2008

Pamphlet to Accompany Geologic Map GMC-34: Geologic Map of the O’Neill 1° x 2° Quadrangle, Nebraska, with Configuration Maps of Surfaces of Formations

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Pamphlet to Accompany Geologic Map GMC-34

Geologic Map of the O’Neill 1° x 2° Quadrangle, Nebraska, with Configuration Maps of Surfaces of Formations

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http://nebraskamaps.unl.edu
INDEX SHOWING LOCATIONS OF O’NEILL QUADRANGLE
AND OTHER 1° x 2° GEOLOGIC QUADRANGLES
PUBLISHED BY THE U.S. GEOLOGICAL SURVEY

Notes: Photographs in this publication are by R.F. Diffendal, Jr. unless otherwise noted. Sites in photographs may have changed appearance since date of this publication. The map and accompanying pamphlet are available in electronic or paper form from Nebraska Maps and More, located in the first floor lobby of Hardin Hall on the University of Nebraska–Lincoln East Campus. http://nebraskamaps.unl.edu

ISBN-10 1-56161-010-0
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Geologic Map GMC-34

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October 2008

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University of Nebraska Conservation and Survey Division
Geologic Map GMC-34

Geologic Map of the O’Neill 1° x 2° Quadrangle, Nebraska with
Configuration Maps of Surfaces of Formations

by
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H. E. LaGarry, C. L. Timperley and M.E. Perkins

NOTE

This map is necessarily generalized. It is based primarily on data from 7.5’ surficial
geologic quadrangle maps of the map area prepared by the authors principally
from 1991 to 2000, from Voorhies (unpub. data, 1974), as well as data from test-
hole drilling done across the quadrangle by the Conservation and Survey Division,
University of Nebraska, and its cooperators over many years since the 1930s. For
more detailed information, consult the geologic data files of the Conservation and Survey Division,
School of Natural Resources, University of Nebraska–Lincoln. The
quadrangle is mostly covered by vegetation and Holocene sediments. Limited good
exposures of older sediments and bedrock occur usually in road cuts, in quarry
and pit excavations, on valley sides, on stream and river cut banks, and in isolated
erosional remnants on uplands. Users of this map should remember that the scale of
the map is small and allows only a general picture of the geology of the quadrangle
to be depicted. Users should check with the authors regarding specific sites and, if
necessary, do field checks of these sites. As new data become available the authors
intend to update the data sets used in preparation of this quadrangle text and maps
and to issue refined versions, if necessary.

The earliest geologic map that included part of the study area was published by
Charles Lyell in 1845 (Diffendal, 1993). Other geologic maps at different scales that
include all or parts of the map area are by Darton (1899, 1905), Condra (1908),
Schulte (1952), Mendenhall (1953), Lampshire (1956), Burchett (1986), Weeks
and Gutentag, (1981), Weeks and others (1988), Swinehart and others (1994), and
Diffendal and Voorhies (1994). Geologic maps of adjacent areas in Nebraska and
South Dakota include Burchett and others (1975), Burchett and others (1988),
Diffendal (1991), and Souders (2000) for Nebraska and Stevenson and Carlson
(1950, 1951), Baker and others (1952), Collins and French (1958), Schoon and Sevon
(1958), Stevenson and others (1958), and Stevenson and others (1959) for parts of
South Dakota.

Detailed groundwater investigations and associated stratigraphic test drilling (of
parts or all of the map area) were done by Darton (1905), Condra (1908), Reed (1944),
Keech and Schreurs (1953, 1954), Cronin and Newport (1956), Reed (1957), Smith
(1958), Newport (1959), Souders and Shaffer (1969), Souders (1976), Gutentag and
Weeks (1980), Luckey and others (1981), Lawton and Hiergesell (1988), Weeks and
others (1988), Pierce (1989), Rahn and David (1989), Burchett and Smith (1992),

INTRODUCTION

The O’Neill 1° x 2° quadrangle in north-central Nebraska is part of the High Plains section of the Great Plains Physiographic Province (Fenneman, 1931). The
map area is mostly a constructional plain that has been dissected principally since
the Pliocene by the rivers and streams that drain the area. Most of the area south of
the Niobrara River on the west and south of the Elkhorn River from its headwaters
eastward to near the east side of the quadrangle is part of the Nebraska Sand Hills
this area into the Sand Hills, the Lakes Area, and the Wet Meadow and Marsh Plain
(also called the Prairie Plain by Condra, 1946). A smaller area of Sand Hills in
northernmost Holt County on the upland just south of the Niobrara River was also
mapped by Chapman and others (2001), but is geologically younger than the major
Sand Hills area. North of the Nebraska Sand Hills the valleys of the Niobrara River,
the Elkhorn River, the Keya Paha River, Ponca Creek, and their tributaries separate
remnants of the constructional plain from one another. According to Condra (1908,
1946) these remnants include the Holt Plain (northern Holt and Rock Counties),
the Ainsworth Plain (northern Brown County), the Springview Plain (Keya Paha
and west-central Boyd Counties), the Boyd Plain (from northwest to southeast Boyd
County), and part of the Herrick Plain (eastern Boyd County between Ponca Creek
and the Missouri River).

Many geologic studies have been done in the area following proposals for
dam construction projects that had potential for significant impacts on the land and
its people. From time to time proposals for dam construction along the Missouri
and Niobrara rivers and tributaries have led to major data gathering (Niobrara
River Basin Development Association, 1951; U.S. Bureau of Reclamation-Region 7,
Reclamation, 1980, 1992; Cast, 1988). In the late 1980s, Nebraska, one of five states
in a low-level radioactive waste compact, was chosen to be the first host site for a
waste repository. Boyd County in the map area was selected as the first site location.
Many reports were written about site geology and impact including those of Pierce
The general geologic section of Nebraska was last described in some detail by Condra and Reed (1959) and has been refined subsequently by many authors including many of those cited herein. The geologic history of the rocks exposed in the map area began about 87.5 Ma (millions of years ago) during the late Cretaceous when the Niobrara Formation (Meek and Hayden, 1858, 1862), composed primarily of coccolithophorid/foraminiferal-rich chalks and limestones, began to be deposited in the Western Interior Seaway (see Loetterle, 1937, for foraminifera; Pabian, 1979, for notes about larger late Cretaceous fossils). Deposition of these sediments on the floor of the seaway continued until about 82 Ma when the seas withdrew and a regional unconformity was formed at the top of the formation. Relative sea levels rose once again about 76 Ma once again flooding the area (DeGraw, 1975). The Pierre Shale, composed primarily of gray to black shales and mudstones, was deposited on the floor of the seaway in the map area until about 70 Ma, when the seas again withdrew and another regional unconformity began to form, this time at the top of the Pierre. The Pierre has been subdivided into nine members in the study area (Mendenhall, 1953; Schultz, 1952; Diffendal and Voorhies, 1994; Hammond and others, 1995; Watkins, 1997), but these members are not shown on the map. Three calcareous units, the oldest one the Gregory Member, and the Crow Creek and Mobridge members occur between shale members. The Crow Creek is unusual in that it has a basal sandy unit with some gravel that has been interpreted by Hammond and others (1995) as a tsunami deposit generated by the Manson, Iowa, meteorite-impact event. Even younger Cretaceous marine deposits have been reported in eastern South Dakota (Shurr, 1981) and may have also been deposited in the map area, but have either not been found or were eroded away during formation of the unconformity at the top of the Pierre mentioned earlier.

