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Geologic Framework of the Niobrara River Drainage Basin and Adjacent Areas in South Dakota Generally East of the 100th Meridian West Longitude and West of the Missouri River

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**Geologic Framework of the Niobrara River Drainage
Basin and Adjacent Areas in South Dakota
Generally East of the 100th Meridian West Longitude
and West of the Missouri River**

**R.F. Diffendal, Jr.
and
M.R. Voorhies**

**Nebraska Geological Survey
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University of Nebraska-Lincoln**

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May 1994

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Geologic Framework of the Niobrara River Drainage Basin and Adjacent Areas in South Dakota Generally East of the 100th Meridian West Longitude and West of the Missouri River

by R.F. Diffendal, Jr.¹
and
M.R. Voorhies²

Abstract

General geology and stratigraphy of the Niobrara River drainage basin in Nebraska and adjacent parts of South Dakota generally west of the Missouri River is reviewed. Of particular importance are the correlation of the Long Pine Formation of Pliocene age in Nebraska with the Herrick Gravels in South Dakota, the recognition of the members of the Ogallala Group named by Skinner, Skinner and Gooris (1968) and by Skinner and Johnson (1984) in the basin, the acceptance of the relationships of the Miocene and older Tertiary units in the basin to those in the part of the study area in South Dakota as proposed by Skinner and Taylor (1967), Skinner, Skinner and Gooris (1968) and by Skinner and Johnson (1984), and the recognition of the Rosebud Formation of the Arikaree Group (Skinner, Skinner, and Gooris, 1968) in the basin. Rocks now included in the Rosebud were placed previously in the White River Group by the Conservation and Survey Division (Burchett, 1986). A refined geologic map of the area shows the currently known distributions of all of the major units, including the Long Pine/Herrick, the Rosebud, and the Chadron formations, none of which has been shown on a map of the study area previously.

Introduction

This report covers the geology of the eastern part of the Niobrara Basin in Nebraska and adjacent parts of South Dakota. This geology

includes the present scene and the geologic history of the basin. Readers who are interested in the geology of the western part of the basin (not included in this report) should read the works of Swinehart and Diffendal (1990), Swinehart and others (1985), and Souders (1981) cited in the references, the works of R. M. Hunt, Jr., of the University of Nebraska State Museum and his students (Hunt, 1978, 1990; Hunt and others, 1983; Yatkola, 1978), and the work of Skinner, Skinner, and Gooris (1977) in the library of the University of Nebraska-Lincoln. These reports contain references to most of the earlier geologic work done in that area.

The geology of the area has been studied for a long time. As early as 1845, Charles Lyell, the famous English geologist, published a geologic map of the United States that showed the presence of Cretaceous strata in the area about the mouth of the Niobrara River and the adjacent Missouri River valley (Diffendal, 1993). The Warren, Meek, and Hayden surveys in the late 1850s resulted in considerable expansion of knowledge of the geology of the Great Plains, including the Niobrara Basin. In the late 1800s and the early 1900s, the focus of work in the basin was mainly paleontological. The history of these activities is reviewed in detail by Voorhies (1990b, 1990c). Considerable debate arose in the 1930s about the stratigraphic names of some of the strata in the basin (Johnson, 1936, 1938; Lugin, 1938, 1939) and was resolved then for a time (Condra and Reed, 1959).

Our present understanding of the general geology of the Niobrara drainage basin east of the 100th meridian comes from the works of a limited number of geologists who have studied the area and written reports about it

