Surficial Geology of the Verdel Quadrangle, Nebraska Portion

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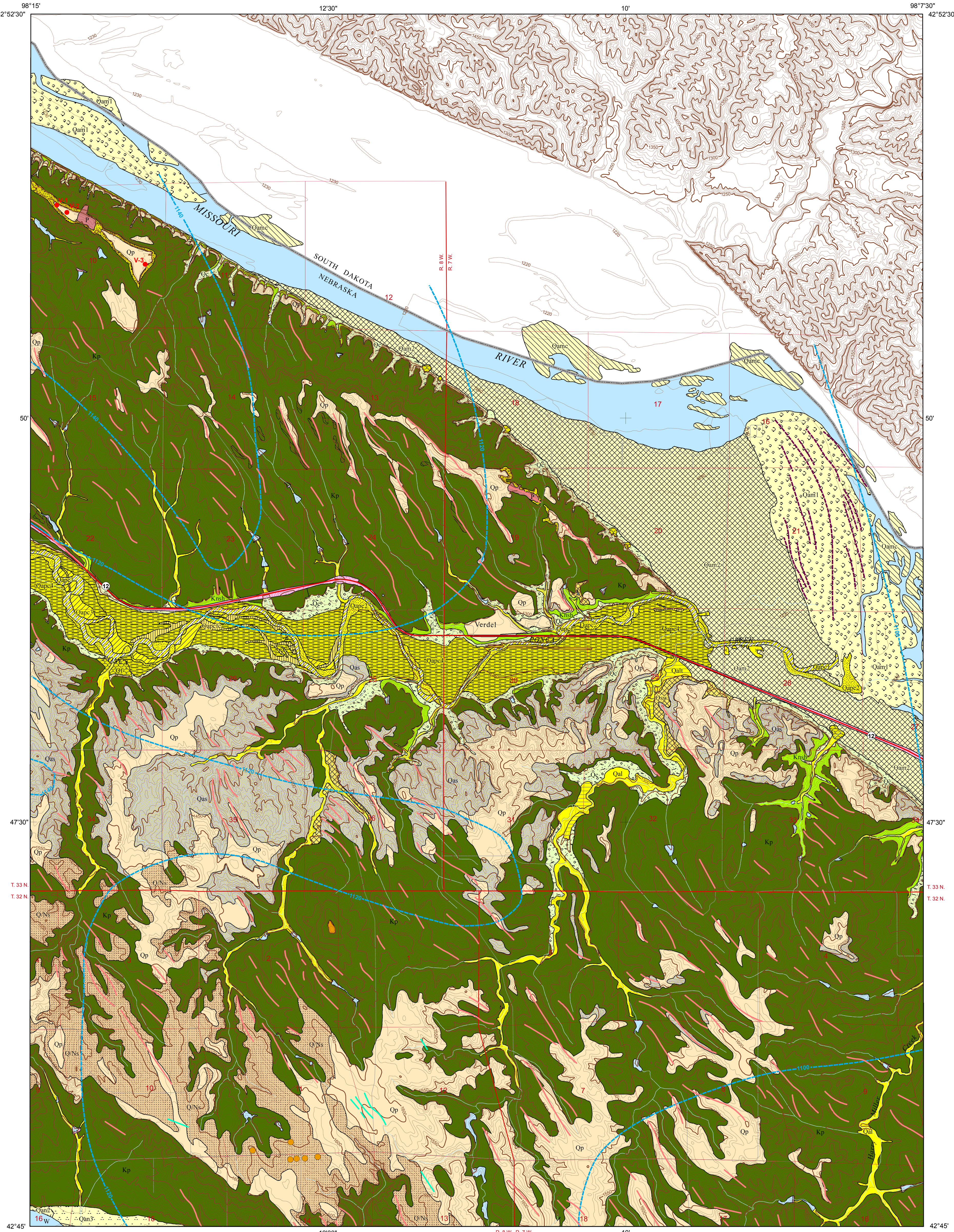


SCALE 1:24,000

1 0.5 0 1 Miles

1,000 0 1,000 2,000 3,000 4,000 5,000 6,000 7,000 Feet

1 0.5 0 1 Kilometers

Projection: UTM zone 14 North, NAD83

Contours from the Nebraska Department of Natural Resources, compiled from USGS 7.5 minute topographic quadrangles

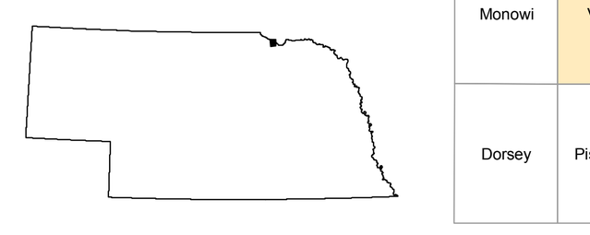
Additional base data derived from 2005 second edition TIGER/line files

N — Magnetic North Declination Approximately 4°36', 2012

CONTOUR INTERVAL 10 FEET

DATUM IS MEAN SEA LEVEL

Lynch NE	Niobrara NW	Niobrara NE
Monowi	Verdel	Niobrara
Dorsey	Pishelville	Verdigre NE



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Knsh **Smoky Hill Chalk Member of the Niobrara Formation (Late Cretaceous, Campanian)**

Light gray to dark gray shaly chalk, weathering prominently white or brownish yellow; also contains multiple, thin bentonites.

