed between ca. 6,450 and 4,400 $^{14}$C yr B.P., and was buried soon after by 4,400 yr B.P.

At Locality MBC-4, all of the alluvium stored beneath the T-2 terrace appears to date to the middle and early late Holocene. Soils and sediments that dated to the Pleistocene-Holocene transition and early Holocene may be deeply buried or may have been removed from this segment of Middle Beaver Creek by localized erosion during the late early Holocene. Hence, there is low potential for buried Paleoindian cultural deposits. However, based on the radiocarbon ages, soils 2 and 3 represent stable geomorphic surfaces during the middle and late Holocene and, therefore, have potential to contain Archaic cultural deposits.

### MBC-5

MBC-5 is approximately 13.0 km north of Goodland, KS and 12.5 km upstream from the confluence of Middle Beaver Creek and South Beaver Creek (Figure 15). At MBC-5, Middle Beaver Creek is a fourth-order stream and drains approximately 86,600 ha.

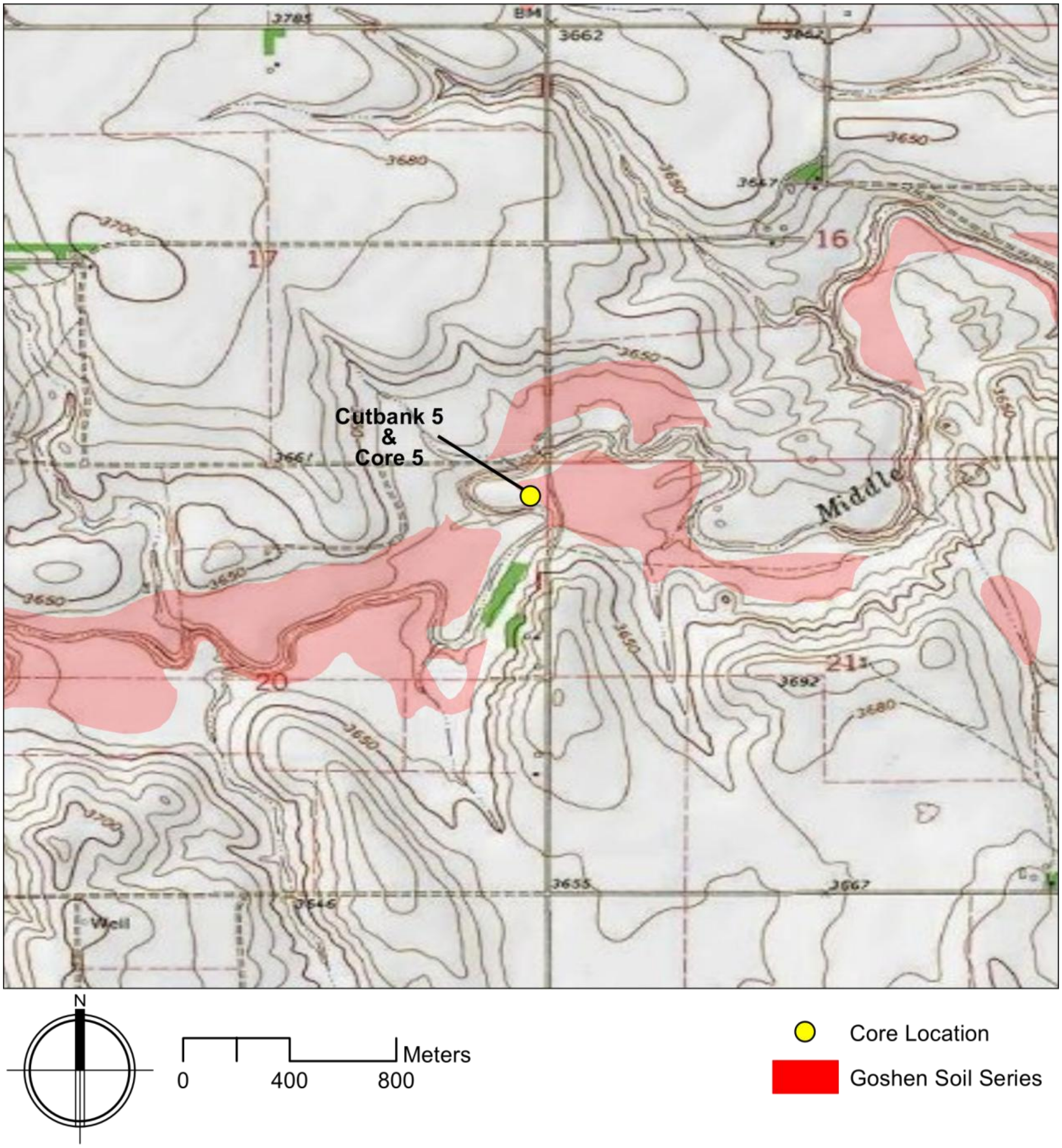

**Figure 15: Excerpt of USGS 7.5 minute Ruleton NE quadrangle map showing locality MBC-5 with the Goshen soil series highlighted**

The valley floor of Middle Beaver Creek is approximately 430 m wide at MBC-5 and consists of two landforms: T-1 and T-2. T-1 is a paired terrace and approximately 2-3 m above the channel floor of Middle Beaver Creek. The T-1 surface is approximately 200 m wide and

**Figure 16: Photograph of T-2 terrace at MBC-5 with Cutbank 5 highlighted**

extends to the valley wall west of Middle Beaver Creek and merges with the T-2 terrace east of the creek. The Bridgeport soil series is mapped on the T-1 surface.

The T-2 surface is separated from the T-1 surface by a gently sloping 1 m-high scarp. The T-2 surface is approximately 230 m wide and extends to the valley wall. The Goshen series is mapped on the T-2 surface. The T-2 fill was examined in a cutbank along the channelized reach of the stream (Figure 16). Three soils are developed in the T-2 fill at this locality (Figure 17). The surface soil (Soil 1) extends to 104 cmbs and has a moderately developed A-Bw-Bt-Btk profile with common, distinct argillans in the Bt and Btk horizons and stage I+ carbonate morphology in the Btk horizon (Table 10 in Appendix II). The matrix of Soil 1 is very dark grayish brown (10YR 3/2) to brown (10YR 4/3) and the texture ranges from fine sandy clay loam and silty clay.

The uppermost buried soil (Soil 2) is at a depth of 104-223 cm below the T-2 surface. Soil 2 has a moderately developed Atk-Bk-BCk profile with common, distinct argillans and stage I+ carbonate morphology in the Atkb1 horizon. Welding of the Btk horizon of Soil 1 onto Soil 2 accounts for the clay films and carbonate morphology in the Atkb1 horizon. The matrix of Soil 2 is brown (10YR4/3) to yellowish brown (10YR5/4) and the texture ranges from fine sandy clay loam to silty clay.

The top of the lowermost buried soil (Soil 3) is at a depth of 223-443 cmbs. Because the lower portion of Soil 3 is obscured by slump, a core was taken 3 m east of the cutbank (Figure 18). Soil 3 has a moderately developed cumulic Ak-Bk profile with stage I+ carbonate morphology in the Akb2 and Bkb2 horizons. The matrix of Soil 3 is very dark grayish brown (10YR 3/2) to light grayish brown (10YR 6/2) and the texture ranges from coarse sandy loam to very fine sandy clay loam. The PDI calculated for the MBC-5 cutbank is 30.80 (Table 18 in Appendix III).

Radiocarbon ages were determined on SOM from three samples collected at MBC-5. SOM from the upper 10 cm of the Atkb1, Ak1b2, and Ak2b2 horizons yielded radiocarbon ages of 6,085±20, 10,005±30, and 10,450±35 B.P., respectively (Table 3). Based on the radiocarbon ages, the A horizon of Soil 3 thickened through the process of cummulization between ca. 10,500 and 10,000 B.P., when pedogenesis kept pace with slow alluviation. Soil 3 was buried soon after ca. 10,000 $^{14}$C B.P. Alluviation slowed again before ca. 6,100 $^{14}$C B.P., allowing Soil 2 to develop. A final episode of alluviation soon after ca. 6,100 $^{14}$C B.P. resulted in the burial of Soil 2.

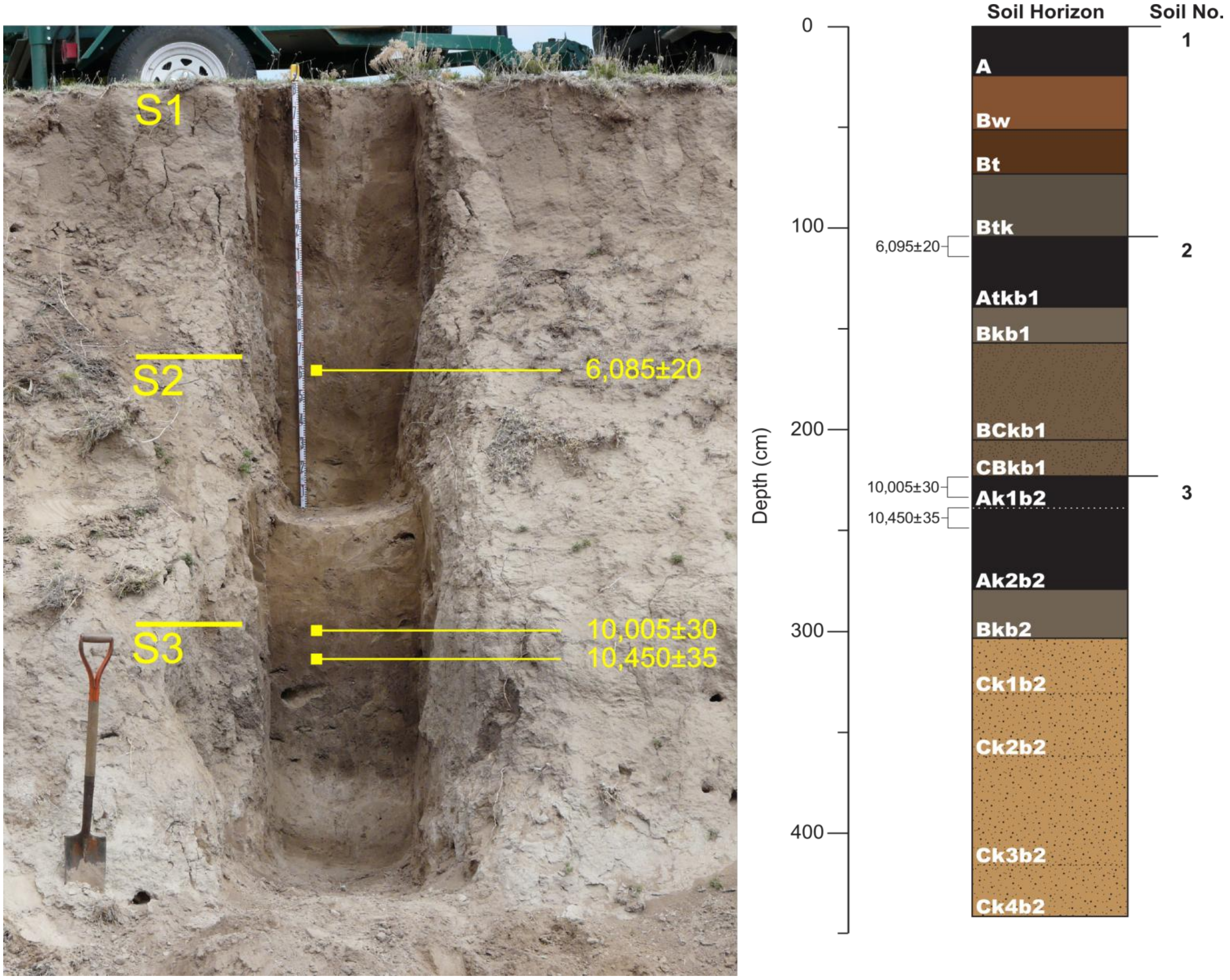

**Figure 17. Cutbank 5 and Core 5 soil profile with radiocarbon chronology**

**Figure 18: Photograph of Cutbank 5 with the location of Core 5 highlighted**

Soil 3 is equivalent in age to the buried soil at the Kanorado Locality that contains stratified Clovis-age and Folsom cultural deposits. Hence, Soil 3 has high potential for yielding Paleoindian-age cultural deposits. In addition, Soil 2 was stable during the middle Holocene, and therefore has potential to yield Archaic cultural deposits.

### MBC-6

Locality MBC-6 is approximately 12.0 km north of Goodland, KS and 5.5 km upstream from the confluence of Middle Beaver Creek and South Beaver Creek (Figure 19). At MBC-6, Middle Beaver Creek is a fourth-order stream and drains approximately 80,464 ha.

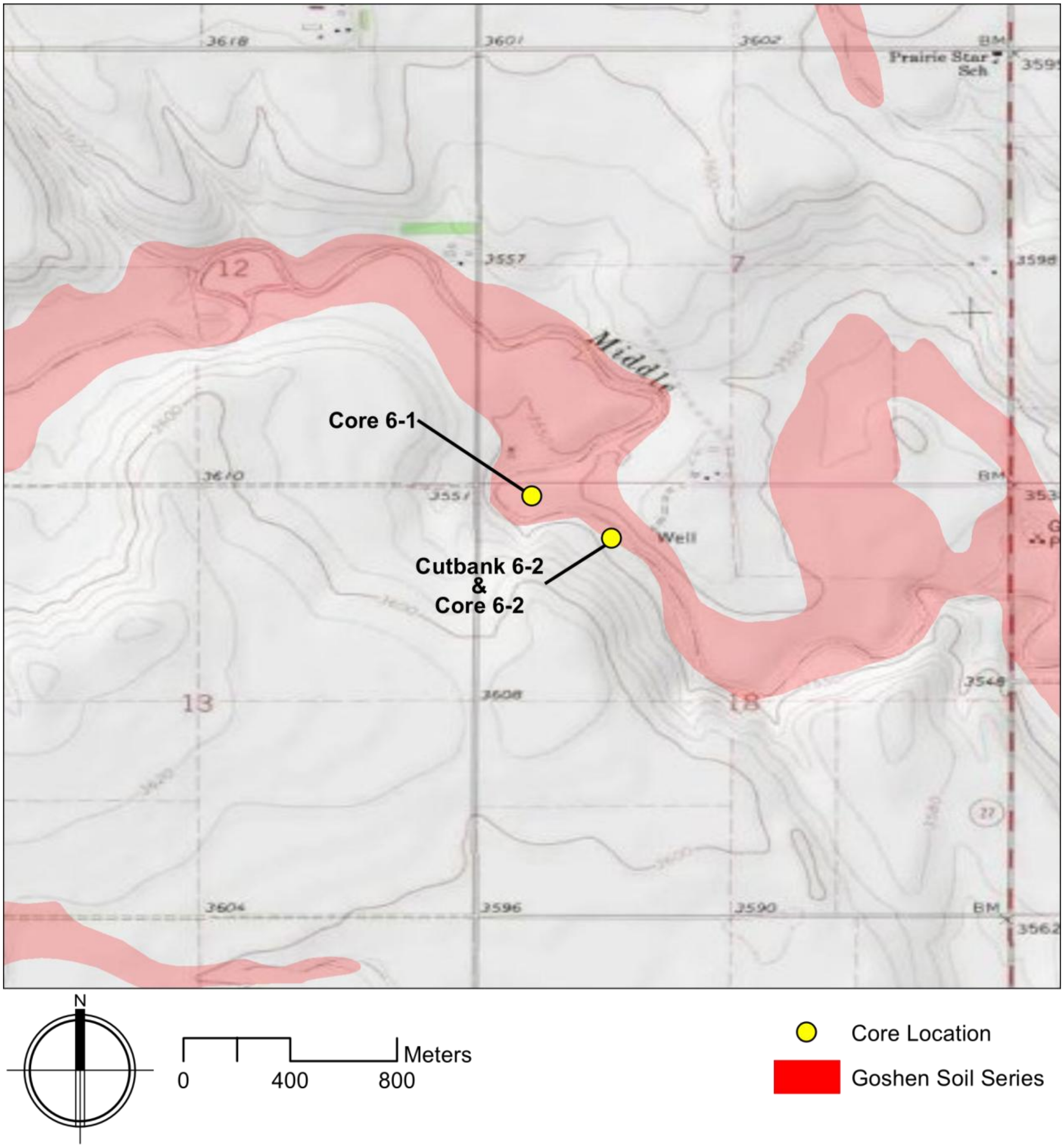

**Figure 19: Excerpt of USGS 7.5 minute Goodland NW quadrangle map showing locality MBC-6 with the Goshen soil series highlighted**

At MBC-6, the valley floor of Middle Beaver Creek is approximately 370 m wide and consists of two landforms: T-1 and T-2. The T-1 surface is approximately 2 m above the channel floor of

Middle Beaver Creek and spans most of the valley floor. The Goshen series is mapped on the T-1 surface.