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mostly since 1950. We present one figure and two tables that show our view of the current state of geological knowledge in the area. Many of the formation and member names applied to Cenozoic strata in the area were defined by Morris Skinner and his co-workers at the American Museum of Natural History in New York (table 1). M. R. Voorhies of the NU State Museum has also published on the geology and paleontology of the Cenozoic units in the basin (Voorhies, 1969, 1971, 1973, 1974, 1981, 1985, 1987a, 1987b, 1990a, 1990b, 1990c, and Voorhies and Goodwin, 1989). Other paleontological studies were done by Backlund and others (1991), Cobban (1951), Cobban and Scott (1964), Dietrich (1951), Evander (1978), Haffner and others (1990), Johnson and Milburn (1984), Landon (1985), Loetterle (1937), and Wellstead (1981). Groundwater studies that included considerable information on the geology of parts of the lower basin were done by members of the U.S. Geological Survey and members of the Conservation and Survey Division of the University of Nebraska-Lincoln: Condra (1903), Cronin and Newport (1956), Gosselin (1991), Newport (1959), Reed (1944), Souders (1976), and Souders and Shaffer (1969). Schulte (1952) and Mendenhall (1953) did theses on the geology of two counties and part of a third in the basin.

Damsite investigations were done by L. D. Cast and other workers at the U.S. Bureau of Reclamation and by workers in other agencies and organizations (Cast, 1988; Niobrara River Basin Development Association, 1951; U.S. Bureau of Reclamation, 1952, 1962, 1977, 1978, 1980, 1992; U.S. Soil Conservation Service, 1973; U.S. Power and Water Resources Service, 1980). Geology and groundwater studies in the South Dakota part of the map area include those by Hedges (1975), Simpson (1960), and Christensen (1974). J. E. Todd (1912) wrote an early work on Pleistocene drainage development in the basin that was followed by works by R. H. Williams (1984) and Voorhies and Goodwin (1989). Landforms have been analyzed for parts of the area by Flint (1955), Swinehart

(1990), and Guthrie (1990). Considerable work has been done and continues to be done by several geologists, hydrogeologists, and other researchers on the geology in and around the site of the proposed low-level radioactive waste storage facility in Boyd County (for example, Pierce, 1989; Rahn and Davis, 1989). Modern soil surveys have been completed for all of the counties in the eastern part of the basin in Nebraska and in the study area in South Dakota (Indra, 1979; Manhke and others, 1978; Plantz and Zink, 1980; Ragon and others, 1983; Schulte, in press; Shurtliff and others, 1988, 1990; Voightlander and others, 1992; and Zink and Schultz, 1985). Geologic maps of the study area in South Dakota have been prepared by Baker and others (1952), Collins and French (1958), Schoon and Sevon (1958), Stevenson and Carlson (1950, 1951), and Stevenson and others (1958, 1959). The area to the east of the study area in Nebraska was mapped by Burchett and others (1988). The authors of this report currently are preparing a geologic map of the O'Neill 1° x 2° area at a scale of 1:250,000 in cooperation with the U.S. Geological Survey.

Pre-Cretaceous Geology

What we know about the pre-Cretaceous geology of the Nebraska part of the eastern Niobrara Basin and areas to the south adjacent to the basin comes from logs and samples from about 50 oil and gas tests and from geophysical surveys. Precambrian rocks include mostly metamorphic rocks and some granite. An extension of the Sioux Quartzite occurs beneath the easternmost part of the basin (Carlson, 1993). Cambrian and Devonian rocks have been found only in the southeasternmost part of the area included in figure 1. Ordovician and Mississippian rocks occur from the southeastern part of the mapped area in Nebraska northwestward into South Dakota (Carlson, 1993). Pennsylvanian-age rocks have been found beneath the western part of the basin, but no Permian, Triassic, or Jurassic rocks are known (Carlson, 1993).

Nebraska

Cenozoic Erathem

Quaternary System

*Holocene and Pleistocene Fluvial Terrace Deposits

(Up to Five)

Holocene and Pleistocene?

Eolian Sand

Pleistocene Peoria Loess (And Possibly Older Loesses)

*Pleistocene Unnamed Fluvial Units Filling Paleovalleys

(Two or More)

Tertiary System

Pliocene Series

*Pettijohn Formation (Skinner in Skinner and Hibbard, 1972)

*Duffy Formation (Skinner in Skinner and Hibbard, 1972)

**Long Pine Formation (Skinner in Skinner and Hibbard, 1972)

**Keim Formation (Skinner in Skinner and Hibbard, 1972)

Miocene Series

Ogallala Group (Darton, 1899; Revised by Lugn, 1938;
Further Revised and Expanded by Swinehart and Others,
1985)

