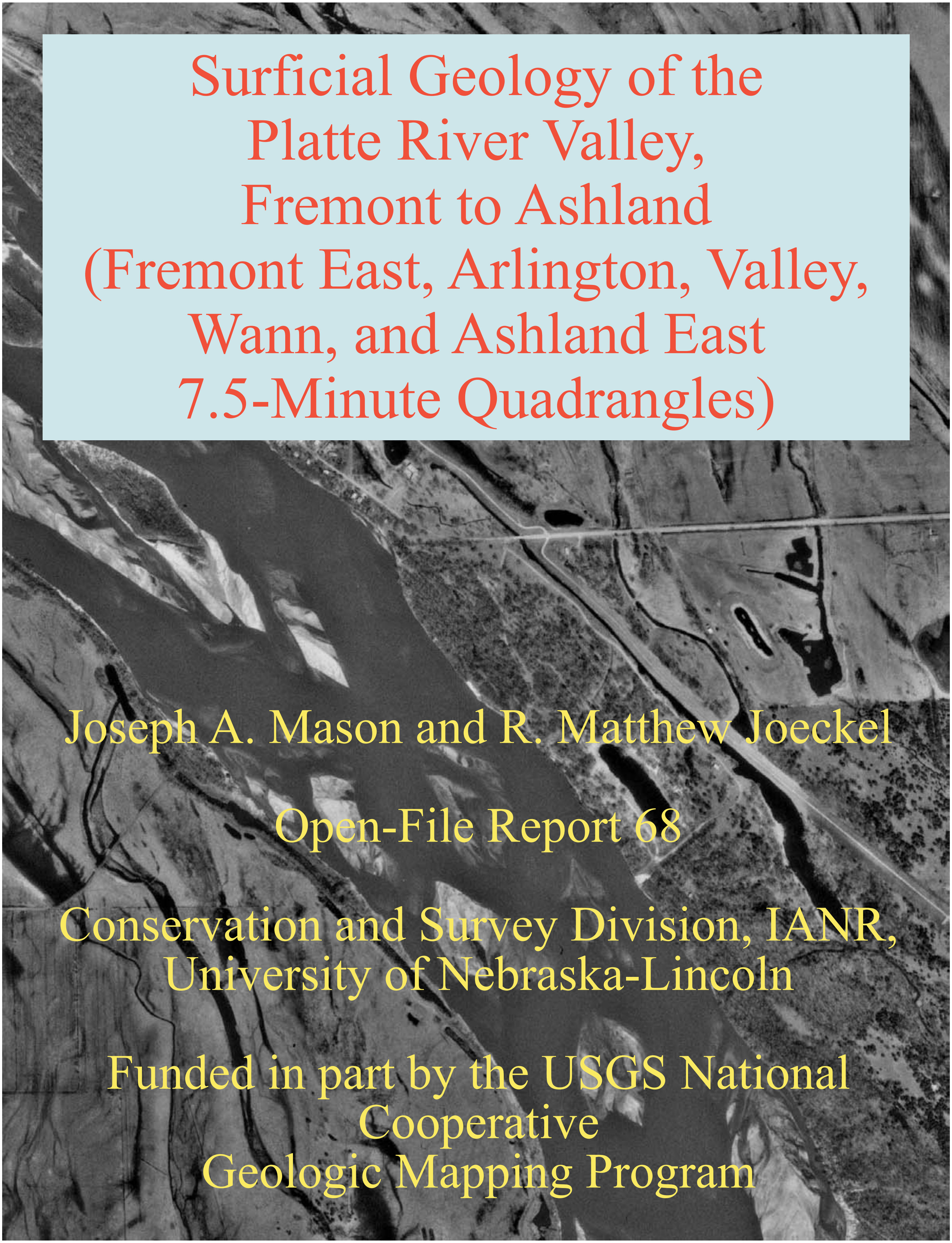

Surficial Geology of the Platte River Valley, Fremont to Ashland (Fremont East, Arlington, Valley, Wann, and Ashland East 7.5-Minute Quadrangles)

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INTRODUCTION

The Platte River valley between Fremont and Ashland contains important groundwater and construction material resources, and is now experiencing rapid suburban expansion. There is a need for more detailed information on the surficial (near-surface) geology and landforms of this part of the Platte Valley, for use in managing and protecting natural resources, planning new construction, and mitigating geologic hazards such as flood damage. This report, and the accompanying surficial geologic maps of five U. S. Geological Survey 7.5-minute topographic map quadrangles (Fremont East, Arlington, Valley, Wann, and Ashland East), are intended to address that need. The report includes an overview of the relations between landforms and surficial geology in the lower Platte Valley and the adjacent uplands, followed by detailed descriptions of the stratigraphic units portrayed on the maps.

Two types of geologic maps have been prepared for each quadrangle. One is a map of *surficial geology*, showing only the uppermost sediments in the vertical succession of strata. Units on this map portray deposits that are generally thicker than about 5 feet (1.5 m), although some of these deposits are thinner than 5 feet immediately adjacent to their boundary with other map units. The other map is called a *stack map* and represents, in broad terms, the entire vertical succession or stack of sediments down to Cretaceous or Pennsylvanian bedrock. Units on the stack map represent various combinations of geologic materials with different properties, as well as the vertical sequence in which they occur. The relationship between subsurface stratigraphy, surficial geologic map units, and stack map units is illustrated in Figure 1. These maps are based in part on direct observation of stratigraphy in exposures such as road cuts or in samples from test hole drilling. Many existing driller's logs from registered wells were also used. Because most surficial deposits in this area are covered by vegetation, roads, or buildings, it was often necessary to reconstruct the surficial and subsurface geology between widely scattered outcrops, test holes, or registered wells. This was accomplished using indirect evidence such as soil surveys and topographic features associated with particular types of deposits, as well as through an understanding of how different geologic materials were deposited. For example, the Peoria Loess (described in detail in a later section) was deposited as wind-blown dust and therefore forms a fairly uniform mantle over ridge tops and gentle slopes, but it was eroded from steeper slopes after deposition. The boundaries of areas covered by Peoria Loess on hill slopes can often be identified by a distinct break in slope gradient. Other map unit boundaries are more difficult to place without good exposures or subsurface data. Both surficial geology and stack maps will be updated in future years as more subsurface information becomes available.