Middle Beaver Creek has migrated laterally and removed all but a small remnant of the T-2 terrace at MBC-6. The T-2 surface is approximately 1 m above the T-1 surface. The Goshen series is mapped on the T-2 surface.

Core 6-1 was taken on the T-1 terrace, approximately 40 m north of Middle Beaver Creek. At least two soils are developed in the T-1 fill at this locality (Figure 20). The surface soil (Soil 1) extends to 47 cmbs and has a weakly developed A-Bw profile (Table 11 in Appendix II). The matrix of Soil 1 is very dark gray (10YR 3/1) to very dark grayish brown (10YR 3/2) and the textures ranges from sandy loam to sandy clay loam. Soil 2 is at a depth of 47-242 cmbs and has a very weakly developed A-C profile. The matrix of Soil 2 is dark gray (10YR 3/1) to dark gray brown (10YR4/2) and the texture ranges from sand to sandy loam. The PDI calculated for Core 6-1 is 7.06 (Table 19 in Appendix III).

A radiocarbon age of 1,595±15 B.P. was determined on SOM from the lower 10 cm of the A horizon in Soil 2 (Table 3). Based on this age, the soil was beginning to form by at least ca. 1,600 $^{14}$C B.P. and was buried soon after that time. This segment of Middle Beaver creek may have been an zone of net erosion, with the majority of the soils and sediments dating to the Pleistocene-Holocene transition and early and middle Holocene removed during the late Holocene. Hence, the T-1 fill at MBC-6 has no potential to yield Paleoindian cultural deposits.

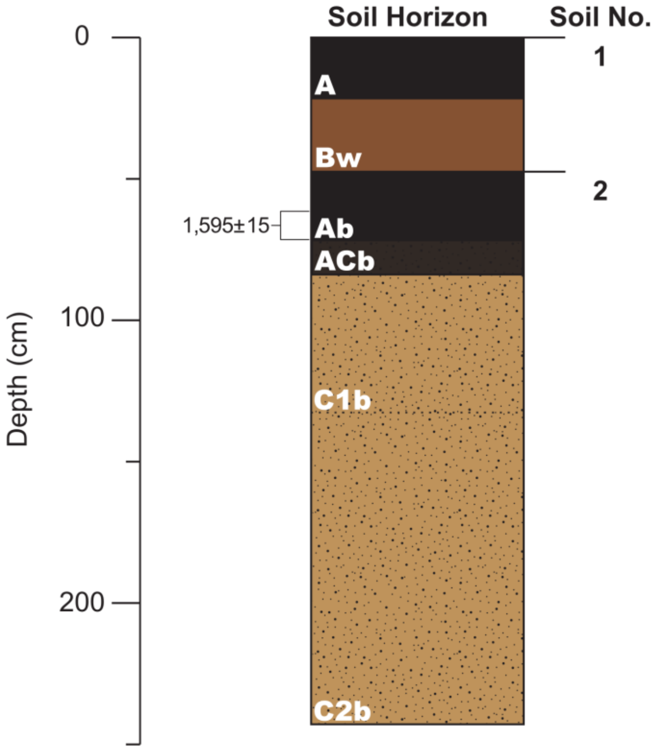

**Figure 20: Core 6-1 soil profile with radiocarbon chronology**

Middle Beaver Creek has migrated laterally into the T-2 fill at MBC-6, exposing a surface soil (Soil 1) and buried soil (Soil 2); (Figures 21 and 22). Soil 1 extends to 100 cmbs and has a weak to moderately developed A-Bw-Bk profile with stage I+ carbonate morphology in the Bk horizons (Table 12 in Appendix II). The matrix of Soil 1 is black (10YR2/1) to brown (10YR4/3) and the texture ranges from loam to silty clay loam. Soil 1 dips to the west, suggesting that it may have formed along the margin of a paleochannel flowing from the adjacent uplands.

**Figure 21: Photograph of T-2 terrace at MBC-6 with the location of Cutbank 6-2 and Core 6-2 highlighted**

Soil 2 is at a depth of 100-215 cmbs and has a moderately developed Ak-Bk profile with stage I+ carbonate morphology. The matrix of Soil 2 is very dark grayish brown (10YR3/2) to dark yellowish brown (10YR4/4) and the texture ranges from silty loam to silty clay loam. The Bk horizon of Soil 1 is welded to Soil 2, as indicated by the films and threads of $CaCO_3$ in the Akb horizon. The PDI calculated for the MBC-6 T-2 cutbank is 26.32 (Table 20 in Appendix III). Core 6-2 was taken approximately 2 m east of the cutbank and about 5 m east of the valley wall in order to examine the lower portion of the T-2 fill. A surface soil resembling Soil 1 in the

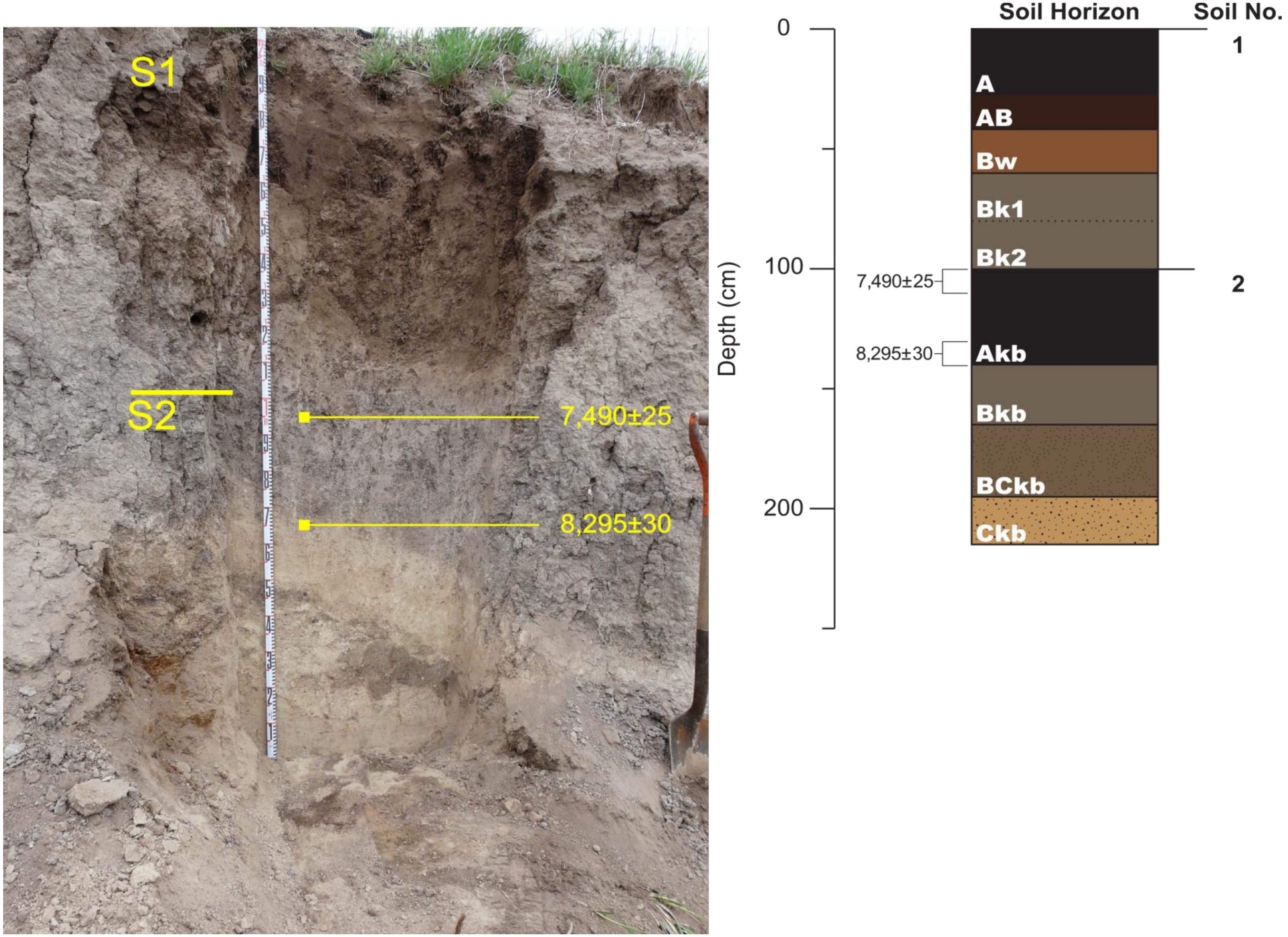

Figure 22. Cutbank 6-2 soil profile with radiocarbon chronology

adjacent cutbank exposure was recorded in the core. However, there was no evidence of a buried soil. Instead, the core intercepted the Ogallala caprock at a depth of 117 cmbs (Figure 23). SOM from the upper and lower 10 cm of the Akb horizon of Soil 2 yielded radiocarbon ages of 7,490±25 and 8,295±30 B.P., respectively (Table 3). Based on these ages, development of Soil 2 was underway by at least ca. 8,300 $^{14}$C B.P., and the soil was buried soon after ca. 7,500 $^{14}$C B.P. Hence, the Soil 2 appears to have been stable during the early Holocene and therefore has high potential to yield Paleoindian and Archaic cultural deposits.

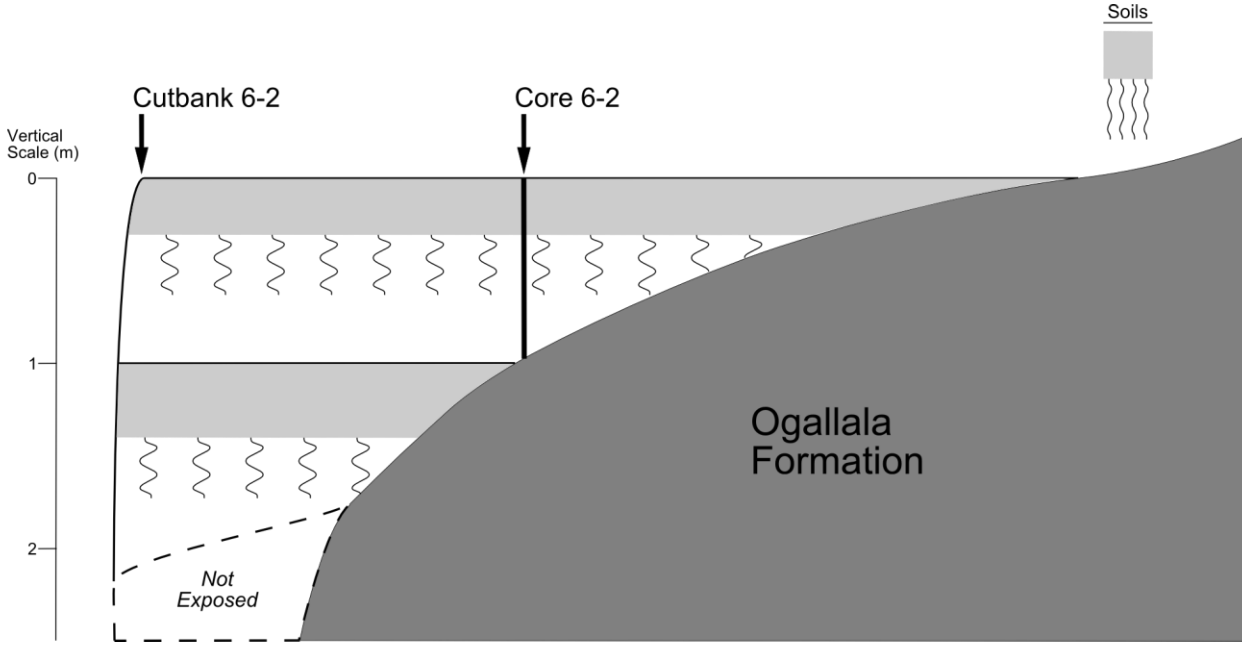

**Figure 23: Cross-section of the T-2 fill adjacent to the valley wall at Locality MBC-6**

# CHAPTER VI

# SUMMARY AND CONCLUSIONS

## Summary

The purpose of this study was to assess the applicability of using a specific NRCS soil series to predict locations that have potential to yield Paleoindian cultural deposits in draws on the High Plains of eastern Colorado and western Kansas. Soil-geomorphic and NRCS soil survey data have been used to predict locations with potential for archaeological deposits in the Ohio River Valley (Stafford and Creasman 2002), Mississippi River Valley (Bettis 1992; Bettis and Hajic 1995), Desert Southwest (Monger 1995), and Central Lowlands of Oklahoma (Artz 1985). However, before such a soil-based approach to predicting areas of archaeological potential had not been employed on the High Plains.

My study focused on Middle Beaver Creek, an intermittent stream, or draw, in eastern Colorado and northwestern Kansas. In a recent geomorphological investigation at the Kanorado Locality in Middle Beaver Creek Valley, Mandel (2008) recorded a prominent buried paleosol dating to the Pleistocene-Holocene transition. At Kanorado the paleosol contains Folsom and Clovis-age cultural deposits and consistently occurs beneath the Goshen soil series, a thick, well-drained Pachic Argiustoll that formed in silty alluvium derived mainly from loess. The Goshen series occurs on low terraces (typically T-1) with slopes ranging from 0 to 3 percent. The primary objective of my study was to determine if soils dating to the Pleistocene-Holocene transition and early Holocene consistently occur beneath terraces mapped with the Goshen soil series throughout the drainage network of upper Middle Beaver Creek. Recognition of such a relationship would allow archaeologists to focus their search for stratified Paleoindian cultural deposits by concentrating on landform sediment assemblages where the Goshen series occurs.