The Niobrara Formation underlies the Pierre Shale in the enclosing region, but it crops out only along the lower parts of the valley walls of the Missouri River and along Ponca Creek. Casual observations of poor exposures may lead to some confusion between the strata of the Smoky Hill Chalk Member of the Niobrara Formation and those of the overlying basal Pierre Shale, but the Niobrara Formation is perceptibly lower in density, firmer, and significantly more calcareous than is the Pierre Shale. In good exposures it is impossible to mistake the two units. The elevation of the contact between the Niobrara Formation and the overlying Pierre Shale in the area of the Verdel Quadrangle is approximately 1280-1300 ft (390-427 m). In much of its mapped area, the Niobrara Formation is obscured by colluvium and in some places along valley walls it is also densely overgrown by trees. The Smoky Hill Chalk shows weak conchoidal fracture, splits into slabs or splinters (rather than fissile chips like the lower part of the Pierre Shale) and it can be further distinguished by its tendency to weather brownish yellow or even slightly reddish at the land surface. Fossil oysters (*Ostrea*) and fish scales can be found in the Smoky Hill Chalk. Crystals of secondary selenite gypsum commonly appear on bedding and fracture planes in weathered strata of the Smoky Hill Chalk. Exposures of the Smoky Hill Chalk Member of the Niobrara Formation can be found: (1) along the Missouri River in sections 10, 11, 12, and 13 of T. 33 N., R. 8 W. (2) along Nebraska Highway 12 in the southern halves of sections 22 and 23 of T. 33 N., R. 8 W., (3) in a cut immediately northwest of the center of section 25, T. 33 N., R. 8 W., and (4) on the south bank of Ponca Creek in the SW¼ NW¼ SW¼ of section 30, T. 33 N., R. 7 W. The contact with the Pierre Shale is generally well-exposed at these sites as well.

Kp **Pierre Shale (Late Cretaceous, Campanian-Maastrichtian)**

Gray to dark gray (weathering light gray, olive gray, olive brown, grayish brown, pale brown, and pale yellow) silt shale to clay shale, with rare, very thin to thin beds of siltstone, very fine sandstone, and bentonite, as well as beds of chalky limestone.

The Pierre Shale is mapped over a large area of the Verdel Quadrangle, and at least 300 ft (91 m) of the unit are exposed, however well or poorly, within the mapped area. The lack of large, unvegetated exposures of the Pierre Shale in the mapped area precludes a detailed lithostratigraphic study of its constituent members, although a protracted biostratigraphic study would likely resolve stratigraphy. We presume that most or all of the Pierre Shale is present in the mapped area, including the Sha ron Springs, Gregory, Crow Creek, DeGrey, Verendrye, Virgin Creek, Mobridge, and Elk Butte members, or their equivalents.

No **Ogallala Group, undifferentiated (Neogene, Middle to Late Miocene)**

Greenish gray (weathering to white) opaline sandstones and unconsolidated, well-sorted, light brown, brown, and yellowish brown, very fine to fine sands, in some places containing a few granules and pebbles.

Greenish gray opaline sandstones ("green quartzites" or orthoquartzites) of the Ogallala Group (cf. Swineford and Frye, 1946; Swineford and Franks, 1959; Skinner and Taylor, 1967) crop out atop "Stony Butte" south-southwest of the town of Verdel in the W½ NE¼ of section 2, T. 32 N., R. 8 W. Opaline sandstones such as these were originally attributed to either the Arikaree Group or to unnamed Pleistocene units (Condra, 1908, Barbour, 1915). For many years, however, the consensus has been that these types of sandstones are characteristic of the Ogallala Group across the Great Plains (e.g., Swineford and Frye, 1946; Swineford and Franks, 1959; Skinner and Taylor, 1967). Those mapped on "Stony Butte" in the Verdel Quadrangle may be within the Valentine Formation of the Ogallala Group, but there are, as yet, no biostratigraphic or geochronologic data supporting such a hypothesis. Scattered blocks of opaline sandstone at surface on the southern edge of the Ponca Creek-Niobrara River divide in the S½ of section 11 and in the N½ of section 14, T. 32 N., R. 8 W. are also derived from the Ogallala Group. The unconsolidated sands surrounding these blocks may be either: (1) unconsolidated Miocene sands of the Ogallala Group, or (2) reworked Miocene sediments (see discussion of mapping unit Q/Ns).

Q/Ns **Cenozoic sands of uncertain origin (Miocene or Quaternary)**

Light brown, brown, and yellowish brown, well-sorted, very fine to fine sands, in some places containing a few granules and pebbles.

Mapping unit Q/Ns is unconsolidated very fine to fine sands in the uplands on the southern edge of the Ponca Creek-Niobrara River divide. These sands are very similar, if not identical, to those of mapping unit Qas. We employ a separate mapping unit for them, however, because of the co-occurrence of scattered blocks of opaline sandstone, a rock type widely considered to be characteristic of the Ogallala Group (Swineford and Frye, 1946; Swineford and Franks, 1959; Skinner and Taylor, 1967). The sands mapped as Q/Ns may merely locally wind-reworked Miocene sediments, and the remnant blocks of opaline sandstone may have been gradually let down from a former, higher stratigraphic level during the process of erosion. Some of the sands mapped as Qas may also be of Miocene age and may not have been reworked. The origins and associations of mapping unit Q/Ns may be illuminated by future studies. The recovery of distinctive Miocene vertebrate fossils from these sediments would verify a hypothesis that the sediments themselves are Miocene. Indeed, Miocene mammalian fossils have been collected from the general area of Knox counties, but none, to our knowledge, have yet been recovered from the area of the Verdel Quadrangle.