These maps are intended for general planning and educational purposes, and can also be used for initial planning prior to more detailed site-specific geologic investigations. They will not be adequate, in many cases, for detailed planning of construction or waste disposal sites or remediation of environmental contamination at specific sites. These maps should allow planners to identify areas that in general have surficial deposits more suitable for domestic or high-capacity water wells. Within these areas, however, local variations in subsurface geology may occasionally result in inadequate groundwater quantity or quality at specific sites.

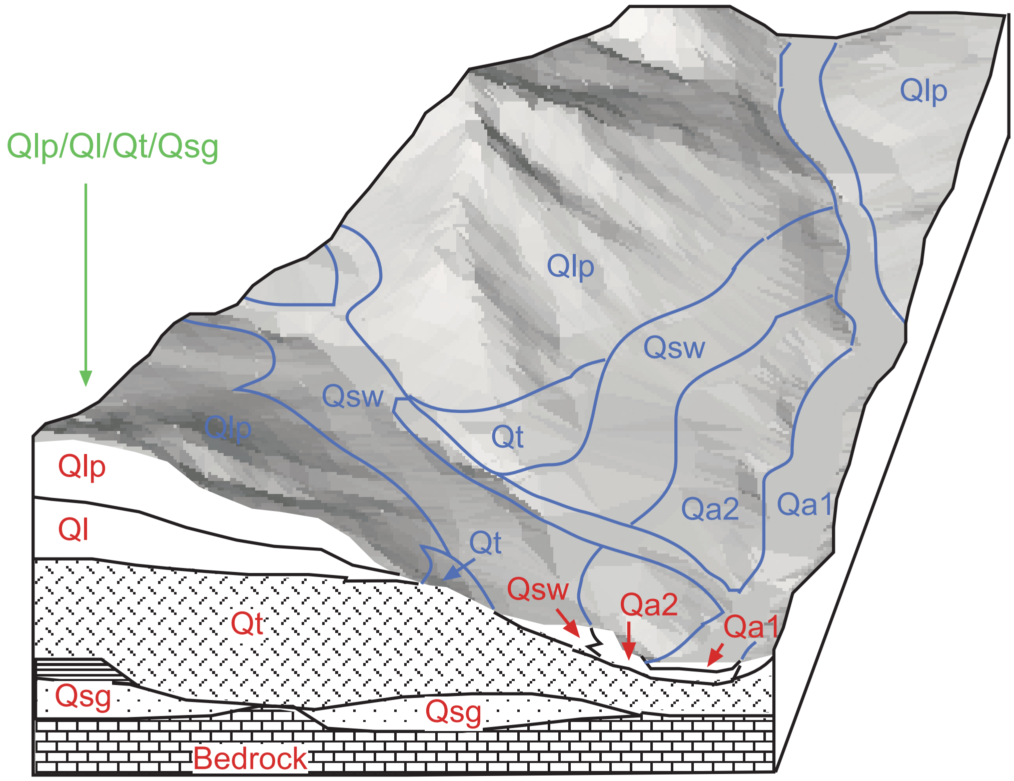


Figure 1. Schematic block diagram illustrating the relationship between topography, stratigraphy, the surficial geologic map, and the stack map. Stratigraphic units are labeled in red in the cross-section at front of block, surficial geologic map units on land surface are labeled in blue, and one example of a stack map unit is indicated in green. In many areas, glacial till (Qt) is not exposed at the land surface, as shown here. In other parts of the region described in this report, particularly near the bluff line, glacial till, underlying sorted sediment (Qsg), and bedrock may all crop out on hill slopes.

Radiocarbon ages of geologic deposits are reported in uncalibrated radiocarbon years before present (yr B.P.) in this report. These may differ significantly from ages in calendar years, particularly for samples older than 10,000 yr B.P.

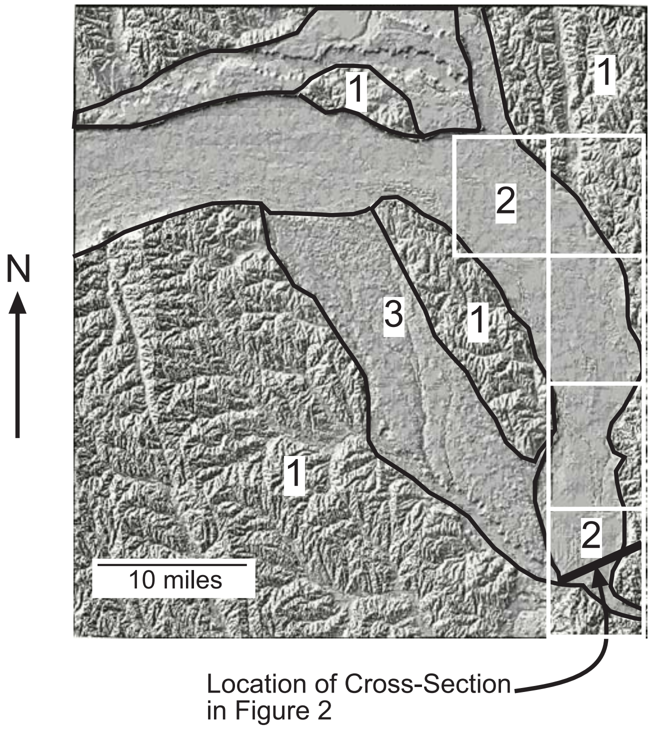
OVERVIEW: RELATIONS BETWEEN LANDFORMS AND SURFICIAL GEOLOGY

The region discussed in this report can be subdivided into three general types of terrain (fig. 2): (1) the rolling uplands east and west of the Platte River valley, which include the alluvial valleys of numerous small streams and several larger streams including Salt Creek and Bell Creek; (2) the broad, low-relief, alluvial lands in the Platte Valley (shared by the Elkhorn River in much of the reach discussed here); (3) the Todd Valley, a broad lowland that is a former valley of the Platte River. A geologic cross-section located in the Ashland East quadrangle (fig. 3) is representative of the stratigraphy of Quaternary deposits in the rolling uplands and Platte River valley and also includes an isolated remnant of sediments typical of those in the Todd Valley.