**Table 4: Potential for Paleoindian cultural components at Middle Beaver Creek study sites based on $^{14}$C ages determined on SOM**

| Study Site | Profile Designation | Alluvial Landform | Soil Number | Age ($^{14}$C B.P.) | Potential for Paleoindian Cultural Deposits |
|---|---|---|---|---|---|
| MBC-1 | Core 1-1 | T-1 | 1 | 7,440±25 | ++ |
| | Core 1-2 | T-2* | 3 | 9,815±25 | ++ |
| MBC-2 | Core 2 | T-1 | 2 | 9,200±25 | ++ |
| MBC-3 | Core 3 | T-1 | n/a | n/a | ++** |
| MBC-4 | Core 4 | T-2 | 2 | 4,370±20 | – |
| | | | 3 | 6,445±20 | + |
| MBC-5 | Cutbank 5 | T-2 | 2 | 6,085±20 | + |
| | | | 3 | 10,005±30 | ++ |
| | | | 3 | 10,450±35 | |
| MBC-6 | Core 6-1 | T-1 | 2 | 1,595±15 | – |
| | Cutbank 6-2 | T-2 | 2 | 7,490±25 | ++ |
| | | | 2 | 8,295±30 | |

Symbols: ++ High Potential, + Low Potential, – No Potential
*Alluvial terrace mapped with Rago soil series
**Potential based on degree of soil development and position within the drainage as compared to other sites.

## Conclusions

Radiocarbon ages determined on SOM from five of the six study sites in the Middle Beaver Creek Valley provide a minimum age of the onset of soil development for surface soils or buried paleosols. As previously noted, the potential for each study site to yield buried

Paleoindian cultural deposits was mostly based on the radiocarbon age determined on SOM from buried and surface soils (Table 4). Localities where the radiocarbon age fell within the Pleistocene-Holocene transition and early Holocene were categorized as having high potential for yielding Paleoindian cultural deposits. Those localities whose ages fell within the middle and late Holocene were categorized as having low to no potential for yielding Paleoindian cultural deposits.

Based on the assemblage of radiocarbon ages, four of the six $^{14}$C-dated localities mapped with the Goshen surface soil have high potential for yielding buried Paleoindian cultural deposits. Of these four, MBC-2 and MBC-5 were dated to the Pleistocene-Holocene transition and likely have the highest potential to yield buried Paleoindian cultural deposits. The radiocarbon ages of the T-1 surface at MBC-1 and buried soil in the T-2 fill at MBC-6 indicates soil development was underway during the early Holocene. Although the radiocarbon ages determined on SOM from the soils in Core 1-1 at MBC-1 and Cutbank 6-2 at MBC-6 post-date the Paleoindian period, those ages represent a minimum time for the onset of pedogenesis; hence the terrace fills at these localities have high potential for yielding Paleoindian cultural deposits. Soils 2 and 3 in the T-2 fill at MBC-4 date to the middle Holocene and late Holocene respectively; hence there is low potential for buried Paleoindina cultural deposits in Soil 3 and no potential for buried Paleoindina cultural deposits in Soil 2. At MBC-6, the T-1 fill dates to the late Holocene and has no potential for buried Paleoindian cultural deposits.

At MBC-3, buried soils do not occur in the T-1 fill and a radiocarbon age was not determined on SOM from the surface soil; however, temporal information was inferred from the results of investigations at MBC-1. Based on the geomorphic and pedologic similarities of

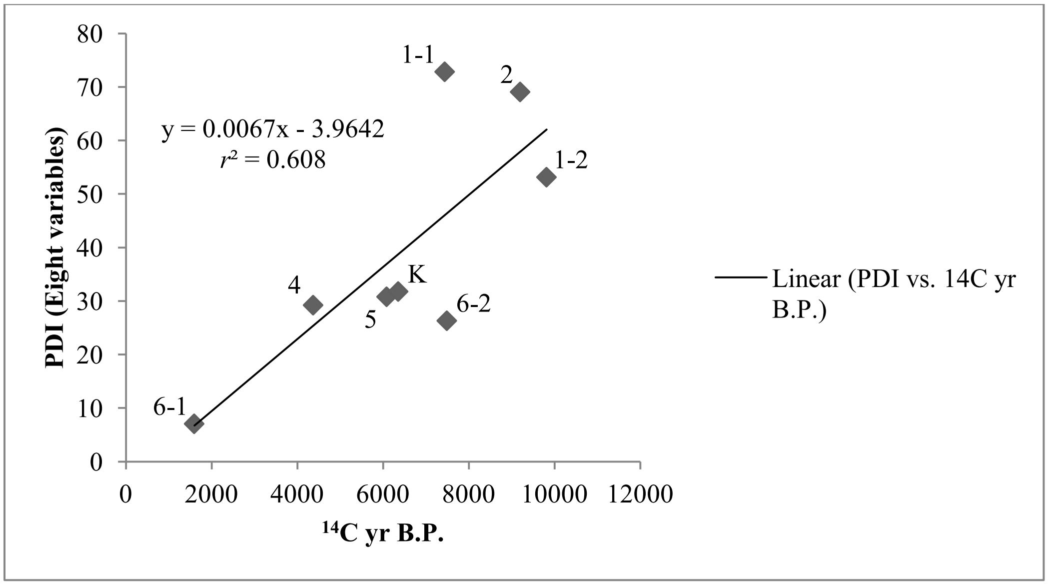

**Figure 24: Scatter plot showing calculated PDI values for radiocarbon dated localities and site 14SN101 (K) versus $^{14}$C B.P.**

MBC-1 and MBC-3, the surface soils formed at both localities around the same time; hence, aggradation of the T-1 fill at MBC-3 probably ceased at least by ca. 7,400 B.P., the radiocarbon age determined on SOM from the Btk3 horizon of the surface soil at MBC-1. Based on this qualitative age estimate, the T-1 fill at MBC-3 has high potential to yield buried Paleoindian cultural deposits.

The age of the T-1 fill at MBC-3 also can be estimated using the PDI values of dated sites. PDI values of the dated localities are plotted on the *x* axis and their respective radiocarbon ages are plotted on the *y* axis (Figure 24). The coefficient of determination ($r^2$) calculated from the regression is 0.608. The $r^2$ value corresponds to 60 percent of the variation among the PDI values at the localities and site 14SN101 is explained by the radiocarbon age. Based on the correlation between PDI value and $^{14}$C yr B.P., it is possible to estimate the age of the T-1 fill at MBC-3 using the regression equation:

$$y = 0.0067x - 3.9642$$

The estimated age of the T-1 fill at MBC-3 is 6,800 $^{14}$C B.P. This estimate is slightly younger than the inference based on the geomorphic and pedologic similarities of MBC-1 and MBC-3 and suggests pedogenesis was underway at MBC-3 by at least the late middle Holocene. A range based on the qualitative and semi-quantitative age estimates suggests the age of the T-1 fill at MBC-3 is likely between ca. 6,800 to 7,400 $^{14}$C B.P. Although the estimated age range includes the late middle Holocene, most of it falls within the early Holocene. Therefore the T-1 fill at MBC-3 has potential to yield Paleoindian cultural deposits.

Results of this study indicate five of the seven alluvial landforms mapped with the Goshen soil series, or approximately 71 percent, have high potential to yield Paleoindian cultural deposits. Of the five alluvial landforms mapped with the Goshen series with high potential to yield Paleoindian cultural deposits, three were T-1 terraces and two were T-2 terraces (Table 4). All of the T-1 terraces were located in the upper reaches of the Middle Beaver Creek drainage network. Conversely, the T-2 terraces were located in the lower reaches of the drainage network. However, the ages of T-1 and T-2 terrace fills with high potential for yielding Paleoindian cultural deposits are more evenly distributed; a T-1 fill with a buried soil that dates to the Pleistocene-Holocene transition was found in the upper reaches of Middle Beaver Creek, as was a T-1 fill with a buried soil that dates to the beginning of the early Holocene. Likewise, a T-2 fill with a buried soil dating to the Pleistocene-Holocene transition was found in lower Middle Beaver Creek as was a T-2 fill with a buried soil dating to the early Holocene.

The results suggest that the co-occurrence of the Goshen series and potential for Paleoindian cultural components is not a coincidence in the Middle Beaver Creek Valley. Therefore, investigations targeting the Goshen soil series have the potential to focus future research on areas with the greatest potential to yield Paleoindian cultural deposits. In addition to

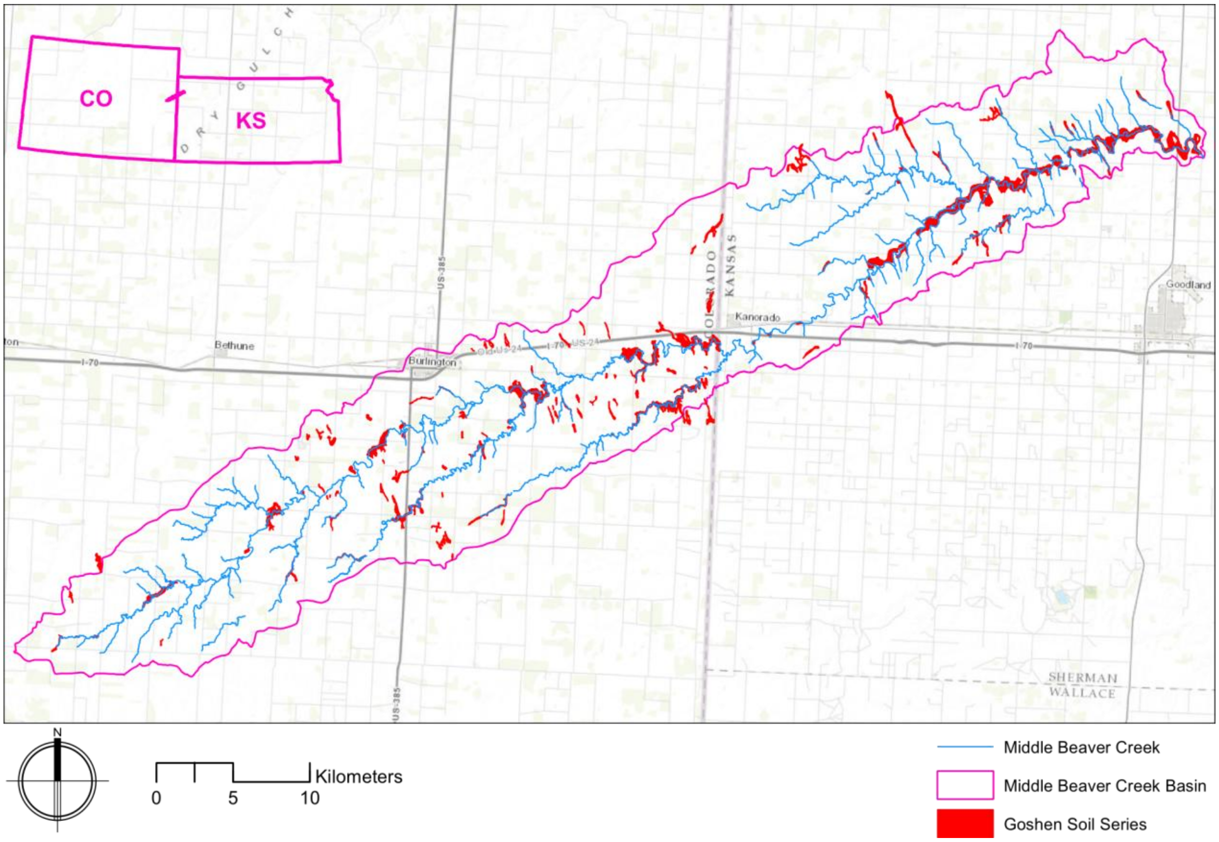

**Figure 25. Middle Beaver Creek drainage basin with areas mapped with the Goshen soil series highlighted**

the potential to yield Paleoindian cultural components, five of the seven alluvial landforms mapped with the Goshen soil series have ages that fall within the beginning of the early Holocene or middle Holocene (Table 3), and therefore have potential to yield Archaic cultural components. Based on the results, alluvial landforms mapped with the Goshen soil series have potential to focus investigations on Paleoindian and Archaic cultural deposits.

Within the entire valley, investigations focused on the Goshen series have the potential to reduce survey size by 96 percent, from 203,184 total acres to 7,425 acres mapped with the Goshen series (Figure 25). Within the area mapped as alluvium in the basin, targeting the Goshen series has the potential to reduce survey size by 59 percent, from 17,901 total acres of alluvium to 7,425 acres mapped as the Goshen series. The results of the current study are very promising. This research has the potential to focus an archaeological survey on areas with potential to yield Paleoindian, as well as Archaic, cultural components in the valley and reduce field time and cost required to complete the survey.

Although the results of the study are encouraging, the study sample size is relatively small. The addition of radiocarbon ages collected from other terraces mapped with the Goshen soil series in the Middle Beaver Creek Valley has the capacity to strengthen the understanding of the co-occurrence between the Goshen series and potential for early cultural components. Conversely, a larger sample set also may clarify why MBC-4 and the T-1 terrace at MBC-6 had no potential for Paleoindian cultural deposits. In addition, a larger sample set has the potential to elucidate temporal-spatial patterns of landscape stability within the terrace fills mapped with the Goshen surface soil. As of now, no discernible pattern was evident in the radiocarbon ages determined on the study sites; soils dating to the middle Holocene and soils dating to the early Holocene were evenly distributed throughout the drainage. If a temporal-spatial pattern of landscape stability exists within the valley, understanding the pattern could help further focus investigations targeting specific cultural complexes.

The current study could be further strengthened by the addition of samples from alluvial terraces and floodplains not mapped with the Goshen soil series. As was evidenced by the early radiocarbon date determined on the T-2 terrace mapped as the Rago soil series at MBC-1, the potential to yield Paleoindian cultural components is not restricted to alluvial landforms mapped with the Goshen series in Middle Beaver Creek. A total of 18 additional soil series and complexes are mapped on terraces or drainageways and floodplains within the Middle Beaver Creek Valley: 11 mapped on terraces and drainageways and 7 mapped on floodplains (Table 1). A broad sample including additional soil series and landforms may clarify if the potential for

Paleoindian cultural deposits in the T-2 fill at MBC-1 was a coincidence. If additional soil series consistently are determined to have potential to yield Paleoindian cultural deposits, understanding similarities between those series and the Goshen series may make it easier to target additional areas of potential in the Middle Beaver Creek Valley. For example, both the Goshen series and the Rago series are classified taxonomically as Argiustolls. The classification suggests surfaces mapped with the Goshen or Rago series have moderately developed soil profiles with argillic subsurface horizons. The presence of argillic horizons in the two series suggests the surface on which they are mapped have been stable for approximately 1,000 - 2,000 years. Although this estimated age is much more recent than the Paleoindian era, it does suggest the landform on which they are mapped have been stable longer than those mapped as very weakly developed Ustifluvents or Fluventic Haplustolls, like the Kit Carson or Bridgeport series, respectively. Among the additional alluvial soil series in the Middle Beaver Creek Valley, those series mapped on terraces and drainageways tend to be taxonomically more similar to the Goshen series, having moderately developed surface soils, than do those mapped on the floodplains. Additional testing focused on expanding the current study may be able to eliminate weakly developed surface soils, like those often mapped on floodplains, from future investigations targeting landforms that have potential to yield Paleoindian or Archaic cultural deposits.

