TR 88 Kuehn Preliminary Geoarcheological Reconnaissance in Badlands National Park, South Dakota 2003

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National Park Service - Midwest Archeological Center

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By

David D. Kuehn

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This report has been reviewed against the criteria contained in 43CFR Part 7, Subpart A, Section 7.18 (a) (1) and, upon recommendation of the Midwest Regional Office and the Midwest Archeological Center, has been classified as

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Making the report available meets the criteria of 43CFR Part 7, Subpart A, Section 7.18 (a) (1).

Abstract

Preliminary geoarcheological investigations were conducted in Badlands National Park, South Dakota, in August of 1997. The purpose of the research was to establish an initial stratigraphic and geomorphic context for archeological materials within the park. This was accomplished by large-scale surface reconnaissance and intensive data collection at a number of representative study sections. The reconnaissance focused on identifying major geomorphic landsurfaces extant in the park area. These include: the Upper Prairie surface and Badlands Wall; the Lower Prairie surface and Sage Creek Basin; Pleistocene (?) Cheyenne River Terraces; and the early Pleistocene/late Tertiary (?) surface. Individual study sections were located at representative examples of late Pleistocene and Holocene sedimentary depositional environments within each of the various landsurfaces. These included sod tables, which are eroded and often isolated bodies of reworked alluvial and colluvial sediments, alluvial lag deposits, eolian loess mantles, alluvial terraces, and alluvial fans. A preliminary geochronologic framework for the various depositional environments was provided by the procurement of conventional and AMS radiocarbon age determinations. These data, along with temporal/spatial information obtained from existing archeological site records, were used to develop general predictive statements about archeological and geological relationships in the park area.

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Introduction

Long known for its scenic beauty, unique geology, and dynamic cultural history, Badlands National Park, South Dakota (Figure 1), is indeed an icon among important place names in the American West. While its scientific and cultural and historical importance is widely recognized, the management of park resources has been made difficult by a paucity of large-scale sponsored research, particularly research which integrates elements of the social sciences with those of the earth sciences. Fortunately this has started to change as federal agencies, legislators, and academicians have begun to recognize the growing need for interdisciplinary collaboration in the management of public lands.

Whether it be wildlife biology, paleontology, or cultural resources, interdisciplinary research has become an important tool for state and federal managers. Within the realm of cultural resource management (CRM), such research now includes input from archeologists, cultural anthropologists, historians, architects, and Native Americans. Of particular usefulness to day to day CRM management has been the growth of geoarcheology, or the application of geoscience methods to the study of archeological questions (cf. Butzer 1982). This usefulness stems from geoarcheology's ability to provide a temporal framework for prehistoric cultural resources and from its ability to aid in the prediction of where cultural remains from various time periods are likely to be found. As a result, federal and state agencies are increasingly calling for sponsored geoarcheological investigations prior to the implementation of large-scale archeological field efforts. The following report presents one example of this growing trend in contemporary CRM by summarizing the results of reconnaissance-level geoarcheological investigations in Badlands National Park. The investigations were conducted by the author during the period of August 8 through August 24, 1997.

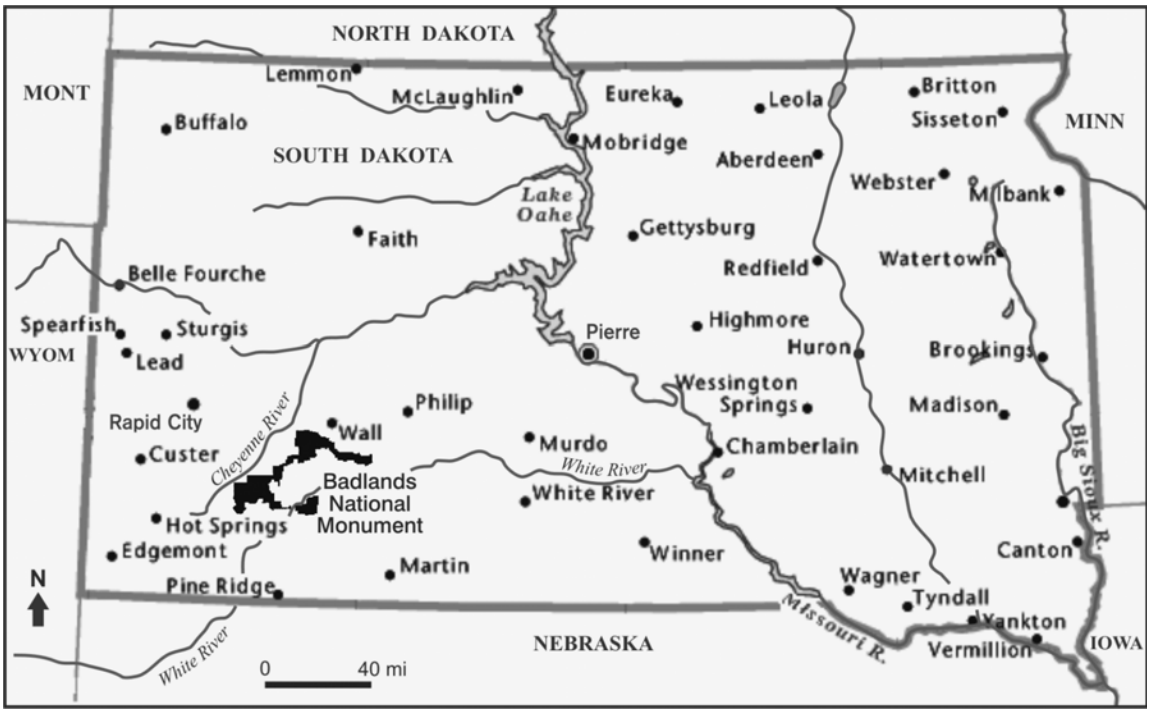

Figure 1. South Dakota, the surrounding area, and the location of Badlands National Park.

Theoretical Background and Project Research Goals

Archeological and geoscience research has been conducted in Badlands National Park and adjacent portions of the White River Badlands since before the turn of the century (Leady 1869; Sheldon 1905; O'Harra 1920; MacClintock et al. 1936, from Nowak and Hannus 1984; Benton and Force 1996; Jones 1993). Because of these efforts, a great deal is known about the bedrock geology, paleontology, and general cultural chronology of the badlands region (Figure 1). In addition, the badlands have been the object of several pioneering studies in geomorphology, particularly studies involving hillslope processes, the evolution of drainage systems, landscape erosion, sediment yield, and equilibrium theory (Churchill 1981; Schumm 1956, 1962; Smith 1958). These have led to the development of some of the more important large-scale models in 20th-century geomorphology (Langbein and Schumm 1958; Schumm 1973, 1977; Schumm and Brakenridge 1987; Strahler 1956). The view that badland landscapes could be viewed as analogues to larger geomorphic systems centered on the belief that badlands were microcosms for a variety of continental landform processes, particularly those involving hillslopes and fluvial systems. As discussed by Bryan and Yair (1982:4), this approach was based on four principal assumptions:

(1) That badland processes are extremely rapid;
(2) That landforms in badlands are analogous to major fluvial landforms in arid and semi-arid climates;
(3) That badland parent materials are weakly cemented yet highly impermeable — factors resulting in the predominance of overland flow as the primary medium of sediment transport; and
(4) That badland processes are simplistic and easily studied.

Although these assumptions are still valid in many respects, more recent studies indicate that badlands are subject to a much higher degree of spatial, temporal, lithological, and processual complexity than was previously recognized (Bryan and Yair 1982:4; Campbell 1982, 1989; Campbell and Honsaker 1982; Stocking 1984). For example, not all badlands are located in areas with arid or semi-arid climates (cf. Lamb 1977; Loffler 1974); erosion rates in badland settings are not always extremely rapid (Yair et al. 1982; Wise et al. 1982); and badland parent materials are not universally impermeable, and therefore, sediment transport is not always dominated by overland flow (Yair et al. 1982). Consequently, badland researchers soon began to develop more integrated theories, theories which combined factors such as spatial/temporal variation, energy transfer, and quantitative process analysis techniques with more traditional concepts of threshold and equilibrium (Graf 1983). Paradigmatic outgrowths of more integrated approaches to the study of badland geomorphology have included elements of catastrophe theory (Graf 1979, 1983; Thornes 1980); long-term landscape evolution, which incorporates the analysis of regional trends, the interpretation of stratigraphic relationships, and the dating of lithostratigraphic units (Bryan et al. 1987; Wells and Gutierrez 1982; Wise et al. 1982); and geomorphic systems theory, which concentrates on the relationships between matter, energy, climate, sediment yield, and equilibrium (Bull 1979; Knighton 1984; Knox 1972; Schumm 1973; Kowal 1997).

Like geomorphology, archeology has also witnessed a multitude of paradigmatic approaches in recent decades, approaches which have also influenced the way archeologists conduct research in highly dynamic environments. These various paradigms include processual, post-processual, neo-evolutionary, neo-historical, contextual, and relativistic perspectives (Trigger 1989). While key elements of processual (cf. Binford 1962, 1965, 1972) and post-processual (cf. Hodder 1982, 1985) archeology are still widely integrated into the drawing of archeological inference (and appropriately so), perhaps the fastest-growing paradigm in contemporary American archeology is the contextual approach, originally named and defined by Butzer (1980, 1982) and Schoenwetter (1981), but which actually emerged out of an amalgamation of the increasing number of interdisciplinary/earth science approaches being applied to archeology (cf. Davidson and Shackley 1976; Gladfelter 1977; Hassan 1979). Since then, contextual archeology has been expanded, redefined, and broadly integrated into the archeological mainstream (cf. Bettis 1995; Holliday 1989; Lasca and Donahue 1990; Rapp and Gifford 1985; Stein and Farrand 1985; Waters 1992).

Contextual archeology, the major theoretical foundation for the present research effort, focuses on the temporal, landscape, stratigraphic, and paleoenvironmental contexts of the archeological record, and

on the various processes of site formation and site modification (Butzer 1982; Hassan 1979; Waters 1992; Stein and Farrand 1985). The contextual approach is by necessity highly interdisciplinary, systemic, and paleoecological in nature. One of its major constituents, along with archeometry, radiometric dating, zooarcheology, and archeobotany, is geoarcheology, which, as stated earlier, involves the application of earth science techniques to the study of archeological questions.

The geoarcheological investigations conducted in Badlands National Park represent an integration of methods and concepts borrowed from geomorphology, stratigraphy, sedimentology, and pedology. The recovered data were subsequently interpreted within the context of the known archeological record; that is, the record as represented by site forms and reports on file at Badlands National Park and at the Midwest Archeological Center, and as summarized in Hannus et al. (2002). The preliminary conclusions drawn from these investigations are based on a number of assumptions that are integral to contextual archeology in general, and to geoarcheology in particular.

These assumptions, which are by no means new to archeologists, are as follows: (1) extant archeological sites, particularly those associated with prehistoric hunter-gatherers, consist of material remains that are not static after they are discarded, but are instead part of a highly dynamic natural environment (Butzer 1982; Schiffer 1987; Wood and Johnson 1978); (2) as such, the spatial, temporal, and material distribution of these sites rarely retain or reflect the entire range of their original behavioral context (Schiffer 1987); (3) most sites therefore require an understanding and reconstruction of site formation processes before the drawing of meaningful archeological inferences may be undertaken (Schiffer 1987; Waters 1992); (4) formation processes can impact the archeological record at both the intra-site and inter-site levels; (5) at both levels, the preservation and completeness of the buried archeological record has a tendency to parallel the preservation and completeness of the associated sedimentological record (Waters 1992; Waters and Kuehn 1996); (6) of the myriad processes and agents active in archeological site formation, none are as spatially widespread or as potentially damaging to the drawing of archeological hypotheses as are large-scale changes in landscape (Waters and Kuehn 1996); (7) while landscape change can, and does, occur under most climatic and geomorphic regimes, some of the more severe consequences take place in highly dynamic erosional settings such as those found in naturally occurring badlands; and finally (8) the types and scale of geologic/geomorphic processes operating in badland settings are significant to the point of hindering, or even precluding, the development of testable hypotheses about such basic archeological research topics as local and regional cultural chronology, settlement patterns, seasonal land-use, and subsistence behavior (Kuehn 1995, 1997; Waters and Kuehn 1996).

It is these basic assumptions that created the need for preliminary geoarcheological investigations in Badlands National Park. The resultant investigations, albeit limited in scope and tentative in their conclusions, were conducted for the specific purpose of aiding in the development of a research design for a multi-year archeological inventory of portions of the park, scheduled to begin in the spring and summer of 1998. Based partially on the results of geoarcheological investigations recently conducted in the Little Missouri Badlands of North Dakota (Kuehn 1995), but also on archeologically relevant earth science research conducted in other portions of the Northern Plains (cf. Albanese 1978; Albanese and Frison 1995; Eckerle and Aaberg 1990; Fredlund 1996; Hannus 1990), the goals of the project are simple: (1) to identify, in a preliminary and highly generalized fashion, those landforms and depositional sedimentary environments within Badlands National Park that have the potential to contain buried, intact, prehistoric cultural resources; (2) to provide archeologists with information regarding the temporal distribution of sites within these landforms and their potential integrity; and (3) to identify some of the more relevant archeological research questions that are likely to have been impacted or made problematic by the geomorphic/pedologic history of the region. These goals were addressed by consulting the available archeological and geological literature and by examining the stratigraphic and pedologic composition of sediments at a number of key study sections in the park.

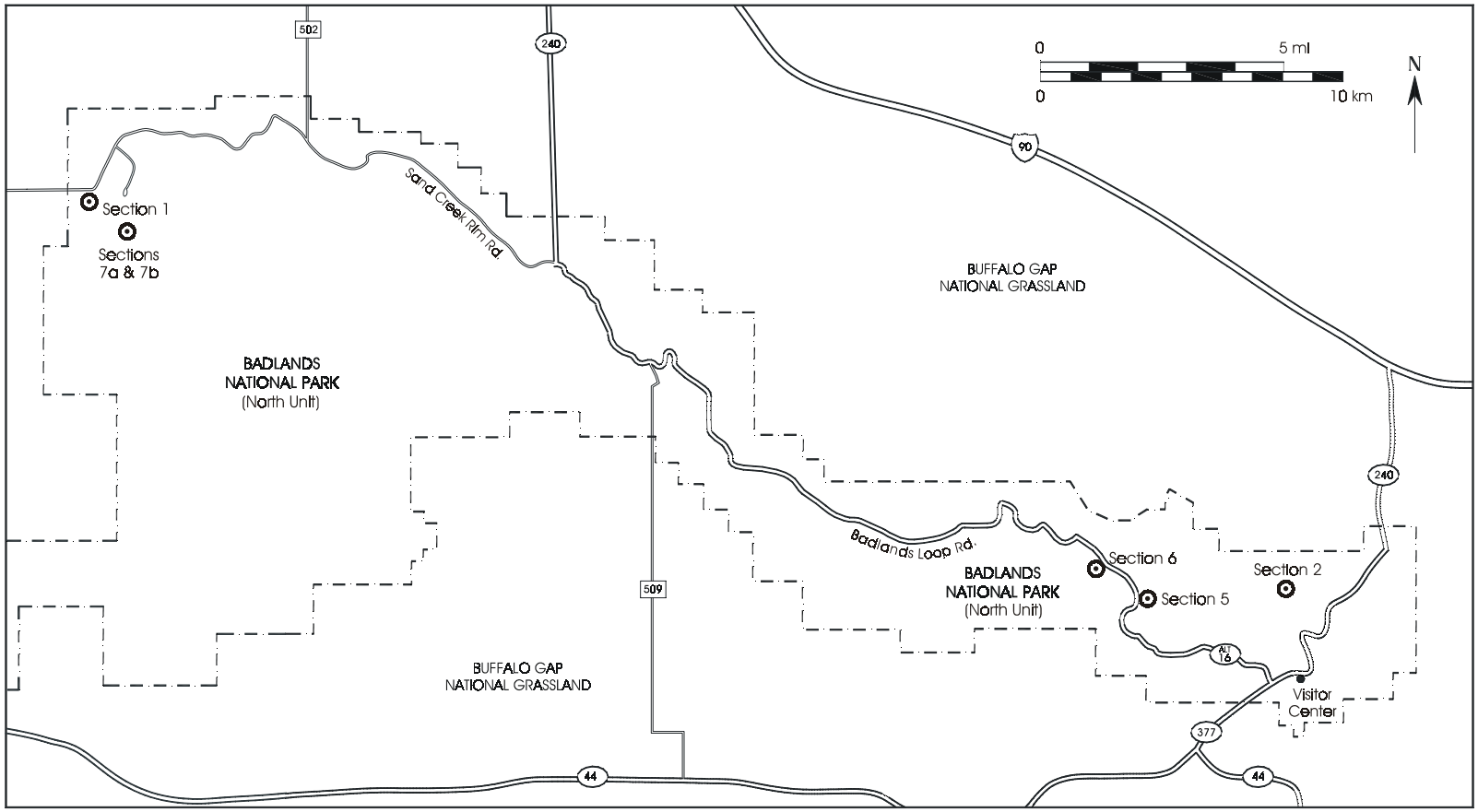

Figure 2. Badlands National Park, North Unit, and the locations of stratigraphic study sections.

Natural, Physiographic, and Geologic Setting

With the current research emphasis on late Quaternary stratigraphy, geomorphology, and natural site formation, it is necessary to first look at certain aspects of the natural environmental and geologic setting of Badlands National Park. We begin with physiography and topography and then turn to bedrock geology and climate.

Physiography and Surface Topography

Like most of western South Dakota, the White River Badlands are located within the Unglaciated Missouri Plateau section of the Great Plains physiographic province (Fenneman 1931). The badlands are situated some 75 to 150 km east of the prominent Black Hills section, a striking product of structural uplifting that began during the early Tertiary soon after the retreat of an inland sea that covered most of the Great Plains until the end of the Cretaceous Period (Darton and Paige 1925; Trimble 1980).

Badlands National Park, comprising some 985 km² (244,000 acres), is divided into a North Unit and a South Unit (Figures 2 and 3). The investigations were concentrated primarily in the North Unit, but some data were collected from the South Unit as well. Most of the park is bordered by the Cheyenne River on the north and the White River on the south. Both are important perennial streams that trend east and are part of the extensive Missouri River drainage system (Figure 1).

Typical of most naturally occurring badlands, those in southwestern South Dakota represent a highly dissected landscape dominated by prominent escarpments; steep, poorly vegetated and often heavily rilled slopes; erosional remnants (i.e., buttes, ridges, inselbergs); headward eroding gullies; piping; high drainage densities; V-shaped valleys; miniature pediments; and substantial amounts of reworked clastic and pyroclastic sediments (Bryan and Yair 1982; Campbell 1989; Schumm 1962; Smith 1958).

Unlike the Little Missouri Badlands in North Dakota, the White River Badlands have been significantly affected by structural activity traditionally thought to be associated with uplift and other tectonic developments in the nearby Black Hills and Rocky Mountains (Clark et al. 1967). Badlands National Park itself contains a well-documented series of parallel linear faults, some of which can be clearly seen along the Loop Road in the North Unit (Clark et al. 1967; R. Benton, personal communication 1997). At present, little is known about the timing and extent of structural activity in the badlands during the late Pleistocene and Holocene.

Having a high degree of topographic variability, the White River Badlands stand in stark contrast to the relatively featureless mixed grass prairie of the Unglaciated Missouri Plateau. This relief is the product of a complex history of Quaternary erosional processes acting on a number of former surfaces. Remnants of these surfaces are clearly visible in the park today and have been described and summarized by a variety of researchers (Ward 1922; Warren 1952; White 1982). The highest surfaces predate the actual formation of the badlands, while others represent strath terraces created when the White and Cheyenne Rivers experienced a series of downcutting episodes during the Pleistocene (White 1982; White and Hannus 1985). It is the latter, and the myriad alluvial and colluvial adjustments that followed, that created the present topography of the badlands. Variables identified as responsible for the downcutting episodes include: (1) glacial alteration of the Missouri River; (2) epeirogeny; and (3) climate change (Warren 1952; White 1982; Stanley and Wayne 1972; White and Hannus 1985).

Concerning former surfaces, White (1982) argues that at least three such downcutting events took place during the Pleistocene, most likely initiated during the Illinoian glacial period but perhaps as recently as the early Wisconsin (circa 100,000 yr BP). Along the middle and lower reaches of the White River, each of these events is represented by a strath terrace, the elevations of which (from oldest to youngest) are 107 m, 91 m, and 61 m above the current channel floor (White 1982:47). The vertical distance between the terraces and the modern river channel decrease progressively upstream (White 1982). In the upper (i.e., westernmost) reaches of the drainage basin, which White did not thoroughly study, the terraces also become less vertically distinct and might actually merge (White 1982:48–49).