In the rolling uplands, up to 300 feet (91 m) of unconsolidated Quaternary sediments unconformably overlie the sandstones and mudrocks of the Cretaceous Dakota Group, which, in turn, overlie Upper Pennsylvanian limestone and shales. Quaternary sediments in the uplands consist of: (1) thick, widespread, well-sorted wind-deposited silt (loess), which is the typical parent material for most upland agricultural soils; (2) thick, widespread, poorly-sorted glacial till, deposited by large ice sheets that episodically covered eastern Nebraska during the Pleistocene and Pliocene; (3) sorted sediment (gravel, sand, silt, or clay) lying above, within, or below glacial tills, and presumed to have been deposited in former streams or lakes; (4) widespread stream deposits (alluvium) in modern small stream valleys; and (5) relatively thin deposits at the foot of slopes that were produced by slopewash and mass-movement (ongoing soil creep and episodic landslides). Outcrops of Cretaceous and Pennsylvanian bedrock are absent in much of the area covered in this report but are common in portions of the Ashland East and Wann quadrangles, particularly near the bluff line where the uplands meet the Platte River valley. In some localities along the bluff line, mass movement deposits are unusually thick (at least 30 feet, or 9.1 m, in one locality).

More than half of each of the 7.5 minute quadrangles mapped for this report is occupied by alluvial lands of the Platte Valley. These alluvial lands are characterized by a complex surface pattern of active Platte or Elkhorn river channels, stream channels formed by those rivers in the past but now abandoned, and smaller flood plain channels formed both by flow from the Platte or Elkhorn rivers during large floods and by groundwater seepage. There are also extensive *splays*, where surface waters spread out and deposited sand and silt across the valley floor during large floods, as well as *flood basins* where flood waters ponded for longer periods of time and deposited predominantly clay and silt. These features provide evidence of the long-term history of surface water flooding and a shallow groundwater table. This geologic record should be of practical interest to builders, urban planners, and homeowners because it identifies areas particularly prone to flood erosion or deposition in the past, as well as areas where groundwater emerges at the surface.

Figure 1. Topography and generalized surficial geology of the lower Platte River valley, Fremont to Ashland, Nebraska. Shaded relief image based on digital elevation models generated from 7.5-minute topographic maps. Quadrangles mapped for this report are outlined in white.



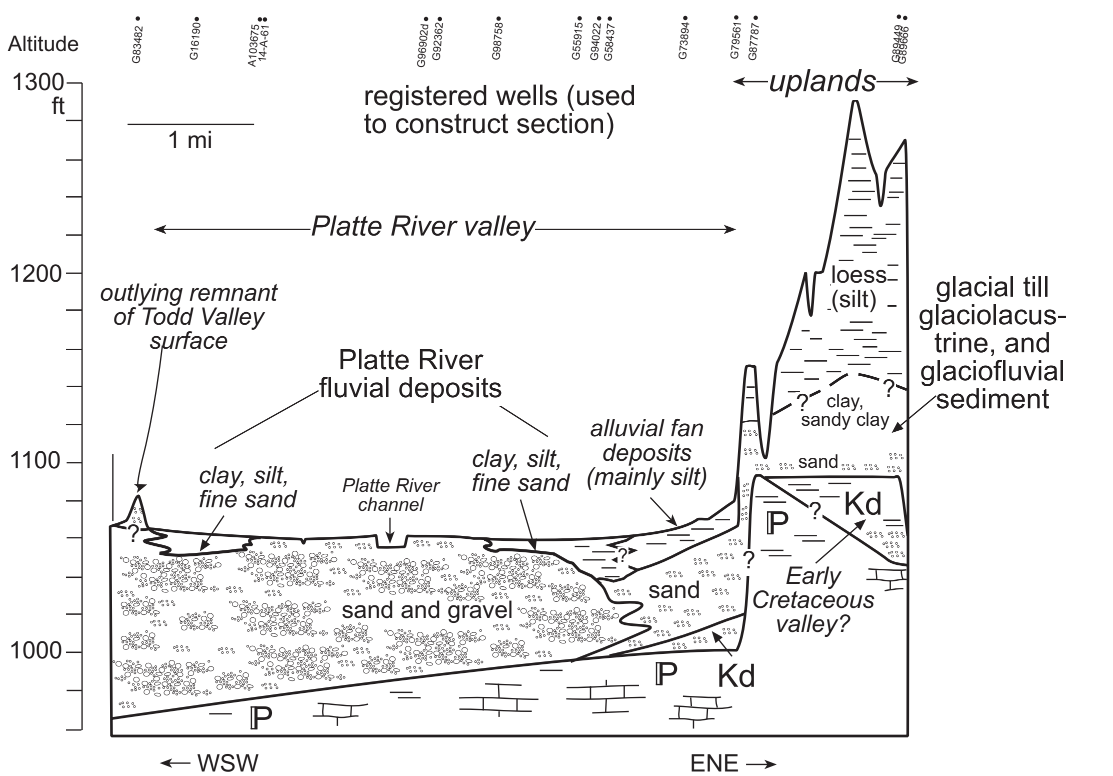
Terrain Type and Generalized Surficial Geology (see report text for more detailed descriptions):

1. **Rolling Uplands**: Loess overlying glacial deposits with rare bedrock outcrops

2. **Platte Valley**: Alluvium of Platte and Elkhorn rivers and smaller streams.