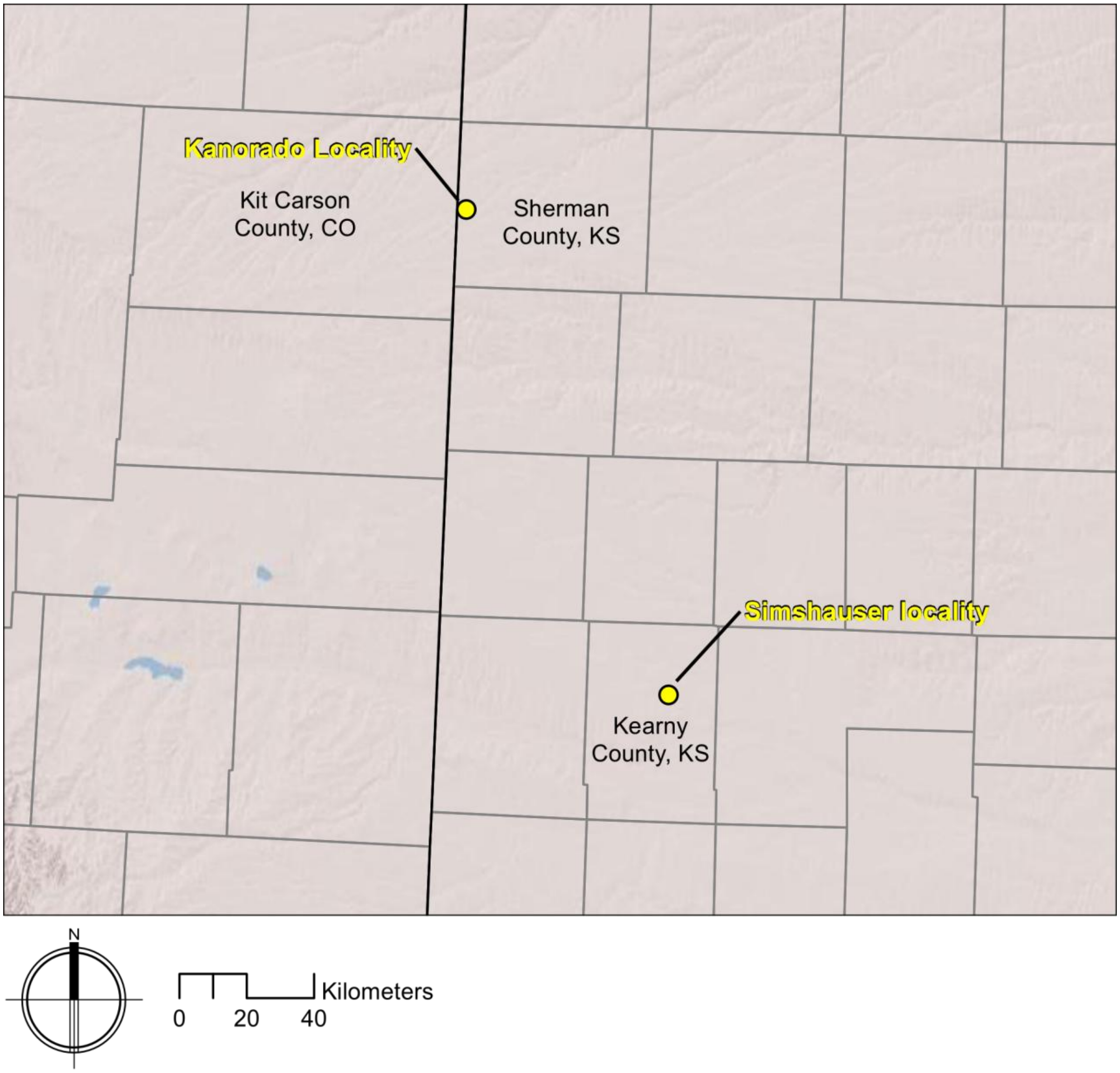

**Figure 26: Map showing location of Simshauser locality in relation to Kanorado locality**

Future Research

The results of this study suggest a methodology similar to the one used in Middle Beaver Creek could be employed in other drainages in the region to focus investigations on alluvial landforms with potential for buried Paleoindian cultural deposits. A potential candidate for future research is the Simshauser locality (14KY102) in Kearny County in southwest Kansas.

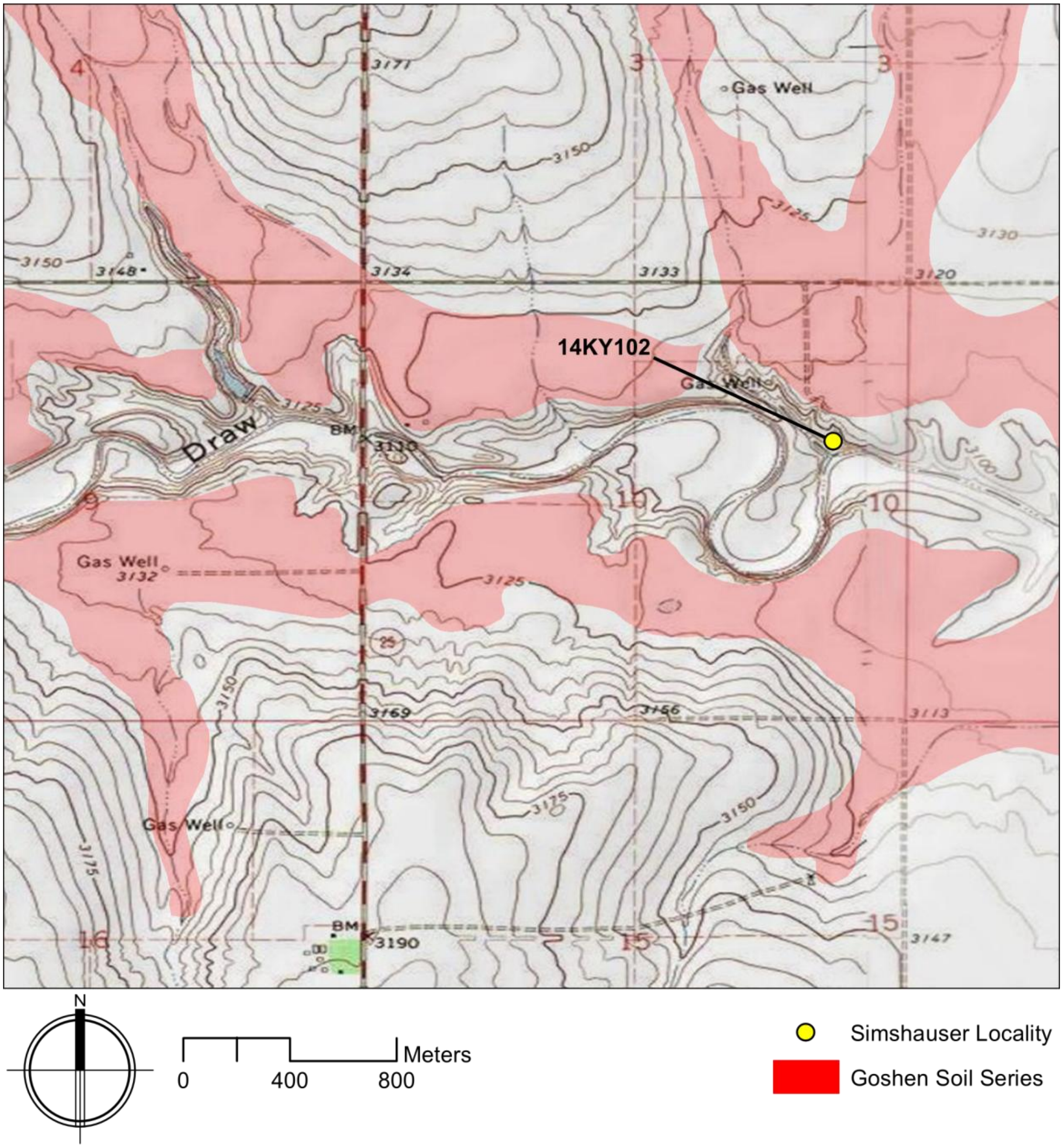

**Figure 26: Excerpt of USGS 7.5 minute Leoti 3 SW and Wolf SW quadrangle maps showing Simshauser locality with the Goshen soil series highlighted**

The Simshauser locality is a stratified Archaic and Folsom-age site located along Mattox Draw, approximately 154.2 km south/southeast of Middle Beaver Creek (Figure 26). The locality consists of buried Paleoindian-age soils contained within a small alluvial fan and the adjacent T-1 terrace fill. Mandel and Hofman (2006) and Mandel (2008) recorded buried soils dating to ca. 8,200 and 13,400 $^{14}$C yrs B.P. within the terrace fill at the Simshauser locality. Like Kanorado, the Goshen soil series is mapped on the terrace at Simshauser (Figure 27). The co-occurrance of buried soils with high potential for yielding Paleoindian cultural deposits and the Goshen soil series at the Simshauser locality suggest that a model identical to the one developed for Middle Beaver Creek can be constructed for Mattox Draw and similar intermittent streams on the High Plains.

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# APPENDIX I

`LOCATION GOSHEN                NE+CO KS SD WY`

Established Series
Rev. JIB/DAY/JWB
05/2006

## GOSHEN SERIES

The Goshen series includes very deep, well drained soils that formed in silty alluvium derived mainly from loess. These soils are in swales and narrow drainageways of uplands and have slopes ranging from 0 to 3 percent. Mean annual air temperature is 9 degrees C. (48 degrees F), and mean annual precipitation is 41 centimeters (16 inches) at the type location.

**TAXONOMIC CLASS:** Fine-silty, mixed, superactive, mesic Pachic Argiustolls

**TYPICAL PEDON:** Goshen loam with a slope of less than 1 percent in a cultivated field. (Colors are for dry soil unless otherwise stated.)

**Ap**--0 to 18 centimeters (0 to 7 inches); grayish brown (10YR 5/2) loam, very dark grayish brown (10YR 3/2) moist; weak fine granular structure; soft, friable; few pebbles on surface; neutral; abrupt smooth boundary.

**A**--18 to 46 centimeters (7 to 18 inches); very dark grayish brown (10YR 3/2) loam, very dark brown (10YR 2/2) moist; weak coarse blocky structure parting to weak fine and medium granular; soft, friable; moderately alkaline; abrupt smooth boundary. (Combined thickness of the A horizon 20 to 51 centimeters (8 to 20 inches) thick)

**Bt1**--46 to 69 centimeters (18 to 27 inches); dark grayish brown (10YR 4/2) loam, very dark grayish brown (10YR 3/2) moist; weak coarse prismatic structure parting to moderate medium subangular blocky; slightly hard, firm; thin nearly continuous films on peds; moderately alkaline; clear smooth boundary.

**Bt2**--69 to 89 centimeters (27 to 35 inches); grayish brown (10YR 5/2) silty clay loam, dark grayish brown (10YR 4/2) moist; moderate fine and medium subangular blocky structure; slightly hard, firm; nearly continuous films on peds; moderately alkaline; clear smooth boundary.

**Bt3**--89 to 127 centimeters (35 to 50 inches); grayish brown (10YR 5/2) silty clay loam, dark grayish brown (10YR 4/2) moist; weak, medium and coarse subangular blocky structure; slightly hard, firm; moderately alkaline; clear smooth boundary. (Combined thickness of the Bt horizons 58 to 102 centimeters (23 to 40 inches) thick)

**C**--127 to 152 centimeters (50 to 60 inches); pale brown (10YR 6/3) silt loam, brown (10YR 4/3) moist; massive; soft, friable; moderately alkaline.

**TYPE LOCATION:** Kimball County, Nebraska; about 14 kilometers (9 miles) north and 3 kilometers (2 miles) west of Kimball, 183 meters (600 feet) south and 37 meters (120 feet) east of the northwest corner, sec. 13, T. 16 N., R. 56 W.

**RANGE IN CHARACTERISTICS:**
Thickness of the solum: 89 to 152 centimeters (35 to 60 inches)
Carbonates in some pedons: 86 to 152 centimeters (34 to below 60 inches
Mollic epipedon: extends into the B horizon and 51 to 114 centimeters (20 to 45 inches) thick

A horizon:
Hue: 10YR
Value: 3 to 5, 2 or 3 moist
Chroma: 2 or 3 dry or moist
Texture: typically loam, but include silt loam and fine sandy loam
Reaction: slightly acid to slightly alkaline.

Bt horizon:
The upper part: colors similar to the A horizon.
The lower part:
Hue: 10YR
Value: 5 or 6, 3 to 5 moist
Chroma: 2 or 3 dry or moist
Reaction: neutral to moderately alkaline
Texture: typically loam and silty clay loam but includes silt loam
Average clay content of the argillic horizon: 24 to 35 percent

BC or BCk horizon is in some pedons.
Texture: silt loam, loam, or very fine sandy loam

C horizon:
Hue: 10YR or 2.5Y
Value: 6 to 8, 4 to 6 moist
Chroma: 2 or 3
Reaction: moderately alkaline
Texture: silt loam, very fine sandy loam, or loam
Carbonates: in the lower part in some pedons
Contrasting material: 102 to 152 centimeters (40 and 60 inches) in some pedons

**COMPETING SERIES:** These are the Hall, Johnstown, Kinsell, Kuma, Lazarus, Mobridge, Simpatico and Zepol series.
Hall soils are in an area of higher rainfall and have lower base saturation.
Johnstown soils have a buried soil and gravelly sand at depths of 102 to 152 centimeters (40 to 60 inches).
Kinsell soils are in an aridic moisture regime bordering on ustic.
Kuma soils have buried paleosols within 20 inches.
Lasarus soils do not contain visible secondary calcium carbonates in the substratum.

Zepol soils have small amounts of volcanic ash in the coarse silt and fine sand fraction.
Kuma soils have a polygenetic solum.
Mobridge soils have chroma of 1 in the A horizon and are shallower to carbonates.
Simpatico soils have moisture control sections that are dry for 15 consecutive days from May 15 to July 15 when the soil temp is greater than 5 degrees C. (41 degrees F.)

**GEOGRAPHIC SETTING:**
Landforms: swales or narrow drainageways of uplands
Slopes: 0 to 3 percent
Parent material: silty alluvium derived mainly from soils formed in loess
Climate: semiarid
Mean annual precipitation: 36 to 48 centimeters (14 to 19 inches)
Mean annual air temperature: 7 to 13 degrees C. (45 to 55 degrees F.)
Flooding: none, rare, or occasional

**GEOGRAPHICALLY ASSOCIATED SOILS:** These are the Alliance, Duroc, Keith, Richfield, Rosebud, and Ulysses series.
Keith soils are higher on the landscape.
Duroc soils do not have an argillic horizon and are slightly higher than Goshen soils.
Alliance, Richfield, and Ulysses soils have a mollic epipedon less than 51 centimeters (20 inches) thick and are above Goshen soils.
Rosebud soils have a mollic epipedon less than 51 centimeters (20 inches) thick, fine-grained sandstone, or limestone between a depth of 51 to 102 centimeters (20 to 40 inches), and are above the Goshen soils.

**DRAINAGE AND SATURATED HYDRAULIC CONDUCTIVITY:**
Drainage: well drained
Runoff: low or medium
Saturated hydraulic conductivity: moderately high
Flooding: none, rare, or occasional

**USE AND VEGETATION:** Most of the acreage is cultivated.
Winter wheat and sorghum are the principal dryland crops.
Corn, alfalfa, sugar beets, field beans, potatoes, and small grains are grown on irrigated soils.
Grasses are primarily of the short and mid type where the soil is in native vegetation.

**DISTRIBUTION AND EXTENT:** Western Nebraska and Kansas, South Dakota, and eastern Wyoming and Colorado. The series is moderately extensive.