The top of the Pierre Shale configuration map (fig. 1) is generalized because of the lack of data points in the map area, but the map does show several valleys formed on the surface of the Pierre. Because the erosion of the Pierre occurred at more than one time from area to area across the quadrangle the valleys were probably not all formed during the same time span between the late Cretaceous, when Pierre deposition ceased, and the late Eocene when the oldest Tertiary formation known in the quadrangle was deposited. Some of the surface configuration may also have been altered by post-Cretaceous faulting (Shurr and others, 1994: Flowerday and Diffendal, 1997; Diffendal and Voorhies, 1994) including some, deposited in the map area (Mendenhall, 1953; Schultz, 1952; Diffendal and Voorhies, 1994; Hammond and others, 1995; Watkins, 1997), but these members are not shown on the map. Three calcareous units, the oldest one the Gregory Member, and the Crow Creek and Mobridge members occur between shale members. The Crow Creek is unusual in that it has a basal sandy unit with some gravel that has been interpreted by Hammond and others (1995) as a tsunami deposit generated by the Manson, Iowa, meteorite-impact event. Even younger Cretaceous marine deposits have been reported in eastern South Dakota (Shurr, 1981) and may have also been deposited in the map area, but have either not been found or were eroded away during formation of the unconformity at the top of the Pierre mentioned earlier.

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During the Cenozoic Era the map area was above sea level and exposed to subaerial erosional and depositional processes. The bedrock was eroded into valley systems (fig. 2) and these were subsequently filled with sediments many times (Skinner and Johnson, 1984; Swinehart and Diffendal, 1990; Diffendal and Voorhies, 1994). These fills are generally broader than those in western Nebraska (Skinner and others, 1977; Swinehart and others, 1985; Swinehart and Diffendal, 1990; Diffendal, 1995).

The oldest Cenozoic deposits in the quadrangle are isolated remnant parts of what has been called the Chadron Formation (Skinner and Johnson, 1984) of Eocene age deposited as valley fills from about 38-34 Ma (fig. 3). This lower part of the traditional Chadron Formation has been renamed and redefined as the Chamberlain Pass Formation in northwest Nebraska (Evans and Terry, 1994; Terry and Evans, 1994) and in the map area (LaGarry and others, 2006). We have adopted this name for the formation in the quadrangle. The Chamberlain Pass Formation typically includes a basal sandstone which is overlain by light pastel-colored, volcaniclastic, claystones and mudstones. The formation has only been found so far in isolated outcrops in western Keya Paha County where it overlies the Pierre Shale.

During part of the Oligocene from about 28.5-24.5 Ma parts of the Rosebud Formation of the Arikaree Group were deposited in paleovalleys crossing parts of the map area (Voorhies, 1973; Skinner and Johnson, 1984; Diffendal and Voorhies, 1994; Timperley and others, 1998; LaGarry and LaGarry, 1999). In western Keya Paha and northern Brown Counties a major valley system was eroded into the Chamberlain Pass Formation and the underlying Pierre Shale (fig. 4). This valley system was subsequently filled with mostly pink volcaniclastic sandstones, siltstones, and mudstones of the Rosebud Formation. Internally the formation has many cut-and-fill sequences (Diffendal and Voorhies, 1994) including some, deposited in tributaries, that appear to be mudflow deposits (figs. 5-7). Remnants of this complex valley system fill are best exposed in Keya Paha County in the vicinity of Meadville and in a borrow pit on the east side of U.S. Highway 183 north of the Niobrara River. Skinner and Johnson (1984) reported that a few undiagnostic fossils have been found in these deposits. No other exposures are known from the study area except for isolated ones farther to the east in west-central Knox County (Voorhies, 1973; Timperley and others, 1998). The Rosebud Formation in this area consists of thin deposits of volcaniclastic clayey siltstones and mudstones that have yielded some vertebrate fossils diagnostic of the Arikaree North American Land-Mammal Age.

A map of formations subjacent to the base of the Ogallala Group (fig. 8) shows the distribution of these units across parts of the map area overlain by the Ogallala. The map pattern reflects the changes in locations of valley cuts and fills prior to deposition of the Ogallala.

The Ogallala Group of Miocene age overlies the units noted above over much of the map area (Wellstead, 1981; Skinner and Johnson, 1984; Diffendal and Voorhies, 1994). Three formations in ascending order, the Fort Randall, Valentine, and Ash Hollow, are recognized here by Diffendal and Voorhies (1994). Fossil plants are locally abundant in the rocks of the group (Landon, 1985; Thomasson, 1987; Haffner and others, 1990; Backlund and others, 1991). Many age-diagnostic vertebrate fossils occur in the Ogallala and allow good correlations of the stratigraphic sequences across the map area (Barbour and Cook, 1917; Voorhies, 1969, 1971, 1974, 1981; Skinner and Johnson, 1984; Voorhies, 1985, 1987b, 1990a, b, c).

The oldest unit of the Ogallala is the Fort Randall Formation, originally described by Skinner and Taylor (1967) from exposures in the Bijou Hills of South Dakota. Diffendal and Voorhies (1994) reported no exposures of this formation from the
Fig. 1. Subsurface configuration of the top of the Cretaceous Pierre Shale Formation. Contour interval 100 ft.
Fig. 2. Example of how Cenozoic fluvial valleys developed in the O’Neill quadrangle area regardless of scale. Just north of Ashfall Fossil Beds State Historical Park on the South Branch of Verdigre Creek remnants of Valentine Formation bedrock are present as islands with younger Quaternary fills present in the channels and beneath the adjacent floodplain.

Fig. 3. Chamberlain Pass Formation exposed in road cut on east side of U.S. Highway 183 south of Springview, Keya Paha County.

Fig. 4. Parts of the Rosebud Formation along county road on the north side of the Niobrara River just west of Meadville, Keya Paha County. These beds are parts of a main valley fill.