3. **Todd Valley**: Loess and eolian sand over alluvium (paleovalley of Platte River)

Figure 3. Cross-section from uplands, across the bluff line to the Platte Valley, Ashland East 7.5-Minute quadrangle, showing surficial deposits and underlying Cretaceous and Pennsylvanian bedrock. Stratigraphy is broadly representative of the region discussed in this report. *Location indicated on Figure 2.*



In the Platte River valley, almost all of the Quaternary strata are clay, silt, sand, or gravel deposited by the Platte and Elkhorn rivers or their tributaries. The nature of shallow subsurface deposits in this valley is closely related to the landforms identified on the land surface. For example, clay and silt deposits up to 30 feet (9.1 m) thick are common in splays or flood basins, but there is little fine-grained material where the landscape is dominated by recently abandoned braided channels of the Platte River. The areas with little silt or clay at the surface have the greatest potential for commercial sand and gravel mining. Parts of the alluvial valley are filled with thick sand and gravel deposited by the Platte River, but sand and gravel is thin or even absent beneath the valley floor in some other locations. The distribution of sand and gravel has great practical significance because it determines the availability of ground water for domestic use or irrigation. Quaternary deposits in the Todd Valley include sand and gravel deposited by the Platte River during the Pleistocene, overlain by wind-blown sand and loess.

DESCRIPTION OF STRATIGRAPHIC UNITS.

Alluvial units are described first, organized first by the stream that was primarily responsible for the deposition of each unit, then from youngest to oldest. The same order is used in the map legends. In many cases, units may include minor amounts of sediment from other streams as well; for example, unit Qae2 is primarily formed by the Elkhorn River (and has typical characteristics of sand-bed meandering stream deposits), but it may occasionally receive sediment from large floods of the Platte River that spill over to the east side of the Platte valley.

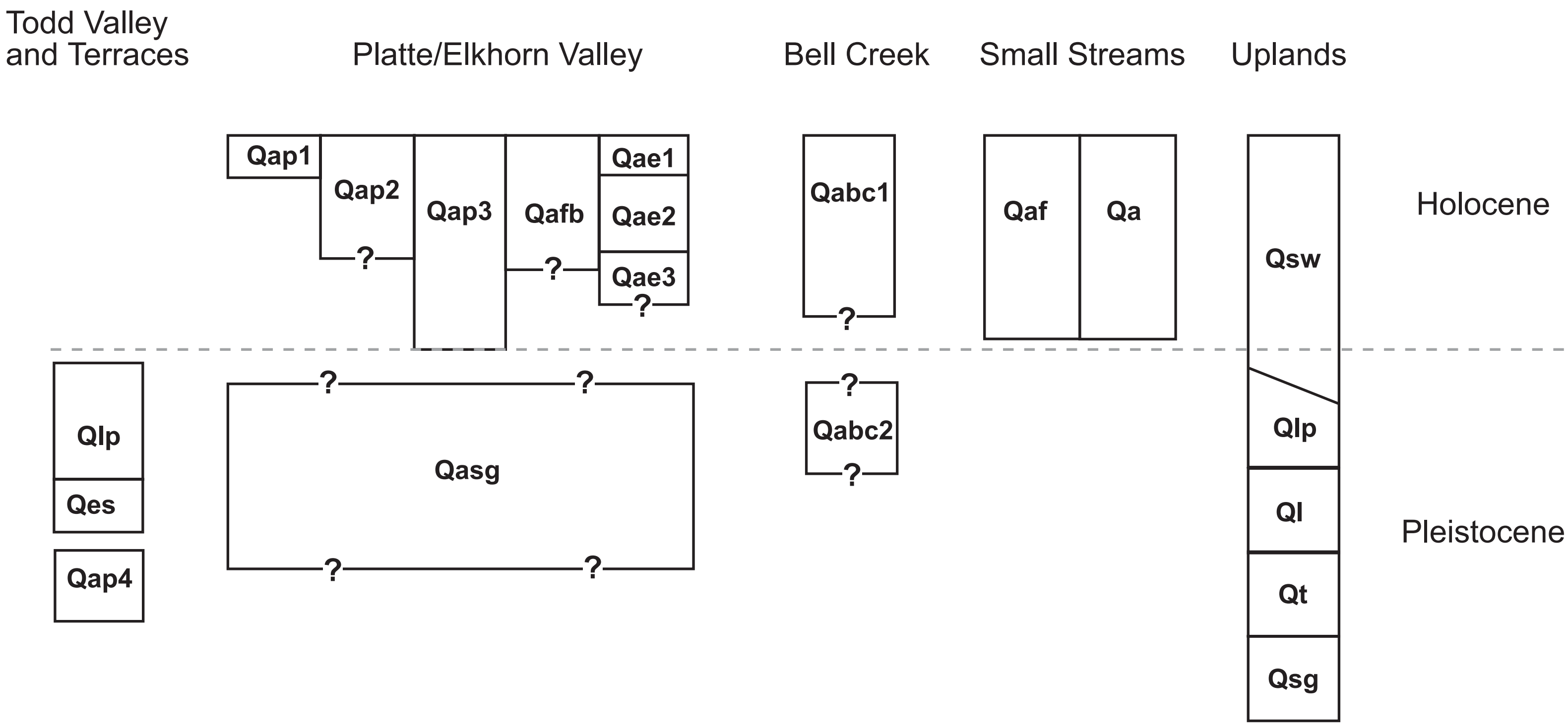
Typical landscape positions of some the units described below are shown in the block diagrams of Figure 1 and the cross-section of Figure 3. Figure 4 illustrates the inferred ages of all of the Quaternary stratigraphic units discussed in this report. In this diagram, units are grouped in columns by terrain type and by stream, for example, deposits of the Platte River form one column, and sediments found in the rolling uplands form another. Younger units are placed above older units; two units that are at the same vertical level are at least partly of the same age. The landforms or stratigraphy characteristic of some of the most important units are illustrated in figures 5 through 9.