Qac **Coarse alluvium containing crystalline cobbles and boulders, interpreted as glacial outwash (Pleistocene)**

White, gray, and grayish brown, horizontally stratified and trough cross-stratified, well-sorted and fine to poorly-sorted very coarse pebbly sand; matrix- and clast-supported pebble to boulder gravels, with common clasts of crystalline rock; rare beds of ripple cross-laminated fine to medium sand; includes strata of pale brown to brown silt overlying the aforementioned sand and gravel interval and rare lenses of brown silt within that interval.

Very coarse alluvium containing cobbles and boulders of granite, gneiss, greenstone, schist, limestone, Niobrara Formation chalk, Pierre Shale ironstone, and Ogallala Group opaline sandstones, appears under two landforms described in detail in the introduction to this map: (1) a dissected flat-topped feature in the N½ of section 10, T. 33 N., R. 8 W; and (2) a broad, gently sloping summit in the NE¼ NW¼ of section 18, T. 33 N., R. 7 W. These sediments are similar to those that were mapped as Qac in the Marty Quadrangle to the northwest of the currently mapped area (Joeckel et al., 2011). Clasts of crystalline rock, which appear to be derived from the Canadian Shield, are well-rounded and a few of them exhibit flat-faceted surfaces similar to those seen on many glacial erratics in nearby glaciated areas. This very coarse alluvium contains a large component of material derived either directly from outwash streams draining the Laurentide ice sheet immediately to the north in present-day South Dakota, or from the erosion of glacial deposits and the transport of that eroded sediment by the Missouri River. We interpret mapping unit Qac as glacial outwash and we hypothesize that a nearly continuous or continuous sheet of outwash extended across the area now marked by the trench of the Missouri River Valley prior to its incision, and that the two features described above are remnants of that sheet.

Qal **Quaternary alluvium of smaller streams (Holocene to modern)**

Clayey silt, silt, sandy silt, and sand.

Small, lower order streams in the mapped area deposit mostly clayey silt, silt, sandy silt, and fine to medium sand. Streams draining basins dominated by surficial materials of either Peoria Loess or Pierre Shale should be expected to deposit more silt and clay than do other streams. Some of the sediments mapped as Qal are similar to those included in mapping unit Qalt.

Qalt **Quaternary alluvium of in terraces of smaller streams (Late Pleistocene to historic)**

Clayey silt, silt, sandy silt, and sand.

Deposits mapped as Qalt are similar to those mapped as Qal . Clayey silt, silt, sandy silt, sand dominate these deposits. Drainages on the Peoria Loess may contain significantly more silt and significantly less coarse sediment, and this condition will be reflected in the textures of terrace deposits. Some areas mapped as Qalt may still be inundated by major flash floods.

Qam1 **Younger Quaternary alluvium of the Missouri River : alluvium in stabilized point bars (Holocene; post-1858)**

White to light brown sand and sandy silt overlying fine to coarse sand or gravelly sand.

These younger alluvial deposits of the Missouri River were deposited after the time of the first General Land Office (GLO) surveys in the late 1850s. Meander scrolls are visible locally on aerial photographs covering areas mapped as Qam1. Areas mapped by Qam1 are also subject to flooding more frequently than are those mapped as Qam2.

Qam2 **Older Quaternary alluvium of the Missouri River : stabilized alluvium (Late Pleistocene-Holocene; pre-1858)**

Brown to dark brown silt and sandy silt overlying fine to coarse sand or gravelly sand.

These older alluvial deposits of the Missouri River were stable parts of the floodplain at the time of the first General Land Office (GLO) surveys in the late 1850s. Areas mapped as Qam2 are characterized by a widespread surficial layer of dark grayish brown sandy silt with common very coarse sand grains and granules and/or brown weakly stratified silt. Unlike Qam1, lateral -accretion topography is no longer visible at the surface in these materials. Areas mapped as Qam2 are subject to flooding only during major flood events.

Qamc **Very young Quaternary alluvium of the Missouri River in active chute channels and islands (modern)**

Silty clay, silt, sandy silt, silty sand, and fine sand overlying fine to coarse gravelly sand.

Mapping unit Qamc includes chute channels and smaller islands that were stabilized and accreted to the Nebraska shore long after the date of the General Land Office (GLO) survey of 1858. Channels and islands included in this mapping unit will be inundated at very high riv er stages.

Qan2 **Young Quaternary alluvium of the Niobrara River (historic)**

Pale brown and light brownish gray silty sand and fine to coarse sand.

A small part of the floodplain of the Niobrara River is present at the southwestern corner of the Verdel Quadrangle. Mapping unit Qan2 includes areas along the Niobrara River in which fluvial deposition has occurred since initial Euramerican settlement, and even into recent decades. These areas are subject to flooding during high-stage flow periods of the Niob rara River. Mapping unit Qan3 is likely to be underlain by Holocene alluvium.

Qan3 **Older Quaternary alluvium of the Niobrara River (Late Holocene)**

Pale brown and light brownish gray silty sand and fine to coarse sand.

A small part of the floodplain of the Niobrara River is present at the southwestern corner of the Verdel Quadrangle. Areas mapped as Qan3 are parts of the floodplain of the Niobrara River, but they are likely to have been stable since the mid-19th century, if not earlier. These areas may still have been flooded frome time to time and may have received comp aratively small increments of overbank sediment since the first Euramerican settlement of the area. Mapping unit Qan3 is likely to be underlain by older Holocene and Late Pleistocene alluvium.

Qapc1 **Youngest Quaternary alluvium of Ponca Creek (modern)**

Very pale brown and light brownish gray fine to coarse sand, but dominantly medium san d, and locally containing a few flat pebbles of eroded Niobrara Formation chalk.