**MLRA SOIL SURVEY REGIONAL OFFICE (MO) RESPONSIBLE:** Salina, Kansas

**SERIES ESTABLISHED:** Scotts Bluff County, Nebraska, 1913.

**REMARKS:**

**ADDITIONAL DATA:** Physical and chemical data from two pedons of Goshen loam are provided in Soil Survey Investigations Report No. 5, pages 52-55.

Modified format by LRM in 2/2006 to include metric conversion and change permeability to saturated hydraulic conductivity.

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National Cooperative Soil Survey
U.S.A.

# APPENDIX II

**Table 5: Core 1-1 soil description**

| Depth (cm) | Soil Horizon | Description |
|---|---|---|
| 0-15 | A | Dark grayish brown (10YR4/2) very fine sandy loam, very dark grayish brown (10YR3/2) moist; weak fine prismatic structure parting to weak medium and fine granular; moderately hard; friable; common fine and very fine roots; common fine and very fine pores; few worm casts; clear smooth boundary. |
| 15-37 | Bt1 | Dark grayish brown (10YR4/2) very fine sandy loam, very dark gray (10YR3/1) moist; weak medium prismatic structure parting to moderate coarse and medium subangular blocky; moderately hard; friable; common, distinct very dark grayish brown (10YR3/2) clay films on ped faces and bridging between sand grains; few fine siliceous gravels; common fine and very fine roots; common fine and very fine pores; few worm casts; clear smooth boundary. |
| 37-60 | Bt2 | Dark grayish brown (10YR4/2) sandy clay loam, very dark grayish brown (10YR3/2) moist; moderate coarse and medium subangular blocky structure; moderately hard; friable; many, distinct very dark grayish brown (10YR3/2) clay films on ped faces and bridging between sand grains; few fine siliceous gravels; common fine and very fine roots; common fine and very fine pores; few worm casts and open burrows; gradual smooth boundary. |
| 60-82 | Bt3 | Dark grayish brown (10YR4/2) silty clay loam, very dark gray (10YR3/1) moist; weak medium prismatic structure parting to moderate fine subangular blocky; very hard; friable; many, prominent very dark grayish brown (10YR3/2) clay films on ped faces and bridging between sand grains; few fine siliceous gravels; few fine and common very fine roots; common fine and very fine pores; abrupt smooth boundary. |
| 82-108 | Btk1 | Grayish brown (10YR5/2) silty clay, dark grayish brown (10YR4/2) moist; weak medium prismatic structure parting to moderate fine subangular blocky; moderately hard; friable; many, prominent very dark grayish brown (10YR3/2) clay films on ped faces; common films and threads of calcium carbonate; few fine siliceous gravels; few fine and common very fine roots; common fine and very fine pores; gradual smooth boundary. |
| 108-147 | Btk2 | Grayish brown (10YR5/2) sandy clay loam, dark grayish brown (10YR4/2) moist; weak coarse prismatic structure parting to moderate medium subangular blocky; moderately hard; firm; common, distinct dark grayish brown (10YR4/2) clay films on ped faces; common films and threads of calcium carbonate, few fine nodules of calcium carbonate; few fine siliceous gravels; few fine and very fine roots; common fine and very fine pores; gradual smooth boundary. |
| 147-179 | Btk3 | Grayish brown (10YR5/2) sandy clay loam, dark grayish brown (10YR4/2) moist; weak coarse prismatic structure parting to moderate medium subangular blocky; moderately hard; firm; common, distinct dark grayish brown (10YR4/2) clay films on ped faces; common films and threads of calcium carbonate, few fine nodules of calcium carbonate; few fine siliceous gravels; few fine and very fine roots; common fine and very fine pores; clear smooth boundary. |
| 179-200 | CBk | Brown (10YR5/3) sandy loam, grayish brown (10YR5/2) moist; very weak medium and fine subangular blocky; slightly hard; friable; many films and threads of calcium carbonate, nearly continuous coatings of calcium carbonate on clasts; few fine siliceous gravels; few very fine roots; common fine and very fine pores; clear smooth boundary. |
| 200-220+ | Ck | Pale brown (10YR6/3) sand, brown (10YR5/3) moist; single grained; loose; many films and threads of calcium carbonate, nearly continuous coatings of calcium carbonate on clasts; common coarse, medium, and fine siliceous gravels; few very fine roots. |

**Table 6: Core 1-2 soil description**

| Depth (cm) | Soil Horizon | Description |
|---|---|---|
| 0-37 | A | Brown (10YR4/3) silty clay loam, very dark grayish brown (10YR3/2) moist; moderate coarse and medium granular structure; slightly hard; very friable; many fine and very fine roots; common very fine pores; common worm casts and open burrows; gradual smooth boundary. |
| 37-63 | Bt1 | Dark grayish brown (10YR4/2) silty clay loam, very dark grayish brown (10YR3/2) moist; moderate medium and fine prismatic structure parting to moderate fine subangular blocky; moderately hard; friable; common, distinct very dark grayish brown (10YR3/2) clay films on ped faces; few medium and fine siliceous gravels; common fine and very fine roots; common very fine pores; common worm casts; gradual smooth boundary. |
| 63-91 | Bt2 | Brown (10YR4/3) silty clay, dark grayish brown (10YR4/2) moist; moderate medium and fine prismatic structure parting to moderate fine subangular blocky; slightly hard; friable; common, distinct very dark grayish brown (10YR3/2) clay films on ped faces; few medium and fine siliceous gravels; common fine and very fine roots; common very fine pores; common worm casts; clear smooth boundary. |
| 91-124 | Btk | Brown (10YR5/3) silty clay, dark grayish brown (10YR4/2) moist; moderate medium and fine prismatic structure parting to moderate fine subangular blocky; hard; firm; common, distinct very dark grayish brown (10YR3/2) clay films on ped faces; common films and threads of calcium carbonate; few medium and fine siliceous gravels; few very fine roots; common fine and very fine pores; clear smooth boundary. |
| 124-152 | Bk | Pale brown (10YR6/3) loam, grayish brown (10YR5/2) moist; weak medium and fine prismatic structure parting to weak fine subangular blocky; slightly hard; firm; common films and threads of calcium carbonate; few very fine roots; common fine and very fine pores; gradual smooth boundary. |
| 152-181 | CBk | Brown (10YR5/3) sandy loam, dark grayish brown (10YR4/2) moist; weak medium and fine subangular blocky structure; slightly hard; friable; common films and threads of calcium carbonate; few very fine roots; common fine and very fine pores; abrupt smooth boundary. |
| 181-208 | Btkb1 | Brown (10YR5/3) sandy clay loam, brown (10YR4/3) moist; moderate medium and fine prismatic structure parting to weak fine subangular blocky; slightly hard; friable; few, faint dark grayish brown (10YR4/2) clay films on ped faces; common films and threads of calcium carbonate; common fine and very fine pores; clear smooth boundary. |
| 208-237 | Akb2 | Grayish brown (10YR5/2) sandy clay loam, very dark gray (10YR3/1) moist; moderate coarse and medium granular structure; moderately hard; friable; common films and threads of calcium carbonate; few medium and fine siliceous gravels; common fine and very fine pores; gradual smooth boundary. |
| 237-275 | Btkb2 | Brown (10YR5/3) sandy clay loam, brown (10YR4/3) moist; weak coarse and medium subangular blocky structure; moderately hard; firm; few faint dark grayish brown (10YR4/2) clay films on ped faces; few films and threads of calcium carbonate; few medium and fine siliceous gravels; common fine and very fine pores; clear smooth boundary. |
| 275-290+ | BCkb2 | Yellowish brown (10YR5/4) sandy loam, dark grayish brown (10YR4/2) moist; weak medium subangular blocky structure; faint laminations; slightly hard; firm; few films and threads of calcium carbonate; few medium and fine siliceous gravels; common fine and very fine pores. |

**Table 7: Core 2 soil description**

| Depth (cm) | Soil Horizon | Description |
|---|---|---|
| 0-40 | A | Dark grayish brown (10YR4/2) silty loam, very dark gray (10YR3/1) moist; moderate medium and fine granular structure; very hard; friable; common fine and very fine roots; common fine and very fine pores; few worm casts and open burrows; clear smooth boundary. |
| 40-50 | AB | Dark grayish brown (10YR4/2) silty loam, dark gray (10YR4/1) moist; weak fine prismatic structure parting to moderate fine granular; very hard; friable; common fine and very fine roots; common fine and very fine pores; few worm casts and open burrows; abrupt smooth boundary. |
| 50-76 | Ab | Dark grayish brown (10YR4/2) silty clay loam, very dark gray (10YR3/1) moist; weak coarse and medium subangular blocky structure parting to moderate medium and fine granular; moderately hard; friable; common fine and very fine roots; few fine and very fine pores; few worm casts; gradual smooth boundary. |
| 76-90 | ABb | Dark grayish brown (10YR4/2) silty clay loam, very dark grayish brown (10YR3/2) moist; weak coarse and medium subangular blocky structure parting to moderate coarse and medium granular; moderately hard; friable; common fine and very fine roots; few fine and very fine pores; clear smooth boundary. |
| 90-124 | Btb | Grayish brown (10YR5/2) silty clay, dark grayish brown (10YR4/2) moist; moderate medium prismatic structure parting to weak fine subangular blocky; moderately hard; firm; common, distinct dark grayish brown (10YR4/2) clay films on ped faces and pore surfaces; common fine and very fine, few coarse roots; common fine and very fine pores; clear smooth boundary. |
| 124-159 | Btk1b | Grayish brown (10YR5/2) silty clay, dark grayish brown (10YR4/2) moist; moderate medium prismatic structure parting to moderate medium subangular blocky; hard; firm; many, distinct dark grayish brown (10YR4/2) clay films on ped faces; common films and threads of calcium carbonate; few fine and very fine roots; common fine and very fine pores; gradual smooth boundary. |
| 159-218 | Btk2b | Grayish brown (10YR5/2) silty clay, dark grayish brown (10YR4/2) moist; moderate medium and fine prismatic structure; very hard; firm; common, distinct dark grayish brown (10YR4/2) clay films on ped faces; common films and threads of calcium carbonate; few fine and very fine roots; common fine and very fine pores; clear smooth boundary. |
| 218-224+ | Btk3b | Light grayish brown (10YR6/2) silty clay, grayish brown (10YR5/2) moist; medium and fine prismatic structure; very hard; very firm; common, distinct dark grayish brown (10YR4/2) clay films on ped faces; many films and threads of calcium carbonate, few medium concretion of calcium carbonate; few fine and very fine roots; common fine and very fine pores. |

**Table 8: Core 3 soil description**

| Depth (cm) | Soil Horizon | Description |
|---|---|---|
| 0-25 | Ap | Dark grayish brown (10YR4/2) silty clay loam, very dark grayish brown (10YR3/2) moist; moderate fine granular structure; slightly hard; very friable; many fine and very fine roots; common very fine pores; clear smooth boundary. |
| 25-44 | A | Brown (10YR4/3) silty clay, very dark gray (10YR2/2) moist; weak medium subangular blocky structure parting to moderate fine granular; slightly hard; very friable; common fine and very fine roots; common very fine pores; few worm casts; gradual smooth boundary. |
| 44-66 | Bt1 | Dark grayish brown (10YR4/2) silty clay, very dark grayish brown (10YR3/2) moist; weak medium prismatic structure parting to moderate fine subangular blocky; slightly hard; friable; many, distinct dark grayish brown (10YR4/2) clay films on ped faces; few fine siliceous gravels; common fine and very fine roots; common very fine pores; gradual smooth boundary. |
| 66-100 | Bt2 | Brown (10YR4/3) silty clay, very dark grayish brown (10YR3/2) moist; weak medium prismatic structure parting to moderate fine subangular blocky; slightly hard; friable; many, prominent dark grayish brown (10YR4/2) clay films on ped faces; common fine and very fine roots; common very fine pores; common very coarse krotovina filled with dark grayish brown (10YR4/2) silty clay; gradual smooth boundary. |
| 100-121 | Btk1 | Grayish brown (10YR5/2) silty clay, dark gray (10YR4/1) moist; weak medium prismatic structure parting to moderate fine subangular blocky; slightly hard; friable; common, distinct dark grayish brown (10YR4/2) clay films on ped faces; common films and threads of calcium carbonate, few fine concretion of calcium carbonate; few fine siliceous gravels; common fine and very fine roots; common very fine pores; clear smooth boundary. |
| 121-153 | Btk2 | Light gray (10YR7/2) silty clay, light grayish brown (10YR6/2) moist; weak medium prismatic structure parting to moderate fine subangular blocky; slightly hard; friable; common, distinct dark grayish brown (10YR4/2) clay films on ped faces; many films and threads of calcium carbonate; common fine and very fine roots; many very fine pores; clear smooth boundary. |
| 153-190 | BCk | Very pale brown (10YR7/3) silty clay loam, brown (10YR5/3) moist; very weak medium and fine subangular blocky structure; slightly hard; friable; common films and threads of calcium carbonate; few very fine roots; common fine and very fine pores; clear smooth boundary. |
| 190-208 | Ck1 | Light gray (10YR7/2) sandy clay loam, light grayish brown (10YR6/2) moist; massive with thin laminations visible; moderately hard; friable; common films and threads of calcium carbonate, few fine concretion of calcium carbonate; few very fine roots; few fine and common very fine pores; clear smooth boundary. |
| 208-235 | Ck2 | Pale brown (10YR6/3) silty clay loam, grayish brown (10YR5/2) moist; massive with thin laminations visible; moderately hard; friable; common films and threads of calcium carbonate, few fine concretion of calcium carbonate; few very fine roots; few fine and common very fine pores; clear smooth boundary. |
| 235-262 | Ck3 | Grayish brown (10YR5/2) silty clay loam, dark grayish brown (10YR4/2) moist; massive with thin laminations visible; moderately hard; very friable; few films and threads of calcium carbonate; few medium and fine siliceous gravels; few very fine roots; many very fine pores; clear smooth boundary. |
| 262-285 | Ck4 | Light yellowish brown (10YR6/4) silty clay loam, dark yellowish brown (10YR4/4) moist; massive with thin laminations visible; moderately hard; very friable; few films and threads of calcium carbonate; few fine siliceous gravels; few very fine roots; many very fine pores; abrupt smooth boundary. |
| 285-335 | C1 | Very pale brown (10YR7/4) sand, brown (10YR5/3) moist; single grained; loose; clear smooth boundary. |
| 335-351+ | C2 | Pale brown (10YR6/3) loamy sand, yellowish brown (10YR5/4) moist; massive; moderately hard; very friable. |