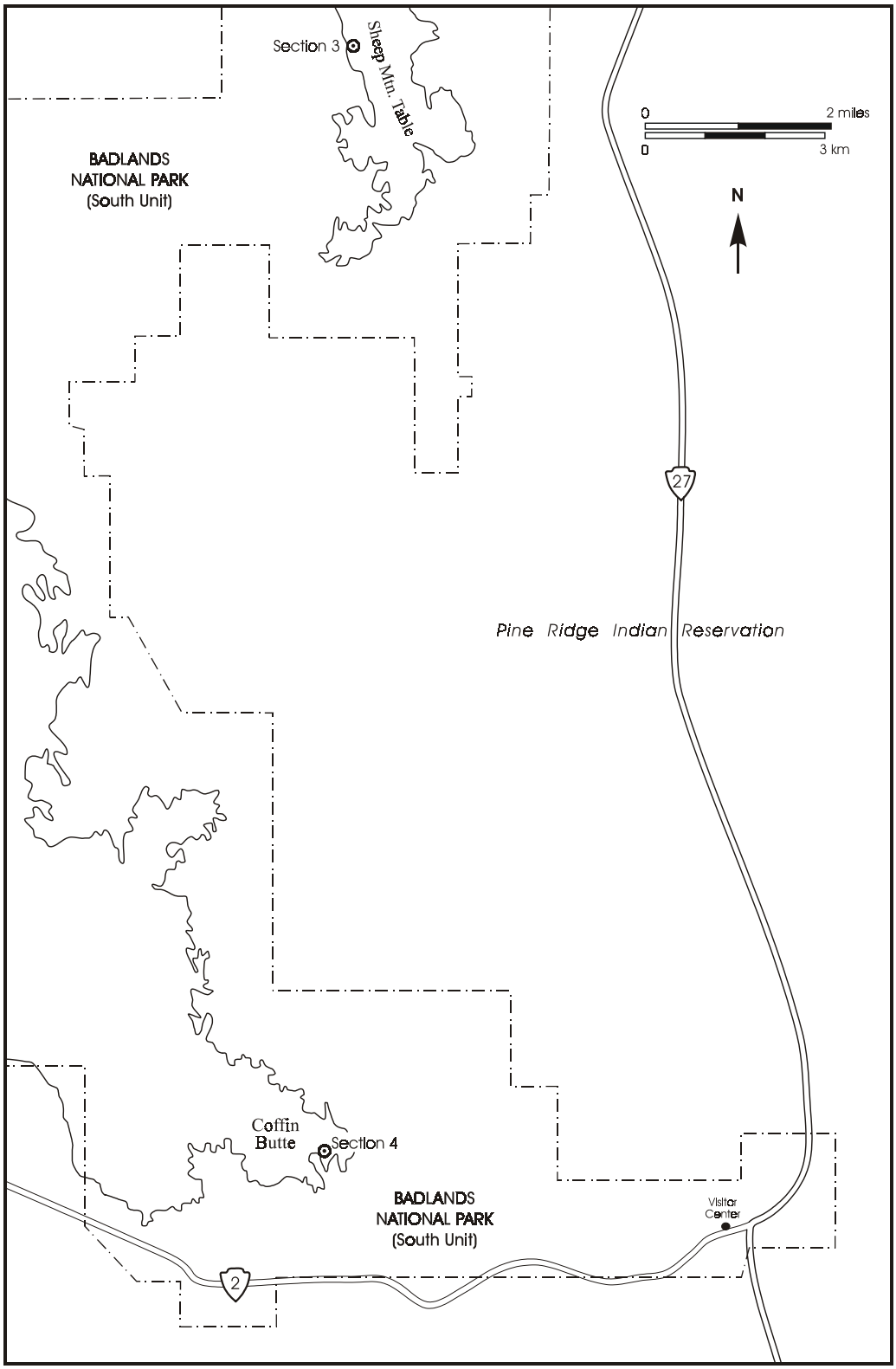

Figure 3. Badlands National Park, South Unit, and the locations of stratigraphic study sections.

In an earlier study, Ward (1922) identified four parallel surfaces in the White River Badlands. These were referred to as the Upper Prairie surface, the Lower Prairie surface, the Badlands Wall, and the modern White River floodplain. White (1982), recognizing the difficulties and ambiguities associated with changing structural, geomorphic, and lithological conditions along the course of the stream, did not correlate the three-terrace sequence identified in the middle and lower reaches with Ward's surfaces in the badlands. He did, however, mention the possibility that the Upper Prairie surface may have graded to the higher 107 m terrace (White 1982:49). He also continued to utilize the concept of Upper and Lower Prairie surfaces during the course of subsequent research in the badlands (White and Hannus 1985). This report will do likewise, but will also examine in some detail a number of even higher and older surfaces.

The Upper Prairie surface has been described as a Pleistocene erosional plain associated with the ancestral White River (Ward 1922; Churchill 1981; White and Hannus 1985). In a stylized map of the northeastern portion of the North Unit, Churchill (1981:Figure 1) labels the Upper Prairie as that portion of the Missouri Plateau north of the Loop Road and Badlands Wall, extending from northeast of Cedar Pass west to an area past the Jackson–Pennington county line. U.S. Geological Survey (USGS) 1:24,000 topographic maps of this locality indicate that the Upper Prairie surface ranges in elevation from 800 to 820 m above mean sea level (amsl). Continuing westward from the county line, the surface begins to noticeably slope uphill, reaching a maximum height of approximately 850 m just north-northeast of a prominent landmark known as the Pinnacles. Back in the northeast portion of the North Unit (i.e., in the area illustrated on the Churchill map), the Badlands Wall is clearly visible as a prominent escarpment marking the northernmost encroachment of badlands erosion onto the Missouri Plateau. In the vicinity of the park headquarters below Cedar Pass, the Wall covers a vertical distance of approximately 60 m (extending from 800 m to 740 m amsl). The bottom of the Wall at this point represents the Lower Prairie surface, which (likely accentuated by sediment deposition off of the escarpment) slopes downhill to the current channel of the White River, the bottom of which has an elevation of 700 m amsl. This represents a vertical drop of about 100 m from the Upper Prairie surface to the modern channel, a distance quite similar to that of the 107 m terrace described by White (1982). Meanwhile, to the northwest of the park headquarters area, the Lower Prairie surface, like its higher counterpart, begins to slope uphill. Below Bigfoot Pass it reaches 750 m amsl.

A short distance further west, below the Grasslands Overlook, the lower surface is broken by a small series of protruding bedrock remnants or inselbergs, some of which reach a maximum elevation of 810 m amsl. On the northwestern side of these remnants, the Lower Prairie surface at the base of the Wall increases in elevation to 760 m, 780 m, and finally 800 m amsl in the area immediately below the Pinnacles near the northern end of Conata Basin. In other words, the Lower Prairie surface below the Wall in the northern portion of Conata Basin is situated at the same elevation (800 m amsl) as the Upper Prairie surface further east above the park headquarters. These variations in elevation, while not directly contradictory to the concept of multiple surfaces, do illustrate the complex nature of vertical landform distribution in the badlands region, complexities that are likely to have significant ramifications to future (i.e., more specifically focused) geoarcheological and geomorphological investigations.

Within and immediately adjacent to the park boundaries, there are also at least two groups of prominent plateaus that contain flat-lying surfaces which are higher in elevation than those reported for the Upper Prairie surface and the top of the 107 m terrace. The first group, which includes Quinn Table, 71 Table, and Kube Table, is concentrated between the western boundary of the North Unit and the Cheyenne River. The long axes of these plateaus are perpendicular to the long axis of the river. Each plateau contains between three and four distinct surfaces separated by clearly visible risers. The most widespread and readily visible surfaces are extant at 870 to 880 m amsl, 860 to 870 m amsl, and 850 to 840 m amsl. Smaller and less distinctive surfaces are evident at 880 to 890 m amsl and, closest to the modern river, at 840 to 830 m amsl. The various surfaces all appear associated with relatively thin deposits of coarse-grained alluvial sand and gravel. The lithology of these lag sediments, together with the orientation of the plateaus and the elevation of their associated surfaces, indicate that they represent former strath terraces of the Cheyenne River, created when the river experienced between three and five episodes of downcutting during the Pleistocene. One or more of these events are presumably synchronous with the episodes of

incision noted earlier by White (1982) and others; however, only the two lowest Cheyenne terraces (i.e., the one from 830 to 840 m amsl, and the one from 840 to 850 m amsl) are vertically similar to those reported along the White River (i.e., the 91 m and 107 m terraces). Furthermore, the highest of the Cheyenne Pleistocene terraces (at 880 to 890 m) is situated at least 140 m above the nearest portion of the modern Cheyenne River channel, the elevation of which is circa 740 m. When compared to the 100 m of incision evident from the top of the Upper Prairie surface to the bottom of the White River in the park headquarters area, the difficulties in terrace correlation become even more apparent.

Finally, an even higher set of plateau surfaces are extant near the extreme southwestern portion of the North Unit and throughout much of the South Unit. Two of the most prominent of these are Sheep Mountain Table and Cuny Table, both with surfaces ranging from 1000 m to 960 m amsl (Figure 3). The corresponding elevational difference between the top of Sheep Mountain Table and the closest portion of the modern Cheyenne River to the north/northwest is 260 m, while the elevational difference between the top of Cuny Table and the closest portion of the White River to the south/southeast is 210 m. These are far greater vertical distances than any of the other surfaces and therefore indicate that they are substantially older. Just how much older is not altogether clear, however; recall that others have already been ascribed the Upper Prairie surface and 107 m terrace surface to the middle and late Pleistocene (White 1982; Ward 1922). Additional clues are evident in reports by Harksen and MacDonald (1969), and White (1982), who report the presence of "Medicine Root gravels" on the upper portion of Cuny Table. Cuny Table is also associated with volcanic ash, tentatively identified as Pearlette (Naeser et al. 1973; Hallburg 1980, from White 1982:46–47). The Medicine Root gravels have been identified as Nebraskan in age (i.e., circa 0.70–1.2 mya), while the Pearlette ash is believed to represent a number of ash units deposited between 0.60 and 2.5 mya (Naeser et al. 1973; Hallburg 1980, from White 1982:47). Some of these higher surfaces are also mantled with what Harksen (1968) identified as Red Dog loess, whose age was estimated as Yarmouthian. Of more potential relevance to archeologists, however, is the presence of a thin "Lip Loess" at the top of the Red Dog sediments, which Harksen (1968) suggests may date from the late Pleistocene to early Holocene.

Bedrock Geology and Aspects of Badland Slope Morphology

The geochronologic sequence of exposed bedrock in the White River Badlands has been well studied and need not be reiterated here in great detail. For more substantive discussions, the reader is encouraged to consult Harksen and MacDonald (1969); Clark et al. (1967); and Retallack (1983). Virtually all of the geologic parent materials in the badlands (including those exposed in Badlands National Park) are comprised of Tertiary-aged (i.e., Oligocene and Eocene) alluvial, lacustrine, and volcanic ash deposits that are, as a general rule, poorly indurated (Clark et al. 1967). The only notable exception to this Tertiary sequence is the Cretaceous-aged Pierre Shale (shallow marine) of the Montana group, which is exposed primarily along the bottom and sides of the larger and more deeply incised stream channels (Clark et al. 1967). The outcrops of Pierre Shale are unconformably overlain by various members of the Eocene Chadron and Oligocene Brule Formations, both of which are components of the Tertiary White River Group (Clark et al. 1967). Relevant units within the Chadron Formation include the Ahearn, Crazy Johnson, and Peanut Creek Members. These members are comprised of multicolored (i.e., tan, gray, greenish, bluish, and red-orange) sandstones, mudstones, shales, and conglomerates, which together attain a maximum thickness of circa 45 m (Clark et al. 1967).

The overlying Brule Formation, which is generally thicker in Badlands National Park than the Chadron, is comprised of the lower Scenic and upper Poleslide Members. Together these have a maximum thickness of circa 120 m and are comprised of mudstones, claystones, shales, sandstones, conglomerates, and volcanic ash. Ash derived from the Yellowstone National Park region is a common feature of the Poleslide Member (Clark et al. 1967). In portions of Badlands National Park, the Brule Formation is overlain by generally fine-grained and weakly cemented sediments of the late Oligocene Arikaree Group. The contact between the Sharps Formation of the Arikaree Group and underlying Brule Formation is marked by a distinctive bed of volcanic ash, known as the Rockyford Ash (Clark et al. 1967; Harksen and MacDonald 1969).

Before leaving this discussion of bedrock geology, it is important to note that the Chadron and Brule Formations constitute by far the most commonly exposed pre-Quaternary sediments within Badlands National Park. The Chadron and Brule deposits are ubiquitous along the Badlands Wall, comprise many of the area's isolated buttes and inselbergs, and are the source of much of the reworked materials that accumulate in substantial deposits below the Wall and at the foot of eroded remnants on the Upper Prairie surface. Many of the latter are mapped as Quaternary alluvium but actually contain both alluvial and colluvially derived materials. It is these sediments that comprise soils in the so-called sod tables which dot the Upper Prairie surface east of the Pinnacles, but are also common on the Lower Prairie surface below the Wall in the Conata and Sage Creek basins. The sod tables are important landform features within Badlands National Park and which will be discussed in far greater detail later in this report.

While the Chadron and Brule Formations may appear lithologically similar to the casual viewer, detailed quantitative studies by Schumm (1956) and others indicate significant variations in bedrock lithology and related hill slope processes. These differences are relevant to geoarcheological research and to questions of archeological site preservation in the badlands region. Schumm (1956) demonstrated that sediments comprising the Chadron Formation have generally high infiltration rates due to desiccation cracking, which in turn results in little surface runoff and reduced slopewash deposition. In contrast, the overlying Brule Formation is harder and far less permeable. As a consequence, slopes on the Brule Formation are influenced primarily by surface runoff, while sediment transport on Chadron Formation slopes is dominated by soil creep (Schumm 1956:695). These lithological and process differences are evident in slope profiles, with the Brule Formation having steep, straight slopes and sharp-crested summits, and the Chadron having more rounded summits and less acute slope angles. While both formations are dominated by clay minerals, particularly illite and montmorillonite, both Schumm (1956) and Smith (1958) attribute the variations in slope form and process to a higher percentage of calcareous cement in the Brule clays.

Hillslope processes and slope morphology in Badlands National Park are also affected by slope aspect. Churchill (1981) for instance, demonstrated that the profiles on south-facing slopes tend to be shorter, steeper, and more rectangular than those on north-facing slopes, which are generally flatter, more morphologically complex, and have a much higher density of rilling (Churchill 1981). These differences were attributed to "topoclimatically controlled differences in process activity" (Churchill 1981:388). It is significant to note that these aspect-related variations are just the opposite of those documented in the Little Missouri Badlands of North Dakota by Clayton and Tinker (1971). There, north-facing slopes were found to be less steep and far less affected by fluvial erosion (via rilling) than south-facing slopes. Churchill (1981) attributed this reversal in aspect-related slope morphology to the absence of vegetation on both north- and south-facing slopes in the White River Badlands as compared to the relatively thick vegetative cover that characterizes most north-facing slopes in the Little Missouri region.

This brief discussion of differences in hillslope form and process in Badlands National Park serves to reinforce the previously stated premise that geomorphic activity in badland environments is not as simplistic and readily understandable as first thought. This complexity has relevance to methodological aspects of geoarcheological and geomorphological research in badland settings, and also to the archeological interpretation of prehistoric subsistence and settlement patterns in such a dynamic region.

Significant Climatic Characteristics

The final significant components of a natural environmental context for the current investigations are those involving climate, particularly conditions of temperature, rainfall, and vegetative cover. As effectively demonstrated by Schumm (1973), Knox (1983, 1984), Langbein and Schumm (1958), and Derbyshire (1976), climate is among the most critical factors influencing the nature and intensity of geomorphic processes. Other key large-scale factors include bedrock lithology (already discussed), eustatic fluctuation, tectonic activity, and human activity. While we can essentially rule out eustatic variables and human activity as significant contributors to the formation of the White River Badlands, bedrock lithology and tectonic activity certainly have had major roles. As stated previously, however, the lithology of badland materials is highly variable and detailed lithologic analysis is, to a large extent, beyond the scope of this

paper. Likewise, as stated previously, little is known about tectonic activity in the badlands region during the period most applicable to archeological site formation (i.e., the Holocene). Within the contextual goals of the present study, this brings climate to the top of the analytical list (in lieu of additional data on Holocene structural activity or bedrock lithology).

The influence of climate on the production, transport, deposition, and preservation of sediment is pervasive and often profound, especially in arid and semiarid regions (cf. Knox 1983). So is the relationship between temperature, precipitation, vegetation, and landform equilibrium and complex geomorphic response (the latter, however, is usually associated with more intrinsic variables). In a very basic sense, but one that is applicable to geomorphology and archeological site formation in Badlands National Park, temperature and rainfall (which together determine rates of evapotranspiration and effective precipitation) are critical in the erosion and transport of sediment, and hence to the often precarious balance between deposition, erosion, and landscape stability. These conditions can directly affect the evolution, configuration, and stratigraphic composition of landforms (Butzer 1976), and hence the preservation and distribution of the archeological record (Waters 1992; Waters and Kuehn 1996).

The modern climate in the White River Badlands is semiarid continental, characterized by high daily, seasonal, and annual variability in precipitation and temperature (National Climatic Data Center 1991). The badlands receive an average of 15 inches (38 cm) of precipitation per year, with approximately half deposited by thunderstorms which frequent the area between April and July (National Climatic Data Center 1991; Churchill 1981). The mean annual temperature in the area is approximately 48°F or circa 9.2°C. Extremes in temperature and wind velocity, however, are dramatic, with high averages of 25°C in July and low averages of -5°C in January. Wind is a persistent aspect of local climate throughout the year. Although averaging about 10 mph annually, summer winds driven by severe thunderstorms can reach 70+ mph. Combined with warm temperatures, summer winds contribute to high local evaporation rates.

As noted by Churchill (1981), most of the exposed slopes in the park are completely devoid of vegetation, a factor which greatly enhances hillslope erosion and the downslope transport of sediment. On more stable park landforms, vegetation includes a variety of mixed grasses, sage, prickly pear cactus, and narrow leaf yucca, along with unwanted species of weeds such as Canadian thistle. Rocky Mountain juniper forms occasional groves along some of the more well-watered (i.e., spring-fed?) portions of the Wall (such as below the Pinnacles and at Cedar Pass) and in hardwood draws. Riparian settings, although rare, can be found along higher-order streams like the White and Cheyenne Rivers, and along lower-order streams such as Sage Creek. Flora in these settings include cottonwoods, ash, green elm, and a number of other woody species.

Field and Laboratory Methods

The geoarcheological investigations in Badlands National Park were designed to collect data from both the field and the laboratory which would aid in the identification of landforms that appear to have the greatest potential for buried, well-preserved archeological materials. This section will outline the methods that guided the field and laboratory efforts.

Field Methods

During the course of the fieldwork component, conducted in August of 1997, three main avenues of research were employed. First, a quick geomorphological and sedimentological reconnaissance of Badlands National Park, particularly the North Unit, was conducted in order to gain a basic understanding of the range and distribution of late Quaternary sediments still extant within the park boundaries. Second, a more detailed reconnaissance was undertaken in selected localities whose sedimentological and pedological characteristics appeared most compatible with the preservation of archeological sites. This level of research relied heavily on a number of sedimentological principles basic to the identification and interpretation of former environments of deposition (cf. Rigby and Hamblin 1972; Boggs 1987; Reineck and Singh 1980; Walker 1984). Primary among these is the concept that depositional sedimentary environments include those dynamic processes and static elements of any particular landscape that are responsible for the production, transportation, and deposition of identifiable bodies of sediment (Boggs 1987). These bodies of sediment have distinctive sets of physical, chemical, and stratigraphic characteristics (Boggs 1987:306; Reineck and Singh 1980). By recognizing these characteristics, particularly lithology, grain size, sorting, and primary sedimentary structure, the investigator can identify under which type of environment a body of sediment was deposited (be it alluvial, colluvial, lacustrine, eolian, or marine). The potential for site preservation is greatest when sites are formed and subsequently quickly buried in environments where sediment deposition occurs under relatively low-energy conditions (cf. Waters 1992). These types of settings include floodplains subjected to fine-grained overbank deposition, many kinds of ponded environments, and a number of low-energy eolian, colluvial, and alluvial environments such as those represented in certain types of loess, sand dune, alluvial fan, and channel fill deposits (Butzer 1982; Waters 1992; Stein and Farrand 1985). Finally, after completion of the second level of reconnaissance, attention focused on the analysis of eight localities considered representative of the range of depositional environments with high archeological potential. These included sections located on the Upper Prairie surface above the Wall, on the slightly higher surfaces thought to represent Pleistocene strath terraces associated with the ancestral Cheyenne River, on the highest plateau surfaces in the region (i.e., those of possible early Pleistocene or Tertiary age), and in the Lower Prairie surface, particularly the Holocene-aged terraces and alluvial fans located in the Sage Creek drainage basin (Figure 2).

At each of the study sections, data collection included: (a) the identification and description of extant lithostratigraphic units on the basis of physical characteristics (i.e., color, texture, sedimentary structure) and bounding disconformities; (b) the identification and description of buried and surface soils and corresponding horizons; (c) the preparation of a scale profile map of each section; (d) photographic documentation; and (e) the collection of soil and sediment samples, including the recovery of at least one sample from each stratigraphic unit and recognizable soil horizon, and the collection of samples for stable carbon isotope and radiocarbon analysis. More specific field methods included the determination of sediment and soil texture, color (via Munsell Color charts), structure, consistence, reaction with hydrochloric acid, boundary or contact characteristics, and special features (cf. Soil Survey Staff 1951). Soil horizon nomenclature followed the Soil Survey Staff (1990) with master and subordinate horizons designated in the field.

The field investigations also addressed the question of natural site formation, particularly those variables related to landscape stability, erosion, and aggradation. For example, stratigraphic units, which were defined on the basis of bounding disconformities and other criteria established by the North American Commission on Stratigraphic Nomenclature (NACOSN 1983), are interpreted as representing discreet

episodes of sediment deposition (cf. Boggs 1987). Erosional events, on the other hand, were recognized primarily on the basis of the topography and abruptness of unit contacts (Boggs 1987; Waters 1992), while both buried and surface soils served as indicators of periods of past and present landscape stability (cf. Birkeland 1984). Other evidence of post-depositional disturbance included the recognition and description of rodent holes, insect activity, root penetration, shrink-swell soil cracking, and human impacts such as road and trail construction.