Fig. 5. Rosebud Formation (Tar) and Chamberlain Pass Formation (Tc) exposed in a barrow pit and in a road cut along east side of U.S. Highway 183 on north side of Niobrara River south of Springview, Keya Paha County. See figure 3. The top of the Chamberlain Pass is a remnant hill that was eroded by the developing Rosebud tributary before Rosebud deposition began.
map area, but subsequent mapping has resulted in their identification in outcrops in south-central Boyd County and northern Brown County. The “Miocene(?) silts” identified from drill hole cuttings and in outcrop in Boyd County by Souders (1976) are parts of the Fort Randall Formation.

The Valentine Formation (Johnson, 1936, 1938; Lugn, 1938, 1939) is unconformable on the older units down through the Pierre Shale (fig. 9). It underlies much of the map area. The Valentine is mostly fluvial sand (fig. 10). It has been subdivided into the Cornell Dam, Crookston Bridge, Devil’s Gulch, and Burge members (Skinner and others 1968; Skinner and Johnson, 1984) not shown on this map. Each of these members is, except for the Devil’s Gulch Member, unconformable and each fills paleovalleys cut into older units. The Crookston Bridge Member, according to Skinner and others (1968, p. 404), has numerous horizons of quartzite (more appropriately called subarkose). These green silica-cemented subarkose beds occur in parts of Knox, Boyd, Keya Paha and others counties in north-central Nebraska, in parts of the Republican River basin in south-central Nebraska (Barbour, 1913), and in the Bijou Hills in south-central South Dakota (Skinner and Taylor, 1967). Subarkose bodies also occur locally at the base and at a higher stratigraphic level in the Cornell Dam Member west of the map area (Skinner and Johnson, 1984, p. 255-256).

The youngest formation of the Ogallala Group is the Ash Hollow Formation (Lugn, 1939; Swinehart and others, 1985; Diffendal, 1995). Skinner and Johnson (1984) subdivided the Ash Hollow into the Cap Rock Member, and the stratigraphically overlying Merritt Dam and unnamed Hemphillian members. The Cap Rock Member is mostly calcareous sandstone and is disconformable on other beds across most of the study area. Because this member is largely indurated (fig. 11) it is easily recognized in outcrop and in drill cuttings. According to Skinner and Johnson (1984) the Merritt Dam Member is also indurated in part, but the sandstones in it are more thinly bedded and less continuous than those in the Cap Rock. Parts of the Merritt Dam Member and the unnamed Hemphillian member were deposited in valley systems carved into the Cap Rock Member and, in the case of the unnamed unit, also into the underlying Burge and Devil’s Gulch members of the Valentine Formation (Skinner and Johnson, 1984, p. 230). This series of cut-and-fill valley fills is typical of the Ogallala Group both in the map area and farther to the west in Nebraska (Skinner and others, 1968; Swinehart and others, 1985).

In contrast to the thick sequences of volcanioclastic sediments in the White River and Arikaree Groups across Nebraska, volcanic ash (or tephra) is only widespread as individual ash shards in the rocks of the Ogallala Group, and is far less common as individual, relatively pure, lentils in the group. At least 9 superposed volcanic ash lentils occur in the upper part of the Ash Hollow Formation exposed in one small drainage basin in western Nebraska (Swinehart and others, 1985, fig. 18). In north-central Nebraska, Skinner and Johnson (1984) reported one lentil, the Hurlbut ash, from the Valentine Formation and at least 6 separate ash lentils from various parts of the Ash Hollow Formation exposed in the map area and in adjacent parts of the Valentine, Nebraska, 1:250,000 quadrangle area.
Fig. 8. Map showing bedrock formations directly subjacent to the base of the Ogallala Group. Tar/Tc is Rosebud Formation and Chamberlain Pass Formation, undifferentiated. Kp is Pierre Shale.
Fig. 9. Natural exposure on south side of the Niobrara River just east of Norden Bridge, Keya Paha County (just to west of western border of the O’Neill quadrangle). Two parts of the Rosebud Formation (Tar₁ and younger Tar₂) are exposed with part of the Valentine Formation of the Ogallala Group covered by vegetation above. Note the deep incision of the river channel into the lower unit of the Rosebud.

Fig. 10. Paleontologists excavating vertebrate fossils from the Valentine Formation fluvial sands at the Railway Quarries near Valentine, Cherry County (on Valentine quadrangle).

Fig. 11. Caprock Member of the Ash Hollow Formation, Ogallala Group, exposed in a road cut on the south side of Nebraska Highway 12, Keya Paha County.
Work in progress (Perkins and others, 1995; Perkins and Nash, 2002; Perkins, written com., 2007) on the geochemistry of tephra lentils in the Ogallala Group of Nebraska, northwest Kansas, and southernmost South Dakota indicates that more than 40 superposed lentils are present in the rocks of the Ogallala Group in this region. Most of the tephra lentils are from sources along the Yellowstone hotspot track (Perkins and Nash, 2002) and ~30 can be correlated on the basis of chemical composition of their glass shards with tephra in age-controlled stratigraphic sections in the Basin and Range, Snake River Plain, and Rio Grande Rift (Perkins and others, 1998; Perkins and Nash, 2002). Of these lentils, 23 have been identified in the O’Neill quadrangle and areas to the west. Several of the tephra layers are of particular interest. The Hurlbut ash of Skinner and Johnson (1984) occurs in the Cornell Dam Member of the Valentine Formation. This tephra lentil is correlated with a 13.6 Ma tephra in both the Rio Grande Rift and the Basin and Range. (Note: all ages are based on $^{40}\text{Ar}/^{39}\text{Ar}$ ages relative to the Fish Canyon sanidine = 28.02 Ma.) This age for the Hurlbut is in agreement with an unpublished $^{40}\text{Ar}/^{39}\text{Ar}$ age from glass shards from this tephra (Swisher, 1992). At or near the base of the Cap Rock Member of the Ash Hollow Formation are the 12.8 Ma Cougar Point Tuff unit III tephra (Turtle Butte, SD), the 12.0 Ma Ibex Hollow tephra (containing the fossils at Ashfall Fossil Beds State Historical Park in Antelope County, Nebraska; Perkins, 1998), and the 11.9 Ma Logan Ranch tephra (found just west of the O’Neill quadrangle). A younger identified tephra in the Ash Hollow Formation in the O’Neill quadrangle is the 11.0 Ma Cougar Point XIII tephra collected from near the top of the formation at the Rick Irwin site in Keya Paha County (Tucker, 2004). Two types of tuff clasts from an Ash Hollow fill also found near this site by Tucker can be correlated with the 10.3 Ma Arbon Valley tephra and the 6.7 Ma Blacktail Creek tephra, respectively. A lentil of the Blacktail Creek tephra has been identified from the post-Cap Rock Member of the Ash Hollow Formation on the west side of Grove Lake in Antelope County, southeast of Ashfall Fossil Beds State Historical Park.

