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On the cover: Pedestal Rock in the Killdeer Mountains, Dunn County. The photo was taken looking southeast from the Medicine Hole Plateau. Pedestal Rock was formed when a block of carbonate and sandstone broke from the south slope of South Killdeer Mountain.

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ABSTRACT

The Chadron, Brule, and Arikaree Formations are, for the most part, poorly exposed in limited and scattered outcrops in southwestern North Dakota. The best exposures of these formations are found in the Chalky Buttes, Little Badlands, and Killdeer Mountains. Previous studies have attempted to date and correlate these rock units with varying degrees of success.

Thirty-one geologic sections were measured and twelve holes were cored on buttes in southwestern North Dakota to characterize and correlate the formations. Prospecting for fossils took place at all known exposures to establish biochronologic control. Tuffs were sampled for fission track dating and trace element fingerprinting from two localities in the Little Badlands and from one locality in the Killdeer Mountains. Thirty claystone samples from the Chadron and Golden Valley Formations were x-rayed for clay analysis. Eighty thin sections were made of sandstone and carbonate samples for petrographic characterization.

The Chadron Formation can be confidently traced lithologically throughout this area. The Chalky Buttes Member, consisting of yellow/green to white sandy mudstones, sandstones, and conglomerates, is formally proposed as the lower member of the Chadron Formation. The South Heart Member is proposed for the overlying sequence of gray to brown smectitic claystones and interbedded limestones of the Chadron Formation. The presence of brontothere remains in both of these members suggests a Chadronian "age".

The pinkish/brown mudstones and siltstones of the Brule Formation are easily distinguished lithologically and by color from the underlying Chadron and overlying Arikaree Formations. However, it is difficult to distinguish between conglomeratic sandstones in the upper Brule and those in the Arikaree Formation. Placement of these conglomeratic sandstones in either the Brule or Arikaree Formations is based on the lithologic character of the overlying rocks. A previously unnamed tuff, the Antelope Creek tuff, occurs in the lower Brule in the Little Badlands. The Brule Formation in North Dakota contains Orellan to Whitneyan "age" mammal faunas.

The Arikaree Formation is represented by conglomeratic sandstones, tuffs, and carbonates in southwestern North Dakota. Conglomeratic butte capping sandstones were placed in the Arikaree Formation. An age of 25.1±2.2 Ma (late Arikareean to early Hemingfordian) was determined from fission track dating of volcanic glass in the middle of the Arikaree Formation in the Killdeer Mountains. Sparse mammal remains in the Arikaree Formation in North Dakota suggest a late Whitneyan to late Arikareean "age".

ACKNOWLEDGEMENTS

This study was a cooperative project between the North Dakota Geological Survey and the United States Geological Survey under the COGEOMAP Program (Project # 14-08-0001-A0805). Richard LeFever, UND, was involved in the initial phases of this study. University of North Dakota students John Kay, Steve McLean, Eric Harvey, and Jim Sorensen assisted with the concentration of glass grains from tuff samples. The following individuals also assisted with various aspects of the study: Mitch Reynolds, Glen Izett, Charles and Nancy Naeser, and Roy Knight, U.S. Geological Survey; James Martin, Phil Bjork, and Janet Whitmore, South Dakota School of Mines and Technology; George Lammers, Manitoba Museum of Man and Nature; Richard Tedford, American Museum of Natural History; Dean Pearson, Pioneer Trails Museum; Bob Purdy and Sergiu Mamay, Smithsonian Institution; Donald Prothero, Occidental College; and Allen Kihm, Minot State University. We thank them for assistance with this project.

We are particularly grateful to Todd Strand, State Historical Society of North Dakota, who processed the photographs used in this publication.

We also wish to thank the following landowners and their families for allowing us access to these buttes. Special gratitude is extended to the late Leonard Buzalsky, Ryan Brooks, Ted Pope, the late Albert Privratsky, Ben Privratsky, the late William Schmidt, George and Edward Schmidt, Ron and Bob Obritsch, Bob Fitterer, Jack Murphy, Alec and Lorin Dvornak, Ken and Ralph Urlacher, Rick Maxiner, Fred Thomas, Nick Biel, Orion Bruvold, Gene Fisher, and Sherman, Jeff, and Laurie Oakland.

We would like to remind people to please ask permission from the appropriate landowner before visiting these buttes. The Little Badlands proper (including Privratsky ranch, Fitterer ranch, and Obritsch ranch) are listed on North Dakota's Registry of Natural Areas because they are important mammal fossil sites.

INTRODUCTION

Purpose

This five-year study of the White River Group (Chadron and Brule Formations) and the Arikaree Formation in southwestern North Dakota was initiated to determine the age and relationships of these middle Cenozoic formations and to map contacts between the units. Lithologic and mineralogic criteria were used to correlate the strata and paleontological and geochemical methods were employed to determine their ages. Determination of the lithologic characteristics, ages, and relationships of these units enable reconstruction of the depositional environments that existed throughout western North Dakota during the time of deposition of these units.

This project was part of the Cooperative Geological Mapping Program (COGEOMAP) between the United States Geological Survey and the North Dakota Geological Survey. The study involved personnel from the North Dakota Geological Survey, the Department of Geology and Geological Engineering at the University of North Dakota, and the United States Geological Survey.

Study Area

Exposures of the Chadron, Brule, and Arikaree Formations in southwestern North Dakota occur in isolated and scattered buttes and butte complexes. These formations in North Dakota occupy an area of only 35,310 acres, roughly one-thousandth of the total area of the state (Figure 1). The three largest areas of outcrop, the Little Badlands, Killdeer Mountains, and Chalky Buttes, when combined, account for 88% of the total known extent of White River and Arikaree strata in the state (Figure 2). These rocks are exposed in 27 individual buttes. Eleven of these buttes have an areal extent of 10 acres or less. Exposures are generally poor to moderate along the larger buttes and poor to absent along the smaller ones. Quite commonly only the capping rock is well exposed at a given butte.

PREVIOUS WORK

Meek and Hayden (1858) initially proposed the name White River for exposures along the White River in Nebraska and South Dakota. This terminology was first applied to outcrops in North Dakota (Chalky Buttes) by Cope (1883a) (Figure 3).

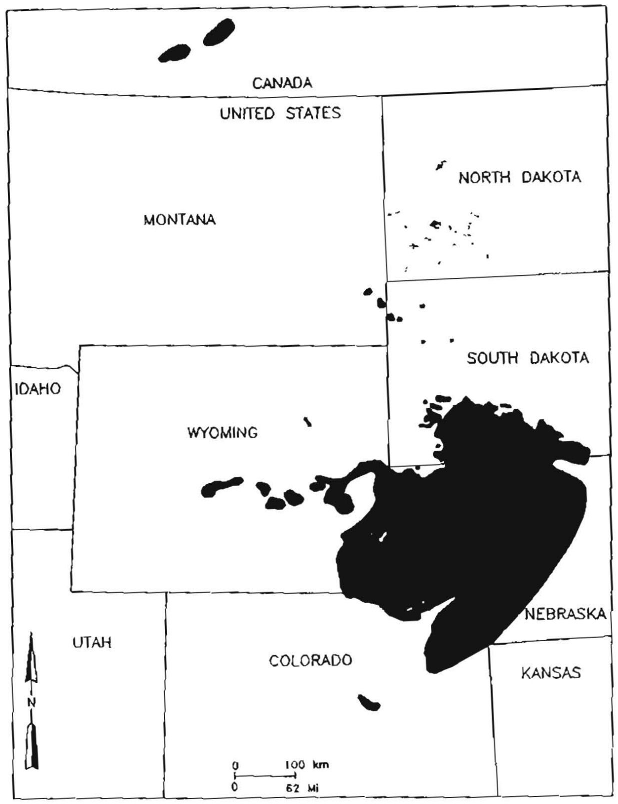


Figure 1. Present extent of the White River Group and Arikaree Formation, and equivalents, in the northern plains (modified from Seeland, 1985).

Douglass (1909) assigned exposures in the Little Badlands to the White River, and Quirke (1918) included the strata of the Killdeer Mountains in the "White River formation" (Figure 3). Leonard (1922) conducted the first comprehensive study of the White River in North Dakota and divided the formation into three informal members: "Lower White River beds", "Middle White River (*Oreodon*) beds", and the "Upper White River beds". Powers (1945) reported these same three beds but used the faunal names: "*Titanotherium* beds", "*Oreodon* beds", and "*Protoceras* beds" (Figure 3). Darton (1899) elevated the White River to group status in South Dakota and Nebraska, and recognized two formations, the Chadron and Brule. Denson et al. (1959) recognized the White River as a group in Bowman County, North Dakota. A formal division of the White River Group occurred in North Dakota when Moore et al. (1959) used the terminology Chadron and Brule Formations. Seager et al. (1942) were first to suggest that rocks of Miocene age may overlie the White River in North Dakota. Moore et al. (1959) were first, however, to

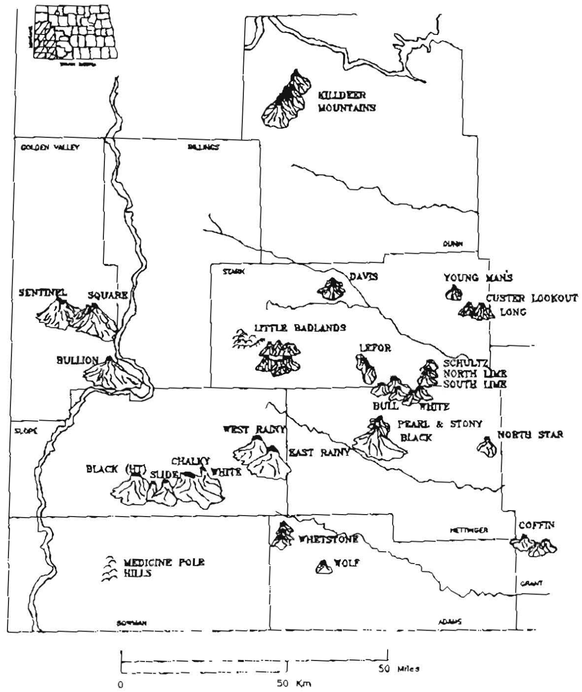


Figure 2. Buttes containing White River or Arikaree strata in southwestern North Dakota.

use the term Arikaree Formation in North Dakota for 70 feet of sandstone capping the Chalky Buttes (Figure 3).

Following the early work of Cope, Douglass, Quirke, and Leonard, the most detailed and comprehensive studies of the White River Group and Arikaree Formation in North Dakota were done by geologists exploring for uranium, claystone, or limestone during the 1940s, 1950s and 1960s. The most important of these studies were by Clarke (1948), Wyant and Beroni (1950), Beroni and Bauer (1952), Hansen (1953), Bergstrom (1956), Moore et al. (1959), and Denson and Gill (1965). Clarke (1948) measured sections and produced geologic maps of the Chalky Buttes and Little Badlands. Hansen (1953) measured sections and drilled holes on the limestone-capping buttes in Stark and Hettinger Counties. Moore et al. (1959) measured geologic sections on Sentinel, Bullion, Black (HT), and Chalky Buttes.

Denson and Gill (1965) measured sections at 16 localities in southwestern North Dakota. Their geologic cross-section was the most detailed and comprehensive correlation of these units prior to this study. In addition, they collected rock samples from numerous buttes, prepared and described 30 thin sections, analyzed 47 heavy mineral separations, and chemically characterized six carbonate rocks from North Dakota. They found few, if any, biostratigraphically diagnostic fossils outside of the Little Badlands and Chalky Buttes areas. Therefore, they based most of their Chadron, Brule, and Arikaree Formation correlations on lithologic and mineralogic criteria. Denson and Gill were first to assign the tuffaceous-marlstone caprock of the Killdeer Mountains to the Arikaree Formation and suggested a Miocene age for the Arikaree Formation based on two Miocene fossils found in presumed equivalent rocks near Ekalaka, Montana. Their recognition of the Arikaree Formation in North Dakota was based on three specific criteria: (1) the Arikaree Formation unconformably overlies the Brule Formation; (2) lithologic similarity to Arikaree strata in the South Dakota Badlands; and (3) chemical composition, e.g., they found the suspected Arikaree carbonate rocks to be enriched in magnesium, sodium, potassium, strontium, and iron compared to Chadron carbonates.

Sato and Denson (1967) studied the petrography of nonopaque heavy minerals in approximately 700 Tertiary rock samples from North and South Dakota, Wyoming, Nebraska, and Colorado. They demonstrated that the rocks of the Fort Union, Golden Valley, White River, and Arikaree Formations could be differentiated by comparison of nonopaque heavy minerals.

Prior to 1969, geologists placed the thick capping sandstones of Sentinel, Square, Bullion, and Black (HT) Buttes into either the Sentinel Butte Formation or the White River Group. Denson (1969) proposed, after thin section analysis, that the sandstones capping these buttes are actually correlative with sandstones in the Golden Valley Formation. Hickey (1977), however, maintained that these thick fluvial sandstones were not part of the Golden Valley Formation but are from the Sentinel Butte Formation.

Furman (1970) compared the capping sandstones of several buttes in western North Dakota. He determined that the sandstones at the top of Chalky and Slide Buttes have an analcime content of 15 percent compared to 30 percent for the sandstones ("arkoses") capping Sentinel and Square ("Flat Top") Buttes. He further determined that the analcime content of the sandstones increases upward in the unit. Furman followed Denson (1969) and placed these

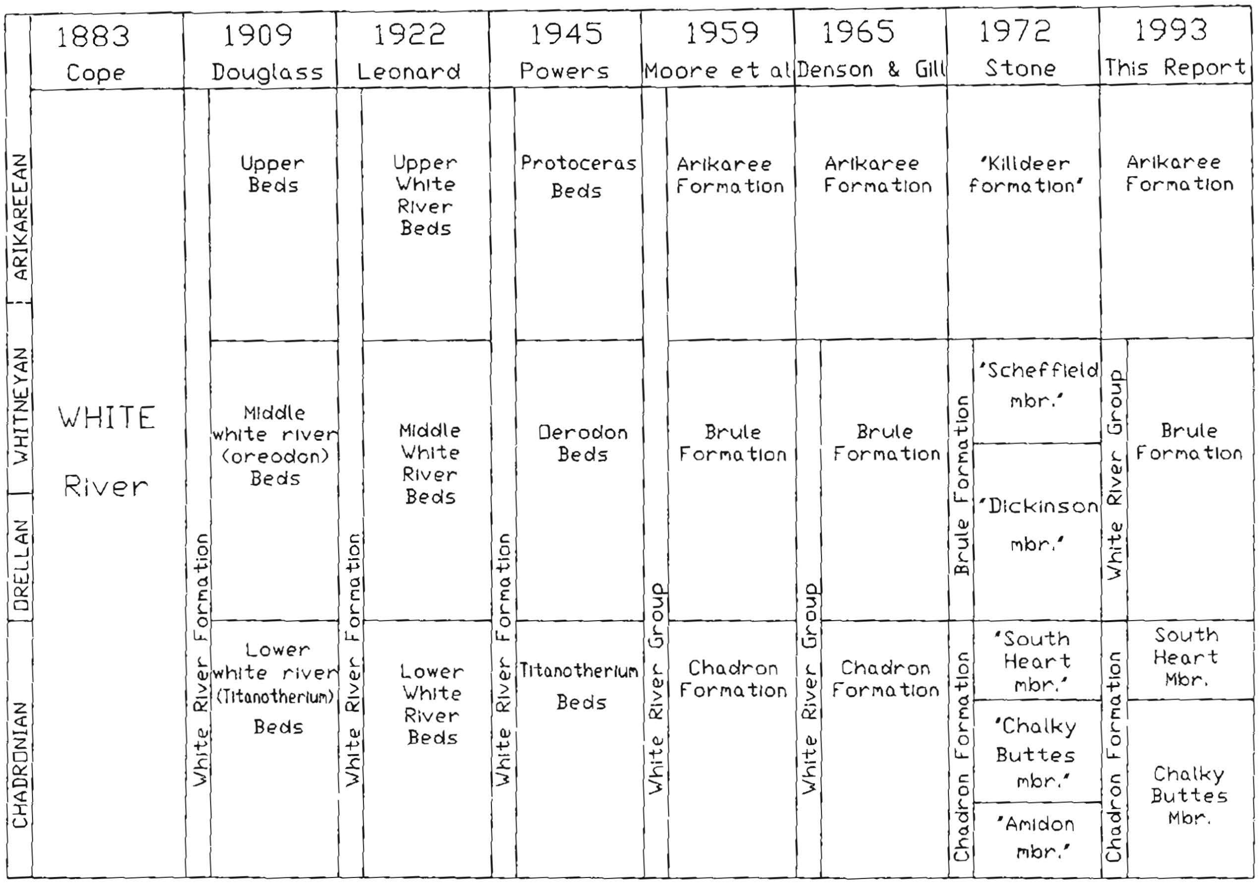


Figure 3. History of stratigraphic nomenclature for the middle Cenozoic of southwestern North Dakota.

analcime-bearing sandstones in the Golden Valley Formation.

Denson and Chisholm (1971) analyzed 3000 heavy mineral separates from Tertiary sedimentary rocks in North and South Dakota, Nebraska, Colorado, Wyoming, and Montana. They determined that these rocks could be differentiated into six major lithogenetic units (Paleocene, lower Eocene, upper Eocene, Oligocene, lower Miocene, and upper Miocene and Pliocene) based on characteristic heavy mineral assemblages.

Stone (1973) measured 11 sections in the Chalky Buttes, Little Badlands, and Killdeer Mountain areas and constructed a geologic cross-section based on those measurements. Stone (1972, 1973) defined informal members of the Chadron and Brule Formations which he suggested could be correlated throughout western North Dakota. He named three new members in the Chadron Formation ("Amidon", "Chalky Buttes", and "South Heart") and two new members in the Brule Formation ("Dickinson" and "Schefield"). He also informally proposed a new name, "Killdeer formation", for the caprock exposed in the Killdeer Mountains and on isolated buttes in southwestern North Dakota. Stone rejected the term Arikaree Formation in favor of the "Killdeer formation" because he felt the caprock on North Dakota buttes was "lithologically distinct from the type Arikaree of Nebraska or Arikaree in the Big Badlands of South Dakota" (Stone, 1973 p. 143). Hoganson (1986) noted however, that none of the new stratigraphic names that Stone suggested were formally proposed in accordance with the rules established in the North American Stratigraphic Code and must be considered informal. Stone's two member division of the Brule Formation was found to be of questionable utility by Hoganson and Lammers (1992). Although Stone listed the informal members that he felt were present at the buttes he studied, he did not present measured geologic sections outside of the Chalky Buttes, Little Badlands, and Killdeer Mountains. As a result, it is not possible to precisely determine where he placed his lithostratigraphic contacts on the buttes outside of these three areas.

Delimata (1975) conducted a detailed stratigraphic study of the Killdeer Mountains. One of Delimata's primary goals was to find fossil evidence in these rocks that would unequivocally indicate their age, but he was unable to find any vertebrate fossils in the caprock of these mesas. The only fossils that Delimata noted, besides trace fossils, were ostracods in one thin section. Delimata suggested a Pliocene age for the Killdeer Mountain strata based on mineralogy and preservation of tuffs.

Boyer (1981) studied the mineralogy and the bedding characteristics of the interbedded mudstones and carbonates capping Sentinel Butte, Golden Valley County. He did not determine the age or stratigraphic affinities of the caprock but speculated on paleoenvironmental conditions during deposition of these lacustrine beds.

Seeland (1985) compiled published information on Oligocene paleogeography of the northern Great Plains and from information available in North and South Dakota, inferred the presence of two major streams trending northeast into western North Dakota from northeastern Wyoming and southwestern South Dakota during the early Oligocene.

The petrography of the tuffaceous caprocks in the Killdeer Mountains was studied by Forsman (1986). He determined that glass shards within the tuffs were of sufficient quality that these beds could be dated by fission track methods and deposits could be compared and possibly correlated to other known tuffs by trace element fingerprinting.

Very few studies of fossils from the White River Group and Arikaree Formation have been undertaken in North Dakota compared to stratigraphically equivalent units in other areas of the midcontinent (e.g., the Big Badlands of South Dakota). The only prior comprehensive study of the fossils from these units in North Dakota was by Hoganson and Lammers (1992) but their investigation was primarily restricted to the vertebrates of the Brule Formation. They recognized over 60 vertebrate taxa in the Brule and determined that at least the lower Brule is Orellan in age.

Clausen (1982, 1987, 1989) presented a hypothesis that the White River Group in North Dakota is not middle Cenozoic in age, as has been widely accepted, but is Pleistocene in age. His interpretation was based on the mineralogic similarity between Chadron gravels and gravels capping the divide between the Yellowstone and Redwater Rivers in Montana, and on incision rates of the Yellowstone River and its major tributaries. Ashworth (1986) countered Clausen's interpretation by citing the presence of Oligocene age fossils in these rock units.

Recently, the late Paleogene timescale has undergone significant revision due to development of the apparently more precise laser-fusion argon/argon dating of ashes compared to the older K/Ar method and progress made in magnetic stratigraphy (Prothero and Swisher, 1989, 1992; Cande and Kent, 1992). In this revision, the Chadronian land mammal "age" is considered to be late Eocene and not early Oligocene. In addition, the Orellan and Whitneyan land mammal "ages" are early Oligocene. The Eocene/Oligocene boundary is placed between the Chadronian and Orellan (about 34 Ma), not between the Duchesnian and Chadronian as previously defined. In addition, all but the latest Arikareean is considered Oligocene in age.

FIELD METHODS

Regional Field Reconnaissance

Field reconnaissance of the geologic type-sections of the Chadron and Brule Formations near Scenic, South Dakota and the Monroe Creek and Harrison Formations (Arikaree Group) near Pine Ridge and Harrison, Nebraska was conducted to determine lithologic and weathering characteristics. In addition, numerous other outcrops of these formations, along with the Sharps and Gering Formations (Arikaree Group), were examined in the Little Badlands of South Dakota and along Pine Ridge in Nebraska. White River and Arikaree strata were also examined in the Ekalaka and Long Pine Hills in southeastern Montana and the Slim Buttes, Short Pine Hills, and Cave Hills in northwestern South Dakota.

Measured Sections

Thirty-one geologic sections were measured (approximately 5,300 feet) on the buttes of western North Dakota (Figure 4). Lithologic samples were collected at each significant change in lithology (250 samples). Particular attention was focused on sampling possible tuff layers and identifying fossiliferous zones within these units. At least two additional tuff layers and several vertebrate and in-

Figure 4. Measuring geologic section on Square Butte. View is to the northwest, Ed Murphy in foreground.

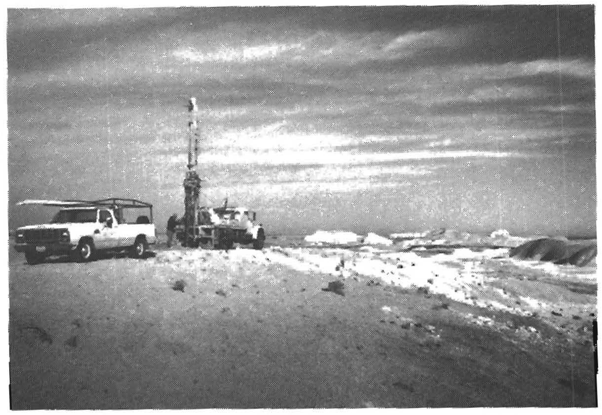


Figure 5. Coring the base of the Chadron Formation at Privratsky ranch in the Little Badlands.

invertebrate fossil sites were discovered during this project. Group and formation contacts were plotted on U.S.G.S 7½-minute quadrangle maps.

Coring Program

A series of holes were cored at the base of outcrops, or in areas of poor or nonexistent outcrops, to obtain accurate information about lithologies of underlying strata and positions of stratigraphic contacts (Figure 5). The North Dakota Geological Survey's Mobile Drill B-50 hollow stem auger truck was used to core these holes. The holes averaged 51 feet in depth and were cored from top to bottom using 3-inch diameter Shelby tubes. A total of 613 feet of sedimentary rock was cored in 12 holes on 10 buttes in western North Dakota. This core is curated and housed in the North Dakota Geological Survey's warehouse in Bismarck.

Fossil Prospecting

In addition to the search for fossils which occurred while measuring sections, independent prospecting for fossils at butte exposures was conducted over the five-year span of the project.

LABORATORY METHODS

Fossil Identification

Fossil specimens were prepared by standard techniques and were identified through review of published descriptions of White River taxa and by comparison to specimens at the Manitoba Museum of Man and Nature and at the South Dakota School of Mines and Technology Geology Museum. Fossils collected during this study are cataloged into the North Dakota State Fossil Collection, housed in the Heritage Center in Bismarck, or are in the paleontology collection at the Manitoba Museum of Man and Nature, Winnipeg.

Thin Sections

Eighty thin sections of rock samples were prepared to assist in characterization and correlation of lithologic units. Initially, thin sections were made of most of the coarser grained rock samples collected while measuring sections. A second set of thin sections was made from samples obtained from the sandstone caprocks at Bullion Butte, West Rainy Butte, and Obritsch ranch, Little Badlands. Carbonate rock units were also sectioned and examined as part of the characterization of these units.

X-Ray Analysis

Claystones from both the measured section rock samples and from drill cores were subjected to x-ray analysis. Standard techniques for clay analysis, including ethylene glycol solvation, were utilized. These claystones were analyzed to determine if clay mineralogy could be used to distinguish the units.

Glass Preparation

A lengthy laboratory procedure was necessary to obtain glass separates for fission track and trace element (fingerprinting) analysis of tuffs. Samples initially required disaggregation which was accomplished by ultrasonic treatment in a water bath. Sodium montmorillonite was liberated from each of the samples during the ultrasonic treatment. Samples were repeatedly decanted and bathed until free of authigenic clays. Authigenic erionite was also present in most of the tuff samples but was gradually removed by the cumulative sample preparation procedures.

Following disaggregation, samples were separated into silt and sand size classes by wet sieving. Sand grains were then passed through a Franz Iso-dynamic Magnetic Separator. Glass, together with quartz and feldspar grains, was preferentially concentrated as a less magnetic fraction. Glass concentrates were obtained by settling the less-magnetic fractions in tetrabromoethane mixed with acetone to yield a specific gravity of 2.54 g/cm^3. Eventually glass concentrations of $>90\%$ purity were obtained for each sample.

Fission Track Analysis

Fission track analysis of glass shards from a Arikaree Formation tuff collected in the Killdeer Mountains was performed by Nancy Naeser with the Isotope Branch of the U.S. Geological Survey in Denver, Colorado. The laboratory derived corrected fission track ages using the isothermal plateau annealing technique after Westgate (1989).

Trace Element Analysis

Trace element analysis or fingerprinting of the glass separates from 6 samples (3 different localities) were performed by R.J. Knight with the Isotope Branch of the U.S. Geological Survey in Denver, Colorado using instrumental neutron activation analysis.

WHITE RIVER GROUP

Chadron Formation in the Upper Midwest

Darton (1899, p. 41) proposed the name Chadron Formation for a sequence of "sandy clay of light greenish-gray color, usually with coarser beds at the bottom, including deposits of gravels often several feet thick" formerly known as the "*Titanotherium* beds" which occurs in northern Nebraska. He did not specify a type section or type locality for the Chadron. To end some of the confusion brought about by this omission, Harksen and Macdonald (1969) suggested a type section for the Chadron Formation in the SW¼SW¼SE¼ section 28 (T2S, R13E), Pennington County, South Dakota. The Chadron, at that locality, rests unconformably on the Pierre Formation and consists of a thin (< 10 feet) basal conglomerate overlain by approximately 100 feet of "popcorn" weathered clay containing thin (< 3 feet) lenses of marlstone. The upper contact of the Chadron Formation is not present at the type section, but is conformable with the Brule Formation elsewhere in the area.

Outcrops of the Chadron Formation occur in portions of six states: western North Dakota; southeastern Montana; northwestern, southwestern, and south-central South Dakota; northwestern Nebraska; southeastern Wyoming; and northeastern Colorado (Figure 1).

Chadron Formation in North Dakota

The basal formation within the White River Group in North Dakota is the Chadron Formation. In most exposures, the Chadron contains a basal member consisting of 10 to 80 feet of light colored, gravel-bearing, cross-bedded sandstone and sandy mudstone which is formally named, in this report, the Chalky Buttes Member (Figure 6). Overlying the Chalky Buttes Member is a 10 to 100 foot interval of green to gray smectitic (these claystones have been referred to, but not verified as, bentonites in previous reports, therefore they are referred to as smectites or swelling claystones in this report) claystone containing lenticular beds of freshwater limestone. The name South Heart Member is formally proposed for this interval (Figure 6). The South Heart Member forms distinctive grayish rounded caps, "haystacks", on the tops of buttes and hills in the Little Badlands and Chalky Buttes areas. The Chadron Formation in North Dakota ranges in thickness from a maximum of 170 feet in the Chalky Buttes to less than 10 feet in the Killdeer Mountains. Brontothere and other vertebrate remains have been recovered from both the Chalky Buttes and South Heart Members in North Dakota (Appendix C). Ostracods, algal crusts, and gastropods have been found in the South Heart Member freshwater limestones.

Strata Underlying the Chadron Formation in North Dakota

Bullion Creek Formation

Throughout North Dakota, the White River

Group rests unconformably on the Fort Union Group. The oldest of these units is the Bullion Creek Formation (Paleocene) which is comprised of alternating sandstone, siltstone, mudstone, claystone, and lignite lithologies (Figure 7). It is distinguished from the underlying Slope Formation (formerly the upper member of the Ludlow Formation) and the overlying Sentinel Butte Formation by its bright coloration, dominantly yellows and greens. The White River Group rests unconformably on the lower Bullion Creek Formation at only one locality, the Medicine Pole Hills.

Sentinel Butte Formation

Approximately one half of the occurrences of White River strata in North Dakota unconformably overlie the Sentinel Butte Formation (Paleocene). The Sentinel Butte Formation consists of alternating lithologies of sandstone, siltstone, mudstone, claystone, and lignite and is distinguishable from overlying formations because of its overall darker gray and brown coloration.

Golden Valley Formation

The Golden Valley Formation unconformably underlies the White River Group in many areas of southwestern North Dakota (Figure 7). The Golden Valley is divided into two members, the lower Bear Den Member (Paleocene) and upper Camels Butte Member (Eocene). Light colored kaolinitic claystones, mudstones, and sandstones that weather to bright white, gray, or orange characterize the Bear Den Member. The Camels Butte Member is montmorillonitic and consists mostly of brown to gray micaceous sandstones, siltstones, mudstones, claystones and lignite. Although no diagnostic vertebrate fossils have been recovered from the Bear Den Member, megaflora, mollusk and pollen remains indicate a Clarkforkian (latest Paleocene) age for the member (Hickey, 1977). Plants from the lower Camels Butte represent a transition from the Bear Den to the upper Camels Butte. Paleoflora from the upper Camels Butte Member suggest an early Wasatchian (early Eocene) age for the upper part of this member (Hickey, 1977). An early Wasatchian age for the upper part of the Camels Butte Member was initially suggested by vertebrate fossils (Jepsen, 1963; West, 1973), but Schoch (1986), after re-examination of the vertebrates, determined that the upper Camels Butte is middle Wasatchian (but still early Eocene) in age. Mollusks from the member also indicate a Wasatchian age (Hickey, 1977).

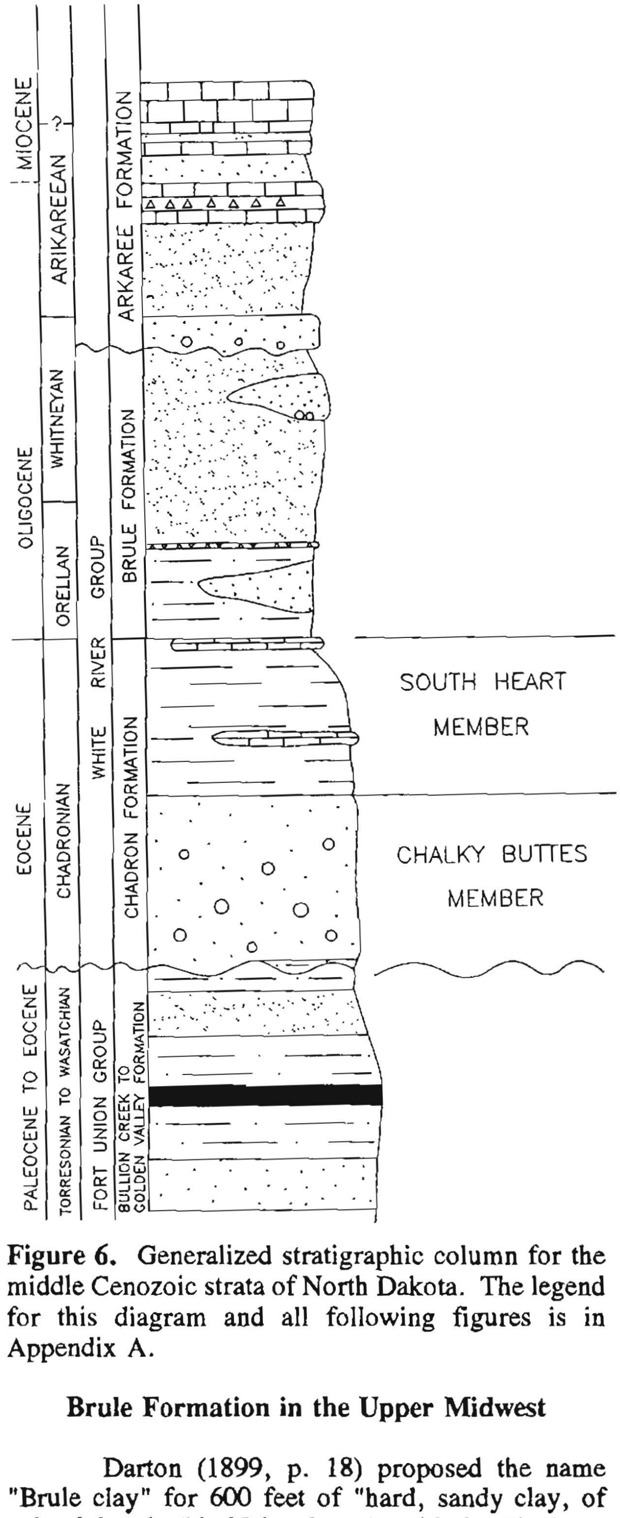


Figure 6. Generalized stratigraphic column for the middle Cenozoic strata of North Dakota. The legend for this diagram and all following figures is in Appendix A.

Brule Formation in the Upper Midwest

Darton (1899, p. 18) proposed the name "Brule clay" for 600 feet of "hard, sandy clay, of pale-pink color" in Nebraska. As with the Chadron, Darton did not designate a type section for the Brule. To rectify this problem, Schultz and Stout (1955) selected one of Darton's sections in Nebraska as the

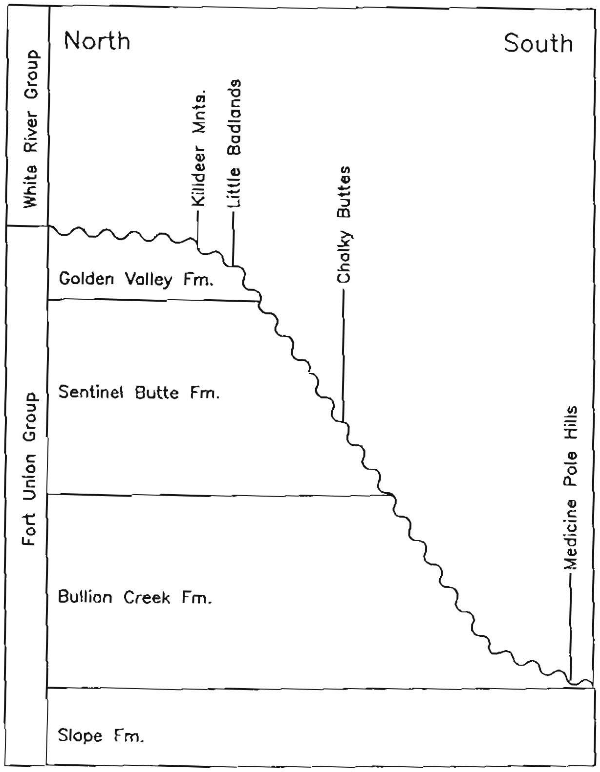


Figure 7. Generalized cross-section of the White River/Fort Union Group contact in western North Dakota.

type section. Harksen and Macdonald (1969), however, argued that this section was not valid because it was not Darton's intent to have the type section in western Nebraska. They instead proposed type sections for two members of the Brule Formation, the Scenic and Poleside Members, from two of Bump's (1956) sections in the Badlands of South Dakota (Figure 8). The type section proposed for the Scenic Member is located in the SW¼ section 27 (T3S, R13E) Pennington County and the type section for the Poleside Member is in the NW¼ section 33 and SW¼ section 28 (T43N, R44W), Shannon County, South Dakota. The Brule Formation at these type sections, when combined, consists of 440 feet of alternating beds of reddish brown to tan siltstone, mudstone, and claystone and conformably overlies the Chadron Formation. The Scenic Member contains thin beds of marlstones and the Poleside Member contains a 10-foot thick channel conglomerate (identified as a *Protoceras* channel) in the upper portion of the type section.

Brule Formation in North Dakota

The Brule Formation is characteristically light brown to pink in color, although the rocks can also be gray and green. It conformably overlies the South Heart Member of the Chadron Formation in North Dakota (Figure 6). The lower portion of the Brule consists of complexly interbedded lithologies of claystones, calcareous mudstones, freshwater limestones, tuffs, and cross-bedded sandstones. The channel sandstones are generally less than 10 feet thick and often contain mammal fossils. The upper portion of the Brule consists primarily of alternating beds of mudstone and swelling clays. Conglomeratic sandstones are present in the upper part of the Brule exposed in the Rainy Buttes and in portions of the Little Badlands. The Brule Formation varies in thickness in southwestern North Dakota from a maximum of 215 feet at Fitterer ranch in the Little Badlands to less than 20 feet in the Chalky Buttes, Slope County. In many places in the Chalky Buttes it is entirely absent.

By far the greatest diversity of vertebrate fossils in the White River Group in North Dakota occurs in the Brule Formation. Most of these fossils have been recovered from the lower portion of the formation. By virtue of the abundant and diagnostic vertebrate fossils, the lower Brule is the most precisely dated unit within the White River Group in North Dakota. An Orellan land mammal "age" is indicated by these fossils for the lower Brule (Skinner, 1951; Stone, 1973; Hoganson and Lammers, 1985, 1992). Stone (1973) and Kihm (1990) proposed a Whitneyan "age" for the upper Brule in North Dakota based on sparse vertebrate fossil evidence. An Orellan "age" for the lower Brule and a Whitneyan "age" for the upper Brule is confirmed in this study.

ARIKAREE GROUP

Arikaree Group in the Upper Midwest

In 1899, Darton proposed the name Arikaree Formation for 400 to 500 feet of gray sandstone containing lenses of conglomerate, volcanic ash, and concretions unconformably overlying the Brule Formation in western Nebraska. The Arikaree was elevated to group status by Hatcher (1902) and divided into the Monroe Creek and Gering "sandstones" Formations. The areal extent of the

Arikaree Group includes portions of northwestern Nebraska, eastern Colorado, western South Dakota, eastern Wyoming, southeastern Montana, and southwestern North Dakota. As presently defined, the Arikaree Group consists of, beginning at the base, the Sharps, Monroe Creek, and Harrison Formations in South Dakota, and the Gering, Monroe Creek, and Harrison Formations in Nebraska (Figure 8).

Sharps Formation

The Sharps Formation was named for approximately 340 feet of "massive tan silt and volcanic ash" (Harksen et al., 1961, p. 674). Channel sandstones, conglomerates, and lenses of marlstone are present in the formation and it also contains peculiarly shaped concretions which Harksen and others referred to as "potato-balls" (p. 677). The type sections are located in the SW¼NW¼ section 31, T41N, R42W and in the NW¼ section 30, T39N, R43W near Sharps Corner in Shannon County, South Dakota. The Sharps Formation conformably overlies the Brule Formation and is conformably overlain by the Monroe Creek Formation (Harksen et al., 1961).

Gering Formation

Darton (1899) applied the name Gering Formation to approximately 200 feet of light gray sandstone at the base of the Arikaree in western Nebraska. Although he did not designate a type section, he stated that its "greatest development in the Platte Valley is south-southwest of Gering" (Darton, 1899, p. 29). The sandstone is generally coarse grained, but varies from fine to coarse, pebbly, massive to cross-bedded, and in places contains small vertical pipes which appear to be burrows. The Gering Formation unconformably overlies the Brule Formation and is conformably overlain by the Monroe Creek Formation.

Monroe Creek Formation

The Monroe Creek Formation was named by Hatcher for approximately 200 feet of "very light colored, finer-grained, not very hard but firm and massive sandstones" (Hatcher, 1902, p. 117). Although Hatcher did not specify a type-section locality, subsequent workers have determined that it was his intention that exposures at the mouth of Monroe Creek Canyon, 5 miles north of Harrison, Nebraska serve as the type section. The Monroe Creek Formation is conformably overlain by the Harrison Formation.

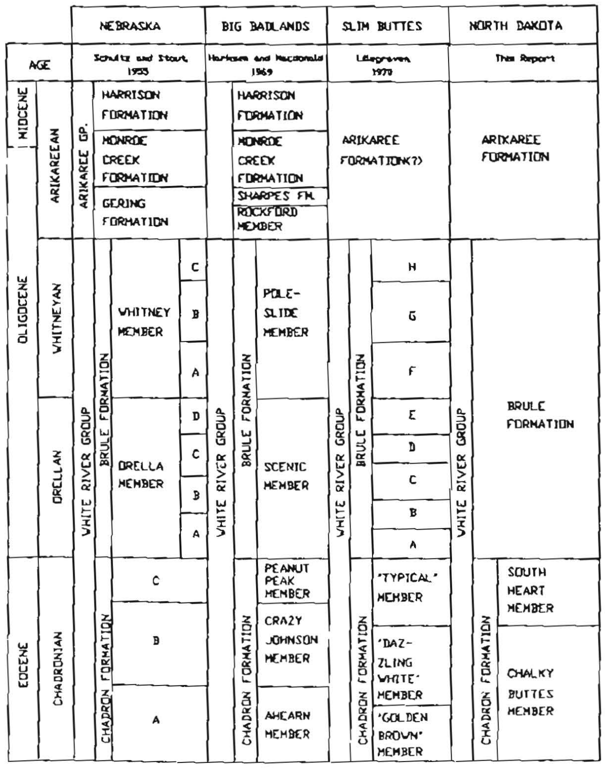


Figure 8. Stratigraphic nomenclature and correlation of middle Cenozoic rocks in the upper Great Plains (modified from Stone, 1973).

Harrison Formation

Hatcher (1902) named the Harrison Formation for 200 feet of fine grained sandstones exposed near the town of Harrison, Nebraska. He noted that these sandstones contain "siliceous tubes arranged vertically" (Hatcher, 1902, p. 117). Near Agate Fossil Beds State Park, Nebraska, the Harrison Formation consists of a very fine to fine grained sandstone. This sandstone contains very small burrows with internal cuspate structures.

Arikaree Formation in North Dakota

The Arikaree Formation terminology was first applied in North Dakota by Moore et al. (1959) for the caprock in the Chalky Buttes. The strata exposed in the upper part of the Killdeer Mountains, Dunn County, originally considered part of the White River Group, were placed in the Arikaree Formation and assigned a Miocene age by Denson and Gill (1965). Denson and Gill based their interpretation on the presence of an unconformity at the base of the exposures and because the rocks are lithologically similar to those in the Big Badlands of South Dakota from which Arikareean fossils had been recovered. Stone (1973) informally renamed the caprock in the Killdeer Mountains the "Killdeer formation" and suggested that the "Killdeer formation" formed the caprock on many of the isolated buttes in southwestern North Dakota.

The Arikaree Formation in North Dakota is a lithologically variable sequence of concretionary, cross-bedded, calcareous sandstones, siltstones, silty claystones, carbonates, and tuffs unconformably overlying the White River Group and overlain by thin unconsolidated deposits (mostly gravel) whose source and age are unknown (Figure 6). The base of the Arikaree is commonly marked by a conglomerate. Sparse Whitneyan and Arikareean "age" mammal fossils have been recovered from the Arikaree Formation in North Dakota.

KILLDEER MOUNTAINS

Introduction

The following 18 chapters contain discussions of the geology and paleontology of many of the buttes in western North Dakota. These discussions consist of summaries of previous geologic investigations of each locality followed by information obtained during this study. Some chapters include many buttes grouped together because of geographic proximity, similar lithologic and outcrop characteristics, or both.

The Killdeer Mountains consist of two mesas (North Killdeer Mountain and South Killdeer Mountain) which rise approximately 700 feet above the surrounding countryside in northern Dunn County (Plate 1). The Killdeer Mountains received their name from a translation of the Sioux name applied to this area "Tah-kah-o-kuty" which means "the place where they kill deer" (Williams, 1966). The mesas occupy an area of approximately 4,800 acres in portions of sections 26, 34, and 35 (T147N R96W), and sections 2, 3, 8-10, 15-23, 26-33 (T146N R96W). The Killdeer Mountains may contain the thickest combined accumulation of White River and Arikaree strata in the state (450 feet).

Quirke (1918) conducted the first comprehensive study of the geology of the Killdeer Mountains and suggested that the capping sedimentary rocks were part of the White River. Leonard (1922) agreed and included the upper 400 feet of strata exposed in the Killdeer Mountains in the White River. Denson and Gill (1965) placed the caprock in the Arikaree Formation and did not recognize the White River Group in the poorly exposed underlying rock. Stone (1973) did not believe that any of the caprock exposed in North Dakota was correlative with the Arikaree Group in other states and informally proposed a new rock-stratigraphic unit, the "Killdeer formation", for the strata capping the Killdeer Mountains. Delimata (1975) applied Stone's "Killdeer formation" terminology to the Killdeer Mountains and suggested that, due to the rhyolitic composition of the tuffs, the rocks may be Pliocene in age. Delimata's 51 measured sections in the Killdeer Mountains reflect the comprehensiveness of his study. Quirke (1913), Denson and Gill (1965), and Stone (1973) also measured sections in the Killdeer Mountains. A detailed petrographic analysis of the tuffs in the Killdeer Mountains was presented by Forsman (1986). All workers subsequent to Quirke have placed the Killdeer Mountain caprock in either the White River Group or Arikaree Formation (e.g., Kline, 1942; Powers, 1945; Benson, 1952; Bergstrom, 1956; Clayton, 1970, 1980).

Fort Union Group

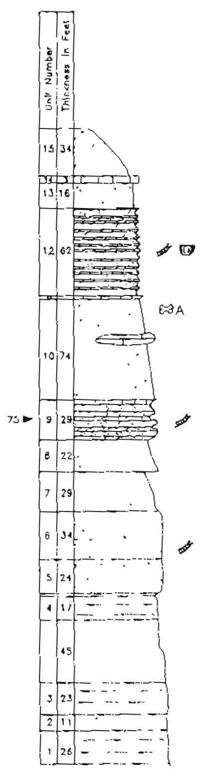
The countryside surrounding the Killdeer Mountains and the lower slopes of the two large mesas are comprised of the Golden Valley Formation (Figures 9-13a; Plate 1). The Bear Den Member, the kaolinite-rich lower member of the Golden Valley, prominently crops out on a hill in section 2 (T145N R96W). Channel sandstones of the Camels Butte Member, the micaceous upper member of the Golden Valley, are well exposed on the trail leading up to North Mountain (SE¼ section 3, T146N R96W). The Camels Butte Member is also well exposed in the SW¼ section 31 (T146N R96W), where it consists of alternating beds of brown to gold, micaceous sandstones, siltstones, and mudstones with thin lignite stringers.

The North Dakota Geological Survey drill rig could not penetrate the well-indurated Killdeer Mountain caprock. Therefore, holes were drilled as close as possible to the base of the lowest ledge-forming caprock. Slopes beneath the lowest rock ledge are generally steep and only two locations were level enough to drill. One hole was drilled 20 feet below the base of the lowest carbonate/tuff outcrop (section 34, T147N R96W). The second was drilled on the southern tip of North Mountain, approximately 80 feet below the base of the lowest carbonate ledge-forming unit (section 3, T146N R96W) (Appendix B). Examination of the core from these holes indicates that they were both drilled below the base of the Chadron Formation.

Chadron Formation

The base of the White River Group (Chadron Formation) is not well exposed anywhere in the Killdeer Mountains. The unconformable contact between the Chadron and Golden Valley Formations can be exposed by digging at only two known localities, both on South Killdeer Mountain: the NW¼NE¼NE¼ and the northeast corner of section 27 (T146N R96W) (Figures 9, 10). This unconformity occurs at elevations ranging from 2950 to 3000 feet above sea level in this area. The Chadron Formation is well exposed in the NE¼SW¼SW¼ section 31 (T146N R96W). How-

Figure 9. Aerial photograph of the Medicine Hole Plateau on the southeast edge of South Killdeer Mountain (146-96-27 ne). View is to the northwest.



SOUTH KILLDEER MOUNTAIN, (Medicine Hole Plateau) T146N R96W ne to nw section 27
Dunn County Elevation: 3280 feet

ARIKAREE FORMATION

Unit 15: Siltstone, light gray/green (w&f), moderately indurated.
Unit 14: Carbonate.
Unit 13: Sandstone, light gray/green (f&w), very fine grained, silty, poorly cemented.
Unit 12: Carbonate and siltstone, buff to gray (w&f), eight-1 foot thick carbonate lenses interbedded with 5 foot thick beds of siltstone, the carbonate lenses contain numerous small holes, burrows (?).
Unit 11: Carbonate, gray/buff (f&w), surface is irregular and cupped due to erosion.
Unit 10: Sandstone, buff to white (w&f), very fine to fine grained, moderately to well cemented, massive, contains small, white concretions which often are hollow but do not appear to be root casts or burrows.
Unit 9: Sandstone, (Burrowed Marker Unit), light gray/green to gray (w&f), sandstone is very fine grained, silty, ripple cross-bedded, poorly to very well cemented, calcareous, tuffaceous, contains numerous small and large scale burrows. Cemented lenses are generally 6 to 8 inches thick.
Unit 8: Sandstone, light gray/green (f), light dark gray (w), silty, calcareous, moderately to well cemented, ripple cross-bedded, calcareous laminae, basal 5 feet contains burrows.
Unit 7: Sandstone, light gray/green (w&f), very fine grained, silty, cross-bedded., moderately cemented.
Unit 6: Siltstone, gray to gray/green (w&f), poorly to moderately cemented, contains dark green chert nodules, calcareous lenses and laminae, contains small burrows at the base.
Unit 5: Siltstone, dark green to green (f), light gray/green (w), contains sand lenses, moderately cemented, contains spherical and dumbbell shaped concretions.

CHADRON FORMATION

Chalky Buttes Member

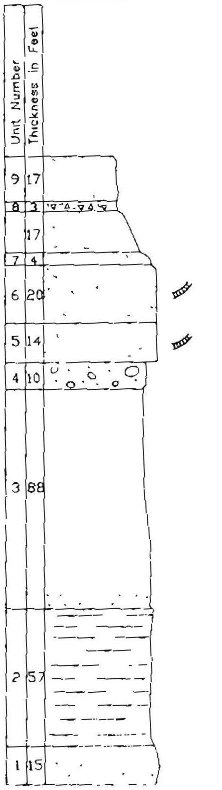
Unit 4: Mudstone, light green to yellow/green (f), buff (w), sandy.

GOLDEN VALLEY FORMATION

Unit 3: Mudstone, gray/green (f), light gray/tan (w), silty, iron oxide stained, fissile.
Unit 2: Sandstone, dark red/brown to tan (w&f), medium grained, micaceous, cross-bedded, poorly cemented, iron oxide stained.
Unit 1: Mudstone, yellow/brown to tan (w&f), silty, micaceous.

Figure 10. Measured geologic section on the southeast edge of South Killdeer Mountain.

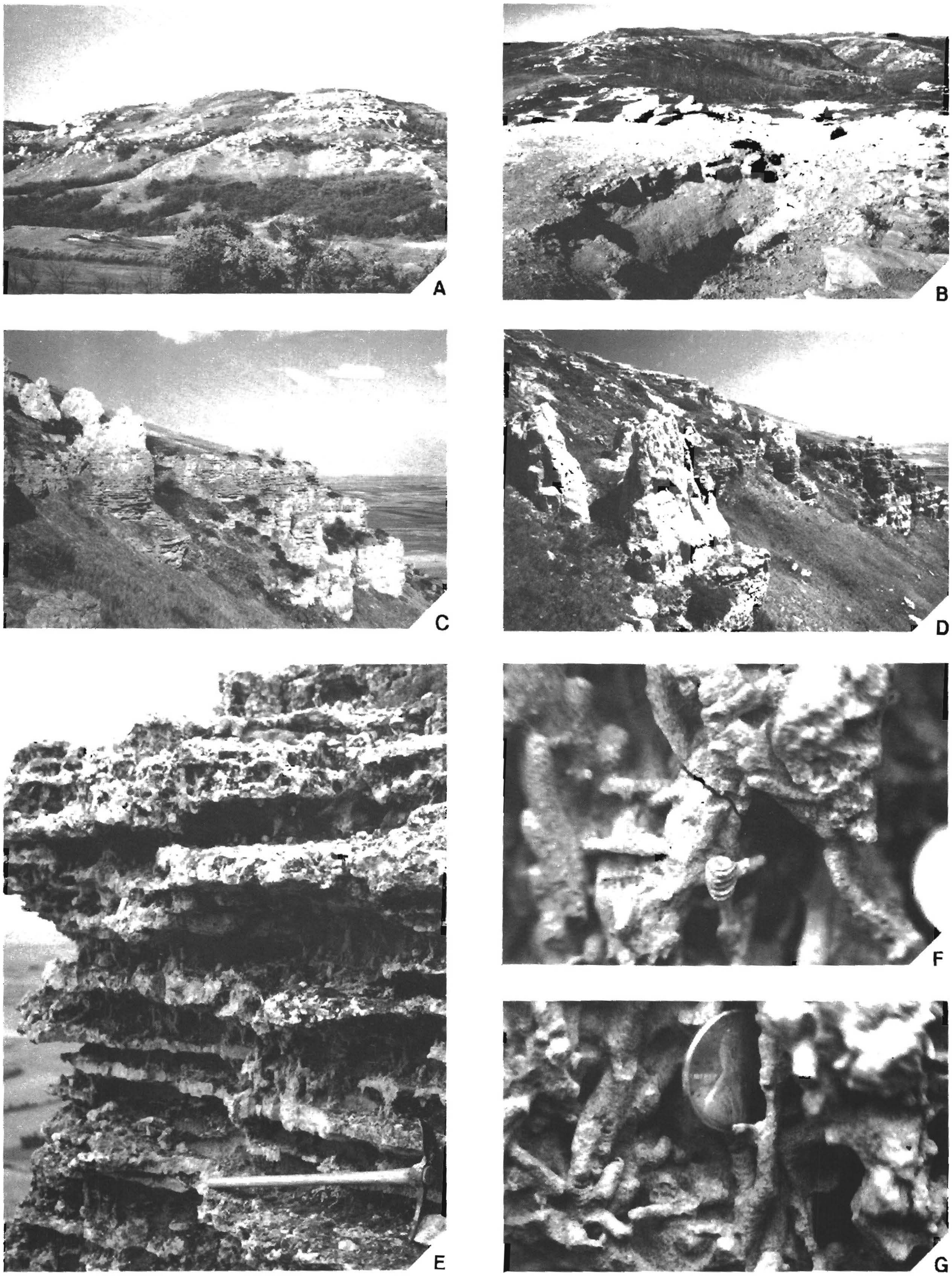
Figure 11. Aerial photograph of the southwest corner of South Killdeer Mountain (146-96-31 swne). View is to the north.



SOUTH KILLDEER MOUNTAINS (southwest corner) T146N R96W swne section 31
Dunn County Elevation: 3180 feet

	ARIKAREE FORMATION
Unit 9:	Siltstone, gray/white (w&f), calcareous.
Unit 8:	Tuff, white to bright white (w&f).
Unit 7:	Siltstone, green/gray to white (w&f), very well indurated, calcareous, ripple cross-bedded, contains lenses of sandstone.
Unit 6:	Siltstone, gray/white (w&f), calcareous, contains small burrows.
Unit 5:	Siltstone, gray/white (w&f), moderately indurated, contains large burrows, contains pellets or sphericules.
	CHADRON FORMATION
	Chalky Buttes Member
Unit 4:	Mudstone, tan to gray (w&f), pebbly, contains randomly oriented pebbles and cobbles, fractured, has the general appearance of till.
Unit 3:	Sandstone, gray/green to green (w&f), very fine to coarse grained, poorly sorted, clayey, poorly cemented, iron oxide stained at base.
	GOLDEN VALLEY FORMATION
	Camels Butte Member
Unit 2:	Claystone, yellow/green to red (w&f), silty, blocky, iron oxide stained.
Unit 1:	Sandstone, yellow/brown (w&f), very fine grained, silty, micaceous, iron oxide staining.

Figure 12. Measured geologic section on the southwest edge of South Killdeer Mountain.


A
B
C
D
E
F
G

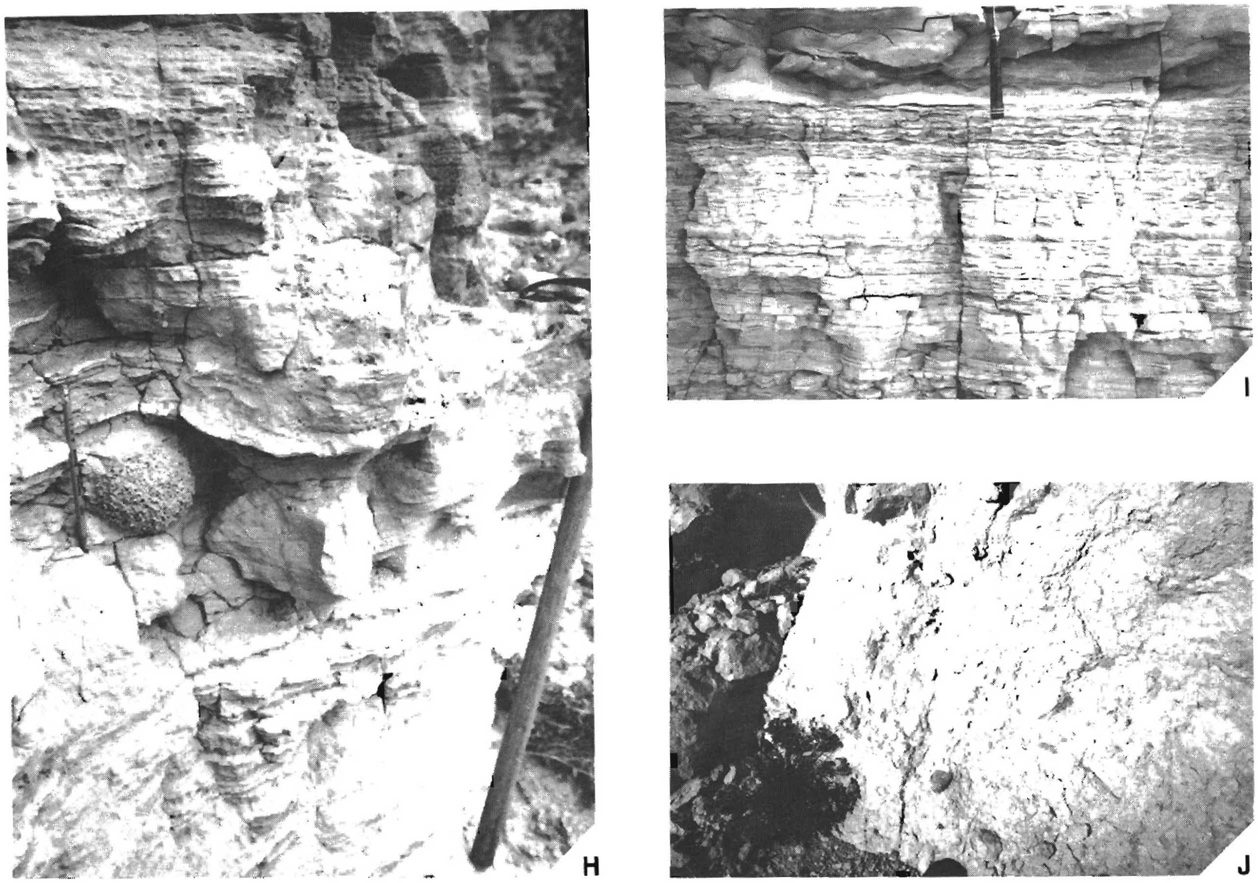


Figure 13. Exposures, sedimentary structures, and trace fossils of the Chadron and Arikaree Formations in the Killdeer Mountains. A, southeast edge of South Killdeer Mountain, including the Medicine Hole Plateau (146-96-27 ne). View is to the northwest. B, Medicine Hole (foreground), a 70-foot deep, 2-foot wide fissure in sandstone and carbonate caprock created by slope movement (146-96-27 nwnene). C, the burrowed marker unit, between sandstones, southeast corner of South Killdeer Mountain (146-96-27 nwnene). D, sandstone overlying the burrowed marker unit (foreground), and the burrowed marker unit (background), below Medicine Hole Plateau southeast edge of South Mountain (146-96-27 nwnene). E, the burrowed marker unit is a tuffaceous, burrowed sandstone containing lenticular calcareous concretions. Tuff samples were obtained from the friable intervals. F and G, cuspate internal structure of burrows in the burrowed marker unit. H, spherical concretion, of unknown origin, within laminated siltstone in the Arikaree Formation (146-96-27 nenwne). I, oscillating ripple marks in laminated siltstone (Arikaree Formation) (146-96-27 nenwne). J, poorly sorted, pebbly mudstone in the Chadron Formation, southwest corner South Killdeer Mountain (146-96-31 neswne).

ever, the attitude of the beds suggest that the Chadron is not in place at this locality, and the position of the basal contact is not thought to be reliable. In the Killdeer Mountains, the Chadron Formation consists of yellow/green sandy mudstone and clayey sandstone (Chalky Buttes Member), the South Heart Member is not present. The basal Chadron sandstone is generally medium to coarse grained in section 27 but is noticeably coarser grained and contains abundant pebbles in section 31. The sandy mudstone is assigned to the Chadron Formation because of its characteristic yellow/green color and the presence of medium to coarse quartz grains. Slump blocks of pebbly sandstone occur in both the southeast and southwest corners of South Killdeer Mountain. Sandstones in these slump blocks are very similar in appearance to the Chalky Buttes Member sandstones exposed in the Little Badlands. However, pebbles of volcanic rock, characteristic of the Chalky Buttes Member in southwestern North Dakota, were not observed at this locality. The Chadron is only 17 to 22 feet thick in section 27 but may be as much as 90 feet thick in the NE¼SW¼NE¼ section 31 (T146N R96W) (Figures 11, 12). There are few exposures below the caprock in section 31. Sandy mudstone, typical of the Chadron Formation, was discovered after excavating a small pit at a point approximately 90 feet below the base of the caprock in section 31. Sandy mudstone was also found in additional excavations higher in the section. Because of poor exposures, slumping could not be ruled out in this area. The apparent abrupt thickness changes in the

Chadron Formation may be due to original channel configurations.