Laboratory Methods

Laboratory analyses, initiated immediately after the completion of fieldwork, were conducted at Texas A&M University, the University of Arizona, the University of Texas, Austin, and at the laboratories of Geochron, Inc. Variables selected for analysis were determined by their potential to contribute to the understanding of principal sedimentary depositional environments, the morphology and extent of regional soil development, the age of particular stratigraphic units and soils, and basic aspects of climatic conditions during the late Pleistocene and Holocene. Consequently, the laboratory research focused on:

(1) *General soil and sediment characteristics*. These included grain-size distribution (utilizing the pipette settling method for the clay and silt-sized fractions, and dry sieving for the sand and larger fractions), total carbon content (determined through dry combustion in a total carbon analyzer), total inorganic carbon, expressed as $CaCO_3$ equivalent (determined through the use of a Chittick apparatus), and percentage of organic carbon (calculated on the basis of the difference between total carbon and total inorganic carbon (cf. Holliday and Stein 1989). The data on particle-size distribution were presented in terms of total sand, silt, and clay percentages expressed in mm and according to the textural classes outlined in the Soil Survey Staff (1951). Organic carbon is presented by percentage, as are carbonate, in the form of $CaCO_3$ equivalent. The laboratory data are presented in Appendix A.

(2) *Stable carbon isotope composition of soil organic carbon*. This was determined through dry combustion of soil organic matter into CO_2, with the resultant isotopic composition determined by mass spectrometry. The resultant data, outlined in Appendix B, were used to interpret the nature of C_3 and C_4 biomass associated with each of the buried soils, thus contributing to an understanding of local vegetative conditions during periods of pedogenesis, and thereby to an understanding of local paleoclimate (cf. Cerling et al. 1989; Herz 1990; Boutton et al. 1993; Boutton et al. 1998).

(3) *Radiocarbon age determinations of samples collected from key stratigraphic units and paleosols*. These were determined by conventional assay and by accelerator mass spectrometry (AMS). In all, ten radiocarbon age determinations were obtained from samples collected from eight individual stratigraphic sections. The samples consisted of charcoal, preserved organic material, bone apatite, and bulk soil humates. The resultant ages, standard deviations, and stratigraphic/spatial proveniences are summarized in Appendix C. All ages have been ^{13}C corrected.

Results of Investigations: Summary of Stratigraphic Study Sections

The preliminary geoarcheological research in Badlands National Park yielded information from two conceptual sources: observation and actual physical analysis. Observation is visual and does not necessarily require physical activity or direct physical contact on the part of the investigator (such as digging, scraping, walking, measuring). In the field, information obtained through observation included the identification of different surfaces, landform categories, and to some extent, different types of sedimentary depositional environments. Most observational information was gathered during the reconnaissance survey portions of the fieldwork. Information based on physical analysis, on the other hand, involves greater expenditure of effort and actual physical contact. In the field, physical analysis included the cutting of stratigraphic profiles, the determination of soil color using a Munsell chart, and the collection of samples using a trowel or rock hammer. Most of these types of data collection were conducted during the course of investigations at the individual study sections. Under normal circumstances, laboratory work usually involves some degree of physical analysis (e.g., the placement and shaking of sediments in sieves, the treatment of samples with HCl). Because most of the physical effort in the field was devoted to analysis of the individual study sections, the summary begins there.

Because of limited time and funding, detailed stratigraphic and pedologic investigations could only be conducted at a small number of localities (n = 8). This created the need to choose sections which exhibited not only good potential for site preservation, but which also cumulatively represented the broadest range of depositional environments and greatest time depth. Identifying such a combination of sections was one of the principal goals of the reconnaissance surveys.

The eight sections chosen for study are summarized according to their association with the various landsurface categories outlined earlier; specifically: the Upper Prairie surface and Badlands Wall; the Pleistocene (?) Cheyenne River terraces; the early Pleistocene/late Tertiary (?) surface, and the Lower Prairie surface. The latter is further subdivided into modern floodplains, Holocene terraces, and Holocene alluvial fans (Figures 2 and 3). We begin with the various upland settings.

Upper Prairie Surface/Badlands Wall

A number of localities were investigated in upland settings along the Loop Road in the eastern portion of the North Unit (Figure 2). This area includes the Upper Prairie surface that lies generally north of the road at elevations ranging from 800 to 820 m, and also the edge of the Badlands Wall located immediately south of the road (Ward 1922; Churchill 1981).

Sod Tables

All of the study sections located on the Upper Prairie surface were associated with so-called “sod tables,” unique landforms that have received a fair amount of previous archeological attention (cf. Jones 1993) but little in the way of detailed stratigraphic description. Although similar in overall appearance, sod tables actually exhibit a great deal of variability in terms of detailed stratigraphic description. Sod tables are comprised of reworked alluvial and colluvial sediments (with the possibility of some eolian material) which have been deposited below, and extending away from, eroded bedrock remnants (i.e., inselberg-like features), or below larger and more prominent bedrock slopes (like areas beneath the Wall).

They are generally massive and/or planar bedded and contain predominately fine-grained clays, silts, loams, and fine sands. They do, however, occasionally contain thin to thick beds of coarse sand and gravel, and remnants of former channel cuts that have filled with both imbricated gravels and massive to laminated finer materials. The lithology of sod tables is therefore determined by the lithology of the adjacent parent material source (generally the Chadron, Brule, and Sharps Formations) and by the depositional environments associated with their aggradation. Field observations and laboratory analyses indicate that they are predominately the products of slopewash deposition and deposition from rill networks, but also from the deposition of channel lag materials. Sod tables have what appear to be flat surfaces (hence the name) but which, in actuality, exhibit a high degree of variability in slope angle. The surfaces, how-

ever, are covered with grasses, although modern soils are generally poorly developed (i.e., Entisols or Inceptisols). Buried soils are a common feature. These include single thin A horizons, thick and organic-rich Millic epipedons, and truncated B (usually Bk) horizons of variable thickness. The tables themselves range in thickness from less than 0.5 m to over 5 m and are generally elongated, but can also be round, square, or highly amorphous in plan view.

Sod tables appear to be remnants of former alluvial plains, slopewash aprons, and/or, nearer the bedrock source, some colluvial footslopes (cf. Selby 1985). Virtually all sod tables have been isolated into inselberg-like forms by erosion, predominately the meandering and downcutting of ephemeral streams. Sod tables are not uncommonly associated with exposed archeological materials, especially within the uppermost 1 to 1.5 m of fill. A number of formally recorded and evaluated sod table sites have been assigned to the Plains Woodland or Plains Village traditions on the basis of diagnostic ceramics and a number of associated radiocarbon ages (Jones 1993).

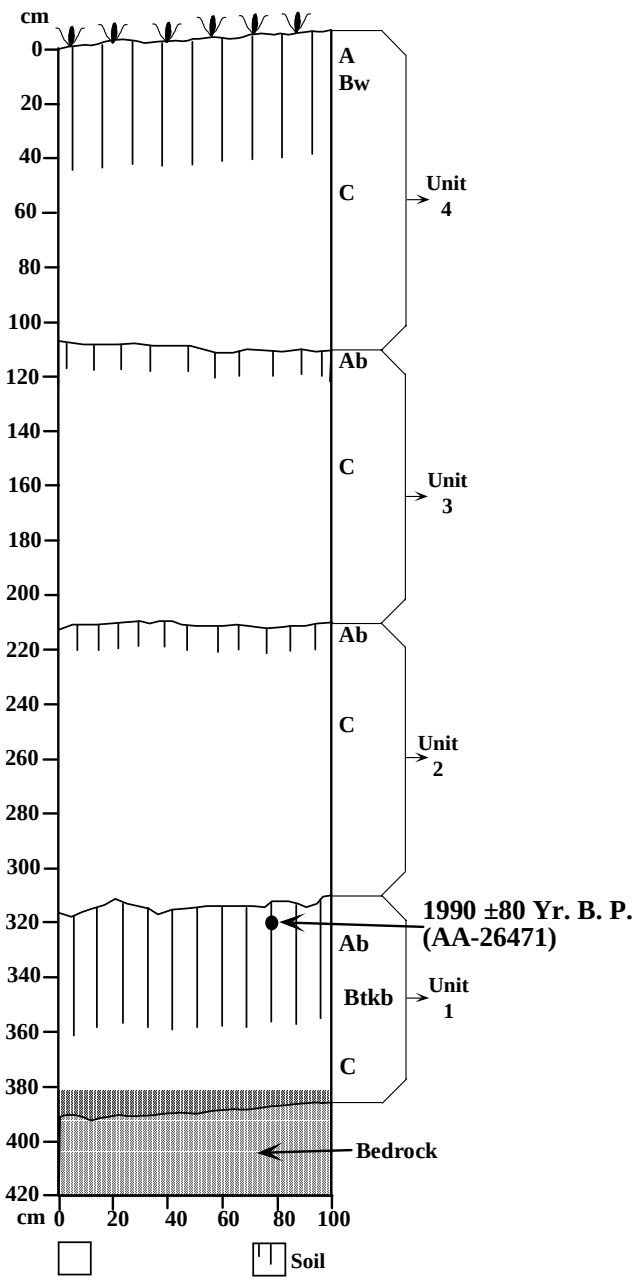

Figure 4. Profile of Stratigraphic Section 2.

The sedimentological and pedogenic investigation of sod tables focused on three of the more promising of those observed during the field investigations. These are situated on the Upper Prairie surface adjacent to the Loop Road and are associated with Sections 2, 5, and 6 (Figure 2).

Stratigraphic Section 2

Stratigraphic Section 2 was located at a cutbank exposure along the eastern side of a 4-m-thick sod table. The base of the table fill lies unconformably on Brule or Sharps Formation sediments about 3 m above the channel of a small ephemeral stream due east of the old northeast entrance station road (Figure 4). Sod tables in this area are abundant and include some of the thickest of those observed in the park.

This particular locality was first shown to the author by Rachael Benton, Badlands National Park paleontologist. It is somewhat unusual in that the table profile contains evidence of a number of cut-and-fill sequences, including one large and three smaller channels. These channels apparently incised White River Group sediments and were then in-filled with sod table alluvium. The bottom of the former channels, particularly the three smaller ones, contain a thick, organic-rich paleosol that appears to have weathered directly out of the White River materials. This soil and the overlying sediments are comprised of silty clay loams and silt loams. Further to the southeast, the table fill also contains one or more medium beds of sand and gravel that have been truncated laterally by a small gully that cuts through the table in a perpendicular fashion. The gravelly units were not evident on the opposite

side of the gully. Slightly to the northwest, the sediments at Section 2 are arranged into four stratigraphic units, each of which is topped with a soil. The most well developed is the one at the base of the section (Unit 1, S1 soil), which exhibits an A/Btkb/C profile. The two overlying buried soils (Unit 2, S2 soil and Unit 3, S3 soil) contain only weak Ab/C profiles. These buried A horizons are 6 to 10 cm thick respectively. The soil at the top of the table is only slightly more developed, consisting of an A/Bw/C profile. The S1 soil, which is of potential significance to the present study and also to studies more specifically devoted to the reconstruction of late Quaternary climates, contains a loamy Mollic epipedon (10YR 3/2 moist) with a high amount of organic carbon (1.08 percent). Refer to Appendices A and D for more detailed analysis information. This is by far the darkest paleosol observed in the area and is a strong, but not infallible, indicator of a fairly lengthy period of stability under grassland conditions (cf. Fenton 1983).

A bulk sample of the Unit 1, S1 soil A horizon yielded an AMS radiocarbon age of 1990 ± 80 yr BP (AA-26471). This age indicates that approximately 4 m of alluvial sediment was deposited at Section 2 within the last circa 2,000 years. This aggradation, however, was interrupted by at least two periods of relatively brief landscape stability, followed by renewed aggradation and formation of the modern surface soil. Prior to 2000 BP, the section witnessed one or more events of channel incision into the clay-rich sediments of the White River Group. The timing of this incision is not known, but appears to have been associated with lateral stream migration, as evident by the presence of multiple in-filled channel cuts within the same sod table. By circa 1,900 years ago, incision ceased and landscape stability resulted in the formation of the S1 Mollisol. This period of pedogenesis was then followed by the punctuated aggradation of the remainder of the sod table. After, and perhaps periodically throughout, the deposition of the sediments visible in the table, renewed stream incision eroded the former alluvial surface(s) into the isolated remnant we see preserved today. With discussion of the additional sod tables, it will become evident that similar sequences of deposition, stability, and erosion occurred throughout the Holocene, although the horizontal, vertical, and temporal extents of these events appear to have been highly variable.

Stratigraphic Section 5

This section consists of a vertical cutbank exposed along the northern margin of a sod table located approximately 4 km west-northwest of Section 2 and about 0.5 km east of the Fossil Exhibit Trail. This popular stopping point for park visitors is adjacent to the Loop Road immediately north of Norbeck Pass (Figure 2). The table sediments consist of 2.8+ m of mostly thin planar-bedded or pedogenically altered loam, silty loam, and silty clay; the base of which again overlies eroded bedrock (i.e., Brule and Sharps Formation materials). In this area, a series of southwest-trending ephemeral channels have deeply dissected the tables and the underlying bedrock. For example, the floor of one such channel lies 8 to 10 m below the bottom of the Section 5 ta-

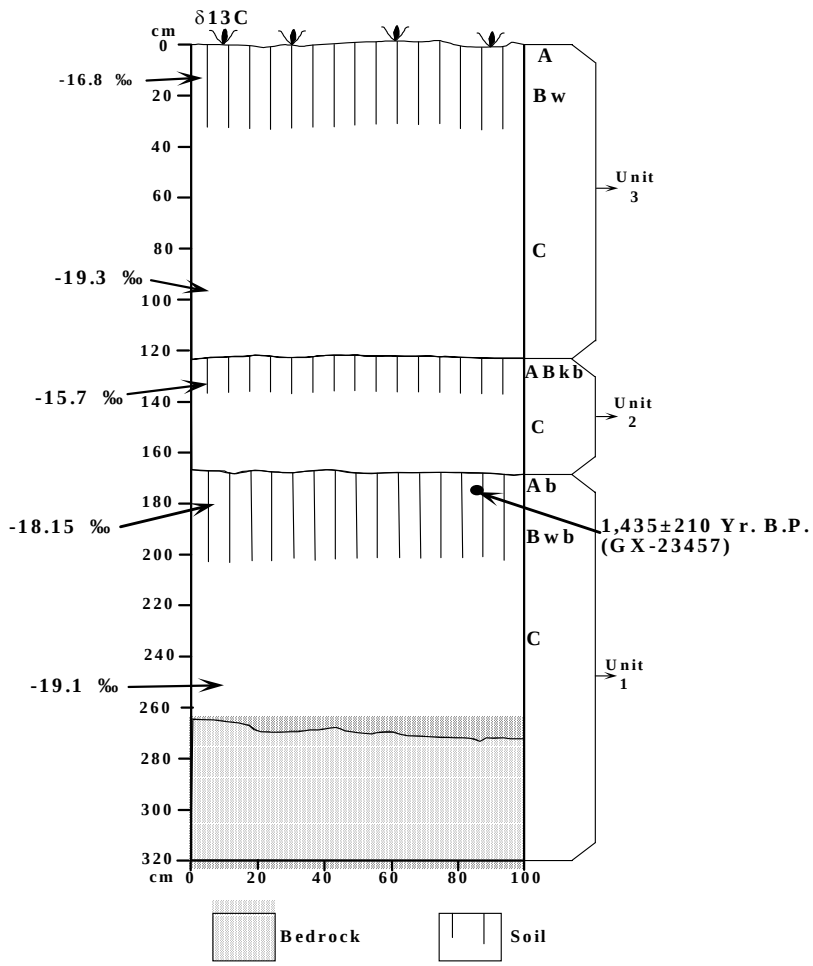

Figure 5. Profile of Stratigraphic Section 5.

ble-fill sediment. The source of the reworked alluvial, and possibly colluvial, deposits at Section 5 is a series of bedrock inselbergs and dissected ridges which lie above the Badlands Wall within 200 m of the section and which form part of Norbeck Pass.

Section 5 contains three lithostratigraphic units, again definable on the basis of bounding soils (Figure 5). The lowest unit, Unit 1, is a 1.1-m-thick bed of somewhat rilled silty loam topped with a visually distinctive, albeit not particularly well developed, paleosol (Figure 5). The soil contains an Ab/Bwb/C profile. The dark (10YR 3/2 moist) A horizon is, at maximum, 15 cm thick and has an organic carbon content of 0.75 percent, which is the highest of any in the section (Appendix A). The underlying Bwb horizon is 6 cm thick, is slightly lighter in color (10YR 5/3 moist), and exhibits weak medium subangular blocky structure. A Late Prehistoric hearth feature (apparently isolated in terms of exposed materials), is extant about 15 m north-northeast of Section 5 in the same Unit 1 soil (which was very easily traceable). The hearth consists of a 56-cm long by 28-cm deep V-shaped basin, cut into the S1 surface and filled with broken pieces of fire-cracked rock, mammal bone, and abundant fragments of wood charcoal. A sample of the latter, which was concentrated along the bottom of the feature, yielded a standard radiocarbon age of 1435 ± 210 BP (GX-23457).

The Unit 1 soil at Section 5 is overlain by Unit 2, a 46-cm-thick bed of silty clay (Figure 5). The upper unit contact is marked by the presence of a second buried soil (S2), which consists only of a 12-cm-thick ABkb horizon (10YR 4/3 moist), also of silty clay. Organic carbon in the former surface soil yielded a value of 0.49 percent, which is the lowest of the three A horizons in the section (Appendix A).

The upper portion of the section is represented by Unit 3, a 1.26-m-thick bed of predominately thin planar-bedded silty loam (10YR 6/3 moist). The top 26 cm of the unit contains a weakly developed surface soil (Figure 5), comprised of a brown (10YR 4/3 moist) loamy A horizon and a lower Bwk horizon of brown (10YR 5/3 moist) silty loam. The B horizon has some evidence of limited $CaCO_3$ translocation, in the form of very sparse filaments along ped faces. The A horizon has an organic carbon content of 0.62 percent (Appendix A), which is second highest in the section. Not surprising, the lowest amounts of organic carbon are found in the pedogenically unaltered C horizons, where values range from 0.13 percent in Unit 3 to 0.22 percent in Unit 1 (Appendix A).

Stratigraphic Section 5 is one of three localities from which stable carbon isotope data were recovered. Delta ^{13}C values of soil organic carbon were obtained from samples collected from Unit 1 (Ab and C horizons), Unit 2 (ABk horizon), and Unit 3 (A and C horizons). By representing the relative contribution of decomposed C_3 and C_4 plants to the organic carbon pool in soils, stable carbon isotope values are a potentially useful measure of past vegetative communities, and hence, an increasingly valuable tool in climatic reconstruction, primarily the reconstruction of environmental temperature and, not as directly, of effective moisture conditions (cf. Cerling et al. 1989; Schwartz 1988; Boutton 1996). The use of stable carbon analysis in climatic reconstruction is an increasingly common tool among a large number of scientific disciplines, including geoscience, ecology, biology, physical anthropology, and archeology. Consequently, many archeologists are by now aware of the principles, applications, and numerous caveats associated with the interpretation of soil-derived $\delta^{13}C$ data. Therefore, an extensive reiteration of these concepts and potential pitfalls is not necessary at this time. Likewise, the stable carbon data summarized herein are intended only as an aid to the interpretation of late Quaternary climatic/geomorphic relationships in the region of the park as they may relate to the preservation and distribution of archeological materials. For more substantive discussions regarding soil $\delta^{13}C$ and paleoenvironments in the northern Great Plains, the reader is encouraged to consult, among others, Kelly et al. (1991), Boutton et al. (1998), Fredlund and Tyson (1995), and Kuehn (1995).

As summarized in Appendix B, the carbon isotope values associated with soils at Section 5 show a predominance of C_4 plants, ranging from -15.7 to -19.3. This suggests that surface vegetation during the late Holocene had a significant amount of warm season grasses (cf. Kelly et al. 1991; Boutton et al. 1998), although the potential contribution of C_3 and C_4 plant species to the overall vegetative biomass does appear to have fluctuated rather considerably. For example, a sample collected from near the bottom of Unit 1 yielded a value of -19.1, which may indicate a corresponding surface biomass comprised of

circa 55 to 60 percent C_4 plants (cf. Boutton et al. 1993:Figure 4). In the upper portion of the same unit, the percentage of C_4 vegetation increases to 65 percent of the former biomass (mean $\delta^{13}C$ value of -18.15). Recall that this buried A horizon is associated with a hearth-derived charcoal age of 1435 ± 210 BP (Figure 2, Appendix C). The contribution of C_4 plants reaches a peak of -15.7 in the ABk horizon of overlying Unit 2, suggesting that as much as 80 percent of the organic matter in the S2 soil may have derived from C_4 grasses. This value could be an indication that climatic conditions during the formation of the S2 soil were warmer, and perhaps drier, than at present. In the youngest package of sediment, Unit 3 values decreased to -19.3 from the lower portion of the unit and to -16.8 in modern surface A horizon. The latter is still strongly C_4, however, and reflects a biomass comprised of about 70 to 75 percent C_4 plants. It is somewhat higher than the $\delta^{13}C$ composition of surface and near-surface soils reported from other sections within the White River Badlands, the Black Hills, and additional locations along the Missouri River Trench further to the east. For example, in Badlands National Park the surface A horizon on Sheep Mountain Table yielded a stable carbon isotope value of -18.7 (as reported here), while Fredlund and Tyson (1995) report that the modern vegetative community in the White River Badlands is dominated by mixed grasses such as *Agropyron* sp., which have a $\delta^{13}C$ value of -19.0. In the Black Hills region, Fredlund and Tyson (1995) report a $\delta^{13}C$ value on organic carbon of -18.0 from surface soils in the Wind Cave area. Likewise, Kelly et al. (1991), studying the carbon isotopic composition of modern upland grassland communities in the Great Plains, present surface values of soil organic matter ranging from about -19.0 at a locality near Pollock, South Dakota, to circa -17.5 at a site near Thompson, South Dakota. These values are well within the range of those reported from surface soils in a number of grassy upland localities in western North Dakota (cf. Boutton et al. 1998; Kuehn 1995; Hartman et al. 1998). Cumulatively, the studies just referred to indicate that the organic matter in modern, well-drained surface soils in the western Dakotas is dominated by warm-season mixed grasses produced under semi-arid conditions. Most of these soils have $\delta^{13}C$ values that tend to concentrate between -19.0 to -17.0, indicating a contribution of C_4 plants on the order of 60 to 70 percent.