Effects and impacts on vertebrate health from inhalation of volcanic dust has been documented by M.R. Voorhies for the Ogallala, and by extension to earlier and more recent falls. The tephra lentil at Ashfall Fossil Beds contains fully articulated skeletons of mammals, birds, other vertebrates, and fossils of invertebrates and plants (figs. 12-14) Voorhies, 1981, 1985, 1990a; Voorhies and Thomasson, 1979). Cancellous bony overgrowths on mammal skeletons at the site indicate that they had Marie’s Disease, a pulmonary illness triggered, in this case, by ash inhalation. Riley and others (2003) and Rose and others (2003) discussed the shapes, atmospheric transport, and health impacts of such ashfalls.

The base of the Ogallala Group configuration map (fig. 15) is drawn on an unconformable surface produced primarily by fluvial erosion of valley systems crossing the quadrangle. There were at least two of these periods of erosion into pre-Ogallala bedrock, one prior to deposition of the Fort Randall Formation and one prior to deposition of the Valentine Formation. Thus, the surface drawn on the configuration map, is probably a composite surface, but it does show two principal pre-Ogallala valleys crossing the quadrangle and coalescing in central Antelope County. Swinehart and Diffendal (1990) noted this too. After Ogallala deposition ceased the top of the Ogallala was eroded primarily by fluvial processes and a major paleovalley, thought to be the valley of the ancestral Platte River, formed across the Sand Hills Ecoregion and the map area (fig. 16). The westernmost side of this paleovalley is just to the west of the western border of the O’Neill quadrangle and trends north-northeastward into South Dakota (Swinehart and Diffendal, 1990, fig. 3-9).

The Broadwater Formation (Pliocene) fills the paleovalley noted above and overlies the Ogallala Group over large areas south of the Niobrara River valley (Swinehart and Diffendal, 1990; Diffendal and Voorhies, 1994) and north of the valley in parts of Keya Paha and Boyd Counties (fig. 17). The Broadwater differs from all of the older Tertiary units previously described because it is composed predominantly of fluvial sand and gravel. The gravel clasts are mostly from sources in the Southern Rocky Mountains in southern Wyoming and Northern Colorado and reach sizes that are larger than distant source gravels found in any of the Ogallala Group units discussed above. Skinner and Hibbard (1972) subdivided the Pliocene (called by them “early Pleistocene”) deposits in the map area into the Keim, Long Pine, Duffy, and Pettijohn Formations. Diffendal and Voorhies (1994) continued their use, but reassigned them to the Pliocene (about 3.5-2.5 Ma). Stanley (1971), Stanley and Wayne (1972), Swinehart and others (1985), and Swinehart and Diffendal (1990) clearly documented.
that the Broadwater Formation can be traced in outcrops and in drill holes from western Nebraska to the map area and is all part of one huge fluvial deposit laid down in the bed of the ancestral Platte River (fig. 18). Since the Broadwater Formation was named and described much earlier than the Keim-Pettijohn (see Swinehart and Diffendal, 1997) we will call the formation in the map area the Broadwater, rather than the Keim-Pettijohn.

The Broadwater can be traced nearly to the South Dakota border in Keya Paha and Boyd Counties and correlates with the Herrick Gravels in southeastern South Dakota (Stevenson and Carlson, 1950; Baker and others 1952; Pinsof, 1985; Diffendal and Voorhies, 1994). Fossils from the Broadwater Formation and correlative units in South Dakota are distinctive of the Pliocene Blancan North American Land-Mammal Age (Skinner and Hibbard, 1972; Pinsof, 1985; Voorhies, 1987a; Voorhies and Goodwin, 1989; Diffendal and Voorhies, 1994). At the time of deposition of the Broadwater and correlative units the ancestral Platte probably continued northward in eastern South Dakota and North Dakota and joined the ancestral Missouri River, which continued on to Hudson Bay in Canada (Diffendal and Diffendal, 2003a).

Some sediments in the quadrangle are known that have ages between those of the youngest of the Pliocene Broadwater and those of the late Pleistocene Wisconsinan. These Plio-Pleistocene sediments are mostly buried beneath younger eolian deposits principally in the main area of the Nebraska Sand Hills. They are primarily alluvial sands (some with minor gravel), silty sands, silts, lacustrine mucks and peats and toward the top of the sequence in places, eolian sands. Paleosols cap some units.
Fig. 15. Subsurface configuration of the base of the Ogallala Group. Contour interval 100 ft.
Fig. 16. Subsurface configuration of the top of the Ogallala Group. Contour interval 100 ft.
These sediments were deposited in a valley system eroded into the Broadwater by rivers crossing the area. After deposition, some of these sediments were locally eroded and re-deposited by winds.

Remnants of a high terrace fill occur discontinuously along the south valley side of the Niobrara River in Brown and Rock Counties. No fossils have been obtained from this fill to date.

The fluvial deposits capping the most prominent high terrace (fig. 19) along the Niobrara River and tributaries are late Wisconsinan and have yielded Rancholabrean North American Land-Mammal Age vertebrate fossils (Voorhies and Goodwin, 1989; Voorhies, 1990c). Larson (2001) and Larson and Swinehart (2001) have called these fluvial sand and gravel deposits the Connely Flat Beds and have traced them from the Valentine 1:250,000 quadrangle along the Niobrara River Valley onto this quadrangle. Souders (1976) reported "high terrace deposits" in some places along the north valley side of the Niobrara River in Boyd County. We have verified that these are from the same terrace fill remnants and that there are also similar remnants in northern Holt and southern Knox Counties. Equivalent deposits along the Missouri River in Boyd County contain large armored mud balls and boulders reworked from glacial deposits (figs. 20-21). Holocene fluvial sand and gravel deposits of as many as five other terraces and some valley fills occur discontinuously along the Niobrara River Valley at terrace levels lower than the high terrace on the east side of the Valentine 1:250,000 quadrangle (Voorhies, 1990c). Some are present in the map area. The gravel compositions of these deposits vary from one another both along the length of the valley across the quadrangle and with position above the valley floor. These differences reflect the changes in gravel sources in the fill. To the west the gravels are mostly reworked from the Broadwater and older formations. Where Cretaceous or Miocene rocks are adjacent to the fills, clasts from these can be found along with reworked Broadwater gravels. In a few places on the east side of Verdigre Creek tributary fills contain clasts reworked from glacial and glaciofluvial sources just to the east of the quadrangle and from the Missouri River drainage (Todd, 1912; Stanley and Wayne, 1972; Williams, 1984; Voorhies and Goodwin, 1989; R.F. Diffendal, Jr., and R.G. Goodwin, unpublished pebble counts data). Some of these fluvial deposits including those of the high terrace are important local aquifers (Savage, 1989). Gravels eroded from distant sources (e.g., the Southern Rocky Mountains or to the north and west of the glacial border) have intermediate diameters mostly less than 3 in. Larger diameter distant clasts are presently known to occur in discontinuous late Pleistocene and Holocene fills along the Missouri River in Boyd County, Nebraska. Some of these reach boulder sizes. Blocks and boulders of locally eroded Ogallala quartzites occur in remnants of late Pleistocene and Holocene fills in northeastern Keya Paha County, Nebraska, and adjacent parts of southern South Dakota, north of the Keya Paha River.