A pebbly mudstone, assigned to the Chadron Formation, is exposed at the base of the lowest ledge-forming unit in the SE¼SW¼NE¼ and the NE¼SW¼NE¼ section 31 (T146N R96W). This mudstone has many characteristics of glacial till i.e., it is poorly sorted and contains randomly oriented pebbles and cobbles, but it could not be properly investigated due to the limited extent of the outcrop (Figure 13j).

Denson and Gill (1965) did not recognize the Chadron Formation in the Killdeer Mountains and interpreted the Arikaree Formation to be unconformably underlain by the Golden Valley Formation (Eocene). Stone (1973) also did not recognize the Chadron Formation in his measured section from the Killdeers, likely a result of the poor exposures below the caprock in that area. However, he did suggest that both the Brule and Chadron Formations may be present below the Arikaree in the Killdeer Mountains. Stone did note "dazzling white" sandstone, typical of the Chalky Buttes Member, at two other localities in the Killdeer Mountains. The Bear Den Member of the Golden Valley Formation is, however, the "dazzling white" sandstone at one of these localities (SW¼NW¼ section 11, T146N R96W). The second of Stone's localities could not be located, but his description matches slump blocks along the Medicine Hole trail in the southeast corner of section 22 (T146N R96W). Stone also reported smectite beds in what he interpreted to be the Chadron Formation but the only locality information he gives for these beds is the south end of South Killdeer Mountain, and the outcrop could not be located.

Lithologies of most rocks beneath the caprock in the Killdeer Mountains can not be accurately determined because of poor exposures. Dark green sandstones (perhaps correlative with the Chadron) are found in isolated outcrops located one hundred feet above exposures of the Golden Valley Formation in the northeast portion of North Killdeer Mountain. Similar green sandstones were also encountered in the deepest hole drilled on North Mountain.

Brule Formation

Stone (1973) noted that a small outcrop on the southeast corner of South Killdeer Mountain contained mudstones of the upper Brule Formation, but his observation could not be verified during this study. Numerous concretions and nodules, similar to those found in the Brule Formation in the Little Badlands, are present in the lower portion of the ledge-forming gray siltstones. These concretions are spherical to dumbbell in shape and are 5 to 6 inches in their maximum dimension. However, the nodular siltstone appears to be conformable with the overlying Arikaree strata and, therefore, was placed in the Arikaree Formation. The Brule Formation was not detected in the Killdeer Mountains during this study.

Arikaree Formation

The caprock of the Killdeer Mountains consists of 330 feet of tuffaceous siltstones, sandstones, and carbonates. The sandstones are cross-bedded and both the sandstones and the siltstones are calcareous and occasionally contain small burrows (Figure 13h,i). Limestone and dolostone are dominant throughout the upper portion of the capping section (Delimata, 1975). The carbonate beds may exceed 25 feet in thickness but generally consist of 1- to 3-foot-thick beds which are separated by 5-foot-thick siltstones. Forsman (1986) determined that nearly all of these lithologies contain volcanic glass, and can be characterized as being from slightly to highly tuffaceous.

One of the most prominent ledge-forming units occurs 100 to 150 feet above the base of the caprock (Figure 13a). This ledge former is 15 to 30 feet thick and contains interbedded tuffaceous sandstone and siltstone with occasional carbonate lenses (Figure 13c,d). It is conspicuous because it contains abundant fossil burrows and has been informally referred to as the "main, ledge-forming concretionary sandstone" by Stone (1972), the "wormy marker unit" by Delimata (1975), and the "burrowed marker unit" by Forsman (1986) (Figure 13e-g). We have adopted Forsman's terminology based on the presence of identifiable burrows but without evidence to indicate that these burrows were necessarily made by worms. The burrowed marker unit consists of alternating layers of well-indurated/burrowed beds and recessed friable beds which contain few, if any, preserved burrows. Forsman (1986) determined that the indurated and friable units were mineralogically similar except for the abundant calcite cement which had replaced most of the glass shards in some of the indurated layers. Forsman speculated that the thick accumulation of tuffaceous material resulted from wind and running water depositing this material into low lying areas, such as lakes and perhaps stream valleys. The burrowed marker unit is observed in portions of both

North and South Killdeer Mountain, but is best exposed beneath Medicine Hole Plateau in the northeast corner of section 27 (T146N R96W) (Figure 13b). A thick channel sandstone overlies the burrowed marker unit in the Medicine Hole area (Figure 13d).

Nine samples were collected from friable intervals of the burrowed marker unit for geochemical analysis of volcanic glass grains. Five of these samples were submitted to the United States Geological Survey Geochemistry Laboratory in Denver, Colorado for fission track dating and trace element fingerprinting.

Quirke (1913) and Delimata (1975) interpreted the Killdeer Mountains to be an inverted lake basin. The lacustrine carbonates have protected the underlying sedimentary rock from erosion. Quirke (1913) discovered pebbles in the basal portion of the carbonates and cross-bedded sandstone in outcrops along the southwest edge of South Killdeer Mountain. He suggested that these sediments were deposited by a river which entered the lake near this area. The well-cemented, cross-bedded, micaceous sandstone in the southwest corner of South Killdeer Mountain, that Quirke cited as evidence for this interpretation is, however, part of the Golden Valley Formation and the pebbly and sandy mudstones immediately overlying these Golden Valley sandstones appear to be part of the Chadron Formation. Therefore, the two fluvial rock units that Quirke (1913) cited as evidence for his theory of a fluvial system entering a lacustrine system in the southwest corner of South Killdeer Mountain are much older than the overlying carbonate caprock. Field observations made during this study support the theory that the Killdeer Mountains area is an inverted lake basin.

Paleontology

Virtually everyone who has studied the geology of the Killdeer Mountains (e.g., Quirke, 1918; Stone, 1973; Delimata, 1975) has searched for biochronologically significant fossils with no success. Prospecting for fossils in the Killdeers for this study also proved fruitless. A group from the Frick Laboratory of the American Museum of Natural History led by Morris Skinner in 1954 did find some oreodont remains five feet below the rim and 300 yards southwest of Medicine Hole Plateau. Two oreodont genera (Appendix C) were identified which indicate a late Arikareean (early Miocene) age for the strata capping the Killdeer Mountains (Tedford, 1989). These are the youngest fossils found at any of the western North Dakota buttes and suggest that the caprock at the Killdeer Mountains is younger than the caprock in the other buttes studied. The only other fossils that have been identified from the Killdeer Mountains are burrows and ostracods from the ledge-forming, capping sandstones and carbonates (Appendix C).

CHALKY BUTTES AND WHITE BUTTE, SLOPE COUNTY

Introduction

The Chalky Buttes are comprised of a series of several buttes including White and Rattlesnake Buttes. They form a north trending complex in portions of sections 10, 14, 15, 22, 23, 25, 26, and 35 (T134N R101W); 30 and 31 (T134N R100W); 2 (T133N R101W); and 6 (T133N R100W), Slope County (Plate 2). The areal extent of the Chalky Buttes is approximately 3,251 acres. The buttes rise 400 to 500 feet above the surrounding countryside. Strata are well exposed throughout the Chalky Buttes but some of the best exposures occur at White Butte, the highest point in North Dakota (3,506 feet) (Figures 14-17). Many of the earliest studies of the White River Group and Arikaree Formation in North Dakota took place in the Chalky Buttes. Babcock and Clapp (1906) referred to these buttes as the Chalk Buttes because of the white color of the exposed rocks. The name was apparently changed to Chalky Buttes by homesteaders.

White Butte was the first place in North Dakota that rocks of the White River Group were identified (Cope, 1883a). All subsequent workers have agreed on the existence of the White River Group in the Chalkys and its lower contact but have differed on the placement of the groups upper boundary and whether or not the Arikaree Formation caps some of these buttes (Figure 18). The most detailed studies of this area have been by Douglass (1909), Leonard (1922), Skinner (1951), Moore et al. (1959), Denson and Gill (1965), and Stone (1973).

Fort Union Group

The White River Group in the Chalky Buttes rests unconformably on the Sentinel Butte Formation. The Sentinel Butte Formation is approximately 200 feet thick in the Chalky Buttes, one half to one third of the Sentinel Butte Formation's maximum thickness. It is well exposed along the north side and the west slopes of the Chalky Buttes in sections 2, 10, 15, and 22 (T134N R101W).

Chadron Formation

The Chadron Formation unconformably overlies the Sentinel Butte Formation in this area. The unconformity is well exposed throughout the Chalky Buttes, especially in sections 15 and 22 (T134N R101W) (Figure 19a,b). This contact is easily recognizable because of the sharp contrast between the white, sandy mudstones and pebbly sandstones of the Chadron and the somber-colored siltstones, mudstones, and claystones of the Sentinel Butte Formation. In some places the contact is marked by a 1- to 2-foot-thick reddish/purple resistent bed of analcime which has been interpreted as a paleosol (Furman, 1970). A white or brightly colored bleached or weathered horizon is present beneath the contact in many areas in the Chalky Buttes.

The Chadron Formation is well exposed throughout the Chalky Buttes and consists of a sandy mudstone and pebbly sandstone (Chalky Buttes Member) at its base (Figure 19c-g). The Chalky Buttes Member is 70 to 90 feet thick in this area and contains 2- to 4-inch-diameter pebbles of quartz and volcanic rock (Figure 19f). Silicified fossil wood fragments are also common in these sandstones. These sandstones exhibit large scale, cross-stratification. The upper part of the Chadron Formation consists of gray/green smectitic claystone interbedded with thin, lenticular limestone beds (South Heart Member). The claystone forms prominent nonvegetated benches that can be traced easily throughout the Chalky Buttes (Figure 19h,i). This claystone ranges in thickness from 75 to 100 feet in this area. Draping of the claystone creates problems in accurately measuring the true thickness of the member.

Brule Formation

The Brule Formation is very thin where present in the Chalky Buttes. It was only 25 feet thick where measured on White Butte and absent from the geologic section measured on Chalky Buttes. Denson and Gill (1965) also found the Brule to be only locally present and from 12 to 65 feet thick (Figure 19j). The Brule Formation at Chalky Buttes is comprised of pink to buff colored nodular siltstones. Judging from the greater thickness of the Brule Formation in nearby areas, a significant portion of the formation was likely removed from the Chalky Buttes by erosion prior to deposition of the overlying Arikaree Formation.

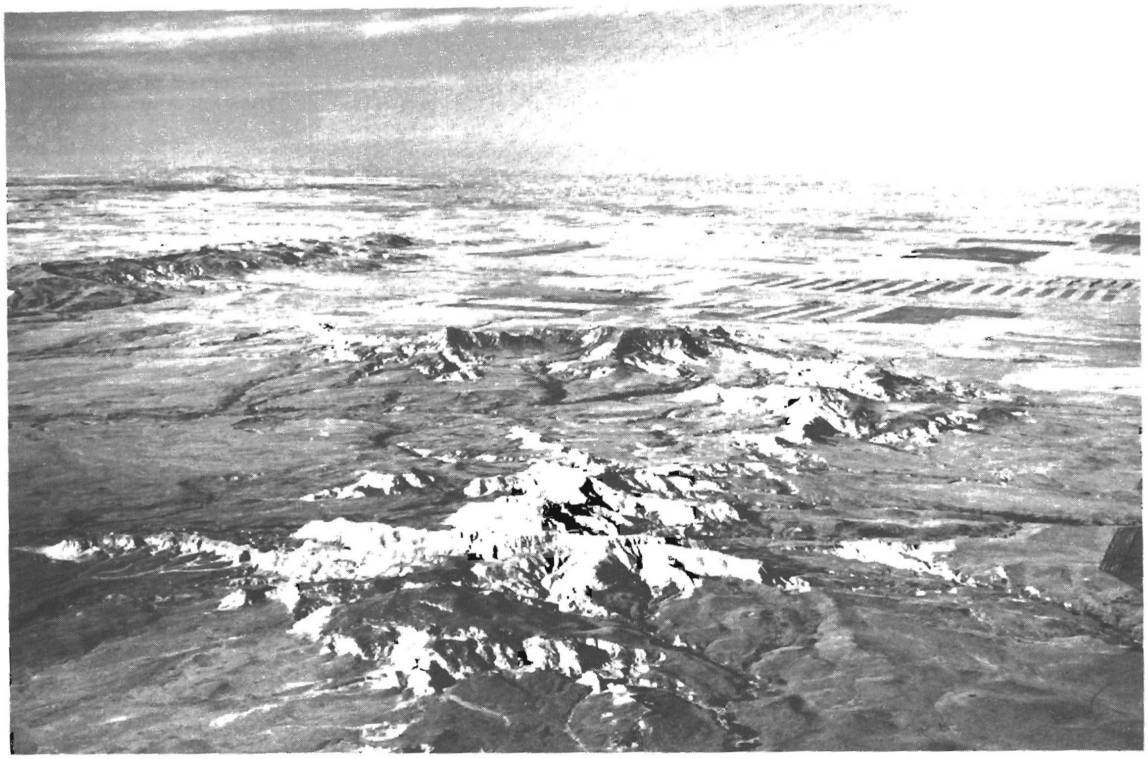
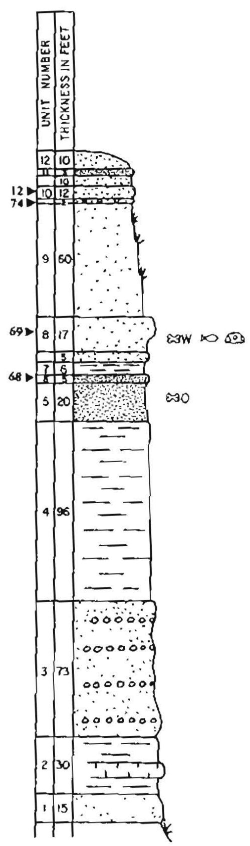


Figure 14. Aerial photograph of the Chalky Buttes, Slope County. White Butte is in the center of the photograph. View is to the north.



WHITE BUTTE
Slope County

T134N R101W E SEC 25
Elevation: 3506 feet

ARIKAREE FORMATION

Unit 12: Sandstone, grey to white (f&w), poorly cemented, clean.

Unit 11: Siltstone, grey to white (f&w), poorly to moderately cemented.

Unit 10: Sandstone, medium to light green (f&w), fine grained, 2-foot-thick conglomerate at base contains fossils, middle zone is well cemented - the rest is poorly cemented, contains small burrows.

Unit 9: Sandstone, medium to light green (w&f), very fine to fine grained, poorly cemented, poorly exposed, some clay zones.

Unit 8: Sandstone, medium to light green (w&f), fine to medium grained at basal 6 feet, very fine grained remainder of unit, quartz subrounded grains, moderately to extremely well cemented at top, cross-bedded, base contains green clay pebbles, fossiliferous.

Unit 7: Claystone, green (w&f), silty.

BRULE FORMATION

Unit 6: Siltstone, white (w&f), weathers to rounded surface.

Unit 5: Siltstone, light to medium grey (w&f), clayey, contains small vugs, highly fractured, ash (?), weathers to rounded surfaces.

CHADRON FORMATION

South Heart Member

Unit 4: Claystone, light to medium brown (f), green to pink (w), popcorn texture, contains white concretionary zones.

Chalky Buttes Member

Unit 3: Sandstone, light grey/green to dull white (w&f), conglomeratic, silty and some clay, very fine to coarse grained, mostly quartz, gravel is subrounded to well rounded, gravel up to 4 inches in diameter, volcanics and frosted quartz, some wood, cross-bedded, very poorly sorted.

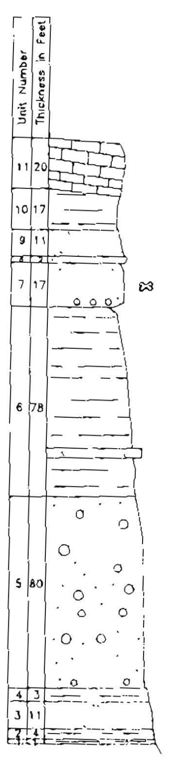
SENTINEL BUTTE FORMATION (middle of unit)

Unit 2: Claystone, purple-white at base to light medium brown at top (w&f), popcorn texture, highly fractured claystone in center may contain ash.

Unit 1: Sandstone, light gray (f) to dazzling white (w), silty and clayey, very fine to medium quartz grains, poorly to moderately cemented, iron oxide layers, steep slopes.

Figure 15. Measured geologic section at White Butte, Slope County.

Figure 16. Aerial photograph of the Chalky Buttes, Slope County. White Butte is in the right foreground, Black Butte is in the left background. View is to west-northwest.



CHALKY BUTTES
Slope County

T134N R101W se section 15 to nw section 23
Elevation: 3484 feet

	ARIKAREE FORMATION
Unit 11:	Siltstone and/or Marlstone, gray/green (f), white (w), vuggy in places, this unit contains, conglomeratic lenses, pebbles, chert nodules, the dip of this unit indicates it has been let down.
Unit 10:	Claystone, medium to dark gray (f) to gray/green (w).
Unit 9:	Siltstone, light to dark green (f), light gray/green (w), very well cemented, contains brown concretionary layers.
Unit 8:	Siltstone, gray to dark green (f), gray/white to brown (w), very well indurated, concretions, ledge former, bulbous texture.
Unit 7:	Sandstone, medium to dark green (f), medium to light green (w), medium to fine grained, conglomeratic at base, fines upward into very fine sand and silt, moderately to poorly cemented, fossiliferous.
	CHADRON FORMATION
	South Heart Member
Unit 6:	Claystone, gray to green (f), gray to brown (w), popcorn texture.
	Claystone, gray to white (w&f), very well indurated, silicified smectite.
	Claystone, gray/green to orange (f), dark gray/brown (w), iron oxide staining, laminae, occasional silicified zone, popcorn texture.
	Chalky Buttes Member
Unit 5:	Sandstone, gray to white to yellow (w&f), moderately to poorly indurated, fine to coarse grained, conglomeratic, pebbles and cobbles of quartz and rock fragments including volcanic, some horizons contain high percentage of clay.
	SENTINEL BUTTE FORMATION
Unit 4:	Claystone, light gray to dark gray (w&f), some iron oxide staining.
Unit 3:	Siltstone, yellow to orange (f&w), coarsening upward to very fine sandstone, laminae, moderately to well cemented, iron oxide concretionary layers.
Unit 2:	Claystone, light to dark gray (w&f).
Unit 1:	Claystone, black/brown (w&f), carbonaceous.

Figure 17. Geologic measured section at the Chalky Buttes, Slope County.

Arikaree Formation

The Arikaree Formation unconformably overlies the Brule Formation in the Chalky Buttes. Strata assigned to the Arikaree Formation in this area are comprised of limestones and gray/green to white sandstones, siltstones, and claystones. The sandstones at or near the base of the Arikaree are generally conglomeratic and contain igneous rock, siltstone, and claystone pebbles (Figure 19k). These sandstones often contain mammal bone fragments. Small burrows, similar to those observed in the Arikaree Formation in the Killdeer Mountains, were noted in a sandstone 25 feet below the top of White Butte (Figure 19l).

The Arikaree Formation is 125 feet thick at White Butte and 67 feet thick in the section measured in the Chalky Buttes. Denson and Gill (1965) determined that the Arikaree had a minimum thickness of 135 feet prior to erosion in this area. Large blocks of coarse Arikaree sandstone and limestone are present at the top of Chalky Buttes (sections 22 and 23) (Figure 19m). Air photo examination of the area west of the antennae tower indicates that most of the Arikaree has undergone slumping. It is evident from the orientation of these blocks that they are not in place and have been let down and rotated, suggesting that the Arikaree Formation was, at one time, much thicker in this area.

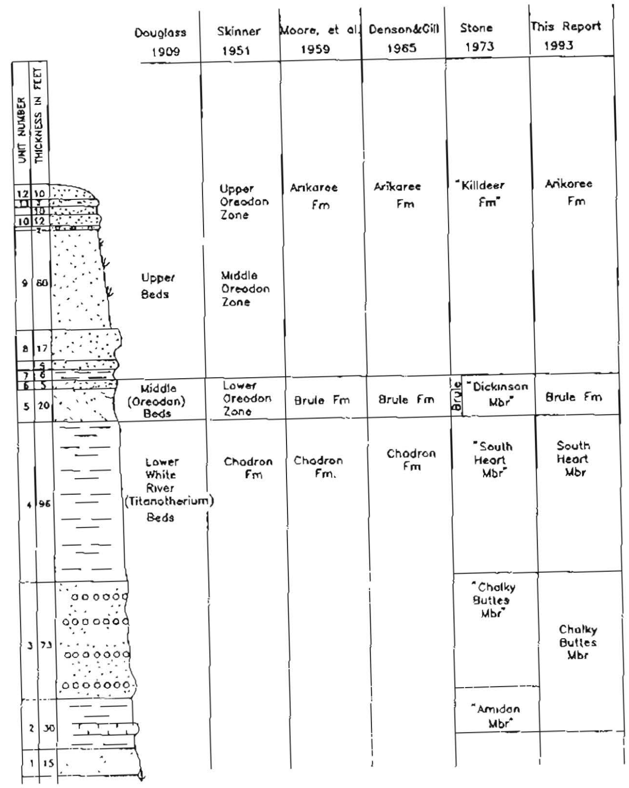
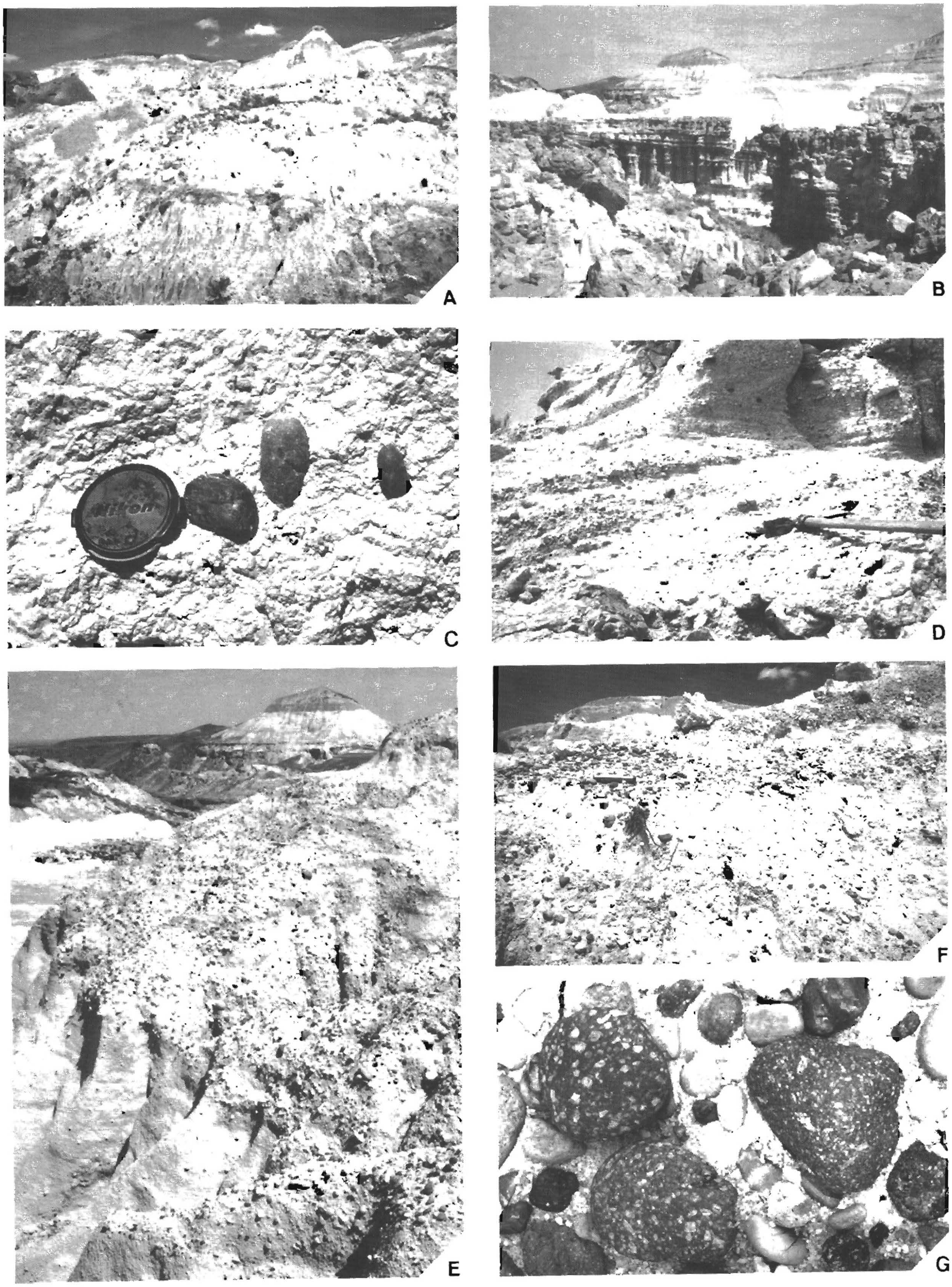


Figure 18. History of stratigraphic nomenclature for the middle Cenozoic at White Butte, Slope County.

Paleontology

The first scientific collection of Oligocene age fossils in North Dakota was made by Cope (1883a) from White Butte, Slope County (Appendix C). Cope referred to these fossiliferous rocks as the White River Formation primarily because of the mammal fossils found. Douglass revisited this site in 1905 and in a series of articles described some of the mammal fossils (horse and rhinoceros) that he found (Douglass, 1908a, 1908b, 1909). Leonard (1919) also collected mammal fossils from White Butte during his early study of the White River in North Dakota. Other stratigraphic studies of the White River have also reported fossils collected at White Butte (e.g., Babcock and Clapp, 1906; Denson and Gill, 1965; Stone, 1973). Morris Skinner and others with the Frick Laboratory of the American Museum of Natural History collected fossils from White Butte and Chalky Buttes in the 1950s. Some of those fossils have been subsequently described in systematic reviews such as the one concerning the insectivore genus *Centetodon* by Lillegraven et al. (1981). Chalky Buttes and White Butte mammal fossil assemblages were included in Hoganson and Lammers' (1992) study of the vertebrate fauna of the Brule Formation in North Dakota. Studies of fossils from specific mammal groups such as the rodents (Korth, 1981; Kihm, 1990) and lagomorphs (Wretling, 1991) are currently underway.

Most fossils recovered from the Chalky Buttes and White Butte are remains of mammals from the Brule Formation (Appendix C). An Orellan land mammal "age" is suggested by these mammal assemblages although some of the early collections from White Butte have been interpreted to be Whitneyan in age (Wood et al., 1941). The oreodont *Leptauchenia decora* was recovered from basal Arikaree Formation sandstones at White Butte during this study which further suggests a Whitneyan "age" for at least a portion of the upper strata on White Butte.


A
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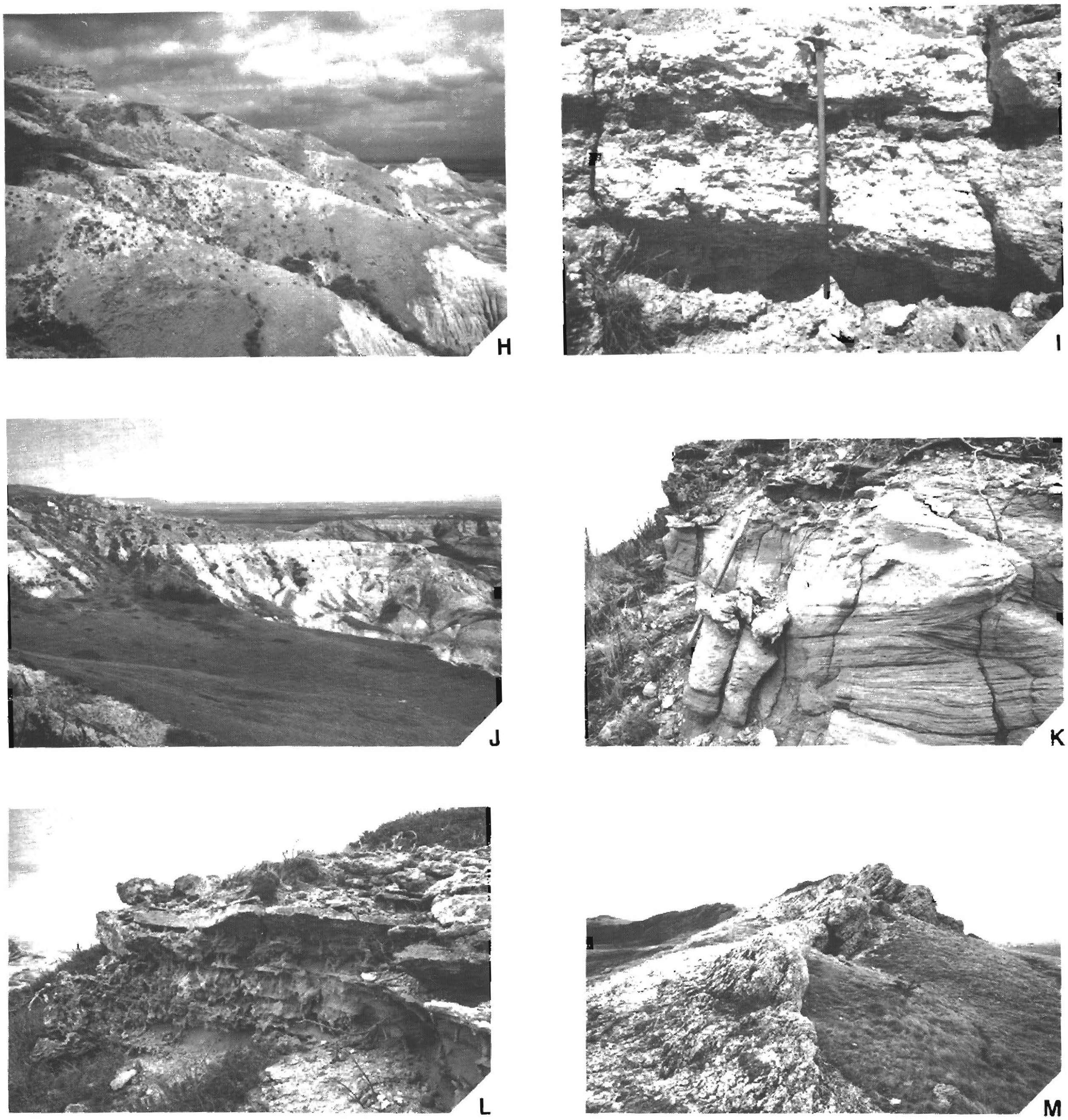


Figure 19. Exposures of the Chadron, Brule, and Arikaree Formations in the Chalky Buttes, Slope County. **A**, unconformity between the Chadron and Sentinel Butte Formations (134-101-15 sese). The rocks in this area have been disturbed by slumping. **B**, channel sandstone in the Sentinel Butte Formation underlying the Chadron unconformity, the South Heart Member caps the butte in the background (134-101-15 sesene). **C**, randomly oriented pebbles in mudstone near the base of the Chalky Buttes Member (134-101-15 sese). **D**, oriented pebbles following bedding planes in a conglomeratic sandstone of the Chalky Buttes Member (134-101-15 nesese). **E**, randomly oriented pebbles in conglomeratic sandstone in the Chalky Buttes Member (134-101-15 sesene). **F**, conglomeratic sandstone and pebbly mudstone of the Chalky Buttes Member, the South Heart Member caps the hill in background (134-101-15 nesese) **G**, pebbles of volcanic porphyries characteristic of the Chalky Buttes Member (134-101-25 nenwse). **H**, smectitic claystone of the South Heart Member drapes the slopes. The Brule Formation caps the butte in foreground and the Chalky Buttes Member is visible in the right foreground and background (134-101-25 nwsene). **I**, silicified, smectitic claystone bed in the South Heart Member (134-101-15 nwsese). **J**, Chadron, Brule, and Arikaree Formations on the southwest side of White Butte, Slope County (134-101-25 nenwse). **K**, sandstone in the Arikaree Formation near the top of White Butte, Slope County (134-101-25 nwnese). **L**, burrowed sandstone in the Arikaree Formation approximately 40 feet below the top of White Butte, Slope County (134-101-25 nenese). **M**, displaced carbonate and conglomeratic sandstone blocks let down from higher in section. A ridge of displaced blocks can be traced southward along the crest of the Chalky Buttes (134-101-23 swsw).

SLIDE BUTTE

Introduction

Slide Butte is a moderately sized butte located one mile east of Black Butte and 1.5 miles west of the Chalky Buttes in the NE¼ section 29 and the NW¼ section 28 (T134N R101W), Slope County (Plate 2). The butte rises approximately 250 feet above the surrounding countryside. The top of the butte includes approximately 24 acres. Slide Butte received its name following a large mass movement of a combined debris flow and rock fall which occurred on the north side of the butte in the spring of 1930 and 1932 (Figure 20). Large blocks of the capping sandstone broke away from the butte when portions of the underlying claystone gave way. The mass movement was misinterpreted by some local residents as a volcanic eruption and was reported in the press as far away as Minneapolis, Minnesota (Murphy, 1986). Sandstones of the Sentinel Butte Formation are well exposed at the base of the butte and clinker, created from the burning of the HT Butte lignite bed, is present in the ravine northwest of the butte.

Wyant and Beroni (1950) were first to suggest that rocks capping Slide Butte were part of the White River rather than the Fort Union Group. Moore et al. (1959), Denson and Gill (1965), and Stone (1973) agreed with this interpretation but Furman (1970) interpreted the capping strata to be part of the Golden Valley Formation. Both Wyant and Beroni (1950), and Denson and Gill (1965) published measured sections from Slide Butte.

Fort Union Group

The lower slopes of Slide Butte consist of the Sentinel Butte Formation (Figures 20, 21). The HT Butte lignite at the top of the Bullion Creek Formation has burned throughout much of the area west of the butte, and the resulting clinker marks the base of the Sentinel Butte Formation.

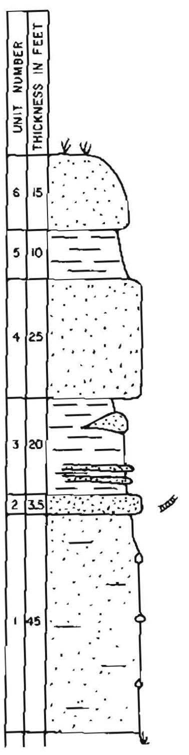
Chadron Formation

The base of the Chadron Formation at this locality consists of a conglomeratic sandstone (Chalky Buttes Member) containing pebbles mostly of volcanic porphyries (Figure 22a) and is quite similar in appearance to the Chalky Buttes Member at Chalky Buttes, except it is much thinner. This conglomeratic sandstone is thickest and best exposed at the southwest corner of the butte. The Chalky Buttes Member was not initially recognized at the southeast corner of the butte when the geologic section was measured because it is thin and finer grained than along the southwest edge of the butte. The conglomeratic sandstone is overlain by a purple smectitic claystone which is overlain by a sandstone caprock (Figure 22b-d). Both the upper part of the conglomeratic sandstone and the sandstone caprock are moderately to well cemented and moderately sorted, not typical characteristics of Chadron sandstones at other localities in North Dakota. The silty smectitic claystone is, however, characteristic of the South Heart Member of the Chadron Formation. Portions of this claystone are similar in appearance to beds in other areas which are known to contain analcime, a characteristic sometimes associated with the unconformity at the base of the Chadron Formation.

The capping sandstone above this claystone is highly fractured and weathered (Figure 22c). This sandstone is not similar to sandstones in the Brule Formation and does not contain a basal conglomerate or exhibit other criteria characteristic of the Arikaree Formation. The capping sandstone was placed in the Chadron Formation even though sandstones have not been included in the South Heart Member at any other locality in western North Dakota.

Others (Moore et al., 1959; Denson and Gill, 1965) have also included the 55 feet of sedimentary rock above the base of the conglomerate on Slide Butte in the Chadron Formation. Stone (1973) included the rock capping Slide Butte as part of his "Amidon member" (basal Chadron Formation). His reasons for including these rocks in the "Amidon member" are unclear since at least some of the rocks in this butte are lithologically similar to his overlying members of the Chadron Formation. It is not possible to determine what, if any, additional lithologies were included in Stone's "Amidon member" at Slide Butte because he did not present a measured section. No fossils have been reported from Slide Butte or were collected there during this study.

Figure 20. Photograph of Slide Butte, Slope County. The scarp of a large combination-rock fall and debris flow is present on the north side of the butte. View is to the southwest.



SLIDE BUTTE
Slope County

T134N R101W W SEC 28
Elevation: 3340 feet

CHADRON FORMATION

Unit 6: Sandstone, light to medium yellow/brown, moderately to well cemented, highly fractured.

Unit 5: Claystone, burgundy to gray to light brown (w&f), popcorn texture, silty.

Unit 4: Sandstone, medium brown (w&f), very fine to coarse grained - generally fine to medium, very well cemented, large scale cross-bedding.

Unit 3: Claystone, gray to light yellow/brown (w&f), silty, popcorn texture, sand and silt lenses near base (1-2 ft. thick), contains a 2- to 3-foot-thick conglomeratic sandstone lens near top.

SENTINEL BUTTE FORMATION

Unit 2: Sandstone, light gray to light yellow/brown (w&f), very fine grained, small to medium scale cross-bedding, moderately to poorly cemented, may contain burrows, iron oxide stained.

Unit 1: Sandstone, gray to yellow/brown (w&f), very fine grained, very silty, micaceous, moderately cemented, contains numerous iron oxide layers, very clayey, contains calcite concretions and large iron oxide concretions, also contains welded iron oxide sphericules.

Figure 21. Measured geologic section at Slide Butte, Slope County.

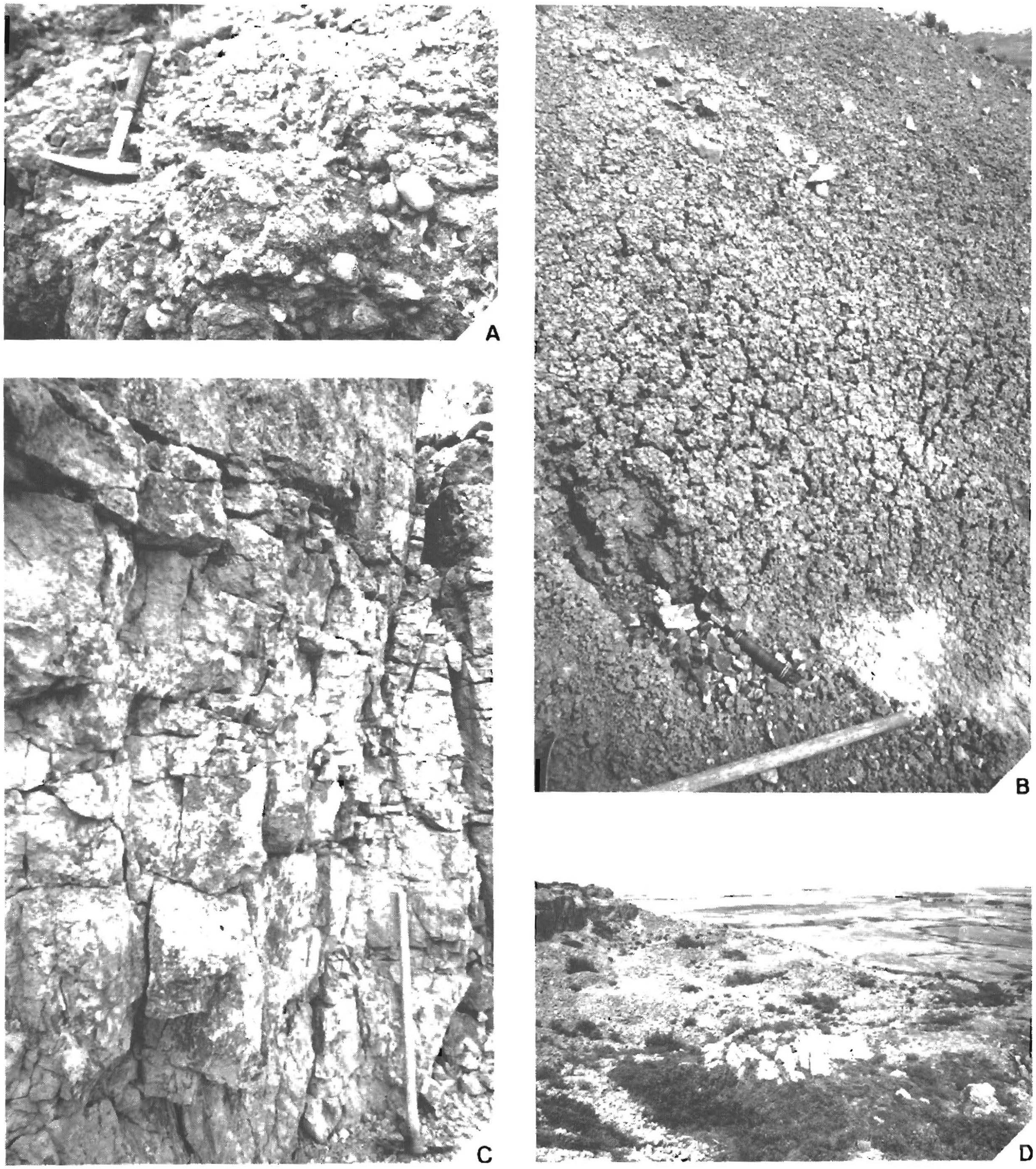


Figure 22. Lithologies and exposures of the Chadron Formation at Slide Butte, Slope County. **A**, conglomeratic sandstone at the base of the Chalky Buttes Member on the southwest corner of Slide Butte (134-101-29 sesene). **B**, popcorn surface texture of smectitic claystone in the South Heart Member (134-101-28 swswnw). **C**, highly fractured nature of sandstone capping Slide Butte (134-101-29 sesene). **D**, depression resulting from combination rock fall and debris flow on the north end of Slide Butte, view is to the southwest (134-101-29 nesene).

TEPEE BUTTE

Introduction

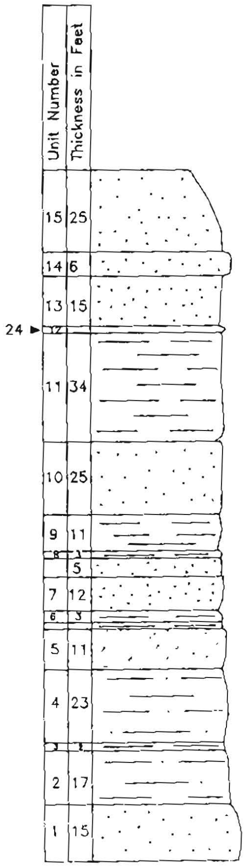
Tepee Butte, likely named for its conical shape, is a small butte located halfway between Black Butte and Slide Butte in the NW¼ section 29 (T134N R101W), Slope County (Figure 23; Plate 2). Tepee Butte rises 200 feet above the surrounding countryside and the top of the butte encompasses an area of only 3 acres. Moore et al. (1959) placed the capping sandstone in the Sentinel Butte Formation. Denson and Gill (1965), Stone (1973), Clayton (1980), and Carlson (1983) all agreed with that interpretation.

Fort Union Group

The Sentinel Butte Formation comprises all of Tepee Butte and most of the area around the butte (Figure 24). Alternating beds of sandstone, siltstone, and mudstone of this formation are well exposed along the southeast face of the butte. The Bullion Creek Formation is exposed in the base of the ravine east of the butte. Clinker from the burning of the HT Butte lignite bed, marking the base of the Sentinel Butte Formation, can be traced in outcrop at the top of this ravine.

The top 45 to 50 feet of Tepee Butte is capped with a sandstone that is fine to coarse grained, poorly to moderately cemented, massive at the base and cross-bedded at the top. This sandstone can be split into three distinct beds. The middle, moderately cemented bed forms a ledge around the butte and separates the upper and lower poorly consolidated sandstones. From a distance, the sandstone cap appears to rest unconformably on the underlying rocks, but no evidence of an unconformity, such as pebbles or rip-up clasts, were found at the base of the capping sandstone (Figure 23). No vertebrate fossils have been reported from or found during this study at Teepee Butte.

Figure 23. Photograph of Tepee Butte, Slope County. View is to the north.



TEPEE BUTTE
Slope County

T134N R101W nw SEC 29
Elevation: 3299

SENTINEL BUTTE FORMATION

Unit 15: Sandstone, gray to buff (w&f), medium grained, moderately cemented, cross-bedded.

Unit 14: Sandstone, yellow/brown (w&f), fine to medium grained, moderately cemented, massive.

Unit 13: Sandstone, gray/white (w&f), very fine to fine grained, silty at base, moderately cemented, contains iron oxide concretions, welded iron oxide spheres or pellet concretions, some mica flakes.

Unit 11: Claystone, dark brown to black (w&f), carbonaceous.

Unit 10: Sandstone, gray to yellow/white (w&f), very fine to fine grained, silty, poorly cemented, iron oxide concretions, contains welded iron sphere concretions, yellow staining at top of unit.

Unit 9: Claystone, dark gray/brown to black (w&f), popcorn texture.

Unit 8: Mudstone, dark brown to black (w&f), carbonaceous, going to coal.

Unit 7: Sandstone, yellow/brown (w&f), fine grained, very well cemented, cross-bedded.

Unit 6: Mudstone, dark brown to black (w&f), carbonaceous, contains fossil wood, going to coal.

Unit 4: Mudstone, gray to gray/green, iron oxide concretions, silty.

Unit 3: Claystone, dark brown to black (w&f), carbonaceous.

Unit 2: Mudstone, gray to gray/green (w&f), iron oxide concretions.

Unit 1: Sandstone, gray to brown (w&f), very fine to fine grained, moderately cemented, stained, iron oxide lenticular concretions.

Figure 24. Measured geologic section at Tepee Butte.

BLACK BUTTE, SLOPE COUNTY

Introduction

Black Butte (originally named HT Butte) is a relatively large mesa located 2.5 miles west of the Chalky Buttes (Figure 25). The butte was originally named for the HT ranch, a prominent horse ranch established in 1884 by the Little Missouri Horse Company. The HT ranch stretched from this butte north to the Little Missouri River. The name Black Butte was likely derived from the dark color of this butte when compared to the white colored rocks at nearby Chalky Buttes. Black Butte extends over portions of sections 19 and 30 (T134N R101W) and sections 23-25 (T134N R102W) in Slope County (Plate 2). This butte rises approximately 550 feet above the surrounding countryside and was for many years incorrectly identified as the highest point in North Dakota. The top of Black Butte covers an area of approximately 400 acres.

The capping sandstone of Black Butte was originally assigned to the Sentinel Butte Formation by Leonard (1908, 1922) and Douglass (1909). Douglass (1909) quoted Leonard as stating that the sandstone capping Black Butte is the same sandstone seen beneath the White River Group in the Chalky Buttes. Leonard felt that the sandstone dipped sufficiently to the east to account for difference in elevation between the two occurrences (3400 feet on Black Butte to 3120 feet in the Chalky Buttes). Following these early studies, there has been little consensus about this capping sandstone. Moore et al. (1959), Denson and Gill (1965), and Stone (1973) placed this sandstone in the Sentinel Butte Formation whereas Hares (1928), Seager et al. (1942), Powers (1945), Wyant and Beroni (1950), Bergstrom (1956), Denson et al. (1959), Clayton (1980), and Carlson (1983) placed it into either the White River Group or Arikaree Formation.

Fort Union Group

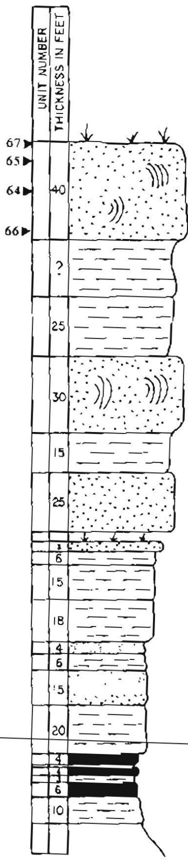
The Sentinel Butte Formation is well exposed at the southeast edge of Black Butte where the geologic section was measured. The HT Butte lignite bed, is exposed just below the base of the formation and approximately 200 feet of alternating beds of sandstones, mudstones, and siltstones of the Sentinel Butte Formation was measured in that area (Figure 26).

Black Butte is capped by approximately 40 feet of very fine to fine grained, cross-bedded, moderately cemented sandstone (Figure 27a-d). This sandstone is multicolored, ranging from red to yellow/brown, suggesting it has undergone a prolonged period of weathering. No conglomerates were identified at its base, although some rip-up clay clasts are present (Figure 27e). This caprock is not similar in appearance to most Sentinel Butte sandstones. Leonard (1922) noted that the northeasterly dip of the capping sandstone would account, in part, for its absence at the same elevation in the Chalky Buttes, 3 miles to the east (Figure 28). In the Chalky Buttes, a sandstone with the same general appearance as the Black Butte caprock occurs in the Sentinel Butte Formation, 20 to 40 feet below the base of the Chadron Formation, in the SE¼SE¼SW¼ section 10 (T134N R101W). No biostratigraphically significant fossils were found in this caprock to assist in correlation or age assignment.

Chadron Formation

A thin pod of light green chert is present above the capping sandstone on Black Butte (Figure 27f). Moore et al. (1959) and Denson and Gill (1965) suggested that this chert is a "silicified bentonite" and correlative with the upper part of the Chadron Formation. In this study, the chert is regarded as part of the South Heart Member of the Chadron Formation because of its lithologic similarity to chert lenses within the smectitic claystones of the upper part of the Chadron in other areas of southwestern North Dakota.

Figure 25. Aerial photograph of Black Butte, Slope County. Tepee, Slide, and Chalky Buttes are in the background. View is to the southeast.



BLACK BUTTE
Slope County

T134N, R101W, SW SEC 19
Elevation: 3370 feet

CHADRON FORMATION
South Heart Member
Chert, light to medium green.
SENTINEL BUTTE FORMATION

Unit 16: Sandstone, red, orange, yellow/orange (w) to yellow/brown (f), very fine to fine grained, well indurated, noncalcareous cement, cross-bedded, very mottled, unfossiliferous.

Unit 15: Claystone, light purple (w&f), contains lenses of nonindurated clay.

Unit 14: Claystone, white to dazzling white (w&f), contains a thin siliceous lens, kaolinitic, similar in appearance to Bear Den Member.

Unit 13: Sandstone, yellow-gray to gray (w&f), moderately cemented, contains rip-up clast zones and contorted beds, cross-bedded, iron oxide stained, very fine to silt size grains, micaceous.
Claystone, bright white to gray (w&f), popcorn texture.

Unit 12: Claystone, light gray to orange, silty, contains iron oxide concretions, and light colored silt zones.

Unit 11: Sandstone, yellow to orange (w&f), very fine to fine grained, poorly cemented, prone to slumping, thickness approximated.

Unit 10: Sandstone, yellow-orange (w&f), very fine grained to silt, moderately cemented, calcite cement, iron oxide stained.

Unit 9: Claystone, light gray-white to brownish-gray (w&f), contains carbonaceous zones from midway to top of unit.

Unit 8: Claystone, brownish gray (w&f) poorly consolidated, popcorn texture.

Unit 7: Claystone, gray-brown to light brown (w&f), very well indurated, contains small spherical iron oxide concretions.

Unit 6: Siltstone, grayish brown (w&f), sandy.

Unit 5: Claystone, gray (w&f), popcorn texture.

Unit 4: Sandstone, gray (w&f), very fine to fine grained, fining upward to silt, contains some lenticular concretion zones.

Unit 3: Claystone, light yellow-gray, contains limonite rich zones, jarosite zones, and spherical concretions, also some smectite rich zones.

BULLION CREEK FORMATION
Lignite, HT Butte bed (top).
Claystone, light gray.
Lignite.
Claystone, white (w&f), two to three inch concretion zone at base.

Unit 2: Lignite, this coal series forms a widespread thick clinker, HT Butte bed (base).

Unit 1: Claystone, gray (w&f), smectite, heavily slumped.

Figure 26. Measured geologic section at Black Butte, Slope County.

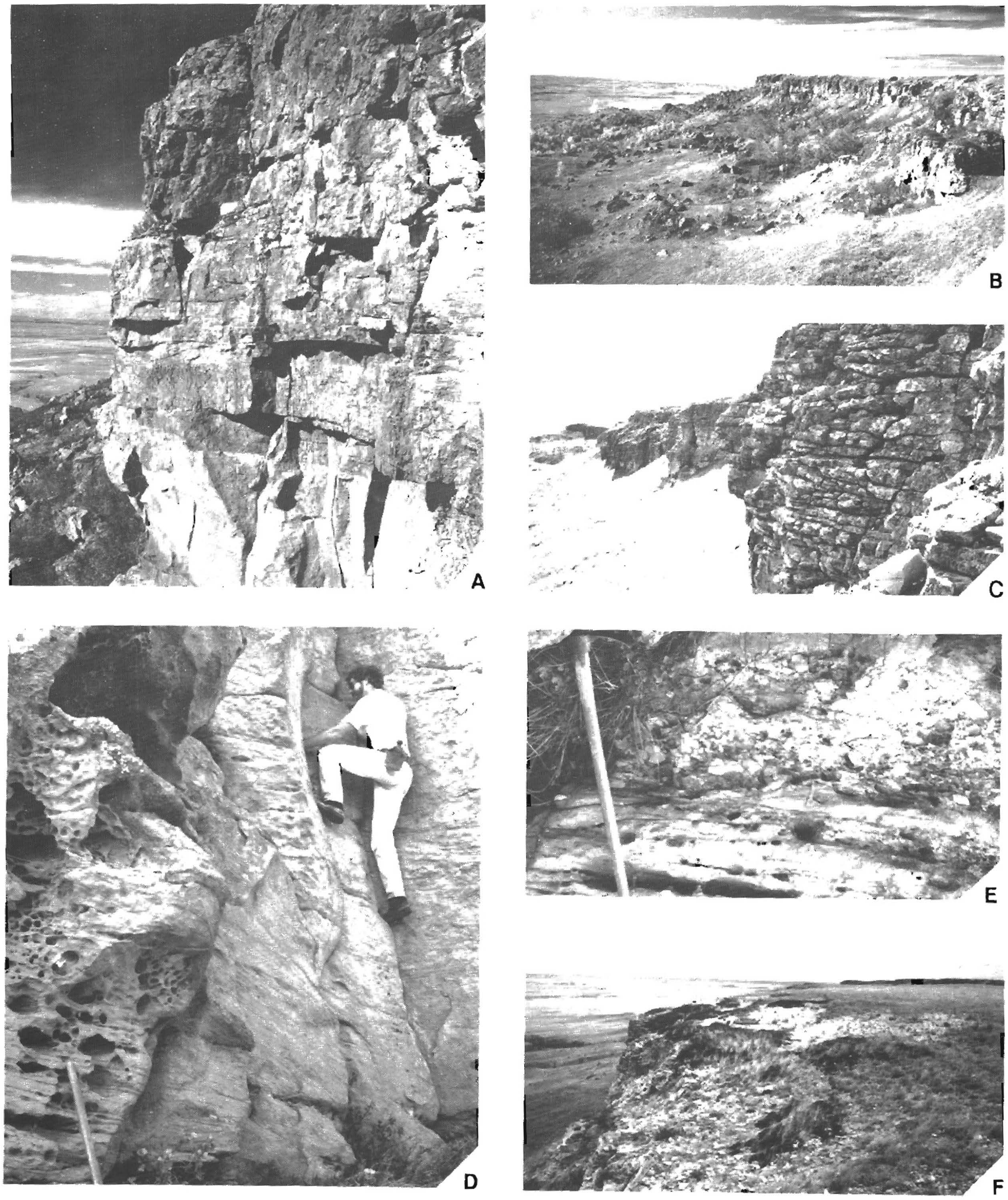


Figure 27. The caprock of Black Butte, Slope County. A, fractured nature of capping sandstone (135-101-25 nenene). B, blocks of capping sandstone that have broken from the rim of Black Butte obscuring the underlying geology, view to the west (135-101-24 swsw). C, fractured sandstone caprock and vegetated talus slope covering the underlying geology, view is to the west (134-101-30 nwnwnw). D, Nels Forsman inspecting cross-bedding and fluted weathering patterns in the sandstone caprock (134-101-30 nwnwnw). E, rip-up clasts of sandstone and siltstone near the base of the capping sandstone (134-101-30 nwnwnw). F, a thin deposit of light to dark green chert, representing the Chadron Formation, overlying the capping sandstone (134-101-19 seswsw).

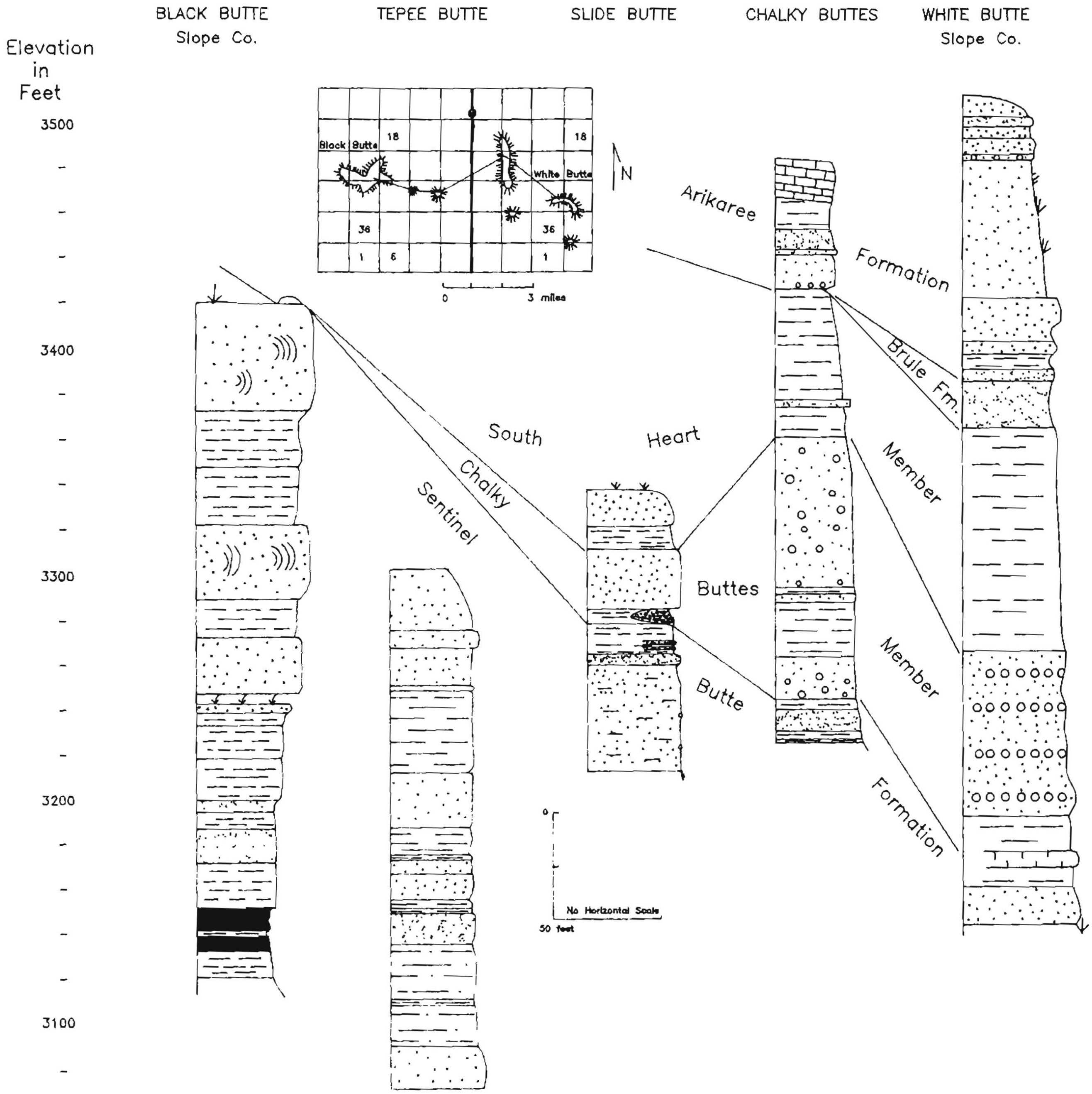


Figure 28. Geologic cross-section from Black Butte to the Chalky Buttes, Slope County.