Ash Hollow Formation (Engelmann, 1876)

*Unnamed Hemphillian Member (Skinner and Johnson, 1984)

**Merritt Dam Member (Skinner and Johnson, 1984)

**Caprock Member (Skinner, Skinner, and Gooris, 1968)

Valentine Formation (Barbour and Cook, 1917)

**Burge Member (Skinner, Skinner, and Gooris, 1968)

**Devil's Gulch Member (Skinner, Skinner, and Gooris, 1968)

**Crookston Bridge Member (Skinner, Skinner, and Gooris,
1968)

**Cornell Dam Member (Skinner and Johnson, 1984)

Lower Miocene-Upper Oligocene Series

Arikaree Group (Darton, 1899; Revised by Lugn, 1938)

*Rosebud Formation (Matthew and Gidley, 1904; Detailed
by Skinner, Skinner, and Gooris, 1968)

Lower Oligocene-Upper Eocene Series

White River Group (Meek and Hayden, 1858; Refined by
Lugn, 1938)

Chadron Formation? (Darton, 1899)

Mesozoic Erathem

Cretaceous System

Upper Cretaceous Series

Pierre Shale (Meek and Hayden, 1862)

Niobrara Formation (Meek and Hayden, 1862)

South Dakota

Cenozoic Erathem

Quaternary System

*Holocene and Pleistocene Fluvial Terrace
Deposits

Holocene and Pleistocene?

Eolian Sand

Pleistocene Loess

*(Equal to Bon Homme Gravel and Tyndall
Sand of Christensen, 1974, east of Missouri
River)

Tertiary System

Pliocene Series

*Herrick Gravels (Stevenson and Carlson,
1950)

Miocene Series

Ogallala Group

Ash Hollow Formation

*Caprock Member

Valentine Formation

*Burge Member

Devil's Gulch Member

**Fort Randall Formation (Skinner and Taylor,
1967)

Lower Miocene-Upper Oligocene Series

**Turtle Butte Formation (Skinner, Skinner,
and Gooris, 1968)
Rosebud Formation

Lower Oligocene-Upper Eocene Series

White River Group

Chadron Formation?