Qae1 Elkhorn River Alluvium, late historic meander belt segments (late Holocene)

Sand and silty sand, with possible lens-shaped bodies of silty clay in low areas, overlying medium-to-coarse sand and gravel

Elkhorn River alluvium deposited largely since the river channel was straightened in 1910-1912: this alluvium formed as the Elkhorn River migrated laterally and developed new meanders, eroding one bank while accreting sediment to the point bar on the opposite bank. Qae1 can usually be distinguished from older alluvium because it is covered by trees growing in rows of increasing age with greater distance from the present river channel. The youngest parts of this unit are covered only by willow and other shrubs or, in places, bare sand. Meander development since 1912 has occurred mainly along several discrete reaches of the river, resulting in several meander belt segments

Figure 4. Correlation of the Quaternary stratigraphic units discussed in this report



where Qae1 is extensive, separated by river reaches with only a few small areas of this unit. The surface of Qae1 generally displays prominent parallel ridges, or scrolls, 3-5 feet (1 to 1.5 m) high. In some places there are also larger channels eroded across point bars during floods (chutes). Much of the shallower sediment in this unit is fine sand, although medium-to-coarse sand and gravel is probably present at depth. There is little information on subsurface stratigraphy in Qae1, but data from the adjacent areas of Qae2 suggest a total thickness of about 30 to 50 feet (9.1 to 15 m), generally directly overlying bedrock of the Dakota Group. Thicker alluvium is present in the area between King Lake and Waterloo, but the deeper sand and gravel in this area may have been deposited by the Platte River (see discussion on Qae2, and stack map). A shallow water table and high flood hazard make any type of development in Qae1 inadvisable. In addition, river reaches where this unit is extensive are likely to experience rapid channel migration in the future, also placing at risk any structures built in these areas. Prehistoric artifacts should not occur in Qae1 unless they were reworked from older deposits by the river.

Qae2 Elkhorn River Alluvium, older meander belt (Holocene)

Silt, clay, and fine sand overlying medium to coarse sand and gravel

Elkhorn River alluvium deposited mainly before channel straightening in 1912: this unit covers areas that have not been occupied by the river channel since 1912, but still exhibit fluvial landforms such as meander scrolls or abandoned channels. Qae2 is mostly covered by agricultural crops or forest that is not growing in distinct rows paralleling the channel, as in Qae1. This unit contains low ridges or scrolls similar to those in Qae1, but they have been draped by finer grained sediment, significantly smoothing the original scroll topography. The finer-grained sediment was probably deposited from water moving slowly across areas of Qae2 during overbank floods. This unit also contains oxbow lakes (e.g. King Lake) as well as other abandoned channels that have now become filled with sediment. Numerous registered well logs from Qae2 indicate that the typical vertical sequence of sediment includes 15 to 25 feet (4.6 to 7.6 m) of fine sand, silt, or clay, overlying 15 to 30 feet (4.6 to 9.1 m) of medium-to-coarse sand and gravel, which in turn rests on bedrock or older Quaternary deposits. The typical thickness of the basal coarse sand and gravel may represent the depth of channel scour during large floods. Thicker sand and gravel in an area between King Lake and Waterloo is tentatively interpreted as buried Platte River alluvium (Qap4) underlying Qae2 (see stack map). The fine-grained upper part of the alluvium in Qae2 is often dark-colored because of its high organic matter content, and locally it contains one or more buried soil horizons. The channel deposits underlying Qae2 are prehistoric, and are presumed to be of Holocene age, although no radiocarbon ages are available. The surface of this unit still occasionally accumulates sediment during floods.

There is a significant flood hazard in Qae2, but this has not prevented extensive residential development, including the communities of Waterloo, King Lake, and Riverside Lakes. Structures built on Qae2 may also be at risk of destruction by Elkhorn River channel migration, particularly where they are near large areas mapped as Qae1 (indicative of rapid recent channel migration). Groundwater is available at a shallow depth in Qae2, and is probably adequate for irrigation in most areas but is more susceptible to contamination from the surface than water from deeper sources. Use of water from sandstones in the underlying Dakota Group is preferable for domestic water supply, if the quantity and quality of water from this source are adequate. Sand and gravel has been mined in one large commercial operation in this unit (at the present location of Riverside Lakes), but the fine-grained surficial sediments make sand and gravel extraction less attractive here than in Qap1 or Qap2. Artifacts and archeological sites could occur throughout the upper fine-grained cap of Qae2.

Qae3 Elkhorn River Alluvium, smooth surface (Holocene)

Silt, clay, and fine sand overlying medium-to-coarse sand and gravel

Elkhorn River alluvium in areas that do not display any evidence of former channels or meander scrolls: the smooth surface of Qae3 probably reflects the fact that the Elkhorn River channel has not been in these areas for hundreds or thousands of years. The surface of Qae3 may still accumulate sediment during large floods. The characteristics of Qae3 are otherwise similar to those of Qae2, except that the surficial fine-grained sediment may be thicker in areas mapped as Qae3. This is the main reason for mapping the latter unit separately.

Qapl Platte River alluvium, recently active braided channel belt (late Holocene)

Well-sorted fine-to-coarse sand, with local thin, patchy surficial deposits of silt or clay

Braided channels abandoned by the Platte River as it migrated in historic time or in the latest Holocene: aerial photographs indicate that some of the mapped area is < 60 years old, with some lateral shifts in course being as recent as 1983-1993. Parts of Qap1 are distinguished on the maps based on distinctive landforms, described separately below. The following generalizations on sediment characteristics, resource potential, and hazards apply to the unit as a whole.

The surface of this unit retains the form of bars and channels similar to those visible in the active river channel today (fig. 5). Surficial deposits of silt or clay are usually less than 5 feet (1.5 m) thick, and in many places are completely absent. Platte River channel deposits of medium-to-coarse sand and gravel are at or near the ground surface. Silt and clay beds do occur locally within these channel deposits but are generally thin if present at all. The sand and gravel contains abundant pink grains of potassium feldspar and fragments of granitic rock, reflecting the original sources of Platte River sediment in the central Rocky Mountains. Qap1 is subject to flooding and generally has a shallow water. Although many vacation cabins and some permanent homes are built in this unit, they are