LITTLE BADLANDS

Introduction

In this report, the term Little Badlands is used to describe the 23,040-acre area of White River Group and Arikaree Formation strata exposed in portions of 7 townships in southwestern Stark County (including T137N R97-98W, T138N R96-98W, and T139N R97-98W) (Plate 3). The Little Badlands proper, at times referred to as the South Heart Badlands, occupies portions of sections 13, 14, 17, 20-23, 27-31 (T138N R98W) (Plate 3). The Little Badlands represent the single largest outcrop area of White River Group rocks in North Dakota, although the outcrops are generally poor throughout much of this area. The best exposures are found in five general areas: White Butte in section 32 (T139N R97W), Schmidt ranch/Turtle Valley (western half of Little Badlands proper) in sections 20, 21, 29, and 30 (T138N R98W) (Figures 29, 30; Plate 3), Privratsky ranch (east half of Little Badlands proper) in sections 13, 14, 22, and 23 (T138N R98W) (Figures 31, 32; Plate 3), Obritsch ranch in sections 28 and 29 (T138N R97W) (Figures 33, 34; Plate 3), and Fitterer ranch in sections 7, and 16-18 (T137N R97W) (Figures 35, 36; Plate 3).

The Little Badlands, along with the Chalky Buttes and the Killdeer Mountains, have received the most attention from scientists investigating the White River Group and Arikaree Formation in North Dakota. Douglass (1909) was first to report the presence of "White River Beds" in the Little Badlands. All subsequent workers in this area have agreed on the presence of the White River Group and on the placement of the contact between the Chadron and Brule Formations. Controversy has arisen however, regarding the presence or absence of the Arikaree Formation in the Little Badlands and the placement of the contact between the Brule and Arikaree Formations. Some of the most significant studies in the Little Badlands area have been by Douglass (1909), Leonard (1922), Skinner (1951), Holland (1957), Denson and Gill (1965), Stone (1973), Larsen (1983), Hoganson (1986), and Hoganson and Lammers (1992).

Fort Union Group

The White River Group rests unconformably on the Golden Valley Formation throughout the Little Badlands (Figure 37a). The thickest exposures of the Golden Valley are in the Schmidt ranch/Turtle Valley area where in excess of 100 feet of the Camels Butte Member of the Golden Valley Formation is exposed (Figures 30, 37b). The Camels Butte Member consists of alternating light brown to golden beds of micaceous sandstone, siltstone, mudstone, and thin lignites at this locality.

Chadron Formation

The basal contact of the Chadron Formation with the Golden Valley Formation is well exposed throughout the Little Badlands proper, White Butte, and at Fitterer ranch. The conglomeratic sandstone and mudstone at the base of the Chadron Formation (Chalky Butte Member) ranges from 10 to 20 feet thick in this area (Figures 30, 32, 36) and is overlain by the South Heart Member consisting of 10 to 30 feet of smectitic claystone containing thin lenses of limestone. This claystone caps many of the small buttes in the Little Badlands proper. The draping of this claystone gives these buttes a characteristic "haystack" appearance (Figure 37c-e). Portions of the South Heart claystones are silicious. These resistent, silicious smectitic claystones cap many of the small ridges and hills in the NW¼ section 12 (T138N R97W) and in the southern half of sections 25 (T138N R97W), 18, 19, and 28-30 (T138N R96W) (Figure 37f).

Brule Formation

The Little Badlands contain the thickest exposures of the Brule Formation in North Dakota. The best exposures are at Privratsky ranch (section 23, T138N R98W), Obritsch ranch (sections 28 and 29, T138N R97W), and Fitterer ranch (sections 7 and 16-18, T137N R98W) (Figure 37g-j). The Brule, in this area, consists of light brown to buff mudstones, siltstones, and sandstones. Brown and tan colors are characteristic of this formation. Nodular siltstones, mudstones, and thin beds of white siltstones that contain mudstone or claystone inclusions and weathered surface pits are also characteristic of the Brule, especially the lower part of the formation.

Skinner (1951) informally named a thin, fossiliferous sandstone, located 45 to 80 feet above the base of the Brule Formation northwest of the Fitterer ranch (SE¼ section 7, T137N R97W), the "Fitterer channel". Stone (1973) called this sandstone the "Fitterer Bed" and applied this name to a number of channel sandstones that occur in the lower portion

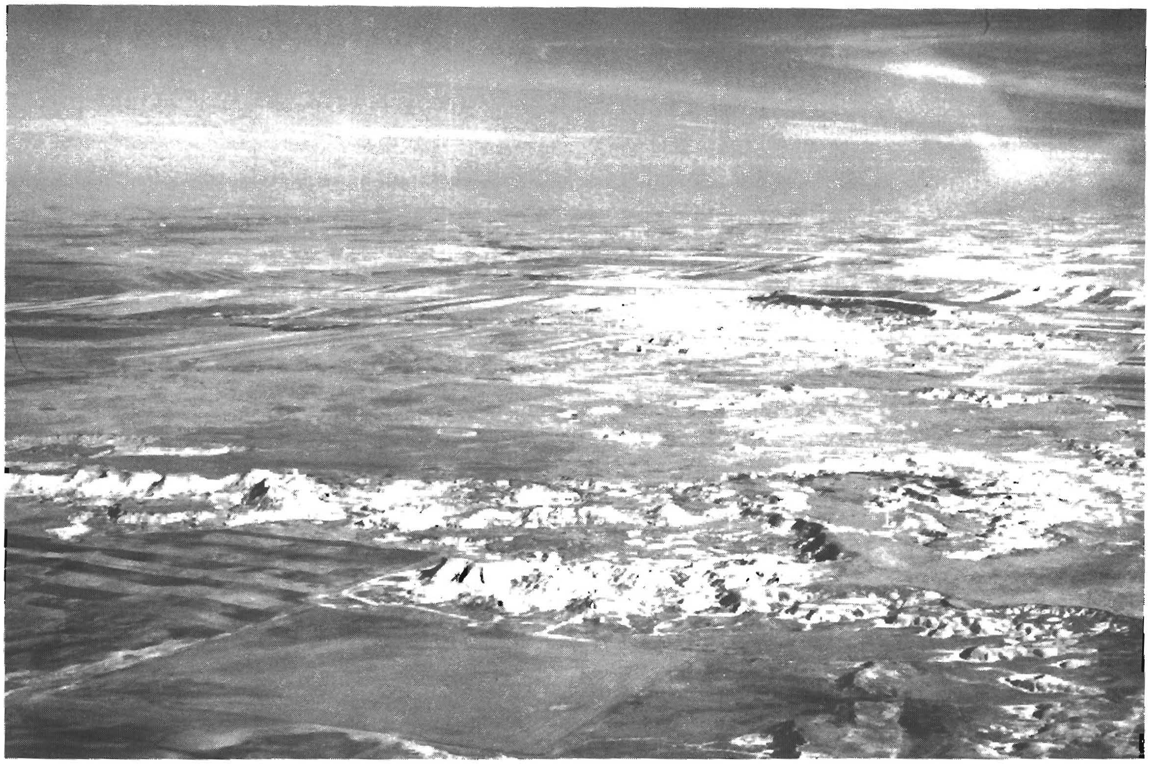
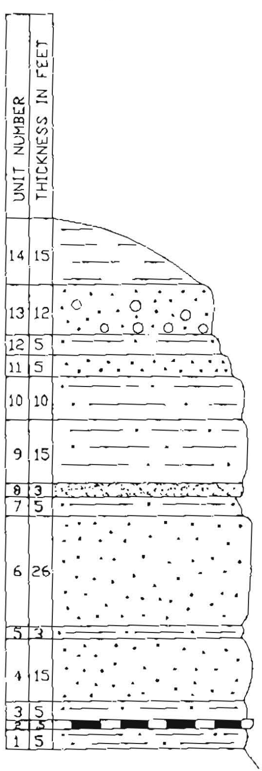


Figure 29. Aerial photograph of Turtle Valley, Little Badlands. Turtle Valley is in the foreground, Little Badlands proper is in the background. View is to the east.

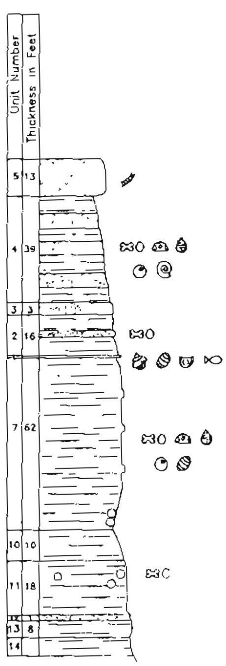


LITTLE BADLANDS, TURTLE VALLEY — T138N R98W 20 sene
Stark County — Elevation: 2730

	CHADRON FORMATION
	South Heart Member
Unit 14:	Claystone, light to medium brown (w&f), smectitic, popcorn texture.
	Chalky Buttes Member
Unit 13:	Conglomerate, light brown to gray (w&f), pebbles of igneous rocks, bedrock sandstone, varies from sandstone to mudstone.
	GOLDEN VALLEY FORMATION
	Camels Butte Member
Unit 12:	Mudstone, purple/gray at base, yellow/green at top (w&f),silty to clean, iron claystone layers.
Unit 11:	Sandstone, light to medium gray (w&f), very fine grained, silty, micaceous.
Unit 10:	Mudstone, light to medium gray to brown (w&f), claystone lenses, numerous thin limonite/claystone layers.
Unit 9:	Mudstone, light to medium gray (w&f), silty, smectitic, iron stained.
Unit 8:	Siltstone, gray to white (w&f), moderately to very well cemented, contains stem molds.
Unit 7:	Mudstone, light to medium brown (w&f), silty, iron stained at base.
Unit 6:	Sandstone, gray to medium brown (w&f), very fine to fine grained, silty, micaceous, cross-bedded, iron stained and thin limonite claystone layers.
Unit 5:	Mudstone, light gray to gray/green (w&f), silty, micaceous, forms prominent light colored band, contains root traces or needles.
Unit 4:	Sandstone, yellow/brown to light gray (w&f), very fine grained, silty, micaceous, iron stained and limonite concretions, contains a few interbedded mudstone layers.
Unit 3:	Mudstone, light to dark gray, micaceous, silty, contains thin limonite concretions.
Unit 2:	Flint.
Unit 1:	Mudstone, gray to brown (w&f), silty, limonite stained.

Figure 30. Measured geologic section at Turtle Valley, Little Badlands.

Figure 31. Aerial photograph of Privratsky ranch, Little Badlands proper. Knobhill is located in the right foreground. View is to the northwest.



LITTLE BADLANDS PROPER, KNOB HILL
Stark County

T138N R98W ne section 6 to swne section 23
Elevation: 2850 feet

BRULE FORMATION

Unit 5: Siltstone, buff-gray (w), light gray (f), some very fine sand grains, laminated to ripple cross-bedding, moderately to well cemented at base to poorly cemented at top, small burrows, bench forming unit.

Unit 4: Claystone and Siltstone, alternating beds of claystone, medium brown (f) light medium brown (w), silty, and siltstone, light brown (f) to gray/brown (w), clayey, some layers contain clay clasts, most beds greater than 4 feet thick.

Unit 3: Siltstone, light brown (f), to medium red/brown (w), contains clay inclusions or clasts, pumacey appearance, moderate to well cemented, 6-inch thick nodular zones at top, middle, and base of unit.

Unit 2: Claystone and Siltstone, alternating beds of claystone gray/brown (f) to medium/dark brown (w), silty blocky, siltstone is light gray/green (f) to buff gray (w), clay moderately indurated, there is a 3- to 4-foot thick silt with nodular weathering 10 feet above the base, 2-foot thick, ripple cross-bedded sandstone is located 13 feet above the base.

Unit 1: Siltstone, light gray/green (f) to gray/white (w), clay clasts, calcareous, white marker bed, Antelope Creek tuff, contains snails, ostracods, and fish fossils, more indurated at base.

Unit 7: Mudstone, brown to pink (w), medium to dark brown (f), interbedded silty claystone, noncalcareous, nodular and clayey siltstone, with claystone clasts, the clasts are noncalcareous, the matrix is silt, calcareous, with a slight color change to light gray/green near base, dark brown nodular concretions near base of unit.

CHADRON FORMATION

South Heart Member

Unit 10: Claystone, gray to brown, popcorn texture.

Chalky Buttes Member

Unit 11: Mudstone, light gray (w), light gray/white (f), sandy near top and base, quartz pebbles etc. in concretionary layer near middle of unit.

GOLDEN VALLEY FORMATION

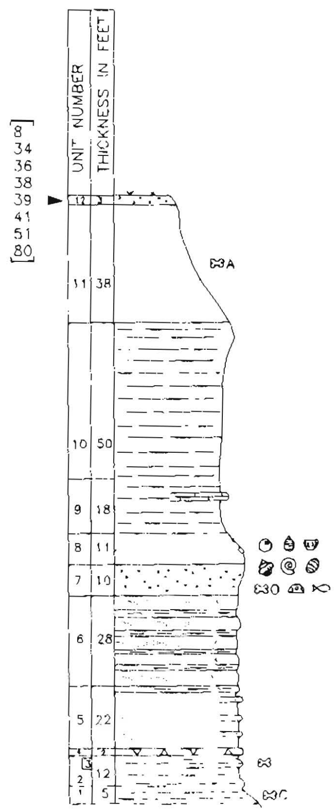
Unit 12: Siltstone, gray to purple (w), gray/brown to dark brown (f), clayey, organic rich.

Unit 13: Claystone, light gray/white (w), to white/green (f), clean to silty, numerous polygonal joints at surface, some iron oxide staining along joints.

Unit 14: Claystone, gray to red/brown (w), light gray to red/brown (f), silty to clean, micaceous.

Figure 32. Measured geologic section at Privratsky ranch, Little Badlands proper.

Figure 33. Aerial photograph of Obritsch ranch, Little Badlands. View is to the southeast (138-97-27 west half and 29 east half).



LITTLE BADLANDS, OBRITSCH RANCH T138N R97W nw/se Section 29
Stark County Elevation: 2937

ARIKAREE FORMATION

Unit 12: Sandstone, gray/green, fine to coarse grained, very well cemented, contains gravel lenses, 6- to 8-foot thick wedge of slumped material along south side.

Unit 11: Siltstone, light gray, moderately to poorly cemented.

BRULE FORMATION

Unit 10: Claystone, buff to gray/pink (f) to buff (w), moderately indurated, popcorn surface, upper portion is a ledge former.

Unit 9: Claystone, medium brown (f) to light gray-brown, (w), popcorn surface, contains a 2-foot thick carbonate lens.

Unit 8: Siltstone, gray/green (f) to light gray (w), very indurated, contains numerous joints and fractures, contains one inch spherical concentrations, weathers to rounded surfaces, pockmarked surface.

Unit 7: Sandstone, dark green (f) to gray/green (w), fine to coarse grained, moderately to well cemented, contains some clay zones, cross-bedded, contains mammal bones.

Unit 6: Sandstone, Siltstone, and Claystone, interbedded, sandstone and siltstone is light gray to green (f) to buff (w), layers are from 2 inches to 5 feet in thickness, contain some dark green horizons of poorly developed chert, moderately cemented. Claystone is medium brown (f) to buff (w), layers are generally less than 6 inches thick, popcorn surface.

Unit 5: Siltstone, pink to buff (f) to light pink/white (w), popcorn surface, contains 3-4 cemented lenses of up to 8 inches in thickness.

Unit 4: Tuff (Antelope Creek tuff), bright to dull white (w & f), chalky in appearance.

Unit 3: Carbonate lens, gray/pink (w & f), contains mammal bones.

Unit 2: Claystone, pinkish gray (w & f), silty, basal 6 inches is well cemented-ledge former, numerous ledges throughout unit.

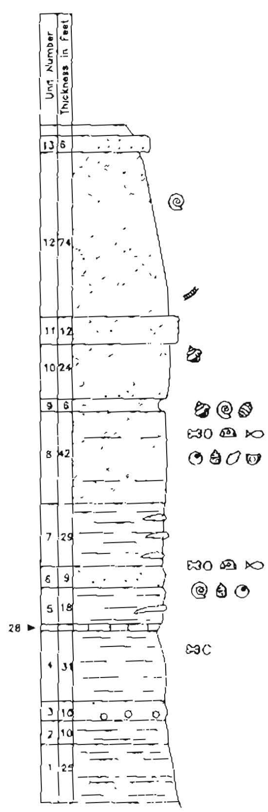
CHADRON FORMATION

South Heart Member

Unit 1: Claystone, brown (f) to pinkish gray (w), popcorn surface.

Figure 34. Measured geologic section at Obritsch ranch, Little Badlands.

Figure 35. Photograph of Fitterer ranch, Little Badlands. View is to the north (137-97-7).



LITTLE BADLANDS, FITTERER RANCH
Stark County

T137N R97W sw/se section 6 and nw section 17
Elevation: 2980 feet

ARIKAREE FORMATION

Unit 13: Sandstone, light gray/green (f), to dark gray/green (w), medium to very fine grained, quartz and rock fragments, moderately to well cemented, silica cemented, moderately sorted.

BRULE FORMATION

Unit 12: Siltstone, light brown to medium brown (w), light gray/brown (f), poorly to moderately cemented, clay clasts, highly jointed.

Unit 11: Siltstone, gray/brown to light brown (f), buff to brown (w), some very fine sand grains, bulbous, cliff forming unit.

Unit 10: Siltstone, light gray/brown to light brown (f), light gray brown (w), very well indurated, bulbous weathering pattern, highly jointed.

Unit 9: Siltstone, light brown (f), medium to dark brown (w), contains medium to dark brown silty clay pebbles, slope forming unit, fossiliferous.

Unit 8: Siltstone and Claystone, interbedded, light brown/gray (w) to light gray (f), siltstone is sandy, and cross-bedded, siltstone beds are 1- to 10-feet thick, claystone beds are 6 inches to 3 feet thick.

Unit 7: Siltstone and Claystone, interbedded, light gray/brown (f), to medium dark brown (w), fossiliferous at base, contains three nodular siltstone layers.

Unit 6: Sandstone, (Fitterer Bed), light to medium gray to gray/green, very fine to coarse grained, generally fine grained, quartz and rock fragments, green rock fragments, moderately to poorly sorted, cross-bedded, 2-foot thick foresets, some clay inclusions, fossiliferous.

Unit 5: Claystone, red brown to pink (f), light brown to pink (w), silty, root traces, popcorn texture, contains 1- to 5-foot thick, red/brown to white, calcareous nodules or marlstone layers with clay interclasts.

CHADRON FORMATION

South Heart Member

Unit 4: Claystone, medium brown (f), to gray/brown (w), silicious, blocky, popcorn texture, drapes over underlying rock, titanothere remains within top 10 feet of this unit.

Chalky Buttes Member

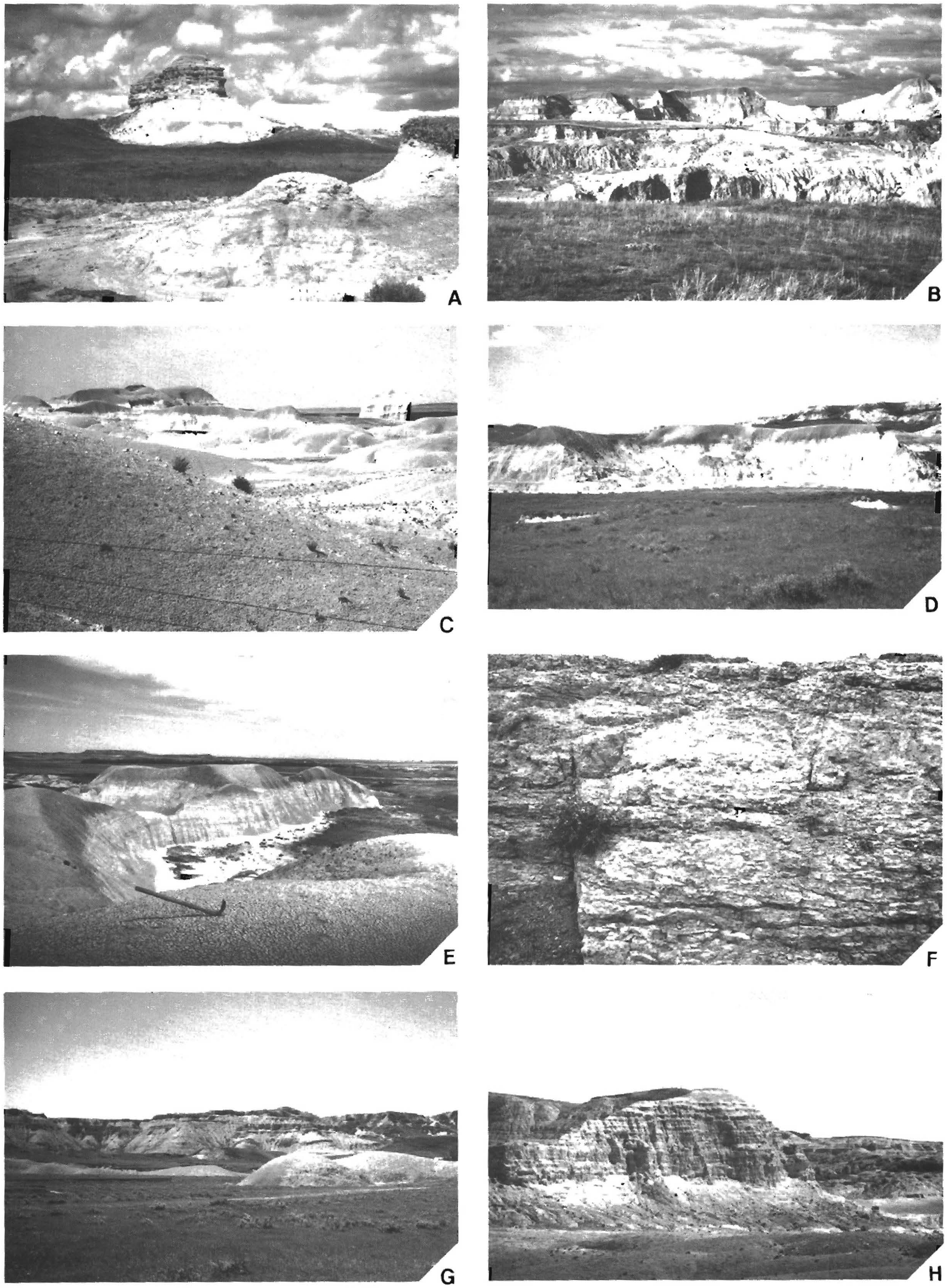
Unit 3: Sandstone, light gray to white (f&w), very coarse to gravel, conglomeratic, volcanic and quartz pebbles, clayey, gray/green clay, poorly sorted.

GOLDEN VALLEY FORMATION

Unit 2: Claystone, gray/green (w&f), slightly silty, some iron oxide staining, popcorn texture.

Unit 1: Siltstone and Claystone, alternating beds, light gray (w&f), clayey siltstone to silty claystone, micaceous, iron oxide banded, iron oxide claystone concretions, some very fine sand, iron oxide stained joints.

Figure 36. Measured geologic section at Fitterer ranch, Little Badlands.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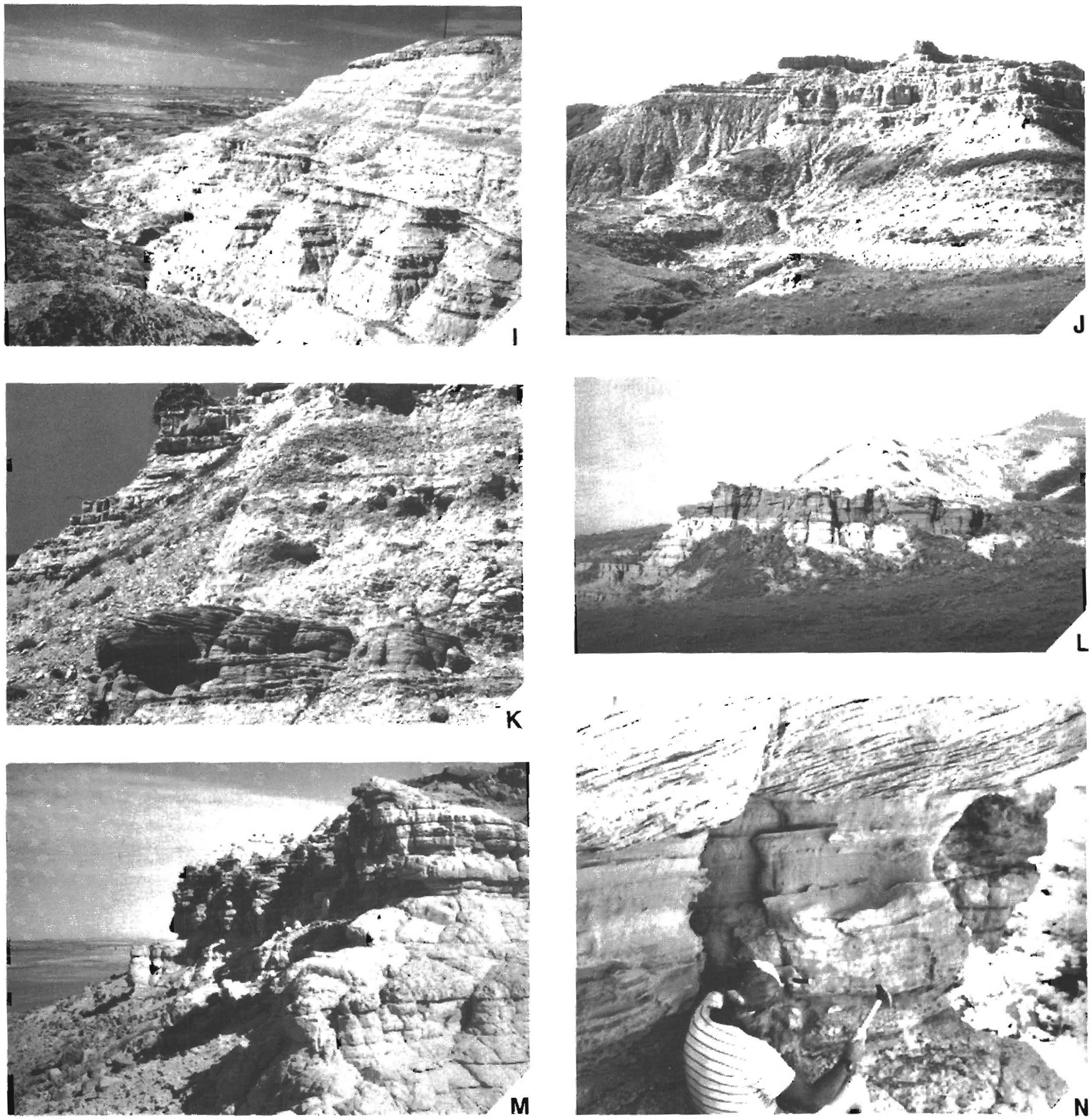
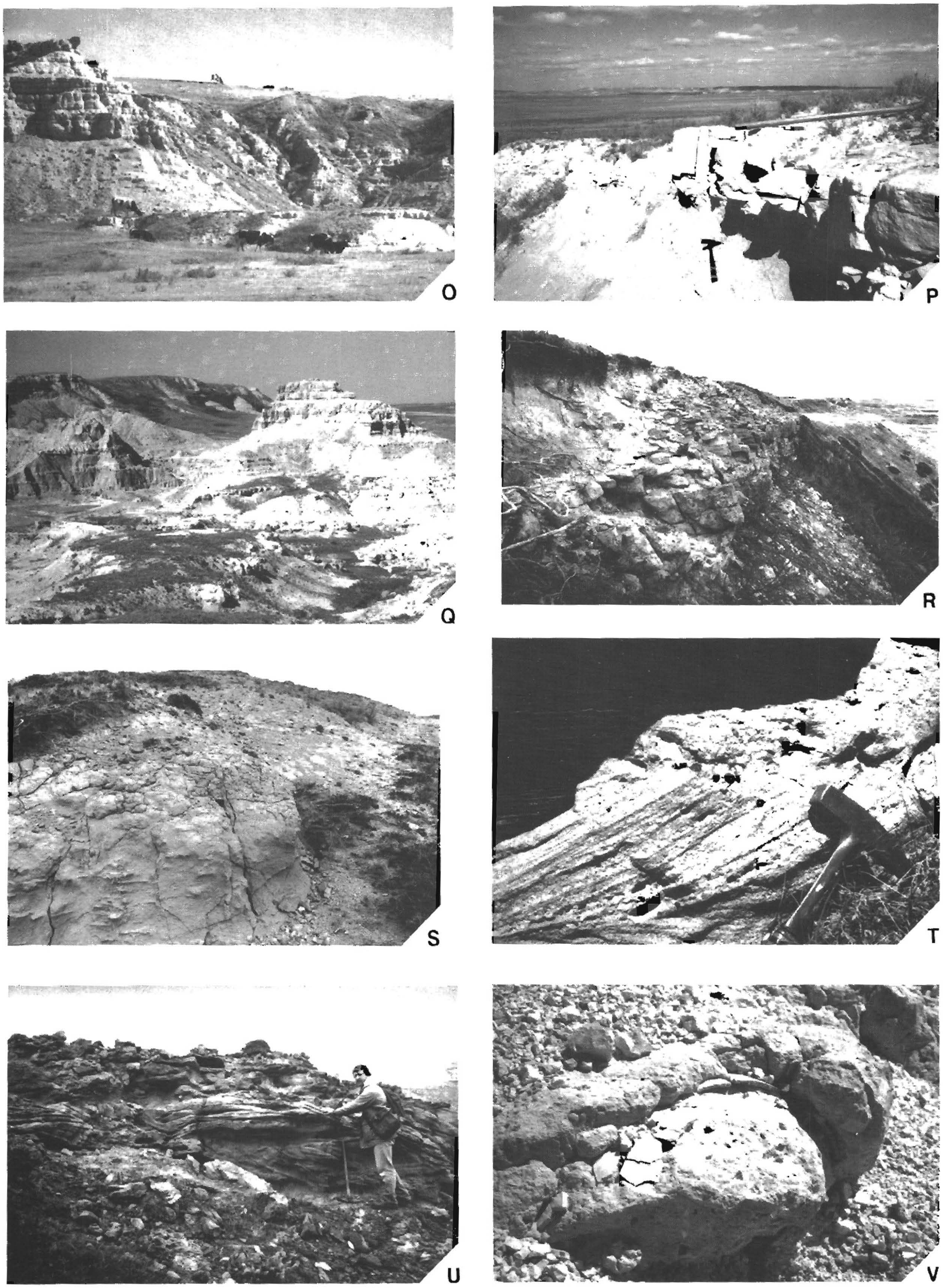


Figure 37. Exposures, sedimentary structures, and fossils of the Golden Valley, Chadron, Brule, and Arikaree Formations in the Little Badlands. **A**, Golden Valley Formation in the foreground, the Chadron Formation caps Haystack Butte in the background (139-97-29 swsw). View is to the northwest. **B**, Chadron Formation caps the buttes and is underlain by the Golden Valley Formation in Turtle Valley (138-98-20 nene). View is to the east. **C**, South Heart Member is at the surface in the foreground and caps the buttes in the background at Privratsky ranch (138-98-22 ne). View looking west. **D**, Golden Valley Formation at the base, South Heart Member caps the buttes in the foreground at Fitterer ranch (137-97-7 swne). **E**, popcorn surface texture of smectitic claystone in the South Heart Member, underlain by Golden Valley Formation, Fitterer ranch (137-97-7 swne). View is to the northeast, Radio Tower Butte is in the background. **F**, silicified smectite from the South Heart Member exposed in a burrow pit (138-96-29 swsw). **G**, South Heart Member in the foreground, the cliffs are comprised of the Brule Formation, and the Arikaree Formation caps the highest point at Fitterer ranch (137-97-17 nw). **H**, South Heart Member in foreground, the northwest facing slope of Knob Hill is comprised of alternating siltstones and claystones of the Brule Formation, Privratsky ranch (138-98-23 swne). **I**, alternating siltstones and claystones of the Brule Formation in the south facing slope of Knob Hill, Privratsky ranch (138-98-23 seswne). **J**, siltstones and mudstones of the Brule Formation, Fitterer ranch. Excavated area at base of cliff is fossil quarry of Hoganson and Lammers (1992) in the "Fitterer bed" (137-97-17 nesenw). **K**, 4-foot thick channel sandstone in the Brule Formation (138-98-24 sene). **L**, 10-foot thick green, channel sandstone in the Brule Formation, Obritsch ranch (138-97-29 senwse). **M**, pinchout of green, channel sandstone, Obritsch ranch (138-97-29 senwse). **N**, George Lammers removing a rhinoceros femur from a siltstone immediately below the green, conglomeratic, cross-bedded sandstone in the Brule Formation, Obritsch ranch (138-97-28 neswnw).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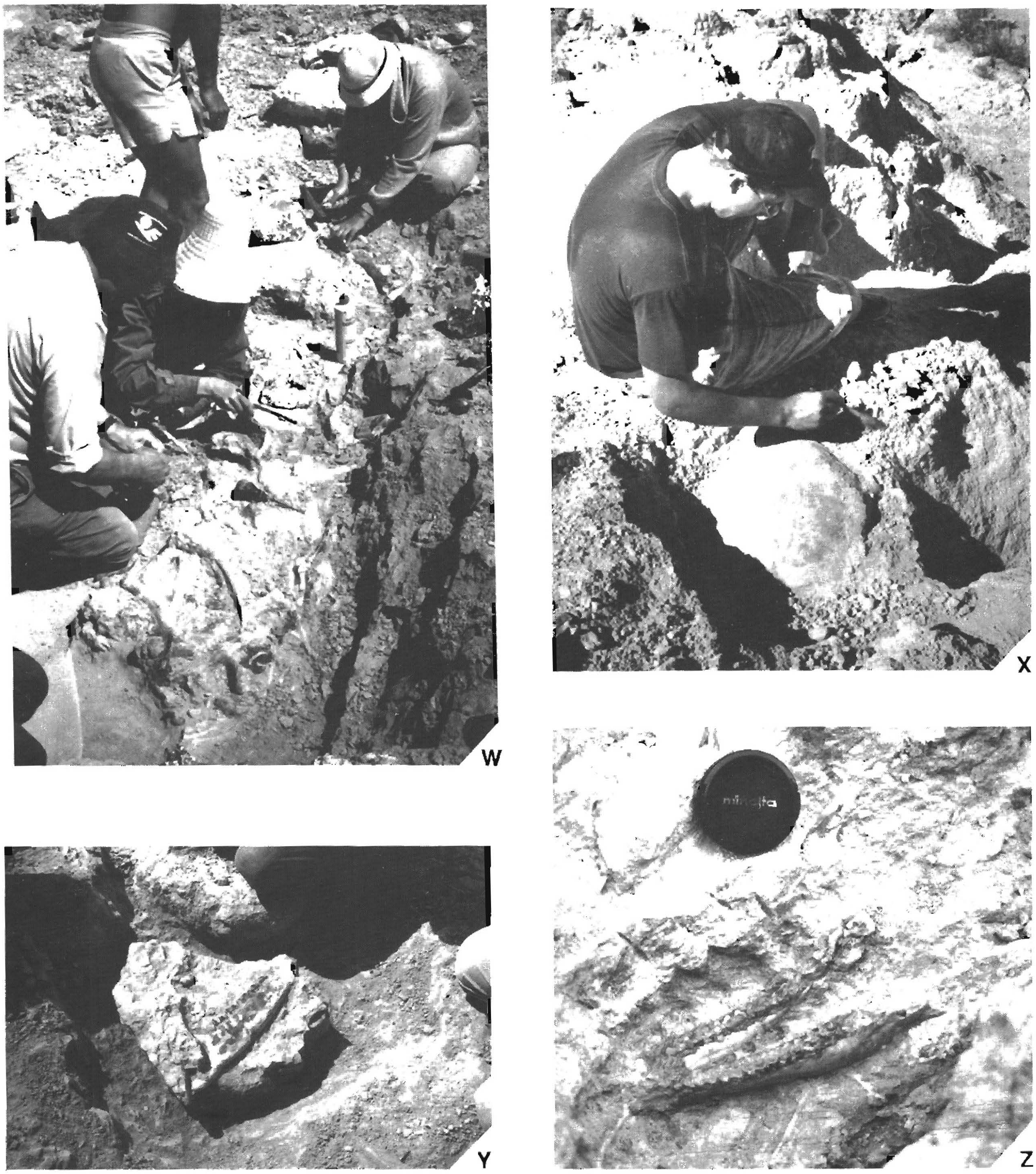


Figure 37 (cont.) **O**, Antelope Creek tuff in lower Brule Formation, Obritsch ranch (138-97-29 nwswse). **P**, closeup of Antelope Creek tuff, view to the northwest, Obritsch ranch (138-97-29 nwswse). **Q**, Antelope Creek tuff in the lower Brule Formation at Fitterer ranch (137-97-7 swnwse). **R**, Arikaree Formation sandstone caprock at Fitterer ranch (137-97-17 sesenw). **S**, sandstone caprock and underlying siltstone of the Arikaree Formation at Obritsch ranch (137-97-28 seswnw). **T**, closeup of cross-bedded conglomerate caprock at Obritsch ranch, Arikaree Formation (137-97-28 seswnw). **U**, John Hoganson at a mammal fossil-bearing sandstone ("Fitterer bed") near base of the Brule Formation at Fitterer ranch (137-97-17 nesenw). **V**, partially eroded tortoise (*Stylemys*) shell (30 inches across) in the nodular siltstone just below the Antelope Creek tuff, Fitterer ranch (137-97-7 seseneswv). **W**, excavation of rhinoceros (*Subhyracodon*) bones from the "Fitterer bed" at Fitterer ranch (137-97-17 seswnene). **X**, excavation of a tortoise (*Stylemys*) shell from Brule Formation at Privratsky ranch (138-98-23 nene). **Y**, rhinoceros (*Subhyracodon*) jaw (16 inches long) being excavated from the "Fitterer bed" at Fitterer ranch, Little Badlands (137-97-17 seswnene). **Z**, horse (*Mesohippus*) jaws (7 inches long) being excavated from the "Fitterer bed" at Fitterer ranch, Little Badlands (137-97-17 seswnene).

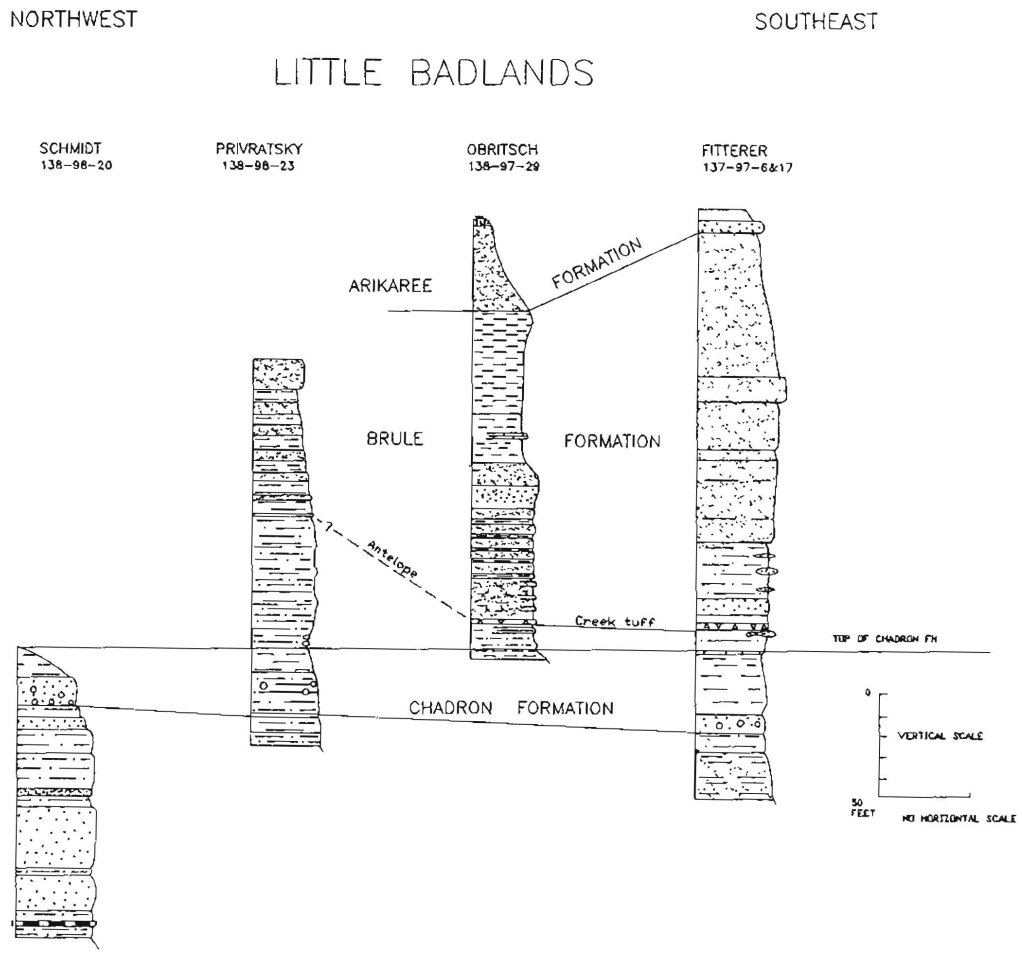


Figure 38. Geologic cross-section in the Little Badlands, Stark County.

of the Brule Formation. Stone also called a 10-foot-thick, highly fossiliferous, dark green to gray/green cross-bedded sandstone, present 60 feet above the base of the Brule Formation at Obritsch ranch, the "Fitterer Bed" (Figures 34, 37l-n). This sandstone is highly conspicuous at this locality and in the ridge north of the Obritsch ranch (in sections 17 and 18, T138N R97W). Stone's correlation of channel sandstones in the Brule was questioned by Hoganson and Lammers (1992) because of the inherent problems of correlating channel sandstones in an area of limited outcrops.

During the course of this study, a two-foot-thick tuff was discovered 12 feet above the base of the Brule Formation at Obritsch ranch (SE¼NE¼SE¼ section 29, T138N R97W) (Figure 37o,p). A thin tuff bed was also discovered 63 feet above the base of the Brule at Fitterer ranch (NE¼SW¼ section 7, T137N R97W) (Figure 37q). Stratigraphic position, appearance, and trace element content of these tuffs indicate they are correlative and we propose that this bed informally be called the "Antelope Creek tuff" for its occurrence on both sides of Antelope Creek (Plate 3). Skinner (1951) named a white siltstone bed 50 to 60 feet above the base of the Brule Formation in the Little Badlands proper (Privratsky ranch) and at the Fitterer ranch site the "white marker zone". The Antelope Creek tuff is Skinner's "white marker zone" at the Fitterer ranch (Hoganson and Lammers, 1992). The Antelope Creek tuff may be equivalent to the "white marker zone" in the Little Badlands proper, but no volcanic glass was found in that bed during petrographic analysis (Figure 38). These beds may still be correlative; volcanic glass may be missing in the Little Badlands proper as a result of alteration or replacement.

Stone (1973) divided the Brule Formation into two members, the "Dickinson member" and the "Schefield member". Hoganson (1986) pointed out that these members were never formally proposed in accordance with the rules established in the North American Stratigraphic Code and must be considered informal stratigraphic names. Stone's "Dickinson member" consists of the mudstones and sandstones in the lower portion of the Brule Formation. His "Schefield member" consists of alternating beds of siltstone and claystone in the upper part of the Brule Formation. The "Schefield member" is distinguishable from the underlying "Dickinson member" by the change in outcrop character from the fluted slopes of the "Dickinson" to banded cliffs of the "Schefield". Stone's members of the Brule Formation are not used in this report because they are of limited use in the Little Badlands, and are generally not recognizable outside of this area.

Skinner (1951), Denson and Gill (1965), and Stone (1973) presented measured geologic sections at Fitterer ranch in the Little Badlands. They agreed on the placement of the contact at the base of the Brule Formation but not the formation's upper contact. Skinner (1951) designated the capping sandstone at Fitterer ranch as one of his units (6G) but did not separate it from the underlying Brule Formation. Denson and Gill (1965) and Hoganson and Lammers (1992) placed the top of the Brule Formation at the base of this caprock while Stone (1973) placed the top of the Brule at a break in slope within a mudstone ("calcareous silty, claystone") 47 feet below the base of the caprock. There seems to be little reason to place the upper contact of the Brule anywhere but at the base of the capping sandstone at this locality.

Arikaree Formation

The Arikaree Formation is a gray/green conglomerate or sandstone which caps small buttes at Fitterer ranch (sections 17 and 18, T137N R97W), Obritsch ranch (sections 28 and 29, T138N R97W), and Radio Tower Butte (sections 33 and 34, T138N R97W) (Figure 37r-t). The Arikaree is generally poorly exposed; the best outcrops of the formation are at Radio Tower Butte and at the Fitterer ranch in the southwest corner of section 17 (Brown Butte). As in the Chalky Buttes, a conglomerate is often at or very near the base of the Arikaree in this area. The Arikaree Formation reaches a maximum thickness of 30 feet in the Little Badlands (Figure 38).

Paleontology

Earl Douglass, Carnegie Museum of Pittsburgh, was first to collect fossils from the area now known as the Little Badlands (Douglass 1908a, 1909), referred to as the Little Badlands proper in this report (Appendix C). Leonard (1922) also listed several vertebrate taxa collected in the Little Badlands. Morris Skinner and associates from the Frick Laboratory of the American Museum of Natural History made important collections of fossils from the Fitterer ranch, Obritsch ranch, and Little Badlands proper localities sporadically from 1944 to 1964. Approximately two thousand vertebrate fossil specimens collected during that time are now housed at the American Museum of Natural History. Many of those specimens have been examined for taxonomic studies (e.g., oreodonts, Schultz and Falkenbach, 1956, 1968; equids, Prothero and Shubin, 1989; and hyaenodontids, Mellett, 1977: see Appendix C). A few vertebrate fossil taxa from the Little Badlands have been listed in reports primarily concerned with the stratigraphy of the Little Badlands (e.g., Denson and Gill, 1965; Stone, 1973).

Fossil assemblages from Fitterer ranch, Obritsch ranch, and Little Badlands proper were the major focus of Hoganson and Lammers' (1992) study of the vertebrate fauna of the Brule Formation in North Dakota (Figure 37u-z). They identified fossils of fish, amphibians, reptiles, birds and at least 60 taxa of mammals from the Brule Formation in the Little Badlands area. Hoganson and Lammers (1992) also noted the occurrence of ostracods, freshwater and terrestrial gastropods, insect trace fossils, mammal coprolites, hackberry tree endocarps, charophyte oogonia and algal mats in the Brule Formation in the Little Badlands. Rodents (Kihm, 1990) and lagomorphs (Wretling, 1991) from the Brule in the Little Badlands proper have also recently been studied.

The Brule Formation in the Little Badlands contains a diverse assemblage of vertebrate fossils but these fossils are primarily recovered from the lower part of the formation; fossils are sparse in the upper Brule (Hoganson and Lammers, 1992). Hoganson and Lammers interpreted this assemblage to indicate an Orellan land mammal "age" for at least the lower part of the formation. Kihm (1990) suggested that the upper part of the Brule Formation in the Little Badlands may be Whitneyan in age. Fossils are extremely sparse in the Chadron Formation in the Little Badlands but brontothere fragments have been found at the Fitterer ranch, Obritsch ranch, Little Badlands proper, and White Butte (Stark County) localities possibly indicating a Chadronian "age" for the formation. Fossils are also extremely uncommon in the Arikaree Formation in the Little Badlands area. However, the occurrence of the castorid *Palaeocastor* in the Arikaree Formation at the Obritsch ranch locality implies an Arikareean "age" for the formation (Figure 37s).

EAST AND WEST RAINY BUTTES

Introduction

The Rainy Butte complex consists of four buttes: East and West Rainy Butte, a small unnamed outlier north of East Rainy Butte, and Baldy Butte. The Rainy Buttes apparently were named by early freighters traveling the stage line between Dickinson and Belle Fourche, South Dakota. The freighters often became stuck near these buttes because the trail went through slow drying gumbo (Williams, 1966). These buttes occupy an area of approximately 972 acres in portions of sections 17-22, 27, and 33-35 (T135N R98W), 13 and 24 (T135N R99W), and sections 3 and 4 (T134N R98W), Slope County (Plate 4). East and West Rainy Butte are relatively large mesas which rise approximately 400 to 500 feet above the surrounding countryside. Outcrops below the capping sandstone at East and West Rainy Buttes are generally sparse. The best outcrops were found on the southwest corner of East Rainy Butte, the outlier north of East Rainy Butte, Baldy Butte, and the east edge of West Rainy Butte. Two geologic sections were measured, one on East Rainy Butte and its north outlier and one on the east end of West Rainy Butte (Figures 39-42).

Seager et al. (1942) were first to determine that White River deposits were present at East and West Rainy Buttes. Bergstrom (1956), Denson and Gill (1965), Stone (1973), Hickey (1977), Clayton (1980), and Carlson (1983) also indicated the presence of the Arikaree Formation and/or White River Group in these buttes. Denson and Gill (1965) are the only previous workers to present measured geologic sections of these buttes.

Fort Union Group

The Sentinel Butte Formation is present at surface throughout the countryside surrounding the Rainy Buttes (Plate 4). Exposures of this formation are generally restricted to small knolls and road cuts. Carlson (1983) mapped the Golden Valley Formation at the base of the Rainy Buttes but most previous workers have not recognized the Golden Valley Formation in this area (Hickey, 1977; Clayton, 1980). A white, micaceous siltstone exposed near the base of both East and West Rainy Butte is mapped in this report as the Bear Den Member of the Golden Valley Formation (Figures 40, 42, 43b). The Chadron Formation rests unconformably on the Bear Den Member at both buttes. The Golden Valley Formation is less than 30 feet thick in this area.

Chadron Formation

The base of the Chadron Formation in the Rainy Buttes consists of less than 10 feet of sandy mudstone (Chalky Buttes Member) (Figures 40, 42). This mudstone is overlain by smectitic claystone of the South Heart Member, the base of which is silicified at East Rainy and Baldy Buttes (Figure 43a,c). The South Heart Member caps Baldy Butte, and it is the silicified portion of this member that forms the ledge at the top of the butte. The South Heart Member is much thicker at East Rainy (80 feet) than it is at West Rainy Butte (20 feet) but is capped at both buttes by thin carbonate lenses.

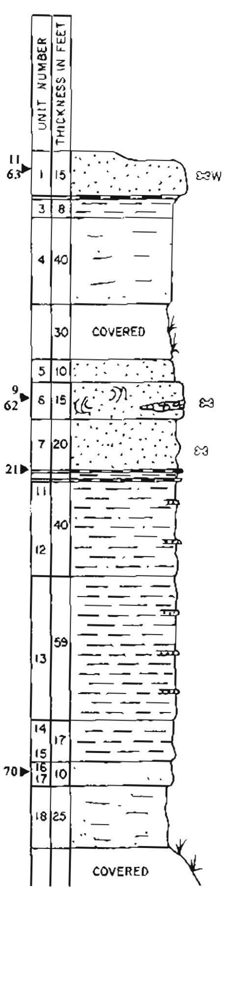
Brule Formation

The Brule Formation at East and West Rainy Butte consists of pink/brown siltstone and mudstone that contain thin, white, silicious or tuffaceous beds. Sandstones that occur near the middle of the Brule at these buttes are fine to medium grained, conglomeratic near their bases, and are cross-bedded (Figure 43d,e). The Brule sandstone at West Rainy Butte appears to thin and thicken, and in some cases there appear to be multiple sandstones at this stratigraphic position (Figure 43f). This sandstone however, maintains the same relative thickness throughout this area but the degree of cementation and therefore its outcrop pattern are variable. Denson and Gill (1965) placed these sandstones in the Arikaree Formation because of the presence of basal conglomerates in the sandstones. However, typical Brule lithologies (pink/brown siltstones and mudstones) overlie these sandstones on both buttes suggesting that they are part of the Brule Formation. The Brule section at the Rainy Buttes is very similar to the Brule at Obritsch ranch in the Little Badlands. The lower portion of the Brule on East Rainy Butte contains two thin (< 4 inch thick) silicious beds that are tentatively identified as silicified peat. The Brule Formation is estimated to be 150 to 180 feet thick at East and West Rainy Buttes.

Arikaree Formation

The Arikaree Formation consists of sandstone capping West Rainy Butte and sandstone and claystone that caps East Rainy Butte. The capping sandstones are fine to coarse grained, conglomeratic,

Figure 39. Aerial photograph of the east end of East Rainy Butte. View is to the northeast.



EAST RAINY BUTTE — T135N R98W SE SEC 34
Slope County — Elevation: 3310 feet

ARIKAREE FORMATION

Unit 1: Sandstone, light grey to light yellow/brown (f) to pink, grey, yellow, and orange (w), fine to coarse grained, contains coarse sand and conglomeratic lenses, moderately cemented, cross-bedded, contains claystone pebbles.

Unit 2: Dendritic Chert.

Unit 3: Claystone, olive green (f&w), highly indurated, silicious, dendritic pattern.

BRULE FORMATION

Unit 4: Siltstone, medium brown (f&w), clayey.

Unit 5: Sandstone, grey/buff (f&w), very fine grained, silty, contains brown claystone lenses up to 2 feet in thickness.

Unit 6: Sandstone, grey (f) to yellow, red, orange (w), fine to medium grained, some coarse, quartz and rock fragments, cross-bedded, very well cemented, contains a 3-foot thick conglomerate zone which contains vertebrate fossils (top of north outlier).

Unit 7: Sandstone, light grey to light brown (w&f), fine grained, subangular quartz and rock fragments, poorly cemented, at 12 feet goes to moderately cemented, medium coarse grained, fossiliferous.

Unit 8: Silicified Peat, white to brown (w&f), silicious.

Unit 9: Claystone, olive green (f) to buff (w), silty, contains well indurated zones.

Unit 10: Silicified Peat.

Unit 11: Claystone, medium brown (f) to buff (w), silty, well indurated zones.

Unit 12: Siltstone, white to gray, approx. 8 inches thick.

CHADRON FORMATION

South Heart Member

Unit 13: Claystone, pink/grey to buff (w&f), popcorn texture, very indurated, contains pebbles and contains white clay lenses (equivalent to top unit on Baldy Butte).

Unit 14: & 15: Claystone, grey to dark grey (f) to light grey to buff (w), very indurated, fractured, iron oxide stained, clay filled fractures, slight color change to pink at 8 feet.

Chalky Buttes Member

Unit 16: Mudstone, off-white (f&w) contains some very fine sand.

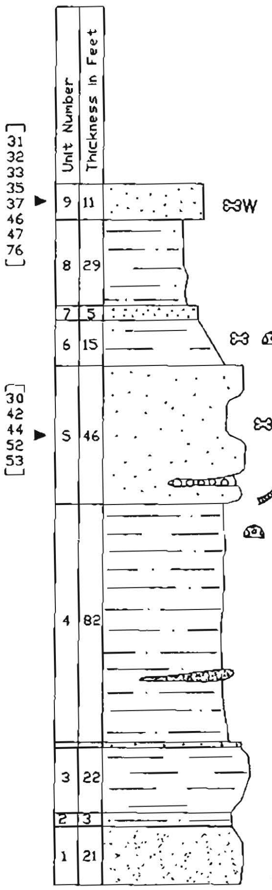
GOLDEN VALLEY FORMATION

Unit 17: Siltstone, off-white (f&w), micaceous, flaggy to massive, dazzling white, very fine sand.

Unit 18: Siltstone, grey/white (f&w), clayey, very micaceous.

Figure 40. Measured geologic section at East Rainy Butte.

Figure 41. Aerial photograph of West Rainy Butte. View is to the east, Baldy Butte is in the background.



WEST RAINY BUTTE T135N R98W senenw section 20
Slope County Elevation: 3330 feet

ARIKAREE FORMATION

Unit 9: Sandstone, light gray/green (f&w), fine to medium grained, moderately sorted, cross-bedded at base, rip-up clasts at base, moderately to well cemented, contains small to medium burrows at base.

BRULE FORMATION

Unit 8: Mudstone, light red/brown (f), light/brown (w), silty, blocky.

Unit 7: Sandstone, gray/green (f), light gray/brown (w), fine to coarse grained, poorly sorted, poorly to moderately cemented, contains pellets or sphericules of sand grains.

Unit 6: Mudstone, light brown (f), gray/brown (w), silty, moderately indurated, fossiliferous (jaw bone).

Unit 5: Sandstone, gray to gray/green (w&f), fine to coarse grained, fines upward, contains lens of volcanic pebbles, rip-up clasts (mudstone) lenses, cross-bedded, poorly cemented at base, very well cemented near middle of unit, small burrows at base, fossiliferous throughout unit.

Unit 4: Mudstone, light pink to brown (f), pink to buff (w), silty, contains thin silicious beds, and thin, white mudstone beds.

CHADRON FORMATION

South Heart Member

Unit 3: Claystone, yellow/gray (f) to pink (w), popcorn texture, 3 inch carbonate layer at top of unit.

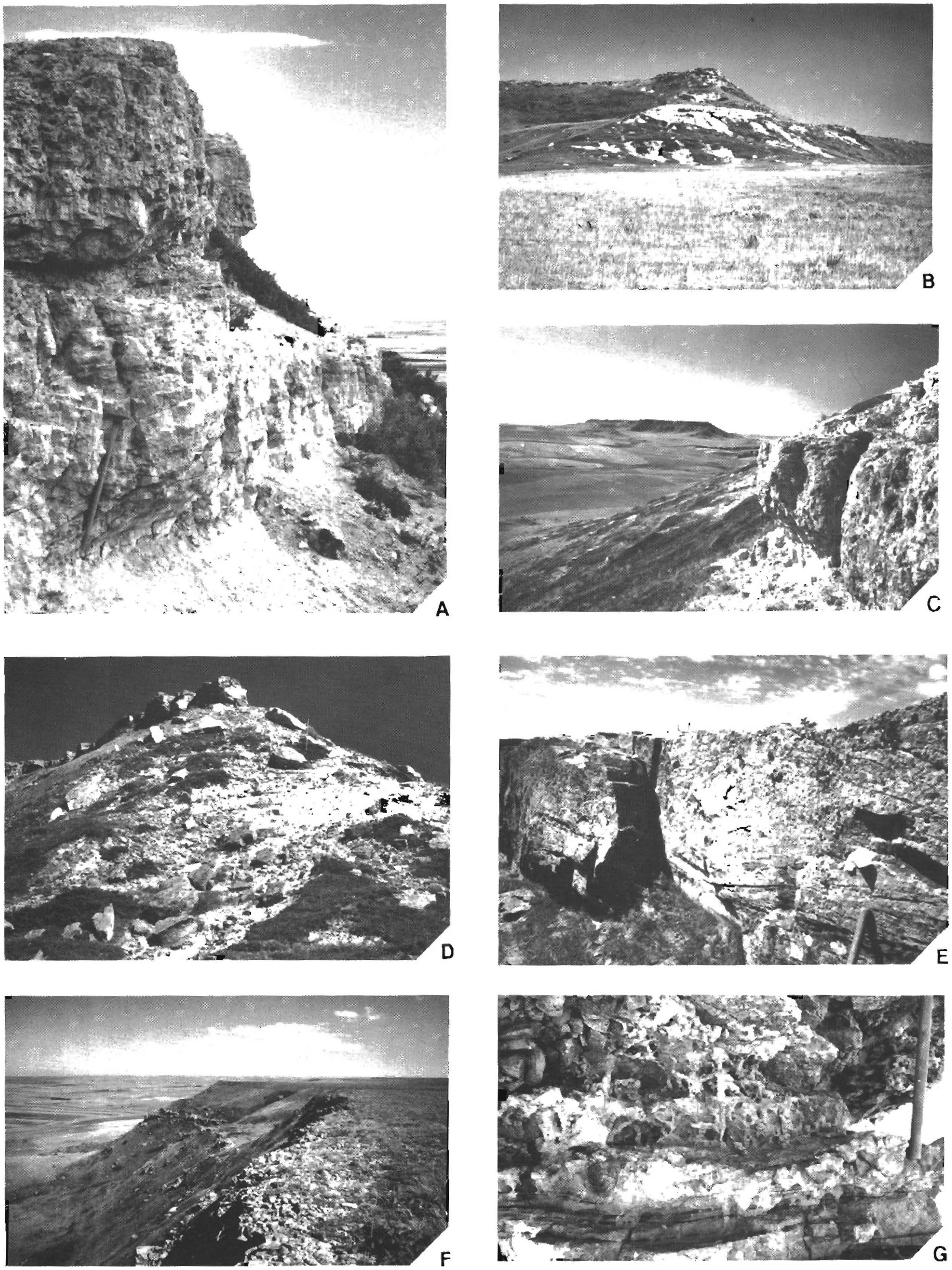
Chalky Buttes Member

Unit 2: Mudstone, yellow/gray (f), buff (w), sandy, quartz grains.

GOLDEN VALLEY FORMATION

Unit 1: Siltstone, gray/white (w&f), poorly indurated, micaceous, iron oxide stained at top.

Figure 42. Measured geologic section at West Rainy Butte.