There are, of course, examples of soils which exhibit significant variation from this apparent norm. For example, surface soils on some upland settings in the Little Missouri Badlands have yielded stable carbon values as low as -22 to -23, which indicates a predominance of C_3 species and a concomitant reduction in the contribution of C_4 plants to less than 30 percent (Boutton et al. 1998; Kuehn 1995). Meanwhile, back in Badlands National Park, another fairly high $\delta^{13}C$ value on organic carbon (-14.6) was obtained from the surface soil at Stratigraphic Section 6, a sod table located several kilometers to the northwest of Section 5. There are numerous possible causal factors responsible for these types of variation, which could include the input of organic carbon from variable parent material sources, landform and soil associations, complex response to changes in local geomorphic thresholds, proximity to ground water, grazing conditions, and natural and human fires, to mention but a handful. It is therefore clear that a great deal of additional research is necessary in order to more clearly understand the origin, nature, and extent of C_3/C_4 variability in soil organic matter in this portion of the northern Great Plains.

Stratigraphic Section 6

The site of Stratigraphic Section 6 is a vertical exposure associated with yet a third sod table, this one located several kilometers northwest of Section 5, between Norbeck Pass and Big Foot Pass (Figure 2). The section contains 2.7 m of silty clay, silty loam, and clay loam arranged in six stratigraphic units (Figure 6, Appendix A). Each contains a buried or surface soil, the upper four of which are all weakly welded. More precisely, the Bk horizon of the Unit 6 surface soil is overprinted onto the Ab horizon of the underlying Unit 5 soil, thus turning it into an ABkb horizon (Figure 6). In addition, the Bkb horizon of Unit 4 is partially overprinted onto the A horizon of underlying Unit 3 (also transforming it into an ABkb). This type of overprinting results in what are called “polygenetic” or “composite” soils—soils that are the product of more than one episode of pedogenesis (Lowe and Walker 1984; Birkeland 1984; Waters 1992). Polygenetic soils are fairly common in a variety of relatively stable landscapes—landscapes where pedogenesis is not quickly terminated by subsequent sediment deposition of sufficient thickness to isolate the former surface and prevent it from being affected by the translocating processes that occurred during later pedogenic episodes. This appears to be the case with regard to the geomorphic history of the upper

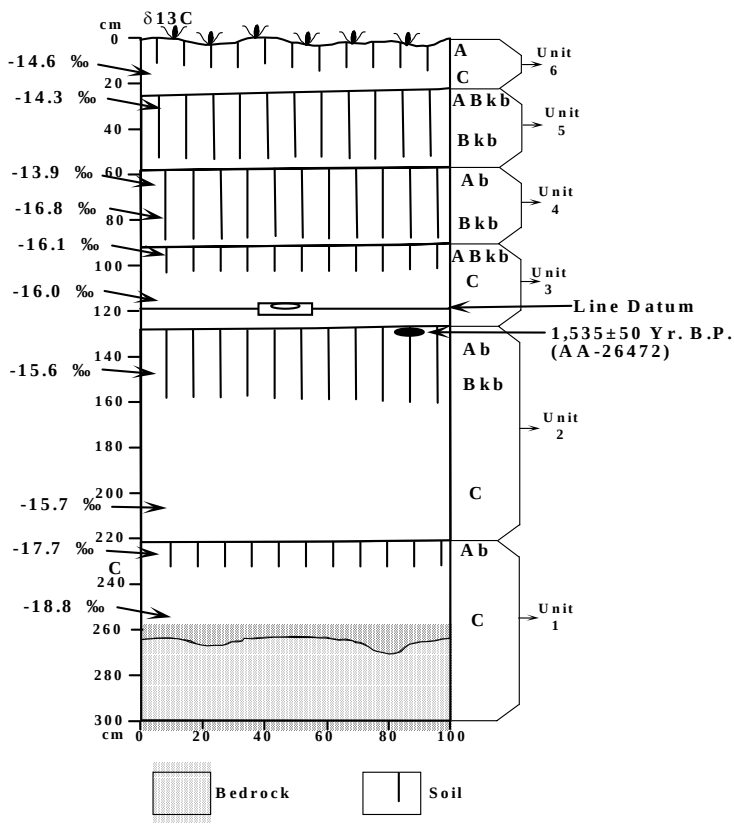

Figure 6. Profile of Stratigraphic Section 6.

1.0 m of Section 6. In the lower 1.7 m, polygenetic soils are not readily evident. Instead, this portion of the section contains two vertically separated soils, one at the top of Unit 2 (S2) and one at the top of Unit 1. The former is prominent darkly colored soil comprised of a 20 cm thick, very dark grayish brown Ab horizon (10YR 3/2 moist) of silty clay, underlain by an 18-cm-thick Bkb horizon, also of silty clay, but somewhat lighter (10YR 4/2 moist) and containing sparse to moderate amounts of carbonates (threads and small powdery forms). The Ab horizon has an organic carbon content of 0.53, as compared to the lower, pedogenically unaltered portion of the unit, which is a clay loam containing 0.34 percent organic carbon (Appendix A). The soil topping basal Unit 1 consists of a single thin (i.e., 5 cm) Ab horizon of silty clay (10YR 4/3 moist), with an organic carbon content of 0.31 percent. The underlying parent material, which may represent partially weathered Tertiary bedrock, consists of a 40 cm deposit of light brownish gray silty loam (10YR 6/2 moist) with no visible structure and an organic carbon content of 0.16 percent (Figure 6).

The polygenetic soils lying above the prominent Unit 2 soil, overprint four stratigraphic units (3 through 6) whose texture, from lowest to highest, consists of silty clay loam, silty clay, silty clay, and silty loam. Although masked somewhat by translocated carbonates, the A horizons in Units 3 through 6 are still visible, ranging in color from dark brown to very dark grayish brown. They exhibit a steady upward increase in soil organic carbon, with the lowest portion of Unit 3 yielding a value of 0.29 percent and the modern surface horizon yielding a value of 1.57 percent (Appendix A). The corresponding Bk horizons of these soils, as well as the overprinted A horizons, contain carbonates in the form of sparse to common threads and small powdery forms. The most fine-grained soil horizons (comprised of silty clay) include Unit 1 A, Unit 2 Ab, Unit 3 ABkb, Unit 4 Ab, and Unit 5 Abk. These exhibit moderate, fine prismatic to weak fine subangular blocky structure. In the remaining horizons, structure is predominately moderate, medium subangular blocky (Unit 3 C horizon) and weak fine subangular blocky (Unit 6 surface soil).

Radiometric data from Section 6 consist of a single AMS radiocarbon age of 1535 ± 50 yr BP on CO_2 derived from a bulk soil sample collected from the Unit 2 Ab horizon (AA-26472, Appendix C). This late Holocene age is consistent with the range of ages previously recovered from archeological sites in similar sod table settings in Badlands National Park (Jones 1993).

Finally, a total of 10 stable carbon isotope samples was collected from each of the soil A horizons, the unaltered parent material in the three lowest stratigraphic units (Units 1, 2, and 3), and from the Unit 4 Bkb horizon (Appendix B). From the bottom to the top of the section, these samples produced values ranging from -18.8 to -14.6 (Appendix B). The upward progression toward higher values, however, was not constant. While the $\delta^{13}C$ value in the A horizon of basal Unit 1 was -17.7 (indicating a biomass comprised of about 65 percent C_4 plants), the value in the A horizon of overlying Unit 2 was -15.6 (indicating

a biomass comprised of circa 75 to 80 percent C_4). The $\delta^{13}C$ ratios remained rather similar in Unit 3 (-16.0 or about 70 percent C_4) but increased noticeably to a high in the Unit 4 A horizon of -13.9, which suggests a C_4 input as great as 80 to 90 percent of the available biomass. The values from Unit 4 upwards, decrease slightly to -14.3 in the Unit 5 ABkb and to -14.6 in the Unit 6 surface A, both of which suggest C4 input somewhere on the order of circa 80 percent.

Pleistocene (?) Cheyenne River Terraces

A single study section (Section 1) was used to investigate the stratigraphic composition of the alluvial lag sediments associated with the previously described Pleistocene terraces above the Cheyenne River. The section was located along the southeastern margin of Quinn Table at the edge of the 860–870 m surface (Figure 2).

Quinn Table: Stratigraphic Section 1

Stratigraphic Section 1 was situated at the top of a steep cut immediately above, and to the southwest of the Sage Creek Campground (Figure 2). The vertical cut is approximately 15 m high and appears to be the result of relatively recent slumping. The base of the scarp is the site of CCC Spring, which was actively flowing during the time of the field investigations. Because Tertiary bedrock in this locality was observed quite near the surface, the study section is relatively thin (1.20 m). This is not to suggest that bedrock is this close to the surface throughout Quinn Table; topographic variability is likely to result in some areas that are more depressed and hence, filled with possible Holocene sediment. In any case, Section 1 consists of Unit 3, a thin (0.2 m) surface bed of coarse sandy loam (of possible sand dune or sand sheet origin) overlying 0.9–1.0 m of coarse-grained alluvium (Unit 2), and a basal deposit of highly weathered claystone (Unit 1). The latter appears to represent the top of Tertiary bedrock sediments (Figure 7).

The weathered claystone (Unit 1), exposed at a depth of 1.2 m, contains at least 79 percent massive clay and has an organic carbon content of 0.27 percent (Appendix A). The unit matrix color is 5Y 6/3 moist, but there are abundant sand-sized nodules of iron oxide (5YR 2.5/1 moist). The thickness or lower boundary of this unit has not been determined.

The contact between Units 1 and 2 is abrupt and somewhat irregular (Figure 7). Other than indicating an erosional unconformity, the contact is significant in that it was marked by the presence of a thin organic mat that appeared potentially datable by radiocarbon analysis. The mat consisted of a thin lamina of friable bioturbated silty very fine sand. Many of the sand grains were covered with reddish brown (2.5YR 4/4) iron oxide.

The mat also contained small amounts of coarse, sand-sized calcite (5YR 8/1). A sample of the mat material was examined by Christopher Caran, a consulting geologist and geochemist, the results of his microscopic and limited chemical

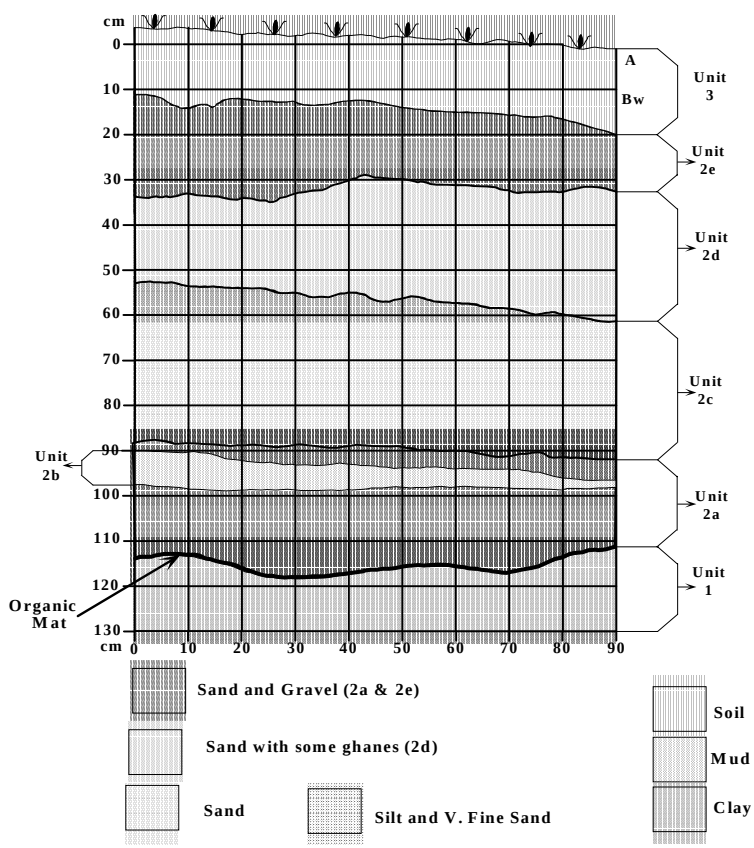

Figure 7. Profile of Stratigraphic Section 1.

analysis are presented in Appendix D. Basically, Caran suggests that the mat could represent a layer of moss that was deposited on top of the Unit 1 clay bedrock after it was partially truncated by the erosive action of the former Cheyenne River. The mat was then buried by channel lag sediments prior to the initiation of the downcutting that produced the terrace surface. It remained buried until examination of the section by the author. Subsequent to burial, however, the organic material (which yielded a $\delta^{13}C$ value of -24.9) began to decompose under water-saturated conditions created by discharge from the former water table. During this period, iron and manganese began to fix to the remaining organic matter, resulting in small iron oxide nodules. As the water table lowered in response to downcutting, it increased in alkalinity, precipitating calcite and gypsum, which eventually formed small nodules. Since then, the mat has been relatively undisturbed except for periodic root penetration from the overlying plant community.

A sample of the organic material was submitted to the University of Arizona AMS Laboratory and yielded an age of 2010 ± 65 yr BP (AA-26468). This age is much too young to accurately reflect the timing of the deposition of the overlying channel lag materials and is therefore considered unreliable. One plausible explanation for the aberrant age could be that the moss layer observed by the author was established over 55,000 years ago, and is thus devoid of measurable contemporaneous carbon. The younger age could reflect the introduction of late Holocene carbon into the mat from root penetration. Regardless of the cause, the investigations at Stratigraphic Section 1 did not yield data which could shed light on the timing of the downcutting episodes responsible for the various terrace surfaces evident on Quinn, 71, and Kube Tables.

Early Pleistocene/Tertiary (?) Surfaces

The oldest, highest surfaces in Badlands National Park were investigated by two stratigraphic study sections, one located along the top edge of Sheep Mountain Table (Section 3), and one along the top of Cuny Table (Section 4). Both sections are in the South Unit of the park and represent the oldest packages of late Pleistocene/Holocene sediment encountered during the course of the present study (Figure 3).

Sheep Mountain Table: Stratigraphic Section 3

This prominent landmark, rising over 150 m above the surrounding Lower Prairie surface, is mantled with Quaternary sands and silts and at least several meters of late Pleistocene/Holocene loess. Stratigraphic Section 3 was located along the western edge of the table in an area where the loess was particularly well exposed in a steep vertical scarp (Figure 8). The section is comprised of 2.7 m of eolian silt which unconformably overlies a thick bed of unconsolidated silty loam (depth unknown). The investigations focused on the loess mantle, which contained a well-preserved sequence of five buried soils. Using the soils as indicators of punctuated loess deposition, the section was divided into seven stratigraphic units (Figure 8). The lowest (Unit 1) represents the silty loam basal material, which is predominately planar-laminated and pale olive in color (5Y 6/3 moist). It is, however, interbedded with occasional darker, grayish brown (2.5Y 5/2), thin horizontal beds and convoluted laminae. The silty loam overlies Tertiary bedrock and is most likely Pleistocene in age. It may correlate to the middle/late Pleistocene Red Dog loess, as identified on upland plateaus throughout the badlands region by Harksen (1968).

The lowest loess unit, Unit 2, is a 0.8-m-thick bed of clayey loam which has been pedogenically altered into an Akb/Btkb soil (S1). The Akb horizon is 0.4 m thick and very dark gray (10YR 3/1 moist) in color with abundant carbonates in the form of coalescing filaments and powdery forms (10YR 7/1). The S1 and overlying S2 soils are polygenetic, and therefore the high carbonate content in the Unit 2 Ab horizon is the result of translocation from the upper soil. In other words, the Unit 2 Ab horizon also represents the Bk horizon of the Unit 3 soil. In addition to the thickness of the epipedon and its dark matrix color, the Unit 2 Akb soil yielded an organic carbon content of 1.01, second only to the modern surface A horizon (Appendix A). AMS analysis of the organic carbon fraction of the buried A horizon yielded an age of 8255 ± 70 yr BP (AA-26470).

The bottom portion of Unit 2 consists of a clay loam Btkb horizon which sits unconformably on the older unit of laminated silty loam. The Btkb exhibits an increased clay content and abundant carbonates in the form of filaments and medium-sized powdery forms. Although carbonate translocation almost certainly occurred during the S1 period of pedogenesis (as did clay translocation), one cannot rule out the possibility of additional carbonate input from the Bk horizon in the overlying Unit 3 soil, given the highly polygenetic nature of both soils (Figure 8). A sample of organic carbon extracted from the lower Btkb soil yielded an AMS radiocarbon age of 12,010 ± 80 yr BP (AA-26469). This age is substantially older than the 8200 BP date obtained from the Unit 2 A horizon. Because all of the carbonates in the sample were removed during pretreatment, the difference in the ages of the two horizons may actually indicate that the Btkb represents an earlier episode of loess deposition and soil formation that was followed by erosional truncation and the deposition of the Unit 2 A sediment. Subsequent carbonate translocation occurred during the original pedogenic event, and also perhaps during the soil forming intervals that followed the deposition of Unit 2 and even Unit 3. This is a complex combination of events, but one not unlike soils identified in the Oahe Formation sequence of late Pleistocene and early to middle Holocene loess deposits in the Little Missouri Badlands (Kuehn 1995).

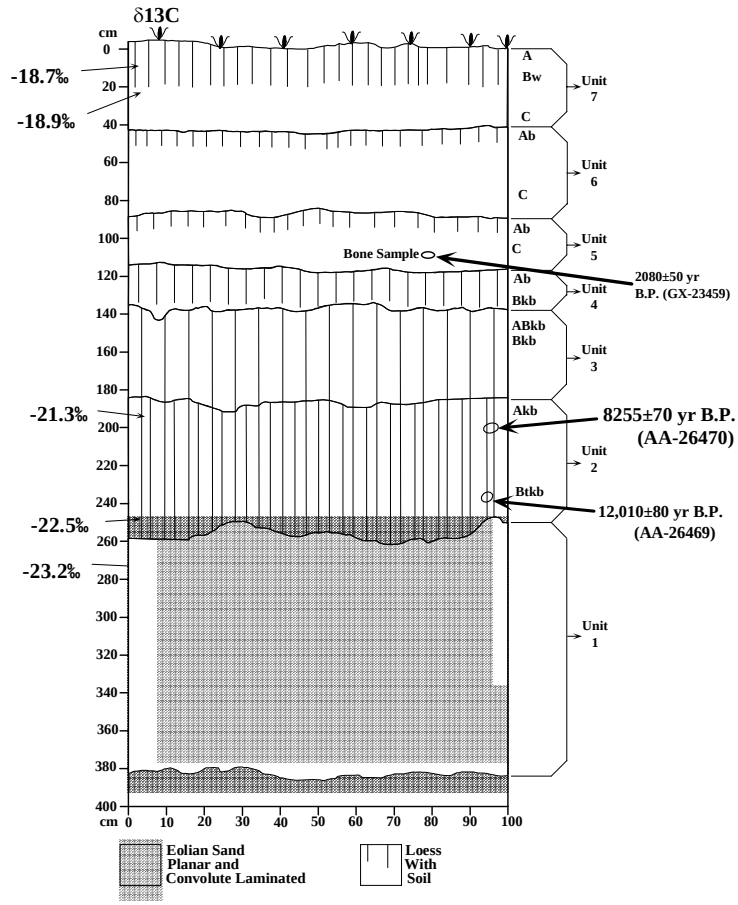

Figure 8. Profile of Stratigraphic Section 3.

Unit 3 is situated in the central portion of the section and is comprised of a 0.5-m-thick bed of clay loam (Figure 8, Appendix A). The entire unit has been pedogenically altered and represents the uppermost soil in the above described polygenetic sequence; in this case a very dark gray (10YR 3/1 moist) ABkb horizon with a clear irregular boundary and moderate amounts of organic carbon (0.69). It also contains sparse to moderate carbonate threads (hence the ABk designation); however the carbonates increase in the lower portion of the soil and actually form a Bk horizon which has been imprinted onto the former A horizon of the S1 soil (Figure 8). The irregular upper boundary of the unit, together with the accumulation of some carbonates in an otherwise dark-colored horizon, suggests that the upper portion of the epipedon (i.e., the former surface) may have been truncated by wind deflation subsequent to the S2 period of pedogenesis. Again, stratigraphic position, the relatively high level of soil carbonate accumulation, and the evidence for erosional truncation are similar to a number of Pick City Member soils described in the North Dakota Badlands (Kuehn 1995).