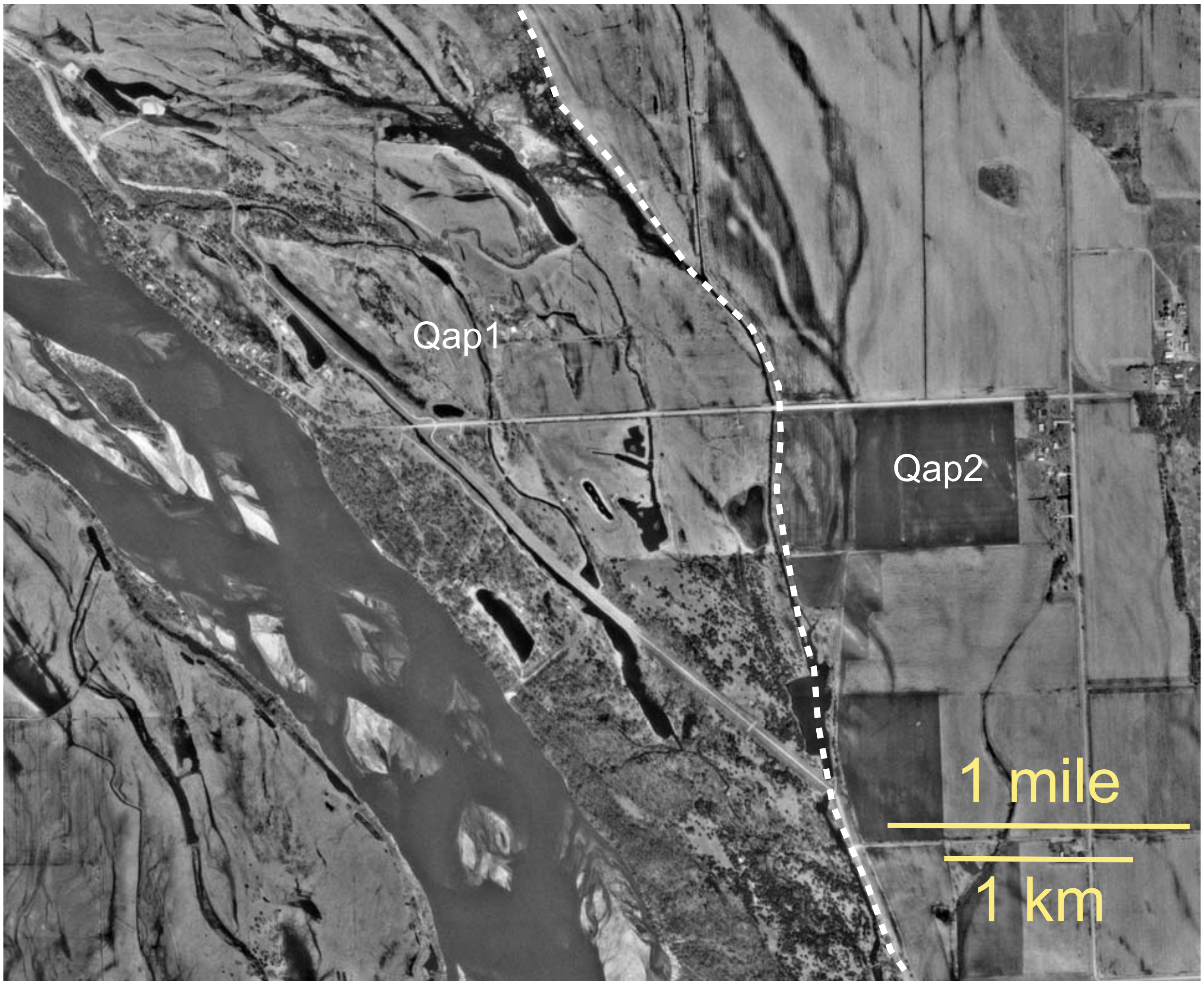


Figure 5. Illustration of the contrast between Qap1 and Qap2 on air photos. Qap2 has a thin mantle of fine-grained sediment, creating a smoother surface texture. Qap2 is also better drained than Qap1. Area shown is in the Valley quadrangle, south of the town of Valley.

prone to flood damage and may be inaccessible for long periods after floods. More extensive residential, commercial, or industrial development in this unit is not advisable.

Qap1 contains particularly valuable groundwater resources, which are critical if the Omaha and Lincoln metropolitan areas continue to grow at their present rate. Groundwater can be pumped at very high rates from this unit, as is done in the Lincoln Water System well field to the south of the Wann Quadrangle. This high-volume groundwater extraction relies on induced recharge from the Platte River through the coarse-textured subsurface sediment of Qap1. Sand and gravel can easily be mined from this unit because of the absence of fine-grained surficial material; however, most commercial sand and gravel pits are in Qap2, which has better road access and less potential for damage from flood waters. Only very young archaeological sites or artifacts are likely to occur in Qap1.

Qap1 (sand splay) Prominent fan-like hummocky sand deposits occurring within unit Qap2 or at its boundary with unit Qap2.

Relatively young, hummocky surficial sand deposits within or at the edge of Qap1 that have a distinct, fan-like form on air photos: these areas represented rapid sand deposition where flood waters left the main channel of the Platte. In some cases, recent sand deposits appear to overlie pits and channels scoured into older sediment. The largest area mapped as Qap1 (sand splay) occurs east of the Platte River in the Ashland East quadrangle. Although large quantities of sand were deposited in this area during a flood in late winter, 1993, the sand splay here is visible on air photos from 1949. Therefore, this large splay is probably the product of repeated sand deposition each time a major flood occurs in this part of the Platte valley. Prominent sand splays are also located on the narrow peninsula separating the Platte and Elkhorn rivers in the southern Wann Quadrangle. These splays were unvegetated in 1993 and probably also formed during the large late winter flood of that year. A splay on the east side of the Elkhorn River near its mouth probably also formed from Platte River flood water in 1993 and is included in this mapping unit. A splay at the western edge of Qap1 on the west side of the Wann Quadrangle is somewhat older and may have formed when the main Platte channel was located farther west than at present.

Qap1 (sand ridge) Platte River alluvium, prominent linear sand ridges

Distinct, narrow linear ridges of well-sorted fine-medium sand approximately 10-15 feet (3.1 to 4.6 m) high: the ridges approximately parallel the present course of the Platte River and occur as short, closely spaced segments in Qap1 in the Ashland East quadrangle. Gravel apparently is not present within the upper part of the ridges. The origin of the sand ridges is uncertain. They may in part be natural levees, that is, ridges of sediment deposited where flood waters leave the active river channel. The ridges appear too high and narrow to be unmodified natural levees, however, and it is likely that they were built up in part of wind-blown sand. Sand could have blown off nearby areas of exposed stream channel deposits when the river was at low flow. A line of vegetation at the channel margin might have trapped the sand, producing the present linear ridge.