**Table 9: Core 4 soil description**

| Depth (cm) | Soil Horizon | Description |
|---|---|---|
| 0-31 | A | Brown (10YR4/3) sandy loam, very dark gray (10YR3/1) moist; moderate coarse and medium granular structure; slightly hard; friable; many fine and very fine roots; common fine and very fine pores; common worm casts and open burrows; gradual smooth boundary. |
| 31-62 | Bw | Dark grayish brown (10YR4/2) silty clay loam, very dark gray (10YR3/1) moist; weak medium and fine prismatic structure parting to weak fine subangular blocky; slightly hard; friable; few medium and fine siliceous gravels; common fine and very fine roots; common fine and very fine pores; common worm casts; clear smooth boundary. |
| 62-81 | Ab1 | Light grayish brown (10YR6/2) silty clay loam, dark gray (10YR4/1) moist; weak medium and fine subangular blocky structure parting to moderate medium and fine granular; slightly hard; friable; common fine and very fine roots; common fine and very fine pores; common worm casts; gradual smooth boundary. |
| 81-93 | Btkb1 | Pale brown (10YR6/3) silty clay, dark grayish brown (10YR4/2) moist; weak medium and fine prismatic structure parting to weak fine subangular blocky; slightly hard; friable; common, distinct very dark grayish brown (10YR3/2) clay films on ped faces; common films and threads of calcium carbonate; common fine and very fine roots; common fine and very fine pores; clear smooth boundary. |
| 93-108 | Bkb1 | Light grayish brown (10YR6/2) silty clay loam, grayish brown (10YR5/2) moist; weak medium and fine prismatic structure parting to weak fine subangular blocky; slightly hard; friable; many films and threads of calcium carbonate, few fine concretion of calcium carbonate; common fine and very fine roots; common fine and very fine pores; clear smooth boundary. |
| 108-135 | BCkb1 | Light grayish brown (10YR6/2) very fine sandy clay loam, dark grayish brown (10YR4/2) moist; weak medium prismatic structure; slightly hard; friable; few films and threads of calcium carbonate; common very fine roots; common very fine pores; gradual smooth boundary. |
| 135-149 | CBkb1 | Very pale brown (10YR7/3) very fine sandy clay loam, brown (10YR5/3) moist; very weak medium and fine subangular blocky structure; slightly hard; friable; few films and threads of calcium carbonate; few very fine roots; common very fine pores; clear smooth boundary. |
| 149-182 | Ckb1 | Light yellowish brown (10YR6/4) sandy loam, brown (10YR5/3) moist; massive; moderately hard; friable; few films and threads of calcium carbonate; few very fine roots; common very fine pores; abrupt smooth boundary. |
| 182-205 | ABkb2 | Pale brown (10YR6/3) silty loam, brown (10YR5/3) moist; weak medium prismatic structure parting to moderate medium and fine granular; moderately hard; friable; common films and threads of calcium carbonate; few very fine roots; few fine and common very fine pores; clear smooth boundary. |
| 205-235 | BCkb2 | Light yellowish brown (10YR6/4) silty loam, yellowish brown (10YR5/4) moist; weak medium prismatic structure parting to weak medium subangular blocky; hard; firm; few films and threads of calcium carbonate; few medium and fine siliceous gravels; common fine and very fine pores; clear smooth boundary. |
| 235-256 | Ck1b2 | Pale brown (10YR6/3) silty loam, brown (10YR5/3) moist; massive with thin laminations visible; moderately hard; friable; common films and threads of calcium carbonate; few medium, common fine and very fine pores; few gastropod shells; clear smooth boundary. |
| 256-281+ | Ck2b2 | Light yellowish brown (10YR6/4) silty clay loam, dark grayish brown (10YR4/2) moist; massive with thin laminations visible; moderately hard; friable; common films and threads of calcium carbonate; few medium and fine siliceous gravels; common fine and very fine pores. |

**Table 10: Cutbank 5 and Core 5 soil description**

| Depth (cm) | Soil Horizon | Description |
|---|---|---|
| 0-24 | A | Brown (10YR4/3) fine sandy clay loam, very dark grayish brown (10YR3/2) moist; weak fine granular structure; hard; friable; many fine and very fine roots; few medium and fine pores; common worm casts and open burrows; gradual smooth boundary. |
| 24-51 | Bw | Brown (10YR5/3) fine sandy clay loam, dark grayish brown (10YR4/2) moist; weak fine subangular blocky; moderately hard; friable; common fine and many very fine roots; many medium, fine, and very fine pores; many worm casts and open burrows; gradual smooth boundary. |
| 51-73 | Bt | Brown (10YR5/3) silty clay loam, dark grayish brown (10YR4/2) moist; weak medium prismatic structure parting to weak fine subangular blocky; slightly hard; friable; common, distinct dark grayish brown (10YR4/2) clay films on ped faces; common fine and many very fine roots; many medium, fine, and very fine pores; many worm casts and open burrows; clear smooth boundary. |
| 73-104 | Btk | Grayish brown (10YR5/2) silty clay loam, brown (10YR4/3) moist; moderate medium prismatic structure parting to moderate fine subangular blocky; slightly hard; friable; common, distinct dark grayish brown (10YR4/2) clay films on ped faces; many films and threads of calcium carbonate; common fine siliceous gravels; common fine and many very fine roots; many medium, fine, and very fine pores; many worm casts and open burrows; clear smooth boundary. |
| 104-139 | Atkb1 | Pale brown (10YR6/3) silty clay, brown (10YR4/3) moist; weak medium prismatic structure parting to weak fine granular; hard; friable; common, distinct dark grayish brown (10YR4/2) clay films on ped faces; many films and threads of calcium carbonate; few fine and common very fine roots; common fine and very fine pores; few worm casts and open burrows; gradual smooth boundary. |
| 139-157 | Bkb1 | Brown (10YR5/3) silty clay loam, brown (10YR4/3) moist; weak fine subangular blocky structure; hard; very friable; few films and threads of calcium carbonate; few fine and very fine roots; common fine and very fine pores; gradual smooth boundary. |
| 157-205 | BCkb1 | Light yellowish brown (10YR6/4) fine sandy clay loam, yellowish brown (10YR5/4) moist; very weak fine subangular blocky structure; hard; very friable; few films and threads of calcium carbonate; few fine and very fine roots; common fine and very fine pores; gradual smooth boundary. |
| 205-223 | CBkb1 | Pale brown (10YR6/3) fine sandy loam, brown (10YR4/3) moist; very weak fine subangular blocky structure with laminations visible; moderately hard; friable; common films and threads of calcium carbonate; fine and very fine roots; common fine and very fine pores; common very coarse krotovina filled with grayish brown (10YR5/2) silty loam; abrupt smooth boundary. |
| 223-239 | Ak1b2 | Brown (10YR5/3) very fine sandy loam, very dark grayish brown (10YR3/2) moist; weak fine granular structure; slightly hard; friable; many films and threads of calcium carbonate; many fine and very fine roots; common medium, fine and very fine pores; clear smooth boundary. |
| 239-279 | Ak2b2 | Grayish brown (10YR5/2) very fine sandy clay loam, very dark grayish brown (10YR3/2) moist; weak fine granular structure; slightly hard; friable; few films and threads of calcium carbonate; many fine and very fine roots; common medium, fine and very fine pores; many very coarse krotovina filled with brown (10YR5/3) very fine sandy loam; gradual smooth boundary. |
| 279-303 | Bkb2 | Light gray (10YR7/2) loam, light grayish brown (10YR6/2) moist; moderate medium and fine prismatic structure; moderately hard; very friable; many films and threads of calcium carbonate; few fine siliceous gravels; few fine and very fine roots; common fine and very fine pores; clear smooth boundary. |
| 303-331 | Ck1b2 | Light gray (10YR7/2) loam, dark grayish brown (10YR4/2) moist; massive with thin laminations visible; very hard; firm; common films and threads of calcium carbonate; few medium and fine siliceous gravels; common fine and many very fine pores; clear smooth |

| | | |
|---|---|---|
| | | boundary. |
| 331-362 | Ck2b2 | Very pale brown (10YR7/4) sandy loam, yellowish brown (10YR5/4) moist; massive with thin laminations visible; hard; friable; common films and threads of calcium carbonate; few medium and fine siliceous gravels; common fine and many very fine pores; few gastropod shells; abrupt smooth boundary. |
| 362-416 | Ck3b2 | Light gray (10YR7/2) coarse sandy loam, yellowish brown (10YR5/4) moist; single grained; hard; loose; common films and threads of calcium carbonate; common medium and fine siliceous gravels; common fine and many very fine pores; abrupt smooth boundary. |
| 416-443 | Ck4b2 | Very pale brown (10YR7/4) loamy coarse sand, dark grayish brown (10YR4/2) moist; single grained; slightly hard; loose; common medium and fine strong brown (7.5YR4/6) redoximorphic iron depletions; common films and threads of calcium carbonate, few fine concretion of calcium carbonate; many medium and fine siliceous gravels; common fine and many very fine pores; |

**Table 11: Core 6-1 soil description**

| Depth (cm) | Soil Horizon | Description |
|---|---|---|
| 0-21 | A | Brown (10YR4/3) sandy loam, very dark grayish brown (10YR3/2) moist; moderate coarse and medium granular structure; slightly hard; very friable; common fine and very fine roots; common fine and very fine pores; few worm casts and open burrows; clear smooth boundary. |
| 21-47 | Bw | Brown (10YR5/3) sandy clay loam, very dark gray (10YR3/1) moist; weak medium prismatic structure parting to weak medium and fine subangular blocky; soft; friable; common fine and very fine roots; many fine and very fine pores; clear smooth boundary. |
| 47-71 | Ab | Dark grayish brown (10YR4/2) sandy loam, very dark gray (10YR3/1) moist; weak medium and fine subangular blocky structure parting to weak medium and fine granular; soft; friable; common fine and very fine roots; common fine and very fine pores; clear smooth boundary. |
| 71-83 | ACb | Grayish brown (10YR5/2) loamy sand, dark grayish brown (10YR4/2) moist; very weak medium and fine subangular blocky structure; soft; friable; few fine siliceous gravels; common fine and very fine roots; common fine and very fine pores; clear smooth boundary. |
| 83-132 | C1b | Light grayish brown (10YR6/2) loamy sand, dark gray (10YR4/1) moist; massive; slightly hard; very friable; few medium and fine siliceous gravels; common fine and very fine roots; abrupt smooth boundary. |
| 132-242+ | C2b | Pale brown (10YR6/3) sand, dark grayish brown (10YR4/2) moist; single grained; soft; very friable; few fine siliceous gravels; few very fine roots. |

**Table 12: Cutbank 6-2 soil description**

| Depth (cm) | Soil Horizon | Description |
|---|---|---|
| 0-27 | A | Dark grayish brown (10YR4/2) loam, very dark grayish brown (10YR3/2) moist; weak fine granular structure; moderately hard; friable; many fine and very fine roots; common fine and very fine pores; common worm casts and open burrows; gradual smooth boundary. |
| 27-42 | AB | Dark grayish brown (10YR4/2) loam, black (10YR2/1) moist; very weak fine subangular blocky structure parting to weak medium and fine granular; hard; friable; many fine and very fine roots; common fine and very fine pores; many worm casts and common open burrows; gradual smooth boundary. |
| 42-60 | Bw | Grayish brown (10YR5/2) silty loam, dark brown (10YR3/3) moist; weak fine subangular blocky structure; moderately hard; friable; few fine siliceous gravels; many fine and very fine roots; many fine and very fine pores; many worm casts and common open burrows; gradual smooth boundary. |
| 60-80 | Bk1 | Grayish brown (10YR5/3) silty loam, brown (10YR4/3) moist; weak medium prismatic structure parting to weak fine subangular blocky; hard; friable; common films and threads of calcium carbonate; few fine siliceous gravels; many fine and very fine roots; many fine and very fine pores; common worm casts and open burrows; clear wavy boundary. |
| 80-100 | Bk2 | Grayish brown (10YR5/3) silty clay loam, brown (10YR4/3) moist; moderate medium prismatic structure parting to moderate fine subangular blocky; very hard; friable; many films and threads of calcium carbonate; common fine and very fine roots; many fine and very fine pores; few worm casts and open burrows; clear smooth boundary. |
| 100-140 | Akb | Grayish brown (10YR5/2) silty clay loam, very dark grayish brown (10YR3/2) moist; weak medium prismatic structure parting to moderate coarse and medium granular; moderately hard; very firm; many films and threads of calcium carbonate; common very fine roots; common fine and very fine pores; few worm casts; few very coarse krotovina filled with grayish brown (10YR5/3) silty clay loam; clear smooth boundary. |
| 140-165 | Bkb | Pale brown (10YR6/3) silty loam, dark yellowish brown (10YR4/4) moist; moderate medium and fine prismatic structure; hard; very firm; common films and threads of calcium carbonate; few fine and very fine roots; many fine and very fine pores; abrupt wavy boundary. |
| 165-195 | BCkb | Pale brown (10YR6/3) silty loam, brown (10YR4/3) moist; weak coarse and medium prismatic structure parting to very weak fine subangular blocky; hard; very firm; common films and threads of calcium carbonate; few fine and very fine roots; many fine and very fine pores; many very coarse krotovina filled with grayish brown (10YR5/2) silty clay loam; abrupt wavy boundary. |
| 195-215+ | Ckb | Pale brown (10YR6/3) silty loam, brown (10YR4/3) moist; massive with thin laminations visible; hard; very firm; common fine yellowish brown (10YR5/8) redoximorphic iron depletions; common films and threads of calcium carbonate; many fine and very fine pores. |

# APPENDIX III

**Table 13: Core 1-1 PDI calculations and values**

| | PM (Ck) | A | Bt1 | Bt2 | Bt3 | Btk1 | Btk2 | Btk3 | CBk |
|---|---|---|---|---|---|---|---|---|---|
| **HORIZON PROPERTIES** | | | | | | | | | |
| Horizon Thickness | | 15.00 | 17.00 | 23.00 | 22.00 | 26.00 | 39.00 | 32.00 | 21.00 |
| Color-Dry | 10YR6/3 | 10YR4/2 | 10YR4/2 | 10YR4/2 | 10YR4/2 | 10YR5/2 | 10YR5/2 | 10YR5/2 | 10YR5/3 |
| Color-Moist | 10YR5/3 | 10YR3/2 | 10YR3/1 | 10YR3/2 | 10YR3/1 | 10YR4/2 | 10YR4/2 | 10YR4/2 | 10YR5/2 |
| Structure | sg | 1pr→1gr | 1pr→2sbk | 2sbk | 1pr→2sbk | 1pr→2sbk | 1pr→2sbk | 1pr→2sbk | .5sbk |
| Dry Consistence | lo | h | h | h | vh | h | h | h | sh |
| Moist Consistence | lo | fr | fr | fr | fr | fr | fi | fi | vfr |
| Texture | s | vfsl | vfsl | scl | sicl | sic | scl | scl | sl |
| Clay Films | n/a | n/a | 2dpf | 3dpf | 3ppf | 3dpf | 2dpf | 2dpf | n/a |
| Carbonate Stage | II | n/a | n/a | n/a | n/a | I+ | II | II | II |
| **QUANTIFIED SOIL FIELD PROPERTIES** | | | | | | | | | |
| Color Paling | | 20.00 | 30.00 | 20.00 | 30.00 | 20.00 | 20.00 | 20.00 | 10.00 |
| Melanization | | 40.00 | 40.00 | 40.00 | 40.00 | 20.00 | 20.00 | 20.00 | 10.00 |
| Texture | | 20.00 | 20.00 | 70.00 | 60.00 | 80.00 | 70.00 | 70.00 | 10.00 |
| Dry Consistence | | 30.00 | 30.00 | 30.00 | 40.00 | 30.00 | 30.00 | 30.00 | 20.00 |
| Moist Consistence | | 20.00 | 20.00 | 20.00 | 20.00 | 20.00 | 30.00 | 30.00 | 10.00 |
| Structure | | 40.00 | 45.00 | 30.00 | 45.00 | 45.00 | 45.00 | 45.00 | 15.00 |
| Clay Films | | 0.00 | 70.00 | 80.00 | 90.00 | 80.00 | 70.00 | 70.00 | 0.00 |
| Carbonate Stage | | 0.00 | 0.00 | 0.00 | 0.00 | 30.00 | 40.00 | 40.00 | 20.00 |
| **NORMALIZED VALUES FOR PROPERTIES** | | | | | | | | | |
| Color Paling | | 0.33 | 0.50 | 0.33 | 0.50 | 0.33 | 0.33 | 0.33 | 0.17 |
| Melanization | | 0.47 | 0.47 | 0.47 | 0.47 | 0.24 | 0.24 | 0.24 | 0.12 |
| Texture | | 0.10 | 0.10 | 0.35 | 0.30 | 0.40 | 0.35 | 0.35 | 0.05 |
| Dry Consistence | | 0.30 | 0.30 | 0.30 | 0.40 | 0.30 | 0.30 | 0.30 | 0.20 |
| Moist Consistence | | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 | 0.30 | 0.30 | 0.10 |
| Structure | | 0.67 | 0.75 | 0.50 | 0.75 | 0.75 | 0.75 | 0.75 | 0.25 |
| Clay Films | | 0.00 | 0.78 | 0.89 | 1.00 | 0.89 | 0.78 | 0.78 | 0.00 |
| Carbonate Stage | | 0.00 | 0.00 | 0.00 | 0.00 | 0.25 | 0.33 | 0.33 | 0.17 |
| **INDEX RESULTS** | | | | | | | | | |
| Σ of Normalized Values | | 2.07 | 3.10 | 3.04 | 3.62 | 3.36 | 3.38 | 3.38 | 1.05 |
| ÷ by Number of Properties (8) | | 0.26 | 0.39 | 0.38 | 0.45 | 0.42 | 0.42 | 0.42 | 0.13 |
| × by Horizon Thickness | | 3.88 | 6.58 | 8.75 | 9.96 | 10.91 | 16.48 | 13.52 | 2.76 |
| Σ of Horizon Properties | **PDI** | 72.84 | | | | | | | |