Mesozoic Erathem

Cretaceous System

Upper Cretaceous Series

Pierre Shale

Niobrara Formation

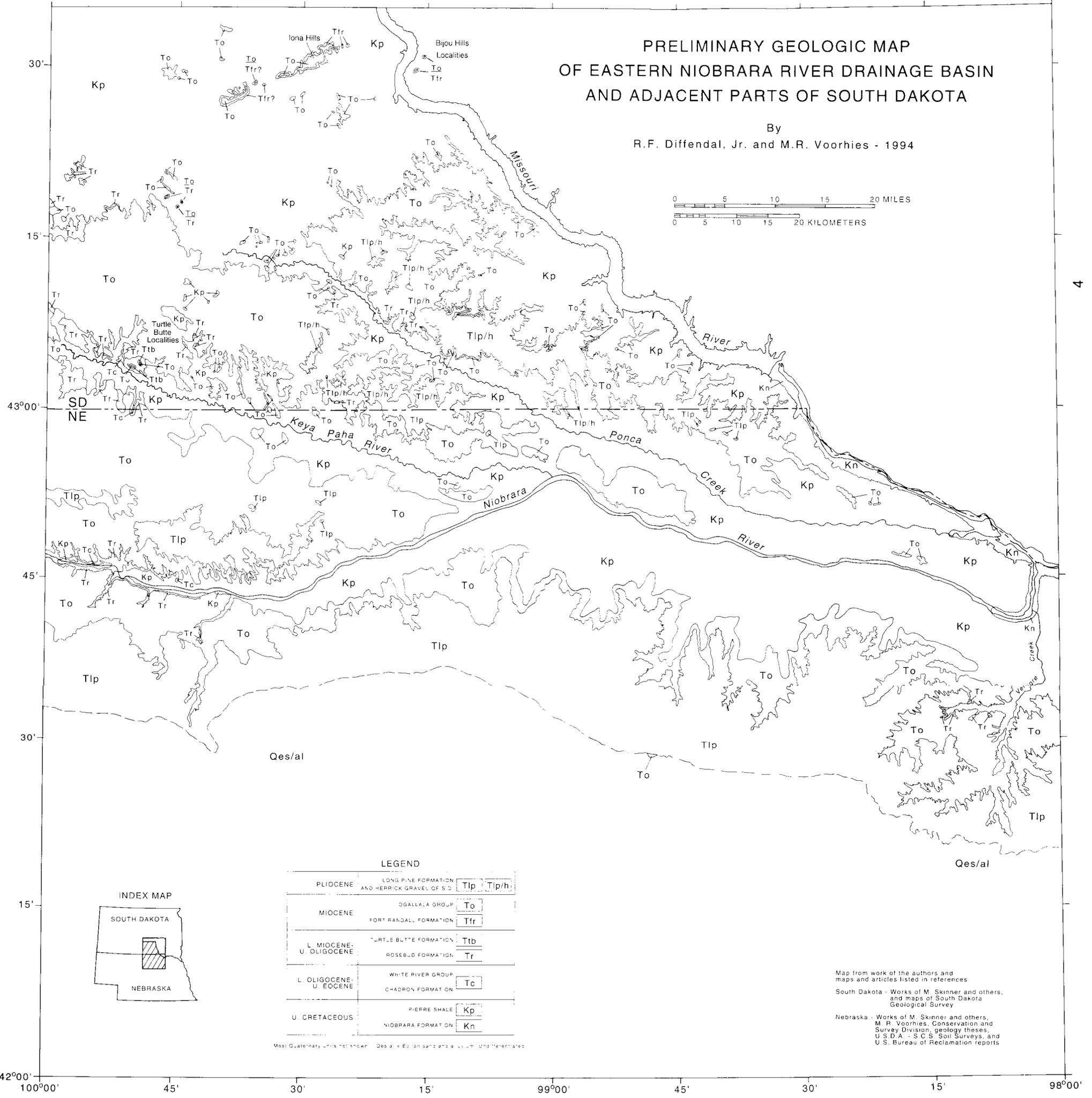
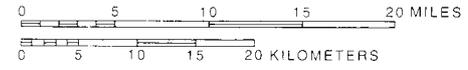
**=Contains fossil mammal remains of national/international significance

*=Contains fossil mammal remains of local/regional significance

Table 1. Cenozoic and Late Mesozoic Deposits Along the Eastern Part of the Niobrara Drainage Basin in Nebraska and in Adjacent Parts of South Dakota West of the Missouri River

PRELIMINARY GEOLOGIC MAP OF EASTERN NIOBRARA RIVER DRAINAGE BASIN AND ADJACENT PARTS OF SOUTH DAKOTA

By
R.F. Diffendal, Jr. and M.R. Voorhies - 1994



LEGEND

PLIOCENE	LONG PINE FORMATION AND HERRICK GRAVEL OF S.D.	Ttp/h
MIOCENE	OGALLALA GROUP	To
	FORT RANDALL FORMATION	Tfr
L. MIOCENE - U. OLIGOCENE	TURTLE BUTTE FORMATION	Ttb
	ROSEBUD FORMATION	Tr
L. OLIGOCENE - U. EOCENE	WHITE RIVER GROUP	Tc
	CHADRON FORMATION	
U. CRETACEOUS	PIERRE SHALE	Kp
	NIOBRARA FORMATION	Kn

Most Quaternary units not shown. Qes/al = Eolian sand and silt, undifferentiated.

Map from work of the authors and maps and articles listed in references.
South Dakota - Works of M. Skinner and others, and maps of South Dakota Geological Survey.
Nebraska - Works of M. Skinner and others, M. R. Voorhies, Conservation and Survey Division, geology theses, U.S.D.A. - S.C.S. Soil Surveys, and U.S. Bureau of Reclamation reports.