The areas mapped as Qapc1 can be identified as the results of very recent (generally post-1950) in-channel and point bar deposition in Ponca Creek. Examinations of General Land Office (GLO) surveys dating to 1858, indicate that, overall, the meanders of Ponca Creek have migrated little i n the area of the Verdel Quadrangle since that time, as appears to be the case in the Lynch Quadrangle (Joeckel et al., 2010). Appreciable lateral migration of the channel of Ponca Creek, and subsequent lateral growth of point bars and cut banks, has occurred locally in recent decades. Such growth is represented in the rendering of Qapc1 on this map. The course of Ponca Creek across the floodplain of the Missouri River has changed appreciable since the time of GLO surveys because of channelization, and n o trace of the ca. 1858 channel can be found in modern aerial photographs of that area. Areas mapped as Qapc1 are hazardous for building or other permanent use and will flood during higher-stage flows of Ponca Creek.

Qapc2 **Young Quaternary alluvium of Ponca Creek (historic)**

Gray, light brownish gray, very pale brown, and brown sandy silt, silty fine sand and fine to coarse, but dominantly medium, sand.

The areas mapped as Qapc2 can be identified as the results of channel and point -bar migration during the Euramerican settlement period (1854-present) on the basis of General Land Office (GLO) surveys and aerial photograph series beginning in 1938. Many of these areas are covered by riparian woodland, probably because they were unsuitable for farming when intensive agricultural land use began. Sediments included in this mapping unit are dominantly thin - to thick-bedded, sandy silt, silty fine sands, and medium sands. These strata contain very weakly -developed buried soils. Areas mapped as Qapc2 experience overbank flooding during major flow periods of Ponca Creek.

Qapc3 **Older Quaternary alluvium of Ponca Creek (Late Holocene; probably early historic)**

Gray, light brownish gray, very pale brown, and brown sandy silt, silty fine sand and fine to coarse, but dominantly medium, sand.

Areas mapped as Qapc3 show evidence for the lateral migration of Ponca Creek in geologically recent times, but prior to the initiation of General Land Office (GLO) surveys, and probably within a few centuries prior to Euramerican settlement. Sediments inc luded in this mapping unit are essentially identical to those of Qapc2. Areas mapped as Qapc3 may be flooded episodically.

Qapc4 **Older Quaternary alluvium of Ponca Creek (Holocene)**

Gray, light brownish gray, dark grayish brown, very pale brown, brown, and dark brown sandy silt, silty fine sand and fine to coarse, but dominantly medium, sand.

Areas mapped as Qapc4 are in long-term agricultural use and rarely (if ever, in distal floodplain positions) experience overbank flooding. In early aerial photographs dating to as early as 1938 the se areas generally appear smooth and comparatively uniform in tone, and they show no evidence for meander scrolls and channels. Therefore, surficial sediments mapped as Qapc4 are interpreted as being older than those of mapping unit Qapc3. Sediments included in this mapping unit are like those of Qapc2 an d Qapc3, but mapping unit Qapc4 is generally characterized by a surface layer of very dark grayish brown to dark brown fine sandy silt. Areas mapped as Qapc4, particularly those close to the modern channel of Ponca Creek, may be flooded episodically.

Qapcfc **Flood channels of Ponca Creek (modern)**

Light brownish gray and very pale brown fine to medium sand.

A few persistent flood channels crossing older alluvial deposits (usually those of mapping unit Qapc4) can be identified on the basis of aerial photographs dating to 1938 and after , up until the present day. The deposits of these flood channels are very thin, and they overlie the older alluvial units that are mapped directly adjacent to them at any point. They are mapped separately chiefly becau se they indicate flood hazards during high-stage flows of Ponca Creek.

Qas **Alluvial sands, probably reworked by wind, on terrace surfaces at various levels (Quaternary)**

Pale brown, light brown, brown, and yellowish brown, well-sorted, very fine to fine sands, in several places containing a few granules and pebbles.

This mapping unit was employed by Joeckel et al. (2010) to depict unconsolidated very fine to fine sands in the uplands on both sides of Ponca Creek, but existing mostly on the northern slopes of the Ponca Creek-Niobrara River divide. These sands may have few to common granules to pebbles of crystalline rock types. Mapping unit Qas is presumed to consist of multiple Pleistocene terrace deposits of the ancient Ponca Creek, very little is known about the constituent sediments. As yet, there is no paleontologic or geochronologic age control on deposits mapped as Qas, and there are no large vertical exposures of them from which stratigraphic relationships might easily be discerned. The overall very fine to fine texture of these sands, as well as their generally high degree of sorting, suggests that they may have been reworked, at least locally, by winds during the Pleistocene. The distinction between mapping unit Qas and mapping unit Q/Ns (see forthcoming discussion) is arbitratry. The origins and associations of mapping unit Qas may be illuminated by future studies.

Qasp **Splay deposits (modern)**

Light brownish gray and very pale brown fine to medium sand.

Splay deposits produced by overbank flooding events along Ponca Creek since the first aerial photograph year of 1938 can be identified through the examination of series of aerial photographs. Splay deposits are very thin and overlie older alluvial deposit s of mapping units such as Qapc4 and Qam2.

Qc **Colluvium (Holocene-modern)**

Dominantly grayish brown silty clay to silt with weathered fragments of chalk from the Niobrara Formation or shale from the Pierre Shale, plus other materials.