The map area is mostly covered by surficial deposits composed chiefly of eolian sand, loess, colluvium, and the alluvium noted above (Manhke and others, 1978; Indra, 1979; Plantz and Zink, 1980; Ragon and others, 1983; Zink and Schultz, 1985; Indra and others, 1988; Shurtleff and others, 1988; Shurtleff and others, 1990; Voightlander and others, 1992; Shurtleff and others, 1993; Schulte and others, 1997). Pleistocene glacial deposits lie just to the east of the eastern boundary of the quadrangle. The eolian sand is in the form of dunes and sand sheets (fig. 22). Swinehart (1990), Swinehart and others (1994), and Stokes and Swinehart (1997) described these dunes and detailed their development. The dunes were formed and modified a number of times during the Holocene and include dune fields with distinctive morphologies and different ages. In the three parts of the Nebraska Sand Hills Ecoregion, the Sand Hills, the Lakes Area, and the Wet Meadow and Marsh Plain areas, eolian, alluvial fan, and lacustrine deposits occur in low areas and beneath lakes. The pond deposits include peats, mucks, marls, sands and other sediments. The loess is complex and includes interbeds of sand (Souders and Shaffer, 1969). We have called the loess Peoria Loess of late Pleistocene age, but some may be older. Colluvium is present generally as a thin mantle over much of the surface of the map area and has been mapped separately by Swinehart and others (1994) and by us where it is most prominent. To the east of the quadrangle, Guthrie (1990) noted oriented erosional and depositional landforms formed by winds during the Pleistocene.

The general Cenozoic environmental changes affecting the quadrangle and adjacent areas have been discussed in a number of papers for the units noted above (Haffner and others, 1990; Backlund and others, 1991; Diffendal, 1991; Diffendal and
Fig. 18. Subsurface configuration of the top of the Broadwater Formation. Contour interval 100 ft.
Fig. 19. High terrace (Q₃) on south side of Niobrara Valley, south of Meadville, Brown County, looking west.

Fig. 20. Armored mudball in Q₃ deposit capping terrace on west side of Missouri River, Boyd County.

Fig. 21. Granite boulder reworked from Pleistocene glacial deposits on east side of Missouri River in adjacent South Dakota in Q₃ deposit in figure 20.

Fig. 22. Sandhills. Adjacent low wet meadows formed due to high water table.
Voorhies, 1994; Retallack, 1997; Fox, 2000; Smith, 2002; Passey and others, 2002). The general trend from the Eocene through the Pliocene has been from a warm moist climate to a drier climate through time with significant global climate change in the latest Miocene. Major cooling, starting in the late Pliocene, increased as the various ice ages affected the area through the Pleistocene (Flint, 1955).

The O’Neill 1° x 2° quadrangle area is a major scenic and agricultural area of Nebraska. The Niobrara River, in part, is designated as a national scenic river and the Missouri is a national recreational river. Tributaries on the south side of the Niobrara are excellent trout streams. There are abundant wildlife resources across the quadrangle including waterfowl, turkeys and deer. Niobrara State Park (Flowerday and Diffendal, 1997), Keller Park State Recreational Area, Neligh Mills State Historical Site, and the famous Ashfall Fossil Beds State Historical Park (Voorhies, 1981, 1985, 1990a) are all excellent public sites. In 1804 the Lewis and Clark Corps of Discovery noted several major geological features along the Missouri and lower Niobrara rivers that can still be viewed today (Diffendal, 1999; Diffendal and Diffendal, 2003a,b). Agriculture includes hay meadow harvesting, alfalfa production, irrigated and dry land grain crop production, potato farming, hog and dairy cattle farming, and beef cattle ranching (fig. 23).

Deformation has affected parts of the area. Earthquake faults are usually hidden beneath surficial deposits, but have been noted in Cretaceous rocks (fig. 24) just east of Spencer Dam and at Niobrara State Park (Flowerday and Diffendal, 1997). Valley rebound was reported by Hearty and Stotler (1988). These phenomena may be more widespread across the area than previously thought because they are widespread in adjacent parts of South Dakota (Shurr and others, 1994) and in south-central Nebraska (Diffendal and others, 2002).

The quadrangle area has many geologic natural resources. These include good soils and excellent supplies of surface water (Bentall, 1991; U.S. Soil Conservation Service, 1973), groundwater (Gaul, 1993; and references cited in the earlier “Note” above), and some industrial minerals (Pollard, 1969; Burchett and Eversoll, 1994). Sand and gravel deposits are abundant in some areas. Volcanic ash lentils (Barbour, 1916, p.378-384) and quartzite (Barbour, 1913) are present. Geothermal resources occur in the mapped area (Gosnold and Eversoll, 1983).

Geologic hazards that affect the quadrangle include extreme weather elements, earthquakes, landslides, floods, and river-bed aggradation. Extreme weather elements that affect the U.S. Great Plains from time to time include droughts, high winds, tornadoes, large hail, heavy rains, and blizzards. Small earthquakes have been documented (Burchett, 1990). Landslides (Eversoll, 1991; Shroder and Bishop, 1995) are common in the northern part of the area in the Missouri-Niobrara drainage basins particularly, but not exclusively, on lands underlain by the Cretaceous marine Pierre Shale (fig. 25). Significant aggradation of the beds of the lower Niobrara and Missouri rivers (figs. 26-27) has occurred in response to the impounding of part of the Missouri River upstream from the Gavins Point Dam (Flowerday and Diffendal, 1997).

With the completion of this U.S. Geological Survey funded mapping project some minor changes on the “Geologic Bedrock Map of Nebraska” (Burchett, 1986) were needed to improve the map. This has been done in figure 28 of this report.