Qap2 Platte River alluvium, former braided channel belt, fine-grained sediment thin or absent (Holocene)

Well-sorted fine-to-coarse sand, with thin, patchy surficial deposits of silt or clay

Coarse-grained deposits formed in late Holocene braided channel belts of the Platte River, with a thin, patchy cover of fine sediment deposited after the river abandoned these channel belts: the pattern of bars and braided channels that formed when this unit was part of the active Platte channel is still visible in some areas but has been modified by sediment deposition or erosion during floods (fig. 5). Parts of Qap2 are distinguished on the maps based on distinctive landforms such as flood channels, sand ridges, and splays, described separately below. The following generalizations on sediment characteristics, resource potential, and hazards apply to the unit as a whole.

The surface of Qap2 is covered with a network of anabranching (dividing and recombining) channels. Most carry little or no flow except during large floods or when the water table is very high, as in an unusually wet spring. Some of these channels are barely visible on the ground and can only be clearly detected using air photos. The pattern formed by these channels probably reflects the original topography of the braided Platte channel, but the pattern is also influenced by flow across the flood plain during large floods and possibly by groundwater seepage at times of high groundwater table. The sediment at the ground surface is fine-to-medium sand or with some areas of silt or clay, generally less than 3 feet (1 m) thick. Below this is medium-to-coarse sand and gravel up to at least 90 feet (27 m) thick, with rare thin beds of silt or clay. Although the channel deposits in the subsurface of Qap2 are prehistoric, the surficial materials may be very young, because of ongoing sediment erosion and deposition during floods.

Qap2 contains the most valuable sand and gravel resources in eastern Nebraska. There is little or no fine-grained overburden, and large volumes of high-quality sand and gravel can be mined from areas with good road access to both Omaha and Lincoln. Groundwater can also be pumped at high rates from Qap2, although the potential yield may be less than in Qap1 because induced recharge from the Platte is less likely at a greater distance from the active channel. A large portion of Qap2 has been inundated by floods in recent decades, but the unit does contain areas of higher ground that remain above water even during large floods. Although the groundwater table is shallow in this unit, it is still somewhat better drained than Qap1, and is much more extensively used for agriculture and residential development. Relatively young archaeological sites or artifacts may occur in Qap3, particularly in better-drained locations such as on the sand ridges described below

Qap2 (sand ridge) Platte River alluvium, prominent linear sand ridges

Distinct, narrow linear ridges of well-sorted fine-medium sand approximately 10-15 feet (3.1 to 4.6 m) high, roughly paralleling the modern course of the Platte River: a nearly continuous ridge follows the boundary between Qap2 and Qap3 through much of the Valley and Wann quadrangles, while shorter ridge segments occur within Qap2. Two or more closely spaced, parallel ridges occur in a few places, for example, just northwest of the town of Valley. Gravel apparently is not present within the upper part of the ridge, but the ridges are probably underlain by coarse sand and gravel as is the rest of Qap2. Exposures are limited, but faint horizontal lamination was visible at one location where a former sand pit was excavated into a ridge segment. The sand ridges in Qap2 are very similar in form to those in Qap1, and probably have a similar origin. See discussion of Qap1 (sand ridge) above for possible mechanisms of sand ridge formation. The higher sand ridges in Qap2 provide high ground above most or all floods of the Platte River, and many older houses are built on these ridge segments. Part of the town of Valley is also on a complex of somewhat lower ridges.

Qap2 (flood channels) Prominent single or multiple channels with associated alluvial ridges and small splays.

Prominent belts of single or multiple, moderately sinuous channels that cross large areas of Qap2: water flows in some of these channels for most of the year, fed by groundwater seepage, but they are likely to be primarily shaped by flow escaping from the Platte during moderate-to-large floods. Patterns on air photos suggest that during particularly large floods, water cuts across the meanders of these channels, forming nearly straight conduits for water and sediment. Two groups of interconnected, sinuous flood channels exit the west side of the Platte River at bends in the main river channel in the western Wann and Valley quadrangles, with one leading ultimately to a large complex of sand splays in the Wann and Ashland East quadrangles. Some water from both of these flood channel belts probably returns to the main Platte channel farther downstream. Another belt of flood channels originally exited the east side of the Platte in the southern Valley Quadrangle and carried flood waters from there to the Elkhorn River, although its upper end is now obscured by gravel pits. There is usually a slight ridge on either side of the flood channels (included in the mapping unit), that was probably built up as a natural levee when sediment-laden water escapes from the channel into surrounding low-lying areas. There are also small, fan-shaped splays of sand along some of the channels that were not mapped separately. Several older farmsteads are built on the alluvial ridges along these flood channels. These ridges probably represent somewhat higher and drier sites under most flow conditions, but they are exposed to flood damage when the channels are at bankfull stage or overflowing.

Qap2 (sand splays) Prominent fan-like hummocky sand deposits occurring within unit Qap2 or at its boundary with unit Qap3.

Hummocky surficial sand deposits within or at the edge of Qap2 that have a distinct fan-like shape on air photos: these areas are interpreted as splays deposited rapidly where flood water left one of the flood channels described above or broke through a sand ridge into Qap3. The head of the "fan" in each case is on one of the flood channels or at a low point in a sand ridge. Similar splays were formed near the modern Platte channel in the flood of 1993. The age of the splays mapped in Qap2 is unknown, and it is not certain whether sediment deposition will occur in these areas during future floods. The sediment at the surface is fine or medium sand, often containing pebbles at a shallow depth (in contrast to the sand ridges). These splays appear to be preferred building sites, probably because they are slightly higher above the water table than surrounding areas and have well-drained soils. If the splays are still sites of rapid deposition during floods, however, extensive damage to houses or other structures could occur there.

Qap3 Platte River alluvium, thick fine-grained sediment (Holocene and Pleistocene).

Silty sand, silt, and clay, with occasional beds or lenses of medium-coarse sand and gravel

Relatively fine-grained sediment, at least 5 feet (1.5 m) thick, and generally 10 to 30 feet (3.1 to 7.7 m) thick deposited mainly during large overbank floods of the Platte River: the fine-grained deposits overlie late Pleistocene and possibly Holocene channel courses of the Platte River. Parts of Qap3 are distinguished on the maps based on distinctive landforms, described separately below. The following generalizations on sediment characteristics, resource potential, and hazards apply to the unit as a whole.