Table 14: Core 1-2 PDI calculations and values

| | PM (Ck*) | A | Bt1 | Bt2 | Btk | Bk | CBk |
|---|---|---|---|---|---|---|---|
| **HORIZON PROPERTIES** | | | | | | | |
| Horizon Thickness | | 37.00 | 26.00 | 28.00 | 33.00 | 28.00 | 29.00 |
| Color-Dry | 10YR6/3 | 10YR4/3 | 10YR4/2 | 10YR4/3 | 10YR5/3 | 10YR6/3 | 10YR5/3 |
| Color-Moist | 10YR5/3 | 10YR3/2 | 10YR3/2 | 10YR4/2 | 10YR4/2 | 10YR5/2 | 10YR4/2 |
| Structure | sg | 2gr | 2pr→2sbk | 2pr→2sbk | 2pr→2sbk | 1pr→1sbk | 1sbk |
| Dry Consistence | lo | sh | h | sh | h | sh | sh |
| Moist Consistence | lo | vfr | fr | fr | fi | fi | fr |
| Texture | s | sicl | sicl | sic | sic | l | sl |
| Clay Films | n/a | n/a | 2dpf | 2dpf | 2dpf | n/a | n/a |
| Carbonate Stage | II | n/a | n/a | n/a | I+ | I+ | I+ |
| **QUANTIFIED SOIL FIELD PROPERTIES** | | | | | | | |
| Color Paling | | 10.00 | 20.00 | 10.00 | 10.00 | 10.00 | 10.00 |
| Melanization | | 40.00 | 40.00 | 30.00 | 20.00 | 10.00 | 10.00 |
| Texture | | 60.00 | 60.00 | 80.00 | 80.00 | 30.00 | 20.00 |
| Dry Consistence | | 20.00 | 30.00 | 20.00 | 30.00 | 20.00 | 20.00 |
| Moist Consistence | | 10.00 | 20.00 | 20.00 | 30.00 | 30.00 | 20.00 |
| Structure | | 30.00 | 55.00 | 55.00 | 55.00 | 40.00 | 20.00 |
| Clay Films | | 0.00 | 70.00 | 70.00 | 70.00 | 0.00 | 0.00 |
| Carbonate Stage | | 0.00 | 0.00 | 0.00 | 15.00 | 15.00 | 15.00 |
| **NORMALIZED VALUES FOR PROPERTIES** | | | | | | | |
| Color Paling | | 0.17 | 0.33 | 0.17 | 0.17 | 0.17 | 0.17 |
| Melanization | | 0.47 | 0.47 | 0.35 | 0.24 | 0.12 | 0.12 |
| Texture | | 0.30 | 0.30 | 0.40 | 0.40 | 0.15 | 0.10 |
| Dry Consistence | | 0.20 | 0.30 | 0.20 | 0.30 | 0.20 | 0.20 |
| Moist Consistence | | 0.10 | 0.20 | 0.20 | 0.30 | 0.30 | 0.20 |
| Structure | | 0.50 | 0.92 | 0.92 | 0.92 | 0.67 | 0.33 |
| Clay Films | | 0.00 | 0.78 | 0.78 | 0.78 | 0.00 | 0.00 |
| Carbonate Stage | | 0.00 | 0.00 | 0.00 | 0.13 | 0.13 | 0.13 |
| **INDEX RESULTS** | | | | | | | |
| Σ of Normalized Values | | 1.74 | 3.30 | 3.01 | 3.22 | 1.73 | 1.24 |
| ÷ by Number of Properties (8) | | 0.22 | 0.41 | 0.38 | 0.40 | 0.22 | 0.16 |
| × by Horizon Thickness | | 8.03 | 10.72 | 10.55 | 13.29 | 6.04 | 4.50 |
| Σ of Horizon Properties | **PDI** | 53.14 | | | | | |

** - No parent material recorded during investigation.  Parent material properties of MBC-1, T-1 used as proxy.*

**Table 15: Core 2 PDI calculations and values**

| | PM (Ck1*) | A | AB | Ab | ABb | Btb | Btk1b | Btk2b | Btk3b |
|---|---|---|---|---|---|---|---|---|---|
| **HORIZON PROPERTIES** | | | | | | | | | |
| Horizon Thickness | | 40.00 | 10.00 | 26.00 | 24.00 | 34.00 | 35.00 | 59.00 | 47** |
| Color-Dry | 10YR7/2 | 10YR4/2 | 10YR4/2 | 10YR4/2 | 10YR4/2 | 10YR5/2 | 10YR5/2 | 10YR5/2 | 10YR6/2 |
| Color-Moist | 10YR6/2 | 10YR3/1 | 10YR4/1 | 10YR3/1 | 10YR3/2 | 10YR4/2 | 10YR4/2 | 10YR4/2 | 10YR5/2 |
| Structure | m | 2gr | 1pr→2gr | 1sbk→2gr | 1sbk→2gr | 2pr→1sbk | 2pr→2sbk | 2pr | 2pr |
| Dry Consistence | h | vh | vh | h | h | h | h | vh | vh |
| Moist Consistence | fr | fr | fr | fr | fr | fi | fi | fi | vfi |
| Texture | scl | sil | sil | sicl | sicl | sic | sic | sic | sic |
| Clay Films | n/a | n/a | n/a | n/a | n/a | 2dpf | 2dpf | 2dpf | 2dpf |
| Carbonate Stage | II | n/a | n/a | n/a | n/a | n/a | I+ | I+ | II |
| **QUANTIFIED SOIL FIELD PROPERTIES** | | | | | | | | | |
| Color Paling | | 10.00 | 10.00 | 10.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Melanization | | 60.00 | 50.00 | 60.00 | 60.00 | 40.00 | 40.00 | 40.00 | 20.00 |
| Texture | | 0.00 | 0.00 | 10.00 | 10.00 | 40.00 | 40.00 | 40.00 | 40.00 |
| Dry Consistence | | 10.00 | 10.00 | 0.00 | 0.00 | 0.00 | 0.00 | 10.00 | 10.00 |
| Moist Consistence | | 0.00 | 0.00 | 0.00 | 0.00 | 10.00 | 10.00 | 10.00 | 20.00 |
| Structure | | 30.00 | 45.00 | 35.00 | 35.00 | 50.00 | 55.00 | 40.00 | 40.00 |
| Clay Films | | 0.00 | 0.00 | 0.00 | 0.00 | 70.00 | 70.00 | 70.00 | 70.00 |
| Carbonate Stage | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **NORMALIZED VALUES FOR PROPERTIES** | | | | | | | | | |
| Color Paling | | 0.17 | 0.17 | 0.17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Melanization | | 0.71 | 0.59 | 0.71 | 0.71 | 0.47 | 0.47 | 0.47 | 0.24 |
| Texture | | 0.00 | 0.00 | 0.05 | 0.05 | 0.20 | 0.20 | 0.20 | 0.20 |
| Dry Consistence | | 0.10 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 0.10 |
| Moist Consistence | | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 0.10 | 0.10 | 0.20 |
| Structure | | 0.50 | 0.75 | 0.58 | 0.58 | 0.83 | 0.92 | 0.67 | 0.67 |
| Clay Films | | 0.00 | 0.00 | 0.00 | 0.00 | 0.78 | 0.78 | 0.78 | 0.78 |
| Carbonate Stage | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **INDEX RESULTS** | | | | | | | | | |
| Σ of Normalized Values | | 1.47 | 1.60 | 1.51 | 1.34 | 2.38 | 2.47 | 2.32 | 2.18 |
| ÷ by Number of Properties (8) | | 0.18 | 0.20 | 0.19 | 0.17 | 0.30 | 0.31 | 0.29 | 0.27 |
| × by Horizon Thickness | | 7.36 | 2.01 | 4.89 | 4.02 | 10.12 | 10.78 | 17.07 | 12.81 |
| Σ of Horizon Properties | **PDI** | 69.07 | | | | | | | |

** - No parent material recorded during investigation.  Parent material properties of MBC-3 used as proxy.  **-Core refused 6cm into Btk3b horizon. Estimated depth based on average of two overlying Btk horizons.*

**Table 16: Core 3 PDI calculations and values**

| | PM (Ck1) | Ap | A | Bt1 | Bt2 | Btk1 | Btk2 | BCk |
|---|---|---|---|---|---|---|---|---|
| **HORIZON PROPERTIES** | | | | | | | | |
| Horizon Thickness | | 25.00 | 19.00 | 22.00 | 34.00 | 21.00 | 32.00 | 37.00 |
| Color-Dry | 10YR7/2 | 10YR4/2 | 10YR4/3 | 10YR4/2 | 10YR4/3 | 10YR5/2 | 10YR7/2 | 10YR7/3 |
| Color-Moist | 10YR6/2 | 10YR3/2 | 10YR2/2 | 10YR3/2 | 10YR3/2 | 10YR4/1 | 10YR6/2 | 10YR5/3 |
| Structure | m | 2gr | 1sbk→2gr | 1pr→2sbk | 1pr→2sbk | 1pr→2sbk | 1pr→2sbk | 1sbk |
| Dry Consistence | h | sh | sh | sh | sh | sh | sh | sh |
| Moist Consistence | fr | vfr | vfr | fr | fr | fr | fr | fr |
| Texture | scl | sicl | sic | sic | sic | sic | sic | sicl |
| Clay Films | n/a | n/a | n/a | 3dpf | 3ppf | 2dpf | 2dpf | n/a |
| Carbonate Stage | II | n/a | n/a | n/a | n/a | II | I+ | I+ |
| **QUANTIFIED SOIL FIELD PROPERTIES** | | | | | | | | |
| Color Paling | | 0.00 | 0.00 | 0.00 | 0.00 | 10.00 | 0.00 | 0.00 |
| Melanization | | 60.00 | 70.00 | 60.00 | 60.00 | 40.00 | 0.00 | 10.00 |
| Texture | | 10.00 | 40.00 | 40.00 | 40.00 | 40.00 | 40.00 | 10.00 |
| Dry Consistence | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Moist Consistence | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Structure | | 30.00 | 35.00 | 45.00 | 45.00 | 45.00 | 45.00 | 20.00 |
| Clay Films | | 0.00 | 0.00 | 70.00 | 90.00 | 70.00 | 70.00 | 0.00 |
| Carbonate Stage | | 0.00 | 0.00 | 0.00 | 0.00 | 20.00 | 0.00 | 0.00 |
| **NORMALIZED VALUES FOR PROPERTIES** | | | | | | | | |
| Color Paling | | 0.00 | 0.00 | 0.00 | 0.00 | 0.17 | 0.00 | 0.00 |
| Melanization | | 0.71 | 0.82 | 0.71 | 0.71 | 0.47 | 0.00 | 0.12 |
| Texture | | 0.05 | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 | 0.05 |
| Dry Consistence | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Moist Consistence | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Structure | | 0.50 | 0.58 | 0.75 | 0.75 | 0.75 | 0.75 | 0.33 |
| Clay Films | | 0.00 | 0.00 | 0.78 | 1.00 | 0.78 | 0.78 | 0.00 |
| Carbonate Stage | | 0.00 | 0.00 | 0.00 | 0.00 | 0.17 | 0.00 | 0.00 |
| **INDEX RESULTS** | | | | | | | | |
| Σ of Normalized Values | | 1.26 | 1.61 | 2.43 | 2.66 | 2.53 | 1.73 | 0.50 |
| ÷ by Number of Properties (8) | | 0.16 | 0.20 | 0.30 | 0.33 | 0.32 | 0.22 | 0.06 |
| × by Horizon Thickness | | 3.92 | 3.82 | 6.69 | 11.29 | 6.65 | 6.91 | 2.32 |
| Σ of Horizon Properties | **PDI** | 41.59 | | | | | | |

Table 17: Core 4 PDI calculations and values

| | PM (Ckb1) | A | Bw | Ab1 | Btkb1 | Bkb1 | BCkb1 | CBkb1 |
|---|---|---|---|---|---|---|---|---|
| **HORIZON PROPERTIES** | | | | | | | | |
| Horizon Thickness | | 31.00 | 31.00 | 19.00 | 12.00 | 15.00 | 17.00 | 14.00 |
| Color-Dry | 10YR6/4 | 10YR4/3 | 10YR4/2 | 10YR6/3 | 10YR6/2 | 10YR6/2 | 10YR6/2 | 10YR7/3 |
| Color-Moist | 10YR5/3 | 10YR3/1 | 10YR3/1 | 10YR4/1 | 10YR4/2 | 10YR5/2 | 10YR4/2 | 10YR5/3 |
| Structure | m | 2gr | 1pr→1sbk | 1sbk→2gr | 1pr→1sbk | 1pr→1sbk | 1pr | .5sbk |
| Dry Consistence | h | sh | sh | sh | sh | sh | sh | sh |
| Moist Consistence | fr | fr | fr | fr | fr | fr | fr | fr |
| Texture | sl | sl | sicl | sicl | sic | sicl | scl | scl |
| Clay Films | n/a | n/a | n/a | n/a | 2dpf | n/a | n/a | n/a |
| Carbonate Stage | I | n/a | n/a | n/a | I+ | II | I | I |
| **QUANTIFIED SOIL FIELD PROPERTIES** | | | | | | | | |
| Color Paling | | 30.00 | 40.00 | 30.00 | 30.00 | 30.00 | 30.00 | 10.00 |
| Melanization | | 40.00 | 40.00 | 10.00 | 10.00 | 0.00 | 10.00 | 0.00 |
| Texture | | 0.00 | 40.00 | 40.00 | 70.00 | 40.00 | 30.00 | 30.00 |
| Dry Consistence | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Moist Consistence | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Structure | | 30.00 | 40.00 | 45.00 | 40.00 | 40.00 | 30.00 | 15.00 |
| Clay Films | | 0.00 | 0.00 | 0.00 | 70.00 | 0.00 | 0.00 | 0.00 |
| Carbonate Stage | | 0.00 | 0.00 | 0.00 | 45.00 | 60.00 | 30.00 | 10.00 |
| **NORMALIZED VALUES FOR PROPERTIES** | | | | | | | | |
| Color Paling | | 0.50 | 0.67 | 0.50 | 0.50 | 0.50 | 0.50 | 0.17 |
| Melanization | | 0.47 | 0.47 | 0.12 | 0.12 | 0.00 | 0.12 | 0.00 |
| Texture | | 0.00 | 0.20 | 0.20 | 0.35 | 0.20 | 0.15 | 0.15 |
| Dry Consistence | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Moist Consistence | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Structure | | 0.50 | 0.67 | 0.75 | 0.67 | 0.67 | 0.50 | 0.25 |
| Clay Films | | 0.00 | 0.00 | 0.00 | 0.78 | 0.00 | 0.00 | 0.00 |
| Carbonate Stage | | 0.00 | 0.00 | 0.00 | 0.38 | 0.50 | 0.25 | 0.08 |
| **INDEX RESULTS** | | | | | | | | |
| Σ of Normalized Values | | 1.47 | 2.00 | 1.57 | 2.79 | 1.87 | 1.52 | 0.65 |
| ÷ by Number of Properties (8) | | 0.18 | 0.25 | 0.20 | 0.35 | 0.23 | 0.19 | 0.08 |
| × by Horizon Thickness | | 5.70 | 7.77 | 3.72 | 4.18 | 3.50 | 3.23 | 1.14 |
| Σ of Horizon Properties | **PDI** | 29.23 | | | | | | |