ACKNOWLEDGMENTS

Over the years many people have helped us during our studies across the quadrangle area. The authors thank the many farmers, ranchers, and other people who allowed us to work and study the geology on private and public lands of the map area. We also thank F.A. Smith, D.A. Eversoll, V.L. Souders, S.O. Lackey, V.H. Dreeszen, L. Howard, J.B. Swinehart, R.K. Pabian (University of Nebraska Conservation and Survey Division), S.S. Kaplan (University of Nebraska–Lincoln, Department of Geosciences), S. Holen (Denver Museum of Nature and Science), M.F. Skinner (American Museum of Natural History), S. Tucker (University of Nebraska State Museum), R.E. Otto (Superintendent, Ashfall Fossil Beds State Historical Park), V.L. McGuire (U.S. Geological Survey), B.V. Hanson and J. J. Gottula (Nebraska Department of Environmental Quality) for their help and advice at times during the course of the work leading to this map and text.

D. Ebbeka drafted maps and did layout. L. M. Howard and J. Nothwehr used ARC/GIS software for production of maps.

Field mapping for this project was funded by the Conservation and Survey Division of the University of Nebraska–Lincoln, by the University of Nebraska State Museum, and by the U.S. Geological Survey through grants from its STATEMAP program. Most of the mapping was done primarily from 1991 through 2000. We thank these agencies for their support.
Fig. 23. Land use/land cover map. Irrigated fields appear as circles on map (from Dappen and others 2007).
Fig. 24. Probable fault in the Cretaceous Pierre Shale Formation, north side of Niobrara River, just east of Spencer Dam west of U.S. Highway 283, Boyd County.

Fig. 25. Landslides displacing parts of former section of Nebraska State Highway 12, Knox County, south of Niobrara, Nebraska.

Fig. 26. Aerial photograph of confluence of Niobrara River with the Missouri River near upstream end of Lewis and Clark Reservoir. Note delta building into reservoir at mouth of Niobrara River and avulsed channel to the right (west) of the former main channel of river. Photograph taken in 1996.

Fig. 27. Former channel (left) and new channel after avulsion (right) of Niobrara River looking south-southeast from Niobrara State Park, Knox County.
Fig. 28. Revision of the O'Neill 1° x 2° quadrangle part of the Geologic Bedrock Map of Nebraska (Burchett, 1986).
CONVERSION FACTORS

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CORRELATION OF MAP UNITS

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EXPLANATION

L    Landslide area-Active during field mapping

F    Probable fault in Cretaceous Pierre Shale Formation

X    Volcanic ash (va) lentil in Ogallala Group

q    Green silica cemented sub-arkosic sandstone from the Valentine Formation, Ogallala Group

ld, ss Boundary between Qes dune types; ddc—Dome-like dunes, compound; dds—Dome-like dunes, simple and complex; ld—Linear dunes; ss—Sand sheet; bd—Barchan dunes (after Swinehart, 1990)
**DESCRIPTION OF MAP UNITS**

[In some areas, natural exposures are either too small to show on the map or are covered by varying thicknesses of younger deposits yet reveal the nature of the underlying unit. In these areas, the underlying unit is shown as a denominator (for example Ql/Kp). Fossil floras have been studied by Voorhies and Thomasson (1979), Thomasson (1990), and Haffner and others (1990). Invertebrate fossils diagnostic of some of the ages and restricted to stratigraphic positions of some of the map units have been identified by G.J. Loetterle, R.K. Pabian and other paleontologists at the University of Nebraska. Vertebrate fossils collected from the map units have been identified by M.R. Voorhies, M.F. Skinner, and other paleontologists of the University of Nebraska State Museum and of the American Museum of Natural History. Many of these invertebrate and vertebrate fossils are housed principally at these museums. Unless otherwise noted all units described below are bounded above and below by unconformities. Each map unit includes small areas of younger and older units too small in area to map separately at the scale of the map.]

**Qa1**  
**Younger alluvium (Holocene)**

Commonly sand, sand and gravel, with minor silt and sandy silt beds, light brown to pale olive; Gravels from Missouri River consist of clasts reworked from Quaternary glacial and outwash deposits along the South Dakota side of the river, from eroded Tertiary and Cretaceous bedrock along valley sides, from late Tertiary fluvial deposits on top of Tertiary bedrock on the Nebraska side of the river. Gravels from the Niobrara River and its tributaries mostly do not include clasts reworked from glacial and outwash deposits except for those parts of the alluvium downstream from the confluence of the Niobrara River with Verdigris Creek. Gravel clasts in alluvium of the Elkhorn River include some reworked Pliocene and locally pieces of sandstone and Pliocene eroded from Miocene bedrock. The alluvium of the Calamus River has some gravel reworked from Pliocene alluvium. Clast compositions reflect the bedrock and younger sediments in drainage basins. Unit composed of channel, flood-plain, terrace and alluvial fan deposits. Channel bases of the Missouri, Niobrara, and parts of the Elkhorn Rivers are scoured from bedrock and can have deep and narrow anastomosing patterns. The unit locally consists of areas of colluvium, eolian sand, and bedrock too small to map separately. Equivalent in part to unit Qe of Souders (2000) and to terrace fills T-0 and T-1 of Mandel (1997). Thickness from 0 to more than 100 ft.

**Qes**  
**Eolian sand (Holocene and upper? Pleistocene)**

Well sorted fine sand, pale-brown, pale-yellowish brown, and dark-yellowish-brown; laminated, cross-stratified and/or horizontally bedded; burrows and vertebrate tracks may be common (Swinehart and Diffendal, 1997). Locally contains several paleosols. Includes interdune deposits of eolian and lacustrine fine sand, organic-rich sandy silt, and lacustrine mud, muck, and peat. The highest dunes in the map area are in the southwest. These are compound- or simple and complex dome-like dunes up to 260 ft high (Swinehart, 1990). These extend east-northeastward from Brown and northern Blaine Counties across central Rock County and into western Holt County. Maximum heights decrease eastward too. A belt of linear dunes occurs on either side of Calamus River across parts of southern Brown, Rock and Holt Counties and parts of northeastern Blaine and northern Loup and Garfield Counties. A smaller belt of linear dunes occurs south of the Niobrara River in northwestern Brown County (Swinehart, 1990). These linear dunes are up to 60 ft high, about 500 ft wide, and up to one mi or more long. Sand sheets of moderate and low relief have been recognized by Swinehart (1990). Moderate relief sand sheets have been mapped by him in eastern Keya Paha County; northeastern and, to a more limited extent, southeastern Brown County, parts of Rock, Holt, Antelope, northern Loup, and northern Wheeler Counties. Low relief sand sheets occur in parts of southern Holt, northern Wheeler, and southern Antelope Counties. Swinehart (1990) also reported small areas of barchan dunes in eastern Keya Paha County and south-central Holt County. Stokes and Swinehart (1997) and Nicholson and Swinehart (2005) reported 6 episodes of sand dune activity in the Nebraska Sand Hills during the Holocene. The longest of these was from about 9200 to 7000 cal yr BP. WNW-ESE orientation of linear dunes shown on the map may reflect the large wind shift near the end of the Medieval Warm Period (800-1000 BP) noted in the Nebraska Sand Hills south and west of the map area by Sridhar and others (2006). Some small areas of younger and older deposits and bedrock may be included. Equivalent in part to unit Qe of Souders (2000). Thickness to more than 260 ft.