Colluvium appears on foot- and toeslopes in the mapped area, particularly on the lower slopes of the valleys of the Missouri River and Ponca Creek. Colluvium merges downslope with alluvium (e.g., mapping unit Qal) or with fan sediments (mapping unit Qf) and it is likely to be either barely distinguishable or undistinguishable from either of those sediments at any given point of transition.

Qf **Quaternary alluvial fan sediments (Holocene -modern)**

Dominantly grayish brown silty clay to to silt with fragments of chalk from the Niobrara Formation or shale from the Pierre Shale, plus sediments derived from the erosion of upslope deposits of loess, eolian sands, etc.

Multiple, very small, low-angle alluvial fans lie along the southern valley walls of the Missouri River and along the valley of Ponca Creek. They are identifiable at ground level with the help of a topographic map and they are elevated slightly above toeslope and floodplain surfaces. Fan deposits in the mapped area consist of thin increments of colluvium and alluvium transported from adjacent uplands by overland flow.

Qp **Peoria Loess (Late Pleistocene [Late Wisconsinan])**

Light brownish gray, brown, pale brown, and light yellowish brown clayey silt and medium to coarse silt

The eolian silts of the Peoria Loess are distributed sparsely and very discontinuously across the mapped area and vary considerably in thickness. Very thin and sandy loess appears atop, and partially amalgamated into, some of the high, flat summits in the mapped ar ea and in such cases it may be difficult to separate as a distinguish the Peoria Loess as stratigraphic unit. Thicker Peoria Loess, ranging from approximately 2 to 2.5 m in thickness, appears on the surfaces of landforms underlain by mapping unit Qac (see discussion of this mapping unit).

Qsw **Slopewash (Holocene, including modern deposits)**

Silty clay, silt, and very fine to fine sand.

Slopewash is derived from the erosion and downslope transportation and deposition of unconsolidated surficial sediments. It is mapped on the lower slopes of landforms covered with materials such as sand and loess, and it is distinguished from colluvium because it does not have a major component of material derived from the erosion of local bedrock. Slopewash deposits are thin and merge with alluvium (e.g., mapping unit Qal) or other surficial sediments (e.g., mapping unit Qc), and they may be locally indistinguishable from materials such as the distal alluvium of small streams (mapping unit Qal). In many places in the Verdel Quadrangle, slopewash overlies the Pierre Shale on foot and toeslopes.

F **Fill**

Artificial fill, typically derived from local sources.

This mapping unit is intended to portray significant accumulations of artificial fill in dams, road embankments, and other manmade structures. Most of the fill in structures in the uplands is derived from the excavation of the Pierre Shale.

P **Pit**

Two gravel pits, one active and the other inactive, are mapped on the Verdel Quadrangle.

W **Water**

Landslide

Prominent high-relief oriented ridge line interpreted as a product of eolian erosion

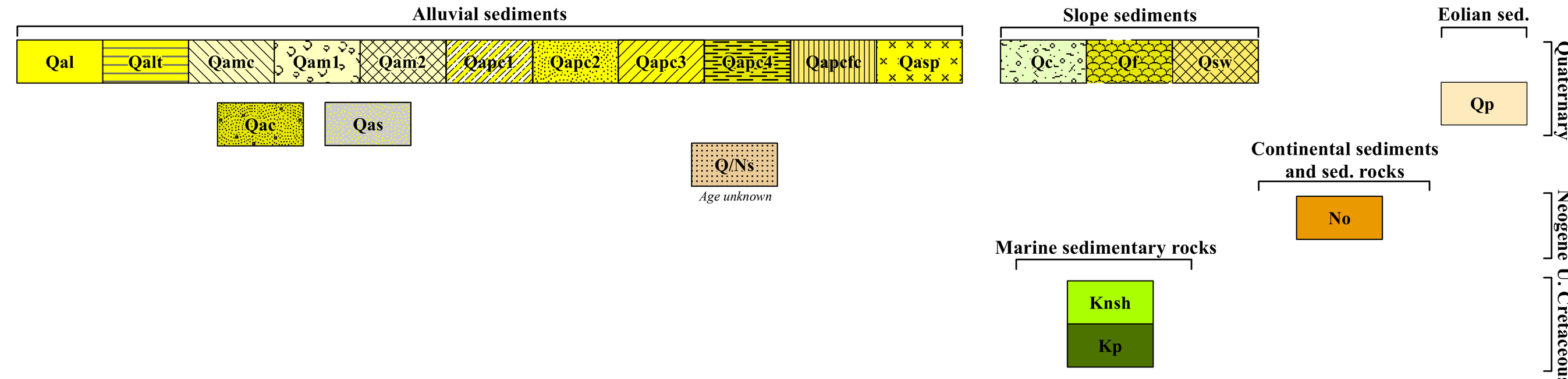
Low-relief oriented feature mapped from aerial photography and interpreted as a product of eolian processes

Top of Codell Sandstone aquifer (feet)

Meander scrolls

Isolated blocks of Ogallala Group opaline sandstone

Test hole location



This geologic map was funded in part by the USGS National Cooperative Geologic Mapping Program. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

Overview Verdel Quadrangle, Nebraska Portion

Geographic Setting and Geomorphology

The Verdel Quadrangle lies in northwestern Knox County, Nebraska and in the adjacent parts of Bon Homme and Charles Mix counties in southern South Dakota. Only the Nebraska portion of the Verdel Quadrangle is presented as a geologic map in this document.