A
B
C
D
E
F
G

cross-bedded, burrowed, and contain rip-up clay clasts at the base (Figure 43f,g). The capping sandstone at East Rainy Butte is underlain by green, silicious claystone that is placed in the Arikaree Formation because of its dissimilarity with the underlying Brule. The Arikaree Formation is 11 to 23 feet thick at these buttes.

Paleontology

The only previous report of fossils from the Rainy Buttes was by Prothero and Shubin (1989) who noted the presence of the equid *Miohippus obliquidens* indicating to them a late Whitneyan "age". No fossils were noted in the Chadron Formation at these buttes during this study. Vertebrate fossils of possible Whitneyan age were recovered in the upper portion of the Brule Formation and the Arikaree Formation (the capping sandstone) on West Rainy Butte (Appendix C). The anthracotheriid *Elomeryx armatus* was identified from the Arikaree Formation on East Rainy Butte perhaps suggesting a Whitneyan "age" for that capping sandstone.

Figure 43 (opposite page). Exposures, sedimentary structures, and trace fossils of the Golden Valley, Chadron, Brule, and Arikaree Formations at the Rainy Buttes. **A**, silicified smectite (South Heart Member) at the southwest end of East Rainy Butte (135-98-33 nwse). **B**, Bear Den Member of the Golden Valley Formation exposed in foreground, southwest corner of East Rainy Butte (135-98-33 swse). **C**, silicified smectite (South Heart Member) capping Baldy Butte (135-98-21 sese). View to the west, West Rainy Butte is in the background. **D**, pink mudstone overlain by sandstone caprock (Brule Formation) at outlier north of East Rainy Butte (135-98-27 sese). **E**, channel sandstone (Brule Formation) capping outlier north of East Rainy Butte (135-98-27 sese). **F**, sandstone caprock (Arikaree Formation) along north slope of West Rainy Butte, view is to the east (135-98-19 nene). Underlying sandstone is in the Brule Formation. **G**, burrows in base of capping sandstone (Arikaree Formation) at north end West Rainy Butte (135-98-18 sese).

BLACK BUTTE, HETTINGER COUNTY

Introduction

Black Butte is a medium sized, elongate butte trending northeast in the south half of section 12 (T135N R95W), Hettinger County. The butte rises approximately 500 feet above the surrounding countryside and the top has an areal extent of 91 acres. Rocks are poorly exposed beneath the sandstone caprock along the butte except at the southwest corner where the geologic section was measured (Figures 44-46).

The presence of the White River Group at Black Butte was first determined by Benson (1952). Denson and Gill (1965) identified the Chadron, Brule, and Arikaree Formations at Black Butte and presented a measured geologic section. Stone (1973), Trapp and Croft (1975), Hickey (1977), and Clayton (1980) all agreed that the White River Group and Arikaree Formation are present at Black Butte.

Fort Union Group

The White River Group (Chadron Formation) unconformably overlies the Golden Valley Formation at this locality. The unconformity occurs in a 15-foot thick covered interval under which the Camels Butte Member of the Golden Valley Formation is found. The Bear Den Member of the Golden Valley Formation is well exposed at the base of the outcrop in the southwest corner of the butte, 40 to 50 feet below the base of the Chadron Formation. The Sentinel Butte Formation occurs at the base of Black Butte and is also present throughout the surrounding countryside (Figure 47a).

Chadron Formation

The lithologies of both the White River Group and Arikaree Formation at Black Butte are similar to those at the Rainy Buttes located 25 miles to the west. The basal part of the Chadron Formation (Chalky Buttes Member) consists of a minimum of 20 feet of yellow/green sandy mudstone (Figure 45). The color and the presence of rounded, fine to medium grained quartz grains in a clay matrix at this site is characteristic of the Chalky Buttes Member. Pebbles, ordinarily common to this member, were not observed in outcrop or as float on the surface of this unit. This sandy mudstone is overlain by 30 feet of smectitic claystone (South Heart Member), the basal portion of which is silicified and forms a prominent ledge (Figure 45).

Brule Formation

The Brule Formation is approximately 60 feet thick at Black Butte but only half of the unit is exposed. The formation consists of nodular buff mudstone and siltstone. These nodules of white siltstone with brown claystone inclusions are characteristic of the Brule Formation as noted in the Little Badlands and the Rainy Buttes (Figure 45).

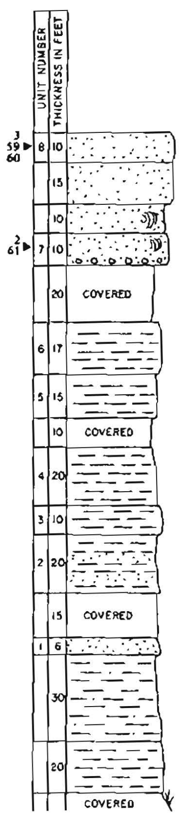
Arikaree Formation

The Arikaree Formation at this butte consists of 45 feet of fine to coarse grained, conglomeratic, and cross-bedded capping sandstone (Figures 45, 47b). This sandstone can be divided into four 10- to 15-foot thick beds based on color, grain size, and degree of cementation.

Paleontology

No fossils have been previously reported from Black Butte, Hettinger County. During this study, unidentifiable rhinoceros remains were recovered from the upper portion of the capping sandstone.

Figure 44. Aerial photograph of Black Butte, Hettinger County. View is to the northeast, Pearl and Stony Buttes are visible in the background.



BLACK BUTTE T135N R95W S½ SEC 12
Hettinger County Elevation: 3112 feet

ARIKAREE FORMATION

Unit 8: Sandstone, medium grey (f&w), fine to coarse grained, very well cemented.
Sandstone, medium grey (f&w), coarse grained, often conglomeratic, wood and shale chunks.
Sandstone, buff-grey, moderately to poorly cemented, medium to fine grained, cross-bedded.

Unit 7: Sandstone, medium grey (f&w), conglomerate at base, medium to coarse grained, pebble layer, cross-bedded, moderately well cemented.

BRULE FORMATION

Unit 6: Claystone, purplish/pink to pink/brown (f&w), contains white nodules, ledge former.

Unit 5: Claystone, purple to green (f&w), pebbly.

CHADRON FORMATION

South Heart Member

Unit 4: Claystone, green/yellow (f) to purple/grey (w), popcorn texture.

Unit 3: Mudstone, medium purple to green (f) to light purple and green (w), silicious, jointed, prominent ledge former.

Chalky Buttes Member

Unit 2: Claystone, yellow/green (f&w), contains well rounded quartz grain lenses.

GOLDEN VALLEY FORMATION

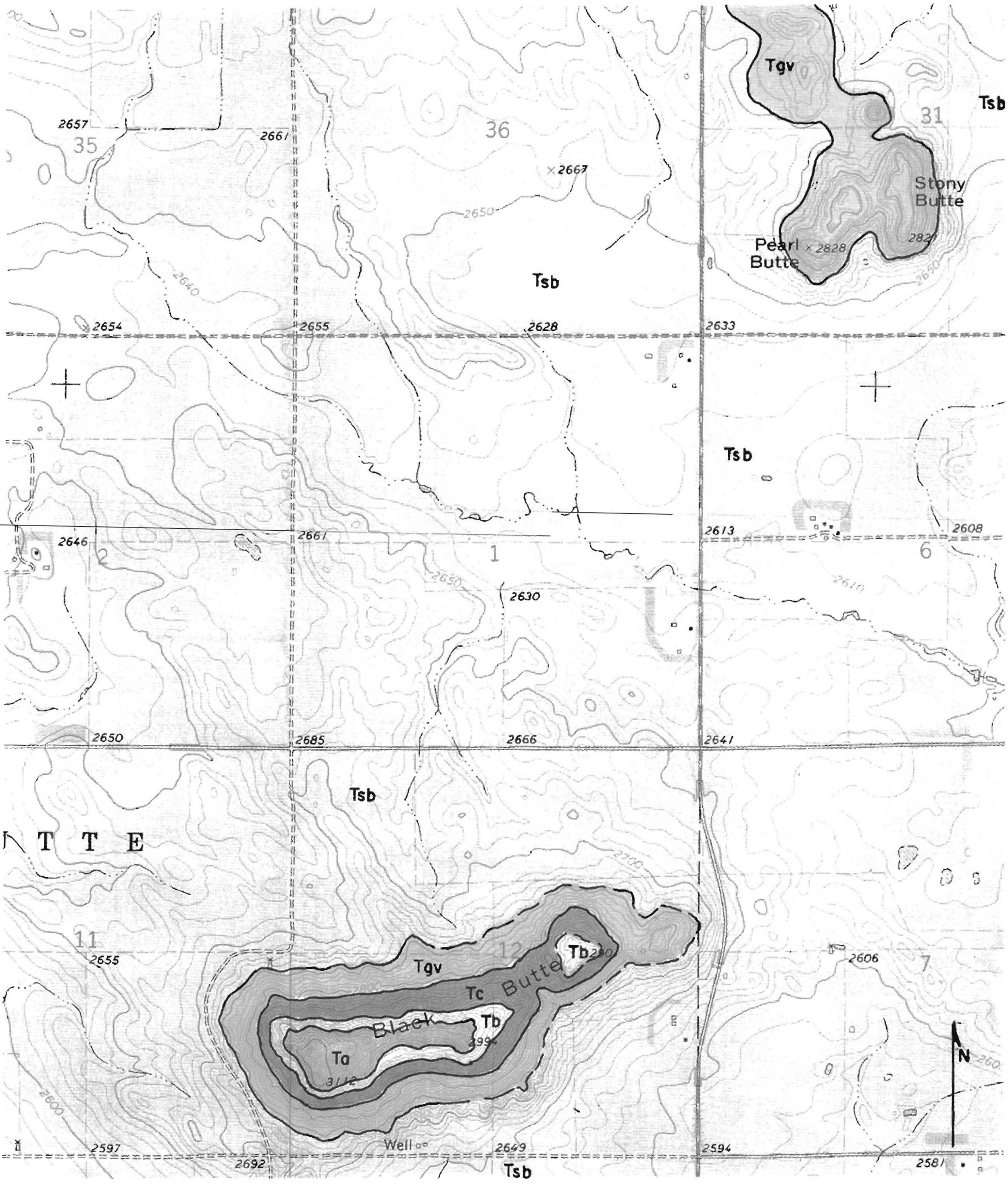
Camels Butte Member

Unit 1: Sandstone, yellow/brown (f&w), medium to fine grained, poorly cemented micaceous.
Claystone, red/brown to buff (f&w), silty, very micaceous.
Alamo Bluff Lignite, 3 inches thick.

Bear Den Member

Claystone, white to gray (f), dazzling white (w), micaceous, kaolinitic.

Figure 45. Measured geologic section at Black Butte, Hettinger County.



Ta Arikaree Formation Tb Brule Formation Tc Chadron Formation Tgv Golden Valley Formation Tsb Sentinel Butte Formation
——— Lithostratigraphic contact. — — — — Contact approximated. Contour interval is 10 feet. Scale: 2.6 inches = 1 mile.

Figure 46. Geologic map of Black, Pearl, and Stony Buttes, Hettinger County (U.S. Geological Survey Stony Butte Quadrangle).

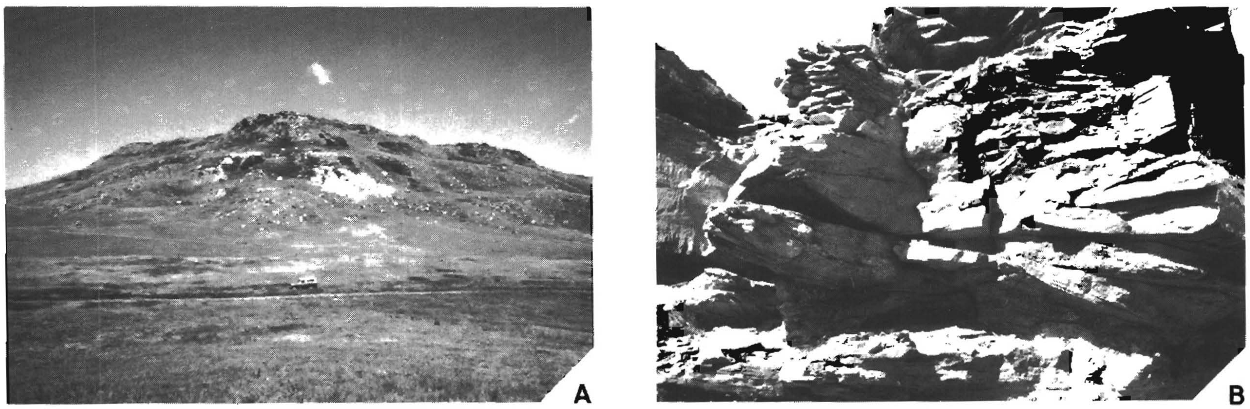


Figure 47. Exposures and sedimentary structures at Black Butte, Hettinger County. **A**, exposures of the Golden Valley, Chadron, Brule, and Arikaree Formations along the southwest face (135-95-12 nwswsw). The Bear Den Member of the Golden Valley Formation comprises the brightly colored outcrops near the base of the butte. **B**, sandstone caprock (Arikaree Formation).

PEARL AND STONY BUTTES

Introduction

Pearl and Stony Buttes are two small sister buttes located in the SW¼ section 31 (T136N R94W), Hettinger County (Figure 46). The buttes rise approximately 200 feet above the surrounding area and have a combined total extent of approximately 30 acres.

Trapp and Croft (1975) mapped the sandstone capping Pearl and Stony Buttes as Arikaree Formation and a portion of the underlying rock as the "White River Formation". Hickey (1977) placed the sandstone at these buttes in the White River Group and Clayton (1980) mapped the caprock as undifferentiated with an age range of Oligocene to Pliocene.

Fort Union Group

The Bear Den Member of the Golden Valley Formation is exposed at Stony Butte. Both Pearl and Stony Buttes are capped by approximately 25 feet of very fine to coarse grained, micaceous, cross-bedded, and moderately cemented sandstone (Figures 48-49). These sandstones are interpreted to be part of the Camels Butte Member of the Golden Valley Formation based on mica content and the southeast paleocurrent direction. Hickey (1977) determined that the prevailing direction of paleotransport during Camels Butte deposition in southwestern North Dakota was to the southeast. In contrast, the paleosurface at the base of the Chadron Formation slopes to the northeast. No fossils have been reported from these buttes and none were found during this study.

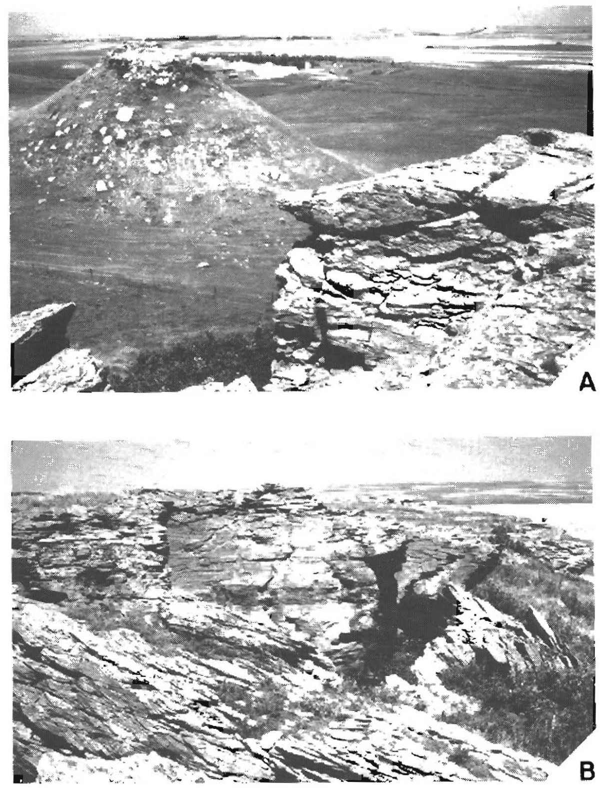
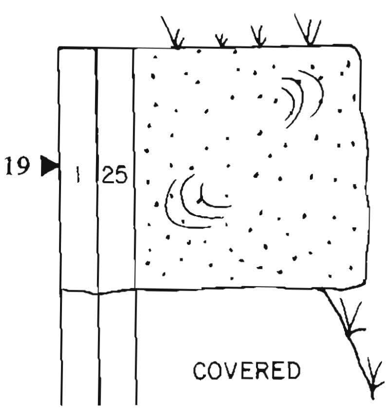


Figure 49. Exposures and sedimentary structures at Pearl and Stony Buttes. **A**, cross-bedded sandstone caprock of Stony Butte in the foreground, Pearl Butte in the background, view to the southwest (136-94-31 sw). **B**, cross-bedded sandstone caprock at Stony Butte (136-94-31 nesw).



PEARL AND STONY BUTTES
Hettinger County

T136N R94W SW SEC 31
Elevation: 2828 feet

GOLDEN VALLEY FORMATION
Camels Butte Member

Unit 1: Sandstone, white to white/yellow (f) to pink, green, yellow/brown (w), very well cemented at base (10-15 feet), flaggy and moderately cemented remainder of outcrop, grain size coarsens upward from very fine to medium grained size, contains large mica flakes.

Figure 48. Measured geologic section at Stony Butte, Hettinger County.

SQUARE BUTTE

Introduction

Square Butte, also known as Flat Top Butte, is a relatively large, northwest-trending mesa located in the SE¼ section 8 (T139N R103W), Golden Valley County (Figures 50-52). Two outliers are associated with the butte, one to the southeast (section 16) and the other to the southwest in the southwest quarter of section 8. Square Butte rises approximately 400 feet above the surrounding area and the top has an areal extent of 204 acres. A geologic section was measured at the southwest outlier because it is the area of best outcrops (Figure 51).

Square Butte is capped by 75 feet of massive sandstone. There has not been a consensus among previous workers regarding the age of this caprock. Leonard (1922), Moore et al. (1959), Denson et al. (1959), and Hickey (1977) placed the sandstone capping Square Butte in the Sentinel Butte Formation. Denson (1969) and Furman (1970) placed this sandstone in the Golden Valley Formation. Hares (1928), Seager et al. (1942), Powers (1945), Brown (1948), Beroni and Bauer (1952), Benson (1952), Bergstrom (1956), Denson and Gill (1965), Stone (1973), Clayton (1980), and Carlson (1983) placed the capping sandstone in either the White River Group or the Arikaree Formation. Brown (1948) found "Oligocene" fossils in conglomeratic beds overlying the massive sandstone at this butte.

Fort Union Group

Alternating sandstones, siltstones, mudstones, claystones, and lignite of the Sentinel Butte Formation comprise the surrounding badland topography and the lower two thirds of Square Butte. East of the butte, in sections 11 and 12 (T139N R103W) the HT Butte lignite bed has burned creating clinker at the base of the Sentinel Butte Formation (Figure 52).

In the southwest quarter of section 8, the capping sandstone is underlain by 22 feet of kaolinitic claystone and sandstone of the Bear Den Member of the Golden Valley Formation (Figure 53a). The claystone and sandstone were determined to be the Bear Den Member based on the dazzling white color and the presence of kaolinite, mica, small spherical iron concretions, and predominance of iron staining, all characteristic of the Bear Den Member in Dunn and Stark Counties.

The sandstone capping Square Butte is generally very fine to fine grained, massive, moderately cemented, and contains lenses of green claystone pebbles at its base (Figures 51, 53a). This capping sandstone is placed in the Golden Valley Formation, rather than in the Chadron Formation, based on its lithologic characteristics and the absence of typical Chadron pebbles.

Chadron Formation

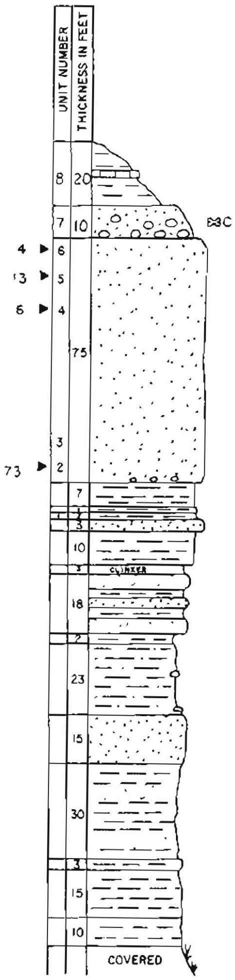
The massive sandstone on Square Butte is overlain by approximately 10 feet of conglomerate of the Chalky Buttes Member of the Chadron Formation (Figures 51, 53b,c). Pebbles in the conglomerate consist of igneous and volcanic rock fragments, the latter of which include the pink/brown porphyries typical of the Chalky Buttes Member in southwestern North Dakota. This conglomerate is generally poorly cemented, but can be very well cemented and is best exposed along the north edge of the butte (Figure 52).

Smectitic claystones (South Heart Member), containing lenses of marlstone and silicified claystone, overlie the conglomerate in some poor exposures (Figure 51). These claystones are 10 to 20 feet thick and are best exposed in a small knoll on the highest point near the north edge of Square Butte.

Paleontology

Fossil fragments, tentatively identified as brontothere remains, were recovered from the conglomerate on the north edge of Square Butte. Brown (1948, p. 1267) also reported the presence of "teeth and other vertebrate remains of Oligocene age" in the conglomerate at the top of Square Butte. Brown's fossils are housed in the Smithsonian Institute and at least some of them are brontothere remains (Purdy, pers. comm., 1993). The presence of brontothere fossils suggest a Chadronian land mammal "age".

Figure 50. Aerial photograph of Square Butte. View is to the east.



SQUARE BUTTE (Flat Top) T139N R103W SW SEC 8
Golden Valley Co. Elevation: 3305 feet

CHADRON FORMATION
South Heart Member

Unit 8: Claystone, light to dark green, smectitic, contains lenses of silicious claystone and carbonates.

Chalky Buttes Member

Unit 7: Conglomerate, typical Chadron gravels (i.e., pink/brown porphyries, etc.), contains brontothere fossils.

GOLDEN VALLEY FORMATION

Units 3-6: Sandstone, lime green (f&w), fine to very fine grained, quartz and clay grains, clay pebble lenses (dark green), moderately cemented.

Unit 2: Sandstone (basal 10 feet) grey/green to brown (f&w), very fine to fine grained, moderately cemented, micaceous, contains green clay pebbles.

Bear Den Member

Claystone, grey/green (f) to dazzling white (w), iron oxide stained, iron sphericules, kaolinitic.

Unit 1: Claystone, green to red/brown (f&w), very indurated.

Claystone, green (f) to light green (w).

Sandstone, medium brown (f&w), very fine grained to silt, calcite cement, hummocky cross-bedding.

Claystone, purple/grey (at base) to grey (f) and white (w), zoned, micaceous, waxy.

SENTINEL BUTTE FORMATION

Clinker and ash, red/orange to purple.

Claystone, siltstone, and sandstone, alternating beds, buff to light grey/brown, micaceous, sandstone is very fine grained, contains flattened spherical concretions up to 6 inches in diameter.

Claystone, brown (W&F) purplish top 2 inches, carbonaceous to lignite.

Claystone and siltstone, buff to light grey (f&w), thin bedded, numerous clay filled joints, micaceous, iron oxide stained, contains calcite cement, concretions and iron oxide pebble lenses.

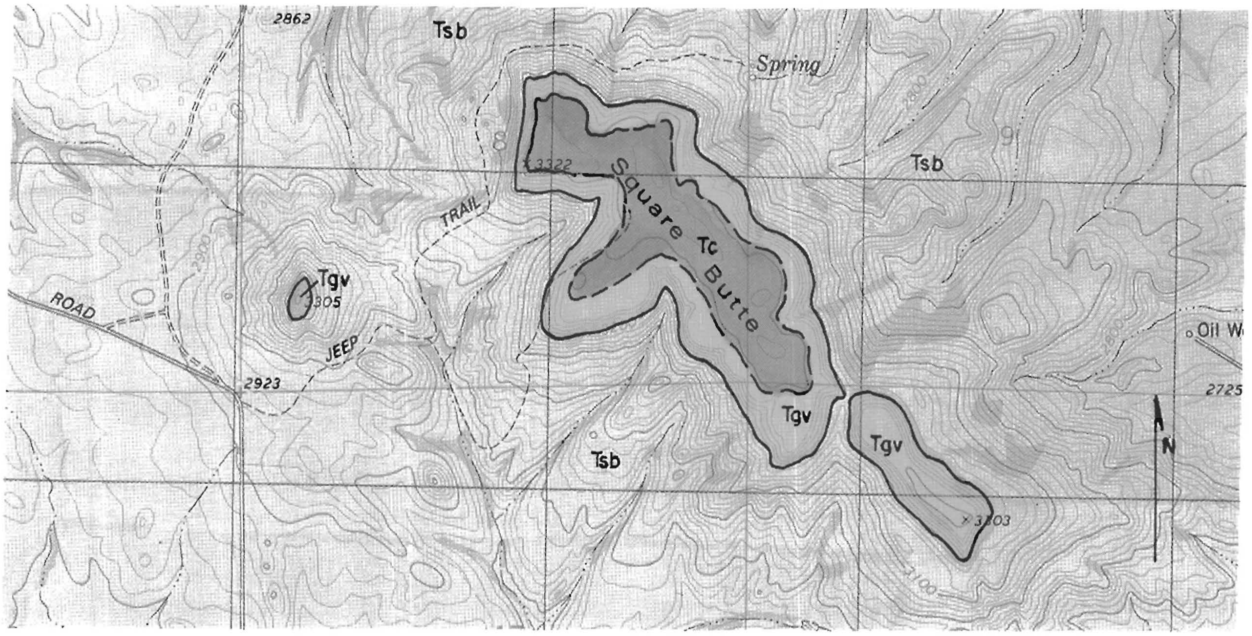
Sandstone, buff to light yellow/brown (w&f), fine to medium grained, moderately cemented, iron oxide stains, contains lenses of clay pebbles, micaceous.

Claystone and siltstone, light grey/brown to tan (w&f).

Claystone, purplish/brown to dark brown (w&f), carbonaceous, some lignite lenses, contains large selenite crystals.

Claystone, grey (f) to bright white (w), iron oxide concretions.

Figure 51. Measured geologic section at Square Butte.



Tc Chadron Formation — Lithostratigraphic contact. – – – Contact approximated.
Tgv Golden Valley Formation — Contour interval is 20 feet.
Tsb Sentinel Butte Formation — Scale: 2.6 inches = 1 mile.

Figure 52. Geologic map of Square Butte (U.S. Geological Survey Square Butte Quadrangle).

Figure 53. Exposures at Square Butte. A, kaolinitic claystone (Bear Den Member; Golden Valley Formation) underlying sandstone caprock (Golden Valley Formation) at Square Butte outlier (139-103-8 sw). B, Chadron gravels (Chalky Buttes Member) overlying thick sandstone on the northwest of butte (139-103-8 swne). South Heart Member of the Chadron Formation is present beneath the grass covered slope. C, Chadron gravels and brontothere remains on top of Square Butte (closeup photo of figure 53b).

SENTINEL BUTTE

Introduction

Sentinel Butte is a large flat-topped butte or mesa which rises approximately 600 feet above the surrounding countryside (Figures 54-56). It is separated into two areas by a small saddle. This butte, along with a small outlier to the southeast, covers approximately 225 acres in portions of sections 5, 6, 8, and 9 (T139N R104W), Golden Valley County, 4 miles west of Square Butte (Figure 56). Sentinel Butte is believed to be named for two Arikaree Indian sentinels or scouts (American Black Eagle and Standing Together) who were slain in this area (Williams, 1966).

The geology of Sentinel Butte was first studied by White (1883), who discovered spectacular fish fossils in the calcareous claystone and thin limestone beds at the top of the butte. Because of lithologic similarities and the presence of fish fossils, White felt that these beds were part of the "Green River group". Cope (1883b) later described these fish and, although he found them to be similar to types found in the "Green River beds," would not correlate these rocks with that unit based solely on the fossils. Leonard (1908, 1922) placed these beds in the "White River formation" and identified (Leonard, 1922) the thick sandstone underlying the calcareous claystones as the Sentinel Butte Formation. Denson and Gill (1965) placed the capping claystones and marlstones in the Chadron Formation in their cross-section, but in their text, speculated that these beds might be part of the Arikaree Formation. Subsequent workers have agreed that the claystones at the top of the butte are part of the White River Group or Arikaree Formation but have disagreed about the placement of the underlying sandstone. Boyer's (1981) petrographic study of the capping carbonates of this butte cited unpublished data on the fossil fish suggesting an age range from middle Oligocene to middle Miocene. Moore et al. (1959), Denson and Gill (1965), and Stone (1973) agreed with Leonard and placed the sandstone underlying the calcareous claystones in the Sentinel Butte Formation. Brown (1948) recognized an unconformity at the base of the "cliff-making sandstone" on Sentinel Butte. The presence of this unconformity and the similarity of the sandstone with a sandstone containing "Oligocene" fossils capping Square Butte led Brown to suggest that the sandstone caprock on Sentinel Butte may be Eocene or Oligocene in age. Hares (1928), Powers (1945), Wyant and Beroni (1950), Benson (1952), Bergstrom (1956), Clayton (1980), and Carlson (1983) placed this thick capping sandstone in the White River Group or Arikaree Formation. Clarke (1948) called the capping sandstone the Wasatch Formation (Eocene) while Denson (1969) and Furman (1970) placed it in the Golden Valley Formation.

Fort Union Group

The Sentinel Butte Formation is present at the surface in a 1/2 to 3/4 mile area surrounding the butte. The alternating beds of sandstone, siltstone, mudstone, claystone, and lignite of this formation are well exposed on the east flank of Sentinel Butte. A six-foot lignite (Nunn bed of Moore et al., 1959) occurs approximately 125 feet below the top of the butte in that area. This lignite has burned along the north side of the butte and baked 20 to 30 feet of the overlying rocks (Figures 55, 57a).

Approximately 75 feet of sandstone overlies the Nunn bed at Sentinel Butte (Figures 55, 57b,c). On the north side of the butte this sandstone is split into two beds by 15 feet of green interbedded siltstone and claystone. The lower sandstone is green to brown, fine grained and moderately cemented. The upper sandstone is generally buff to white, green at the base, medium grained, and contains rip-up clay clasts near the base. These sandstones are mapped as Golden Valley Formation (Camels Butte Member) based primarily on their similarity to the sandstone caprock at Square Butte. The green color of the interbedded siltstone and claystone between these sandstones, is similar to claystones in the Golden Valley and Chadron Formations at other localities. The Bear Den Member, a white kaolinitic mudstone or siltstone, present beneath the sandstone at Square Butte, was not identified below the massive sandstone at Sentinel Butte (Figure 55).

Chadron Formation

The 50 feet of green calcareous claystone capping Sentinel Butte contains at least three thin carbonate beds bearing fish fossils, burrows, and silicious zones (Figures 55, 57d). This claystone is placed in the South Heart Member of the Chadron Formation because of the lithologic similarity between the carbonate lenses in the claystones with carbonate lenses in the South Heart Member of the Chadron Formation at other localities in southwestern North Dakota.

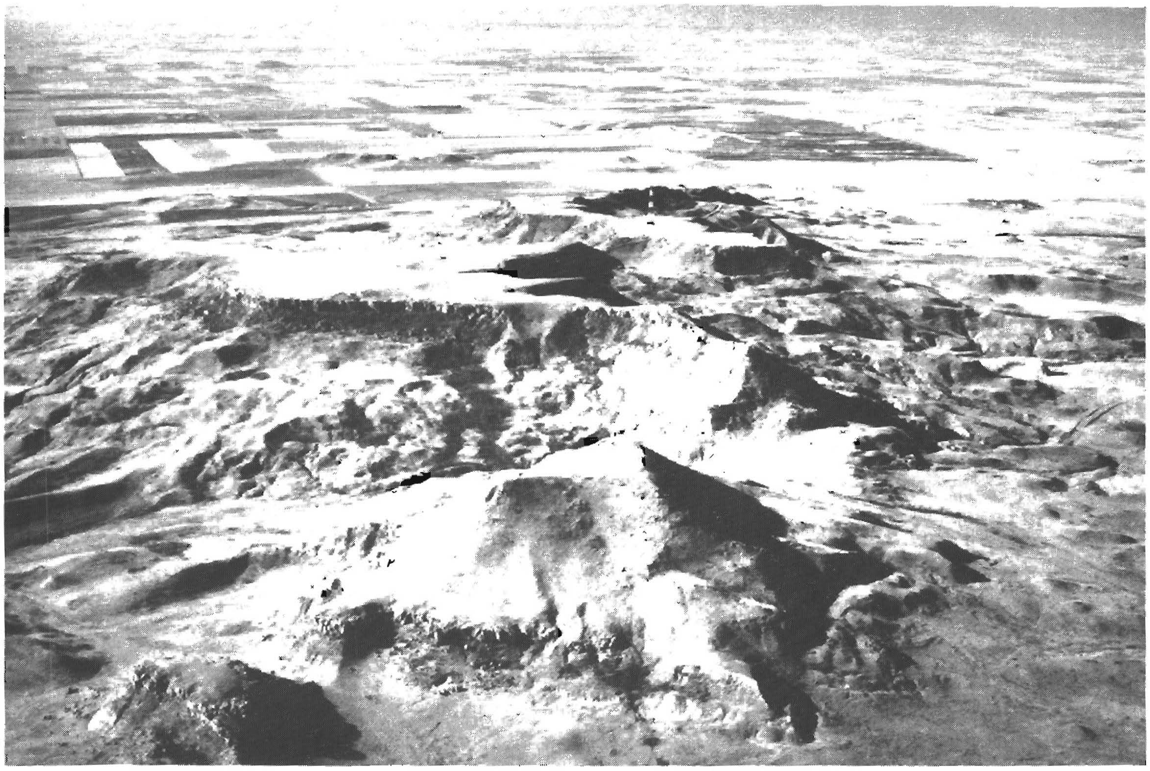
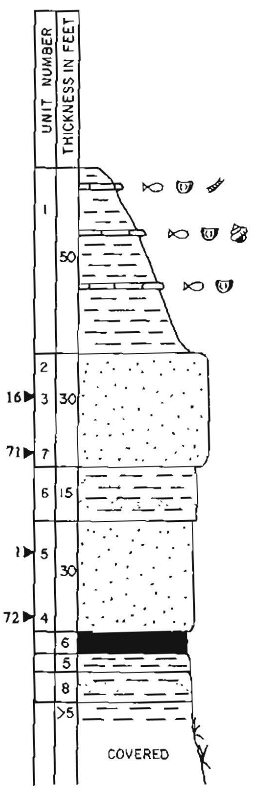


Figure 54. Aerial photograph of Sentinel Butte. View is to the northwest.



SENTINEL BUTTE
Golden Valley Co.

T139N R104W SW SEC 6
Elevation: 3430 feet

CHADRON FORMATION
South Heart Member

Unit 1: Claystone, green (f&w), blocky, marly, contains 3 limestone lenses, massive to flaggy, generally less than 6 inches thick, contains fish fossils and vertical burrows, flint nodules at surface.

GOLDEN VALLEY FORMATION

Units 2 & 3: Sandstone, buff to grey/white (f&w), contains iron oxide nodules.

Unit 7: Sandstone, green (f&w), medium grained, moderately cemented, contains clay pebbles, basal 10 feet of unit 2.

Unit 6: Claystone and siltstone, medium to dark green (f&w), interbedded.

Units 4 & 5: Sandstone, green/brown (f&w), fine grained, moderately cemented, iron oxide stained.

SENTINEL BUTTE FORMATION

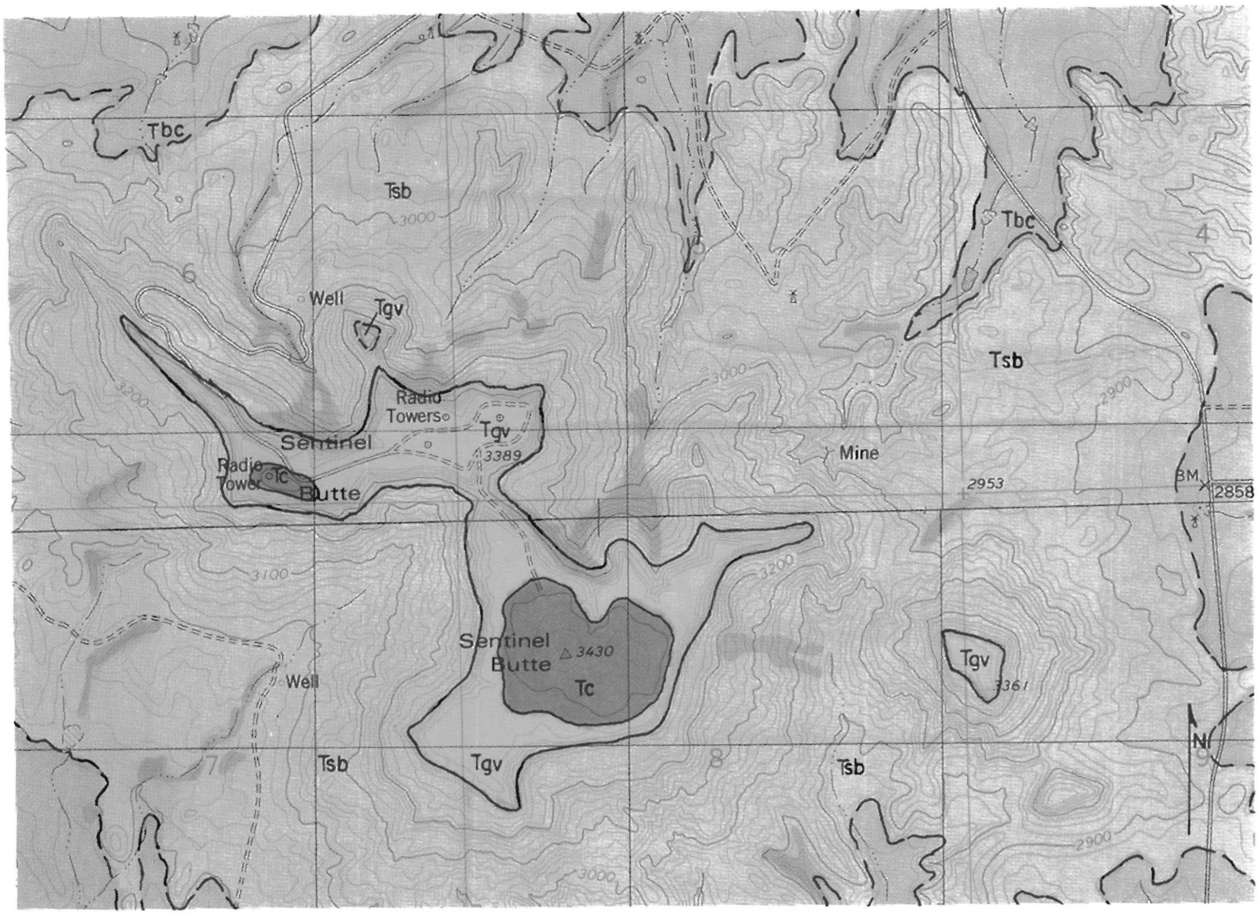
Lignite.

Claystone, medium to light grey (w&f), clear.

Claystone, siltstone, and sandstone, interbedded, yellow brown (f&w), very fine grained sand, iron oxide claystone.

Claystone, grey/blue to brown (w&f), carbonaceous.

Figure 55. Measured geologic section at Sentinel Butte.



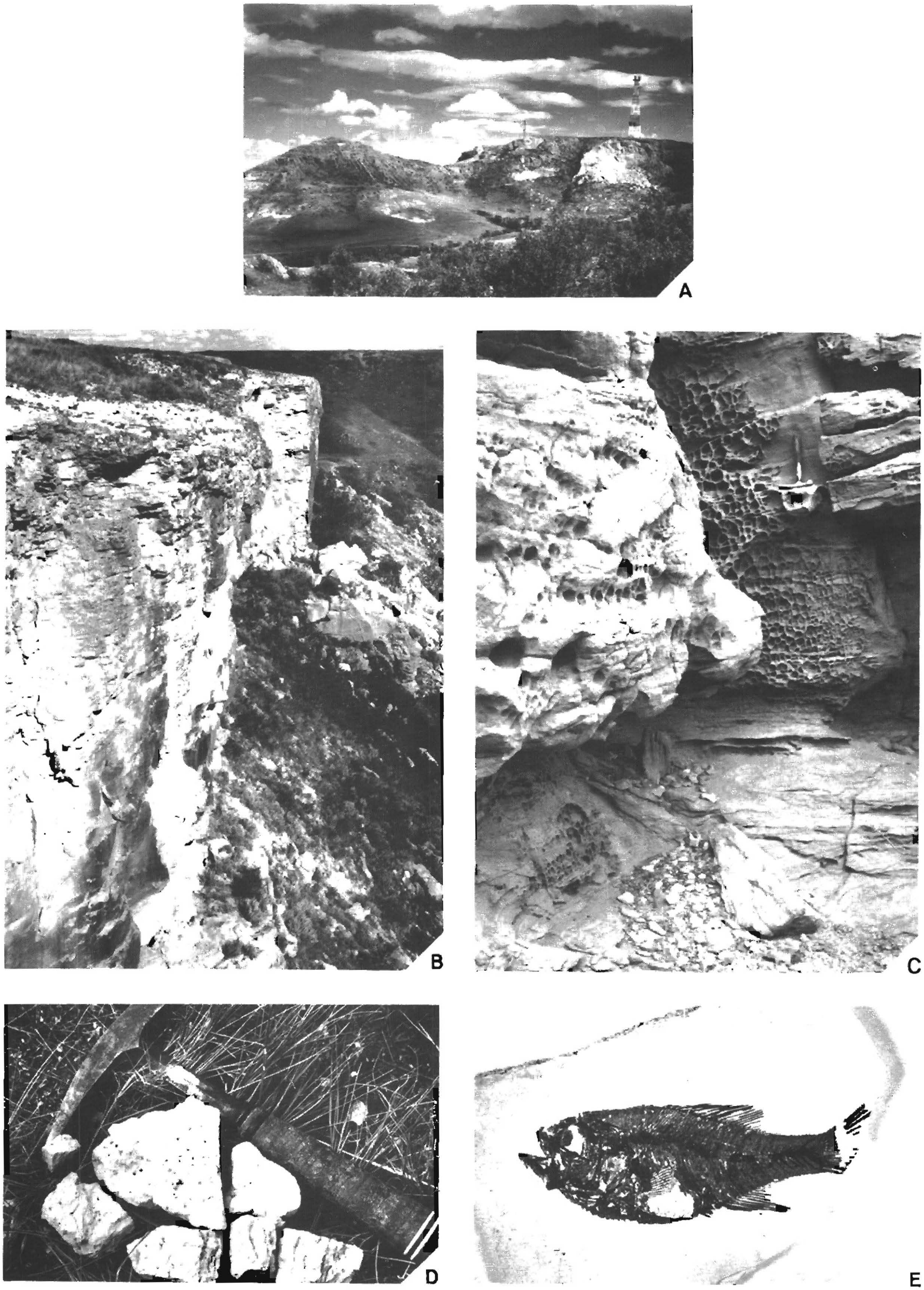
Tc Chadron Formation — Lithostratigraphic contact. Tgv Golden Valley Formation - - - - Contact approximated. Tsb Sentinel Butte Formation Contour interval is 20 feet. Tbc Bullion Creek Formation Scale: 2.6 inches = 1 mile.

Figure 56. Geologic map of Sentinel Butte (U.S. Geological Survey Sentinel Butte and Sentinel Butte SE Quadrangles).

Paleontology

White (1883) discovered exquisitely preserved fish fossils in the carbonate caprock of Sentinel Butte. Cope (1883b) identified two new species of Percidae from these fossils (Figure 57e) (Appendix C). Feldmann (1962) noted the association of these fish fossils with freshwater gastropods and ostracods. In his exhaustive petrographic study of these carbonates, Boyer (1981) recorded, in addition to fish, the presence of algae, ostracods, fish coprolites, and burrows.

Figure 57 (opposite page). Exposures, sedimentary structures, and fossils at Sentinel Butte. **A**, slumping exposing the capping sandstone along the northern portion of Sentinel Butte, view is to the east (139-104-6 nwse). Clinker, from the burning of a lignite bed in the Sentinel Butte Formation, forms the prominent point on the north side of the butte. **B**, sandstone caprock and underlying vegetation covered talus slope (139-104-6 swse). **C**, honeycomb weathering features in the sandstone caprock (139-104-8 nwnw). **D**, burrows or root casts in marlstone bed near the top of the butte (139104-6 swse). **E**, fish, *Plioplarchus*, from capping carbonate bed, (139-104-6) (Photo courtesy of F.D. Holland, Jr., Professor Emeritus University of North Dakota).


A
B
C
D
E

BULLION BUTTE

Introduction

Bullion Butte is a relatively large y-shaped mesa that occupies portions of section 7 and 18 (T137N R102W), Billings County (Figures 58-60). The butte rises approximately 700 feet above the surrounding countryside and the top has an areal extent of approximately 195 acres. The butte is capped by brightly colored claystones which are underlain by a thick sandstone. Rocks immediately below this sandstone are not exposed at this butte. A geologic section was measured along the southeast limb of Bullion Butte (Figure 59).

There has been no consensus concerning the age of the sandstone near the top of Bullion Butte. Several reports have placed the sandstone in the Sentinel Butte Formation (Leonard, 1922; Moore et al., 1959; Denson et al., 1959; Denson and Gill, 1965; Stone, 1973) however, Denson (1969) and Furman (1970) placed this sandstone into the Golden Valley Formation. Others have identified the sandstone as part of the White River Group or Arikaree Formation (Hares, 1928; Seager et al., 1942; Powers, 1945; Bergstrom, 1956; Benson, 1952; Clayton, 1980; and Carlson, 1983). Most workers have placed the brightly colored claystones capping the butte in the White River Group or Arikaree Formation (Denson and Gill, 1965; Stone, 1973).

Fort Union Group

The badlands topography surrounding Bullion Butte is carved out of brightly colored sandstones, siltstones, claystones, and mudstones of the Bullion Creek Formation. The characteristic yellows and greens of the Bullion Creek are generally easy to distinguish from the more somber grays and browns of the overlying Sentinel Butte Formation. The Sentinel Butte Formation comprises all of Bullion Butte, except the capping sandstone and overlying claystones, and is well exposed along the west slope of the butte.

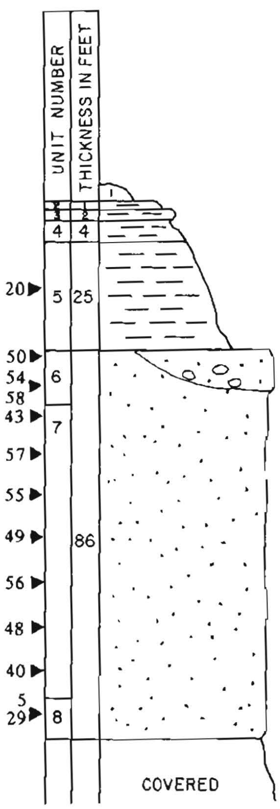
The white to brown, very fine to fine grained sandstone near the top of Bullion Butte is approximately 90 feet thick (Figures 59, 61a,b,d). It is moderately cemented and the base of the sandstone appears massive but cross-bedding is faintly visible in the upper portion. Small-diameter burrows occur in the upper part of the sandstone (Figure 61d). Other than these trace fossils, the sandstone is unfossiliferous. This sandstone is mapped as Golden Valley Formation because of its lithologic similarity to the sandstones at Sentinel and Square Buttes.

Chadron Formation

In the northwest corner of the butte, a lens of gray/green, medium to coarse grained sandstone overlies the massive fine grained Golden Valley sandstone (Figure 61c,e). This sandstone contains conglomeratic lenses of chert and other rock pebbles and is interpreted to be the Chalky Buttes Member of the Chadron Formation.

This conglomeratic sandstone is overlain by approximately 50 feet of brightly colored (green, purple, and yellow) smectitic claystone believed to be the South Heart Member of the Chadron Formation. The lower part of this claystone exhibits "popcorn" weathering surface features and the upper 10 feet is silicious. Pebbles and cobbles of carbonate rock were found in the soil horizon but no carbonate beds were found in place. These brightly colored claystones are similar to claystones in the South Heart Member of the Chadron Formation at the Little Badlands and Chalky Buttes (Figure 61f). The carbonate lag is lithologically similar to carbonate lenses generally associated with the South Heart Member.

Figure 58. Photograph of the southeast face of Bullion Butte. View is to the northwest.



BULLION BUTTE
Billings County

T137N R102W SE SEC 18
Elevation: 3358 feet

CHADRON FORMATION
South Heart Member

Unit 1: Carbonate lag in soil horizon.

Unit 2: Claystone, grey/brown (f), highly weathered, silicious.

Unit 3: Claystone, green (f) to white, red, and yellow (w), very indurated, highly fractured.

Unit 4: Claystone to clay, yellow/green (f).

Unit 5: Claystone, green (f) to yellow/orange and purple (w), may contain pods of brightly colored claystones, there is no weathering halo evident on this unit.

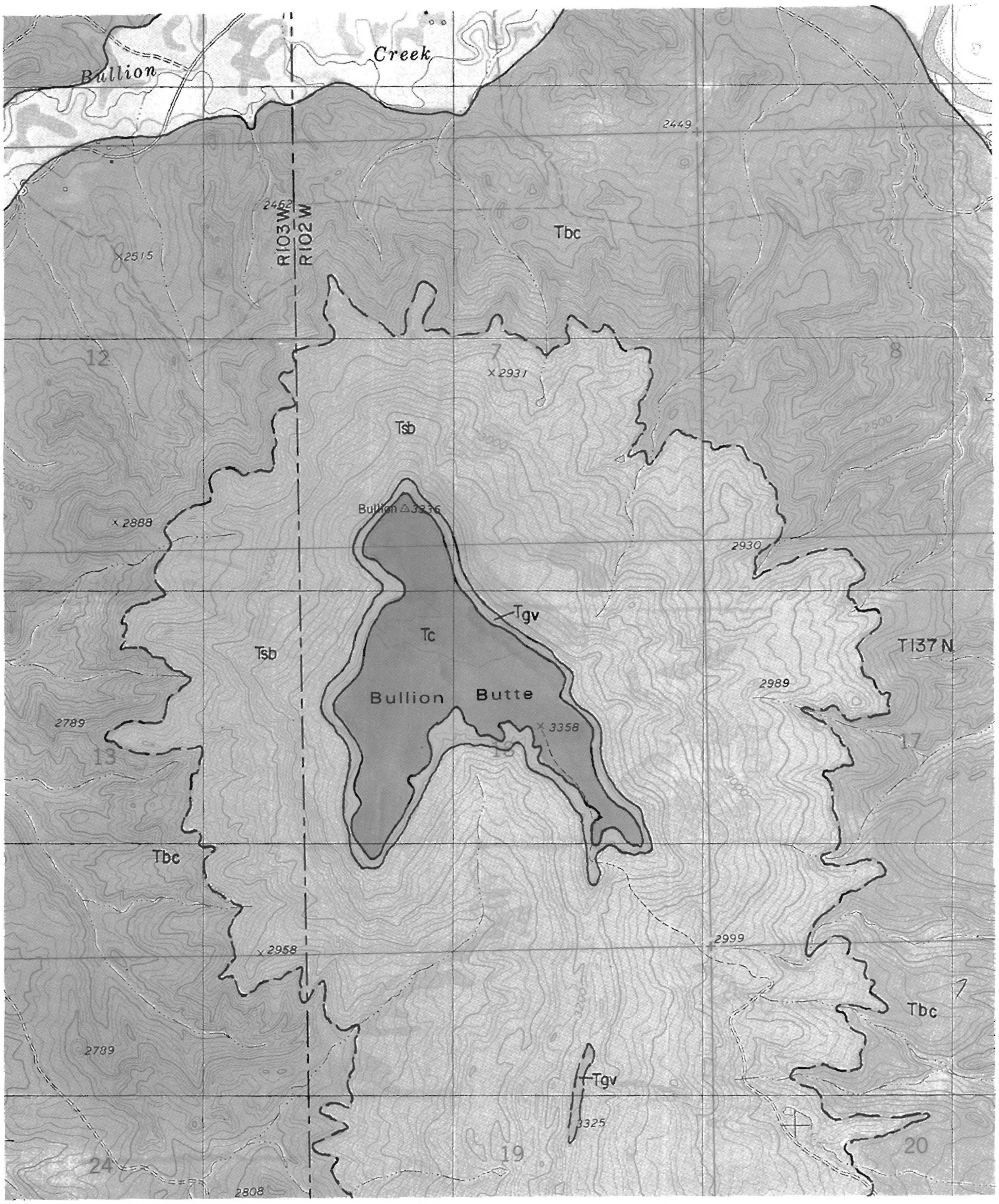
Chalky Buttes Member

Unit 6: Sandstone, green to yellow/brown, coarse grained sandstone, conglomeratic, contains chert and volcanic rock pebbles, poorly to extremely well cemented.

GOLDEN VALLEY FORMATION

Unit 7 & 8: Sandstone, buff to light yellow/brown for basal 4 feet then to dazzling white (f) to buff (w), very fined grained to silt, moderately cemented, micaceous, appears cross-bedded in upper portion, may contain rare, small diameter burrows.

Figure 59. Measured geologic section at Bullion Butte.



Qal Quaternary alluvium Tc Chadron Formation Tgv Golden Valley Formation Tsb Sentinel Butte Formation Tbc Bullion Creek Formation
—— Lithostratigraphic contact. – – – –Contact approximated. Contour interval is 20 feet. Scale: 2.6 inches = 1 mile.

Figure 60. Geologic map of Bullion Butte (U.S. Geological Survey Bullion Butte Quadrangle).

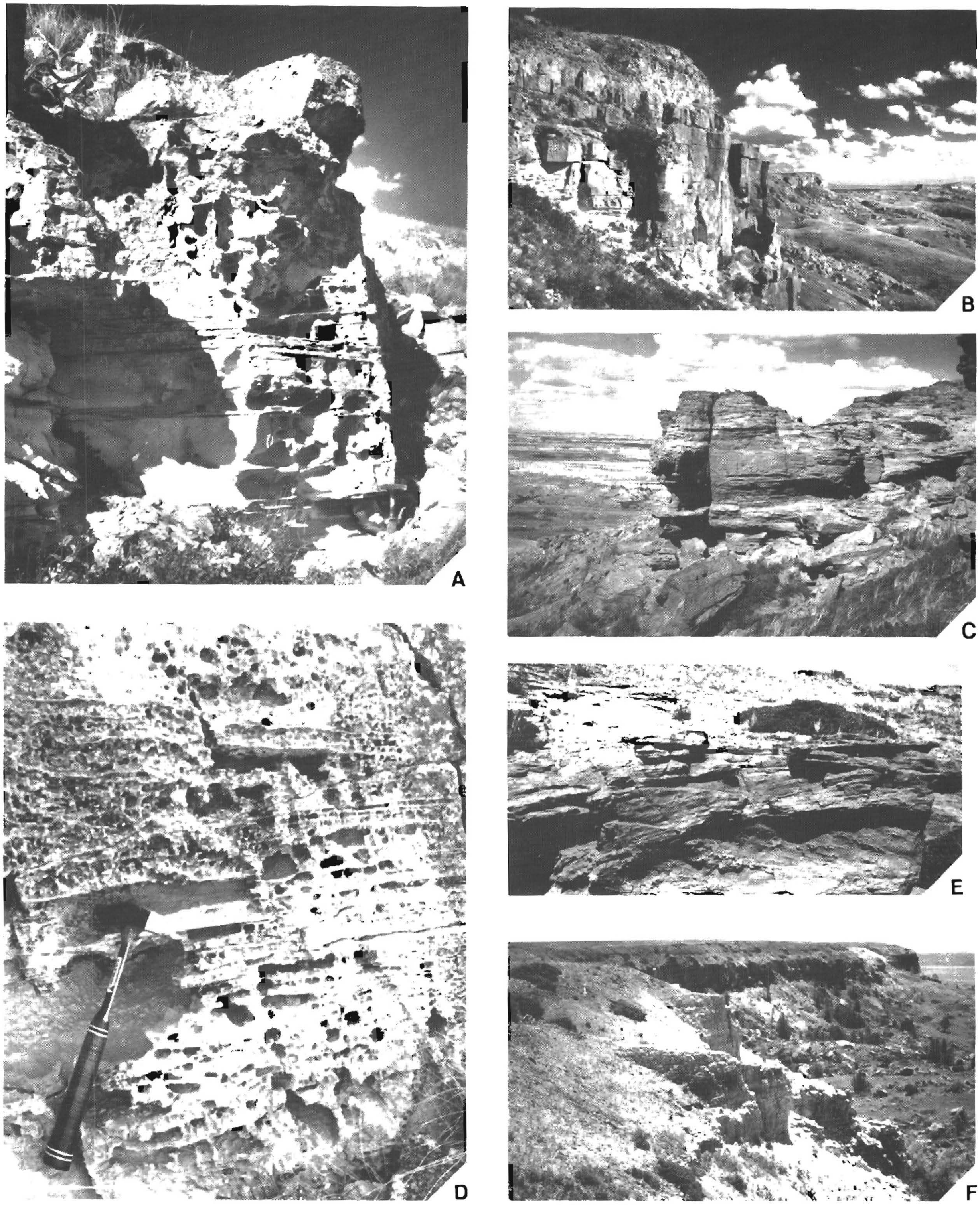


Figure 61. Exposures and sedimentary structures of the Golden Valley and Chadron Formations at Bullion Butte. **A**, honeycomb weathering patterns in the Golden Valley sandstone (137-102-18 nenwse). **B**, massive character of the sandstone rimming Bullion Butte, view to the southeast (137-102-nwnwse). **C**, green to yellow/brown conglomeratic sandstone at top of northwestern corner (137-102-7 neswsw). **D**, burrows in Golden Valley sandstone (137-102-18 nenwse). **E**, green to yellow/brown conglomeratic Chadron sandstone at top of northwestern corner of butte (137-102-7 nenwse). **F**, popcorn weathering surface features and highly jointed nature of multicolored claystone at top of butte (137-102-18 neswsw).

MEDICINE POLE HILLS

Introduction

The Medicine Pole Hills are a series of small hills and buttes that occupy portions of sections 1-3, 9-12 (T130N R104W), 19-22 and 30 (T131N R103W), and 24, 25, 35, and 36 (T131N R104W), Bowman County (Figure 62; Plate 5). The tops of the buttes comprise an area of approximately 1400 acres and rise approximately 200 feet above the surrounding countryside. Outcrops of rocks capping these buttes are generally poor.

Leonard (1922) was first to discover the presence of the White River Group capping some of the Medicine Pole Hills. Subsequent workers agreed with Leonard's findings (Hares, 1928; Benson, 1952; Denson et al., 1959; Denson and Gill, 1965; Stone, 1973; and Clayton, 1980). Carlson (1979) did not map the White River in this area because he could not determine from the limited outcrops whether the rocks at the top of the buttes were lag, ie., had been let down from higher in the section, or in place (Carlson, pers comm, 1992).

Fort Union Group

The countryside surrounding the southern portion of Medicine Pole Hills consists of alternating sandstones, siltstones, mudstones, claystones, and lignites of the Slope Formation (Plate 5). The top of the Slope is a brightly colored kaolinitic mudstone, siltstone, or sandstone called the Rhame Bed. This bed is exposed 30 feet below the top of a butte in the northeast quarter of section 2 (T130N R104W) (Figures 62, 63). The Bullion Creek Formation overlies the Slope Formation and in turn is overlain by White River rocks in this area. The Bullion Creek Formation is only 20 feet thick at the above locality but is thicker in the northern half of the Medicine Pole Hills. A channel sandstone is at the top of the Bullion Creek Formation in section 2 (T130N R104W)(Figure 64a).

Chadron Formation

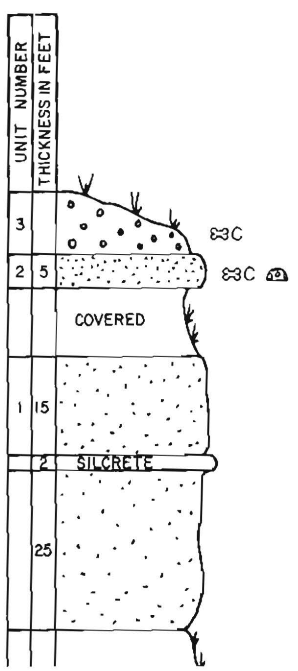
The Chadron Formation in the Medicine Pole Hills consists of 10 to 15 feet of sandstone and conglomerate of the Chalky Buttes Member (Figure 63). This sandstone is medium to coarse grained (coarser grained than the underlying Fort Union sandstones), poorly to moderately cemented, contains vertebrate fossils, and often forms a bench at the crest of the buttes. The conglomerate that overlies the sandstone occurs at the very top of the buttes and is generally 3 to 15 feet thick. This conglomerate is a vertebrate-fossil bearing gravel that contains quartz latite porphyry fragments and volcanic breccias (Figure 64b,c).

Two holes were drilled on one of the Medicine Pole Hills in an attempt to determine whether the gravel was in place or was lag (Appendix B). The gravel in one of the drill holes (NW¼SE¼NE¼ section 2, T130N R104W) was moderately to well cemented indicating that it is likely in place.

Paleontology

Chadronian fossils (brontotheres) were first discovered in the Medicine Pole Hills by Leonard (1922). Additional fossils were reported from the Chadron Formation in this area by Hares (1928), Benson (1952), and Denson et al. (1959) (Appendix C). Observations made during this study indicate that a diverse Chadronian "age" vertebrate fauna, the most diverse fauna of this age yet discovered in North Dakota, is present in the Medicine Pole Hills. These fossils are currently being studied by Dean Pearson, Pioneer Trails Museum, Bowman, North Dakota.