**Ql**  
**Loess (Holocene to middle? Pleistocene)**

Wind deposited silt and sandy silt, noncalcareous to slightly calcareous, very pale brown. Caps older Pleistocene and Pliocene deposits and some areas of older bedrock primarily in the eastern part of the map area. Interstratified with eolian sand in places in Antelope County (Souders and Shaffer, 1969). Locally may correlate with the Bignell Loess (Holocene) and the Peoria Loess (late Wisconsin) or older. Equivalent to eolian parts of units Qe and Ql of Souders (2000). Thickness generally less than 20 ft, but may be much greater if sequences in Antelope County and adjacent areas are entirely included.

**Qca**  
**Colluvium and alluvium (Holocene and upper? Pleistocene)**

Sand, silt, and gravel, ranges of brown and gray colors due to differences in colors of parent materials and durations of weathering; occur principally on valley side slopes. Unit grades laterally into alluvial deposits. Thickness usually from 0 to 40 ft, locally thicker.
Older alluvium 1 (Holocene)
Same as Qa₂ except that no clasts from Niobrara Formation (upper Cretaceous) are present. Caps strath and fill terrace remnants along parts of valley sides of all rivers and tributaries in the map area. Deposits are usually unconsolidated, but may be locally cemented with ferruginous or calcareous cements. Figure 29 shows courses of rivers that deposited this and older alluvium across the map area that have been postulated by earlier authors. Thickness 0-50 ft.

Older alluvium 2 (upper Pleistocene)
More extensive deposits principally along the Niobrara River, its tributaries, mostly on south side of the river, along Ponca Creek and the Keya Paha River, and discontinuously along the Missouri River in Boyd County. Same clast types as Qa₂ except at higher position on valley side. Top of fill about 175 ft above the valley floor. Called “Unnamed High Terrace” by Voorhies (1990c) and the “Connely Flat beds” by Larson (2001) and Larson and Swinehart (2001). Voorhies (1990c, p. 95) lists a late Pleistocene mammalian fauna typical of the Rancholabrean North America Land-Mammal age including species of bison, prairie dog, Richardson ground squirrel, pika, and wolverine from these deposits. Larson (2001) reported a radiocarbon age date from a paleosol at the top of the unit of 9,320 +/-60 years old and an AMS date of 14,300 +/-65 years old on terrestrial gastropod shells from a silt in the fill. Diffendal (in Holen, 1997) reported angular pieces of specular hematite and other distant clasts on surface of fill along Ponca Creek. These clasts appear to be rocks used by Native Americans when they made camps or settlements on this fluvial terrace, a position safer from flooding than Qa₁ and Qa₂. Discontinuously along the Nebraska side of Missouri River in Boyd County gravels contain distant-source boulders from north of the Pleistocene glacial border. This fill is cemented in places by calcium carbonate and iron oxide cements. Thickness to 80 ft.

Older alluvium 3 (upper-mid? Pleistocene)
Sand and gravel occurs in remnants along south side of Niobrara River in Brown and Rock Counties. Gravel clasts include reworked Ogallala Group (Miocene) rocks and granite, anorthosite, and other rocks reworked from the Broadwater Formation (Pliocene). Thickness to 50 or more ft.

Unnamed Formation (Plio-Pleistocene)
Eolian sand, lacustrine peats and diatomites, alluvial sands, green silty sands and sandy silts. Unit between the eolian sand (Qes) and the Broadwater Formation (Tb) beneath the Nebraska Sand Hills Ecoregion. Equivalent to units Ql (in part) and TI of Souders (2000). Thickness up to 280 ft or more.

Broadwater Formation (Pliocene)
Fluvial pebble gravel and sand. Pebbles include clasts typical of Rocky Mountains areas in north-central Colorado and in south-central and southeastern Wyoming (Stanley, 1971; Stanley and Wayne, 1972; Swinehart and others, 1985; Swinehart and Diffendal, 1990; Swinehart and Diffendal, 1997). Trough cross stratification and plain bedding observed in gravel pits and natural exposures. Mammalian vertebrate fossils typical of the Blancon North American Land-Mammal Age include Stegomastodon, Borophagus, Gigantocamelus, Ondatra, Geomys, and Equus (Dolichohippus) (see Diffendal and Voorhies, 1994). Swinehart and Diffendal (1997) reported at least three finer-grained beds, some called members by earlier workers, within the gravel and sand body in its type area in western Nebraska. Skinner and Hibbard (1972) recognized an older, finer grained unit, the Keim Formation; a sand and gravel unit, the Long Pine Formation; another finer grained unit, the Duffy Formation; and another sand and gravel, the Pettijohn Formation in Brown and Rock Counties. Since Stanley and Wayne (1971) and Swinehart and Diffendal (1990) have demonstrated that the Broadwater and the Keim-Pettijohn units are parts of one continuous formation we have chosen to call the unit the Broadwater Formation in the map area. Members of the Broadwater Formation are not shown on map. Equivalent to unit Tg of Souders (2000). Composite thickness in outcrop about 275 ft; 308 ft in test hole.