The upper circa 1.4 m of Section 3 are comprised of four medium-thick beds of loam, and fine to very fine sandy loam (Figure 8, Appendix A). Again, each is associated with a soil, but these are not as thick nor as well developed as the soils in underlying Units 2 and 3. For example, only the Unit 4 (S3) soil contains evidence of carbonate translocation; a Bkb horizon with common $CaCO_3$ threads along ped faces. The overlying soils in Units 5 and 6 contain only weak dark brown A horizons (10YR 3/2 and 10YR 3/1 respectively). The modern surface soil (S6 in Unit 7) is only slightly more well developed, ex-

hibiting an A/Bw profile. The A horizon is a dark grayish brown (10YR 4/2 moist) very fine sandy loam, while the Bw horizon is a 10YR 4/3 fine sandy loam with weak subangular blocky structure.

Stable carbon isotope samples were collected from each stratigraphic unit in Section 3, both from A and/or B soil horizons and from unaltered parent material. The results, presented in Appendix B, indicate a noticeably higher input of C_3 plants in the overall biomass associated with the section soils when compared to values recovered from Study Sections 5 and 6 (sod tables on the Upper Prairie surface). The only exception is that of the S1 surface soil at Section 3, which yielded $\delta^{13}C$ values of -18.9 (C horizon) and -18.7 (surface A horizon). Together these indicate a C_4 input of about 60 percent (Boutton 1996), which as discussed earlier, is in keeping with $\delta^{13}C$ values from other surface soils in the region (with values ranging from -19.0 to -17.0).

In all of the remaining underlying units, stable carbon values ranged fairly consistently between -20 and -23 (Appendix B), representing between 50 and 30 percent C_4 biomass (Boutton 1996). The lowest value (-23.2) was obtained from Unit 1, the Pleistocene laminated silty loam unit at the base of the section (Appendix B). The next lowest (-22.5) was obtained from the Btkb horizon situated at the bottom of Unit 2 and associated with a radiocarbon age of circa 12,000 yr BP. This value is similar to those recovered from more or less synchronous Aggie Brown Member soils in the Little Missouri Region (Kuehn 1995; Boutton et al. 1998), and reflects a predominance of C_3 plants produced under relatively cool and moist conditions during the late Pleistocene (Boutton et al. 1998). The values generally increase upward in the stratigraphic sequence from the Unit 2 Btkb (Appendix B). In the Akb horizon of the same unit, associated with a radiocarbon age of 8200 yr BP, the value is -21.3, which represents a C_4 plant input of only about 40 percent. The remaining units, including Unit 5, which was associated with a radiocarbon age of 2080 yr BP, have values that fairly consistently range from -20 to -21 (or circa 45 to 50 percent C_4 biomass).

Bone gelatin from a bison (?) metatarsal or metacarpal recovered from the Unit 5 C horizon (at 1.1 m below surface) produced an AMS radiocarbon age of 2080 ± 50 yr BP (GX-23459). This date is stratigraphically and temporally similar to radiocarbon ages obtained from several Riverdale Member loess localities in the Little Missouri Badlands (Kuehn 1995) which were deposited between 4500 yr BP to present (Clayton et al. 1976; Kuehn 1995). Together with the ages of 8200 and 12,000 yr BP from Unit 2 and the evidence for soil formation under conditions of reduced precipitation in the overlying Unit 3, S2 soil (i.e., the high levels of carbonate accumulation), this indicates that the eolian sediments at Stratigraphic Section 3 are lithologically, pedogenically, and temporally similar to the Aggie Brown, Pick City, and Riverdale Members of the Oahe Formation in the badlands of western North Dakota (cf. Kuehn 1997). Regardless, the important point here is that, whether or not the loess sequence extant in stratigraphic Section 3 is eventually viewed as analogous to the Oahe Formation, upland settings such as this have some of the most complete sediment records (spanning the late Pleistocene through the Holocene) of any major landform category in the White River Badlands, with the rare exception of sites such as Lange-Ferguson. Another example of a similar setting, although not as well exposed or documented, is Stratigraphic Section 4 on Cuny Table.

Cuny Table: Stratigraphic Section 4

The final upland setting to be examined is Cuny Table, another high, prominent surface remnant (Figure 3). Stratigraphic Section 4 consists of a 4.5-m-thick eolian deposit, of which only the upper 2.3 m was exposed. The lower portion was covered by talus material. The entire 4.5-m-thick section was underlain by a bed of coarse alluvial sand and gravel which has been previously correlated with the early Pleistocene Medicine Root gravels (Harksen and MacDonald 1969; White 1982). These lag deposits are in turn underlain by Tertiary-aged bedrock. In other portions of Cuny Table, which covers an area over 9 miles long by 3 miles wide, surface sediments are potentially complex, and include visible sand dunes, and, according to other researchers, accumulations of late Tertiary/early Quaternary Pearlette ash (Naeser et al. 1973, Hallburg 1980, from White 1982:46–47) and possible deposits of the middle to late Pleistocene Red Dog loess (Harksen 1968). In any case, Stratigraphic Section 4 focused solely on an eolian man-

tle that appears Holocene and perhaps late Pleistocene in age. Given the size of the plateau, the spatial distribution of this mantle cannot presently be estimated.

The exposed portion of Section 4 contains a minimum of four stratigraphic units, each of which is again capped with a soil (Figure 9). The lowest, Unit 1, is a thick bed of sandy clay loam, all of which has been pedogenically altered (i.e., a Bkb horizon). The soil contains significant (Stage 2) amounts of carbonates present as coalesced filaments and abundant powdery forms, mostly concentrated along ped faces. The soil lacks a visible A horizon, which, together with an abrupt upper boundary, is suggestive of post-pedogenic truncation. Organic carbon recovered from the Unit 1 soil produced an AMS radiocarbon age of 6000 ± 65 yr BP (AA-26467). Again, this age, together with the high carbonate content and stratigraphic position of the soil, suggest that it may be analogous to paleosols in the Pick City Member of the Oahe Formation identified in the Little Missouri region (Kuehn 1995, 1997). It is also similar to what Reider (1980, 1990) and others, refer to as "Altithermal soils," which are extant at a number of archeological sites in Wyoming and Colorado.

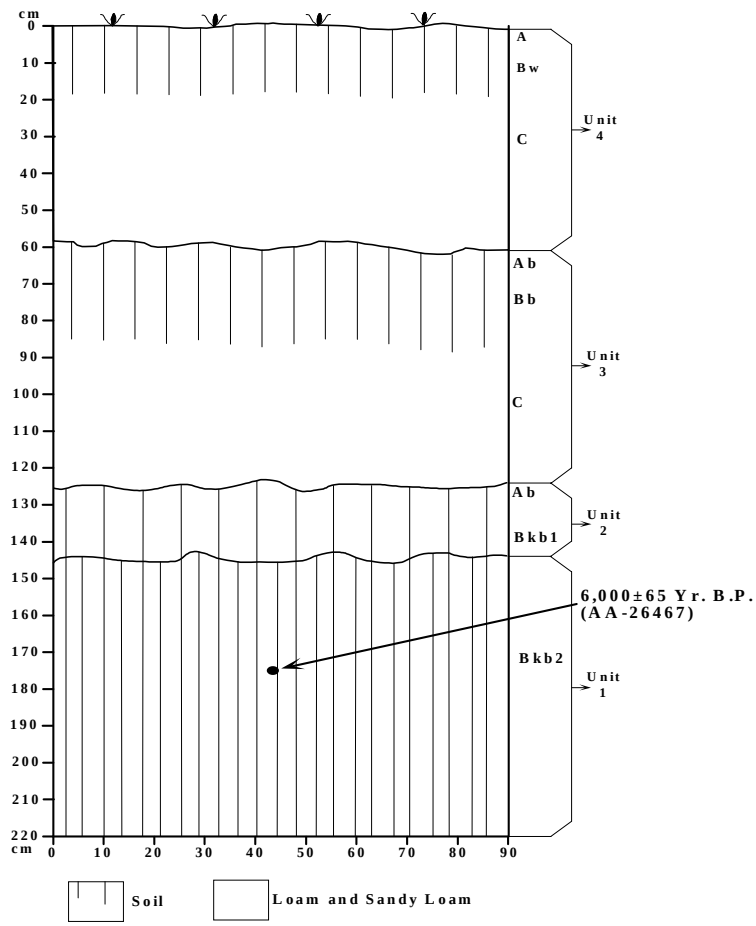

Figure 9. Profile of Stratigraphic Section 4.

Unit 2 lies apparently unconformably over Unit 1 and consists of a 0.2-m-thick bed of loam, all of which has been pedogenically altered into an Ab/Bk profile (S2) (Figure 9). The S2 soil contains a 12-cm-thick Ab horizon (10YR 3/2 moist) and an underlying Bk horizon that is imprinted onto the former epipedon of the Unit 1 soil; much in the same manner as the lower soils described at Section 3 (Figure 8). The carbonates in the S2 soil, while exhibiting similar forms, are not quite as abundant as they are in the S1 soil. In addition, the S2 A horizon has an organic carbon content that is four times greater than the organic carbon in Unit 1 (0.4 percent vs. 0.1 percent, Appendix A). No radiometric data were recovered from Unit 2, but its position and pedogenic characteristics again suggest a probable middle Holocene age, perhaps deposited and pedogenically altered during still relatively warm and dry climatic conditions.

The upper two units (3 and 4) were not studied in detail because of limited field time. They are, however, thick beds of very fine sandy loam with thin A/Bw profiles. Their position in the section and a relative paucity of carbonates suggests short-lived pedogenic episodes that likely occurred during the late Holocene.

Lower Prairie Surface/Sage Creek Basin

The final two study sections are situated in what may generally be called lowland settings. These settings contain myriad depositional sedimentary environments and associated landforms that vary considerably in age and elevation. For the sake of convenience, however, they are all combined under the rubric of the Lower Prairie surface (Ward 1922). In very general terms, this term refers to all landforms situated below the Badlands Wall, including modern and former floodplains, and the channels of modern streams

and gullies. Investigations into these types of landforms were concentrated in the Sage Creek Basin (Figure 2), and included fairly extensive surface reconnaissance and the examination of two stratigraphic study sections. Both sections are located along the South Fork of Sage Creek and include a terrace and an alluvial fan environment. While the facies associated with these depositional environments can be identified and differentiated on the basis of lithology and primary sedimentary structure (cf. Reineck and Singh 1980), they are often difficult to recognize in the field due to the complex nature of vertical and horizontal facies relationships in badland environments (cf. Campbell 1989; Kuehn 1995). This complexity is partially erosional (i.e., the truncation of floodplain and fan fills, etc.), and partially depositional in origin. While erosional events obviously remove sediments, depositional processes tend to not only bury sediments, but also mask the contacts between facies (Waters 1992). Examples of the latter include the sporadic but more or less ongoing deposition of slopewash, both in the form of thin aprons or thick valley fills, and colluvium, which can include slumps, creep, and debris flow deposits (Ritter 1978).

Previous geomorphic investigations in lowland environments within the White River Badlands have been conducted by Schumm (1956); Ward (1922); Harksen (1974); White and Hannus (1985); White (1982); Kowal (1997); Haynes (1985); and Hannus (1990), among others. Of these, the investigations by Kowal (1997) on the recent geomorphology of Sage Creek are the most immediately relevant. The various reports on the alluvial stratigraphy of the Paleoindian Lange-Ferguson site (Hannus 1990; Haynes 1985; White and Hannus (1985), are also relevant to the focus of the present research, but they additionally illustrate the fact that some lowland sediment packages as old as the late Pleistocene are still, remarkably, preserved in an area as geomorphically dynamic as the badlands. Such preservation, however, is likely to be very rare.

Holocene Terraces and Alluvial Fans

White and Hannus (1985) describe two major episodes of late Pleistocene/Holocene alluvial deposition within the White River Badlands; one between about 10,500 and 5000 yr BP (termed the first alluvial episode), and one between circa 2500 and 850 yr BP, termed the second alluvial episode (White and Hannus 1985). The data recovered by Kowal in her work at Sage Creek and the data gathered during the course of the present investigations tend to support the basic temporal framework of this model. Perhaps more important, both White and Hannus (1985) and Kowal (1997) are able to identify similarities between the timing of these two main events with reported alluvial and/or climatic chronologies from other portions of the Great Plains (cf. Bluemle and Clayton 1982; Albanese and Wilson 1974; May 1986; Fredlund 1996). The chronology is also quite similar to the late Quaternary alluvial history of the Little Missouri Badlands as interpreted by Kuehn (1993, 1995); Gonzalez (1987), and Hamilton (1967). In spite of these similarities, there are, however, differences in synchronicity, preservation, and geomorphic processes that still hamper the correlation of late Quaternary alluvial sediments, both locally and regionally.

At the local scale, that is within the White River Badlands, variability is evident both between drainage basins and perhaps even within a single drainage system. Noting the probability that the second major alluvial episode (2500–850 yr BP) was likely interrupted by multiple smaller-scale erosional events, White and Hannus (1985:92) point out two very important factors: first, they recognize that complexity is likely to occur within small spatial and temporal scales; and second, they elucidate the probability that many of the smaller events were the result of complex response to conditions of local geomorphic thresholds. That a portion of one drainage basin may be experiencing alluvial aggradation, while another basin is experiencing erosion, is a common geomorphic characteristic of badland environments, a characteristic due to differences in bedrock lithology, gullying, slope aspect, fire-induced vegetative change, hillslope erosion, piping, and isolated colluvial events such as slumping. These differences can result in numerous variations in sediment yield, sediment storage, and stream base-levels at any given time within a relatively small area (Schumm 1973; Campbell 1989; Kuehn 1995). In addition to noting local complex-response mechanisms, White and Hannus (1985:92) also point out that climatically induced changes in alluvial processes may also be time-transgressive across large physiographic regions. When one adds these complex set of variables together, one is faced with a problem of correlation, of the ability to recognize, trace, and demonstrate conclusively, the presence of a particular alluvial lithostratigraphic unit (a

named terrace, for instance) in different localities. This issue was identified by Albanese and Wilson (1974:17) and Albanese (1978: 389) as the major hindrance to both regional correlation within the Northwestern Plains, and to climatic reconstruction based on climate/sediment yield/sediment storage data.

This fundamental research problem is fortunately decreasing in scope, as more geomorphic and geoarcheological investigations are being conducted within specific drainages throughout the Great Plains. With the cumulative data gathered by various investigators who have conducted research in the region, more of the large-scale picture emerges. Meanwhile, however, the purpose of the present reconnaissance was not to construct or deconstruct any particular alluvial chronology, but to identify for archeologists areas that are most likely to contain contextually intact prehistoric materials. A fine-tuning of the local alluvial geomorphic history of the badlands region is well beyond the scope of this project. Therefore, it is both appropriate and judicious to use the basic framework of the two-episode model already identified by White and Hannus (1985).

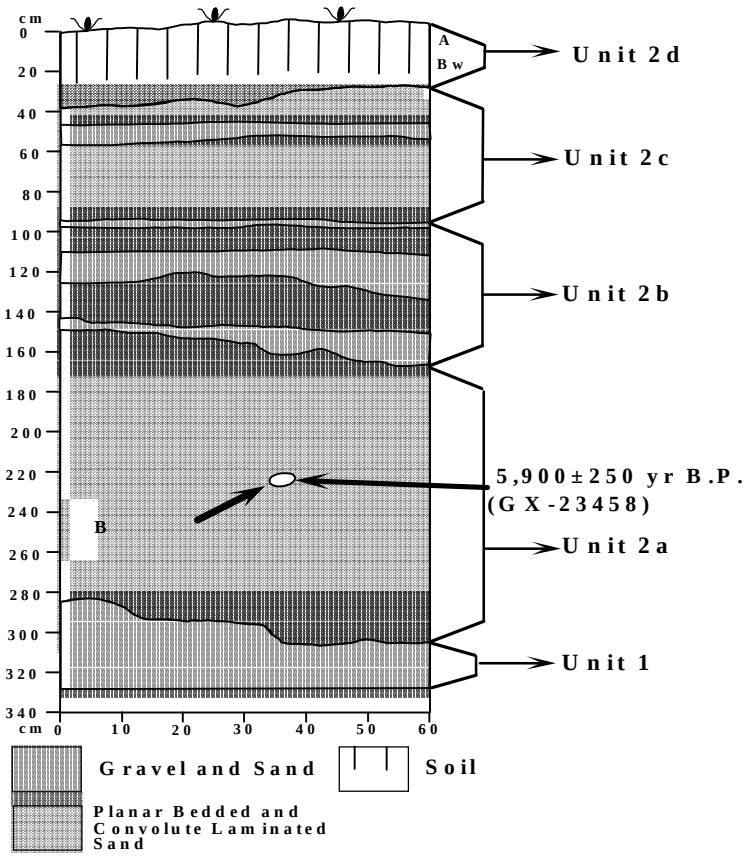

Figure 10. Profile of Stratigraphic Section 7a.

Kowal (1997) identified two extant Holocene terraces along a 3-km section of the main branch of Sage Creek in the North Unit of the park. One, labeled the T2 terrace, is comprised of alluvial valley fill which aggraded between 2200 and 800 years ago, and was formed after Sage Creek experienced a period of channel incision and reduced meandering around 200 yr BP (Kowal 1997:70). The incision, together with previous erosion of the upper portion of the T2 fill, created an alluvial strath terrace identified as T1. The T2 tread rises approximately 6.5 to 7 m above the modern channel floor, while the T1 tread is about 3.5 to 4.0 m lower (Kowal 1997:31, 32). Both contain the same, generally fining-upward, unit of late Holocene alluvial valley fill (Kowal 1997). The estimated timing of the valley fill is synchronous with the second alluvial episode of White and Hannus (1985).

Not identified in Kowal's immediate Sage Creek study area were sediments deposited during the first alluvial episode (circa 10,500–5000 BP), although Kowal notes the presence of possible older terrace or alluvial fan surface remnants several meters above the T2 tread (Kowal 1997). The sediments associated with the first episode were studied in the Lange Creek drainage and at the associated Lange-Ferguson site a short distance south of the South Unit (White and Hannus 1985; Haynes 1985; Hannus 1990). Unlike the rather consistent fining-upward sequence of the T2 (i.e., second episode) alluvial fill in Sage Creek, the sediment identified at several eroded alluvial remnants (referred to as "buttes") at Lange-Ferguson are more complex and range from silty pond sediments associated with mammoth remains near the lower portion of one of the buttes, to overlying units of sand and sand with mudstone gravels (Hannus 1990:Figure 6).

Figure 11. Photograph of Stratigraphic Sections 7a and 7b.

Two adjacent stratigraphic sections were investigated along Sage Creek during the course of the current effort. These contain what appear to be deposits associated with both the second episode T2 terrace fill and the first alluvial episode. The latter is referred to as the T3 terrace fill. It is represented at Stratigraphic Section 7a, while the T2 fill, and overlying alluvial fan sediments, are represented at Section 7b, which is extant in a clearly visible cut and fill sequence immediately adjacent to the T3 remnant (Figures 10, 11, 12). Both sections are situated along an extensive vertical cut exposed on the western bank of the South Fork of Sage Creek (Figure 2). The exposure, which forms the outside edge of a meander loop opposite an actively aggrading point bar, is located a short distance south of the Sage Creek Campground, and 2.5 km southwest of the Main Fork of Sage Creek (Figure 2).

It is important to note here that fluvial stream deposits associated with the T1, T2, and TO terrace fills along the South Fork of Sage Creek are clearly differentiated from local alluvial fan and colluvial apron facies on the basis of color. The former, throughout at least the lower several km of the South Fork valley, are rather uniformly light gray in color while the latter are noticeably more brown (reflecting the color of the adjacent local bedrock from which they originated).

Stratigraphic Section 7a, visible in the southern portion of a large cutbank, consists of 2.6 m of exposed alluvial sediments, the tops of which lie approximately 11 m above the present floor of the channel. This is very similar to the elevation of the so-called “butte” tops at the Lange-Ferguson site, which lie 12 m above Lange Creek and are representative of the first alluvial episode. The lower portion of Section 7a, below 2.6 m below the ground surface, is obscured by talus and thick vegetation, thus the actual thickness of the T3 alluvium is unknown. A portion of the modern T0 floodplain, which rises about 1.5 m above the channel bottom, is inset against the base of the section, while Pierre Shale bedrock is exposed at the base of adjacent Section 7b immediately to the north. The upper contact of the shale bedrock rises in the direction of Section 7a as a result of channel cutting that occurred after deposition of the T2 terrace fill. Again, the cut and fill sequence at Section 7b is clearly visible in the exposure (Figure 11). Another cut and fill sequence is likely present along the southern margin of 7a, although in this instance, the contact appears to be with the T1 rather than T2 fill. This contact was again obscured by colluvium and vegetation.

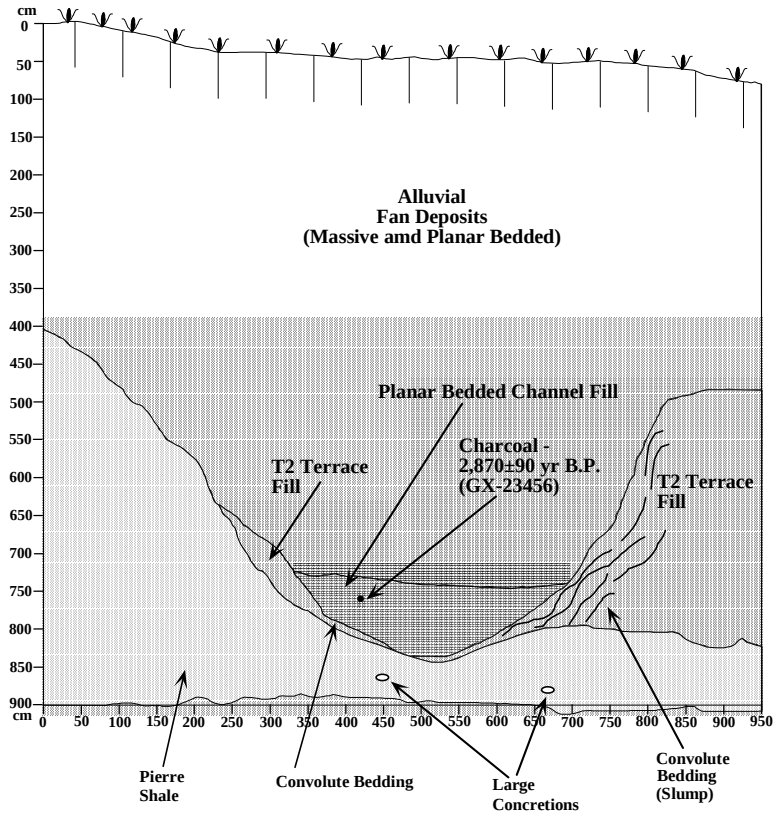

Figure 12. Profile of Stratigraphic Section 7b.