Figure 62. The southern end of the Medicine Pole Hills (130-104-2 east 1/2). View is to the northeast. The Chalky Buttes Member caps the hills. The Rhame Bed, representing the top of the Slope Formation, is a brightly colored bed near the base of the hills.



MEDICINE POLE HILLS
Bowman County

T130N R104W NE SEC 2
Elevation: 3447 feet

CHADRON FORMATION
Chalky Buttes Member

Unit 3: Gravel, up to 3-inch diameter - most are 2 inch or less, mostly frosted quartz and volcanics, petrified wood (up to 3 feet long), vertebrate fossil fragments (rounded).

Unit 2: Sandstone, grey (w) to grey/green (f), medium to coarse grained, some quartz pebbles, moderately cemented.

BULLION CREEK FORMATION

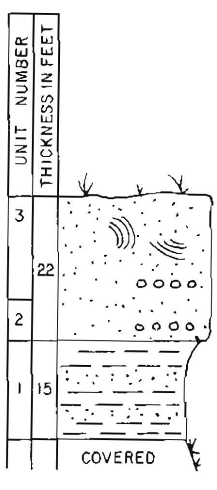
Unit 1: Sandstone, grey to buff (w) to yellow-brown (f), fine to very fine grained, quartz, mica flakes, dirty, poorly cemented to moderately cross-bedded.

SLOPE FORMATION

Rhame Bed: Sand and silt, grey (f), bright to dazzling white (w), generally all white but some color zoning, moderately to poorly cemented, capped by 1- to 2-foot thick silcrete, blocks form lag over most hillsides.

Figure 63. Measured geologic section at the Medicine Pole Hills.

Figure 65. South Whetstone Butte, photo taken from Whetstone Butte. View to the southwest.



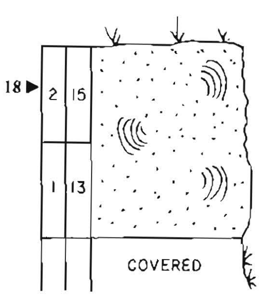
WHETSTONE BUTTE
Adams County

T132N R98W SE SEC 29
Elevation: 3149 feet

CHADRON FORMATION
Chalky Buttes Member

Unit 3: Sandstone, light green/grey, coarse grained, mostly quartz, contains lenses of well rounded pebbles up to 2½ inches in diameter--average 1 inch, pebbles mostly are volcanic although some shale and some flint, large scale cross-bedding, base is iron cemented.

Unit 1: Sandstone and claystone, yellow/green to light green, medium grained sand, interbedded.



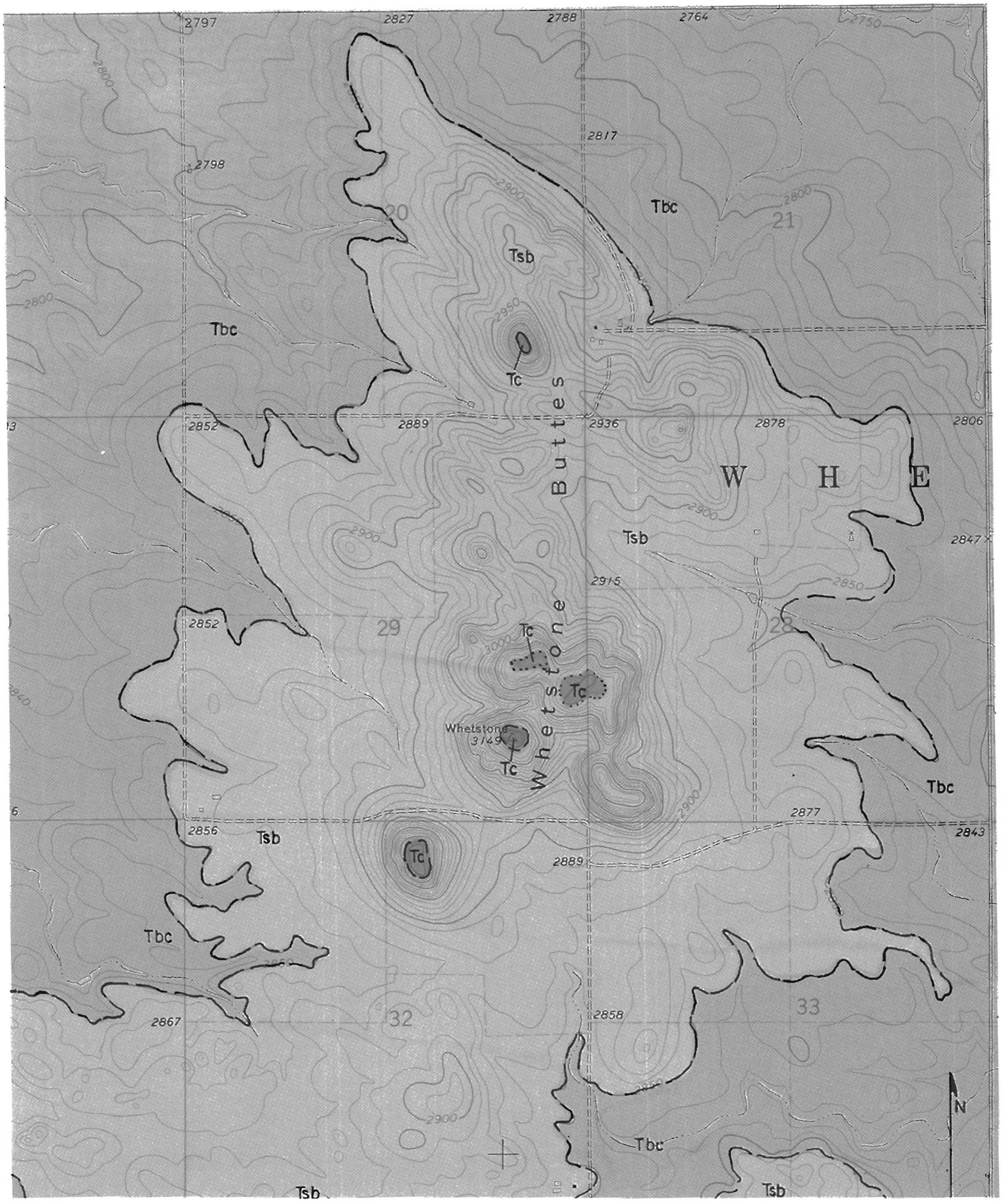
SOUTH WHETSTONE BUTTE
Adams County

T132N R98W NW/NE SEC 32
Elevation: 3100 feet

CHADRON FORMATION
Chalky Buttes Member

Units 1 & 2: Sandstone, light grey/green, fine to medium grained--no pebbles, quartz and rock fragments, moderately cemented, fines upward, cross-bedded, Unit 1 is flaggy and Unit 2 is massive.

Figure 66. Measured geologic sections at Whetstone and South Whetstone Butte.



Tc Chadron Formation   Tsb Sentinel Butte Formation   Tbc Bullion Creek Formation

—— Lithostratigraphic contact. — — — —Contact approximated. ······· Contact inferred. Contour interval is 10 feet. Scale: 2.6 inches = 1 mile.

Figure 67. Geologic map of the Whetstone Buttes (U.S. Geological Survey Whetstone Buttes Quadrangle).

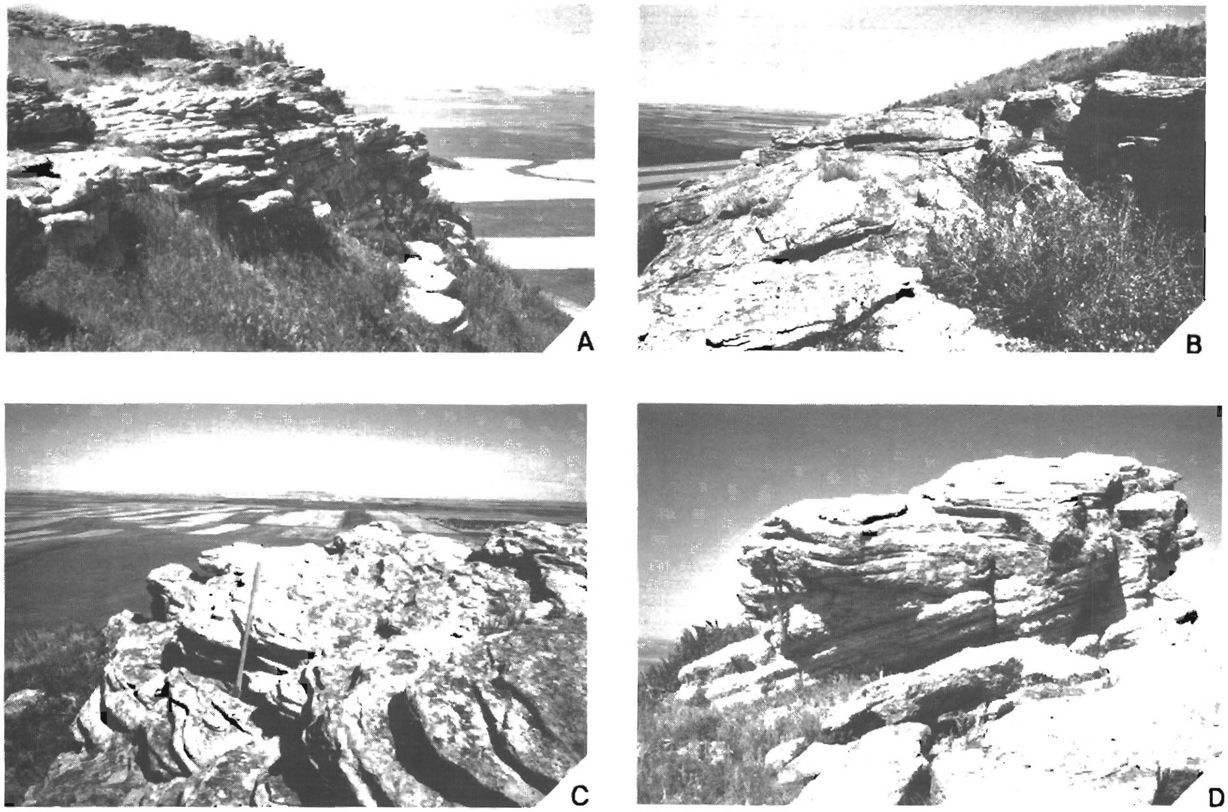


Figure 68. Caprock at Whetstone, South Whetstone, and North Whetstone Buttes. **A**, sandstone capping South Whetstone Butte (132-98-32 nwnwne). **B**, well exposed sandstone (Chalky Buttes Member) near top of North Whetstone Butte. Conglomerate overlies sandstone (Chalky Buttes Member) but is covered by vegetation in this photo (132-98-20 sese). **C** and **D**, conglomerate (Chalky Buttes Member) capping Whetstone Butte (132-98-29 nwsese).

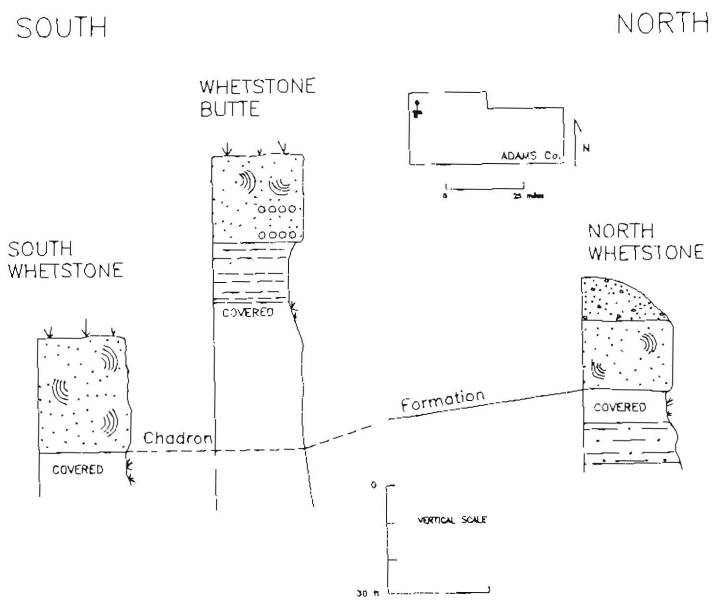


Figure 69. Geologic cross-section of Whetstone Buttes.

WOLF BUTTE

Introduction

Wolf Butte is a small northwest-trending elliptically shaped butte located in the NW¼SE¼ section 23 (T131N R97W), Hettinger County (Figures 70-72). The butte received its name from large wolf dens that were present around the butte (Williams, 1966). Wolf Butte rises approximately 300 feet above the surrounding countryside and the top of the butte has an areal extent of approximately 10 acres. There are no outcrops below the capping sandstone. A geologic section was measured along the east face of the butte.

Benson (1952, p.99) placed 65 to 80 feet of sandstone caprock "that contains a few pebbles" at Wolf Butte in the White River. Stone (1973) placed the capping sandstone at this butte in his "Killdeer formation" in the text of his report but lists only the Chadron Formation as being present at this butte in the appendices. Carlson (1979) included the caprock of Wolf Butte in the Sentinel Butte Formation and Clayton (1980) mapped this caprock as "Oligocene, Miocene, or Pliocene in age".

Fort Union Group

The capping sandstone on Wolf Butte is fine to very fine grained, moderately to very well cemented, cross-bedded, unfossiliferous, and is 18 feet thick (Figures 71, 73a-c). The upper part of this sandstone contains numerous holes one quarter to one inch in diameter. The holes are interpreted to be caused by differential weathering but may represent root casts.

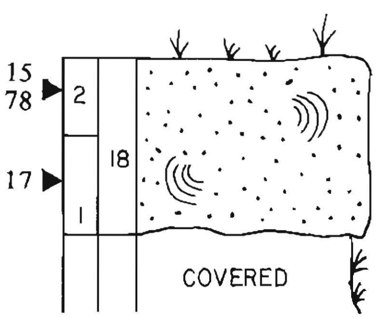
Chadron Formation

There are a few, thin (< 1 foot) lenses or pods of pebbly sandstone at the top of Wolf Butte. These lenses are comprised of medium to coarse grained sandstones that contain volcanic pebbles. These pebbles, which are similar to those found in the Chalky Buttes Member, are also present as float throughout the top of the butte. The sparse sandstone lenses and the pebbles are remnants of the Chadron Formation and correlate with the well-exposed conglomerate on Whetstone Butte. The sandstones are unfossiliferous.

Figure 70. Wolf Butte, view to the southwest.

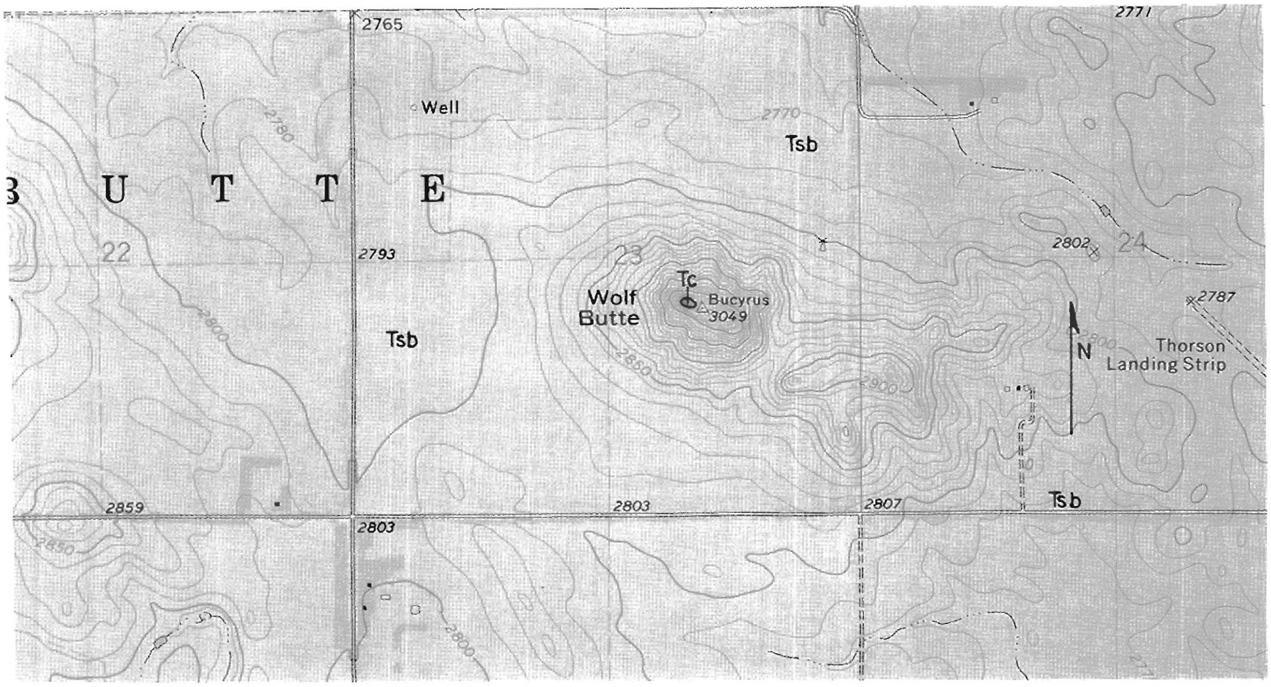
WOLF BUTTE
Adams County

T131N R97W SE SEC 23
Elevation: 3049 feet



CHADRON FORMATION
Chalky Buttes Member
Conglomerate, gray to gray/green, medium to coarse grained, pebbles of chert and volcanic rock fragments, moderately cemented, very small outcrop.
SENTINEL BUTTE FORMATION
Units 1 & 2: Sandstone, buff-white (f) to yellow, orange, pink, and red (w), very fine to fine grained, quartz and rock fragments, moderately to well cemented, cross-bedded, Unit 2 contains holes of unknown origin.

Figure 71. Measured geologic section at Wolf Butte.



Tc Chadron Formation
Tsb Sentinel Butte Formation
Tbc Bullion Creek Formation
——— Lithostratigraphic contact.
– – – Contact approximated.
Contour interval is 10 feet.
Scale: 2.6 inches = 1 mile.

Figure 72. Geologic map of Wolf Butte (U.S. Geological Survey Wolf Butte Quadrangle).

Figure 73. Exposures and sedimentary structures of the capping sandstone at Wolf Butte. A and B, holes possibly caused by differential weathering (131-97-23 senwse). C, absence of outcrops below the capping sandstone, view to the west (131-97-23 senwse).

DAVIS BUTTES

Introduction

Davis Buttes are a series of five buttes northeast of Dickinson that occupy portions of sections 19 and 30 (T140N R95W), and 13, 24, and 25 (T140N R96W), Stark County. These buttes rise approximately 200 to 250 feet above the surrounding countryside (Figures 74-77). The top of the largest butte in the southeast quarter of section 24 extends over an area of approximately 160 acres and the other four butte tops range in size from 10 to 60 acres. Sandstone caprock is the only rock well exposed on these buttes.

Trapp and Croft's (1975) geologic map of Stark County places the rocks comprising Davis Buttes in the Golden Valley Formation. Hickey (1977) and Clayton (1980) interpreted the caprock of these buttes to be in the White River Group. Denson and Gill (1965, plate 3) did not indicate the presence of "Oligocene-Miocene rocks" at Davis Buttes, and Stone (1973) did not include these caprocks in his appendix of the known exposures of middle Cenozoic rock units.

Fort Union Group

The Golden Valley Formation is present at the surface in the area surrounding Davis Buttes. The brightly colored, kaolinitic Bear Den Member of the Golden Valley Formation, is well exposed in outcrops southeast of the buttes.

The sandstone capping Davis Buttes is approximately 6 to 10 feet thick (Figures 74a,b, 76). It is white to yellow/brown, fine to medium grained, micaceous, and moderately to well cemented. A hole 66 feet deep was drilled on the north side of the largest butte to determine lithologies of beds beneath the caprock because of the general absence of exposures below the capping sandstone. This drill hole was begun approximately 20 feet below the well-cemented caprock. Lithologies below the capping sandstone consist of 30 feet of poorly cemented sandstone underlain by alternating beds of sandstone, siltstone, and claystone interpreted to be entirely Golden Valley Formation. Typical Chadron conglomerates and mudstones are not present in these buttes and the caprock is interpreted to be part of the Golden Valley Formation. The micaceous sandstones and siltstones beneath the capping sandstone are typical of the Golden Valley Formation elsewhere (Figure 76). No fossils have been reported from Davis Buttes and none were found during this study.

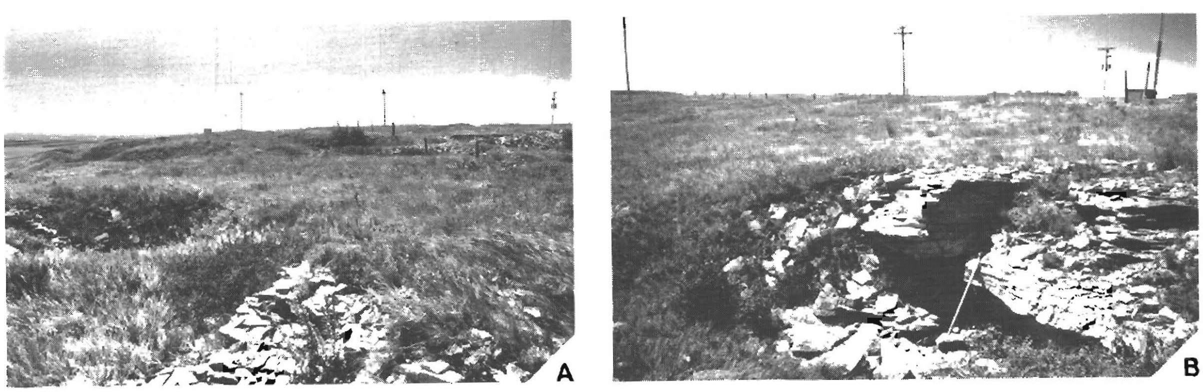


Figure 74. Capping sandstone at Davis Buttes. **A** and **B**, exposures of flaggy to massive capping sandstone (140-96-24 sese).

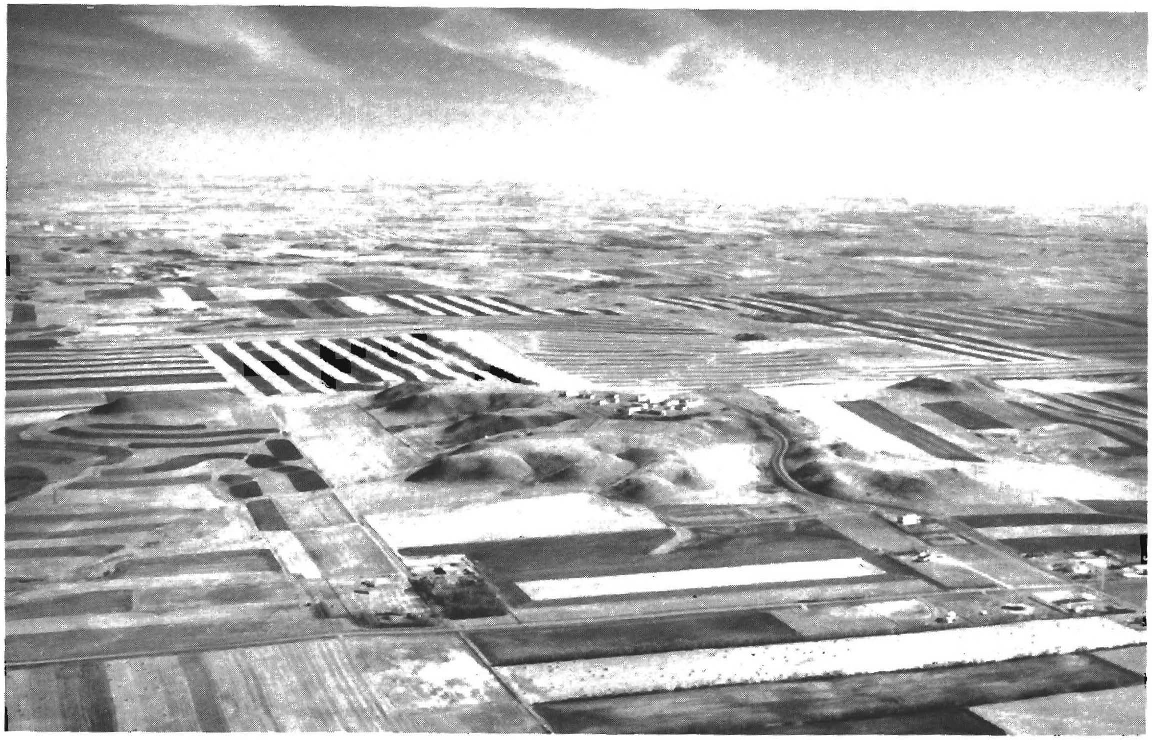
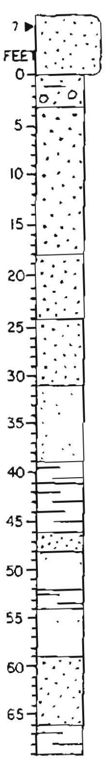


Figure 75. Aerial photograph of Davis Buttes. View is to the southeast.



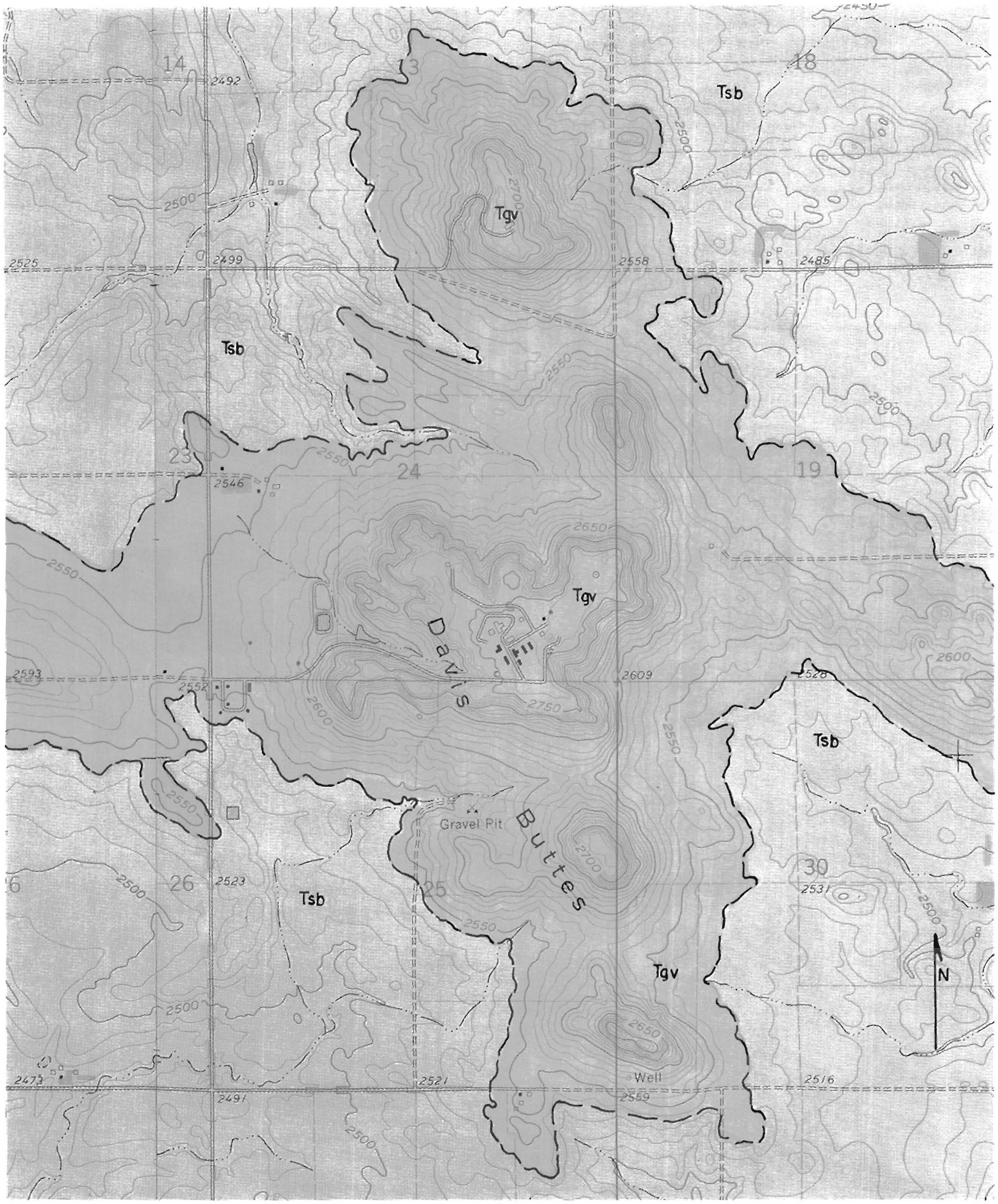
DAVIS BUTTES
Stark County

T140N R96W SW/NE/SE Section 24
Elevation 2740 feet

GOLDEN VALLEY FORMATION
Camels Butte Member

Outcrop	Sandstone, pink, yellow, and brown (w), white-light yellow/brown (f), fine to medium grained, medium grained mica flakes, moderately to very well cemented, flaggy to massive.
Drill Hole	
Feet	
0-3	Colluvium, lag, sandstone blocks and soil.
3-18	Sandstone, white gray to green/gray, medium to fine grained quartz and rock fragments, subrounded to subangular, poorly cemented, micaceous, limonite stained.
18-24	Sandstone, gray to white, fine grained quartz, micaceous, extremely well cemented.
24-31	Sandstone, medium brown to reddish brown, medium to fine grained quartz, poorly cemented, iron oxide stained.
31-39	Siltstone, light gray, clayey, iron oxide stained.
39-41	Claystone, gray to purple, silty, iron oxide stained.
41-46	Claystone, light gray to green, silty, micaceous, contains black mineral grains at base.
46-48	Sandstone, light gray/green to yellow/brown, very fine to fine grained, micaceous poorly cemented.
48-52	Siltstone, light gray, clayey, contains lignite fragments.
52-54	Claystone, gray to yellow/brown, clean.
54-59	Siltstone, gray to light brown, micaceous, iron oxide stained.
59-66	Sandstone, yellow/brown, very fine to fine grained, micaceous, iron oxide stained.
66-69	Claystone, gray, clean, contains iron oxide concretionary layers.

Figure 76. Measured section and drill hole lithology at Davis Buttes.



Tgv Golden Valley Formation Tsb Sentinel Butte Formation

——— Lithostratigraphic contact. – – – Contact approximated. Contour interval is 10 feet. Scale: 2.6 inches = 1 mile.

Figure 77. Geologic map of Davis Buttes (U.S. Geological Survey Davis Buttes and Dickinson North Quadrangles).

CARBONATE-CAPPED BUTTES OF EASTERN STARK AND EASTERN HETTINGER COUNTIES

Introduction

Several limestone-capped buttes in eastern Stark and eastern Hettinger Counties are grouped together because of lithologic similarity, general proximity, and relatively small size (Plates 6 and 7). Babcock and Clapp (1906) noted that part of this area was locally referred to as "limestone ridge". Several of these buttes, Young Man's and Antelope Buttes, and "a large area of low flat-topped buttes south and southeast of Lefor, in southern Stark County", were first identified as containing White River rocks by Seager et al. (1942, p. 1416). These buttes were the subject of geologic investigations during the 1940s and 1950s to determine the economic potential of limestone beds near the tops of these buttes as sources of portland cement (Powers, 1945; Thorsteinsson, 1949; Hansen, 1953). Hansen's (1953) study was the most detailed and includes data from measured geologic sections and numerous boreholes drilled on these buttes.

Young Man's Butte

Young Man's Butte is a small conical-shaped butte located 2 miles west and 1 mile north of the Antelope interchange on U.S. Interstate 94, in the NE¼SE¼NE¼ section 11 and NW¼SW¼NW¼ section 12 (T139N R92W), Stark County (Plate 6). Young Man's Butte was named for the lone survivor of a party of 106 Crow Indians who were surrounded and killed by the Sioux for trespassing in their hunting grounds. Legend has it, that a young man struggled to the top of the butte and stabbed himself to death, while singing his death song, rather than risk capture (Williams, 1966). Young Man's Butte is the farthest north occurrence of these carbonate-capped buttes. The butte rises 100 feet above the surrounding countryside and its top has an areal extent of approximately 3 acres. Outcrops are fair to poor along the south-facing slope. A geologic section was measured along the scarp of a slump on the south face. The Golden Valley Formation comprises the middle portion of the butte. Both the base of the butte and the surrounding area are comprised of the Sentinel Butte Formation (Figure 78). Discussion of Chadron caprock at Young Man's and the other buttes will be deferred until later in this chapter.

Custer Lookout

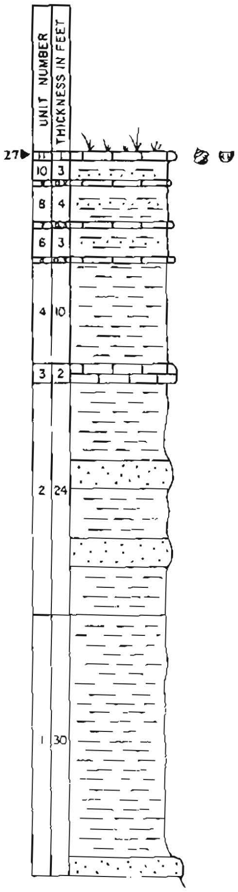
Custer Lookout (referred to as Antelope Butte by Hansen, 1953) is a small, southeast-trending, elliptical shaped butte located 1.5 miles east and 0.5 miles south of the Antelope Interchange on U.S. Interstate 94, in the SE¼SE¼SW¼ section 16 (T139N R91W), Stark County (Plate 6). There is 205 feet of relief on the butte and its top covers an area of 4.5 acres. Outcrops are poor to nonexistent. A geologic section was measured along road cuts on the north side of the butte supplemented by considerable digging on the southeast face. The Golden Valley Formation comprises the lower 3/4 of Custer Lookout. The Bear Den Member is exposed on a small knoll northwest of this butte (Figure 78).

Long Butte

Long Butte is a medium sized, flat-topped butte located one mile southeast of Custer Lookout in the northeast quarter of section 22 and the western third of the northwest quarter of section 23 (T139N R91W), Stark County (Plate 6). There is 180 feet of relief on the butte and the areal extent of its top is approximately 50 acres. Outcrops are poor to nonexistent below the carbonate cap rock except along the southwest corner of the butte where a geologic section was measured. A 43-foot deep hole was cored at the top in SE¼NE¼NE¼ section 22. This hole was drilled in an old test pit, excavated to evaluate the economic potential of the carbonate caprock, because the auger could not penetrate the three-foot-thick carbonate caprock. In this drill hole the unconformity at the base of the White River Group (Chadron) was encountered at an elevation of 2640 feet. The base of the Chadron is also exposed in outcrop at this butte (Figure 78). The lower part of the butte consists of the Golden Valley Formation.

Lefor Butte

Lefor Butte (referred to as Long Butte by Hansen, 1953) is a long, narrow northwest-trending butte located 2.5 miles west of the town of Lefor, Stark County (Plate 7). The butte and nearby town were named for Adam A. Lefor who, along with his family, immigrated to this area from Hungary in 1893 (Williams, 1966). The butte averages only 1000 feet



YOUNG MAN'S BUTTE T139N R92W SE/SE/NE 11
Stark County Elevation: 2747 feet

CHADRON FORMATION
South Heart Member

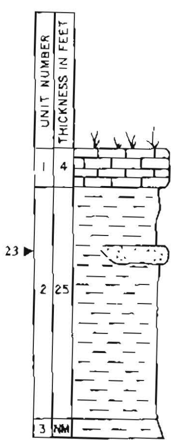
Unit 11: Limestone, buff to white (f) to grey-white (w), highly fractured.
Unit 10: Mudstone, olive-green (f) to medium brown (w), contains sand and silt zones.
Unit 9: Limestone, buff to white (f) to grey-white (w), highly fractured.
Unit 8: Mudstone, olive-green (f) to medium brown (w), contains sand and silt zones.
Unit 7: Limestone, buff to white (f) to grey-white (w), highly fractured.
Unit 6: Mudstone, olive-green (f) to medium-brown (w), contains sand zones.
Unit 5: Limestone, buff to white (f) to grey-white (w), very fractured.
Unit 4: Claystone, olive green (f) to brown (w), very blocky.
Unit 3: Limestone, buff (f) to grey-white (w).

Chalky Buttes Member

Unit 2: Claystone, light olive-green (f) to brown (w), blocky, contains 2- to 3-foot thick sand lenses.

GOLDEN VALLEY FORMATION
Camels Butte Member

Unit 1: Claystone, grey-blue (f) to light grey-brown (w), iron oxide stained, micaceous, contains cross-bedded sandstone lens.



CUSTER LOOKOUT T139N R91W SE/SE/SW SEC 22
Stark County Elevation: 2705 feet

CHADRON FORMATION
South Heart Member

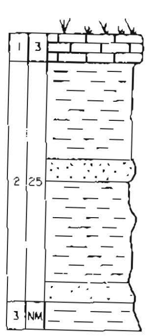
Unit 1: Limestone, white to buff (f) to grey-white (w), flaggy, contains thin green clay beds (1 inch) contains chert nodules.

Chalky Buttes Member

Unit 2: Claystone, olive green (f) to green-white (w), blocky, contains at least one 2-foot sand lens.

GOLDEN VALLEY FORMATION
Camels Butte Member

Unit 3: Claystone, grey-brown (f) to yellow-brown (w), micaceous, iron oxide staining, gypsum.



LONG BUTTE T139N R91W SE/NE/NE Section 22
Stark County Elevation 2660 feet

CHADRON FORMATION

Feet — **South Heart Member**

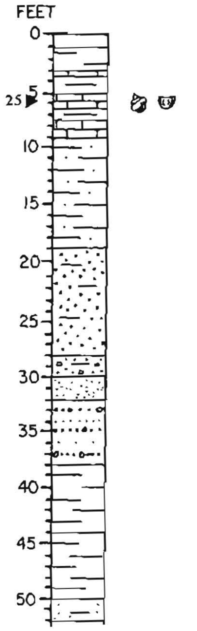
0-3 Carbonate layer.
3-11 Claystone, green, silty.

Chalky Buttes Member

11-17 Sandstone, yellow/green, fine to coarse grained quartz and rock fragments, subrounded grains, clayey, poorly indurated, coarsening downward, contains subrounded quartz pebbles.

GOLDEN VALLEY FORMATION
Camels Butte Member

17-20 Siltstone, light green, clayey.
20-21 Claystone, light green to medium green, silty, silt lenses, iron oxide concretion lens.
21-23 Sandstone, gray, very fine grained, silty, micaceous.
23-30 Claystone, gray to gray/brown, silty, yellow precipitate at the top, iron oxide concretionary layer.
30-36 Claystone, gray to brown, clean to silty, iron oxide stained, contains two inch purple clay layer at 30 feet.
36-39 Claystone, purple, clean to silty.
39-42 Claystone, green to purple, red (iron oxide) precipitate.
42-43.5 Claystone, dark gray to brown, carbonaceous, contains lignite stringers.



LEFOR BUTTE
Stark County

T137N R95W SE/NW/SW Section 12
Elevation 2840 feet

CHADRON FORMATION
South Heart Member

Measured Section

0-1 Topsoil
1-3 Claystone, gray to green, blocky, highly weathered.
3-3.5 Carbonate layer.
3.5-5 Claystone, gray to green, highly weathered.
5-6.5 Carbonate layer.
6.5-7.5 Claystone, light green (w) to dark green (f), blocky.
7.5-9 Carbonate layer.
9-19 Claystone, light green to buff (w), dark green to buff (f), silty. Contains two 3 inch white clay layers.

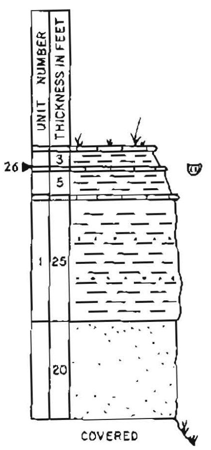
Drill Hole

Chalky Buttes Member

0-8 Sandstone, gray/green, clayey, subrounded quartz, grains.
8-9 Sandstone, gray/green, fine grained, quartz, rounded, iron oxide stain.
9-11 Sandstone, gray/green to yellow/green, fine to coarse quartz, pebbles, clayey.
11-11.5 Sandstone, yellow to yellow/green, very fine to coarse, pebbles, quartz and rock fragments, clayey.
11.5-13 Siltstone, gray, sandy, gray and yellow clay lenses.
13-18.5 Siltstone and Sandstone, interbedded, silt is gray to yellow, clayey; sand is gray, silty, fine to coarse grained quartz, contains quartz and rock fragments, clayey.
18.5-19 Sandstone, yellow/green, fine to coarse grained, quartz and rock fragments.
(37.5-38)

GOLDEN VALLEY FORMATION

19-19.2 Limonite Concretion, yellow/brown to purple.
19.2-25 Claystone, gray to gray/green going to dark gray at base, silty to clean, iron oxide stained. Thin organic horizon at base.
23-31 Claystone, purple/gray to gray, clean, greasy, limonite stained.
31-33 Siltstone, gray to brown, very fine grained sand and clay lenses, micaceous, iron oxide stained.
(50-52)



NORTH STAR (Shepard Butte)
Hettinger County

T135N R91W NE SEC 28
Elevation: 2820 feet

CHADRON FORMATION
South Heart Member

Units 2-4: Carbonate lenses and claystone.

Chalky Buttes Member

Unit 1: Mudstone, olive green (f) to yellow/green to pink (w), contains lenses of coarse quartz grains.
Note: No organics at contact.

GOLDEN VALLEY FORMATION
Bear Den Member

Siltstone and sandstone, white, micaceous, iron oxide stained, spherical iron concretions.

Figure 78. Measured geologic sections and drill hole lithologies at Young Man's, Custer Lookout, Long, Lefor, and North Star Buttes.

in width but extends for 4.6 miles, covering approximately 390 acres in portions of sections 12, 13, and 24 (T137N R95W), and 19, 29, 30, and 32 (T137N R94W). Lefor Butte rises approximately 100 feet from its base to top. Outcrops are fair to poor along the butte. A geologic section was measured along the face of a rock quarry in section 12 (NW¼NE¼SW¼). A 33-foot hole was cored at the base of the quarry in section 12 (Figure 78).

Schultz Butte

Schultz Butte (although unnamed on the USGS topographic map, this butte was referred to as Schultz Butte by Denson and Gill, 1965) is a small north-trending butte in the NW¼ section 19 (T137N R92W), Stark County (Plate 7). Schultz Butte is the farthest north of three buttes that trend northeast for a distance of 2.5 miles (Figure 79). There is 180 feet of relief on this butte and the areal extent of its top is approximately 9 acres. A geologic section was measured at the southeast corner of the butte where limestone beds of the Chadron Formation are well exposed but the rocks interbedded with the limestones are poorly exposed. The base of the Chadron was not exposed on this butte (Figure 80).

North Lime Hill

North Lime Hill is a small north-trending elliptical butte in the west half of section 30 (T137N R92W), Stark County (Plate 7). There is approximately 250 feet of relief on the butte and the areal extent of its top is approximately 6 acres. Outcrops are poor to nonexistent throughout most of the butte but a geologic section was measured at the southeast corner. The Chadron/Golden Valley contact is exposed in a small gully in this part of the butte (Figures 79, 80).

South Lime Hill

South Lime Hill is a small west-trending elliptical butte in the NW¼SE¼ section 36 (T137N R93W), Stark County (Plate 7). The butte rises 240 feet above the surrounding area and the top of the butte has an areal extent of 15 acres. Outcrops below the carbonate caprock are rare and poor. A geologic section was measured in the southwest corner of South Lime Hill at the only significant outcrop on the butte (Figures 79, 80). The contact between the Chadron and Golden Valley Formations is exposed in the southwest corner of the butte.

Bull Butte

Bull Butte is an east-trending butte that occupies approximately 112 acres in the south half of section 18 (T136N R93W), Hettinger County (Plate 7). There is approximately 200 feet of relief at this butte. Rocks are poorly exposed beneath the carbonate caprock on this butte. A geologic section was measured along the northeast face of the butte (Figures 81, 82).

White Butte, Hettinger County

White Butte (referred to as Cosgrove Butte by Powers (1945) and as Colgrove Butte by Thorsteinsson (1949) and Hansen (1953)) occupies approximately 730 acres and includes portions of sections 8,9, and 15-18 (T136N R93W), Hettinger County (Plate 7). The butte stands approximately 200 feet above the surrounding countryside. White Butte is the name given this butte on U.S. Geological Survey White Butte West Quadrangle; however, the use of another name such as Cosgrove or Colgrove would help to alleviate confusion since there are two other White Buttes in this area (Stark and Slope Counties). Outcrops are generally poor along the sides of the butte. The best section is in the southeast corner of the butte where the Chadron/Golden Valley contact is exposed (NE¼SE¼NE¼ section 16). A 74-foot hole was cored on top of this butte in the NE¼NE¼NW¼ section 17 (Figure 82).

North Star Butte

North Star Butte (referred to as Shepard Butte by Benson (1952) and Stone (1973)) is a very small butte located in the NE¼ section 28 (T135N R91W), Stark County (Plate 6). The butte rises approximately 200 feet above the surrounding countryside and has an areal extent at the top of approximately 6 acres. A geologic section was measured at the only outcrop, other than the capping carbonate beds, at the southwest end of the butte. At that exposure, the Chadron is underlain by white, micaceous sandstones and siltstones that are mapped as the Golden Valley Formation. The unconformity between the Chadron Formation and the Golden Valley Formation is also well exposed in this outcrop (Figures 78, 83e).

Chadron Formation in Carbonate-Capped Buttes

Thirty to eighty-five feet of Chadron Formation is exposed at the tops of these carbonate-capped buttes. The unconformity at the base of the Chadron Formation was mapped at these buttes at elevations ranging from 2,650 to 2,800 feet. This unconformity was recognizable in both outcrop and drill core by a change in color and lithology from the characteristic green and yellow/green sandy mudstones of the Chalky Buttes Member to the browns and blue siltstones, sandstones, and mudstones of the underlying Golden Valley Formation (Figure 83e).

Hansen (1953) suggested the White River (only the Chadron Formation is present in these buttes) could be split into three distinct units in these buttes: a basal sand, a middle clay, and an upper clay and limestone sequence. Hansen's "basal sand" corresponds to the Chalky Butte Member and his "middle clay" and "upper clay and limestone sequence" correspond to the South Heart Member. The base of the Chadron Formation in this area consists of 3 to 50 feet of pebbly, yellow/green clayey sandstone to sandy mudstone (Figure 83d,e). The basal clayey sandstone is a fine-grained facies of the Chalky Buttes Member as typically seen at Chalky Buttes and in the Little Badlands. Quartz latite porphyry pebbles, characteristic of this unit elsewhere, were not found at these buttes; instead, the pebbles are primarily chert. Yellow/orange to white fossil wood, common in the Chalky Buttes Member throughout western North Dakota, was also found in this unit at these buttes. The yellow/green color of these beds and the presence of rounded quartz grains

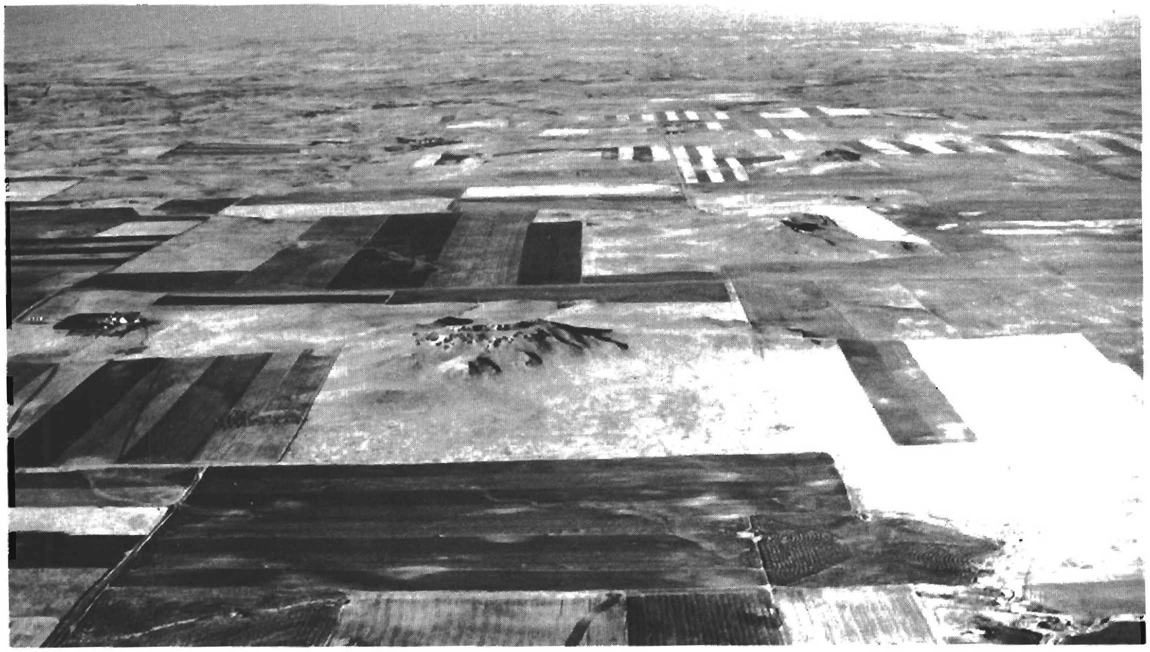
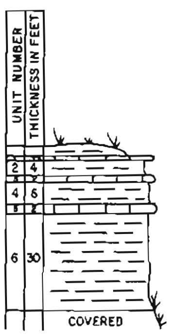


Figure 79. Aerial photograph of South Lime and North Lime Hills and Schultz Butte. View looking to the north, South Lime Hill in the foreground.



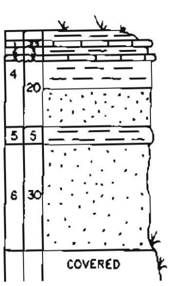
SCHULTZ BUTTE T137N R92W NW SEC 19
Stark County Elevation: 2687 feet

CHADRON FORMATION
South Heart Member

Unit 1: Carbonate, white (w), flaggy.
Unit 2: Claystone, light green to yellow/green.
Unit 3: Carbonate, white (w), flaggy.
Unit 4: Claystone, light green to yellow/green.
Unit 5: Carbonate, white (w), flaggy, poor exposure may be a slump of Unit 3.

Chalky Buttes Member

Unit 6: Claystone, light green to yellow/green (f), blocky. Contact is covered but at approx. 2630 feet.



SOUTH LIME HILL T137N R93W Ctr. E½ SEC 36
Stark County Elevation: 2754 feet

CHADRON FORMATION
South Heart Member

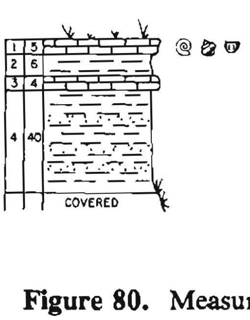
Unit 1: Carbonate, purple/grey (f&w), top 1 foot is massive, base is flaggy.
Unit 2: Claystone, grey (f) to purple/grey (w).
Unit 3: Carbonate, light grey (f) to white (w), top foot is massive, the base is flaggy.

Chalky Buttes Member

Unit 4: Mudstone, yellow/green (f) to light green (w), sandy, sand is fine to medium grained quartz, some quartz pebbles.

GOLDEN VALLEY FORMATION
Bear Den Member

Siltstone, gray to white (w&f), micaceous.



NORTH LIME HILL T137N R92 W E½ SEC 30
Stark County Elevation: 2739 feet

CHADRON FORMATION
South Heart Member

Unit 1: Carbonate, white (w).
Unit 2: Claystone, green/yellow to light green (f), blocky.
Unit 3: Carbonate, pink gray (f) to white (w).

Chalky Buttes Member

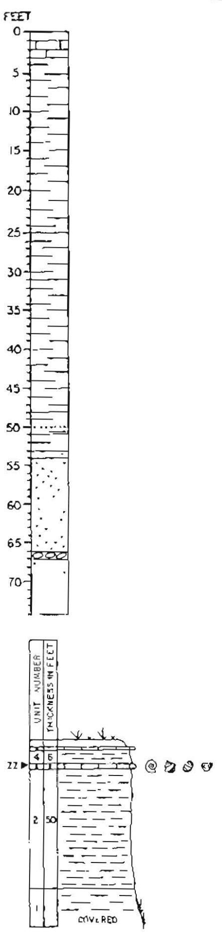
Unit 4: Mudstone, yellow/green (f) to light green (w), sandy, interbedded sand lenses, predominantly sand in basal ½, sand is fine to coarse grained, some quartz pebbles.

GOLDEN VALLEY FORMATION

Unit 5: Claystone, purplish/pink (f) to light gray (w), blocky, micaceous.
Unit 6: Sandstone, buff to brown (F) to buff/yellow (W), fine grained, clayey.

Figure 80. Measured geologic sections at Schultz Butte, South Lime Hill, and North Lime Hill.

Figure 81. Aerial photograph of Bull Butte. View is to the north.



BULL BUTTE — T136N R93W SEC 18
Hettinger County — Elevation: 2748 feet

CHADRON FORMATION
South Heart Member

Unit 5: Carbonate, white, flaggy.
Unit 4: Claystone, olive-green (f) to yellow-green (w), blocky.
Unit 3: Carbonate, buff (f) to white (w), massive to flaggy, fossiliferous, shells.

Chalky Buttes Member (basal 10 feet)

Unit 2: Claystone, green/yellow (f), blocky.

GOLDEN VALLEY FORMATION

Unit 1: Mudstone, red/brown (f), silty, very micaceous.

WHITE BUTTE — T136N R93W NE/NE/NW Section 17
Hettinger County — Elevation 2750 feet

Feet	
0-1	Topsoil
	CHADRON FORMATION
	South Heart Member
1-3	Carbonate
3-25	Claystone, white to dark green, silty, moderately to well indurated, dark gray/green clasts or replacement structures, fractured.
25-31	Claystone, medium brown to green, contains gray/white zones, clean to silty.
31-48	Claystone, gray/brown to yellow/green, clean to silty, some silt zones, interval from 44 to 48 contains black mineral, possibly manganese oxide crystals.
	Chalky Buttes Member
48-51	Mudstone, gray/green to yellow/brown, contains lenses of coarse subangular to subrounded quartz grains.
	GOLDEN VALLEY FORMATION
51-53	Claystone, blue, clean.
53-54	Siltstone, brown to blue (mottled), clayey, silt is brown, and the clay is blue.
54-66	Sandstone, yellow/brown to light brown, very fine to coarse grained quartz, subrounded, poorly cemented, coarsens downward, contains lenses of blue sand.
66-67	Rip-up clasts, blue sand clasts in coarse brown sand matrix.
67-74	Sandstone, gray/blue, very fine to fine grained, silty.

Figure 82. Measured geologic section at Bull Butte and drill hole lithologies at White Butte.

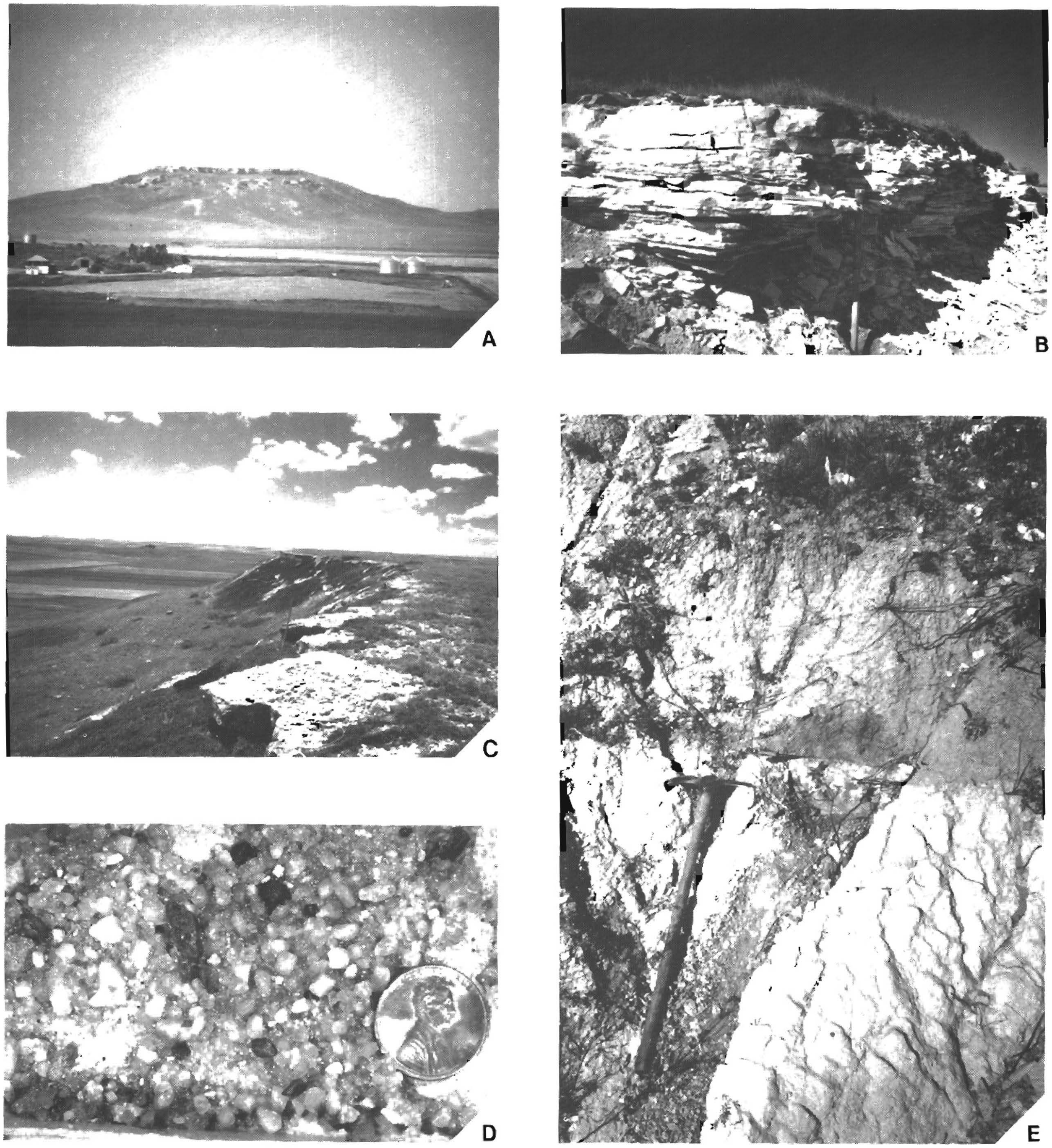


Figure 83. Exposures and lithologies of the Chadron Formation at the carbonate-capped buttes of eastern Stark and Hettinger Counties. **A**, South Lime Hill, view to the north (137-93-36 nenwse). **B**, carbonate lens (South Heart Member) capping Custer Lookout exposed in roadcut at the top of the butte (139-91-16 sesesw). **C**, carbonate caprock (South Heart Member) on South Lime Hill (139-97-36 nenwse). **D**, coarse grains of quartz and rock fragments from muddy sandstone (Chalky Buttes Member) at Long Butte (139-91-22 swsene). **E**, contact (at knife) between the Chadron and Golden Valley Formations on the west slope of North Star Butte (135-91-28 ne).

in a clay matrix (sandy mudstone) appears to be characteristic of the Chalky Buttes Member in this area. Hansen (1953) identified volcanic glass in the Chadron Formation at these buttes and suggested that ash and sand were deposited together in a fluvial setting. He speculated that the alteration of the volcanic glass to bentonite changed this unit from a tuffaceous sandstone to a clayey sandstone or sandy mudstone. This would explain the presence of pebbles and coarse to medium-sized sand grains in a claystone matrix.

Hansen's "middle clay" (corresponds with the lower part of the South Heart Member) varies from 10 to 40 feet in thickness. The claystone is generally light to dark green, smectitic, noncalcareous to slightly calcareous, and although poorly exposed, exhibits a faint popcorn texture on outcrop surfaces.

The upper part of the South Heart Member present at these buttes consists of calcareous claystones interbedded with lenticular limestone beds. These claystones are smectitic and similar in appearance to the underlying claystones except that they are generally calcareous. There are, on the average, two limestone beds at a given site although there may be as many as six (Figures 83a-c, 84). These limestone beds are generally 1 to 2 feet thick, although beds as thick as 5 feet have been observed. They are generally bright white to gray on weathered surfaces and light tan to gray on fresh surfaces. These limestones contain brown chert nodules that generally comprise less than 5 percent of the bed but may comprise as much as fifty percent. Hansen's (1953) geologic cross-section of these buttes shows that the limestone beds are lenticular and can not generally be traced laterally across the buttes.

Paleontology

The only previous report of fossils from these carbonate-capped buttes was by Hansen (1953). He documented the occurrence of several species of freshwater snails in the carbonates of Lefor and White (Hettinger Co.) Buttes (Appendix C). In addition to freshwater snails, fossils of terrestrial snails (pupillids), charophyte oogonia, ostracods, and fish were found in the carbonates of these buttes during this study (Appendix C). None of these fossils appear to be of biochronologic significance.