The Nebraska portion of the Verdel Quadrangle lies immediately southward and westward of the Laurentide glacial limit, at the very eastern edge of the Great Plains. In the ecoregions map of Chapman et al. (2001), the area of the Verdel Quadrangle lies within the Northwestern Glaciated Plains Level III Ecoregion, even though the Nebraska part of the quadrangle does not appear to have been glaciated during the Pleistocene. The mapped area is very close to the Lautentide glacial limit in South Dakota, however, and periglacial conditions must have existed in the area during a large portion of Pleistocene times. The Laurentide Ice Sheet actually extended into the South Dakota portion of the Marty Quadrangle, to a position at or near the present north bank of the present Missouri River in Charles Mix County, South Dakota. In Nebraska, the glacial limit lies in the eastern half of Knox County and the nearest mapped tills are approximately 14 mi (23 km) east of the eastern edge of the quadrangle. The Nebraska portion of the Verdel Quadrangle lies within the United States Department of Agriculture Natural Resources Conservation Service (NRCS) Major Land Resource Area (MLRA) 63B Southern Rolling Pierre Shale Plains (United States Department of Agriculture, Natural Resources Conservation Service, 2006).

The very scenic topography of the Nebraska portion of the Verdel Quadrangle is generally characterized by rolling uplands (Fig. 1). It can be subdivided into: (1) the trench-like and generally straight-sided valley of the Missouri River, which is incised deeply into Cretaceous bedrock of the Niobrara Formation (Fig. 2); (2) rolling uplands and dissected, narrow, high and nearly flat hill summits (tables) of the Missouri-River-Ponca Creek divide; (3) the valley of Ponca Creek, which is deeply incised into Cretaceous bedrock; and (4) the rolling uplands of the Ponca Creek-Niobrara River divide, which include multiple, comparatively broad, nearly flat upland summits (tables). Very small portion of the valley of the Niobrara River is included within sections 15 and 16 of T. 32 N., R. 8 W. at the southwestern corner of the quadrangle. The total relief on the land surface within Nebraska portion of the Verdel Quadrangle exceeds 440 ft (134 m), from the lowest elevation near the center of the eastern margin of the quadrangle in the valley of the Missouri River to the feature known as "Stony Butte" (see forthcoming discussion) in the W½ NE¼ of section 2, T. 32 N., R. 8 W.

There are many smaller topographic features of note in the Verdel Quadrangle. One is a flat-topped hill 1.9 mi (3.0 km) south-southwest of the town of Verdel in the W½ NE¼ of section 2, T. 32 N., R. 8 W (Figs. 3, 4). This hill is known in some accounts as "Stony Butte," but it is not to be mistaken with the feature labeled as Stony Butte in the Pishelville Quadrangle south of the study area. Some local residents and a report by Condra (1908) refer to the feature near Verdel as "Stony Butte," whereas the feature labeled on the Pishelville Quadrangle is more widely known by the name.

There is a prominent, eroded remnant of an old land surface perched on the wall of the valley of the Missouri River, some 225-285 ft (69-87 m) above the present level of the river, and trending roughly northwest-to-southeast across the N½ of section 10, T. 33 N., R. 8 W. This remnant is underlain by silts, very fine to poorly-sorted very coarse sands, and poorly-sorted pebble to boulder gravels (Figs. 5, 6); the coarser sediments in this assemblage are considered in this document to be glacial outwash. It is mantled by Peoria Loess. Furthermore, it is separated by a shallow ravine from a smaller, nearly flat-topped bench of the same approximate elevation lying chiefly within the S½ SE¼ of section 10, T. 33 N., R. 8 W. This bench and the terrace remnant almost certainly formed a continuous surface southward to the wall of the Missouri River at one time. A, loess-mantled, gently-sloping surface is present in the NE¼ NW¼ of section 18, T. 33 N., R. 7 W., and it too is underlain by sediments interpreted as outwash. This surface is analogous to the remnant surface described previously, and it is likely to have been continuous with it, although the two are now separated by a distance of 4.5 km (2.8 mi), in the geologic past. All of the aforementioned features are likely to be remnants of a formerly extensive Pleistocene outwash plain or terrace.

A prominent break in slope on the upper slopes of the valley wall of the Missouri River parallels the course of the river and trends east to southeast from the SW¼ SW¼ of section 10, T. 33 N., R. 8 W to the N½ SE¼ SW¼ of section 20, T. 33 N., R 7 W. This break in slope is a prominent feature of the uppermost elevations along the valley walls of the Missouri River. It appears at approximately 1500-1600 ft (457-488 m) at the western edge of the quadrangle and at 1400-1450 ft (427-442 m) in section 20, T. 33 N., R 7 W. The aforementioned remnants of an outwash plain or terrace are all in close proximity to this break in slope, suggesting that it is a relict Pleistocene feature.

Joeckel et al. (2010) and Joeckel et al. (2011) described roughly northwest-to-southeast-oriented, wind-eroded streamlined ridges and intervening narrow valleys eroded from the Pierre Shale on the Lynch and Marty quadrangles to the west and north of the Verdel Quadrangle. This general "grain" in topography is discernible to some degree in the Verdel Quadrangle as well. Prominent northwest-to-southeast-oriented and north-northwest-to-south-southeast-oriented ridges extend from the rim of the valley wall of the Missouri River in the northern part of the mapped area. Some prominent northwest-to-southeast-oriented ridgelines, typically accompanied by steep northeast-facing slopes, appear in the eastern part of the mapped area, particularly south of Ponca Creek on the divide between that stream and the Niobrara River.