**Table 18: Cutbank 5 and Core 5 PDI calculations and values**

| | PM (Ck1b2) | A | Bw | Bt | Btk | Atkb1 | Bkb1 | BCkb1 | CBkb1 |
|---|---|---|---|---|---|---|---|---|---|
| **HORIZON PROPERTIES** | | | | | | | | | |
| Horizon Thickness | | 24.00 | 27.00 | 22.00 | 31.00 | 35.00 | 18.00 | 48.00 | 18.00 |
| Color-Dry | 10YR7/2 | 10YR4/3 | 10YR5/3 | 10YR5/3 | 10YR5/2 | 10YR6/3 | 10YR5/3 | 10YR6/4 | 10YR6/3 |
| Color-Moist | 10YR4/2 | 10YR3/2 | 10YR4/2 | 10YR4/2 | 10YR4/3 | 10YR4/3 | 10YR4/3 | 10YR5/4 | 10YR4/3 |
| Structure | m | 1gr | 1sbk | 1pr→1sbk | 2pr→2sbk | 1pr→1gr | 1sbk | .5sbk | .5sbk |
| Dry Consistence | vh | h | h | sh | sh | h | h | h | h |
| Moist Consistence | fr | fr | fr | fr | fr | fr | vfr | vfr | fr |
| Texture | l | scl | scl | sicl | sicl | sicl | sicl | scl | sl |
| Clay Films | n/a | n/a | n/a | 2dpf | 2dpf | 2dpf | n/a | n/a | n/a |
| Carbonate Stage | I+ | n/a | n/a | n/a | I+ | I+ | I | I | I+ |
| **QUANTIFIED SOIL FIELD PROPERTIES** | | | | | | | | | |
| Color Paling | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Melanization | | 40.00 | 20.00 | 20.00 | 20.00 | 10.00 | 20.00 | 10.00 | 10.00 |
| Texture | | 20.00 | 20.00 | 30.00 | 30.00 | 30.00 | 30.00 | 20.00 | 0.00 |
| Dry Consistence | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Moist Consistence | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Structure | | 20.00 | 20.00 | 40.00 | 55.00 | 40.00 | 20.00 | 15.00 | 15.00 |
| Clay Films | | 0.00 | 0.00 | 70.00 | 70.00 | 70.00 | 0.00 | 0.00 | 0.00 |
| Carbonate Stage | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **NORMALIZED VALUES FOR PROPERTIES** | | | | | | | | | |
| Color Paling | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Melanization | | 0.47 | 0.24 | 0.24 | 0.24 | 0.12 | 0.24 | 0.12 | 0.12 |
| Texture | | 0.10 | 0.10 | 0.15 | 0.15 | 0.15 | 0.15 | 0.10 | 0.00 |
| Dry Consistence | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Moist Consistence | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Structure | | 0.33 | 0.33 | 0.67 | 0.92 | 0.67 | 0.33 | 0.25 | 0.25 |
| Clay Films | | 0.00 | 0.00 | 0.78 | 0.78 | 0.78 | 0.00 | 0.00 | 0.00 |
| Carbonate Stage | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **INDEX RESULTS** | | | | | | | | | |
| Σ of Normalized Values | | 0.90 | 0.67 | 1.83 | 2.08 | 1.71 | 0.72 | 0.47 | 0.37 |
| ÷ by Number of Properties (8) | | 0.11 | 0.08 | 0.23 | 0.26 | 0.21 | 0.09 | 0.06 | 0.05 |
| × by Horizon Thickness | | 2.71 | 2.26 | 5.03 | 8.06 | 7.49 | 1.62 | 2.81 | 0.83 |
| Σ of Horizon Properties | **PDI** | 30.80 | | | | | | | |

**Table 19: Core 6-1 PDI calculations and values**

| | PM (C1b) | A | Bw | Ab | ACb |
|---|---|---|---|---|---|
| **HORIZON PROPERTIES** | | | | | |
| Horizon Thickness | | 21.00 | 26.00 | 24.00 | 12.00 |
| Color-Dry | 10YR6/2 | 10YR4/3 | 10YR5/3 | 10YR4/2 | 10YR5/2 |
| Color-Moist | 10YR4/1 | 10YR3/2 | 10YR3/1 | 10YR3/1 | 10YR4/2 |
| Structure | m | 2gr | 1pr→1sbk | 1sbk→1gr | .5sbk |
| Dry Consistence | sh | sh | so | so | so |
| Moist Consistence | vfr | vfr | fr | fr | fr |
| Texture | ls | sl | scl | sl | ls |
| Clay Films | n/a | n/a | n/a | n/a | n/a |
| Carbonate Stage | n/a | n/a | n/a | n/a | n/a |
| **QUANTIFIED SOIL FIELD PROPERTIES** | | | | | |
| Color Paling | | 0.00 | 0.00 | 0.00 | 0.00 |
| Melanization | | 0.00 | 0.00 | 0.00 | 0.00 |
| Texture | | 10.00 | 40.00 | 10.00 | 0.00 |
| Dry Consistence | | 0.00 | 0.00 | 0.00 | 0.00 |
| Moist Consistence | | 0.00 | 10.00 | 10.00 | 10.00 |
| Structure | | 30.00 | 40.00 | 30.00 | 15.00 |
| Clay Films | | 0.00 | 0.00 | 0.00 | 0.00 |
| Carbonate Stage | | 0.00 | 0.00 | 0.00 | 0.00 |
| **NORMALIZED VALUES FOR PROPERTIES** | | | | | |
| Color Paling | | 0.00 | 0.00 | 0.00 | 0.00 |
| Melanization | | 0.00 | 0.00 | 0.00 | 0.00 |
| Texture | | 0.05 | 0.20 | 0.05 | 0.00 |
| Dry Consistence | | 0.00 | 0.00 | 0.00 | 0.00 |
| Moist Consistence | | 0.00 | 0.10 | 0.10 | 0.10 |
| Structure | | 0.50 | 0.67 | 0.50 | 0.25 |
| Clay Films | | 0.00 | 0.00 | 0.00 | 0.00 |
| Carbonate Stage | | 0.00 | 0.00 | 0.00 | 0.00 |
| **INDEX RESULTS** | | | | | |
| Σ of Normalized Values | | 0.55 | 0.97 | 0.65 | 0.35 |
| ÷ by Number of Properties (8) | | 0.07 | 0.12 | 0.08 | 0.04 |
| × by Horizon Thickness | | 1.44 | 3.14 | 1.95 | 0.53 |
| Σ of Horizon Properties | **PDI** | 7.06 | | | |

**Table 20: Cutbank 6-2 PDI calculations and values**

| | PM (Ckb) | A | AB | Bw | Bk1 | Bk2 | Akb | Bkb | BCkb |
|---|---|---|---|---|---|---|---|---|---|
| **HORIZON PROPERTIES** | | | | | | | | | |
| Horizon Thickness (cm) | | 27.00 | 15.00 | 18.00 | 20.00 | 20.00 | 40.00 | 15.00 | 30.00 |
| Color-Dry | 10YR6/3 | 10YR4/2 | 10YR4/2 | 10YR5/2 | 10YR5/3 | 10YR5/3 | 10YR5/2 | 10YR6/3 | 10YR6/3 |
| Color-Moist | 10YR4/3 | 10YR3/2 | 10YR2/1 | 10YR3/3 | 10YR4/3 | 10YR4/3 | 10YR3/2 | 10YR4/4 | 10YR4/3 |
| Structure | m | 1gr | .5sbk→1gr | 1sbk | 1pr→1sbk | 2pr→2sbk | 1pr→2gr | 2pr | 1pr→.5sbk |
| Dry Consistence | h | h | h | h | h | vh | h | h | h |
| Moist Consistence | vfi | fr | fr | fr | fr | fr | vfi | vfi | vfi |
| Texture | sil | l | l | sil | sil | sicl | sicl | sil | sil |
| Clay Films | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| Carbonate Stage | I+ | n/a | n/a | n/a | I+ | I+ | I+ | I+ | I+ |
| **QUANTIFIED SOIL FIELD PROPERTIES** | | | | | | | | | |
| Color Paling | | 20.00 | 30.00 | 10.00 | 0.00 | 0.00 | 20.00 | 0.00 | 0.00 |
| Melanization | | 30.00 | 40.00 | 20.00 | 10.00 | 10.00 | 20.00 | 0.00 | 0.00 |
| Texture | | 10.00 | 10.00 | 0.00 | 0.00 | 40.00 | 40.00 | 0.00 | 0.00 |
| Dry Consistence | | 0.00 | 0.00 | 0.00 | 0.00 | 10.00 | 0.00 | 0.00 | 0.00 |
| Moist Consistence | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Structure | | 20.00 | 25.00 | 20.00 | 40.00 | 55.00 | 45.00 | 40.00 | 37.50 |
| Clay Films | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Carbonate Stage | | 0.00 | 0.00 | 0.00 | 15.00 | 15.00 | 30.00 | 0.00 | 0.00 |
| **NORMALIZED VALUES FOR PROPERTIES** | | | | | | | | | |
| Color Paling | | 0.33 | 0.50 | 0.17 | 0.00 | 0.00 | 0.33 | 0.00 | 0.00 |
| Melanization | | 0.35 | 0.47 | 0.24 | 0.12 | 0.12 | 0.24 | 0.00 | 0.00 |
| Texture | | 0.05 | 0.05 | 0.00 | 0.00 | 0.20 | 0.20 | 0.00 | 0.00 |
| Dry Consistence | | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 0.00 | 0.00 | 0.00 |
| Moist Consistence | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Structure | | 0.33 | 0.42 | 0.33 | 0.67 | 0.92 | 0.75 | 0.67 | 0.63 |
| Clay Films | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Carbonate Stage | | 0.00 | 0.00 | 0.00 | 0.13 | 0.13 | 0.25 | 0.00 | 0.00 |
| **INDEX RESULTS** | | | | | | | | | |
| Σ of Normalized Values | | 1.07 | 1.44 | 0.74 | 0.91 | 1.46 | 1.77 | 0.67 | 0.63 |
| ÷ by Number of Properties (8) | | 0.13 | 0.18 | 0.09 | 0.11 | 0.18 | 0.22 | 0.08 | 0.08 |
| × by Horizon Thickness | | 3.61 | 2.69 | 1.65 | 2.27 | 3.65 | 8.84 | 1.25 | 2.34 |
| Σ of Horizon Properties | **PDI** | 26.32 | | | | | | | |

**Table 21: Site 14SN101 PDI calculations and values**

| | PM (Ck*) | A | Bw | Btk | Akb1 | Bkb1 | Akb2 | Bk1b2 | Bk2b2 |
|---|---|---|---|---|---|---|---|---|---|
| **HORIZON PROPERTIES** | | | | | | | | | |
| Horizon Thickness | | 30.00 | 13.00 | 17.00 | 25.00 | 40.00 | 30.00 | 45.00 | 50.00 |
| Color-Dry | 10YR7/2 | 10YR4/2 | 10YR4/3 | 10YR5/3 | 10YR4/3 | 10YR5/3 | 10YR4/2 | 10YR5/3 | 10YR6/3 |
| Color-Moist | 10YR6/2 | 10YR3/2 | 10YR3/3 | 10YR4/3 | 10YR3/3 | 10YR4/3 | 10YR3/2 | 10YR4/3 | 10YR5/3 |
| Structure | m | 1gr | 1sbk | 1sbk | 1sbk | 1sbk | 1gr | 1pr→1sbk | 1pr→1sbk |
| Dry Consistence | h | sh | sh | sh | sh | sh | sh | sh | sh |
| Moist Consistence | fr | fr | fr | fr | fr | fr | fr | fr | fr |
| Texture | scl | sil | sil | sicl | sil | sil | sil | sil | sil |
| Clay Films | n/a | n/a | n/a | 1fpf | n/a | n/a | n/a | n/a | n/a |
| Carbonate Stage | II | n/a | n/a | I+ | I+ | I+ | I+ | I+ | I+ |
| **QUANTIFIED SOIL FIELD PROPERTIES** | | | | | | | | | |
| Color Paling | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Melanization | | 60.00 | 60.00 | 40.00 | 60.00 | 40.00 | 60.00 | 40.00 | 20.00 |
| Texture | | 0.00 | 0.00 | 10.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Dry Consistence | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Moist Consistence | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Structure | | 20.00 | 20.00 | 20.00 | 20.00 | 20.00 | 20.00 | 40.00 | 40.00 |
| Clay Films | | 0.00 | 0.00 | 50.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Carbonate Stage | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **NORMALIZED VALUES FOR PROPERTIES** | | | | | | | | | |
| Color Paling | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Melanization | | 0.71 | 0.71 | 0.47 | 0.71 | 0.47 | 0.71 | 0.47 | 0.24 |
| Texture | | 0.00 | 0.00 | 0.05 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Dry Consistence | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Moist Consistence | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Structure | | 0.33 | 0.33 | 0.33 | 0.33 | 0.33 | 0.33 | 0.67 | 0.67 |
| Clay Films | | 0.00 | 0.00 | 0.56 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Carbonate Stage | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **INDEX RESULTS** | | | | | | | | | |
| Σ of Normalized Values | | 1.04 | 1.04 | 1.41 | 1.04 | 0.80 | 1.04 | 1.14 | 0.90 |
| ÷ by Number of Properties (8) | | 0.13 | 0.13 | 0.18 | 0.13 | 0.10 | 0.13 | 0.14 | 0.11 |
| × by Horizon Thickness | | 3.90 | 1.69 | 3.00 | 3.25 | 4.02 | 3.90 | 6.40 | 5.64 |
| Σ of Horizon Properties | **PDI** | 31.78 | | | | | | | |

* - No parent material recorded during investigation.  Parent material properties of MBC-3 used as proxy.