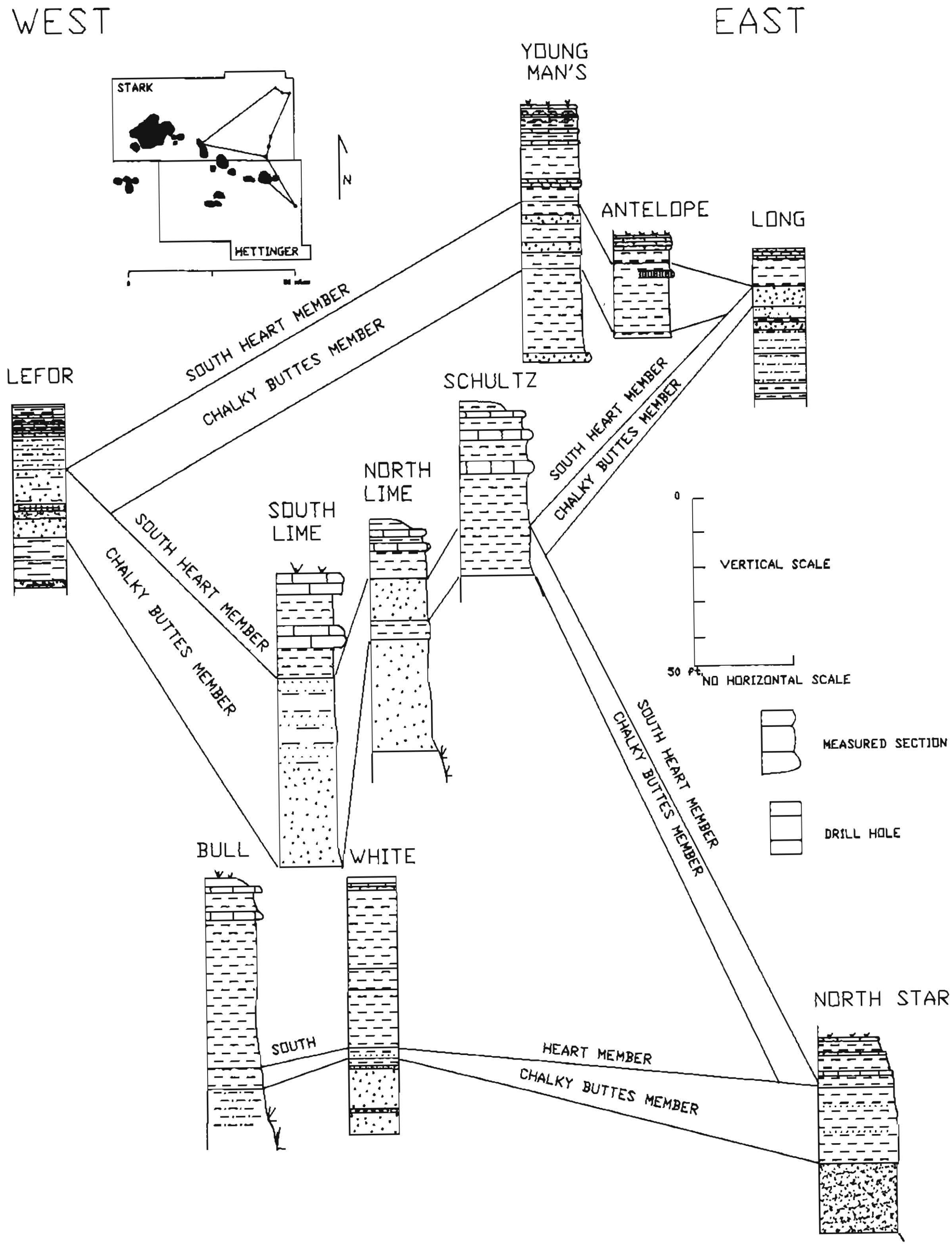


Figure 84. Geologic fence-diagram of the buttes in eastern Stark and Hettinger Counties.

COFFIN BUTTES

Introduction

Coffin Buttes represent the farthest east occurrence of White River and Arikaree rocks in North Dakota. Coffin Buttes are comprised of a series of three buttes, the largest (West Coffin) is located one mile west of the other two (North and South Coffin) (Figures 85-87). Denson and Gill (1965) measured a section on South Coffin Butte and identified the Chadron and Arikaree Formations. Stone (1973) identified the Chadron, Brule, and Arikaree (his "Killdeer formation") Formations at these buttes. Although Stone's section is listed as coming from West Coffin Butte, it is likely that it came from South Coffin Butte.

West Coffin Butte is a small, north-trending butte in the SW¼ section 34 (T132N R90W) and the NW¼ section 3 (T131N R90W), Hettinger County (Figure 87). The butte rises 200 feet above the surrounding countryside, and the areal extent of the top of the butte is approximately 50 acres. West Coffin is capped by a limestone bed (Figure 88a). Outcrops below this limestone are poor.

North Coffin Butte is a small, north-trending elliptical butte located in the SE¼NW¼ section 2 (T132N R90W), Hettinger County (Figure 87). The butte rises 250 feet above the surrounding countryside and has an areal extent at the top of 10 acres. North Coffin Butte is 60 feet higher than West Coffin Butte and is capped by sandstone. A geologic section was measured at the only outcrop on the south side of the butte.

South Coffin Butte is the smallest of the three buttes and is located 1000 feet southwest of North Coffin Butte in the NE¼SW¼ section 2 (T131N R90W), Hettinger County (Figure 87). The butte top has an areal extent of approximately 5 acres. South Coffin Butte is also capped by sandstone and contains the best rock exposures of the three buttes. A geologic section was measured along the northeast face of the butte. North and South Coffin Buttes contain the thickest accumulation of White River sedimentary rocks east of the Little Badlands.

A 43-foot hole was cored on a small knoll 500 feet east of South Coffin Buttes to determine the elevation of the base of the Chadron Formation. The basal contact of the Chadron was identified in this core at an elevation of 2,671 feet (Figure 88c).

Fort Union Group

The Chadron Formation unconformably overlies the Bullion Creek Formation in this area. The Bullion Creek Formation is poorly exposed around the buttes, but consists of alternating beds of sandstone, siltstone, mudstone, claystone, and lignite. The unconformity is marked by heavy iron oxide staining and noticeable fracturing of the first six inches of Bullion Creek claystone beneath the contact (Figure 88c).

Chadron Formation

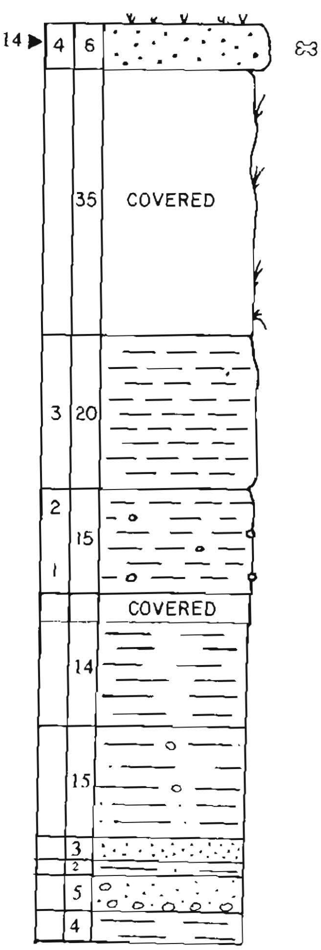
The Chadron Formation is at least 40 feet thick at North and South Coffin Buttes (Figure 86). The Chalky Buttes Member is 25 feet thick and consists of approximately 10 feet of pebbly sandstone and pebbly, sandy mudstone overlain by 15 feet of gray/green to yellow/brown sandy mudstone. The pebbles are subangular to subrounded and up to 4 inches in their largest dimension. They consist, in part, of quartz latite porphyries, quartz, and fossil wood (Figure 88d). These sandstones and mudstones are similar to lithologies observed in the Chalky Buttes Member in both the Little Badlands and Chalky Buttes. The Chalky Buttes Member is overlain at this site by 15 feet of gray/green smectitic claystone (South Heart Member). Lenticular limestone beds are present in the upper portion of this claystone. These limestone beds correlate with the thicker limestone bed that caps West Coffin Butte.

Brule Formation

The Brule Formation at Coffin Buttes consists of at least 35 feet of pink to gray/green silty mudstone and claystone (Figure 86). These rocks are interpreted to be part of the Brule Formation based on their lithology, color, the presence of silicious nodules, and the absence of popcorn surface texture characteristic of the underlying Chadron Formation.

Coffin Buttes are the only localities, east of the Little Badlands, where Brule Formation mudstones occur above thick carbonates. The presence of Brule and possibly Arikaree strata above the carbonate caprock on West Coffin Butte is further evidence that the lower units are part of the Chadron Formation.

Figure 85. Coffin Buttes, view is to the east.



SOUTH COFFIN BUTTE — T131N R90W SEC 2
Grant County — Elevation: 2780 feet

ARIKAREE FORMATION

Unit 4: Sandstone, pink to grey/green (w) grey (f), medium to fine grained quartz and rock fragments, moderately to well cemented, some clay pebble lenses, massive at base, flaggy at top, fossiliferous.

BRULE FORMATION

Unit 3: Claystone, fatigue green to brown (f), to grey/green (w), blocky.

CHADRON FORMATION

South Heart Member

Unit 2: Claystone, grey-buff (f) to pink white (w), contains silicious nodules, blocky.

Drill Hole

Feet

0-1 Soil.

CHADRON FORMATION

South Heart Member

1-14 Claystone, gray/green, blocky, greasy.

Chalky Buttes Member

14-29 Mudstone, gray/green, silty and sandy, contains very fine grained sand lenses from 23-23.5 feet.

29-32 Sandstone, yellow/brown, very fine to fine grained quartz and rock fragments, poorly cemented.

32-34 Mudstone, light green, sandy to silty, pebbly, blocky, greasy.

34-39 Sandstone, light yellow/brown, medium to coarse grained quartz and rock fragments, subrounded to subangular, pebbly.

BULLION CREEK FORMATION

39-43 Claystone, green/gray, iron oxide stained-especially at top of unit, first 6 inches very fractured, contains numerous fossil plant fragments.

Figure 86. Measured geologic section at South Coffin Butte.

Ta Arikaree Formation Tb Brule Formation Tc Chadron Formation Tbc Bullion Creek Formation

—— Lithostratigraphic contact. – – – Contact approximated. ······ Contact inferred. Contour interval is 10 feet. Scale: 2.6 inches = 1 mile.

Figure 87. Geologic map of Coffin Buttes (U.S. Geological Survey Coffin Buttes Quadrangle).

Arikaree Formation

North and South Coffin Buttes are capped by 6 to 15 feet of sandstone (Figures 86, 88b). This sandstone is fine to medium grained, massive near the base and cross-bedded near the top. These capping sandstones are tentatively assigned to the Arikaree Formation, although similar channel sandstones have been observed in the Brule Formation.

Paleontology

Only a few vertebrate fossil fragments, provisionally identified as rhinoceros, were found in the sandstones capping North and South Coffin Buttes. None of these fossils are biochronologically diagnostic. No other fossils have been previously reported from these buttes.

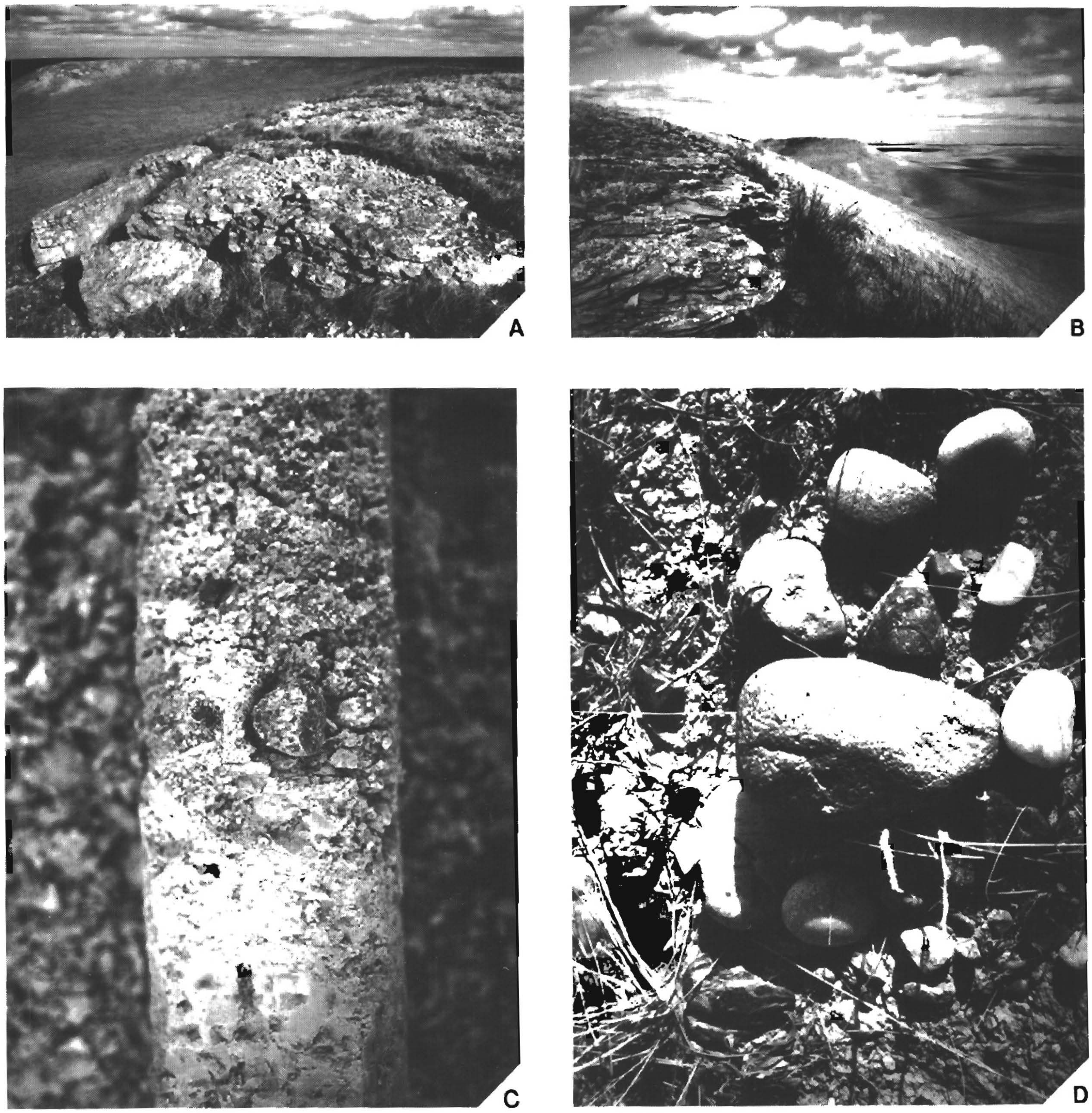


Figure 88. Exposures and lithologies at Coffin Buttes. A, carbonate caprock (South Heart Member) at West Coffin Butte (132-90-34 swsesw). B, flaggy, sandstone caprock (Arikaree Formation) at South Coffin Butte (131-90-2 nwnesw). C, 3 inch diameter core showing the unconformable contact between the Chadron and Bullion Creek Formations (131-90-2 senesw). D, pebbles of volcanic porphyries, rock fragments, and quartz from the Chalky Buttes Member at South Coffin Butte (131-90-2 nwnesw).

PETROGRAPHY

Sandstone Petrography

Lithified sandstone and carbonate samples of this study were examined petrographically as part of the overall effort to characterize these middle Cenozoic strata (Figure 89). A special aim was to determine if petrographic characteristics of the sandstones could be used to distinguish formations, and to serve as an aid in determining stratigraphic levels within the strata being considered.

The sandstones examined are all texturally and mineralogically immature to submature, with a large proportion of unstable components present and with considerable differences in the effects of diagenesis observable between many samples. Most samples are grain-supported with fine grained matrix present in only a few samples. The average grain size encountered in most thin sections is upper fine to lower medium sand (177-350 µm). Descriptive data were collected from all thin sections, but point counts were made only from those samples with clear discernability between framework grains and matrix, and between primary and secondary constituents (approximately 50% of the thin sections). This was done to insure as much as possible a reliable basis for comparing the results from different samples.

Sandstone point count data from fourteen butte localities are reported in Table 1. The data are arranged in Table 1 according to the formation interpreted to contain each sample. Particularly noticeable in each thin section is the proportion of volcanic rock fragments. Samples were generally found to have either a high or a low content of such rock fragments. Thus it appears that these sandstone samples may be divided into two groups based, in part, on their proportion of volcanic rock fragments (Figure 90). Other petrographic characteristics also suggest these same two groups. First, the quartz to total feldspar ratio also differs between these groups and second, the cementation of the two groups commonly differs. Such differences are attributable to changes in provenance and to changes in burial setting and paleoclimatic conditions, insofar as these affect groundwater chemistry. It is reasonable to expect such changes with the passage of geologic time, and the two sandstone petrographic groups do correspond to vertical separation in the geologic column. That is, one group occurs within what is interpreted as Arikaree, Brule, or Chadron strata, and the other group occurs within more problematic rocks known to occur lower in the section, i.e., Golden Valley or Sentinel Butte Formation strata (Figure 90).

Strata mapped as Brule or Arikaree contain sandstones with volcanic rock fragment contents averaging 26%, with quartz to total feldspar ratios ranging from 0.87 to 3.15 and averaging 1.6 (Table 1). Except for sandstones near the top of White Butte, Slope County, these sandstones are nearly all cemented by forms of quartz, ranging from opal to fibrous or mosaic chalcedony to microcrystalline quartz (Figure 89c,d,f). The sandstones from White Butte differ only in being cemented by poikilotopic calcite. The Chadron sandstones from North and South Whetstone Buttes are petrographically very similar to Arikaree and Brule Formation sandstones.

The massive sandstones capping Black (Slope Co.), Square, Sentinel, and Bullion Buttes, mapped in this report as either the Golden Valley or Sentinel Butte Formations, normally either lack or contain a very low proportion of volcanic rock fragments, and have a quartz to total feldspar ratio averaging 3.84 (Table 1). These sandstones are normally cemented by zeolites, and occasionally by kaolinite; silica (quartz) cement is absent (Figure 89e,g,h).

Sandstone thin section interpretations support other petrographic data suggesting Fort Union sandstones are deficient in volcanic rock fragments compared to White River and Arikaree sandstones. Sato and Denson (1967) were also able to group the Cenozoic strata in this area based on petrology. They differentiated between the Fort Union, Golden Valley, White River, and Arikaree strata in the Williston Basin based on nonopaque heavy mineral content and determined that the percentage of volcanic minerals averaged from 2%, 13%, 67%, and 84% in these strata, respectively.

Clay Mineralogy

Clay samples from drill holes were analyzed by x-ray diffraction to characterize the clay mineralogy of White River Group rocks in North Dakota and to assist in determining the contact with the underlying, locally kaolinite-rich Golden Valley Formation, where present. An additional purpose for analyzing these claystones was to determine if significant differences in clay mineralogy exist between the Fort Union and White River Groups. Sodium montmorillonite was the only clay mineral detected in the 24 samples from 6 drill holes. It does not appear that clay mineralogy can be used to distinguish between Fort Union and White River claystones.

TABLE 1 -- PETROGRAPHIC ANALYSIS OF CENOZOIC SANDSTONES											
Fm	TS	Q	Feld	Mica	MRF	PRF	SRF	VRF	URF	Other	Location
A	46	23	23	0	0	5	0	36	12	1	West Rainy
A	31	39	16	1	1	1	0	14	28	1	West Rainy
A	32	28	22	0	0	4	0	22	23	1	West Rainy
A	47	30	12	1	1	11	0	33	11	1	West Rainy
A	33	29	21	0	0	4	0	17	29	0	West Rainy
A	35	38	16	0	0	3	0	18	23	3	West Rainy
A	37	33	18	0	0	4	6	14	24	1	West Rainy
A	63	25	26	0	1	6	0	35	7	0	East Rainy
A	59	41	13	0	1	6	0	18	16	0	Black Butte, Hett.
A	60	32	24	0	0	1	0	31	10	2	Black Butte, Hett.
A	14	26	18	0	3	11	4	33	7	0	Coffin Buttes
A	8	36	19	0	3	10	2	28	0	2	Obritsch Ranch
A	34	32	15	1	1	1	0	21	29	0	Obritsch Ranch
A	36	34	12	2	0	5	0	21	24	0	Obritsch Ranch
A	38	38	18	0	1	12	0	15	14	2	Obritsch Ranch
A	39	29	19	0	0	6	0	17	22	7	Obritsch Ranch
A	41	29	20	0	2	11	0	29	9	0	Obritsch Ranch
A	74	32	21	0	0	10	1	29	6	2	White Butte, S
A	69	22	12	1	1	15	3	35	7	4	White Butte, S
B	42	20	20	1	1	11	0	31	14	1	West Rainy
B	44	28	25	0	0	6	0	24	13	4	West Rainy
B	45	20	23	0	0	11	0	30	14	1	West Rainy
B	52	20	22	1	0	6	0	28	19	3	West Rainy
B	53	23	23	0	0	3	3	35	11	2	West Rainy
B	30	30	15	1	0	1	0	20	29	1	West Rainy
B	62	23	25	0	2	8	3	31	8	0	East Rainy
C	18	27	25	2	1	6	4	25	0	10	S. Whetstone
C	77	23	22	4	0	8	3	36	5	0	N. Whetstone
GV	7	42	17	0	12	15	8	2	10	1	David Butte
GV	19	49	12	1	6	14	5	0	12	2	Stony Butte
GV	50	62	21	0	0	1	0	0	8	7	Bullion Butte
GV	54	49	35	0	0	7	0	2	2	5	Bullion Butte
GV	58	66	25	0	0	1	0	0	3	5	Bullion Butte
GV	70	46	8	0	10	14	10	0	10	2	East Rainy Butte
SB	17	57	16	0	2	5	10	4	0	7	Wolf Butte
SB	78	71	9	0	0	1	2	6	11	0	Wolf Butte
SB	64	29	10	0	8	30	5	0	18	0	Black Butte, Slope

Q=quartz, F=total feldspar, MRF=metamorphic rock fragments, PRF=plutonic rock fragments, VRF=volcanic rock fragments, SRF=sedimentary rock fragments, URF=rock fragments of unknown origin
A=Arikaree Formation; B=Brule Formation; C=Chadron Formation; GV=Golden Valley Formation; SB=Sentinel Butte Formation.

Tuffs

Eleven tuff samples were collected during this study, with the aim of attempting to obtain absolute age data and to derive chemical fingerprints of potential value in correlating the White River and Arikaree tuffs and correlating North Dakota tuffs with strata of other regions. Tuffs were collected from the Fitterer and Obritsch ranch sites in the Little Badlands of Stark County and from the burrowed marker unit in the Killdeer Mountains.

Tuff collected from the Obritsch ranch occurs as a two- to three-foot thick white "siltstone" near the base of bedrock exposures (Figure 34). It is somewhat more resistant to erosion than the overlying materials and so forms a slight ledge (Figure 37o,p). The tuff exposed on the Fitterer ranch also occurs as a 2-foot thick white layer near the base of bedrock exposures (Figure 36). Although separated by a distance of 3 miles, the similarity of lithologies and stratigraphic position of these tuffs suggests they are correlative.

The burrowed marker unit in the Killdeer Mountains is a seventeen-foot thick sequence of alternating indurated and friable layers of tuff or tuffite (Figure 91). Secondary poikilotopic calcite serves as cement in the indurated portions of this unit. Erosion of the friable layers has given the unit a jagged or "comb"-like profile (Figure 13e). Prominent trace fossil burrows are abundant throughout this unit. The burrowed marker unit forms a prominent ledge particularly along the south and southeast sides of South Killdeer Mountain (Figure 13c-g).

Petrologic Evaluation of Tuffs from the Little Badlands

Laboratory evaluations of collected tuff samples were conducted to assess the state of preservation and alteration of glassy components, and to attempt to identify authigenic phenocryst and detritally admixed components. Tuff samples from the Fitterer and Obritsch ranch sites are nearly vitric tuffs, with very minor non-glass components, except for calcite cement. Microscope observations suggest that the glass grains are all coated by secondary opaline silica, but scanning electron microscopy reveals that the grains are etched rather than coated. The etch pits on these glass grains have coalesced to the extent that isolated "islands" of the original surface of the grain are left behind, giving the grains a rough appearance as if non-uniformly coated. Although, the chemical impact of etching on these glass grains is presently not known, it is anticipated that the remaining glass material retains the same proportions of elements that were present prior to dissolution of grain surfaces.

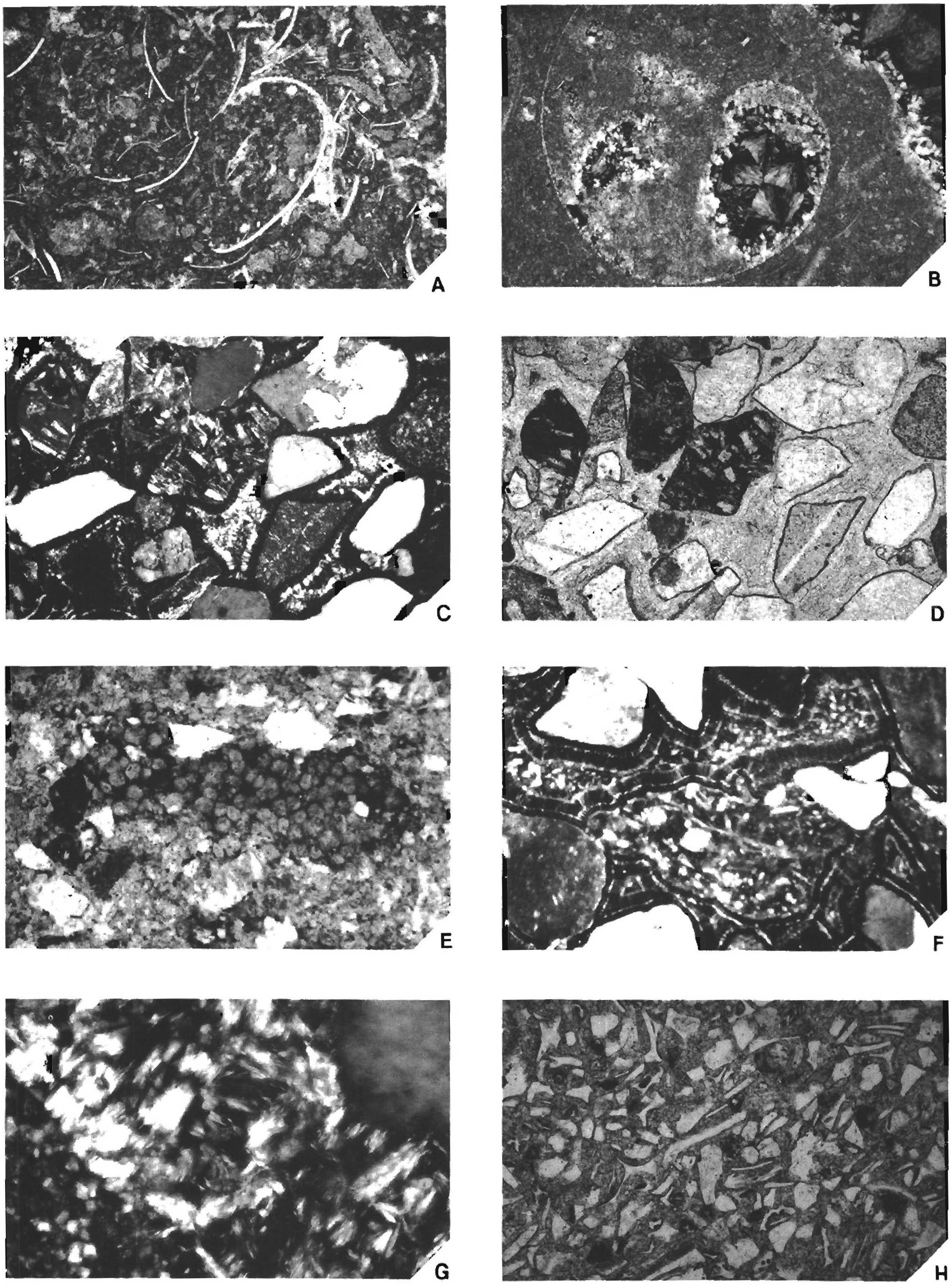
Petrologic Evaluation of Tuffs from the Killdeer Mountains

Killdeer tuffs likely accumulated in a lacustrine setting through both direct airfall contribution and the reworking of more widespread ash mantles. Glass shards comprise from 50 to 77 percent of each tuff sample, with volcanic rock fragments, feldspar, quartz, titano-magnetite and other opaque minerals, hornblende, and pyroxene also present in each sample (Figure 92). Detrital admixture may have occurred in Killdeer tuffs, given their thickness (at least 15 feet) and great distance (at least 650 miles) from any possible Oligocene or Miocene volcanic centers. Much of the tuff section probably accumulated in low areas through the transport by wind and running water of more widespread, but thinner, ash mantles.

Epiclastic material may have become mixed into the tuff during the period(s) of ash-mantle rinsing. However, the tuff section is, overall, highly tuffaceous and there may be within the thicker sequence, individual layers that accumulated directly from airfall with little or no epiclastic input. The initial sample (NDGS #3) submitted to the U.S. Geological Survey for fission-track analysis contained a high percentage of glass shards and was obtained from what appears to be the base of the tuff sequence (Figure 91). If the mantle-rinsing scenario is correct, the chosen sample may represent the original airfall contribution to the Killdeer lake, and thus may contain less epiclastic material than overlying layers.

Glass shards comprise 74 percent of sample NDGS #3. Other components, in their order of abundance, include feldspar, quartz, volcanic rock fragments, unidentified rock fragments, opaque minerals, hornblende, and pyroxene. The majority of glass grains are angular, featureless curved plates or roughly equant grains with one or more raised ribs. Lunate or Y-shaped bubble junction shards are also common (Figure 92a). A minor proportion of

Figure 89 (opposite page). Photomicrographs of selected carbonate and sandstone thin sections. **A**, ostracodal silicified biomicrite from the caprock of Lefor Butte, Chadron Formation (thin section #25, 60x). **B**, ostracodal, gastropodal silicified biomicrite from the caprock of Bull Butte, Chadron Formation (thin section #22, 60x). **C**, capping sandstone from Black Butte, Hettinger County (thin section #59, 60x). Note prevalence of volcanic rock fragments and presence of pore-lining opal cement grading outward to opal CT or fibrous chalcedony followed by micromosaic chalcedony or microcrystalline quartz. **D**, plane polarized view of (C). **E**, capping sandstone from Bullion Butte, showing clusters of analcime which serves as cementing agent in this sample (thin section #43, 60x). **F**, capping sandstone from East Rainy Butte showing complete cementation by silica (thin section #63, 60x). A birefringent material seen coating the earlier formed opal and opal CT or fibrous chalcedony pore-lining cement suggests that a distinct second cementation event formed the pore-filling microcrystalline quartz cement. **G**, authigenic chabazite cement in the capping sandstone of Black Butte, Slope County (thin section #64, 220x). **H**, capping sandstone from Bullion Butte (thin section #75, 60x), showing clusters of analcime which serve as cementing agents in this sample.


A
B
C
D
E
F
G
H

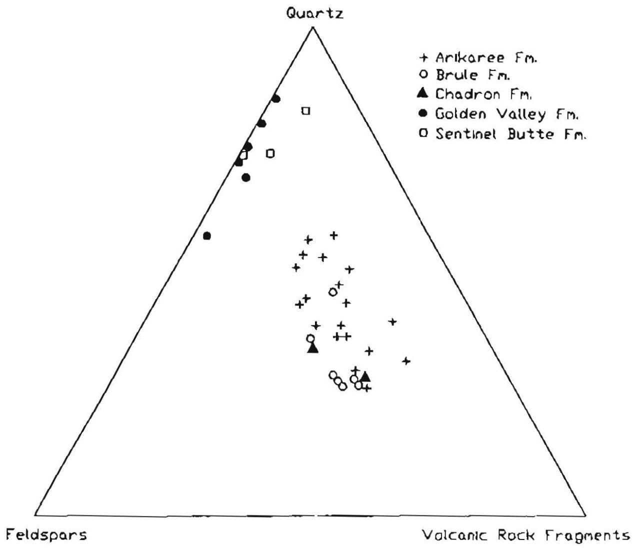


Figure 90. Ternary diagram depicting two petrographic groups of sandstones sampled for this study.

glass grains occur as pumice fragments, some with roughly straight, tube-like vesicles, and others with large, roughly spherical vesicles. Most shards are colorless, but brown or green shards are also present, although rare. The glass is rhyolitic, as determined by microprobe analysis of individual shards (Table 2). Glass grains range in size from fine silt to medium sand.

Weak to moderate birefringence seen along the edges and commonly on the surface of virtually all glass grains from this tuff section is due to authigenic smectite which thinly but uniformly coats each grain. Scanning electron microscope examination revealed that the smectite rests upon the glass rather than being firmly anchored to it (Figure 92b). Smectite coatings also occur on mineral components of the tuff. The clay can be removed from glass and mineral grain surfaces by treatment in an ultrasonic water bath. Clay slurries obtained in this manner were determined by standard X-ray diffraction methods to consist of 17Å montmorillonite.

The surfaces of some, but not all, glass and feldspar grains freed of clay coatings were found to be etched in a manner consistent with chemical dissolution. Apart from surface dissolution features, glass grains freed of clay coatings appear completely isotropic and are not devitrified.

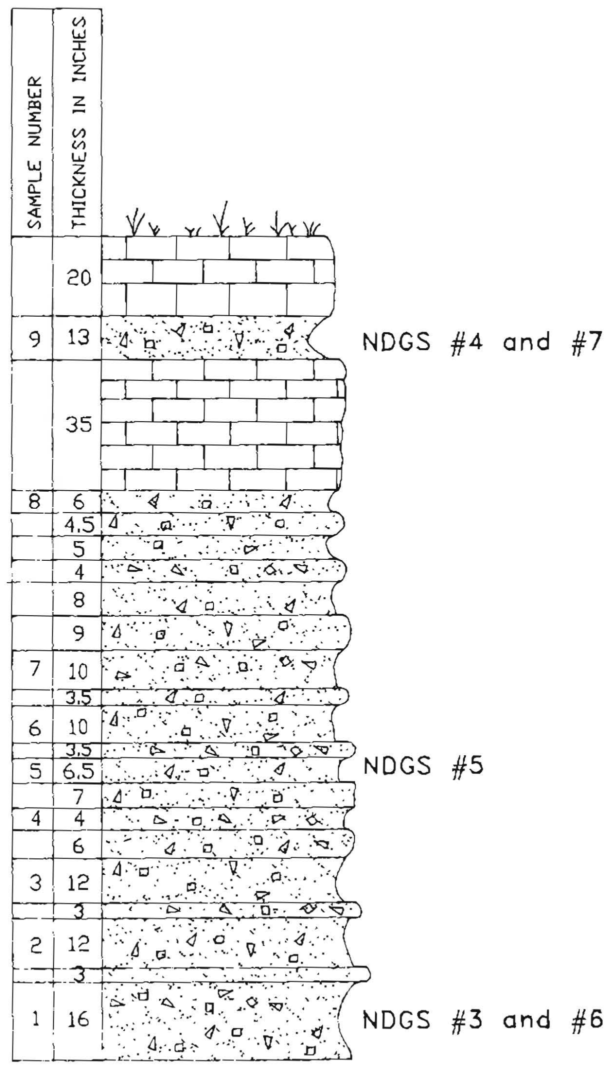


Figure 91. Lithologic column and tuff sample locations for the burrowed marker unit, Killdeer Mountains.

The zeolite mineral, erionite, is found as an authigenic mineral in all Killdeer tuff samples. It occurs as elongate prismatic crystals from 30 to 40 microns in length which project outward into pore spaces from glass and mineral grains and use the montmorillonite coatings as a substrate (Figure 92c).

It appears that, following an early diagenetic period of glass grain surface dissolution, colloidal smectite constituents were precipitated upon all framework grains. Clay coatings may have then

Table 2. Microprobe Analyses of Glass Grains and Authigenic Products From Killdeer Mountain Tuff (NDGS #3).

	Glass*	Clay	Zeolite
SiO_2	78.49	70.37	72.22
Al_2O_3	12.69	14.25	17.09
FeO	0.98	5.06	0.32
MgO	0.00	1.95	2.06
CaO	0.44	1.88	4.39
Na_2O	1.37	1.33	0.00
K_2O	5.22	4.07	3.64
TiO_2	0.13	0.73	0.00
MnO	0.00	0.19	0.14
SO_2	0.00	0.17	0.14

Note: *Mean values given for 10 glass specimens. Total iron as FeO. Calculated H_2O-free. Normalized to 100%.

protected glass grains from further dissolution, as evidenced by the large number of glass grains with entirely smooth, unetched surfaces, revealed after the removal of clay coatings. Erionite crystallization occurred only after montmorillonite precipitation had ceased. Authigenic montmorillonite is presumably an early diagenetic product in Killdeer tuffs and could be dated using the K-Ar method. It was considered that a K-Ar age for the clay would give a minimum age for the tuff sample, but, early in this study, the U.S. Geological Survey rejected the use of authigenic clay material for dating.

Dating of Glass

Although glass separates offer the best chemical fingerprints of tuffs, because glasses best represent the composition of the melt producing the eruption, glass is not the ideal material from which to obtain age information. However, although a few individual phenocryst grains were recognized by the presence of attached glass, these grains are no larger than fine sand and could not be extracted. Also, sandstones in the Killdeer Mountains contain a small percentage of glass grains and so, presumably, also contain reworked phenocrysts. Therefore, mineralogic comparisons of Killdeer tuff and sandstone samples have not provided unequivocal phenocryst determinations. The Killdeer tuffs also contain both potassic feldspar and calcic to intermediate plagioclase grains, so it has not been possible to use comparisons of feldspar species between tuffs and nontuffs to distinguish epiclastic and phenocryst feldspar grains with confidence. In addition, although zircon is normally used for fission track analysis, zircon grains in the sampled tuffs are all of silt size, which renders them useless for fission track work. As a result of the small grain size of these tuffs, the difficulty in recognizing and extracting phenocrysts, and limitations to the analytical procedures able to be employed in this study, glass grains remained the only material available for dating.

A sample (NDGS #3) of a tuff from the base of the burrowed marker unit in the Killdeer Mountains was submitted to the U.S. Geological Survey Laboratory in Denver, Colorado for fission track age determination of glass shards (Figure 91). Nancy Naeser determined a minimum age of 25.1 $\pm$2.2 Ma for this sample. This age of 27.3 - 22.9 Ma represents either the late Oligocene or early Miocene, with the Oligocene/Miocene boundary occurring at 23.7 Ma (Cande and Kent, 1992).

Tuff Correlation

Seven samples of glass separates from tuffs in the Brule and Arikaree Formations of North

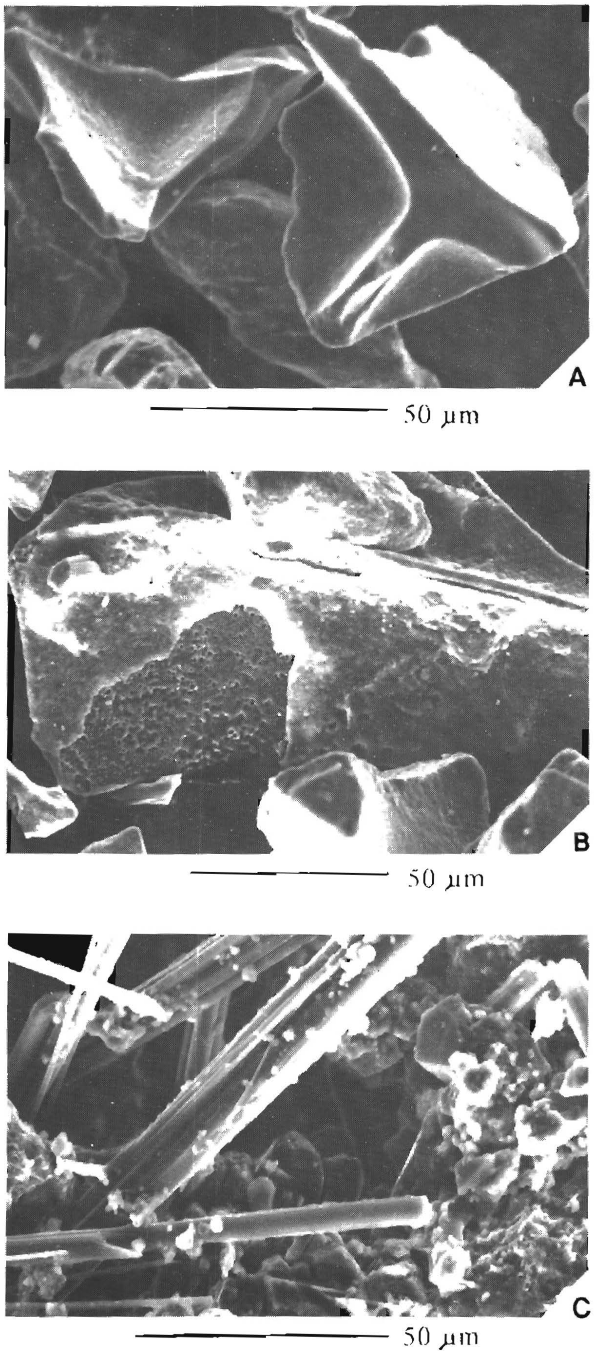


Figure 92. Photomicrographs of glass grains from the burrowed marker unit. **A**, angular glass grains with one or more raised ribs. **B**, smectite coating on glass grain. **C**, authigenic erionite in the burrowed marker unit.

Dakota (NDGS #1-#7) were sent to the U.S. Geological Survey for trace element analysis (Table 3). Sample NDGS #1 is from the Fitterer ranch site and sample NDGS #2 was taken from a suspected equivalent unit at the Obritsch ranch site (Figure 38). Samples NDGS #3 through #7 are each from the burrowed marker unit in the Killdeer Mountains (Figure 91).

Field evidence suggests that the two Little Badlands tuffs may be correlative; they both occur within the lower Brule Formation. The refractive index of glass shards from these tuffs are closely similar (1.498 and 1.497 for the Fitterer and Obritsch tuff samples, respectively), further suggesting that they may be from the same eruption event.

It is not clear whether the entire seventeen-foot-thick burrowed marker unit in the Killdeer Mountains represents a single accumulation of ash or whether multiple eruption events are recorded as discrete layers within the larger unit (Forsman, 1986). Samples from the top, middle, and basal portions of this unit were processed for neutron activation analysis and trace element comparisons.

A Q-mode cluster analysis using eleven rare earth elements was performed using samples from Fitterer ranch, Obritsch ranch, and from upper, middle, and lower portions of the burrowed marker unit (Figure 93). The Killdeer Mountain samples and the Little Badlands samples clearly represent two distinct groups, with the Little Badlands samples showing the closest similarity among all seven samples. This supports the field evidence suggesting that the tuff located at Fitterer ranch is correlative with the tuff at Obritsch ranch. The name "Antelope Creek tuff" is proposed for this bed. Although samples from the burrowed marker unit form a cluster in Figure 93, the similarity between these samples is not as close as the similarity for the Antelope Creek tuff samples. Thus, it appears that more than one event may be recorded within the burrowed marker unit, although the data obtained thus far is inconclusive.

TYPE SECTIONS OF THE CHALKY BUTTES AND SOUTH HEART MEMBERS OF THE CHADRON FORMATION

Chalky Buttes Member

The Chadron Formation can be divided into two members which can be easily recognized, even in scattered and poor outcrops at many of the buttes, throughout western North Dakota. Stone (1973) divided the Chadron into three informal members. To avoid confusion the names proposed by Stone (1973) for his upper two members have been retained.

Table 3. Trace element analysis of glass separates from the Antelope Creek tuff (NDGS #1 & #2) and the burrowed marker unit (NDGS #3-#7).

LAB NO. FIELD NO.		D-378684 NDGS #1	D-378685 NDGS #2	D-378686 NDGS #3	D-378687 NDGS #4	D-378688 NDGS #5	D-378689 NDGS #6	D-378690 NDGS #7
K	%	2.21	2.14	4.35	4.45	4.52	4.44	4.46
CV/K	%	1.	1.	1.	1.	1.	1.	1.
MN	PPM	235.	313.	423.	413.	427.	388.	404.
CV/MN	%	1.	1.	1.	1.	1.	1.	1.
DY	PPM	5.62	5.33	4.23	4.64	4.62	4.52	4.43
CV/DY	%	3.	6.	3.	5.	7.	3.	8.
FE	%	0.788	1.14	0.801	0.807	0.820	0.781	0.751
CV/FE	%	1.	1.	1.	1.	1.	1.	1.
NA	%	2.25	1.86	1.97	1.91	2.02	1.92	1.88
CV/NA	%	1.	1.	1.	1.	1.	1.	1.
BA	PPM	677.	568.	449.	544.	485.	589.	508.
CV/BA	%	1.	1.	1.	1.	1.	1.	1.
SR	PPM	96.	83.	59.1	96.8	72.0	-	81.1
CV/SR	%	20.	25.	5.	4.	8.	-	4.
CO	PPM	0.865	2.32	0.719	0.551	0.616	0.592	0.460
CV/CO	%	1.	1.	1.	1.	1.	1.	1.
NI	PPM	<0.70	-	<2.6	<7.5	<1.9	<0.41	4.67
CV/NI	%	-	-	-	-	-	-	15.
CR	PPM	-	2.0	1.34	1.5	1.1	1.30	1.1
CV/CR	%	-	27.	11.	15.	17.	9.	25.
CS	PPM	2.87	2.83	7.78	7.98	8.11	7.51	7.99
CV/CS	%	1.	1.	1.	1.	1.	1.	1.
HF	PPM	4.72	5.56	4.37	4.62	4.75	4.68	4.48
CV/HF	%	1.	1.	1.	1.	1.	1.	1.
RB	PPM	60.7	56.9	170.	179.	177.	169.	177.
CV/RB	%	2.	1.	1.	1.	1.	1.	1.
SB	PPM	0.654	0.724	1.07	1.15	1.16	1.06	1.12
CV/SB	%	2.	7.	3.	2.	5.	2.	1.
TA	PPM	1.33	1.57	1.67	1.79	1.83	1.75	1.78
CV/TA	%	1.	1.	4.	1.	10.	1.	1.
TH	PPM	6.19	6.85	21.8	22.2	22.5	20.7	21.8
CV/TH	%	1.	1.	1.	1.	1.	1.	1.
U	PPM	2.05	1.92	7.92	8.17	8.48	7.47	8.01
CV/U	%	2.	2.	1.	4.	2.	3.	1.
ZN	PPM	33.9	47.5	46.9	50.3	50.8	47.5	44.1
CV/ZN	%	4.	4.	2.	3.	2.	2.	6.
ZR	PPM	151.	171.	122.	133.	140.	135.	131.
CV/ZR	%	5.	2.	2.	2.	21.	7.	6.
SC	PPM	4.14	5.63	2.83	2.76	2.81	2.74	2.54
CV/SC	%	1.	1.	1.	1.	1.	1.	1.
LA	PPM	23.8	24.3	33.3	34.0	35.0	33.6	33.1
CV/LA	%	1.	1.	1.	1.	1.	1.	1.
CE	PPM	53.5	54.3	66.2	70.1	70.0	67.0	67.2
CV/CE	%	1.	2.	1.	1.	2.	1.	1.
ND	PPM	24.0	24.2	28.1	28.4	29.7	27.6	28.1
CV/ND	%	2.	5.	1.	5.	2.	2.	1.
SM	PPM	5.18	5.24	5.16	5.64	5.78	5.56	5.32
CV/SM	%	1.	1.	1.	1.	1.	1.	1.
EU	PPM	0.600	0.604	0.389	0.432	0.430	0.446	0.414
CV/EU	%	1.	1.	1.	1.	1.	1.	1.
GD	PPM	5.13	5.21	4.25	4.65	4.55	4.72	4.45
CV/GD	%	3.	9.	5.	4.	4.	5.	5.
TB	PPM	0.784	0.771	0.618	0.682	0.693	0.680	0.658
CV/TB	%	1.	1.	1.	1.	1.	1.	1.
TM	PPM	0.545	0.558	0.38	0.410	0.442	0.431	0.433
CV/TM	%	10.	8.	28.	9.	4.	8.	3.
YB	PPM	3.49	3.46	2.55	2.68	2.83	2.73	2.71
CV/YB	%	1.	1.	1.	1.	1.	1.	1.
LU	PPM	0.507	0.507	0.372	0.387	0.413	0.392	0.393
CV/LU	%	3.	9.	7.	1.	1.	1.	1.
W	PPM	0.85	-	2.74	2.86	2.61	2.17	2.48
CV/W	%	19.	-	5.	7.	12.	14.	11.
AS	PPM	10.6	9.0	12.9	12.9	13.3	11.7	12.7
CV/AS	%	3.	21.	2.	2.	3.	4.	3.
AU	PPB	<0.88	<1.6	1.3	<1.0	1.6	2.0	<1.1
CV/AU	%	-	-	28.	-	17.	22.	-

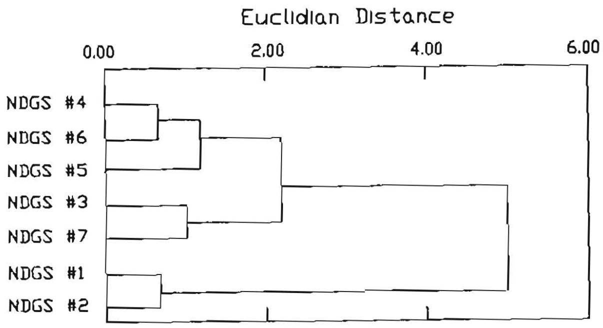


Figure 93. Dendrogram of selected rare earth elements in tuff samples from the Little Badlands and Killdeer Mountains.

Stone's basal member of the Chadron, the "Amidon member" is a thin, < 15-foot-thick, white claystone or mudstone recognizable only in some areas of the Chalky Buttes and Little Badlands. Because of this restricted occurrence it seems more appropriate to include this basal claystone and mudstone, wherever present, with the overlying conglomerate and sandy mudstone as part of the lower member of the Chadron Formation here named the Chalky Buttes Member. This name is derived from the excellent exposures of the member in the Chalky Buttes, Slope County. The type section for the Chalky Buttes Member is the east-facing slope of a north-trending ridge in the NW¼NE¼NE¼ section 25 (T134N R101W), in the Chalky Buttes, Slope County, 6.25 air miles southeast of Amidon (Figure 94; Plate 3). At the type section, the Chalky Buttes Member is 88 feet thick and consists of 15 feet of white to purple mudstone overlain by 73 feet of white to yellow/green conglomerate and sandy mudstone (Figure 15).

The lower, unconformable contact of this member is placed at the top of a two- to three-foot thick analcime bed in the Sentinel Butte Formation. This analcime bed is, however, generally not present at other localities in North Dakota. The contact elsewhere is placed at the sharp, unconformable contact between the white to yellow/green conglomerate, sandy and pebbly mudstone, or claystone of the Chalky Buttes Member and the underlying grey to brown beds of alternating sandstone, siltstone, mudstone, and claystone of the Fort Union Group. In some outcrops, large scale cross-bedding is visible in the Chalky Buttes Member due to orientation of pebbles along slip faces. Pebbles comprised of pink to brown volcanic porphyries appear to be unique to this member. The sandy mudstone consists of subangular to rounded quartz grains in a matrix of yellow/green clay. In outcrops where the beds are finer grained, that is, where a pebbly mudstone is present rather than a pebbly sandstone or conglomerate, the pebbles generally appear to be randomly oriented. Examples of this lithology can be seen at Haystack Butte, Stark County (SW¼SW¼ section 29, T139N R97W).

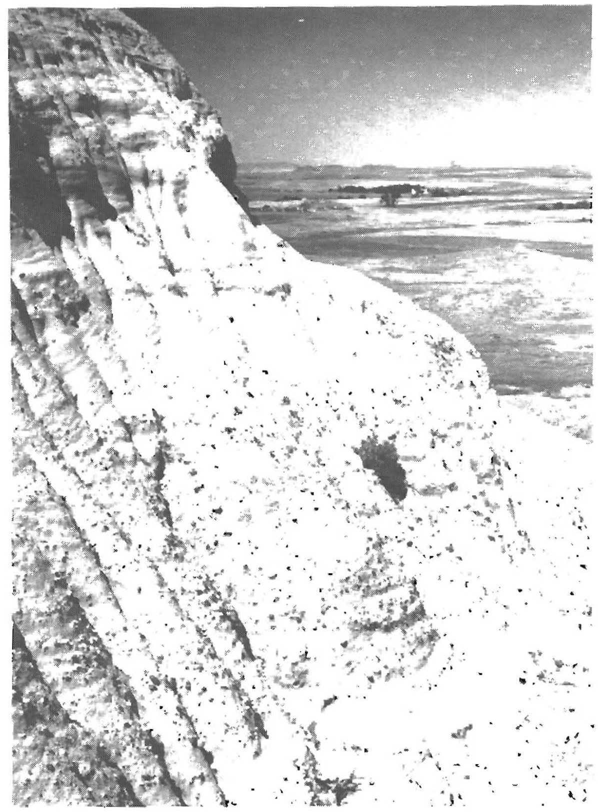


Figure 94. The type section of the Chalky Buttes Member, view is to the north (134-101-25).

The Chalky Buttes Member attains a maximum thickness of 80 feet in the Chalky Buttes, Slope County. It averages 20 feet thick in the Little Badlands, 3 to 10 feet thick at Rainy Buttes, > 20 feet thick at Black Butte, Hettinger Co., > 30 feet thick at Whetstone Buttes, and 5 to 55 feet thick (with an average of 20 feet) at small buttes in eastern Stark and eastern Hettinger Counties.

The Chalky Buttes Member is lithologically similar to the Chadron A bed of Schultz and Stout (1955) in the Big Badlands of South Dakota, and the "dazzling white" unit of Lillegraven (1970) at Slim Buttes, South Dakota (Figure 8).

The lithologies of the Chalky Buttes Member are generally unfossiliferous. Brontothere remains however, have been recovered from the Chalky Buttes Member at several sites in the southwestern part of North Dakota possibly indicating a Chadronian "age" for these rocks (Appendix C).

South Heart Member

The name South Heart Member is proposed, as it was informally proposed by Stone (1973), for the uppermost strata of the Chadron Formation in North Dakota. The South Heart Member is a brown to gray/green smectitic claystone that commonly contains thin (< 5 feet thick) lenses of freshwater limestone or marlstone. This member is conformably underlain by the Chalky Buttes Member of the Chadron Formation and is conformably overlain by the Brule Formation. The type section of the South Heart Member is located at Fitterer ranch in the west face of a north-trending ridge, in the NW¼SW¼NE¼ section 7 (T137N R97W), Stark County, 12 air miles southeast of the town of South Heart and one half mile northeast of a section given by Stone (1973) for his "South Heart member" (Figure 95; Plate 3). The South Heart Member, at the type section, consists of 31 feet of medium brown to gray/brown smectitic claystone (Figure 36). This claystone weathers to a "popcorn" surface texture and drapes over the underlying units making exact determination of thicknesses difficult. The top of this member at the type section is marked by a 1-foot-thick limestone which is overlain by pink/brown siltstones and mudstones of the Brule Formation.

The claystone lithology and color, and the rounded, sparsely vegetated weathering slopes of the South Heart Member are in sharp contrast to the more vertical cliff-forming units both above and below, which makes it an excellent marker horizon throughout western North Dakota. The somber color of the South Heart Member contrasts with the dazzling white of the underlying Chalky Buttes Member and with the pink and light browns of the overlying Brule Formation. Where the characteristic "popcorn" surface is not well exposed, the member can still often be easily recognized because of the resistant, ledge-forming and butte-capping interbedded limestone lenses. Conspicuous fibrous calcite concretions are also found in the member.

The South Heart Member is present in most of the White River outcrops in western North Dakota. It ranges in thickness from 10 to 23 feet at the Little Badlands, 20 to 60 feet at Rainy Buttes, 8 to 55 feet

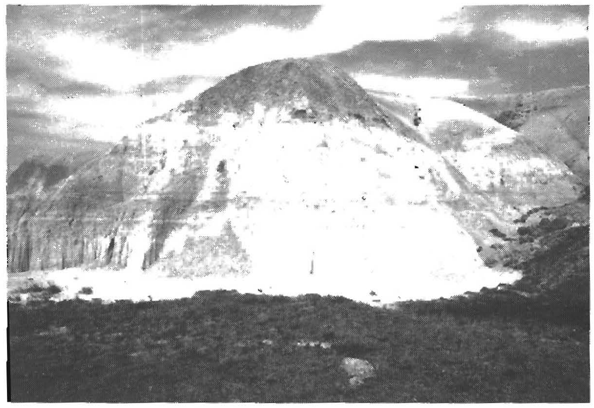


Figure 95. The type section of the South Heart Member, view is to the northeast (137-97-7).

at the small buttes in eastern Stark and eastern Hettinger Counties, and reaches a maximum thickness of 96 feet at White Butte, Slope County.

The South Heart Member is lithologically similar and appears to be stratigraphically equivalent, in part, to the Chadron B and C beds of Schultz and Stout (1955) in the Big Badlands of South Dakota, and the "typical Chadron" of Lillegraven (1970) in the Slim Buttes, South Dakota (Figure 8).

Few fossils have been reported from the South Heart Member in southwestern North Dakota. The only biochronologically important fossils have been brontothere remains which possibly indicate a Chadronian "age" for this member.

LITHOSTRATIGRAPHIC CORRELATION

Basal Unconformity

In North Dakota, the White River and Arikaree unconformably overlie formations ranging in age from late Tiffanian (Bullion Creek Formation) to Clarkforkian (Sentinel Butte Formation), to Wasatchian (Golden Valley Formation). This unconformity is characterized by a sharp to subtle lithologic change from the alternating sandstones, siltstones, mudstones, claystones, and lignites of the Fort Union Group to a conglomerate or sandy mudstone (Chalky Buttes Member) generally present at the base of the White River Group. Pebbles and cobbles of volcanic and plutonic rocks are present in the conglomerates at the base of the Chadron Formation (Chalky Buttes Member) at Chalky Buttes, Slide Butte, Little Badlands, South Killdeer Mountain, Medicine Pole Hills, Whetstone Buttes, and Coffin Buttes. Quartz latite porphyry and volcanic breccia cobbles present in these conglomerates are not found in any other part of the lower or middle Cenozoic section in western North Dakota. When present, these gravels are an important indicator of the Chalky Buttes Member. White to yellow/green sandy mudstones, which contain lenses of rounded and frosted quartz grains ranging in size from fine to coarse, are also characteristic of the Chalky Buttes Member. Small pebbles of plutonic and volcanic rock fragments are also common in these mudstones. The mudstones offer a sharp contrast to the brown and gray, iron oxide-stained mudstones and claystones of the underlying formations of Paleocene and Eocene age.

A 1- to 3-foot thick, dazzling white to multicolored bleached or weathered zone, indicating a prolonged exposure of sediments prior to burial, is present below the unconformity in the Chalky Buttes and Little Badlands areas. This bleached zone is most highly developed at the Chalky Buttes in Slope County. The absence of this weathering horizon at most other observed unconformable contacts suggests that either; 1) erosion was quickly followed by deposition of Chadron deposits at those locations or 2) weathering horizons may have been removed prior to burial at those locations.

A structural contour map of the unconformable contact at the base of the Chadron Formation was constructed using information from measured sections and drill holes (Figure 96). The map indicates that the highest elevation of the unconformity is in the extreme southwest (Medicine Pole Hills) and the lowest elevation occurs in the Little Badlands, Stark County. A paleoslope direction of east-northeast can be inferred from the attitude of the contact.

Electric Log Correlation

Electric logs of the White River and Arikaree rocks were used to assist in correlation of these strata. Few electric logs of these rock units were available, however, outside of the Chalky Buttes, Little Badlands, and Killdeer Mountains. Relatively high concentrations of uranium are locally present beneath the White River/Fort Union contact. It was anticipated that these uraniferous zones might be useful in correlation.

Several hypothesis have been proposed regarding the source and depositional mode of

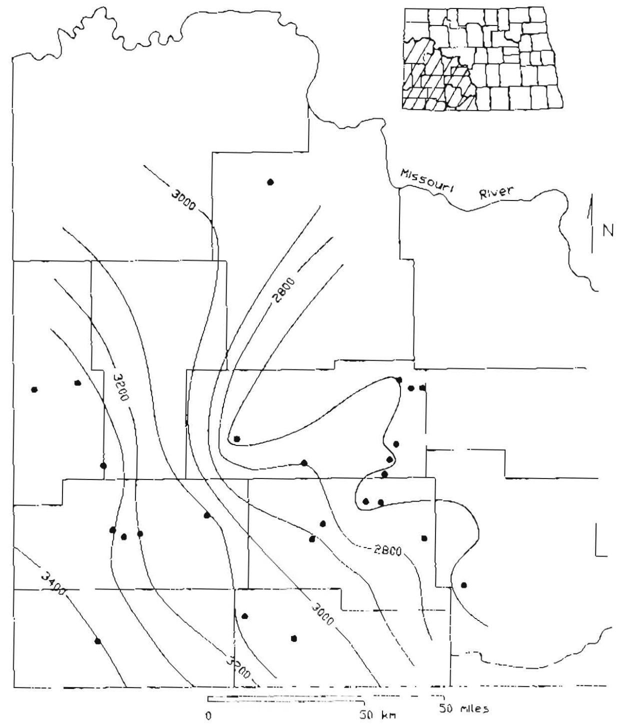


Figure 96. Structural contour map of the unconformity at the base of the Chadron Formation in southwestern North Dakota.

uranium in western North Dakota. Wyant and Beroni (1950) and Beroni and Bauer (1952) suggested that uranium was concentrated in the Paleocene rocks at the time of deposition. In contrast, Denson et al. (1959) and Denson and Gill (1965), believed volcanic ash beds in the White River and Arikaree were the source rocks for uranium in this region. Analysis of these rocks with respect to their uranium content was a focus of the study by Denson and Gill (1965). They determined that radioactive minerals are often concentrated in the first lignite or carbonaceous beds beneath the White River unconformity. Denson and Gill also speculated that this was a result of groundwater leaching through the uranium enriched White River and Arikaree rocks and precipitation of uranium at the first contact with organic-rich sedimentary rocks, such as coal or carbonaceous claystone, due to the change in pH and/or Eh. Lignite is not present in the White River and Arikaree rocks. Therefore, the radioactive deflection or "kick" on the gamma log, if present, indicates strata of the Fort Union Group. The radioactive kick may be found at significant depth below the White River unconformity because it is dependent upon the stratigraphic position of lignite or carbonaceous beds. The electric logs from a shallow drilling project in Dunn, Stark, and Billings Counties demonstrate that the radioactive deflection on the gamma log frequently occurs within the base of a sandstone above a coal (Menge, 1980). Also in the electric logs from Menge's study, radioactivity often is detectable in the second or third coal encountered in the borehole, disputing Denson and Gill's theory.