There are a few small terraces associated with the modern course of Ponca Creek. A prominent terrace is located immediately east of Verdel and north of Ponca Creek in the N½ NW¼ sec. 30, T. 33 N., R. 7 W. Gently-sloping loess-covered surfaces to the east-northeast of this terrace in the S½ SE¼ of sec. 19, T. 33 N., R. 7 W. are also likely to be old terraces of Ponca Creek. Another terrace is present in the center of the W½ of section 25, T. 33 N., R. * W., south of a major bend in Ponca Creek. More extensive, high tables in the SW¼ of section 26 and in the W½ of section 27 of T. 33N, R. 8 W., and possibly elsewhere, may be even older terraces of the ancient Ponca Creek.

Surficial Bedrock and Regolith Geology

The upper part of the Niobrara Formation (Upper Cretaceous; Coniacian-Campanian) crops out in a very narrow band on the lowermost slopes of both the northern and southern valley walls of the Missouri River. We assign the strata in these exposures to the Smoky Hill Chalk Member (Fig. 2). Long stretches of nearly straight-sided valley walls in the enclosing region suggest a degree of bedrock control on drainage. On the Nebraska shore, the Niobrara Formation is exposed in a generally diagonal trend across sections 10, 11, 12, and 13 of T. 33 N., R. 8 W. It is present at a shallow depth under colluvium on the lowermost slopes of the valley farther southeastward from section 12. The Niobrara Formation is the oldest stratigraphic unit exposed within the boundaries of the Marty Quadrangle.

The Pierre Shale (Upper Cretaceous; Campanian-Maastrichtian), which overlies the Niobrara Formation, is the most widely-exposed bedrock unit in the Marty Quadrangle. The Pierre Shale is usually gray to dark gray when fresh, has been weathered by oxidation and local acid rock weathering to a depth of a few to several meters under upland areas. As a result, weathered Pierre Shale strata are typically of much lower color values (i.e., lighter) and higher chromas (i.e., brighter) than is any unweathered material within the same unit. Such color change with weathering can lead a casual observer to confuse weathered Pierre Shale with much younger Neogene sediments (e.g., Peoria Loess) and sedimentary rocks from a distance. The contact between the Pierre Shale and the underlying Niobrara Formation is exposed in multiple places on the Verdel Quadrangle at an elevation of approximately 1280-1300 ft (390-396 m). The most easily accessible exposures of this contact are: (1) in a steep slope on the south bank of Ponca Creek in the SW¼ NW¼ NW¼ of section 30, T.33 N., R. 7 W., immediately east of 516 Avenue bridge south of Verdel; (2) an excavation in a gentle hillslope at the southern margin of the floodplain of Ponca Creek near the center of section 25, T. 33 N., R. 8 W.; and (3) in road cuts along the north side of Nebraska Highway 14 west of Verdel in the S½ S½ of section 23, T. 33 N., R. 8 W.

Strata of the Ogallala Group (Miocene) are definitely exposed within the area of the Verdel Quadrangle. Opaline sandstones or "green quartzites: (*sensu* Barbour, 1915) are attributable to the Ogallala Formation (cf. Frye and Swineford, 1946; Swineford and Franks,1959; Skinner and Taylor, 1967), and not to either the Arikaree Group or to unnamed Pleistocene units as suggested by early authors (Condra, 1908, Barbour, 1915). The only fully documentable *in-situ* exposures of these indurated sandstones are on "Stony Butte" south-southwest of Verdel (Figs. 3, 4), but isolated blocks of sandstone appear in places at the southern edge of the divide between Ponca Creek and the Niorara River. These isolated blocks overlie or are surrounded by unconsolidated very fine to fine sands that we map as Quaternary sediments. It may be, however, that these sands are merely upper parts of the local Ogallala Group succession that were reworked by winds during the Pleistocene, and that remnant sandstone blocks were left behind on wind-eroded surfaces.

Regolith—a collective term for all unconsolidated Earth materials atop unweathered bedrock—in the area of the Verdel Quadrangle consists of loess, silty to sandy alluvium in stream valleys, very fine to fine sands (with or without a few granules or pebbles) on flat upland summits or tables, pebbly to boulder outwash sands and gravels (Figs. 5, 6), colluvium (Fig. 7), and weathered parts of the Niobrara Formation and Pierre Shale.

Subsurface Geology and Geologic Structure

Cretaceous strata underlie thin Quaternary and Neogene sediments and sedimentary rocks in the mapped area. In western Knox County and adjacent areas, the succession of Cretaceous strata encountered in a downward trend from the land surface (i.e., from shallowest to deepest) is: (1) Pierre Shale; (2) Niobrara Formation (215-235 ft or 66-72 m in thickness); (3) Carlile Shale, including the Codell Sandstone of member rank, which is likely to be multiple sandstone bodies within a comparatively thin stratigraphic interval (185-320 ft or 56-98 m in total thickness); (4) Greenhorn Limestone (50 ft or 15 m, or less, in thickness); (5) Graneros Shale, in the traditional usage of the term in Nebraska (approximately 50 ft or 15 m in thickness); and (5) Dakota Formation, equivalent to the Dakota Group in earlier Nebraska Geological Survey publications. The top of the Dakota Formation lies generally at about 715-755 ft (218-230 m) above sea level. Very little is known of the deeper subsurface geology under Cretaceous strata in the mapped area. The top of Precambrian basement rock in the general area of the Nebraska portion of the Verdel Quadrangle is projected to lie at 0-200 ft (0-61 m) above sea level, rising slightly southward.

No geologic structures were identified or mapped in the course of this investigation. Cretaceous strata in the area appear to have only modest regional dips, possibly to the southeast.