Fig. 1. Preliminary Geologic Map of Eastern Niobrara River Drainage Basin and Adjacent Parts of South Dakota

Mesozoic Erathem-Cretaceous System-Lower Cretaceous Series

The Dakota Group of Early Cretaceous age is a source of groundwater in parts of the basin and is known to occur beneath the map area, as do other Cretaceous formations older than the Niobrara.

Mesozoic Erathem-Cretaceous System-Upper Cretaceous Series

The oldest Cretaceous formation exposed in the area is the Niobrara (fig. 1; tables 1 and 2). Limestones and chalks of the Niobrara crop out discontinuously along the sides of the Missouri Valley, the lowermost Niobrara Valley and lowermost Ponca Creek valley. The Niobrara underlies the entire study area. The formation was deposited on the floor of a shallow sea that extended from the position of the present Arctic Ocean south to the present Gulf of Mexico. Marine organisms abounded in the waters of this seaway, and their skeletal elements form the major part of the formation. Beds of bentonite (a claystone formed from altered volcanic ash) indicate that volcanoes were present in land areas to the west that bordered the seaway and that eruptions from these volcanoes affected the seaway. Most paleogeographic reconstructions show that our part of the seaway was much closer to the equator in Niobrara times than it is today, so we have inferred from this and the types of fossils present in the deposit that the waters of the seaway were warm. At the end of deposition of the Niobrara, the seaway shallowed for a time and an erosion surface (unconformity) formed (DeGraw, 1975). The amount of time between the end of deposition of the Niobrara and the start of deposition of the overlying Pierre Shale is not known for certain, but we have used information given to us by D. K. Watkins (1993, personal communication) to estimate the gap at about 6 million years (table 2).

Whatever the length of time represented by the Pierre/Niobrara unconformity, the seas deepened over the study area once again in

Late Cretaceous time. This time the sea-floor conditions were different, and the sediments that were deposited were mostly dark muds with sulfate and other minerals. While clam and oyster fossils are common in the Niobrara (Pabian, 1970), they are largely absent from the Pierre. This indicates that the sea floor was inhospitable to bottom organisms most of the time. Organisms that floated and swam in the waters above the floor, however, are present as fossils in the Pierre, proving that at least the surface waters were habitable. Bentonites also occur in the Pierre, so volcanoes must have been present in distant areas at the time the Pierre accumulated. At the end of Pierre deposition in the area, the seas withdrew. A major gap occurs in the geologic record above the Pierre (table 2). Exactly what happened in the area between deposition of the Pierre and the Chadron Formation of Cenozoic age is not known.

Cenozoic Erathem-Tertiary System-Upper Eocene to Lower Oligocene

Weathered uppermost Pierre Shale occurs in places, indicating that soil-forming processes were going on in the area before deposition of any Cenozoic rocks. The unconformity at the top of the Pierre has considerable relief and has a dendritic drainage pattern resembling those forming in lands underlain directly by Pierre Shale today.

The oldest Cenozoic formation known in the study area is the Chadron Formation of the White River Group. So far as we know, the Chadron in Nebraska was first observed in the study area by V. H. Dreeszen and in South Dakota by M. F. Skinner. The Chadron is known to crop out in only three small areas in Keya Paha County in Nebraska and in the Turtle Butte area in South Dakota (fig. 1). From what we can tell from these limited exposures and from other reports, the Chadron filled valleys eroded into the Pierre. Clays in the Chadron are derived from alteration of volcanic ash and from minerals such as feldspars in the sediments. Western volcanism contributed consid-