Many gamma logs from oil and gas wells in the vicinity of the buttes in this study were discontinued at the base of the surface casing. A radioactive zone is present, however, on five logs run to the surface in these areas; two from the Killdeer Mountains, one from Square Butte, and two from the Little Badlands. The logs from the Killdeer Mountains contain a radioactive deflection at an elevation of approximately 2,700 feet (Figure 97). This is approximately 200 to 300 feet below the anticipated Golden Valley/White River contact. The log from Square Butte contains a radioactive zone at an elevation of 3,044 feet, approximately 230 feet below the elevation of the Golden Valley/White River contact observed in the field. The logs from two wells in the Little Badlands contained radioactive horizons at an elevation of approximately 2,530 feet. The Golden Valley/Chadron contact generally occurs between elevations of 2,600 and 2,850 feet in this area.

All of the radioactive deflections on these logs occurred below the anticipated Fort Union/White River contact. The gamma log deflection is often useful for identifying the highest occurring carbonaceous or lignite bed in the Fort Union Group, but these beds commonly occur tens or, as demonstrated in these five logs, hundreds of feet below the unconformity at the base of the White River Group. In addition, multiple zones of radioactivity may be present at a given site. Therefore, the deflection on the gamma log can not be used to accurately identify the position of the unconformity.

Regional Correlation

The Chadron and Brule Formations in North Dakota favorably compare lithologically with strata at their type sections in the Big Badlands of South Dakota. The lower Chadron generally consists of a gray to "dazzling white" sandy mudstone, sandstone, or conglomerate throughout much of northwestern Nebraska, western South Dakota, and southwestern North Dakota. The smectitic claystone and interbedded limestones at the top of the Chadron is very consistent in appearance throughout this three-state area. These lithologies suggest that fluvial

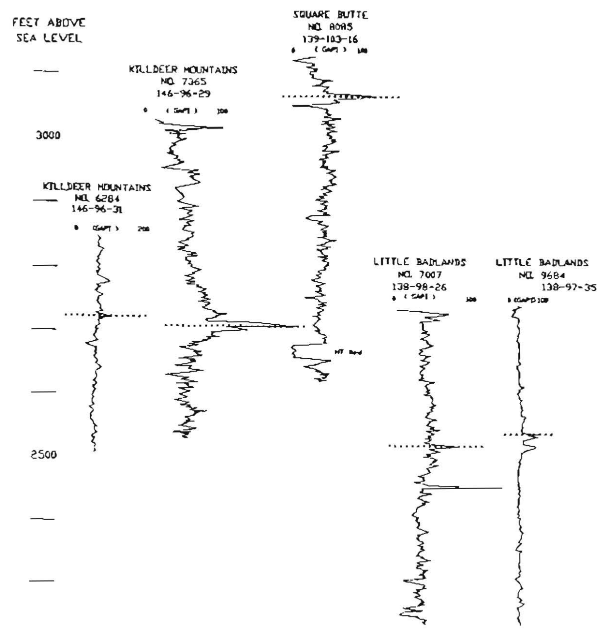


Figure 97. Gamma log profiles through the White River Group and Arikaree Formation in southwestern North Dakota.

systems were dominant during deposition of the Chalky Buttes Member and lacustrine settings were widespread during deposition of the South Heart Member over this area.

Pinkish/brown siltstones and mudstones are characteristic of the Brule Formation throughout this three-state area. However, the Brule in North Dakota does not exhibit as obvious layering or color banding prevalent in the Brule in South Dakota, which is interpreted by Retallack (1983) to be paleosol development.

The Arikaree Formation in North Dakota is most similar in lithologic appearance to the Gering and Harrison Formations of the Arikaree Group in northwestern Nebraska. These units are predominantly gray colored, fine-grained, tuffaceous sandstones and siltstones with interbedded carbonate lenses. Small burrows, similar to those in the burrowed marker unit in the Killdeer Mountains, White Butte (Slope County), and West Rainy Butte are present in both the Gering and Harrison Formations in Sioux County, Nebraska.

Correlation of Massive Sandstones

Most previous studies have considered the thick, massive sandstones capping Sentinel, Square, and Bullion Buttes to be correlative (e.g., Denson, 1969; Furman, 1970; Clayton, 1980). Petrographically, these sandstones are quite similar, generally containing a quartz to feldspar ratio of 2: or 3:1 and low concentrations of volcanic rock fragments. A reliable data base of sandstone petrography for lower and middle Cenozoic strata in the Williston Basin does not exist, however, to compare these values. A detailed petrographic study of the Golden Valley Formation would be especially useful to assist in petrologic correlation of these massive sandstones. The information obtained during this, and previous studies, suggests four possible stratigraphic correlations for the massive sandstone caprocks at Sentinel, Square, Bullion, and Black (Slope Co.) Buttes:

1) The four sandstones may all be part of the Sentinel Butte Formation. However, the sandstones at Square and Bullion Butte are highly zeolitized and sericitized, neither of which is characteristic of sandstones in the Sentinel Butte Formation.

2) The sandstones may be a finer grained facies of the conglomeratic sandstones prevalent in the Chalky Buttes Member. The sandstones at Square and Bullion Butte are overlain by Chalky Buttes conglomerates, the contact between the two lithologies appears sharp, not gradational as would be expected if there was a facies change. The sparsity of volcanic rock fragments in the massive sandstones is further petrologic evidence that these sandstones are not part of the Chalky Buttes Member. A finer grained facies of these conglomerates is present in the Whetstone Buttes where volcanic-rich sandstones underlie more typical Chalky Buttes Member lithologies.

3) The sandstones may be part of an additional lithostratigraphic unit positioned between the Camels Butte Member of the Golden Valley Formation and the Chalky Buttes Member of the Chadron Formation. The stratigraphy of the upper part of the Golden Valley Formation is not well understood in western North Dakota because of limited outcrops and the presence of an unconformity at the top of the formation. Therefore, this scenario can not be ruled out.

4) As mapped in this report, the sandstones may not be correlative. The close proximity of Sentinel, Square, and Bullion Buttes and the lithologic similarity of the overlying rocks suggest that these three sandstones are correlative. The evidence is convincing that the sandstones at these three buttes are overlain by the Chadron Formation. The evidence for this stratigraphic arrangement is less compelling at Black Butte (Slope County). The Bear Den Member of the Golden Valley Formation is present at the base of the massive sandstone on the west outlier of Square Butte suggesting that the overlying sandstone occurs no lower stratigraphically than the Camels Butte Member. The sandstones at Sentinel, Square, and Bullion Buttes are considered part of the Camels Butte Member because of their petrologic similarities to this member and the absence of data which would enable identification of the presence of additional strata between the Camels Butte and Chalky Butte Members (Figure 98). The sandstone caprock at Black Butte (Slope County) was placed in the Sentinel Butte Formation because it appears to be lithologically correlative with a sandstone mapped as Sentinel Butte Formation in the Chalky Buttes.

BIOCHRONOLOGY

Introduction

In 1941 a committee, established by the Vertebrate Paleontology section of the Paleontological Society and led by H. E. Wood, developed a North American mammal geochronology and established eighteen "North American Provincial Ages" including the Chadronian, Orellan, Whitneyan, and Arikareean based primarily on fossil occurrences in South Dakota and Nebraska (Wood et al., 1941). The intent was to establish biochronologic units defined by sequential changes in the Tertiary mammal fauna of North America (Tedford et al., 1987). However, these "Provincial Ages" were in part based on the rock units in which the faunas were found and were technically geochrons rather than strictly biochrons. This created ambiguity in the definition of the "Provincial Ages". These "Provincial Ages" have been and are being redefined based on biostratigraphic criteria and are now called North American land mammal "ages". Additional revisions to these land mammal "ages" have resulted from the advent of: K-Ar dating (beginning in 1964), magnetic polarity stratigraphy (beginning in 1976), and 40Ar/39Ar dating (beginning in the late 1980's)(Prothero and Swisher, 1992).

The sparsity of mammal remains in the White River Group and Arikaree Formation in North Dakota, except for the fairly diverse fauna identified by Hoganson and Lammers (1992) from the lower part of the Brule Formation, restricts application of the North American land mammal "age" biochronology. There is sufficient fossil evidence,

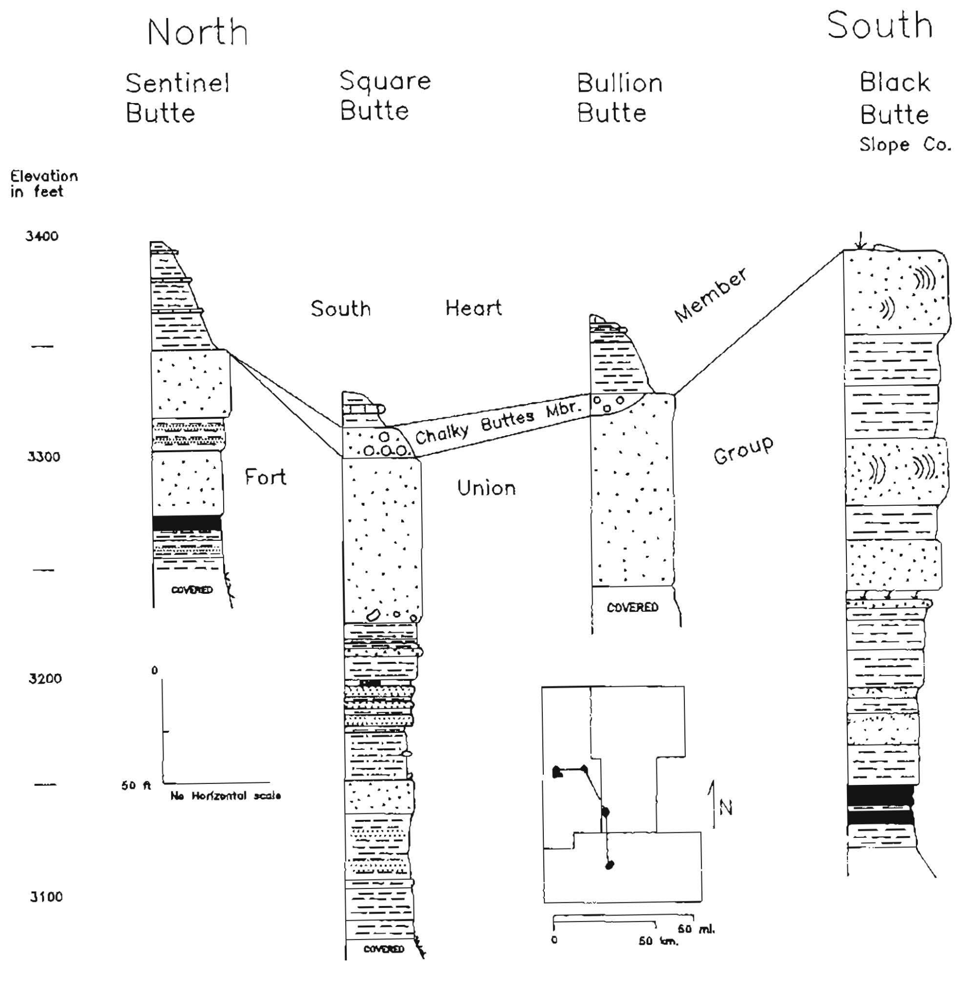


Figure 98. Geologic cross-section of the major sandstone-capped buttes in southwestern North Dakota.

however, to suggest that Chadronian, Orellan, Whitneyan and Arikareean mammal "ages" are present in North Dakota.

Chadronian

Wood et al. (1941) based the Chadronian "age" on the Chadron Formation in Nebraska and South Dakota and included the old term "*Titanotherium* beds" in the definition. They defined the fauna of the Chadronian as the time when titanotheres (brontotheres) and *Mesohippus* co-existed. Emry et al. (1987) have subsequently characterized the Chadronian mammal fauna.

The presence of brontothere fossils in the Chadron Formation in North Dakota has been interpreted to indicate a Chadronian "age" for that formation (e.g., Stone, 1973). Brontothere remains are most common in the Medicine Pole Hills area and were first discovered there by Leonard (1922). Subsequent workers have found additional brontothere remains and other presumably Chadronian fossils, such as possibly the hyaenodon *Hemipsalodon*, at that locality (Appendix C)(Hares, 1928; Benson, 1952; Denson et al. 1959; Kepferle and Culbertson, 1955). The Medicine Pole Hills Chadron fauna is currently being examined by Dean Pearson, Pioneer Trails Museum, Bowman, North Dakota. In addition to specimens from Medicine Pole Hills, fragmentary brontothere remains from the Chadron Formation at the Little Badlands proper, White Butte (Stark County-Little Badlands), Fitterer ranch, Obritsch ranch, and Square Butte localities were recovered during this study. Brontothere teeth were apparently also collected from Square Butte by Brown in the 1940s (Purdy, pers. comm., 1993). The only other report of Chadronian "age" fossils from North Dakota was by Prothero and Shubin (1989) who documented the occurrence of the Chadronian equid *Miohippus assiniboiensis* in the Chadron Formation in the Little Badlands.

Orellan

The Orellan "age" was initially based on the Orella Member of the Brule Formation in Nebraska, South Dakota, and Wyoming and includes the "*Oreodon* beds" of past terminology (Wood et al., 1941). The faunal characteristics of the Orellan "age" are given by Emery et al. (1987).

Skinner (1951) was first to suggest, although he provided little fossil evidence, that all but the upper part of the Brule Formation in North Dakota is Orellan in age. Most subsequent workers have agreed with Skinner's interpretation but without providing much paleontological evidence (e.g., Stone 1972, 1973; Estes, 1970; Hoganson and Lammers, 1985; Hoganson, 1986; and Kihm and Lammers, 1986). Hoganson and Lammers (1992) determined that at least the lower part of the Brule Formation in North Dakota is Orellan in age after identifying more than 60 mammalian taxa from the Brule mostly recovered from the Fitterer ranch, Obritsch ranch, and Little Badlands proper localities. They noted that Orellan "age" faunas are also present at White Butte (Slope County) and Chalky Buttes. The occurrence of Orellan taxa at Hoganson and Lammers' localities was reaffirmed during this investigation (Appendix C). Orellan "age" strata in the Little Badlands is also confirmed by magnetostratigraphy (Prothero et al., 1983). In addition, mammal remains of presumed Orellan "age" were recovered at West Rainy Butte.

Whitneyan

Wood et al. (1941) based the Whitneyan "age" on the Whitney Member of the Brule Formation in Nebraska, South Dakota, and Wyoming and included in their definition the "*Protoceras-Leptauchenia* beds" of old terminology. Mammalian taxa characteristic of the Whitneyan are given by Emery et al. (1987).

Skinner (1951) suggested that the upper part of the Brule Formation at the Fitterer ranch locality is possibly Whitneyan in age although he provided little evidence to support that interpretation. Stone interpreted the upper Brule to be late Orellan through Whitneyan in age primarily based on an oral communication with Morris Skinner who stated that some..." vertebrate remains indicate a Whitneyan age for the upper Brule beds at the Fitterer ranch" (Stone, 1973, p. 79). Hoganson and Lammers (1992) found no paleontological evidence to confirm Skinner and Stone's interpretations and noted that fossils were too sparse in the upper Brule to speculate on the age of the upper part of the formation. Kihm (1990) cited the occurrence of the rodent *Eumys brachyodus* in the Brule Formation in the Little Badlands proper as evidence for a Whitneyan "age" for at least part of the formation. A Whitneyan "age" for the upper part of the Brule Formation in the Little Badlands is also implied by magnetostratigraphy (Prothero et al., 1983).

Early collections of vertebrate fossils from presumably the Brule Formation at White Butte (Slope), called the "White Butte local fauna", were interpreted by Wood et al. (1941) to indicate a Whitneyan "age" for the Brule at that locality. This interpretation was probably based on Douglass' (1908a,b) and (1909) fossil lists from White Butte which included *Mesohippus brachystylus*? and *Aceratherium tridactylum*. Wood et. al., (1941) noted, however, that the "White Butte local fauna" differed from other Whitneyan faunas. Another possible Whitneyan "age" specimen found at the White Butte locality is *Elomeryx* collected by Morris Skinner and associates in 1951. The Whitneyan oreodont *Leptauchenia decora* was recovered from the lower Arikaree Formation at White Butte during this study.

Moore et al. (1959) reported a possible Whitneyan "age" fauna, that included *Miohippus*, *Leptauchenia* and *Protoceras*?, collected from 20 feet above the base of the Brule Formation at Chalky Buttes. Denson and Gill (1965) cited these fossils as indicators of a Whitneyan "age" fauna in North Dakota but cautioned that the fossils were probably recovered from a slump block. *Eporeodon major*? another possible Whitneyan "age" taxon was recovered from Chalky Buttes by Babcock and Clapp (1906).

A probable Whitneyan "age" fauna was discovered during this study from the capping Arikaree Formation sandstones and possibly the upper

Brule Formation exposed at the East and West Rainy Butte localities. This fauna includes *Elomeryx armatus*, *Miohippus*, and *Perchoerus* and is currently being studied by Hoganson. The only other possible Whitneyan "age" taxon that has been reported from the Rainy Buttes is *Miohippus obliquidens* by Prothero and Shubin (1989).

Arikareean

The Arikareean "age" was initially based on the Arikaree Group in western Nebraska (Wood et al., 1941) and includes faunas of the Gering through Harrison Formations. Mammalian taxa characteristic of the Arikareean are given by Tedford et al. (1987).

In 1958, Jean Hough at that time with the University of Chicago, collected a beaver skull from 20 feet below the caprock at Golden Butte (the highest point at the Obritsch ranch locality) from what is interpreted to be the Arikaree Formation. Stout and Stone (1971) identified the specimen as *Palaeocastor*. Stone (1973) cited its occurrence and the presence of *Hypertragulus minor*? and *Amphicaenopus* at White Butte (Slope County) as evidence for an Arikareean "age" for his "Killdeer formation". An additional specimen of *Palaeocastor* from the capping sandstone on Golden Butte was collected during this study. Skinner and associates in 1951 recovered a specimen of *Nanotragulus* from White Butte providing additional evidence for the occurrence of the Arikareean there.

Skinner collected fragmentary oreodont remains from the Arikaree Formation exposed at the Killdeer Mountains in 1954. Two taxa, *Merychyus* and *Merycochoerus*, were identified from that collection which are interpreted to be late Arikareean in age (Tedford, 1989). No additional Arikareean fossils were found during this study from the Arikaree Formation in the Killdeer Mountains.

PALEOGEOGRAPHY, PALEOCLIMATE, AND PALEOENVIRONMENTAL SETTING

The middle Cenozoic was a time of worldwide climatic deterioration. This deterioration resulted in the formation of ice sheets on Antarctica during the late Eocene/early Oligocene which have waxed and waned since that time (Bartek et al., 1992). In the mid-continental United States the climate changed from equable, humid, warm temperate to subtropical conditions during the Paleocene and early Eocene to drier, warm to cool temperate conditions during the late Eocene and Oligocene. These changes caused a major extinction event between the middle and late Eocene (about 40-41 Ma) and a lesser extinction event at the end of the Eocene (about 34 Ma)(Berggren and Prothero, 1992). As in other areas of the mid-continent these climatic events had a profound effect on sedimentological regimes in western North Dakota and the biota that inhabited western North Dakota at that time.

During the middle Cenozoic, the western North Dakota portion of the Williston Basin was an area of low relief marginal to uplifted areas to the west and southwest. Sediments derived primarily from Laramide uplift areas were transported mostly northeastward down the paleoslope onto this area of the ancient Great Plains. This northeasterly drainage pattern was apparently established by at least the early Eocene, dominated during the Oligocene, and continued until the end of the Tertiary (Seeland, 1985). Although this paleogeographic configuration remained relatively constant, the proportion of uplift areas was progressively reduced by erosion and sedimentation.

Western North Dakota was a broad, swampy, fluvial lowland transected by slow moving, aggrading streams during deposition of the Paleocene Bear Den Member of the Golden Valley Formation, similar to the situation earlier in the Paleocene (Hickey, 1977). This was a time of tectonic quiescence with little clastic deposition and dominance of carbonaceous sedimentation. The megaflora of the Bear Den Member is dominated by lowland forest taxa such as *Metasequoia* (dawn redwood) and *Cercidiphyllum* (katsura) similar to other late Paleocene floras from North Dakota (Hickey, 1977). Lakes and swamps inhabited by aquatic plants were present in these lowland forests. This fossil flora indicates that western North Dakota experienced an equable, warm temperate climate during deposition of the Bear Den Member. The fauna during this time is poorly known because few vertebrate, mollusk, and insect fossils have been recovered from the member.

Analysis of vertebrate fossils from the Camels Butte Member of the Golden Valley Formation led Jepsen (1963, p. 673) to suggest that western North Dakota was occupied by "warm, humid swampy lowlands with subtropical forests bordering sluggish streams" during the early Eocene (Wasatchian). Although the depositional setting remained essentially unchanged, except for an increase in deposition of clastic sediments, paleobotanical evidence also suggests a transition to subtropical conditions during deposition of the Camels Butte Member (Hickey, 1977). Plant genera of warm temperate affinities present in the Bear Den Member were gradually replaced by subtropical to even tropical species such as the Eocene indicators *Lygodium kaulfussi* (climbing fern) and *Salvinia preauriculata* (aquatic floating fern). Conifers became less abundant and the woodlands became angiosperm dominated. The subtropical vertebrate fauna that lived during the time of deposition of the Camels Butte Member consisted of aquatic species including fish, turtles, and four genera of crocodilians; tree dwelling taxa including primates; and mammalian forest browsers (Jepsen, 1963).

The late Eocene Chadron Formation rests unconformably on either the Golden Valley, Sentinel Butte, or Bullion Creek Formations in western North Dakota indicating a period of erosion and nondeposition (Figure 7). Unconformities also underlie White River deposits in adjacent states. Seeland (1985) suggested that this widespread erosional surface was formed during a post-Laramide period of tectonic quiescence during the late Eocene. If the Camels Butte Member of the Golden Valley Formation is Wasatchian in age and the Chalky Buttes Member of the Chadron Formation is Chadronian in age, as is indicated by mammal fossils in these units in North Dakota, then this period of erosion could have lasted for at least 14 million years resulting in the removal of much of the Eocene record in North Dakota. The maximum amount of geologic time represented by this unconformity in North Dakota, approximately 18 million years, occurs in the Medicine Pole Hills area where the Chadron overlies the lower Bullion Creek Formation (Tiffanian) resulting in the loss of a minimum of 1000 feet of rock record. A major extinction event, caused by global cooling and increased aridity, took place during this time (about 40-41 Ma) when many animals and plants adapted to warm climates and tropical forests died out (Berggren and Prothero, 1992). Hickey (1977) noted that the Golden Valley Formation was gently warped into northeast trending folds prior to deposition of Chadron sediments. The Golden Valley Formation surface was also extensively oxidized and leached during weathering forming silicified peat beds, like the HS bed, before being covered by the Chadron deposits.

Seeland (1985) suggested that pre-Chadron paleogeography influenced Chadron depositional patterns in North Dakota and that the major valleys formed earlier in the Eocene persisted into the late Eocene. He inferred the presence of two major streams flowing into western North Dakota from northeastern Wyoming and southwestern South Dakota based on the composition of pebbles and cobbles of volcanic rock in conglomeratic sandstones of the Chalky Buttes Member of the Chadron Formation at several localities in southwestern North Dakota. The provenance of the Chalky Buttes conglomeratic sandstones has been a source of contention. Denson and Gill (1965) proposed that the Absaroka volcanic field in northern Wyoming and southern Montana, specifically the Beartooth Mountains, was the source of the volcanic porphyries found in the Chalky Buttes Member (Figure 99). Stone (1973) disagreed and felt that the most obvious

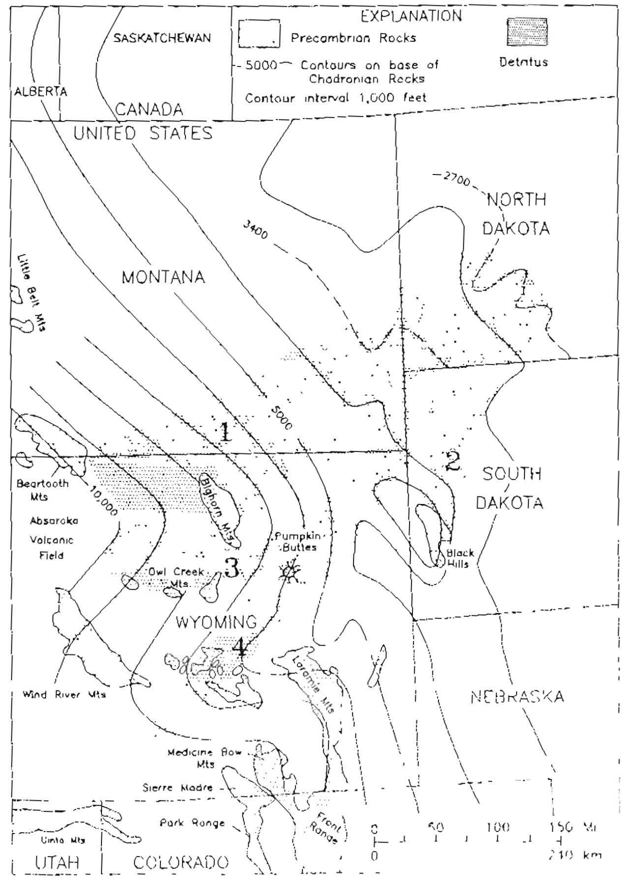


Figure 99. Generalized configuration of the surface at base of the Chadron Formation (or equivalents) in parts of the Northern Rocky Mountains and Great Plain provinces (modified from Denson and Gill, 1965; Seeland, 1985). The following source pathways were suggested by: 1) Denson and Gill (1965), 2) Stone (1973), 3) Seeland (1985), and 4) Ashworth (1986).

source for these deposits was the northern Black Hills, including Bear Butte, Inyan Kara Mountain, Sundance Mountain, and Devils Tower (Figure 99). Stone did note, however, the absence of parent rock in the northern Black Hills for the conspicuous volcanic porphyry pebbles in the Chalky Buttes Member but postulated that those rocks had been removed by weathering. Seeland (1985) offered a compromise by proposing a multiple source hypothesis wherein drainages during the Chadronian provided coarse clastics to western North and South Dakota from both the Absaroka field and the northern Black Hills (Figure 99). Ashworth (1986), in support of a multiple source explanation for the sediments in the Chalky Buttes Member, cited the presence in these sandstones of "*Turritella*" agate from the Bridger Formation derived from southcentral Wyoming. Observations made during this study are consistent with Seeland's and Ashworth's and support the multiple source hypothesis for the conglomeratic sandstone of the Chalky Buttes Member.

The stream valleys gradually filled and the fluvial depositional regime of the Chadron Formation in North Dakota changed from being dominated by coarse clastic deposition in the Chalky Buttes Member to fine grained clastics intercalated with lacustrine carbonates in the South Heart Member. The claystones in the South Heart Member may be, at least in part, fluvially reworked and diagenetically altered fine-grained volcaniclastics such as the Chadron mudstones in eastern Wyoming (Evanoff et al., 1992). Marlstones in the South Heart Member are thin (< 5 feet thick) and laterally restricted indicating that the lakes in which they were deposited were shallow and small. Hansen (1953) suggested that some of the marlstones may have been deposited in ox-bow lakes. Boyer (1981) determined that at least one of these lakes, in the area of Sentinel Butte, underwent several episodes of shrinkage with increased salinity similar to the Great Salt Lake followed by expansion and influx of fresh water. He attributed these cycles of lacustrine expansion and contraction to climatic fluctuations.

The humid, subtropical climate prevalent in the mid-continent during the early and middle Eocene gave way to cooler, drier, more seasonal conditions in the late Eocene (Berggren and Prothero, 1992). This change resulted in a shift from subtropical, closed forest habitats widespread in the early Eocene to more open, subtropical to temperate, woody savanna habitats in the late Eocene (Webb, 1977; Retallack, 1983; Stuckey, 1992). The floristic composition of these savanna habitats in the mid-continent is unknown, except for the presence of hackberry (*Celtis*) trees, because of the lack of fossil flora sites, probably due to nonpreservation. No Chadronian floras have been found in North Dakota to help define these habitats. Temperatures were still warm enough, however, for subtropical snails (Evanoff et al., 1992) and alligators (Hutchison, 1992) to exist in the mid-continent during the Chadronian. The presence of crocodilian fossils in North Dakota Chadron deposits indicates that subtropical to warm temperate conditions existed in North Dakota during the Chadronian. The opening of new habitats allowed new mammalian taxa to either immigrate to or evolve in North America and many of these taxa were members of families that still exist today such as dogs, rabbits, camels, squirrels, and rhinoceroses (Berggren and Prothero, 1992). This "White River Chronofauna" survived with only minor changes throughout the Oligocene and into the early Miocene (Emery et al., 1987). The only diverse Chadronian vertebrate fauna in North Dakota, from Medicine Pole Hills, consists mostly of aquatic taxa including fish, reptiles and amphibians (Dean Pearson, pers. comm.) except for brontothere remains and, at this time, provides little information about North Dakota mammalian communities during the late Eocene.

Lithologies of the Brule Formation in North Dakota, predominantly siltstones, mudstones, and trough-cross bedded sandstones, suggest a fluvial (channel and overbank) depositional system in a rather featureless landscape. Hoganson and Lammers (1992, p. 252) envisioned these lithologies to represent "deposition by a dynamic fluvial system in a savanna setting in which sluggish, loosely-sinuous, aggrading streams, flanked by low-relief levees, transected a broad floodplain containing small ponds and/or ephemeral, swampy areas." Seasonal droughts occurred frequently and flash-flooding, spreading sediment over vast floodplain areas, was common. The cooling and drying trend that began in the late Eocene continued into the Oligocene. Orellan climates in the upper mid-continent were subhumid to semiarid, and by the end of the Oligocene the climate was semiarid to arid and cool temperate with pronounced dry seasons (Retallack, 1983).

This cooling and drying trend was particularly devastating to western interior North American herptofaunas where aquatic taxa, especially freshwater turtles and crocodilians, declined in the late Eocene and by the Orellan only terrestrial tortoises, such as *Stylemys*, persisted (Hutchison, 1992). Regional extinction of terrestrial floras in the high latitudes of North America near the Eocene/Oligocene boundary was also devastating, 80-90% of the genera became extinct (Wolfe, 1992). A mammalian extinction event also took place at the end of the Chadronian when the last of the archaic Eocene browsers (e.g., brontotheres) and tree dwellers (arboreal primates became extinct in North America about this time) were replaced by mammals adapted for grazing (Berggren and Prothero, 1992).

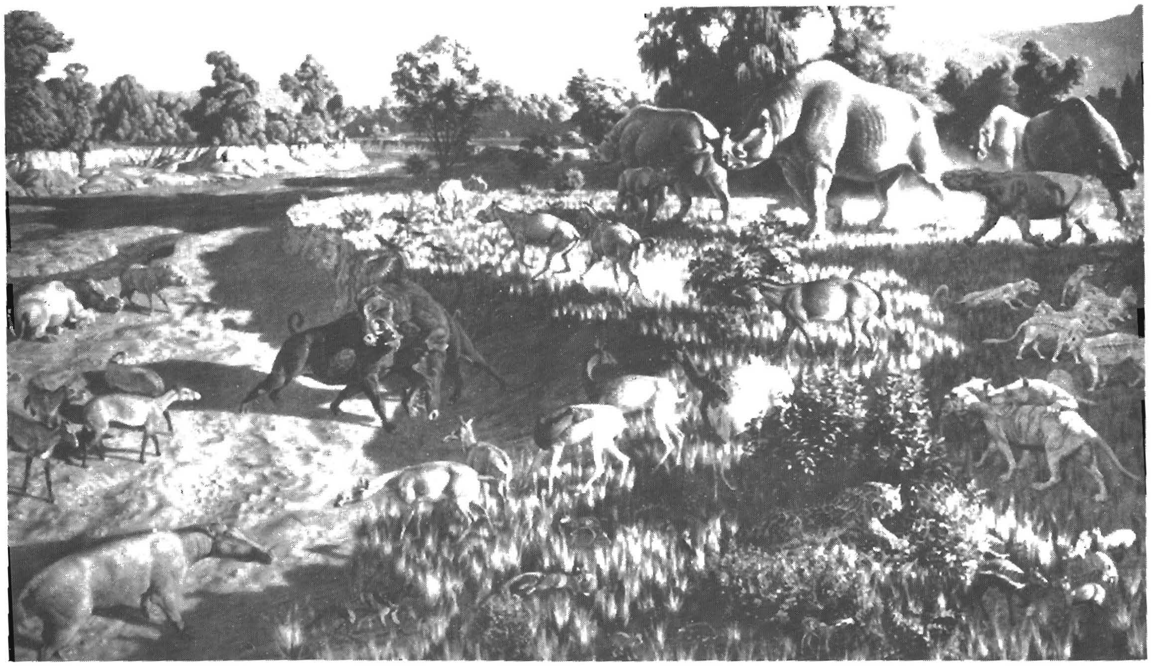
During the Oligocene savanna habitats became increasingly open and savanna adapted animals became diverse. The floras of these savannas are mostly unknown other than the presence of hackberry (*Celtis*) trees because fossil-leaf assemblages and pollen have not been preserved. Retallack (1983, 1992) proposed that gallery woodlands lined the watercourses in the open plains in South Dakota at this time but did not speculate on the composition of those forests. He did suggest that herbaceous vegetation of grasses, forbs, and small shrubs grew in the sparsely vegetated interstream areas. Leopold et al. (1992) argued, however, that grasses were either rare or absent at this time, not becoming abundant until the Miocene, and speculated that the savannas were dominated by woody vegetation.

Hoganson and Lammers (1992) determined that, in North Dakota, the savanna setting consisted of a mosaic of habitats during deposition of the Brule Formation and that at least some of the savanna-adapted biota preferred specific habitats. Their observations, summarized below, were reaffirmed during this study. Gallery woodlands grew along stream margins in this savanna. As in other areas of the mid-continent, endocarps of hackberry (*Celtis*) trees are the only plant fossils preserved and the flora of these woodlands is mostly unknown. Animals that apparently preferred these wooded stream-marginal and open woodland areas, even though they undoubtedly roamed the open savanna too, included the rhinoceroses, *Subhyracodon* and *Metamynodon*; the pig-like entelodont, *Archaeotherium*, the anthracotheriids, *Bothriodon* and *Elomeryx*; oreodonts including *Merycoidodon*; and the horses *Mesohippus* and *Miohippus*. Other inhabitants of the wooded areas included the tortoise, *Stylemys*; the freshwater turtle, *Trionyx*; the rabbit, *Palaeolagus*; the squirrel-like rodent, *Ischyromys*; and the beaver, *Agnotocastor*. Land snails (pupillids and the helicid, *Skinnerelix*), burrowing beetles (*Pallichnus*, pupal cells), sweat bees (*Celliforma*, larval cells) also inhabited the streamside woodlands.

As a generality, the interstream, more open savanna plain was inhabited by the smaller mammals although this observation, as Hoganson and Lammers (1992) pointed out, may be biased by taphonomic influences. This fauna included rodents such as, *Eumys*, *Adjidaumo*, *Paradjidaumo*, *Prosciurus*, and *Ischyromys*; the deer-like ruminant, *Leptomeryx*; the rabbits, *Palaeolagus* and *Megalagus*; and the camilid *Poebrotherium*. The tortoise, *Stylemys* and helicid snail, *Skinnerelix* lived in these open areas but apparently preferred the more wooded habitats. The carnivores, *Dinictis*, *Hesperocyon*, and *Daphonenus* and the insectivorous, *Leptictis* seemed to prefer the open habitats although their fossils are rarely found. Shallow ponds occupied some of the interstream areas. These ponds contained fish, algae (mats and charophyte oogonia), ostracods, and freshwater snails (lymnaeids, physids, and planorbids).

J. H. Matterness' mural in the U. S. National Museum is a depiction of his concept of how the landscape and animals appeared in the mid-continent during the Oligocene (Figure 100). Although this painting was based on fossils found in South Dakota and Nebraska it is, in general, a reasonable representation of the savanna habitats and animals that lived in North Dakota between about 34 and 32 million years ago. The mural is, however, a composite of ages and subenvironments. For example, most of the animals illustrated are taxa that occur in the Orellan in North Dakota except for the brontotheres which presumably became extinct at the end of the Chadronian and *Protoceras* a Whitneyan taxon. In addition, volcanoes although active at this time, were not present in close proximity to North Dakota.

By the end of the Oligocene and into the early Miocene climate in the mid-continent was arid and cool. A temperature minimum for the Paleogene was reached during the late Oligocene (Wolfe, 1978) and the first major ice sheet grounding event in the Ross Sea--Antarctica, comparable to that of the Wisconsinan glacial maximum, occurred about that time (Bartek et al., 1992). During the Whitneyan open grasslands were common in the continental interior of North America and trees grew only along streams (Retallack, 1992). Grass, sedge and composite grassland/parklands with riverine gallery forests occupied this area during the early Miocene (Hunt, 1985). Leopold et al. (1992) even suggested that trees may have been eliminated completely from the upper mid-continent by the end of the Oligocene because of arid conditions.



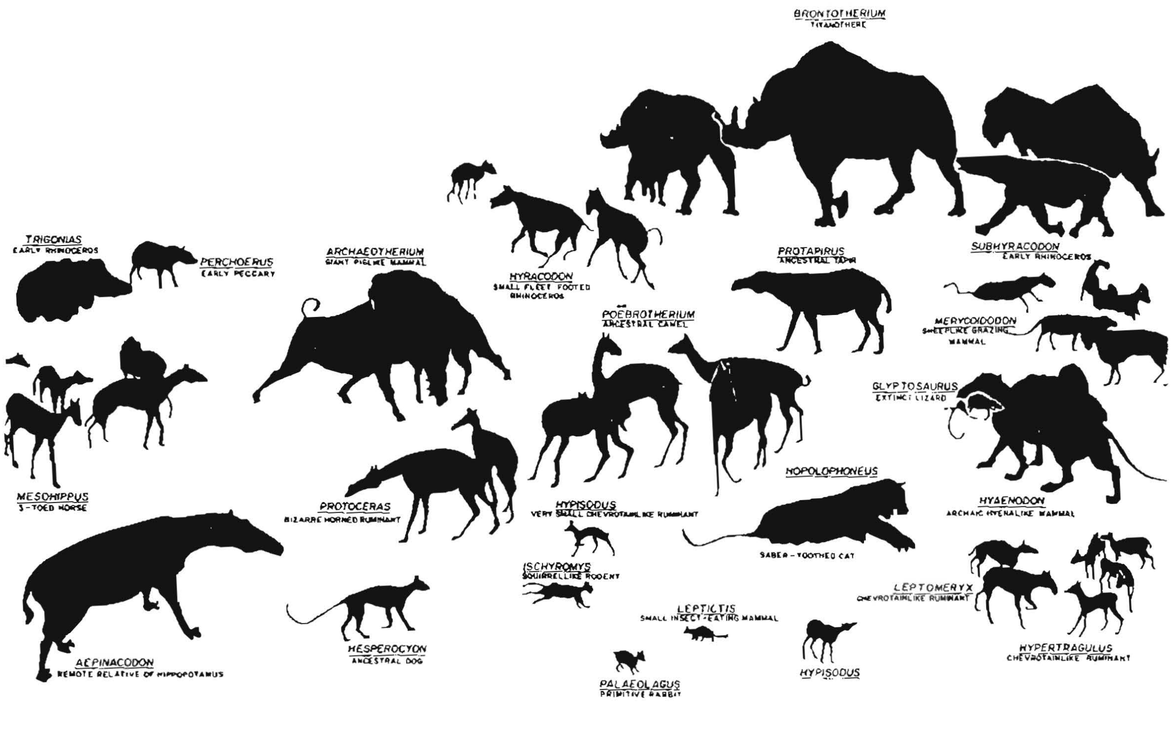


Figure 100. This reconstruction is a reasonable representation of the landscape and animals that inhabited North Dakota about 34-32 million years ago. Although this painting is based on fossils found in South Dakota and Nebraska, many of the same animals lived in North Dakota. The mural was painted by J.H. Matterness and is reproduced with permission of the U.S. National Museum.

Retallack (1992) speculated that aridity and cool temperatures may have created a less productive ecosystem during that time reflected by overall body size decrease in mammals and increase in burrowing taxa. A less productive ecosystem may also partially account for the sparsity of Whitneyan and Arikareean "age" faunas in North Dakota where only a few grassland taxa and the burrowing beaver, *Palaeocastor*, have been found.

ECONOMIC POTENTIAL OF WHITE RIVER AND ARIKAREE ROCKS

Claystone

The economic potential of clay and claystones has been assessed many times in North Dakota. Babcock and Clapp (1906) were among the first to study the potential economic value of the sandy mudstones (Chalky Buttes Member) and smectitic claystones (South Heart Member) in the Chadron Formation. Subsequent workers have analyzed samples from these units to evaluate the clay for use in ceramics and as light weight aggregate, binders, absorptives, alumina sources, etc. (Clarke, 1948; Manz, 1954; Chew and Boyd, 1960). Clarke (1948) estimated that over 10.6 million tons of minable South Heart Member smectitic claystone (his "upper clay") was present in the Little Badlands and Chalky Buttes. He also speculated that the South Heart Member claystones may be of economic use but, they are generally of inferior quality compared to bentonitic claystones in Wyoming and South Dakota.

Sand and Gravel

The Chalky Buttes Member is a potentially valuable source of sand and gravel, particularly in the Chalky Buttes, Medicine Pole Hills, Little Badlands, and Coffin Buttes. The presence of volcanic pebbles in the gravel may render these deposits undesirable as concrete aggregate. Colluvial and alluvial deposits derived, at least in part, from the Chadron, Brule, and Arikaree strata have been commercially mined for sand and gravel in the Chalky Buttes and Killdeer Mountains areas.

Carbonates

Fresh-water carbonates occur in the Chadron, Brule, and Arikaree Formations, but lenticular carbonate beds are most common in the South Heart Member of the Chadron Formation and in the Arikaree Formation at Chalky Buttes and the Killdeer Mountains. Hansen (1953) studied the feasibility of using South Heart Member carbonates in the manufacture of portland cement and calculated that approximately 6.5 million cubic yards of limestone are available from Lefor (Stark County) and White Butte (Hettinger County). Hansen also confirmed an earlier study that the carbonates in the Killdeer Mountains were not well suited as cement rock. Delimata (1975) found the Killdeer Mountain carbonates to be comprised of both limestones and dolostones (Delimata, 1975). None of the Arikaree or Chadron carbonates have yet been exploited for use in portland cement. Carbonates in the Killdeer Mountains and the Chalky Buttes have been crushed, however, and used in road construction.

Tuffs

The Chadron, Brule, and Arikaree Formations contain some strata that are highly tuffaceous in North Dakota. Two glass-rich tuffs have been identified in these units; the Antelope Creek tuff in the Brule Formation in the Little Badlands area and the burrowed marker unit in the Arikaree Formation in the Killdeer Mountains. Even though volcanic glass has many uses including road base construction, concrete admixtures and aggregates, abrasives, cleaners, polishing compounds, slow release fertilizer, ceramics, absorptives, and fillers (Manz, 1973), the feasibility of mining Brule and Arikaree tuffs in North Dakota has not been explored.

Zeolites

It is not surprising, because of the tuffaceous nature of these rock units, that certain beds contain considerable quantities of zeolites. Analcime was previously identified in the caprock of Bullion and Slide Buttes and in the Chadron Formation at Chalky Buttes (Furman, 1970). Erionite was identified in the Arikaree Formation in the Killdeer Mountains during this study. Other zeolites, including mordenite, chabazite, and clinoptilolite, were discovered in Chadron, Brule, and Arikaree sandstones at some buttes. Zeolites are used as desiccants, adsorbents, whitening agents for paper, and soil conditioners (Sheppard, 1973). They have not been commercially exploited in North Dakota.

Uranium

Tuffs in the White River Group and Arikaree Formation have long been thought to be the source rocks for the uranium deposits found today in the sandstones and lignites of the Fort Union Group. Although collectively these strata are likely more uraniferous than the underlying Fort Union Group, the most concentrated uranium deposits in western North Dakota occur within thin zones in the Fort Union. No commercial uranium deposits were reported from the White River and Arikaree rocks in North Dakota during uranium investigations in the 1950s and 1960s (e.g., Beroni and Bauer, 1952; Denson et al., 1959; Moore et al., 1959; Denson and Gill, 1965).

Gold

Tourtelot et al. (1970, p. 351) discovered gold in "rocks of Oligocene, Miocene, and Pliocene ages" in South Dakota and Nebraska. One third of the 140 rock samples they analyzed tested positive for the presence of gold. Although not reported by formation, some of these rock samples likely came from Chadron, Brule, and Arikaree strata. They speculated that potential source areas for gold during the "Oligocene" (likely what we now recognize as Chadronian (Eocene), Orellan (Oligocene) and Whitneyan (Oligocene)) were the northern part of the Hartville uplift or the northern end of the Laramie Mountains and the northern Black Hills. Gold has not been reported from the Chadron, Brule, or Arikaree Formations in North Dakota. It is possible that gold may be found in the Chalky Buttes Member of the Chadron Formation because it was deposited primarily by fluvial systems which may, in part, have received gold-bearing source rocks from the areas identified by Tourtelot et al. (1970).

SUMMARY

Petrology and Lithostratigraphy

The lithologies and stratigraphic relationships of the Chadron, Brule, and Arikaree Formations are described at 27 butte localities in western North Dakota. The Chadron Formation is formally divided into two members. The lower member, named the Chalky Buttes Member, is unconformably underlain by strata of various ages and consists of white conglomerates and sandy mudstones. Gray to brown smectitic mudstones interbedded with freshwater limestones conformably overlie the Chalky Buttes Member and are called the South Heart Member. The South Heart Member typically exhibits a "popcorn" weathered surface and forms "haystack" shaped hills. These members of the Chadron Formation are easily recognized, even in the limited outcrops, in southwestern North Dakota.

The Chadron Formation is conformably overlain by pinkish siltstones and mudstones of the Brule Formation which is also easily recognizable in this area. These siltstones and mudstones are interbedded with channel sandstones, tuffs, and occasional freshwater limestones. The Arikaree Formation, a lithologically variable sequence of concretionary, cross-bedded, calcareous sandstones, siltstones, silty claystones, carbonates, and tuffs, unconformably overlies the Brule Formation in western North Dakota. A conglomerate usually occurs at the base of the Arikaree. Conglomeratic sandstones, at times present in the upper Brule (Figure 101), are difficult to distinguish from those in the basal Arikaree such as at the Rainy Buttes. Placement of these channel sandstones in either the Brule or Arikaree Formation is dependent on whether or not Brule siltstone and mudstone lithologies occur above the sandstones and the age of fossils in the sandstones.

Sandstone Petrography

Chadron, Brule, and Arikaree sandstones are texturally and mineralogically immature to submature with quartz to total feldspar ratios ranging from 0.87 to 3.15. They are generally cemented by forms of quartz, ranging from opal to fibrous or mosaic chalcedony to microcrystalline quartz. These sandstones are easily distinguished petrographically from underlying Fort Union sandstones based on average volcanic rock fragment contents of 26% compared to 1 to 2% for Fort Union sandstones.

Analyses of Tuffs

Tuffs were identified at only three localities restricting their usefulness for correlation. The only fission track age obtainable from these tuffs was from the base of the burrowed marker unit in the Arikaree Formation from the Killdeer Mountains. This radiometric age of 25.1 ± 2.2 Ma is within the late Arikareean to early Hemingfordian (Prothero and Swisher, 1992) and is consistent with the age of at least part of the Arikaree Formation determined by mammal fossil biochronology.

The similarity of the trace element content of tuffaceous samples taken from the 15-foot-thick burrowed marker unit from the Arikaree Formation in the Killdeer Mountains suggests that the ash may represent a single airfall event or closely related airfall events. Trace element analysis of tuffs from

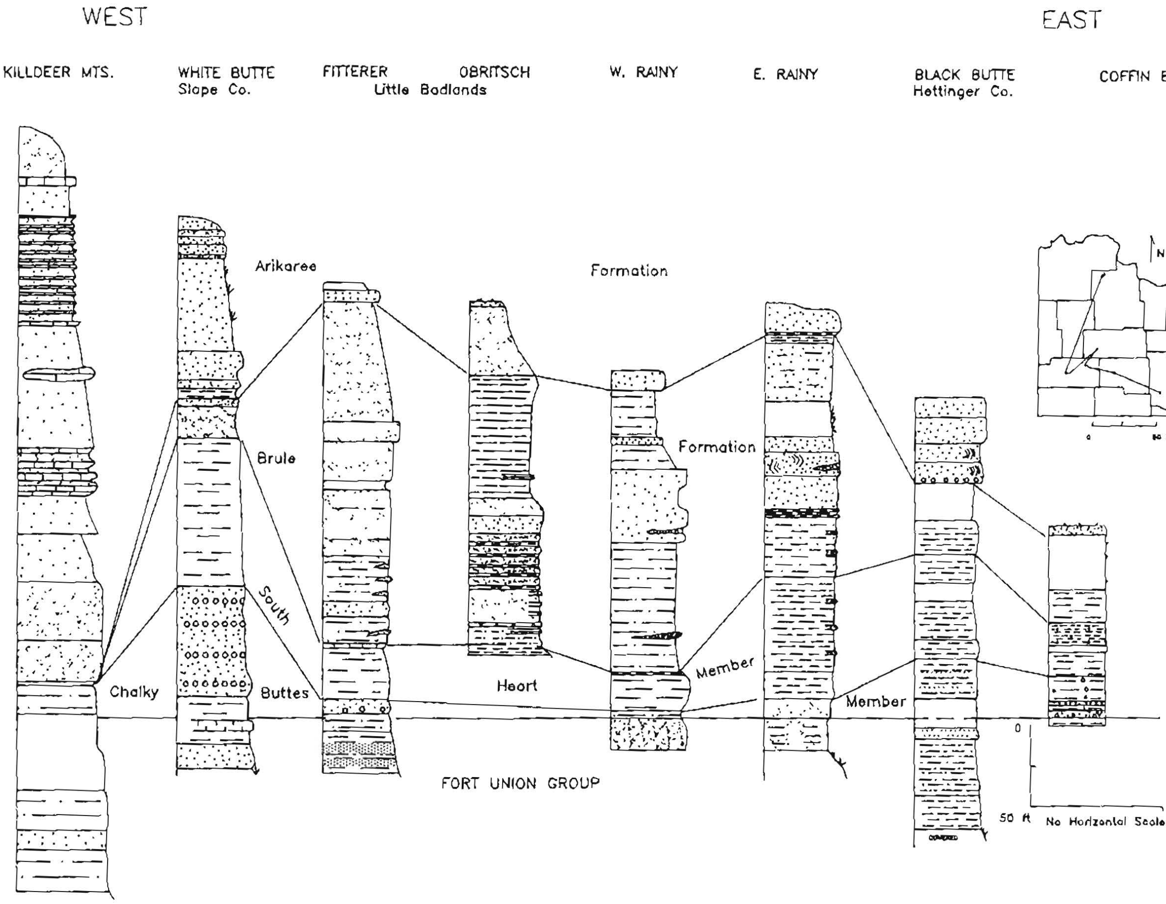


Figure 101. Geologic cross-section of the major buttes in southwestern North Dakota. Datum is the base of the Chadron Formation.

the Brule Formation at the Fitterer and Obritsch ranch localities indicates that these tuffs are correlative and are here called the Antelope Creek tuff.

Paleontology

Vertebrate, primarily mammal, fossils are present in the Chadron, Brule and Arikaree Formations in North Dakota. They are extremely sparse, however, except in the lower Brule Formation with the exception of the recently discovered Chadron local fauna at Medicine Pole Hills. At least 80 vertebrate taxa have been identified from the Brule Formation in North Dakota but only a few taxa have been reported from the Chadron and Arikaree Formations (Appendix C). The flora of these formations is largely unknown because the only plant fossils preserved are hackberry tree endocarps, charophyte oogonia, algal filaments, and root traces. Poorly preserved freshwater and terrestrial gastropods and freshwater ostracods are found in the Chadron and Brule. Trace fossils; beetle pupal cells, bee larval cells, mammal coprolites and burrows, occur in the Brule Formation and burrows are found in the Arikaree Formation.

Biochronology

Mammal fossils found in the Chadron, Brule, and Arikaree Formations indicate that the Chadronian, Orellan, Whitneyan, and Arikareean land mammal "ages" are present in North Dakota. The Orellan is the only age defined in North Dakota by a diverse mammal fauna and indicates that at least the lower part of the Brule Formation is Orellan in age. Mammal remains are sparse in the Chadron, upper

Brule and Arikaree Formations in North Dakota but there is sufficient fossil evidence to suggest that the Chadron is Chadronian in age, that the upper Brule is Whitneyan in age, and that the Arikaree is probably late Whitneyan to late Arikareean in age.

Depositional and Paleoenvironmental Setting

During deposition of the Chadron, Brule, and Arikaree Formations North Dakota was mostly a rather featureless plain marginal to uplifted areas to the west and southwest. Sediments derived from these uplifted areas were transported to the east and northeast across western North Dakota. A notable hiatus of at least 14 million years is represented by the unconformity between the Golden Valley and Chadron Formations. Fluvial depositional systems were dominant during deposition of the Chadron, Brule, and Arikaree Formations although lacustrine conditions were widespread during the late Eocene (South Heart Member).

The middle Cenozoic was a time of global climatic deterioration. The humid, subtropical climate during the early Eocene gave way to cooler, drier, more seasonal conditions during the late Eocene in North Dakota. This change resulted in a shift from subtropical, closed forest habitats during deposition of the Camels Butte Member of the Golden Valley Formation to more open, temperate, woody savanna habitats during deposition of the Chadron Formation. This cooling and drying trend continued into the Oligocene and savanna habitats became increasingly open. By the end of the Oligocene and into the Miocene the climate of North Dakota was semiarid to arid and cool temperate.

Economic Potential

The potential economic value of clays, claystones, and carbonates primarily in the Chadron Formation in North Dakota has been assessed several times in the past but only the carbonates have been exploited and only for road gravels. No commercial uranium deposits have been identified in the White River and Arikaree strata in North Dakota even though there has been numerous investigations. The economic potential of tuffs and associated zeolites and possibly gold in the middle Cenozoic rocks of North Dakota has not been evaluated.

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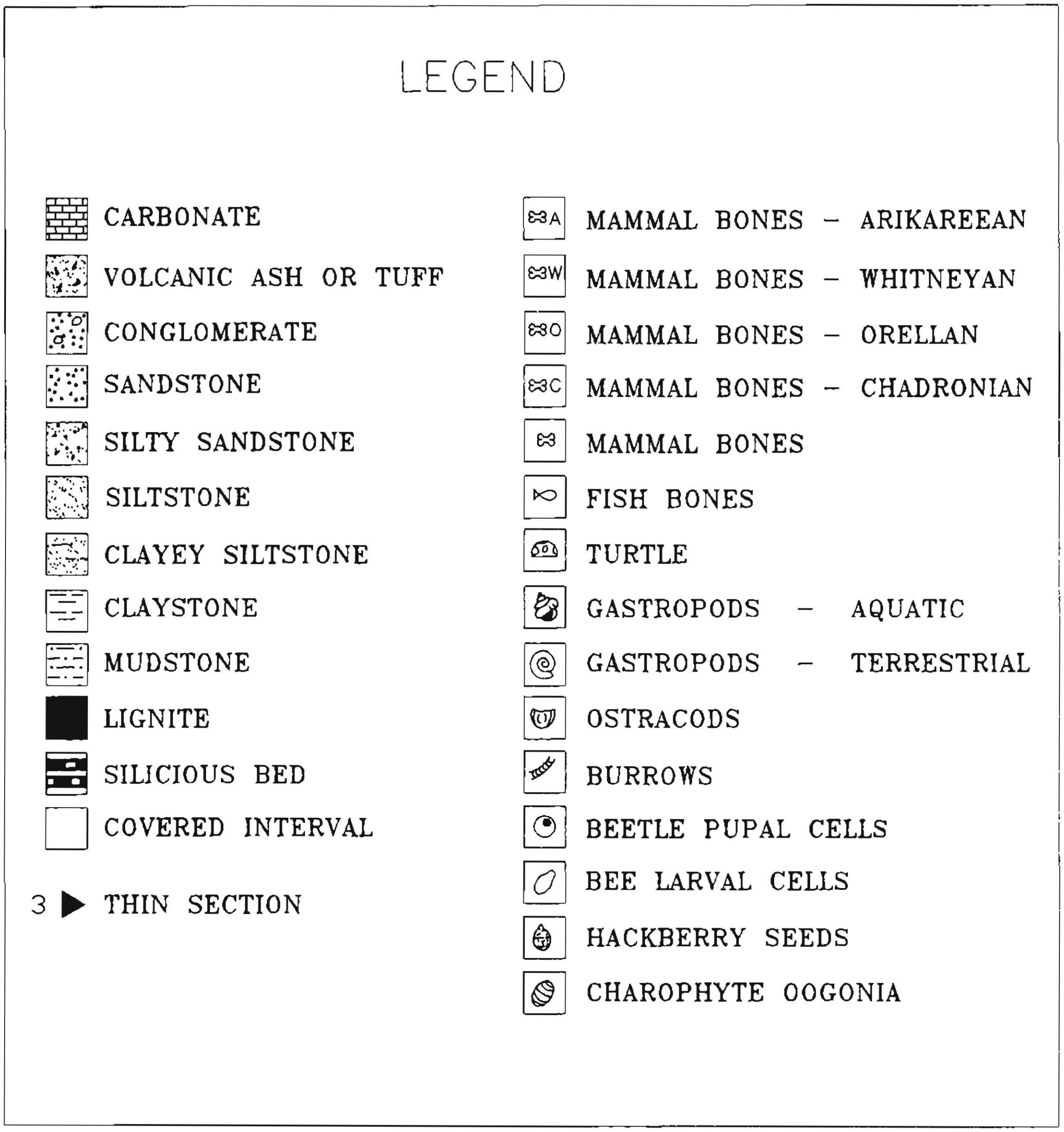
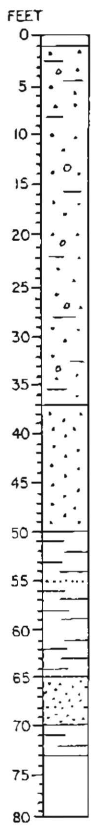
APPENDIX A

Lithologic and Paleontologic Symbols for Diagrams in Text



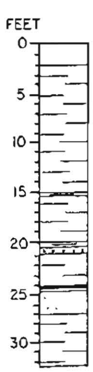
APPENDIX B
Lithologic Description of Selected Boreholes

KILLDEER MOUNTAINS — T147N R96W SE/SW/NE Section 34
Dunn County — Elevation 3020 feet

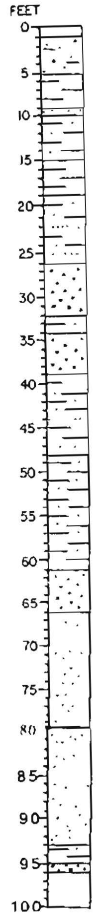


Depth	
0-1	Topsoil.
1-37	Talus, white to gray, fine grained, sandy, rock fragment pebbles, organic horizons.
	GOLDEN VALLEY FORMATION
	Camels Butte Member
37-50	Sandstone, light gray to light green, very fine to medium grained, also medium to coarse grained subrounded quartz and rock fragments, clayey. Note: Moist at 35 feet, saturated at 43 feet.
50-65	Claystone, light to medium green, interbedded sand and silt zones.
65-70	Sandstone, light to dark green, very fine to fine grained, silty, clayey, subangular to subrounded quartz grains, approximately 5% rock fragments, iron oxide stained zones and dark green concretionary zones.
70-73	Claystone, light green to white, silty, micaceous, iron oxide stained.