Groundwater Resources

Potential and realized sources of groundwater in the Marty Quadrangle are the deep, confined bedrock aquifers in: (1) sandstones in the Cretaceous Dakota Formation; and (2) the Upper Cretaceous Codell Sandstone, a member within the Carlile Shale. The latter aquifer is, by far, the most widely used deep aquifer in the area. The top of the Codell aquifer lies at an elevation of about 1090-1150 ft above sea level under the Verdel Quadrangle. In some parts of the encompassing northeastern Nebraska region, wells are also developed in the fractured upper part of local bedrock in the Niobrara Formation.

In the Verdel Quadrangle, a few wells penetrate hundreds of feet (more than one hundred meters) from the land surface to the stratigraphic levels of deeper sandstone aquifers in Cretaceous strata, chiefly the Codell aquifer. Under the highest land surfaces on the Ponca Creek-Missouri River divide, wells must penetrate in excess of 500 ft (150 m) in order to reach the sandstone aquifers in the upper part of the Carlile Shale, and even deeper—another 350 ft (107 m) or more—in order to reach sandstone aquifers within the Dakota Formation. Wells drilled on the floodplain of Ponca Creek and the Missouri River bottomlands can reach the Codell aquifer at depths of 120-150 ft (37-46 m). It is possible that there is a hydraulic connection between the shallow unconfined aquifer in the alluvium of the Missouri River and the Codell aquifer under the bottomlands of the Missouri River, but this hypothesis could not be tested in the course of geologic mapping.

Shallower aquifers in the Verdel Quadrangle are: (3) the thin and shallow, unconfined alluvial aquifer in the alluvium of Ponca Creek, in which very few wells are developed; and (4) the shallow, unconfined alluvial aquifer in the alluvium of the Missouri River, in which many wells are developed on the bottomlands, and particularly in recreational/residential developments. Existing wells on Missouri River bottomlands in the Verdel Quadrangle are generally screened at depths of 19-65 ft (6-20 m) in the alluvium of the Missouri River or at depths of 115-175 ft (35-53 m) in the underlying bedrock, which is presumed to be the Codell Sandstone of the Carlile Shale. A very few registered water wells are developed in unconsolidated surficial sands in the uplands of the Verdel Quadrangle. One such well collects water from very shallow depths in unconsolidated surficial sands in the NE¼ NE¼ NW¼ of section 35, T. 33 N., R. 8 W.

Mineral Resources

There are minor potential and realized mineral resources in the area of the Verdel Quadrangle. Coarse crystalline gravels are currently being mined from the aforementioned remnant landform in the N½ of section 10, T. 33 N., R. 8 W. These gravels appear to extend under the entire feature and they may also be present under the adjacent bench in the SE¼ of section 10, T. 33 N., R. 8 W. Gravel has been mined from what is likely to be the same deposit deposits in the NW¼ of section 19, T. 33 N., R. 7 W.

Extensive heavily vegetated workings on the slopes of "Stony Butte" (Fig. 3) indicate that opaline sandstones were mined there during the early 20th century. Condra (1908) made specific mention of quarrying on the site, but Barbour (1915), although commenting overall on "green quartzites" (opal-cemented sandstones) in Knox County, made no mention of mining in the Verdel area. Opaline sandstone blocks appear locally in the foundations of older buildings in the area, for example, in the foundations of a barn in the SE¼ SE¼ SW¼ of section 11, T. 32 N., R. 8 W., near which small exposures of the same material appear to be present.

A very few attempts at petroleum exploration in the Dakota Formation in Knox County have resulted in dry holes, and the prospectus for future oil and gas developments is minimal at best.

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Figure 1. Panoramic view of typical landscape in Verdel Quadrangle looking northwest to north -northwest from NE corner of section 32, T. 33 N., R. 7 W. Rolling hills on Pierre Shale (mapping unit Kp) , with divide between Ponca Creek and Missouri River (PMD) and Missouri River (MR) visible in distance, and State of South Dako ta visible beyond Missouri River as far skyline.

Figure 2. Exposure of light-colored Smoky Hill Chalk Member of Niobrara Formation (mapping unit Knsh), with lowermost Pierre Shale (Sharon Springs Member) barely visible as dark band below treeline, along south bank of Ponca Creek in SW¼ NW¼ SW¼ of section 30, T. 33 N.

Figure 3. "Stony Butte" in W½ NE¼ of section 2, T. 32 N., R. 8 W., viewed from south Feature is capped by erosion-resistant opaline sandstones of the Ogallala Group (mapping unit No). Lower slopes are on Pierre Shale. Irregular surfaces on slopes of this feature appear to be results of mining operations in early 20th century.

Figure 4. Ogallala Group opaline sandstone exposure at top of "Stony Butte" in W½ NE¼ of section 2, T. 32 N., R. 8 W.

Figure 5. Very coarse and poorly sorted sands and gravels of mapping unit Qac, interpreted herein as outwash sediments, exposed in pit in SE¼ NE¼ NW¼ of section 10, T. 33 N., R. 8 W.

Figure 6. Crystalline boulders , derived from Canadian Shield, from mapping unit Qac in oversize pile of gravel -mining operation at pit in SE¼ NE¼ NW¼ of section 10, T. 33 N., R. 8 W. Scale is approximately 20 cm in length.

Figure 7. Colluvium (mapping unit Qc) consisting of material from both Pierre Shale and Smoky Hill Chalk Member of Niobrara Formation on lower slopes of wall of Missouri River Va lley near center of south line of SE¼ SW¼ SE¼ of section 18, T. 33 N., R. 7 W. Scale is approximately 1 m in length.