The exposed portion of Section 7a contains two major stratigraphic units: (1) Unit 1, a lower bed of massive coarse sand and gravel (including abundant clasts of Pierre Shale); and (2) Unit 2, which is comprised of 3 subunits: an overlying unit of planar-laminated, ripple-laminated, and convoluted sand (Unit 2a), a number of thin horizontal beds of sand and gravel (Unit 2b), and an overlying bed (Unit 2c) of largely planar-bedded sands (Figure 10). The only soil present is that associated with the modern surface, which exhibits an A/Bwk profile. The A horizon is a dark brown (10YR 3/3) loam, while the Bwk horizon is a brown (10YR 4/3) loam with moderate subangular blocky structure and moderate reaction.

A complete bison vertebra was recovered from the Unit 2a planar-laminated sands (Figure 10). Bone apatite from the element yielded a standard radiocarbon age of 5900 ± 250 yr BP (GX-23458). Although bone is certainly not an optimal substance to date, there is presently no evidence to suggest that the apatite radiocarbon age is in itself inaccurate. On the other hand, its temporal and contextual relationship with the T3 terrace sediments is by no means certain. Obviously prior to burial by alluvium, the animal had to decompose after death, become disarticulated, and its skeletal remains had to be transported to the site of final deposition. The excellent state of bone preservation evident on the specimen, and the lack of any noticeable water-generated rounding or smoothing, suggest that it was not transported very far. Also, it was associated with laminated sands and not coarser-grained gravels, suggesting that the flow velocity during the time of the specimens deposition was sufficient to transport sand-sized rather than gravel-sized load (with the bone being lighter than most gravels clasts in the basal unit at the section). This again indicates that the transport distance may have been limited. In addition, the stratigraphic relationship between the T3 fill and that of the T2 fill immediately adjacent in Section 7b, together with the height of the apparently eroded terrace tread (11 m above the modern channel bottom as opposed to the height of T2, which is 6.7–7.0 m) also indicate that the section represents an alluvial deposit that is older than that of the T2 fill. With the radiocarbon age indicative of the time of the animal's death and not its disarticulation and subsequent deposition, all that can be said concerning the stratigraphic context of the bone is that its apparent age must be considered a maximum age of the sediments immediately associated with it.

The lithology and stratigraphy of Section 7a are not representative of classic upward-fining sequences usually associated with meandering streams, except perhaps the lower portion of a point bar sequence (cf. Boggs 1987:356–359; Reineck and Singh 1980). The sequence of horizontally bedded basal gravels overlain by sandy planar and parallel-laminated sands are more typical of bar sequences in braided streams with mixed bedloads of sand and gravel (Cant 1982:121–122). In any case, the sedimentary composition of Section 7a is certainly more similar to portions of the alluvial valley fill deposits associated with the first alluvial episode deposits at Lange-Ferguson than they are to the second episode meandering stream deposits along Sage Creek (cf. Kowal 1997).

Stratigraphic Section 7b forms the northern portion of the large cutbank exposure (Figure 11) and consists of a cut and fill sequence associated with Pierre Shale, T2 terrace fill, and more recent alluvial fan facies. It represents a former tributary stream channel that incised 3.25 m of the T2 terrace fill along with about 0.5 m of the underlying Pierre Shale, before filling with alluvial fan sediment to a height of 9.5 m above the bottom of the present South Fork channel (Figures 11 and 12). The gray (10YR 5/1) and light gray (10YR 6/1) T2 sediments are concentrated along the northern portion of the channel cut, but are also partially preserved along the bottom southern portion as well (Figure 12). The regular alluvial stratigraphy of the terrace fill, as generally described quite accurately by Kowal (1997), has been convoluted by slumping that occurred along the most basal portions of the channel (Figure 12). The very dark gray (10YR 3/1) Pierre Shale is concentrated along the southern portion of the channel, but also underlies both the channel and the T2 fill in the northern end of the section (Figure 12). The upper 8.25 m of the alluvial fan channel fill consists of a brown (10YR 4/3) silty clay and silty clay loam that is arranged in generally thick horizontal beds. The lower 1.25 m of fan material, at the bottom of the channel, are a brown silty loam and silty clay loam arranged in distinctive thin horizontal beds. The remains of a former tree burn are extant in the upper portion of the thin, horizontally bedded alluvial fan sediment (Figure 12). Charcoal recovered from the burn produced a standard radiocarbon age of 2870 ± 90 yr BP (GX-23456). There is again no reason to distrust the accuracy of this age, and the sample itself was recovered from channel fill sediment in relatively good geological context. The only visible soil associated with the entire 7b section is that of the surface soil at the top of the alluvial fan deposits, which contains a 1.0 m thick A/Bw/Bk horizon profile.

At this point it should be stressed that conclusions based on the data recovered from two adjacent sections, and associated with only two radiocarbon ages, are hardly sufficient evidence upon which a sound alluvial chronology can be built. Experience in other badland settings suggests that such chronologies are dependent upon a sufficiently large number of radiocarbon ages from an equally large number of stratigraphic sections, in order to recognize the entire stratigraphic sequence of any given area. Multiple dates are also required in order to identify and rule out the more than occasional age that is either contaminated or in questionable geologic context. With this caveat in mind, the information derived from Sections 7a and 7b are *indications* that: (1) the preservation of T3 terrace sediments associated with the earlier alluvial episode as described by White and Hannus (1985) may have occurred between circa 10,500 and 5000 BP; and (2) the beginning of T2 episode of aggradation may have taken place slightly earlier than the circa 2200 BP age proposed by Kowal on the basis of two radiocarbon ages recovered from the Main Fork of Sage Creek. The differences, however, are relatively minor, i.e., 430 years at one standard deviation between the age recovered from Section 7b and the oldest T2 age reported by Kowal (1997:54). Both ages are reasonably similar to White and Hannus' original estimate of 2500 yr BP for the initiation of the later alluvial episode (1985:92), which as stated earlier, is similar to the timing of the T2 episode of aggradation in the Little Missouri Badlands, i.e., 2700 to 800 yr BP according to Kuehn (1995:166).

Discussion and Interpretations

The following discussion will focus on the geologic and geomorphic context of archeological resources within Badlands National Park. It will do so by examining the spatial and temporal distribution of the known archeological data base, particularly recorded sites with identified temporal and cultural affiliations.

Spatial/Temporal Aspects of the Known Archeological Record

According to existing archeological records on file at Badlands National Park and the Midwest Archeological Center, and as summarized in Hannus et al. (2002), as of 2002, over 12,000 acres within the park have been surveyed for cultural resources. These surveys have resulted in the recording of approximately 257 prehistoric and historic archeological sites and 77 isolated activity areas (Hannus et al. 2002:17). Of this number, about 70 prehistoric sites can be assigned to named cultural groups or general time periods, while 162 remain temporally or culturally unclassified. Although cumulatively these sites represent a significant body of archeological data, only a handful of the recorded sites in the park (n = 13) have been identified as Archaic or older in age. All of the remaining sites with diagnostic artifacts date to within the last circa 2,100 years, and are assigned to the Plains Woodland tradition, Avonlea complex, Besant complex, Plains Village tradition, or to a number of unclassified Late Prehistoric or Protohistoric groups (Hannus et al. 2002:106–141).

The sites older than circa 2,100 yr BP include: three sites containing Paleoindian projectile points; one site identified as Early Plains Archaic; one site identified as Middle Plains Archaic (McKean); and eight sites identified as Late Plains Archaic on the basis of Pelican Lake projectile points and/or radiocarbon ages (Hannus et al. 2002; Jones 1993; Beaubien 1953; Taylor 1961; Mueller 1982; Lueck and Butterbrodt 1984). It should be noted that a number of Archaic and Paleoindian components have been reported from areas adjacent to the park. In addition to the well-studied Lange-Ferguson Clovis site (Hannus 1990), Nowak and Hannus (1981) and Hannus et al. (2002) report that a number of fluted projectile points have been recovered from the White River Badlands area. Additionally, one Early Archaic site was recorded in the vicinity of the park by Wheeler in 1949, and a number of other Middle and Late Archaic sites have been reported by Lueck and Butterbrodt (1984), Sigstad (1974), Sundstrom and Malone (1982), and Nowak and Hannus (1984). Sundstrom (personal communication 1997) reports testing a site in alluvial fan sediments along the White River not far from the park boundary that contained both a Middle Archaic component and an underlying, but yet unidentified, older component.

In addition, previous archeological investigations in the park have resulted in the procurement of radiocarbon ages from at least 16 prehistoric sites (Hannus et al. 2002; Jones 1993). They range from circa 250 yr BP to 2300 yr BP and were recovered from archeological features situated in slump deposits along the face of the Badlands Wall, from sod tables in the Upper Prairie surface just above the wall, and from eroding cultural features in alluvial deposits along Fog Creek (Hannus et al. 2002).

In the North Unit, the largest suite of radiocarbon dates was recovered from the Pinnacles site (39PN9), a multiple component site located in eroded and slumped sod table remnants along the top of the Badlands Wall. The Pinnacles site has been the focus of excavations in 1958, 1993, and 2000 (Taylor 1961; Jones 1996; Hannus et al. 2002). These investigations have resulted in the procurement of at least 14 radiocarbon dates, with single or pooled mean ages ranging from 2329 to 250 yr BP (Hannus et al. 2002:72–95; Jones 1996). Cultural components identified at the Pinnacles site include unclassified Late Plains Archaic, Plains Woodland, and Plains Village.

In the South Unit, virtually all of the available radiocarbon data from archeological sites have come from the Fog Creek drainage. Fog Creek is a prominent ephemeral or seasonal stream located below the southeastern end of Cuny Plateau. The dates, collected from six individual sites, range in age from 1590 ± 70 yr BP to 750 ± 250 yr BP and were recovered from eroding cultural features, some of which were buried by as much as 5 m of reworked alluvial sediment (Jones 1993; White and Hannus 1985).

As briefly mentioned, four additional radiocarbon dates are reported by Kowal in her 1997 MS thesis on the geomorphology of Sage Creek. These were recovered from the second episode alluvial valley fill (one of which was collected from a "hearth" feature), and range in age from 2210 to 270 yr BP (Kowal 1997).

A more recent suite of geomorphic-based radiocarbon dates was recovered by Rawling (in press), as part of dissertation research into eolian deposits in South Unit upland settings. These ages apparently range from late Pleistocene through the early–middle Holocene, however specific results have not yet been made public.

Finally, the current geoarcheological research effort yielded an additional ten radiocarbon ages ranging from 1435 ± 210 yr BP (GX-23457) to 12,010 ± 80 yr BP (AA-26469) that were collected from sod tables on the Upper Prairie surface, from loess mantles on Early Pleistocene/Tertiary (?) surfaces at Sheep Mountain and Cuny Tables, and from the Lower Prairie surface, specifically at a high terrace fill remnant and infilled channel along the South Fork of Sage Creek (Appendix C).

Geologic Context and Archeological Site Potential

In light of the stratigraphic, geomorphic, and archeological data just summarized, it is now possible to draw some tentative conclusions concerning the geological context of prehistoric sites in Badlands National Park. The oldest archeological deposits are associated with the Paleoindian Tradition and are represented by three sites which yielded potentially diagnostic projectile points (Agate Basin and lanceolate). One of the points came from the top of an early Pleistocene/Tertiary plateau surface in the South Unit, and one came from a gravel-covered sod table located on the Upper Prairie surface (Jones 1996; Hannus et al. 2002). The third was recovered from eroded foothills above the White River in the South Unit (Hannus et al. 2002). In addition to Paleoindian materials, the single site with an Early Plains Archaic component was also located on the Upper Prairie surface in the North Unit.

In addition to the Paleoindian and Early Plains Archaic components (and a fair number of Late Prehistoric and Plains Villages sites), sod tables on the Upper Prairie surface are also associated with two of the eight previously recorded Late Plains Archaic/Pelican Lake sites. Recall also, that the three tables most recently studied contained remnant buried soils which yielded radiocarbon ages of 1435 ± 210 yr BP (Section 5), 1990 ± 80 yr BP (Section 2), and 1535 ± 50 yr BP (Section 6). This association between sod table sediments and artifacts with radically different ages suggests that the deposition of sod table parent materials was not part of a single aggradational event. Rather, they appear to represent multiple episodes of alluvial and colluvial aggradation that occurred throughout the Holocene. Subsequent to their deposition, the sediments were highly dissected by processes that were highly variable in scope, forming the spatially discordant sod table erosional remnants that now frequent the Upper Prairie surface.

Cumulatively, the available site data suggest that portions of the Upper Prairie surface near the edge of the Badlands Wall, whether or not associated with sod table deposits, have generally good potential for Late Prehistoric, Archaic, and even Paleoindian sites, although this potential is likely to decrease concurrently with increased age. The same must be said for that portion of the Missouri Plateau that lies between the Pinnacles area and the Pleistocene Cheyenne River strath terraces to the west (Figure 2). This area is rather heavily dissected by a series of stream valleys and interfluves and likely represents a gradation between the Upper Prairie surface and the Pleistocene terrace surfaces. Sites from all prehistoric time periods may occur in these areas, but are more likely to have good archeological integrity in localities where Holocene sediment accumulation has been the greatest (such as valley fills and alluvial fans). Interfluves, or other ridge-like upland landforms here, also have good site potential, but sediments in these settings are likely to be shallow and therefore conducive to the mixing of different cultural components.

Two additional Late Archaic sites were located in prominent slump block deposits just below the top of the Wall. Both sites contain multiple components which also include Late Woodland and Initial Middle Missouri materials (Jones 1996; Johnson 1989). It is not known whether or not the archeological components at these sites are associated with human occupations that took place before, or after, the major

slumping events. In any case, the available archeological data suggest that colluvial deposits along the margin of the Upper Prairie surface have good potential for intact archeological materials, however, the trend here appears to be one of sites dating to the Late Archaic, Plains Woodland, and Plains Village traditions.

The early Pleistocene/Tertiary (?) plateau surfaces, which are most common in the South Unit of the park, contain extensive mantles of eolian silt and sand that have the potential to contain archeological materials dating from Paleoindian through the Late Prehistoric. While deposits of pre-Wisconsin Red Dog loess have been identified on some of the local plateaus (Harksen 1968), at least two, Sheep Mountain Table and Cuny Table, are also mantled with deposits of loess that are late Pleistocene through Holocene in age, and that look to be temporally and lithologically equivalent to the previously described members of the Oahe Formation in North Dakota (Kuehn 1993, 1995). These sections yielded radiocarbon ages which are temporally analogous to ages associated with the late Pleistocene/early Holocene Aggie Brown Member, the early to middle Holocene Pick City Member, and the late Holocene Riverdale Member. This stratigraphic sequence was most well preserved at Stratigraphic Section 3 on Sheep Mountain Table. Whatever name is applied to these eolian materials, such settings have very good potential for materials associated with all major cultural periods. Previous studies in other badland regions suggest that such upland settings are, by and large, substantially less geomorphically dynamic than those in lowland settings such as Holocene terraces, fans, modern stream channels and modern floodplains (cf. Kuehn 1997: Waters and Kuehn 1996).

The oldest site recorded in lowland alluvial settings is one associated with a Middle Plains Archaic (McKean) component that was identified in a terrace setting above the White River. While located outside the actual boundaries of the park, the site, together with data summarized in the subsequent section of this report, suggests that stream valleys do have some potential to contain archeological sites associated with both the earlier and later alluvial episodes (i.e., the entire Holocene). Like the Upper Prairie surface/Badlands Wall area, but much more so, the evidence suggests that sites older than the later episode are likely to be only very rarely preserved. In the Sage Creek Basin, sites dating as old as perhaps 2800 years BP are possible within the lower portions of the T2 terrace fill, but good preservation should be expected only in sediments deposited under relatively low-energy conditions (cf. Waters 1992). The current study suggests that there are, in fact, some isolated remnants of the T3 terrace fill that could date to at least circa 5900 BP and possibly as far back as 10,500 BP. Recall, however, that the T3 fill appears, at this limited stage of the research, to be more coarse-grained than that of the T2 valley fill, and therefore potentially less likely to contain intact materials. There is, of course, always the possibility of the rare exception such as Lange-Ferguson, which was associated with not only the earlier alluvial episode, but also with low-energy pond sediments that are traditionally conducive to good site preservation. Additional locations such as these cannot be ruled out.

Other than the middle Holocene age suggested by the presence of a McKean archeological component, no additional data were gathered during this study from the area's two largest streams, the White and Cheyenne Rivers. As a result, there is little else that can be said about the age of terrace, fan, and floodplain sediments associated with these particular valleys. Previous archeological research conducted outside of the park, however, indicates that alluvial settings along the White River in particular have the potential to contain Paleoindian, Early to Late Archaic, Woodland, Plains Village, and even protohistoric and historic materials (cf. Nowak and Hannus 1981, L. Sundstrom, personal communication 1997). Unfortunately, only a very small portion of the White River valley is actually located within the park boundaries. Therefore, substantive data recovery along the largest streams in the region must await future research efforts. One aspect of potential usefulness to archeologists when working in lowland settings is the apparent distinction in color that was observed along the South Fork of Sage Creek between the TO, T1, T2, and even T3 fluvial sediments, and those deposited under alluvial fan and slopewash environments. Recall that the fluvial sediments appeared uniformly lighter gray in color than the fan and slopewash sediments, that tended to be darker. This dichotomy, however, is solely dependent upon the lithology of the parent material from which the local slopewash and fan sediments were derived, and therefore cannot be expected to occur throughout the lowlands on any predictable basis.

With regard to fan and slopewash sediments, at the present time, there are limited temporal data available to shed light on their archeological potential. The reconnaissance portion of the recent inventory suggests that fans and slopewash aprons are likely to occur in abundance throughout most of the local drainage basins. These can be observed at various heights above the modern channels, although the majority should be situated at about the same height as the T2 and T1 surfaces (due to similar factors of sediment preservation). Others however, will be extant as high as the T3 surface or even higher. Again, these potentially older deposits are not going to be commonplace. The only alluvial fan investigated during the present study was the one extant at Section 7b, which filled a former channel that had incised the T2 terrace sediments, and is therefore, younger than the T2 fill. The same fan also mantled portions of the T2 fill adjacent to the channel cut.

In the Little Missouri Badlands of North Dakota, research suggests that major episodes of alluvial fan aggradation tend to more or less correspond with major events of stream aggradation (Kuehn 1995). This could be related to the fact that both fans and floodplains are affected by climatically induced increases and decreases in sediment yield from adjacent hillslopes. The synchronicity between the two aggradational environments, however, has by no means been conclusively demonstrated, and in fact, local variation in slope morphology, lithology, aspect, and vegetative cover (and also localized episodes of slumping, piping, and gullying), are likely to produce a situation where the preservation of fan sediments may be highly variable, and therefore not particularly amenable to temporal and spatial prediction.

In closing, the above discussion summarizes the body of information currently available concerning contextual relationships between geologic/geomorphic/landform sequences and the distribution and preservation of archeological sites in Badlands National Park. The data gathered were preliminary, and the research itself was at the reconnaissance level. There is much additional work to do if archeologists are going to be able to construct reliable, testable, hypotheses concerning basic topics such as temporal use of the badlands, the role of badland environments within the settlement pattern of seasonally mobile hunter-gatherer groups, and perhaps most importantly, many substantive aspects of the lifeways of the regions oldest cultural groups (i.e., Paleoindian, Early and Middle Plains Archaic). Badland settings are like no others when it comes to the dynamics, complexity, synchronicity, and overall impact of geomorphic processes on the archeological record (Kuehn 1995; Waters and Kuehn 1996). One of the benefits of utilizing a contextual approach to archeological research is that fact that data gathering is not limited to a single scientific discipline: input is required from a multitude of interdisciplinary data sources. It is this collaboration that will eventually fill in the remaining temporal and spatial gaps created by the badlands dynamic geologic history.