KILLDEER MOUNTAINS — T146N R96W NE/SW/NE Section 3
Dunn County — Elevation 2920 feet



Depth	
0-2	Colluvium.
	GOLDEN VALLEY FORMATION
2-15	Claystone, light green to gray/green, clean to silty, iron oxide stained, plant fossil fragments.
15-15.3	Claystone, dark purple to light purple/gray, clean.
15.3-20	Claystone, light green to gray/green, iron oxide stained, clean to silty, contains black mineral grains or organic matter.
20-20.3	Claystone, yellow/brown to brown/purple, silty, micaceous, lignite fragments.
20.3-20.8	Sandstone, gray/brown, medium to fine grained quartz, large mica flakes, iron oxide stained, lignite fragments.
20.8-24	Claystone, yellow/brown to brown/gray, silty, iron oxide stained.
24-24.2	Lignite.
24.2-24.5	Claystone, yellow/brown to dark brown, carbonaceous.
24.5-27	Siltstone, yellow/brown to gray/brown, clayey, iron oxide stained, micaceous.
27-32.5	Claystone, dark to medium brown, lignite stringers.

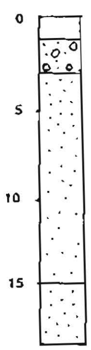


LITTLE BADLANDS, OBRITSCH RANCH
Stark County

T138N R97W SE/NW/SE Section 29
Elevation 2740 feet

Feet

0-1 Topsoil.
1-5 Colluvium, light gray/brown, sandy and silty.
CHADRON FORMATION
5-9 Claystone, medium brown, silty, blocky.
9-10 Siltstone, light yellow/brown, clayey.
10-12 Claystone, medium brown, silty, blocky.
12-12.5 Claystone, green, silty, blocky.
12.5-15 Claystone, light brown to light yellow/green, silty going to clayey silt.
15-19 Mudstone, medium brown with light green staining, very well indurated.
19-26 Claystone, light to medium brown, silty, blocky, contains light gray/brown clayey silt lenses.
26-32 Sandstone, light gray, silty, well to moderately cemented.
32-34 Claystone, medium brown, silty.
34-39 Sandstone, light brown to gray, silty.
39-48 Claystone, light to medium brown, silty, contains silt zones.
48-59 Claystone, medium brown, contains white silt zones, chert nodules, moderately to well indurated, some green claystone.
59-61 Claystone, dark green.
61-66 Sandstone, green, very fine grained, moderately to poorly indurated, very silty.
66-93 Siltstone, green to brown/pink, clayey, contains clay lenses.

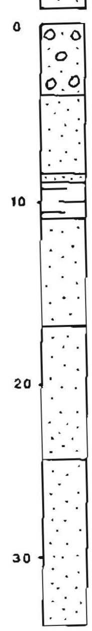


MEDICINE POLE HILLS
Bowman County

T130N R104W NW/SE/NE Section 2
Elevation 3440

Feet

0-1 Topsoil.
CHADRON FORMATION
1-3 Lag Deposit, Sandstone, grey/white to grey, very well to moderately cemented, fine to coarse grained, quartz and rock fragments, green mineral, 6 inch diameter cobbles in sand matrix, contains fossil bone fragments.
3-15 Sandstone, red/brown, medium-coarse grained, poorly to moderately sorted, quartz and rock fragments, poorly cemented, contains small well worn vertebrate fossils, iron oxide stained, heavily iron oxide stained at base.
BULLION CREEK FORMATION
15-18.5 Sandstone, grey/green, medium to coarse grained, quartz and rock fragments, grey/green clay pebbles, cemented at 18.5 and could not penetrate.



MEDICINE POLE HILLS
Bowman County

T130N R104W SE/NE/NE Section 2
Elevation 3444

Feet

CHADRON FORMATION
0-4 Sandstone Lag, up to 5 inch diameter gravel in a loose sand matrix.
4-8 Sandstone, light yellow grey/green, fine to coarse grained, quartz and rock fragments, subrounded to subangular, poorly cemented, contains clay pebbles.
8-8.5 Sandstone, light grey, well cemented.
8.5-9.5 Claystone, olive green.
9.5-11 Claystone, light to medium green.
11-17 Sandstone, light brown to grey, iron oxide stained, fine to coarse grained, quartz and rock fragments, poorly cemented, contains clay pebbles.
17-24 Sandstone, yellow/brown to red/brown, very iron oxide stained, poorly cemented, coarse grained, quartz and chert pebbles, very poorly sorted, micaceous.
BULLION CREEK FORMATION
24-34 Sandstone, red/brown, moderately to well sorted, fine to medium grained, some coarse grained lenses, poorly cemented.

APPENDIX C

List of Taxa from the Chadron, Brule, and Arikaree Formations in North Dakota. Names of some Taxa are Obsolete but are Included for Historical Completeness.

Taxa	Localities: Fitterer Ranch			Obritsch Ranch			Little Badlands																	
	Chadron	Brule	Arikaree	Chadron	Brule	Arikaree	Chadron	Brule	Chalky Buttes	White Butte, Slope County	Killdeer Mountains	East Rainy Butte	West Rainy Butte	Black Butte, Hettinger County	Sentinel Butte	Square Butte	Medicine Pole Hills	South Lime Hills	Lefor Buttes	White Butte, Hettinger County	Bull Butte	Young Man's Butte	North Star Butte	Coffin Buttes
PLANTS																								
Charophyte oogonia		*			*			*													*			
Algae indet.		*						*							27,*					21,23				
Celtis hatcheri Chaney, 1925		*			*			40,*	40,*															
INVERTEBRATES																								
CLASS GASTROPODA																								
Family Helicidae																								
Skinnerelix leidyi (Hall & Meek, 1855)		*			*			*																
Family Pupillidae																								
Pupillidae indet.		*			*													*			*			
Family Lymnaeidae																								
Lymnea shumardi Meek, 1876																				10				
Lymnea sp.																			10					
Lymnaeidae indet.		*			*			*																

Taxa	Localities: Fitterer Ranch			Obritsch Ranch			Little Badlands																
	Chadron	Brule	Arikaree	Chadron	Brule	Arikaree	Chadron	Brule	Chalky Buttes	White Butte, Slope County	Killdeer Mountains	East Rainy Butte	West Rainy Butte	Black Butte, Hettinger County	Sentinel Butte	Square Butte	Medicine Pole Hills	South Lime Hills	Lefor Buttes	White Butte, Hettinger County	Bull Butte	Young Man's Butte	North Star Butte	Coffin Buttes
CLASS GASTROPODA (cont'd)																								
Family Physidae																								
Physidae indet.		*			*													*			*			
Family Planorbidae																								
Planorbis nebrascensis Evans & Shumard, 1854																			10	10				
Planorbis vetulus Meek & Hayden, 1860																				10				
Planorbis sp.																				10				
Lacunorbis sp.																				10				
Planorbidae indet.		*			*													*			*			
Gastropoda indet.		40			*			40							14							*		
CLASS CRUSTACEA																								
Subclass Ostracoda																								
Ostracoda indet.		*			*						35				14,27			*	*	21,23	*	*	*	

Taxa	Localities: Fitterer Ranch			Obritsch Ranch			Little Badlands																	
	Chadron	Brule	Arikaree	Chadron	Brule	Arikaree	Chadron	Brule	Chalky Buttes	White Butte, Slope County	Killdeer Mountains	East Rainy Butte	West Rainy Butte	Black Butte, Hettinger County	Sentinel Butte	Square Butte	Medicine Pole Hills	South Lime Hills	Lefor Buttes	White Butte, Hettinger County	Bull Butte	Young Man's Butte	North Star Butte	Coffin Buttes
VERTEBRATES																								
CLASS OSTEICHTHYES																								
Order Amiiformes																								
Family Amiidae																								
Amia sp.		40																						
Order Cypriniformes																								
Family Cyprinidae																								
Cyprinidae indet.															27									
Order Siluriformes																								
Family Ictaluridae																								
Ictalurus sp.		40,*								40														
Ictaluridae indet.															27									
Family Ariidae																								
Rhineastes sp.					*					1														

Taxa	Localities: Fitterer Ranch			Obritsch Ranch			Little Badlands		Chalky Buttes	White Butte, Slope County	Killdeer Mountains	East Rainy Butte	West Rainy Butte	Black Butte, Hettinger County	Sentinel Butte	Square Butte	Medicine Pole Hills	South Lime Hills	Lefor Buttes	White Butte, Hettinger County	Bull Butte	Young Man's Butte	North Star Butte	Coffin Buttes
	Chadron	Brule	Arikaree	Chadron	Brule	Arikaree	Chadron	Brule																
CLASS OSTEICHTHYES (Cont'd)																								
Order Perciformes																								
Family Centrarchidae																								
Centrarchidae indet.															27									
Family Percidae																								
Plioplarchus whitei Cope, 1883															2,7, 14,28									
Plioplarchus sexispinosus Cope, 1883															2,7, 14,28									
Plioplarchus sp.															*									
Osteichthyes indet.		40, *			*			*		40														
CLASS AMPHIBIA																								
Order Anura																								
Family Pelobatidae																								
Scaphiopus skinneri Estes, 1970		19,23																						
Scaphiopus sp.		40																						

Taxa	Localities: Fitterer Ranch			Obritsch Ranch			Little Badlands		Chalky Buttes	White Butte, Slope County	Killdeer Mountains	East Rainy Butte	West Rainy Butte	Black Butte, Hettinger County	Sentinel Butte	Square Butte	Medicine Pole Hills	South Lime Hills	Lefor Buttes	White Butte, Hettinger County	Bull Butte	Young Man's Butte	North Star Butte	Coffin Buttes
	Chadron	Brule	Arikaree	Chadron	Brule	Arikaree	Chadron	Brule																
CLASS REPTILIA																								
Order Chelonia																								
Family Testudinidae																								
Gopherus sp.		*																						
Stylemys nebrascensis Leidy, 1851		*						*									39							
Stylemys sp.		23,*						*		1			*											
Testudo sp.		*																						
Family Trionychidae																								
Trionyx sp.		*								1,6,*			*	*										
Chelonia indet.		40,*			40,*			40,*		40														
Order Crocodylia																								
Crocodylia indet.							5	4		5							*							
Order Squamata																								
Family Anguidae																								
Peltosaurus sp.		40,*			40,*			40,*																

Taxa	Localities: Fitterer Ranch			Obritsch Ranch			Little Badlands		Chalky Buttes	White Butte, Slope County	Killdeer Mountains	East Rainy Butte	West Rainy Butte	Black Butte, Hettinger County	Sentinel Butte	Square Butte	Medicine Pole Hills	South Lime Hills	Lefor Buttes	White Butte, Hettinger County	Bull Butte	Young Man's Butte	North Star Butte	Coffin Buttes
	Chadron	Brule	Arikaree	Chadron	Brule	Arikaree	Chadron	Brule																
CLASS REPTILIA (cont'd)																								
Squamata indet.		40,*			*			5,*	40	1														
Reptilia indet.		40								5														
CLASS AVES																								
Aves indet.		40,*																						
CLASS MAMMALIA																								
Order Apatotheria																								
?Apatemyidae indet.		*																						
Order Leptictidae																								
Family Leptictidae																								
Leptictis (=*Ictops*) *dakotensis* (Leidy, 1868)								*																
Leptictis haydeni Leidy, 1868		*						40,*	22															
Leptictis sp.								40,*		*														
Ictops sp.								5,40	40	5,6														
Order Insectivora																								

Taxa	Localities: Fitterer Ranch			Obritsch Ranch			Little Badlands																	
	Chadron	Brule	Arikaree	Chadron	Brule	Arikaree	Chadron	Brule	Chalky Buttes	White Butte, Slope County	Killdeer Mountains	East Rainy Butte	West Rainy Butte	Black Butte, Hettinger County	Sentinel Butte	Square Butte	Medicine Pole Hills	South Lime Hills	Lefor Buttes	White Butte, Hettinger County	Bull Butte	Young Man's Butte	North Star Butte	Coffin Buttes
CLASS MAMMALIA (cont'd)																								
Family Geolabididae																								
Centetodon marginalis (Cope, 1873)									26,40															
Family Proscalopidae																								
Arctoryctes galbreathi Reed, 1956		16																						
Oligoscalops sp.									40															
?Apternodontidae indet.		*																						
Order Chiroptera																								
?Chiroptera indet.		*						*		*														
Order Creodonta																								
Family Hyaenodontidae																								
Hemipsalodon? grandis Cope, 1885																	39							
Hyaenodon (*Protohyaenodon*) *crucians* Leidy, 1853		24																						
Hyaenodon (*Neohyaenodon*) *horridus* Leidy, 1853		24						24																

Taxa	Fitterer Ranch: Chadron	Fitterer Ranch: Brule	Fitterer Ranch: Arikaree	Obritsch Ranch: Chadron	Obritsch Ranch: Brule	Obritsch Ranch: Arikaree	Little Badlands: Chadron	Little Badlands: Brule	Chalky Buttes	White Butte, Slope County	Killdeer Mountains	East Rainy Butte	West Rainy Butte	Black Butte, Hettinger County	Sentinel Butte	Square Butte	Medicine Pole Hills	South Lime Hills	Lefor Buttes	White Butte, Hettinger County	Bull Butte	Young Man's Butte	North Star Butte	Coffin Buttes
CLASS MAMMALIA (cont'd)																								
Hyaenodon sp.								40		40							9,12							
Creodonta indet.		40						40																
Order Carnivora																								
Family Felidae																								
Dinictis sp.		*							*								9,12							
?*Eusmilus* sp.		*																						
Hoplophoneus sp.								40		1														
Felidae indet.		*			40,*			40,*																
Family Mustelidae																								
Mustelidae indet.		40						40,*																
Family Canidae																								
Hesperocyon sp.		*			*			*	40,*															
Perictine indet.		*																						
Family Amphicyonidae																								

Taxa	Localities: Fitterer Ranch			Obritsch Ranch			Little Badlands																
	Chadron	Brule	Arikaree	Chadron	Brule	Arikaree	Chadron	Brule	Chalky Buttes	White Butte, Slope County	Killdeer Mountains	East Rainy Butte	West Rainy Butte	Black Butte, Hettinger County	Sentinel Butte	Square Butte	Medicine Pole Hills	South Lime Hills	Lefor Buttes	White Butte, Hettinger County	Bull Butte	Young Man's Butte	North Star Butte	Coffin Buttes
CLASS MAMMALIA (cont'd)																								
Daphoenus dodgei (Scott, 1898)								*																
Daphoenus sp.		*																						
Cynodictus gregarius (Cope, 1893)								7																
Amphicyonidae indet.		*																						
Carnivora indet.		40			40					40														
Order Perissodactyla																								
Family Equidae																								
Mesohippus bairdi (Leidy, 1850)		*						30,*		3														
Mesohippus exoletus (Cope, 1874)		30,40						30,40																
Mesohippus sp.		*			*			5,*	*	5,6,*			*											
Mesohippus brachystylus? (Osborn, 1904)										3														
Miohippus obliquidens (Osborn, 1904)		30,40										30,31												
Miohippus assiniboiensis (Lambe, 1905)							30																	
Miohippus planidens (Lambe, 1905)		40																						

Taxa	Localities: Fitterer Ranch			Obritsch Ranch			Little Badlands		Chalky Buttes	White Butte, Slope County	Killdeer Mountains	East Rainy Butte	West Rainy Butte	Black Butte, Hettinger County	Sentinel Butte	Square Butte	Medicine Pole Hills	South Lime Hills	Lefor Buttes	White Butte, Hettinger County	Bull Butte	Young Man's Butte	North Star Butte	Coffin Buttes
	Chadron	Brule	Arikaree	Chadron	Brule	Arikaree	Chadron	Brule																
CLASS MAMMALIA (cont'd)																								
Miohippus cf. *M. validus* (Osborn, 1904)										40														
Miohippus sp.		*							13,17				*											
Family Brontotheriidae																								
?*Brontops* sp.																	7							
Megacerops prouti (Owen, Norwood, & Evans, 1850)																	39							
Brontotheriidae indet.	*			29,*			29,*									34,*	9,12, 21,*							
Family Hyracodontidae																								
Hyracodon nebrascensis Leidy, 1850					40,*			*																
Hyracodon sp.								5,*	13,17	5,6							9,12							
Family Rhinocerotidae																								
Amphicaenopus sp.									23,36	21,23 (?)														
Subhyracodon occidentalis (Leidy, 1851)		40,*			40,*			7,40 *																

Taxa	Localities: Fitterer Ranch			Obritsch Ranch			Little Badlands																	
	Chadron	Brule	Arikaree	Chadron	Brule	Arikaree	Chadron	Brule	Chalky Buttes	White Butte, Slope County	Killdeer Mountains	East Rainy Butte	West Rainy Butte	Black Butte, Hettinger County	Sentinel Butte	Square Butte	Medicine Pole Hills	South Lime Hills	Lefor Buttes	White Butte, Hettinger County	Bull Butte	Young Man's Butte	North Star Butte	Coffin Buttes
CLASS MAMMALIA (cont'd)																								
Subhyracodon sp.		15,23, *			*			*																
Aceratherium tridactylum (Osborn, 1893)								4		4,5		*(?)	*(?)											
Aceratherium sp.								5		1,5,6														
Metamynodon sp.									*															
Rhinoceros sp.								5																
Rhinocerotidae indet.		*			*			*	*	5,*		*	29,*	*										*
Order Artiodactyla																								
Family Entelodontidae																								
Archaeotherium mortoni Leidy, 1850		*																						
Archaeotherium sp.		*																						
Elotherium ramosum Cope										1,6														
Entelodontidae indet.										40														
Family Leptochoeridae																								
Leptochoeridae indet.		40			40			40																

Taxa	Localities: Fitterer Ranch			Obritsch Ranch			Little Badlands																	
	Chadron	Brule	Arikaree	Chadron	Brule	Arikaree	Chadron	Brule	Chalky Buttes	White Butte, Slope County	Killdeer Mountains	East Rainy Butte	West Rainy Butte	Black Butte, Hettinger County	Sentinel Butte	Square Butte	Medicine Pole Hills	South Lime Hills	Lefor Buttes	White Butte, Hettinger County	Bull Butte	Young Man's Butte	North Star Butte	Coffin Buttes
CLASS MAMMALIA (cont'd)																								
Family Suidae																								
Thinohyus sp.		40																						
Family Tayassuidae																								
Perchoerus sp.													*											
Family Anthracotheriidae																								
Bothriodon sp.		*																						
Elomeryx armatus (Marsh, 1894)												*												
Elomeryx sp.										40														
Family Merycoidontidae																								
Merychyus sp.											31,40													
Merycochoerus sp.											31,40													
Merycoidodon culbertsoni Leidy, 1848		*						5,7,*		5,6														
Merycoidodon sp.		*						5,*	*	5,*														

Taxa	Localities: Fitterer Ranch			Obritsch Ranch			Little Badlands																
	Chadron	Brule	Arikaree	Chadron	Brule	Arikaree	Chadron	Brule	Chalky Buttes	White Butte, Slope County	Killdeer Mountains	East Rainy Butte	West Rainy Butte	Black Butte, Hettinger County	Sentinel Butte	Square Butte	Medicine Pole Hills	South Lime Hills	Lefor Buttes	White Butte, Hettinger County	Bull Butte	Young Man's Butte	North Star Butte	Coffin Buttes
CLASS MAMMALIA (cont'd)																								
Merycoidodon (Anomerycoidodon) dani Schultz & Falkenbach, 1968		18																						
Otionohyus wardi Schultz & Falkenbach, 1968								18																
Otionohyus (Otarohyus) bullatus (Leidy, 1869)		18																						
Eporeodon major (?) (Leidy, 1853)									38															
?Eporeodon sp.									13,17															
Genetochoerus (Osbornohyus) norbeckensis Schultz & Falkenbach, 1968		18																						
Genetochoerus (Osbornohyus) dickinsonensis (Douglass, 1907)								18																
Eucrotaphus dickinsonensis Douglass, 1907								5																
Genetochoerus (Osbornohyus) geygani Schultz & Falkenbach, 1968		18																						
Leptauchenia decora Leidy, 1856										*														
Leptauchenia sp.									13,17															
Paramerycoidodon georgi Schultz & Falkenbach, 1968		18																						

Taxa	Localities: Fitterer Ranch Chadron	Fitterer Ranch Brule	Fitterer Ranch Arikaree	Obritsch Ranch Chadron	Obritsch Ranch Brule	Obritsch Ranch Arikaree	Little Badlands Chadron	Little Badlands Brule	Chalky Buttes	White Butte, Slope County	Killdeer Mountains	East Rainy Butte	West Rainy Butte	Black Butte, Hettinger County	Sentinel Butte	Square Butte	Medicine Pole Hills	South Lime Hills	Lefor Buttes	White Butte, Hettinger County	Bull Butte	Young Man's Butte	North Star Butte	Coffin Buttes
CLASS MAMMALIA (cont'd)																								
Paramerycoidodon (*Barbourochoerus*) sp.		*																						
Miniochoerus starkensis Schultz & Falkenbach, 1956								11																
Miniochoerus (*Paraminiochoerus*) *helprini* Schultz & Falkenbach, 1956								11																
Platychoerus heartensis Schultz & Falkenbach, 1956								11																
Merycoidontidae indet.		8,40, *			*			40,*		1,6,*														
Family Camelidae																								
Poebrotherium sp.								5,*									9,12							
Family Protoceratidae																								
?*Protoceras* sp.									17															
Family Hypertragulidae																								
Hypertragulus minor										23														
Hypertragulus sp.		40								1														

Taxa	Localities: Fitterer Ranch: Chadron	Fitterer Ranch: Brule	Fitterer Ranch: Arikaree	Obritsch Ranch: Chadron	Obritsch Ranch: Brule	Obritsch Ranch: Arikaree	Little Badlands: Chadron	Little Badlands: Brule	Chalky Buttes	White Butte, Slope County	Killdeer Mountains	East Rainy Butte	West Rainy Butte	Black Butte, Hettinger County	Sentinel Butte	Square Butte	Medicine Pole Hills	South Lime Hills	Lefor Buttes	White Butte, Hettinger County	Bull Butte	Young Man's Butte	North Star Butte	Coffin Buttes
CLASS MAMMALIA (cont'd)																								
Nanotragulus sp.										40														
Family Leptomerycidae																								
Leptomeryx evansi Leidy, 1853		*						7,*	*	5,6														
Leptomeryx sp.		*			*			40,*	13,17, *	1,5, 6,*							9,12, 39							
Order Rodentia																								
Family Ischyromyidae																								
Ischyromys typus Leidy, 1856		37,*			*			37,*	*															
Ischyromys sp.		40,*			40,*			5,40, *	5,40, *	5,6,40														
Family Aplodontidae																								
?*Cedromus* sp.									13,17															
Prosciurus sp.		40,*							13,17															
Prosciurus cf. *P. relictus* (Cope, 1873)		40																						
Family Sciuridae																								

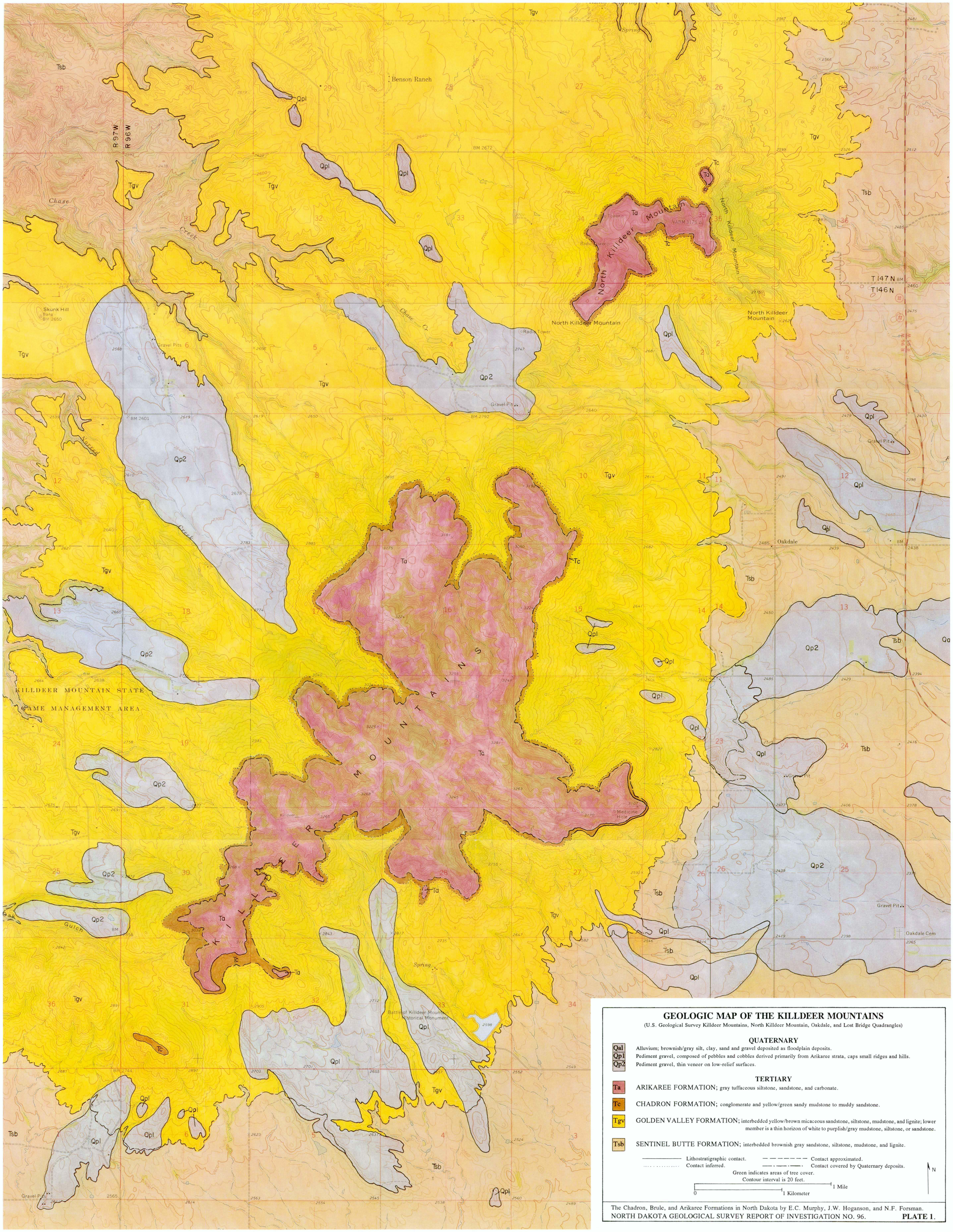
Taxa	Localities: Fitterer Ranch			Obritsch Ranch			Little Badlands		Chalky Buttes	White Butte, Slope County	Killdeer Mountains	East Rainy Butte	West Rainy Butte	Black Butte, Hettinger County	Sentinel Butte	Square Butte	Medicine Pole Hills	South Lime Hills	Lefor Buttes	White Butte, Hettinger County	Bull Butte	Young Man's Butte	North Star Butte	Coffin Buttes
	Chadron	Brule	Arikaree	Chadron	Brule	Arikaree	Chadron	Brule																
CLASS MAMMALIA (cont'd)																								
Protosciurus sp.		*																						
Family Castoridae																								
Palaeocastor complexus		40						40																
Palaeocastor sp.		40				20,23, *																		
Agnotocastor praetereadens Stirton, 1935		*																						
Agnotocastor sp.		40, *							*															
Castor sp.										1														
Family Eutypomyidae																								
Eutypomys thomsoni (Matthew, 1905)								40																
Eutypomys magnus A. Wood, 1937		40																						
Eutypomys sp.		40						40																
Family Eomyidae																								
Adjidaumo douglassi Burke, 1934		*																						
Adjidaumo minimus (Matthew, 1903)		40																						

Taxa	Localities: Fitterer Ranch			Obritsch Ranch			Little Badlands																
	Chadron	Brule	Arikaree	Chadron	Brule	Arikaree	Chadron	Brule	Chalky Buttes	White Butte, Slope County	Killdeer Mountains	East Rainy Butte	West Rainy Butte	Black Butte, Hettinger County	Sentinel Butte	Square Butte	Medicine Pole Hills	South Lime Hills	Lefor Buttes	White Butte, Hettinger County	Bull Butte	Young Man's Butte	North Star Butte	Coffin Buttes
CLASS MAMMALIA (cont'd)																								
Adjidaumo sp.		*							*															
cf. *Adjidaumo* sp.		40																						
Gymnoptychus sp.										5,6														
Paradjidaumo trilophus (Cope, 1873)		40						40	40,*															
Paradjidaumo minor (Douglass, 1901)		40							40															
Paradjidaumo sp.		*							13,17, 40,*															
Family Heteromyidae																								
?*Heliscomys* sp.					*																			
Family Cricetidae																								
Eumys elegans Leidy, 1856		40,*			40,*			40,*	40	32														
Eumys ?obliquidens A. Wood, 1937									40	32														
Eumys brachyodus A. Wood, 1937		40						32																
Eumys planidens (Wilson, 1949)		40																						
Eumys cf. *E. parvidens* A. Wood, 1937									40															

Taxa	Localities																						
	Fitterer Ranch			Obritsch Ranch			Little Badlands		Chalky Buttes	White Butte, Slope County	Killdeer Mountains	East Rainy Butte	West Rainy Butte	Black Butte, Hettinger County	Sentinel Butte	Square Butte	Medicine Pole Hills	South Lime Hills	Lefor Buttes	White Butte, Hettinger County	Bull Butte	Young Man's Butte	North Star Butte	Coffin Buttes
	Chadron	Brule	Arikaree	Chadron	Brule	Arikaree	Chadron	Brule																
CLASS MAMMALIA (cont'd)																								
Eumys cf. *E. exiguus* (A. Wood, 1937)									40															
Eumys sp.		40,*			40,*			40,*	13,17, 40,*	5,6			*											
Cricetidae indet.										25														
Rodentia indet.		8																						
Order Lagomorpha																								
Family Leporidae																								
Palaeolagus haydeni Leidy, 1856		40,*						40,*	40	33,40														
Palaeolagus burkei A. Wood, 1940		40			40			40		40														
Palaeolagus sp.		40,*			40,*			5,32, 40,*	13,17, *	5,6,*														
Megalagus turgidus (Cope, 1873)										33(?)														
Megalagus sp.									*															

Taxa	Localities																							
	Fitterer Ranch			Obritsch Ranch			Little Badlands																	
	Chadron	Brule	Arikaree	Chadron	Brule	Arikaree	Chadron	Brule	Chalky Buttes	White Butte, Slope County	Killdeer Mountains	East Rainy Butte	West Rainy Butte	Black Butte, Hettinger County	Sentinel Butte	Square Butte	Medicine Pole Hills	South Lime Hills	Lefor Buttes	White Butte, Hettinger County	Bull Butte	Young Man's Butte	North Star Butte	Coffin Buttes
TRACE FOSSILS																								
Pallichus dakotensis Retallack, 1984 (beetle pupal cells)		*			*			*	*															
Celliforma ficoides Retallack, 1984 (bee larval cells)		*							*															
burrows		*						*			35,*				27,*									
fish coprolites															27									
mammal coprolites		*						40,*																

Sources: 1) Cope (1883a); 2) Cope (1883b); 3) Douglass (1908a); 4) Douglass (1908b); 5) Douglass (1909); 6) Leonard (1919); 7) Leonard (1922); 8) Skinner (1951); 9) Benson (1952); 10) Hansen (1953); 11) Schulz and Falkenbach (1956); 12) Denson et al. (1959); 13) Moore et al. (1959); 14) Feldmann (1962); 15) Chinburg and Holland (1965); 16) Reed and Turnbull (1965); 17) Denson and Gill (1965); 18) Schulz and Falkenbach (1968); 19) Estes (1970); 20) Stout and Stone (1971); 21) Stone (1972); 22) West (1972); 23) Stone (1973); 24) Mellett (1977); 25) Korth (1981); 26) Lillegraven et al. (1981); 27) Boyer (1981); 28) Kihm and Lammers (1986); 29) Lammers and Hoganson (1988); 30) Prothero and Shubin (1989); 31) Tedford (1989); 32) Kihm (1990); 33) Wretling (1991); 34) Brown (1948) [Purdy, 1993]; 35) Delimata (1975); 36) Stone (1970a); 37) Heaton (1993); 38) Babcock and Clapp (1906); 39) Hares, (1928); 40) Taxa cataloged at the American Museum of Natural History (FAM) collected by Morris Skinner (1944-1964); and * this study.



GEOLOGIC MAP OF THE KILLDEER MOUNTAINS

(U.S. Geological Survey Killdeer Mountains, North Killdeer Mountain, Oakdale, and Lost Bridge Quadrangles)

QUATERNARY

Qal Alluvium; brownish/gray silt, clay, sand and gravel deposited as floodplain deposits.

Qp1 Pediment gravel, composed of pebbles and cobbles derived primarily from Arikaree strata, caps small ridges and hills.

Qp2 Pediment gravel, thin veneer on low-relief surfaces.

TERTIARY

Ta ARIKAREE FORMATION; gray tuffaceous siltstone, sandstone, and carbonate.

Tc CHADRON FORMATION; conglomerate and yellow/green sandy mudstone to muddy sandstone.

Tgv GOLDEN VALLEY FORMATION; interbedded yellow/brown micaceous sandstone, siltstone, mudstone, and lignite; lower member is a thin horizon of white to purplish/gray mudstone, siltstone, or sandstone.

Tsb SENTINEL BUTTE FORMATION; interbedded brownish gray sandstone, siltstone, mudstone, and lignite.

Lithostratigraphic contact. Contact approximated.
Contact inferred. Contact covered by Quaternary deposits.

Green indicates areas of tree cover.

Contour interval is 20 feet.

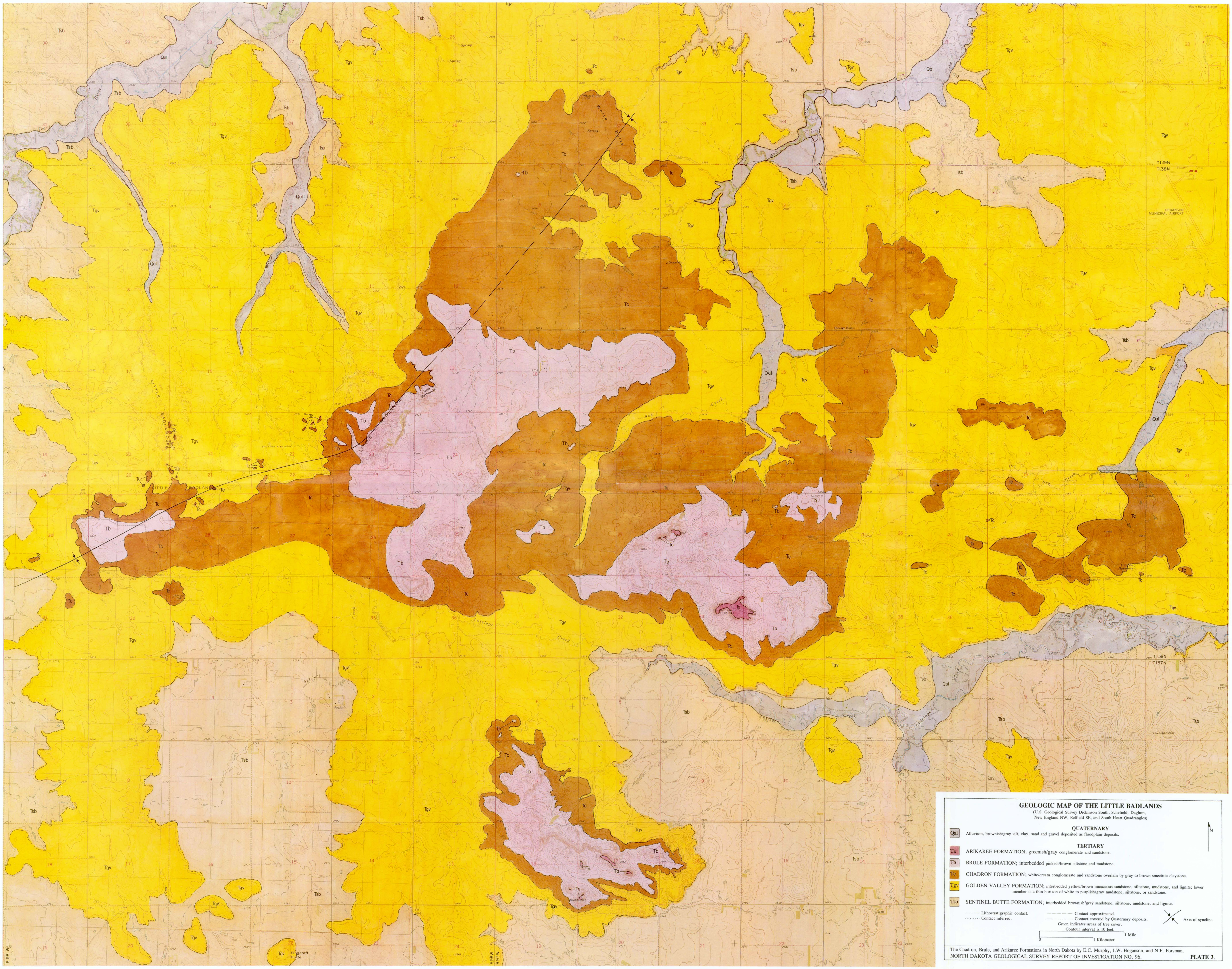
0 — 1 Mile — 1 Kilometer

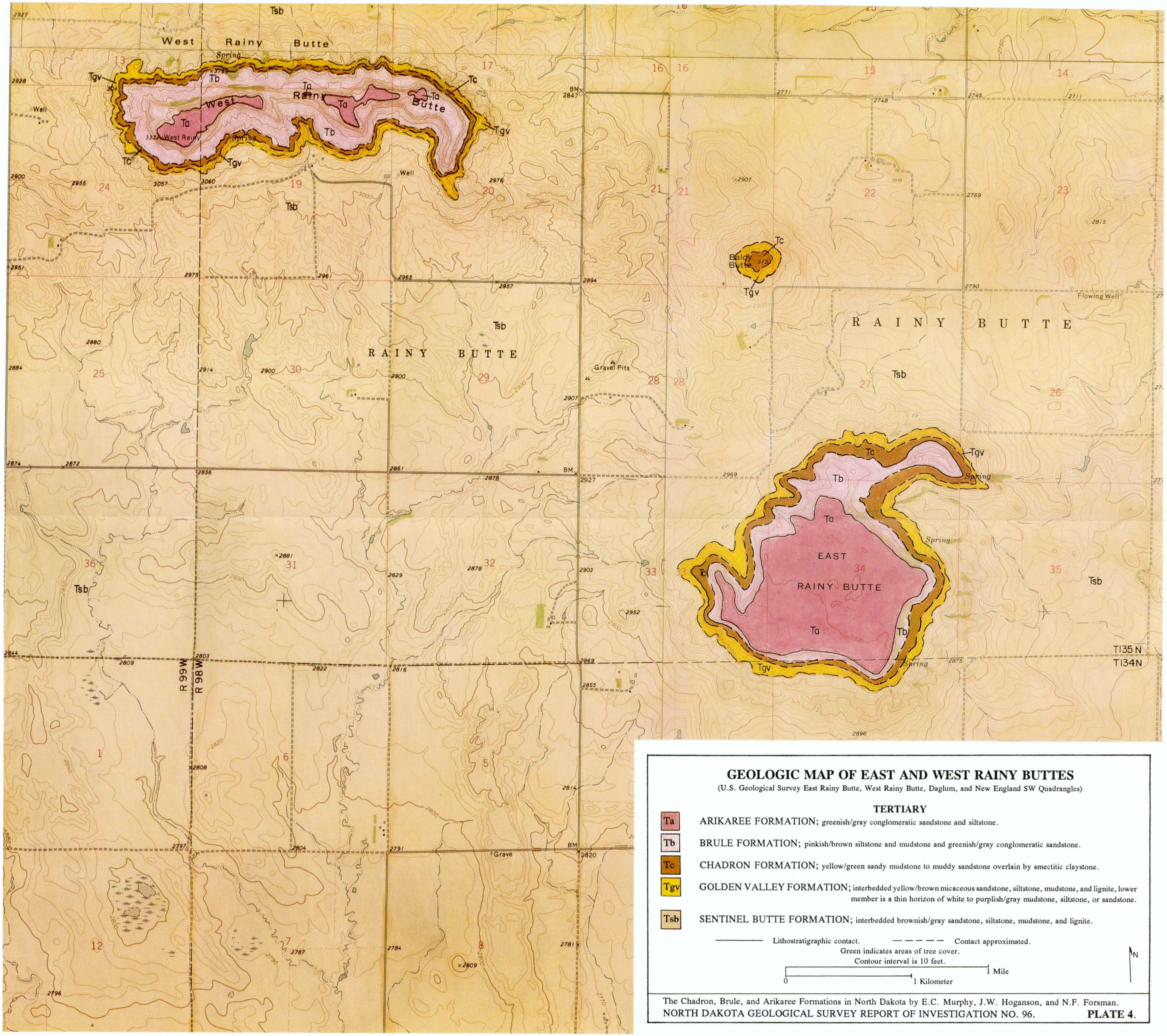
N

The Chadron, Brule, and Arikaree Formations in North Dakota by E.C. Murphy, J.W. Hoganson, and N.F. Forsman.

NORTH DAKOTA GEOLOGICAL SURVEY REPORT OF INVESTIGATION NO. 96. **PLATE 1.**


CENTER
CHALKY BUTTE
CHALKY BUTTE
CONNOR
Boulder Point
Browns Hill
Black Butte
Tepee Butte
Slide Butte
White Butte
Rattlesnake Butte
CHALKY BUTTES
Radio Tower
Storage Bins
Duffy Gulch
Sand Creek
North Fork Cedar Creek
STEWART LAKE
NATIONAL WILDLIFE REFUGE
STEWART LAKE
SPILLWAY
R102W
R101W
R101W
R100W
T134N
T133N
ASH
SHEETS
SHEETS
GEOLOGIC MAP OF BLACK BUTTE AND CHALKY BUTTES
(U.S. Geological Survey Amidon, Amidon SE, Black Butte, and Stewart Lake Quadrangles)
QUATERNARY
Qal Alluvium; brownish gray, silt, clay, sand and gravel deposited as floodplain deposits.
Qp1 Pediment gravel, composed of pebbles and cobbles derived primarily from Chadron, Brule, and Arikaree strata, caps small ridges.
Qp2 Pediment gravel, thin veneer on low-relief surfaces.
Qls Landslide material.
TERTIARY
Ta ARIKAREE FORMATION; interbedded greenish/gray conglomerate, sandstone, siltstone, and carbonates.
Tb BRULE FORMATION; interbedded pinkish/brown siltstone and mudstone.
Tc CHADRON FORMATION; white conglomerate, sandstone, and mudstone overlain by gray to brown smectitic claystone.
Tsb SENTINEL BUTTE FORMATION; interbedded brownish gray sandstone, siltstone, mudstone, and lignite.
Tbc BULLION CREEK FORMATION; interbedded buff and light gray sandstone, siltstone, mudstone, and lignite.
Lithostratigraphic contact.
Contact inferred.
Contact approximated.
Contact covered by Quaternary deposits.
Green indicates areas of tree cover.
Contour interval varies from 10 feet (south) to 20 feet (north).
0
1 Mile
1 Kilometer
N
The Chadron, Brule, and Arikaree Formations in North Dakota by E.C. Murphy, J.W. Hoganson, and N.F. Forsman.
NORTH DAKOTA GEOLOGICAL SURVEY REPORT OF INVESTIGATION NO. 96. PLATE 2.


GEOLOGIC MAP OF THE LITTLE BADLANDS
(U.S. Geological Survey Dickinson South, Schefield, Daglum, New England NW, Belfield SE, and South Heart Quadrangles)
QUATERNARY
Qal Alluvium, brownish/gray silt, clay, sand and gravel deposited as floodplain deposits.
TERTIARY
Ta ARIKAREE FORMATION; greenish/gray conglomerate and sandstone.
Tb BRULE FORMATION; interbedded pinkish/brown siltstone and mudstone.
Tc CHADRON FORMATION; white/cream conglomerate and sandstone overlain by gray to brown smectitic claystone.
Tgv GOLDEN VALLEY FORMATION; interbedded yellow/brown micaceous sandstone, siltstone, mudstone, and lignite; lower member is a thin horizon of white to purplish/gray mudstone, siltstone, or sandstone.
Tsb SENTINEL BUTTE FORMATION; interbedded brownish/gray sandstone, siltstone, mudstone, and lignite.
Lithostratigraphic contact.
Contact inferred.
Contact approximated.
Contact covered by Quaternary deposits.
Green indicates areas of tree cover.
Contour interval is 10 feet.
Axis of syncline.
N
0
1 Mile
1 Kilometer
The Chadron, Brule, and Arikaree Formations in North Dakota by E.C. Murphy, J.W. Hoganson, and N.F. Forsman.
NORTH DAKOTA GEOLOGICAL SURVEY REPORT OF INVESTIGATION NO. 96.
PLATE 3.
DICKINSON MUNICIPAL AIRPORT
T139N
T138N
T138N
T137N
Flagstaff Butte
Daglum



GEOLOGIC MAP OF EAST AND WEST RAINY BUTTES

(U.S. Geological Survey East Rainy Butte, West Rainy Butte, Daglum, and New England SW Quadrangles)

TERTIARY

Ta	ARIKAREE FORMATION; greenish/gray conglomeratic sandstone and siltstone.
Tb	BRULE FORMATION; pinkish/brown siltstone and mudstone and greenish/gray conglomeratic sandstone.
Tc	CHADRON FORMATION; yellow/green sandy mudstone to muddy sandstone overlain by smectitic claystone.
Tgv	GOLDEN VALLEY FORMATION; interbedded yellow/brown micaceous sandstone, siltstone, mudstone, and lignite, lower member is a thin horizon of white to purplish/gray mudstone, siltstone, or sandstone.
Tsb	SENTINEL BUTTE FORMATION; interbedded brownish/gray sandstone, siltstone, mudstone, and lignite.

Lithostratigraphic contact. Contact approximated.

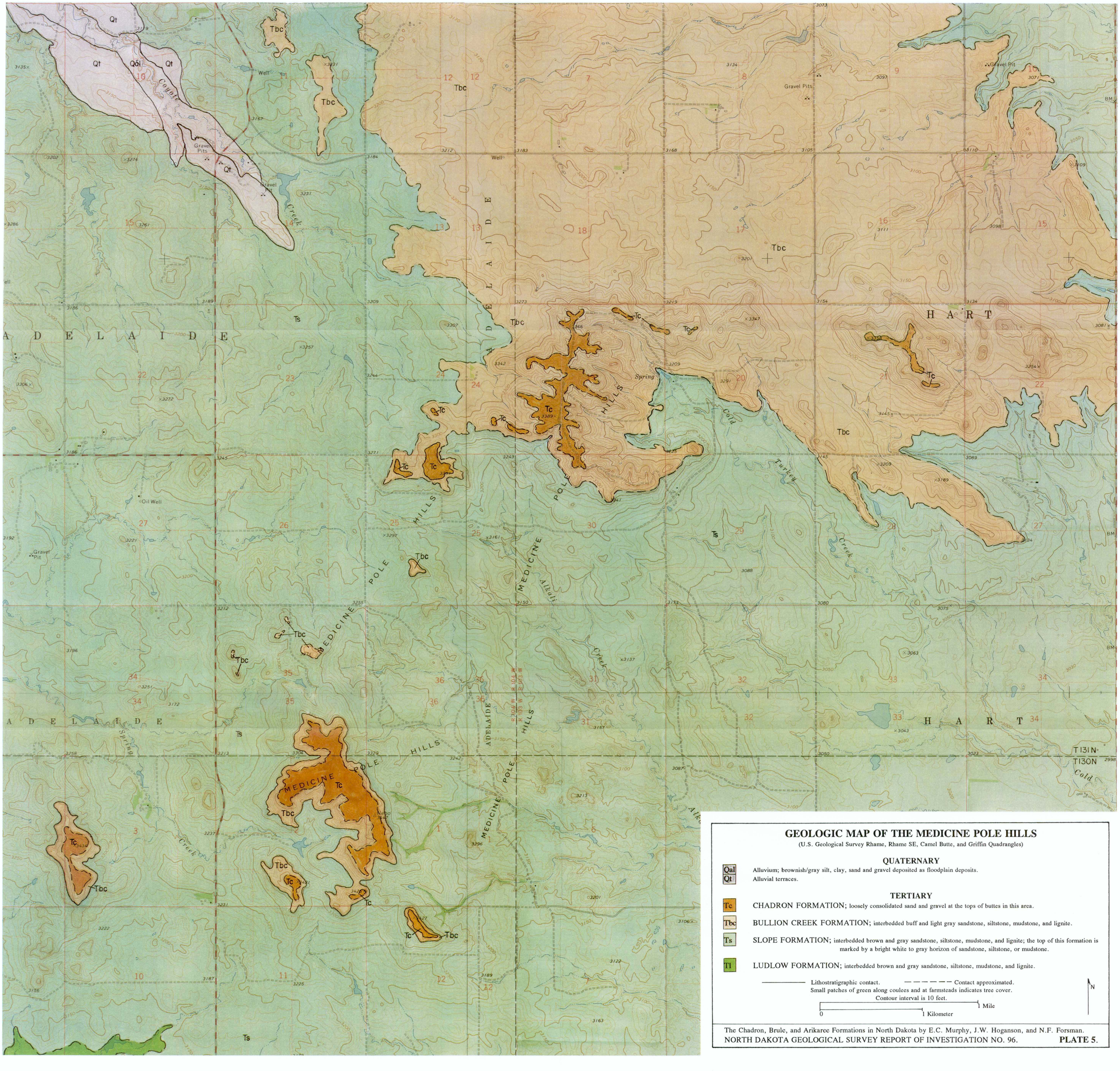
Green indicates areas of tree cover.

Contour interval is 10 feet.

0 1 Mile 1 Kilometer N

The Chadron, Brule, and Arikaree Formations in North Dakota by E.C. Murphy, J.W. Hoganson, and N.F. Forsman.

NORTH DAKOTA GEOLOGICAL SURVEY REPORT OF INVESTIGATION NO. 96. **PLATE 4.**



GEOLOGIC MAP OF THE MEDICINE POLE HILLS

(U.S. Geological Survey Rhame, Rhame SE, Camel Butte, and Griffin Quadrangles)

QUATERNARY

Qal — Alluvium; brownish/gray silt, clay, sand and gravel deposited as floodplain deposits.

Qt — Alluvial terraces.

TERTIARY

Tc — CHADRON FORMATION; loosely consolidated sand and gravel at the tops of buttes in this area.

Tbc — BULLION CREEK FORMATION; interbedded buff and light gray sandstone, siltstone, mudstone, and lignite.

Ts — SLOPE FORMATION; interbedded brown and gray sandstone, siltstone, mudstone, and lignite; the top of this formation is marked by a bright white to gray horizon of sandstone, siltstone, or mudstone.

Tl — LUDLOW FORMATION; interbedded brown and gray sandstone, siltstone, mudstone, and lignite.

Lithostratigraphic contact. — — — — Contact approximated.

Small patches of green along coulees and at farmsteads indicates tree cover.

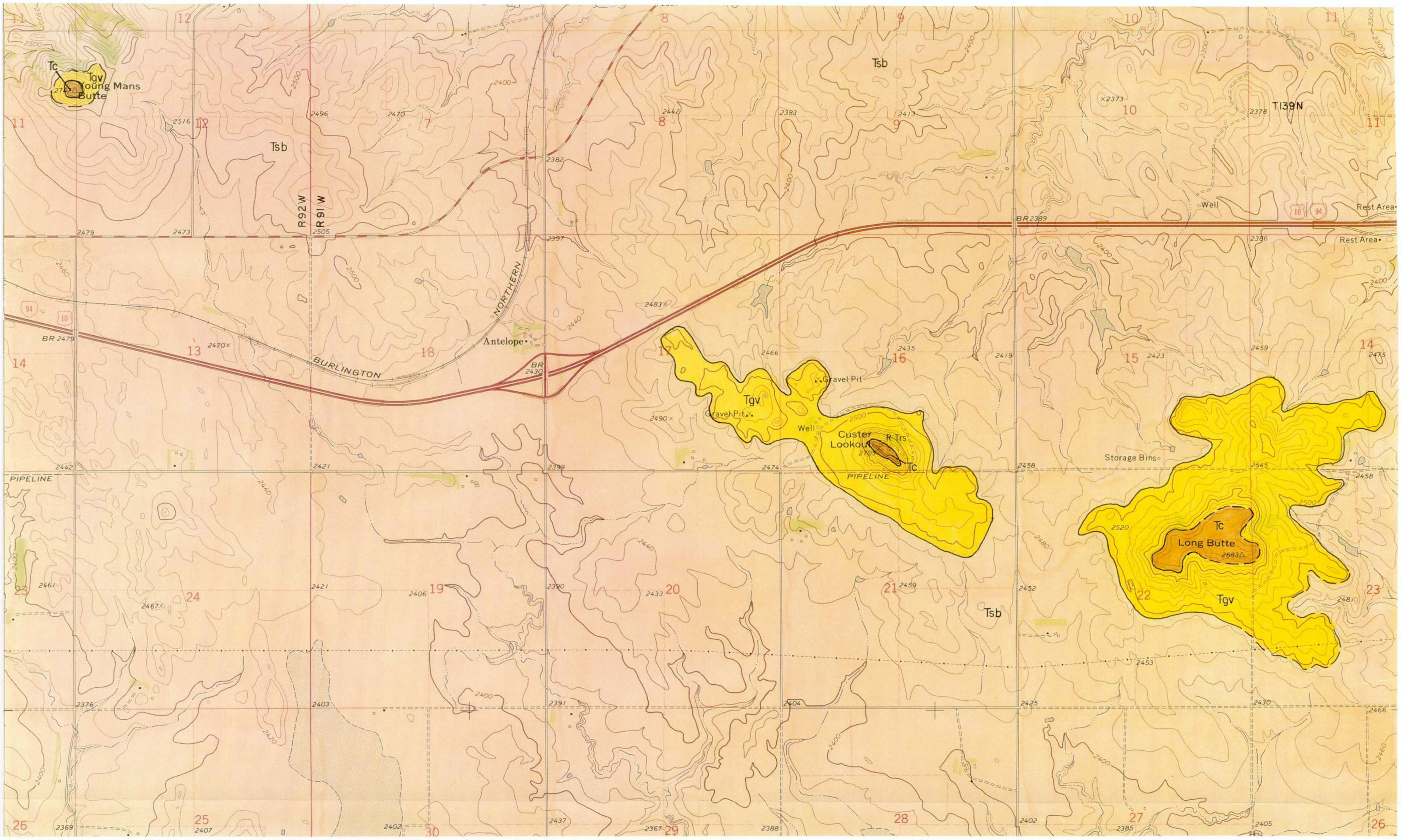
Contour interval is 10 feet.

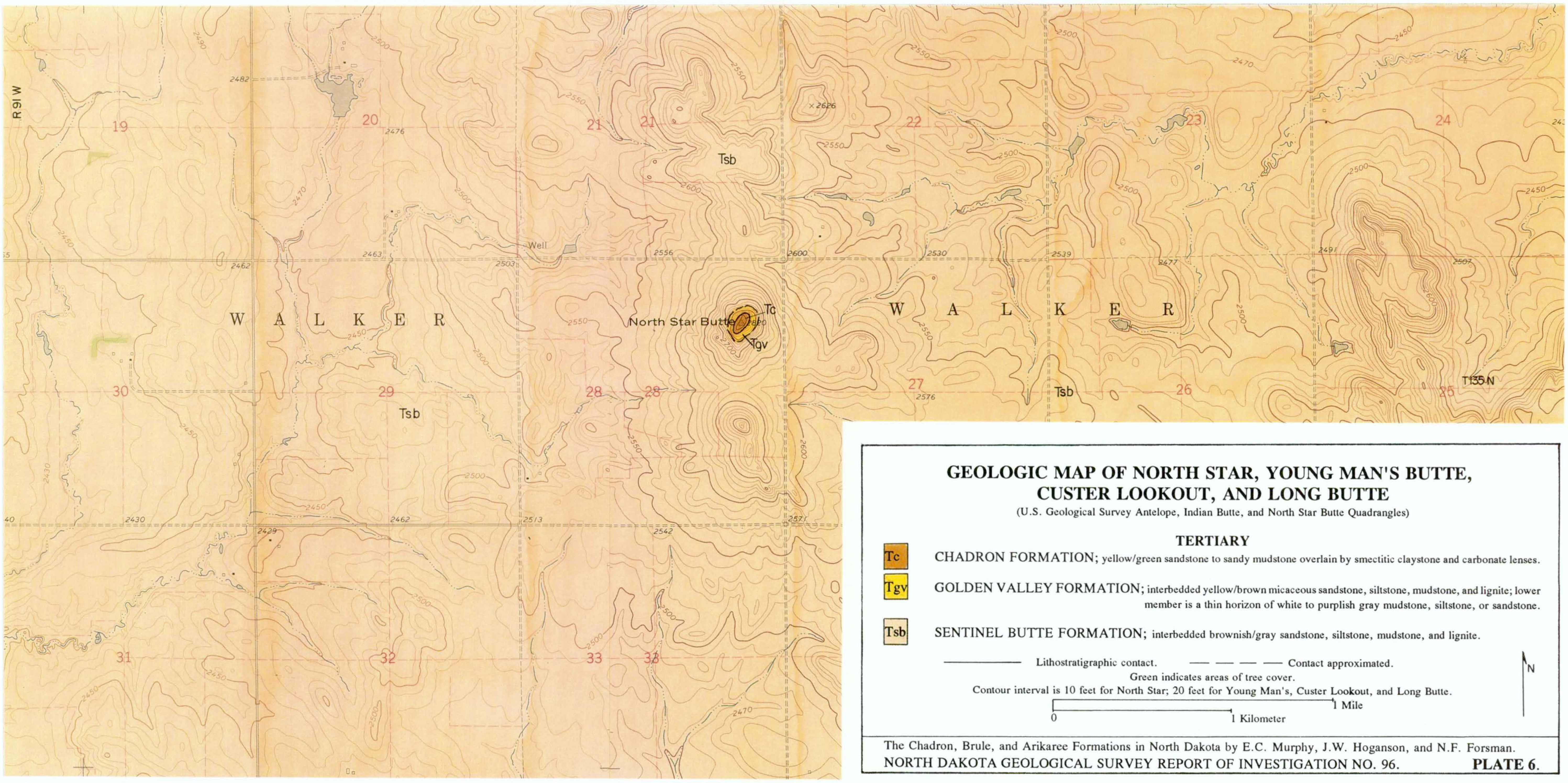
0 — 1 Mile — 1 Kilometer

N

The Chadron, Brule, and Arikaree Formations in North Dakota by E.C. Murphy, J.W. Hoganson, and N.F. Forsman.

NORTH DAKOTA GEOLOGICAL SURVEY REPORT OF INVESTIGATION NO. 96. **PLATE 5.**





GEOLOGIC MAP OF NORTH STAR, YOUNG MAN'S BUTTE, CUSTER LOOKOUT, AND LONG BUTTE

(U.S. Geological Survey Antelope, Indian Butte, and North Star Butte Quadrangles)

TERTIARY

Tc	CHADRON FORMATION; yellow/green sandstone to sandy mudstone overlain by smectitic claystone and carbonate lenses.
Tgv	GOLDEN VALLEY FORMATION; interbedded yellow/brown micaceous sandstone, siltstone, mudstone, and lignite; lower member is a thin horizon of white to purplish gray mudstone, siltstone, or sandstone.
Tsb	SENTINEL BUTTE FORMATION; interbedded brownish/gray sandstone, siltstone, mudstone, and lignite.

——— Lithostratigraphic contact. — — — — Contact approximated.

Green indicates areas of tree cover.

Contour interval is 10 feet for North Star; 20 feet for Young Man's, Custer Lookout, and Long Butte.

0 — 1 Mile — 1 Kilometer

N

The Chadron, Brule, and Arikaree Formations in North Dakota by E.C. Murphy, J.W. Hoganson, and N.F. Forsman.
NORTH DAKOTA GEOLOGICAL SURVEY REPORT OF INVESTIGATION NO. 96. **PLATE 6.**


Tgv
Tc
Tsb
Lefor
STARK CO
HETTINGER CO
T137N
T136N
RIFLE
MADISON
CAMPBELL
Plum Creek
LIME HILLS
Thirtymile Creek
WHITE BUTTE
White Butte
Bull Butte
Campbell Butte
LANDING STRIP
St Michael Ch
GEOLOGIC MAP OF THE CARBONATE-CAPPED BUTTES IN SOUTHEASTERN STARK AND HETTINGER COUNTIES
(U.S. Geological Survey White Butte East, White Butte West, White Butte NE, White Butte NW, Lefor, and Stony Butte Quadrangles)
TERTIARY
Tc CHADRON FORMATION; yellow/green sandstone to sandy mudstone overlain by smectitic claystone and carbonate lenses.
Tgv GOLDEN VALLEY FORMATION; interbedded yellow/brown micaceous sandstone, siltstone, mudstone, and lignite; lower member is a thin horizon of white to purplish/gray mudstone, siltstone, or sandstone.
Tsb SENTINEL BUTTE FORMATION; interbedded brownish/gray sandstone, siltstone, mudstone, and lignite.
Lithostratigraphic contact.
Contact approximated.
Green indicates areas of tree cover.
Contour interval is 10 feet.
1 Mile
0
1 Kilometer
N
The Chadron, Brule, and Arikaree Formations in North Dakota by E.C. Murphy, J.W. Hoganson, and N.F. Forsman.
NORTH DAKOTA GEOLOGICAL SURVEY REPORT OF INVESTIGATION NO. 96
PLATE 7.