* MYBP	FORMATION	SEDIMENT TYPES	KEY GENERA OR SPECIES	TYPICAL FOSSILS	ENVIRONMENT	
0	Terrace Deposits, Eolian Sand, Loess	Sand and gravel caps strath terraces; sand, very pale brown; silt, sandy, very pale brown.	Bison Mammuthus	Large grazing mammals and rodents.	Glacial and interglacial climates alternate.	
	Valley Fills	Sand and gravel from distant and local sources fill paleovalleys.				
5	Pettijohn-Keim Fms.	Sand and gravel, sand, silt, and clay, red to brown; stratified. Sand and gravel, includes anorthosite from Rocky Mountains, cross-stratified. Sand and locally derived gravel filling channels; grades upward to clay-filled pink to gray sand and then to gray sandy clay.	Stegomastodon, Borophagus Giantocamelus, Ondatra Equus, (Dolichhippus), Geomys	Fossils common. Grazing horses, giant camels, short-jawed gomphotheres, and bone-crushing dogs are predominant larger mammals. Burrowing rodents (gophers, ground squirrels) show adaptation to steppe environment while muskrats, voles and shrews indicate a temperate-climate marsh environment.	Temperate grassland/parkland with riverine woodlands	
10	Ash Hollow Formation Ogallala Group	Sandstone, gray, calcareous, interbedded with less consolidated sand and volcanic ash lentils; overlain by thinner bedded calcareous sandstone; younger deep cuts filled with unconsolidated sand.	Megalonyx Pseudhipparion skinneri Pseudhipparion gratum Pseudhipparion retrusum Cranioceras skinneri Bouromyx americanus	B. morrisoni Barbourofelis whitfordi Ustatochoerus major U. skinneri U. profectus U. medius U. shrammi	Fossils abundant, especially tortoises, grass seeds, and large grazing mammals (horses, rhinos, camels, ruminants). Browsers and aquatic vertebrates common only in stream channel deposits. Many species of browsers become extinct during this interval.	Forests persist only in river valleys; savannas occupy interfluvies. Climate still warm but drier than before
	Valentine Formation, Ogallala Group	Sand, pale olive, friable, cross-stratified; sandstone, pale olive, argillaceous; one volcanic ash, light gray; sand and gravel, cross-stratified.	C. mefferdi M. furcatus M. warreni		Fossils abundant. Aquatic species include fish, alligators, turtles. Fossil wood and grass seeds common. Diverse vertebrate microfauna including frogs, toads, salamanders, snakes, lizards, amphisbaenids, shrews, moles, hedgehogs, plesiosoricids, rodents, rabbits, and pikas.	Large permanent streams and well-watered floodplains supporting forests; Savanna woodlands on interfluvies. Frost-free climate.
15	Fort Randall Formation?	Clay, sandy clay, and silty sand, light gray, pink, red, brown, pale olive; barite and calcareous concretion horizons present; strata massive.	Merycodon necatus		Larger mammals include abundant proboscideans (both long-jawed gomphotheres and true mastodons), tapirs, rhinos, horses, chalicotheres, peccaries, oreodonts, camels, ruminants, and carnivores. Among the hoofed mammals grazers individually outnumber browsers at most sites but browsers are more diverse (larger number of taxa).	
20						
25	Turtle Butte Formation, Arikaree Group	Siltstone, white to light gray, tuffaceous; siltstone, calcareous; clay, white; sand and silt; reddish brown; strata massive to thick bedded.	Enhydrocyon crassidens Archaeohippus equianus Megoreodon hollandi Archaeotherium trippensis		Fossils uncommon. Small but diverse samples of fish, lizard, turtle, and mammal fossils known.	Channel and floodplain; warm climate.
	Rosebud Formation, Arikaree Group	Siltstone and silty sandstone, pinkish gray to brown, minor olive colors; massive to stratified, tuffaceous; includes local channels filled with reworked siltstone and sandy siltstone gravels, with silts filling pore spaces between grains, pale pink and some light olive colors, massive to grossly cross-stratified.	Centetodon magna Desmatochoerus Leptauchenia Paleocaster		Fossils rare. A few oreodont, rodent and insectivore jaws.	Floodplain in seasonally arid environment?
30						
35	Chadron Formation?, White River Group	Sand, white; sandy clay, tan to olive; clay, sandy clay, and sand, purple, red, white, and tan; tuffaceous; deeply weathered.			No identifiable fossils known.	Warm, humid fluvial.
70						
75	Pierre Shale	Shale, black, gray, and brown, thinly laminated; chalk, shaley, light gray, laminated; bentonite, white to gray.		Nannofossils Foraminifera Bivalves Ammonoid Cephalopods Sharks, Bony Fish Marine Reptiles		Shallow marine.
80						
85	Niobrara Formation	Chalk, shaley, medium gray; limestone, gray, yellowish-orange, grayish-orange; bentonite, white; stratified.		Nannofossils Foraminifera Ostracods Bivalves Ammonoid Cephalopods Bony Fish, Sharks Marine Reptiles		Shallow marine.