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Appendix A

Summary of Sediment Characterization Analysis

SOIL CHARACTERIZATION LABORATORY
SOIL AND CROP SCIENCES DEPT., THE TEXAS AGRICULTURAL EXPERIMENT STATION

SOIL SERIES: PEDON NUMBER:
SOIL FAMILY:
LOCATION: Badlands Nat'l Park, SD

LAB NO	DEPTH (CM)	HORIZON	PARTICLE SIZE DISTRIBUTION (MM) SAND VC (2.0-1.0)	C (1.0-0.5)	M (0.5-0.25)	F (0.25-0.10)	VF (0.10-0.05)	TOTAL (2.0-0.05)	SILT FINE (0.02-0.002)	TOTAL (0.05-0.002)	CLAY FINE (< 0.0002)	TOTAL (< 0.002)	TEXTURE CLASS	COARSE FRAGMENTS %
			%											
			Strat. Sect. #1 Quinn Table											
D2380	FS# 2	1	0.3	0.5	0.2	0.3	0.4	1.7	16.9	19.0	29.5	79.3	C	
D2381	FS# 3	2a	27.1	38.4	13.1	5.0	4.3	87.9	2.8	6.4	2.1	5.7	CoS	55
D2382	FS# 4	2b	8.0	16.8	7.1	7.1	22.6	61.6	11.8	28.4	2.1	10.0	SL	3
D2383	FS# 5	2c	12.3	31.1	14.3	8.1	12.3	78.1	5.8	14.8	1.7	7.1	LCoS	12
D2384	FS# 7	2d	19.3	33.4	17.6	10.7	5.9	86.9	2.5	5.7	2.5	7.4	LCoS	32
D2385	FS# 6	2e	10.5	26.3	17.2	14.3	12.6	80.9	4.6	10.5	3.2	8.6	LCoS	16
D2386	FS# 8	3-surf.	13.3	29.7	15.4	10.3	8.1	76.8	7.8	14.1	3.0	9.1	CoSL	6
			Strat. Sect. #2 Old NE Rd.											
D2387	FS# 12	1-A	0.3	0.7	2.1	4.4	28.0	35.5	23.5	44.1	5.1	20.4	L	
D2388	FS# 11	1-Btk	0.2	0.3	0.8	2.3	16.3	19.9	30.4	46.1	13.9	34.0	SICL	
D2389	FS# 10	1-C	0.0	0.0	0.1	0.3	1.5	1.9	37.6	44.6	26.6	53.5	SIC	
D2390	FS# 14	2-A	0.0	0.1	0.2	1.3	17.8	19.4	40.7	64.8	5.6	15.8	SIL	
D2391	FS# 13	2-C	0.1	0.1	0.1	0.3	4.4	5.0	58.0	70.6	12.0	24.4	SIL	
D2392	FS# 16	3-A	0.1	0.2	0.3	1.0	7.6	9.2	44.2	57.0	7.1	33.8	SICL	
D2393	FS# 15	3-C	0.0	0.0	0.1	0.3	2.5	2.9	56.7	66.3	13.0	30.8	SICL	
D2394	FS# 18	4-A	0.2	0.8	1.1	3.7	27.8	33.6	31.7	56.9	2.4	9.5	SIL	
D2395	FS# 17	4-C	0.0	0.1	0.2	0.9	19.2	20.4	34.6	66.7	6.2	12.9	SIL	

LAB NO	ORGN C %	pH (H2O) 1:1	NH4OAC EXTR BASES CA	MG	NA	K	TOTAL	KCL EXTR AL	NaOAc CEC	ECEC	BASE SAT %	ESP %	SAR	CAL-CITE %	DOLO-MITE %	CaCO3 EQ %	GYP SUM %
			MEQ/100G														
			Strat. Sect. #1 Quinn Table														
D2380	0.27	.	.	.	.	.	.	.	.	.				6.2	0.6	6.9	.
D2381	0.14	.	.	.	.	.	.	.	.	.				4.0	0.2	4.2	.
D2382	0.28	.	.	.	.	.	.	.	.	.				4.0	0.6	4.7	.
D2383	0.15	.	.	.	.	.	.	.	.	.				3.1	0.4	3.5	.
D2384	0.40	.	.	.	.	.	.	.	.	.				3.1	0.2	3.3	.
D2385	0.37	.	.	.	.	.	.	.	.	.				7.1	0.3	7.4	.
D2386	3.01	.	.	.	.	.	.	.	.	.				1.9	0.2	2.1	.
			Strat. Sect. #2 Old NE Rd.														
D2387	1.08	.	.	.	.	.	.	.	.	.				0.0	0.0	0.0	.
D2388	0.73	.	.	.	.	.	.	.	.	.				3.5	0.2	3.7	.
D2389	0.31	.	.	.	.	.	.	.	.	.				13.2	0.6	13.9	.
D2390	0.67	.	.	.	.	.	.	.	.	.				3.2	0.0	3.2	.
D2391	0.18	.	.	.	.	.	.	.	.	.				4.7	0.1	4.8	.
D2392	1.30	.	.	.	.	.	.	.	.	.				0.0	0.0	0.0	.
D2393	0.31	.	.	.	.	.	.	.	.	.				4.9	0.2	5.1	.
D2394	1.83	.	.	.	.	.	.	.	.	.				0.0	0.0	0.0	.
D2395	0.28	.	.	.	.	.	.	.	.	.				5.8	0.0	5.8	.

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SOIL SERIES: PEDON NUMBER:
SOIL FAMILY:
LOCATION: Badlands Nat'l Park, SD

LAB NO	DEPTH (CM)	HORIZON	PARTICLE SIZE DISTRIBUTION (MM) SAND VC (2.0-1.0)	C (1.0-0.5)	M (0.5-0.25)	F (0.25-0.10)	VF (0.10-0.05)	TOTAL (2.0-0.05)	SILT FINE (0.02-0.002)	TOTAL (0.05-0.002)	CLAY FINE (< 0.0002)	TOTAL (< 0.002)	TEXTURE CLASS	COARSE FRAGMENTS %
			%											
			Strat. Sect. #3 Sheep Mtn. Table											
D2396	FS# 19	1-basal	0.0	0.0	0.1	1.7	24.8	26.6	40.1	66.3	1.3	7.1	SIL	
D2397	FS# 22	2-Akb	0.1	0.7	1.8	5.4	15.0	23.0	24.5	45.1	4.4	31.9	CL	
D2398	FS# 20	2-Btkb	0.2	0.9	1.9	5.8	18.3	27.1	20.9	41.7	10.0	31.2	CL	
D2399	FS# 24	3-ABkb	0.2	1.3	3.0	9.1	17.1	30.7	21.6	41.7	4.4	27.6	CL	
D2400	FS# 25	4-Ab	0.0	0.3	1.1	7.1	26.0	34.5	28.6	49.2	1.4	16.3	L	
D2401	FS# 26	5-Ab	0.1	0.4	2.6	13.1	23.9	40.1	23.6	41.4	1.8	18.5	L	
D2402	FS# 27	6-Ab	0.1	0.6	5.4	35.3	20.8	62.2	12.3	23.6	2.1	14.2	FSL	
D2403	FS# 28	7-A	0.3	0.7	2.6	21.5	29.8	54.9	14.4	29.7	2.6	15.4	VFSL	
			Strat. Sect. #4 Coffin Butte - SE Corner											
D2404	FS# 30	1-Bkb	0.1	6.4	17.5	22.1	11.1	57.2	9.1	21.6	6.0	21.2	SCL	
D2405	FS# 31	2-Bk	0.4	3.8	9.0	13.5	16.3	43.0	21.1	39.4	2.1	17.6	L	
			Strat. Sect. #5 Fossil Trail-Sod Table											
D2406	FS# 33	1-Ab	0.1	0.2	0.2	1.5	20.7	22.7	33.8	54.7	6.1	22.6	SIL	
D2407	FS# 32	1-C	0.0	0.1	0.1	0.3	6.7	7.2	50.1	70.3	11.6	22.5	SIL	
D2408	FS# 34	2-ABk	0.0	0.1	0.1	0.5	6.5	7.2	39.0	48.8	17.1	44.0	SIC	
D2409	FS# 36	3-A	0.2	0.3	0.8	8.7	33.4	43.4	20.8	42.5	4.8	14.1	L	
D2410	FS# 35	3-C	0.0	0.1	0.1	1.5	29.9	31.6	27.4	57.9	5.1	10.5	SIL	

LAB NO	ORGN C %	pH (H2O) 1:1	NH4OAC EXTR BASES CA	MG	NA	K	TOTAL	KCL EXTR AL	NaOAc CEC	ECEC	BASE SAT %	ESP %	SAR	CAL-CITE %	DOLO-MITE %	CaCO3 EQ %	GYP SUM %
			MEQ/100G														
			Strat. Sect. #3 Sheep Mtn. Table														
D2396	0.13	.	.	.	.	.	.	.	.	.				4.2	0.0	4.2	.
D2397	1.01	.	.	.	.	.	.	.	.	.				1.6	0.1	1.7	.
D2398	0.44	.	.	.	.	.	.	.	.	.				3.8	0.4	4.2	.
D2399	0.69	.	.	.	.	.	.	.	.	.				1.1	0.1	1.2	.
D2400	0.77	.	.	.	.	.	.	.	.	.				1.8	0.1	1.9	.
D2401	0.88	.	.	.	.	.	.	.	.	.				1.5	0.2	1.7	.
D2402	0.64	.	.	.	.	.	.	.	.	.				0.8	0.1	0.9	.
D2403	1.07	.	.	.	.	.	.	.	.	.				0.0	0.0	0.0	.
			Strat. Sect. #4 Coffin Butte - SE Corner														
D2404	0.28	.	.	.	.	.	.	.	.	.				0.8	0.1	0.9	.
D2405	0.74	.	.	.	.	.	.	.	.	.				0.9	0.0	0.9	.
			Strat. Sect. #5 Fossil Trail-Sod Table														
D2406	0.75	.	.	.	.	.	.	.	.	.				0.9	0.1	1.0	.
D2407	0.22	.	.	.	.	.	.	.	.	.				6.0	0.4	6.4	.
D2408	0.49	.	.	.	.	.	.	.	.	.				3.2	0.3	3.5	.
D2409	0.62	.	.	.	.	.	.	.	.	.				4.6	0.4	5.0	.
D2410	0.13	.	.	.	.	.	.	.	.	.				5.9	0.0	5.9	.

SOIL CHARACTERIZATION LABORATORY
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SOIL SERIES: PEDON NUMBER:
SOIL FAMILY:
LOCATION: Badlands Nat'l Park, SD

LAB NO	DEPTH (CM)	HORIZON	PARTICLE SIZE DISTRIBUTION (MM) SAND VC (2.0-1.0)	C (1.0-0.5)	M (0.5-0.25)	F (0.25-0.10)	VF (0.10-0.05)	TOTAL (2.0-0.05)	SILT FINE (0.02-0.002)	TOTAL (0.05-0.002)	CLAY FINE (<0.0002)	TOTAL (<0.002)	TEXTURE CLASS	COARSE FRAGMENTS %
			%											
			Strat. Sect. #6 Sod Table Near Grande Hotel											
D2411	FS# 39	1-A	0.1	0.1	0.2	0.7	5.7	6.8	44.7	52.4	18.0	40.8	SIC	
D2412	FS# 38	1-C	0.1	0.3	0.2	1.8	24.0	26.4	26.7	57.1	8.9	16.5	SIL	
D2413	FS# 41	2-Ab	0.1	0.1	0.2	0.6	5.2	6.2	33.1	42.8	17.0	51.0	SIC	
D2414	FS# 40	2-C	0.0	0.1	0.2	2.6	22.5	25.4	23.4	46.0	9.4	28.6	CL	
D2415	FS# 43	3-ABkb	0.0	0.1	0.2	0.3	3.6	4.2	41.5	50.1	21.6	45.7	SIC	
D2416	FS# 42	3-C	0.0	0.0	0.1	0.2	3.5	3.8	51.6	66.1	14.2	30.1	SICL	
D2417	FS# 44	4-Ab	0.0	0.1	0.2	1.0	8.7	10.0	36.6	48.8	16.3	41.2	SIC	
D2418	FS# 45	5-ABk	0.1	0.4	0.6	1.0	5.4	7.5	34.5	43.5	11.9	49.0	SIC	
D2419	FS# 46	6-A	0.1	0.4	0.8	2.2	15.9	19.4	34.0	54.4	4.9	26.2	SIL	
			Strat. Sect. #7a											
D2420	FS# 50	1-CoSa	21.6	23.6	5.8	2.4	3.4	56.8	12.9	20.6	4.7	22.6	SCL	30
D2421	FS# 54	2-A	0.2	5.5	9.7	6.4	15.7	37.5	21.5	38.4	6.4	24.1	L	
			Strat. Sect. #7b											
D2422	FS# 51	2a-lam	0.1	2.6	36.0	28.4	13.3	80.4	4.8	10.6	2.8	9.0	LS	
D2423	FS# 52	2b-thin	17.6	18.6	8.4	4.4	5.4	54.4	14.3	21.2	4.5	24.4	SCL	26
D2424	FS# 53	2c-plan	0.4	10.9	27.5	19.3	15.0	73.1	7.8	16.0	3.0	10.9	SL	
D2425	FS# 56	ch fill	0.1	0.1	0.0	0.1	1.2	1.5	31.1	41.4	18.0	57.1	SIC	
D2426	FS# 57	T2 fill	0.0	0.3	0.7	3.0	38.0	42.0	16.9	42.9	5.7	15.1	L	

LAB NO	ORGN C %	pH (H2O) 1:1	NH4OAC EXTR BASES CA	MG	NA	K	TOTAL	KCL EXTR AL	NaOAc CEC	ECEC	BASE SAT %	ESP %	SAR	CAL-CITE %	DOLO-MITE %	CaCO3 EQ %	GYP SUM %
			MEQ/100G														
			Strat. Sect. #6 Sod Table Near Grande Hotel														
D2411	0.31	.	.	.	.	.	.	.	.	.				5.4	0.3	5.7	.
D2412	0.16	.	.	.	.	.	.	.	.	.				6.0	0.0	6.0	.
D2413	0.53	.	.	.	.	.	.	.	.	.				2.5	0.3	2.8	.
D2414	0.34	.	.	.	.	.	.	.	.	.				4.8	0.1	4.9	.
D2415	0.38	.	.	.	.	.	.	.	.	.				5.8	0.4	6.2	.
D2416	0.29	.	.	.	.	.	.	.	.	.				6.5	0.3	6.8	.
D2417	0.54	.	.	.	.	.	.	.	.	.				6.1	0.0	6.1	.
D2418	1.18	.	.	.	.	.	.	.	.	.				0.9	0.1	1.0	.
D2419	1.57	.	.	.	.	.	.	.	.	.				1.2	0.0	1.2	.
			Strat. Sect. #7a														
D2420	0.12	.	.	.	.	.	.	.	.	.				25.3	1.5	26.9	3.2
D2421	1.04	.	.	.	.	.	.	.	.	.				8.7	0.4	9.1	.
			Strat. Sect. #7b														
D2422	0.09	.	.	.	.	.	.	.	.	.				15.0	0.4	15.4	.
D2423	0.19	.	.	.	.	.	.	.	.	.				21.9	1.7	23.7	.
D2424	0.13	.	.	.	.	.	.	.	.	.				19.4	0.8	20.3	.
D2425	0.20	.	.	.	.	.	.	.	.	.				1.1	0.4	1.5	0.3
D2426	0.06	.	.	.	.	.	.	.	.	.				8.7	0.4	9.1	.

Appendix B

Summary of Stable Carbon Isotope Analysis

GEOCHRON LABORATORIES a division of
KRUEGER ENTERPRISES, INC.

711 CONCORD AVENUE ✦ CAMBRIDGE, MASSACHUSETTS 02138 ✦ U.S.A
TELEPHONE: (617) 876-3691 TELEFAX: (617) 661-0148

STABLE ISOTOPE RATIO ANALYSES — REPORT OF ANALYTICAL WORK

Submitted by: David Kuehn
Badlands National Park
Geoarchaeological Project
Texas A. & M University
210 Anthropology Building
College Station, TX 77843-4352

Date Received: 10/02/97
Date Reported: 11/14/97
Your Reference: O.N. 1443PX61

Our Lab. Number	Your Sample Number	Description	$\delta^{13}C$*
CR-95024	D11 sec 5, unit 1 horizon C, 194-270	Organic Carbon	-19.1
CR-95025	D12 sec 5, unit 1 horizon A, 170-190	Organic Carbon	-18.0 -18.3 *
CR-95026	D13 sec 5, unit 2 horizon Ab, 126-140	Organic Carbon	-15.7
CR-95027	D14 sec 5, unit 3 horizon C, 22-124	Organic Carbon	-19.3
CR-95028	D15 sec 5, unit 3 horizon A, 0-20	Organic Carbon	-16.8

** Duplicate analyses on separate aliquots of original sample.

*Unless otherwise noted, analyses are reported in ‰ notation and are computed as follows:

$$\delta^{13}C_{sample}‰ = \left[\frac{{}^{13}C/{}^{12}C_{sample}}{{}^{13}C/{}^{12}C_{standard}} - 1 \right] \times 1000$$

Where:

$^{13}C/^{12}C$ standard is PDB

And:

$^{13}C/^{12}C$ standard = 0.011237

GEOCHRON LABORATORIES a division of
KRUEGER ENTERPRISES, INC.

711 CONCORD AVENUE ✦ CAMBRIDGE, MASSACHUSETTS 02138 ✦ U.S.A
TELEPHONE: (617) 876-3691 TELEFAX: (617) 661-0148

STABLE ISOTOPE RATIO ANALYSES — REPORT OF ANALYTICAL WORK

Submitted by: David Kuehn
Badlands National Park
Geoarchaeological Project
Texas A & M University
210 Anthropology Building
College Station, TX 77843-4352

Date Received: 10/02/97
Date Reported: 11/14/97
Your Reference: O.N. 1443PX61

Our Lab. Number	Your Sample Number	Description	$\delta^{13}C$*
CR-95029	D16 sec 3, unit 2 horizon Btkb, 240-244	Organic Carbon	-22.5
CR-95030	D17 sec 3, unit 2 horizon Akb, 186-240	Organic Carbon	-21.3
CR-95031	D18 sec 3, unit 3 horizon Abkb, 140-186	Organic Carbon	-20.8 -20.6 **
CR-95032	D19 sec 3, unit 4 horizon Ab, 120-140	Organic Carbon	-20.9
CR-95033	D20 sec 3, unit 5 horizon Ab, 92-100	Organic Carbon	-20.3
CR-95034	D21 sec 3, unit 6 horizon C, 74-92	Organic Carbon	-21.2
CR-95035	D22 sec 3, unit 6 horizon A, 48-74	Organic Carbon	-20.6
CR-95036	D23 sec 3, unit 7 horizon C, 20-48	Organic Carbon	-18.9
CR-95037	D24 sec 3, unit 1 horizon -, 260-380	Organic Carbon	-23.2
CR-95038	D25 sec 3, unit 7 horizon A, 0-20	Organic Carbon	-18.7

** Duplicate analyses on separate aliquots of original sample.

*Unless otherwise noted, analyses are reported in ‰ notation and are computed as follows:

$$\delta^{13}C_{sample}‰ = \left[\frac{{}^{13}C/{}^{12}C_{sample}}{{}^{13}C/{}^{12}C_{standard}} - 1 \right] \times 1000$$

Where:

$^{13}C/^{12}C$ standard is PDB

And:

$^{13}C/^{12}C$ standard = 0.011237

GEOCHRON LABORATORIES a division of
KRUEGER ENTERPRISES, INC.

711 CONCORD AVENUE ✦ CAMBRIDGE, MASSACHUSETTS 02138 ✦ U.S.A
TELEPHONE: (617) 876-3691 TELEFAX: (617) 661-0148

STABLE ISOTOPE RATIO ANALYSES — REPORT OF ANALYTICAL WORK

Submitted by: David Kuehn
Badlands National Park
Geoarchaeological Project
Texas A & M University
210 Anthropology Building
College Station, TX 77843-4352

Date Received: 10/02/97
Date Reported: 11/14/97
Your Reference: O.N. 1443PX611

Our Lab. Number	Your Sample Number	Description	$\delta^{13}C$*
CR-95039	D26 sec 6, unit 1 horizon C, 228-270	Organic Carbon	-18.8
CR-95040	D27 sec 6, unit 1 horizon Ab, 220-240	Organic Carbon	-17.7
CR-95041	D28 sec 6, unit 2 horizon C, 170-220	Organic Carbon	-15.7
CR-95042	D29 sec 6, unit 2 horizon Ab, 130-150	Organic Carbon	-15.6
CR-95043	D30 sec 6, unit 3 horizon C, 100-130	Organic Carbon	-16.0
CR-95044	D31 sec 6, unit 3 horizon Ab, 92-100	Organic Carbon	-16.1
CR-95045	D32 sec 6, unit 4 horizon Bkb, 68-92	Organic Carbon	-16.8
CR-95046	D33 sec 6, unit 4 horizon Ab, 56-58	Organic Carbon	-13.9 -13.9 **
CR-95047	D34 sec 6, unit 5 horizon Abkb, 22-34	Organic Carbon	-14.3
CR-95048	D35 sec 6, unit 6 horizon A, 0-22	Organic Carbon	-14.6

** Duplicate analyses on separate aliquots of original sample.

*Unless otherwise noted, analyses are reported in ‰ notation and are computed as follows:

$$\delta^{13}C_{sample}‰ = \left[\frac{^{13}C/^{12}C_{sample}}{^{13}C/^{12}C_{standard}} - 1 \right] \times 1000$$

Where:

$^{13}C/^{12}C$ standard is PDB

And:

$^{13}C/^{12}C$ standard = 0.011237

Appendix C

Results of Radiocarbon Analysis

GEOCHRON LABORATORIES a division of
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711 CONCORD AVENUE ✦ CAMBRIDGE, MASSACHUSETTS 02138 ✦ U.S.A
TELEPHONE: (617) 876-3691 TELEFAX: (617) 661-0148

RADIOCARBON AGE DETERMINATION — REPORT OF ANALYTICAL WORK

Our Sample No. GX-23456 — Date Received: 09/30/97

Your Reference: letter of 09/25/97 — Date Reported: 10/14/97

Submitted by: Dr. David D. Kuehn
Center for Environmental Archaeology
Texas A&M University
210 Anthropology Building
College Station, Texas 77843-4352

Sample Name: BADL - 7 Strat. Section 7b Valley Fill
Charcoal Sample A

AGE = 2,870 +/- 90 C-14 years BP (C-13 corrected).

Description: Sample of charcoal and sediment.