Ogallala Group, undivided (upper and middle Miocene)
Primarily fluvial sands and sandstones, silty sandstones, pebbly sands and sandstones, calcareous sandstones, silts and siltstones, clays; with minor diatomite and volcanic ash lentils. Subdivided into the Fort Randall (oldest), Valentine, and Ash Hollow Formations in the map area (Diffendal and Voorhies, 1994). These formations not shown on the map. Skinner and Johnson (1984) reported and described members of the Valentine Formation [Cornell Dam (oldest), Crookston Bridge, Devil’s Gulch, and Burge], and the overlying Ash Hollow Formations [Cap Rock (oldest; named in Skinner and others, 1968), Merritt Dam, and unnamed Hemphillian member] in considerable detail. Fort Randall Formation originally described by Skinner and Taylor (1967) from Bijou Hill in South Dakota. Formation consists of silty sand, sandy clay, and clay; shades of light gray, pink, red, brown, and pale olive; barite and calcareous concretion horizons present (see Diffendal and Voorhies, 1994). We assign the Miocene (?) silt beds of Souders (1976) in Boyd County to the Fort Randall. Fossil wood and other plant fossils occur in some members (Voorhies, 1990c; Thomasson, 1990). Key vertebrate species include Merycodus necatus and Ustatochoerus schrammi (see Diffendal and Voorhies, 1994); others include Merychippus sp., Chrysemys, Peromyscus
Fig. 29. Postulated courses of Pliocene and Pleistocene Rivers crossing parts of the map area that have been proposed by previous workers.
(Copemys) (see Skinner and Taylor, 1967). Easily accessible exposures in roadcut at top of north side of Niobrara Valley on Nebraska Highway 11, south of Butte, Boyd County, Nebraska, and on south side of Niobrara Valley north of Stuart, on Stuart-to-Naper road, Holt County, Nebraska. Valentine Formation includes much sand, pale olive, friable; subarkose, pale olive to green, silica cemented; clayey- and silty sands, pale olive to gray; one volcanic ash lentil; sands and gravels, cross-stratified. Lowest member of Valentine, the Cornell Dam of Skinner and Johnson (1984) has calcareous concretions with manganese oxide dendrons not found in other members. All members except Devil’s Gulch are alluvial fills of fluvially eroded valley cuts into older strata. Ash Hollow Formation has basal sandstone, gray, calcareous, interbedded with less consolidated sand and volcanic ash lentils (Caprock Member of Skinner and others, 1968); overlain by thinner bedded calcareous sandstones, pale olive, with several volcanic ash lentil horizons; unconsolidated sand fills paleovalleys eroded into older Ash Hollow and upper Valentine units (Skinner and Johnson, 1984). Formation has many siliceous rhizoliths, hackberry endocarps, and fossil “seeds” occur throughout, but are most common in Caprock member (Skinner and Johnson, 1984; Thomasson, 1990). Key vertebrate fossils include Pseudhipparion gratum, P. skinneri, Barbourofelis whitfordi, B. morrisi, Ustatochoerus skinneri, U. major, Megalonyx, and Prosomys (see Diffendal and Voorhies, 1994). Equivalent to units To and Th of Souders (2000) and to unit To of Burchett and others (1975; 1988). Thickness of group 574 ft in test holes; composite thickness 560 ft or more in outcrop.

**Tc**

**White River Group, Chamberlain Pass Formation (upper Eocene)**

Sandstone and sand, white; authigenic clay cements in sandstones; clay, sandy, tan to olive; clay, sandy clay, and sand, purple, red, white, and yellow; siltstone, pink to green; all tuffaceous; deeply weathered; sands are primarily glassy quartz. Easily accessible exposures along U.S. Highway 183 at site noted above. Maximum exposed thickness of about 77 ft is at this site (Skinner and Johnson, 1984; Diffendal and Voorhies, 1994). All currently known exposures are in Keya Paha County; some subsurface occurrences in Brown County and south shown in Souders (2000) as part of unit Tw. No fossils found in this unit to date. Maximum thickness 77 ft in test hole; 77 ft in outcrop.

**Kn**

**Nobrara Formation (upper Cretaceous)**

Chalk, shale, and limestone, gray to white; weathers to shades of orange; some selenite and iron disulfide present; bentonite seams. Carbonate rocks composed mainly of microscopic calcareous nannofossils and foraminiferal tests (shells). Trace fossils common; macroscopic invertebrates include crabs (Inoceramus; Pseudoherna congesta) and ammonite cephalopods. Vertebrate fossils include shark teeth and denticles; bones, teeth, and scales from boney fish including the giant fish, Xiphactinus (see Flowerday and Diffendal, 1997). Equivalent to unit Kn of Souders (2000) and Burchett and others (1975; 1988). Maximum thickness greater than 400 ft in outcrop; 765 ft in test hole in Rock County.

**Kp**

**Pierre Shale (upper Cretaceous)**

Shale, medium- to dark gray, brownish gray, black, fissile; mudstones, gray to black; lesser chalks, light gray to white. Iron disulfide, selenite, and organic matter common (Diffendal and Voorhies, 1994; Flowerday and Diffendal, 1997; Schulte 1952 and Mendenhall 1953) recognized nine members in the formation not shown on this map. Watkins (1997) described meteorite generated tsunami deposits in the lower calcareous member, the Crow Creek, at Niobrara State Park in Knox County. Fossils include nannofossils, foraminifera, ammonites, clams; shark, bony fish, and mosasaur skeletal debris (Pabian, 1979; Diffendal and Voorhies, 1994; Flowerday and Diffendal, 1997). Equivalent to unit Kp of Souders (2000) and Burchett and others (1988). Maximum thickness greater than 400 ft in outcrop; 765 ft in test hole in Rock County.

**Tar** Arikaree Group, Rosebud Formation (upper Oligocene)

Siltstone and silty sandstone, claystone, pinkish gray, pinkish pale orange, to brownish, olive; volcaniclastic; some conglomerates with claystone and siltstone clasts, brown to olive; plain bedded, cross-stratified, or massive beds. Best exposed along county road on north side of Niobrara River, just northwest of Meadville, Keya Paha County, Nebraska. Formation fills paleovalleys eroded into Cretaceous Pierre Shale. Conglomerates generally confined to tributary paleovalleys; multiple cuts and fills resemble debris flow deposits; best seen in borrow pit on east side of U.S. Highway 183 about 2 mi north of Niobrara River in Keya Paha County. Thin remnants of formation have been found at a few sites in Knox County. Key vertebrate fossils include Centetodon magna, Desmatochoerus, Leptacanthia, Psammechinus, and Nanotragulus (see Voorhies, 1973; Voorhies and Diffendal, 1994; Timperley and others, 1998). Equivalent in part to unit Ta of Souders (2000). Maximum thickness in Keya Paha County more than 100 ft in outcrop, 220 ft in test hole; in Knox County 45 ft in outcrop.

**Kp**

**White River Group, Chamberlain Pass Formation (upper Eocene)**

Sandstone and sand, white; authigenic clay cements in sandstones; clay, sandy, tan to olive; clay, sandy clay, and sand, purple, red, white, and yellow; siltstone, pink to green; all tuffaceous; deeply weathered; sands are primarily glassy quartz. Easily accessible exposures along U.S. Highway 183 at site noted above. Maximum exposed thickness of about 77 ft is at this site (Skinner and Johnson, 1984; Diffendal and Voorhies, 1994). All currently known exposures are in Keya Paha County; some subsurface occurrences in Brown County and south shown in Souders (2000) as part of unit Tw. No fossils found in this unit to date. Maximum thickness 77 ft in test hole; 77 ft in outcrop.
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