* MYBP = Millions of Years Before Present

 = No Rocks of This Age Known in Area

Table 2. Cenozoic and Late Mesozoic Geologic Time Spans, Formations, Sediment Types, Typical Fossils, and General Environments--Eastern Niobrara Basin and Adjacent Parts of South Dakota West of the Missouri River

erable sediment in the form of airfall ash to the Chadron (Swinehart and others, 1985).

Cenozoic Erathem-Tertiary System- Upper Oligocene to Lower Miocene

There is another unconformity separating the Chadron from the overlying Rosebud Formation (table 2). The Rosebud was deposited in paleovalleys eroded into both the Chadron and the Pierre. The Rosebud rock types are noted in table 2. The sand and silt in the Rosebud is dominantly composed of volcanic debris. Gravels in channel fills within the Rosebud are mostly reworked older pieces of Rosebud. This is also true of gravels at the base of the formation, but these may also include pieces of Chadron and Pierre rocks as well. A borrow pit on the east side of U.S. Highway 183 south of Springview about 2 mi (3 km) north of the Niobrara River has multiple cuts in the Rosebud Formation filled with crudely stratified siltstone gravels that may have been deposited by debris flows. An erosion surface separating two parts of the Rosebud is visible to the east of the south abutment of Norden Bridge along the Niobrara just west of the study area. These last two localities demonstrate that multiple cutting and filling of paleovalleys took place during formation of the Rosebud in and adjacent to parts of study area.

The Rosebud Formation crops out extensively along valley sides in the western part of the study area (fig. 1) and also has been found in isolated small areas in the Verdigre Creek drainage basin (fig. 1; and in Schulte, 1952, and Voorhies, 1973). Burchett (1986) called these exposures part of the White River Group, but we believe that they are younger and are the basal part of the Arikaree Group instead, following the opinions of M. F. Skinner on this point.

In South Dakota, a younger unit called the Turtle Butte Formation (fig. 1; tables 1 and 2) unconformably overlies the Rosebud (Skinner, Skinner, and Gooris, 1968). So far as we know, this unit occurs only at Turtle Butte. It has been included in the Arikaree Group with the Rosebud because of the stage of evolution of its

fossils and its large volume of volcanoclastic sediments.

Cenozoic Erathem-Tertiary System- Miocene Series

A long period of erosion separates the Turtle Butte Formation and older units from the younger Miocene units assigned to the Ogallala Group. Skinner and Taylor (1967) described the Fort Randall Formation, which lies unconformably above the Pierre Shale in South Dakota at the Bijou Hills east of the Missouri River, and in the remnants west of the river called the Iona Hills, etc. (fig. 1; tables 1 and 2). While the rocks somewhat resemble the older Turtle Butte Formation, they contain much younger fossils. Skinner and Taylor thought that the formation was equivalent in age to the Lower Snake Creek beds of western Nebraska, but proboscidean and other fossils found subsequent to their report indicate a somewhat younger age for the formation. We have shown this in table 2. So far as we know, the Fort Randall Formation is restricted to the area in South Dakota shown on figure 1.