Pretreatment: The soil sample was dispersed in a large volume of water and the clays and organic matter were isolated by agitation and ultrasound. The fine clay/organic fraction was passed through a fine nylon mesh to filter out any rootlets. The clay/organic fraction was then treated with hot dilute HCl to destroy any carbonates. After filtering, washing, and drying, the clay/organic fraction was then roasted in pure oxygen to produce carbon dioxide for the analysis.

Comment:

$\delta^{13}C_{PDB} = -28.5$ ‰

Notes: This date is based upon the Libby half life (5570 years) for ^{14}C. The error stated is $\pm 1\sigma$ as judged by the analytical data alone. Our modern standard is 95% of the activity of N.B.S. Oxalic Acid.

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711 CONCORD AVENUE ✦ CAMBRIDGE, MASSACHUSETTS 02138 ✦ U.S.A
TELEPHONE: (617) 876-3691 TELEFAX: (617) 661-0148

RADIOCARBON AGE DETERMINATION — REPORT OF ANALYTICAL WORK

Our Sample No. GX-23457 — Date Received: 09/30/97

Your Reference: letter of 09/25/97 — Date Reported: 10/14/97

Submitted by: Dr. David D. Kuehn
Center for Environmental Archaeology
Texas A&M University
210 Anthropology Building
College Station, Texas 77843-4352

Sample Name: BADL - 8 Strat. Section 5 Unit 1 Ab soil
Charcoal Sample A

AGE = 1,435 +/- 210 C-14 years BP (C-13 corrected).

Description: Sample of charcoal.

Pretreatment: The charcoal fragments were separated from any sand, silt, rootlets, or other foreign matter. The sample was then treated with hot dilute HCl to remove any carbonates, and with hot dilute NaOH to remove humic acids and other organic contaminants. After washing and drying, the cleaned charcoal was combusted and the carbon dioxide was recovered for the analysis.

Comment: Extremely small sample; approximately 0.3 grams carbon.

$\delta^{13}C_{PDB} = -24.4$ ‰

Notes: This date is based upon the Libby half life (5570 years) for ^{14}C. The error stated is $\pm 1\sigma$ as judged by the analytical data alone. Our modern standard is 95% of the activity of N.B.S. Oxalic Acid.

GEOCHRON LABORATORIES a division of
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711 CONCORD AVENUE ✦ CAMBRIDGE, MASSACHUSETTS 02138 ✦ U.S.A
TELEPHONE: (617) 876-3691 TELEFAX: (617) 661-0148

RADIOCARBON AGE DETERMINATION — REPORT OF ANALYTICAL WORK

Our Sample No. GX-23458 — Date Received: 09/30/97

Your Reference: letter of 09/25/97 — Date Reported: 10/14/97

Submitted by: Dr. David D. Kuehn
Center for Environmental Archaeology
Texas A&M University
210 Anthropology Building
College Station, Texas 77843-4352

Sample Name: BADL - 9 Strat. Section 7a Unit 2a bone a

AGE = 5,900 +/- 250 C-14 years BP (C-13 corrected).

Description: Sample of bone apatite.

Pretreatment: The bone sample was thoroughly cleaned by repeated washing in distilled water under ultrasound to remove dirt and foreign material. It was then treated with dilute acetic acid to dissolve surficial carbonate materials. After washing and drying, it was crushed to fragments less than 1 mm and was again treated with dilute acetic acid, with periodic evacuation, until evolution of carbon dioxide from normal carbonates ceased. The powder was then washed, dried, and reacted with dilute HCl, under vacuum, to dissolve bioapatite and recover carbon dioxide from the bioapatite for analysis.

Comment:

$\delta^{13}C_{PDB}$ = - 3.9 ‰

Notes: This date is based upon the Libby half life (5570 years) for ^{14}C. The error stated is $\pm 1\sigma$ as judged by the analytical data alone. Our modern standard is 95% of the activity of N.B.S. Oxalic Acid.

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711 CONCORD AVENUE ✦ CAMBRIDGE, MASSACHUSETTS 02138 ✦ U.S.A
TELEPHONE: (617) 876-3691 TELEFAX: (617) 661-0148

RADIOCARBON AGE DETERMINATION — REPORT OF ANALYTICAL WORK

Our Sample No. GX-23459-AMS — Date Received: 09/30/97

Your Reference: letter of 09/25/97 — Date Reported: 11/17/97

Submitted by: Dr. David D. Kuehn
Center for Environmental Archaeology
Texas A&M University
College Station, Texas 77843-4352

Sample Name: BADL Stratigraphic Section 3, Unit 5, Bone a bone

AGE = 2,080 +/- 50 C-14 years BP (C-13 corrected).

Description: Sample of bone gelatin.

Pretreatment: The insoluble residue remaining after bioapatite dissolution was filtered and washed. It was then boiled in slightly acid distilled water to solubilize any collagen present. The broth was filtered through fiberglass and the filtrate was evaporated to dryness to recover collagen as bone gelatin. Rootlets, humic acids, and other contaminants would have been removed by the filter and discarded. The recovered bone gelatin was combusted and the carbon dioxide was recovered and used for the analysis.

The sample was very small and analysis by accelerator mass spectrometry (AMS) was required.

Comment:

$\delta^{13}C_{PDB} = -14.1$ ‰

Notes: This date is based upon the Libby half life (5570 years) for ^{14}C. The error stated is $\pm 1\sigma$ as judged by the analytical data alone. Our modern standard is 95% of the activity of N.B.S. Oxalic Acid.

NSF - Arizona AMS Facility

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TUCSON ARIZONA

Physics and Atmospheric Sciences
1118 E. 4th Street
P.O. Box 210081
Tucson, Arizona 85721-0081

Telephone: (520) 621-6810
Facsimile: (520) 621-9619
AMS@physics.arizona.edu

2 March 1998

David Kuehn
Texas A and M University
210 Anthropology Building
College Station, Texas, 77843-4352

Fax (409) 845-4070

Dear Dr. Kuehn:

Listed below are results of radiocarbon measurements on your six "Badlands" samples. These are results that I previously gave to you by telephone.

AA number	User ID.	Carbon yield	delta 13C permil	Radiocarbon age, years BP
26467	Badlands 1	0.2%	-18.5	6,000 +/- 65
26468	Badlands 2	0.1%	-24.9	2,010 +/- 65
26469	Badlands 3	0.3%	-23.5	12,010 +/- 80
24670	Badlands 4	0.7%	-20.8	8,255 +/- 70
26471	Badlands 5	0.5%	-19.1	1,990 +/- 80
26472	Badlands 6	0.4%	-16.6	1,535 +/- 50

These results are much different from our original ones. We certainly did not succeed in removing all of the carbonates in the original treatments. The results quoted here are, I believe, the best that we can do. We treated the samples in HCl for days. Nevertheless, when carbon yields are as low as these, one must have some suspicion about just what we are measuring.

I am sorry for all of the confusion about the earlier results, and hope that these will be of some use to you. If you want to talk further about them, please give me a call.

Sincerely,

Douglas Donahue

Douglas Donahue

Appendix D

A Description and Interpretation of an Organic Mat Sample from Quinn Table

S. Christopher Caran
Christopher Caran Consulting, Austin, Texas

Introduction

Under the terms of a formal research agreement with the National Park Service,[1] one soil sample was sent to S. Christopher Caran, President, Christopher Caran Consulting, Austin, Texas, for characterization and for determination of its potential for radiocarbon dating. This sample, along with photocopies of David Kuehn's profile drawing and site location map, were delivered to S. Christopher Caran on October 5, 1997. This appendix presents the results of the descriptive analysis and recommendations for radiocarbon analysis.

As received, the sample consisted of one unnumbered soil sample wrapped in a single thickness of aluminum foil (folded), then enclosed in a resealable plastic bag labeled in permanent marker on the outside and with an adhesive paper tag inside. Upon receipt, the sample measured approximately 6 cm by 3 cm by 1.5 cm and had been slightly compressed during transport.

S. Christopher Caran described the sample at his office, where remaining portions of the sample will be kept until further notice. The description, profile drawing, and maps provided data from which the genetic history of the sampled stratum was inferred. The sample's potential for meaningful radiocarbon assay was also assessed.

Provenience and Methods

David Kuehn collected the sample on August 14, 1997, from the base of Stratum 2a in Stratigraphic Section 1, which was located along the southeastern margin of Quinn Table. The general location of Stratigraphic Section 1 is shown in Figure 2 of the main report (page 4). The stratigraphic section is discussed on pages 19 and 20 of the main report, and the relevant profile is shown in Figure 7. The stratigraphic position of the organic mat is indicated in the Figure 7 profile.

The sample was examined with a 10× hand lens and under 28.8× magnification with a binocular microscope. The color of the sample was determined using Munsell soil color charts. Grain-size measurements (grains coarser than clay) were made by direct comparison with a McCollough sand-gauge. Small sections of the sample were disaggregated with deionized water and/or were decalcified with 10% hydrochloric acid solution (aqueous).

Sample Description

The sample's matrix consists of laminated (layers less than 10 mm thick), weakly consolidated, microfractured, diagenetically modified, Tertiary claystone overlain by an adhering lamina of friable, bioturbated silty very fine to fine sand and uncommon medium to coarse sand. Most of the sand and silt grains consist of quartz, but fragments of claystone are also common. The silt and very fine through fine sands are generally subangular, whereas the medium and coarse sands are well rounded. The sandy lamina and regions within the claystone are ferruginous (probably goethite), with moderately to heavily stained and

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[1] NPS Purchase Order PX-6115-97-0133 was administered by the Midwest Archeological Center. The research results as presented here consist of a slightly modified version of S. Christopher Caran's final report, dated October 1997 and entitled *Soil Sample from Badlands National Park, South Dakota, Collected by David D. Kuehn, 14 August 1997: Description and Interpretation of Sample*, on file at the Midwest Archeological Center. Modifications were made only for the purposes of integration with the main report and overall consistency of presentation. There have been no revisions or other kinds of changes made to the data, interpretations, and recommendations given in the original purchase order report.

coated grains ranging in color from reddish brown to red (2.5 YR 4/4 to 5/8). White (5YR 8/1), soft, coarse sand-size, spherical masses of calcite are uncommon within the silty sand. Reaction to 10% hydrochloric acid solution is strong. A few coarse sand-size laths of gypsum also grew invasively within the lamina and along the smooth bedding plane that bounds it. Fine roots are common.

The claystone is pinkish white (5YR 8/2) with abundant black (5YR 2.5/1), hard, subrounded, fine to coarse sand-size nodules of oxidized iron and manganese primarily composed of hematite. Nodules are most common just below the contact with the silty sand, and nodule growth appears to have been invasive into the claystone, probably along former fine root conduits. Black (5YR 2.5/1) pyrolusite (?) dendrites and white (5YR 8/1) calcite coat some fractures and bedding planes.

Reaction to 10% hydrochloric acid solution is mild. The clay composing the claystone is not expansive in water and is probably dominated by kaolinite and/or illite. The claystone fractures into lath-shaped to equant, angular to subangular, fine to coarse sand-size fragments.

Fine roots and hollow fine-root conduits are uncommon, reflecting the second of at least two generations of root penetration. Fine roots also penetrated the claystone soon after it was deposited, producing pores filled with organic matter. This organic matter scavenged iron and manganese from aqueous solution, producing nodules.

The claystone appears to have been uniformly laminated prior to root penetration and nodule growth and might have had low porosity and permeability. Ground water probably perched above the claystone contact and might continue to do so even today, although the contact zone itself—perhaps a few centimeters thick—might be permeable.

Interpretation

The Tertiary claystone (lacustrine) was incised as ancestral Sage Creek began downcutting. Ground water seeping onto the resulting irregular erosion surface might have allowed mosses to colonize that surface, producing an organic mat a few centimeters thick, with roots penetrating a few centimeters into the claystone. The mat was buried beneath fluvial sand with minimal disturbance, although the claystone was at least partly stripped and eroded, contributing sand-size fragments as ripup clasts. Additional sand and gravel deposits accumulated.

Early in its post-burial history, the organic mat underwent decomposition in a low pH geochemical microenvironment along the contact, under water-saturated conditions. This allowed *in situ* development of the ferruginous nodules and coatings by fixing reduced iron and manganese on the organic matter. The pH probably remained low, and water saturation probably persisted until further downcutting disrupted the lateral continuity of the sand and gravel valley-fill aquifer, creating a relict terrace capped by this bed.

As downcutting and badland formation continued, the aquifer became increasingly partitioned but still retained at least some ground water, at least seasonally. This ground water was more heavily oxygenated and had a higher pH than the ground water that initially saturated the sands and gravels. The alkaline seasonal ground water precipitated calcite and gypsum in the sands overlying the claystone contact and along bedding plans and in fractures within the weathering zone of the claystone itself. Because water saturation was only seasonal, the iron-manganese minerals were thoroughly oxidized, producing the rubified coloration.

Assessment of Dating Potential

The stratigraphic section from which this sample was collected is located at the top of an escarpment more than 21 m above the present channel of Sage Creek. The time required to produce this amount of downcutting would likely exceed the practical limit of radiocarbon dating (approximately 50,000 years) in most regions. Because downcutting in the Badlands National Park area was probably relatively rapid, however, the organic matter along the contact between the claystone bedrock and the overlying fluvial deposits in Stratigraphic Section 1 might conceivably be datable.

There are several remaining impediments. The quantity of primary organic matter in the sampled stratum appears to be low and might be largely bound in the ferruginous nodules. A radiocarbon laboratory might be able to concentrate a sufficient amount of this material by leaching the crushed nodules with potassium hydroxide solution. This would yield a material similar to the humic acid fraction of humates, which is dated routinely. Whereas humic acids often enter sediments through pedogenesis long after deposition of the soil parent material, the concentrate from the nodules would likely be roughly contemporaneous with sediment deposition, because these nodules probably formed very early in the burial history of the sediment while reducing conditions were still in effect.

Unfortunately, modern roots have penetrated the deposit and are common in the sediment sample here discussed. This contaminant might make it impossible to obtain a radiocarbon age that accurately reflects the time of deposition of the sand on the claystone contact (i.e., the period of integration of ancestral Sage Creek). By carefully removing the modern roots by floating and mild hydroxide treatment, it might be possible to reduce the contaminants to a minimum, but the probable age of the primary organic matter and its low concentration make it doubtful that a valid age can be obtained.

Recommendations

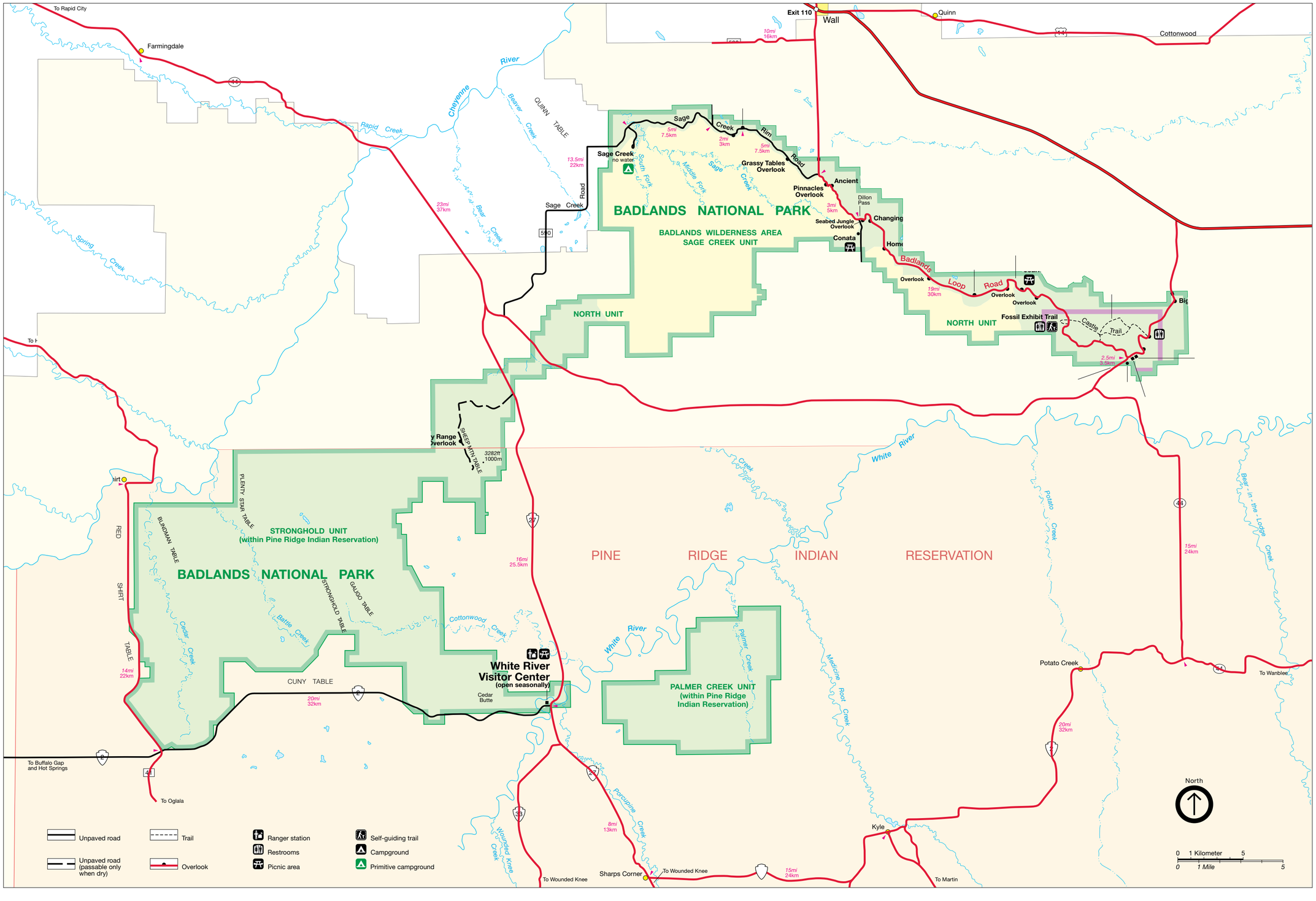
As an independent test of the presence of contaminants, you may wish to assay the stable carbon-isotope ($\delta^{13}C$) ratio of the sample. If the primary organic matter was derived from mosses, the ratio should be in the C_3 range, while the contaminants (probably prairie grasses and herbs) would have a C_4 signature. An intermediate value may serve as a semi-quantitative indicator of the percentage of contamination, allowing correction of the laboratory-calculated radiocarbon age (see Caran et al. 1996).

I recommend obtaining a stable carbon-isotope analysis of the radiocarbon sample, to be performed by the radiocarbon laboratory or by an independent provider—e.g., Thomas Boutton of Texas A&M University—using a split of the concentrate actually used for dating. I also suggest having the sample inspected by a micropaleontologist familiar with diatom communities typically associated with moss colonies. One of my colleagues, Barbara Winsborough, would be the perfect candidate for this assignment. She could confirm or refute my interpretation of the source of the primary organic matter. If the known $\delta^{13}C$ ratio of the inferred source organism is to be used as a check on possible contamination of the sampled stratum, it is essential to identify that source with certainty.

Reference Cited

Caran, S. Christopher, James A. Neely, Barbara M. Winsborough, Francisca Ramirez Sorensen, and Salvatore Valastro, Jr.

1996 A Late Paleo-Indian/Early Archaic Water Well in Mexico—Possible Oldest Water-Management Feature in the New World. *Geoarcheology* 11(1):1–35.


To Rapid City
Farmingdale
Exit 110
Wall
Quinn
Cottonwood
10mi
16km
Rapid Creek
Cheyenne River
Beaver Creek
QUINN TABLE
13.5mi
22km
Sage Creek Road
Sage Creek
no water
Sage Creek Rim Road
5mi
7.5km
2mi
3km
5mi
7.5km
South Fork
Middle Fork
Sage Creek
Grassy Tables Overlook
Pinnacles Overlook
Ancient
Dillon Pass
3mi
5km
Seabed Jungle Overlook
Changing
Conata
Home
BADLANDS NATIONAL PARK
BADLANDS WILDERNESS AREA
SAGE CREEK UNIT
NORTH UNIT
Badlands Loop Road
Overlook
19mi
30km
Overlook
Overlook
Fossil Exhibit Trail
Castle Trail
Big
2.5mi
3.5km
23mi
37km
Bear Creek
Spring Creek
To H
Sheep Mtn Table Overlook
3282ft
1000m
SHEEP MTN TABLE
White River
Creek
Potato Creek
Bear-in-the-Lodge Creek
PLENTY STAR TABLE
BLINDMAN TABLE
STRONGHOLD UNIT
(within Pine Reservation)
BADLANDS NATIONAL PARK
STRONGHOLD TABLE
GALGO TABLE
RED SHIRT TABLE
Cedar Creek
Battle Creek
Cottonwood Creek
16mi
25.5km
PINE RIDGE INDIAN RESERVATION
15mi
24km
White River
Palmer Creek
Medicine Root Creek
White River Visitor Center
(open seasonally)
Cedar Butte
CUNY TABLE
20mi
32km
PALMER CREEK UNIT
(within Pine Ridge Indian Reservation)
Potato Creek
To Wanblee
20mi
32km
To Buffalo Gap and Hot Springs
To Oglala
Porcupine Creek
Wounded Knee Creek
8mi
13km
Kyle
Sharps Corner
To Wounded Knee
To Wounded Knee
15mi
24km
To Martin
North
Unpaved road
Unpaved road (passable only when dry)
Trail
Overlook
Ranger station
Restrooms
Picnic area
Self-guiding trail
Campground
Primitive campground
0 1 Kilometer 5
0 1 Mile 5