A brief hiatus separates the Fort Randall from the main parts of the Ogallala Group in South Dakota, but in Nebraska the lowermost parts of the Valentine Formation are contemporaneous with it. Skinner and co-workers (table 1) have subdivided the Ogallala's two formations, the Valentine and overlying Ash Hollow, into a number of members. These members do have lithologic differences that allow them to be traced laterally in outcrops. No one has successfully traced them in the subsurface, however. They also have not been widely recognized in South Dakota, but Skinner, Skinner, and Gooris (1968) reported some of them at Turtle Butte. Within the Valentine Formation, only the Devil's Gulch Member seems to be conformable everywhere. All the other members are complex valley fills that often look conformable locally, or even regionally, but are shown in Skinner and Johnson (1984) to be far more complex. The basal member of the Ash Hollow Formation, the Cap Rock, is also a regional calcium-carbonate-ce-

mented marker bed, but fills paleovalleys in some places. The other two members of the Ash Hollow also fill paleovalleys eroded into older beds (Skinner and Johnson, 1984). Multiple cutting and filling of paleovalleys during deposition of the Ogallala Group has been recognized in western Nebraska (Swinehart and Diffendal, 1990), and this seems to be the case in places in north-central Nebraska as well, albeit usually on a much more subdued scale. The Ogallala Group in the study area has yielded truly remarkable accumulations of fossil vertebrates. Many of these species are noted in the papers of Skinner and his colleagues. The Ashfall Fossil Beds State Historical Park in northwestern Antelope County is one of the most spectacular of these sites found to date and has been described in detail by Voorhies (1985, 1990a).

Cenozoic Erathem-Tertiary System-Pliocene Series

Skinner and Hibbard (1972) recognized four formations (table 1) now placed in the Pliocene. The oldest of these, the Keim Formation, fills a narrow paleovalley north of Ainsworth, Nebraska. The much more widespread Long Pine Formation and its equivalent in South Dakota, the Herrick Gravels, crop out widely in the study area and occur in the subsurface. Skinner and Hibbard (1972) thought that the Long Pine was an outwash deposit from the Nebraskan Glaciation, but works by Stanley (1971), Stanley and Wayne (1972), Swinehart and others (1985), and Swinehart and Diffendal (1990) have demonstrated conclusively that the fluvial system that deposited the Long Pine came from the Southern Rocky Mountains in southern Wyoming and north-central Colorado.

The Long Pine is a braidplain deposit that fills a very wide paleovalley. This deposit continues across the state line into South Dakota, where it has been mapped as the Herrick Gravels. Fossils from the South Dakota deposits are from the Blancan Land Mammal Age (Pinsof, 1985), as are those from Nebraska. Some of the northwesternmost parts of the Herrick may have been deposited by rivers

from the Black hills or other areas. Pebble studies by Diffendal and colleagues now underway may answer this question. Locally overlying the Long Pine are the Duffy and Pettijohn formations. They are known to occur only in the vicinity of Long Pine and the upper Elkhorn River valley in Nebraska. All four units have been lumped together on figure 1 for reasons of scale.

Cenozoic Erathem-Quaternary System-Pleistocene and Holocene Series

The Quaternary geologic history of the study area is complex. Several geologic units are present, and many of these are unconformable. Noteworthy are the valley fills along Ponca Creek, the eolian sands of the Nebraska Sand Hills, several strath terraces in various drainages, and Holocene alluvium. These are noted on tables 1 and 2, but except for the main part of the Sand Hills, are not shown on figure 1. We are investigating these as part of our mapping project and plan to show at least some of them on the 1:250,000 geologic map.

Possible Evidence of Structures

We have not observed faulting in the area, but several features may indicate structural effects. The discontinuous exposures of the Rosebud and Chadron along the Niobrara River near the western margin of the study area may indicate structural control. The distribution of the Paleozoic rocks shown by Carlson (1993) may also be structurally controlled. The northeastward trend of the northernmost outcrop belts of the Fort Randall, Ogallala, and Long Pine/Herrick units on figure 1 may also indicate structural control, as may lineaments on Landsat images. Displacements along fractures in the Pierre east of Spenser Dam may indicate faulting or landslides.

Geologic Hazards in the Area

Landslides have been and continue to be observed in the Nebraska part of the study area by D.A. Eversoll and other workers at the Con-

ervation and Survey Division of the University of Nebraska-Lincoln. They occur commonly in parts of the Pierre Shale, but also occur in other units. We have seen them develop in the Pierre and the Fort Randall in South Dakota as well. Flooding is also a problem in some areas. Earthquakes have occurred in the study area (U.S. Water and Power Resources Service, 1980).

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