The surface of Qap3 is covered with a network of anabranching (dividing and recombining) channels, most of which carry no flow except during large floods or when the water table is very high. Some of these channels are barely visible on the ground and can only be clearly detected using air photos (fig. 6). The pattern formed by these channels could in part reflect the original topography of the braided Platte channel, but that topography has been covered and obscured by thick fine-grained sediment. The present surface channel pattern could also have developed entirely as a result of flow across the flood plain during large floods. Groundwater seepage at times of high groundwater table probably also has played a role in channel development.

A large borrow pit exposure east of Valley (fig. 7), Conservation and Survey Division (CSD) test holes, and numerous registered well logs all indicate that a stratified, heterogeneous mantle of fine sand, silt, or clay covers large areas of the Platte River valley floor east of Qap2. Thin coarse sand and gravel beds appear at some locations but are not always present, and probably are not continuous over long distances. These thin coarse units may represent bed load moved along the network of anabranching channels on rare occasions when they carry large flows.

Figure 6. Examples of flood channels and a splay complex in an area mapped as Qap3 on the Valley Quadrangle.

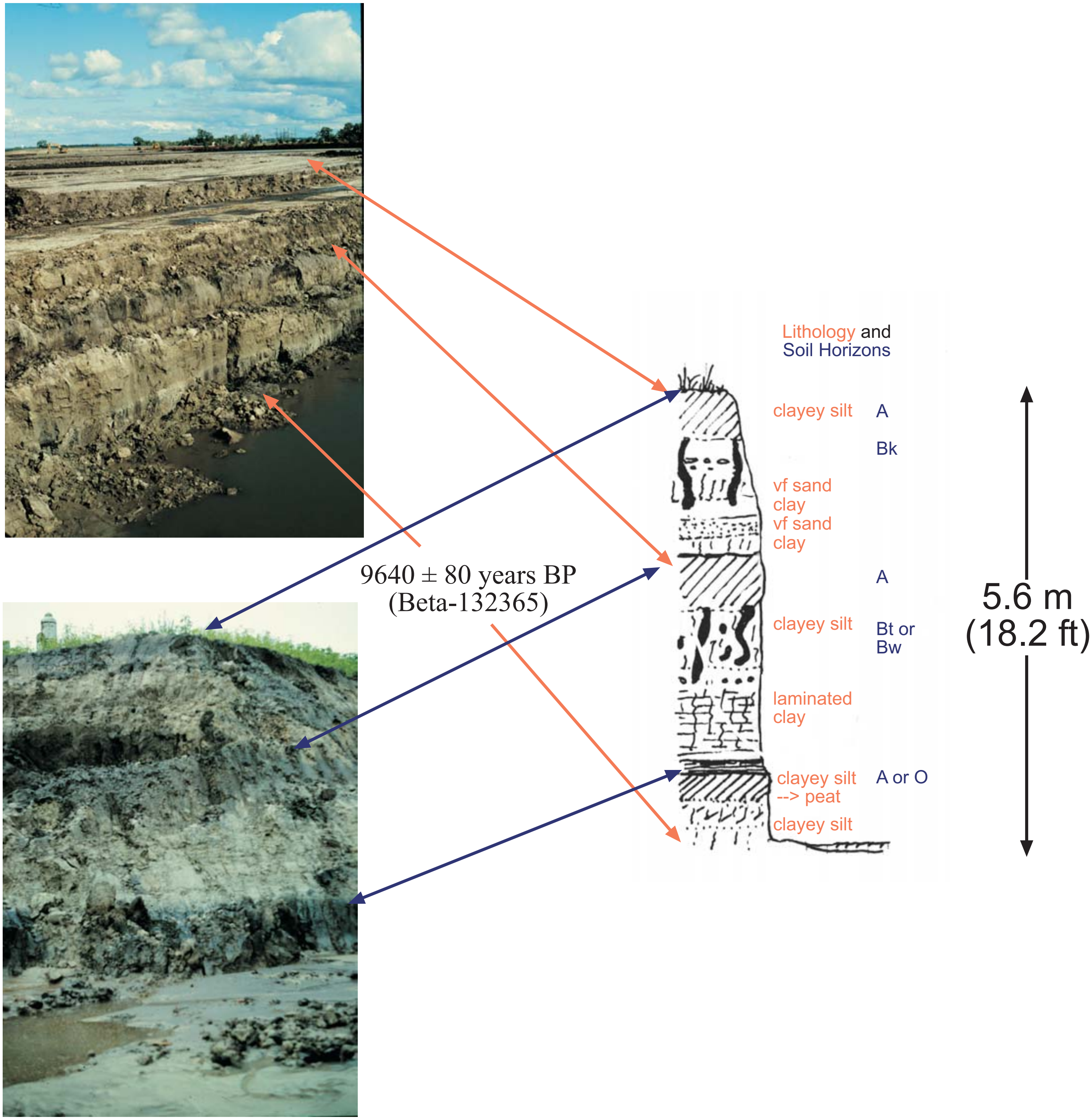


Figure 7. Stratigraphy in a borrow pit located in Qap3, in the Valley Quadrangle. The two photos at left illustrate two faces on the pit. Arrows indicate correlation between depositional units and paleosols in photos and the stratigraphic column to the right. Location of a radiocarbon age obtained from wood near the base of the exposed section is indicated on the upper photo and in the stratigraphic column.

In both the borrow pit (SW 1/4 Section 32, T16N R10E, fig. 6) and an intact core (CSD Core 11-B-99, NW 1/4 Section 32, T16N R10E, fig. 6), there are moderately well-developed buried soils within the fine-grained sediment (fig. 7). In the borrow pit, the deepest soil exposed has high organic matter content and approaches a peat. The buried soils indicate multiple episodes of sediment deposition, separated by long intervals during which deposition was slow or ceased altogether. Registered well logs demonstrate that dark-colored horizons that are probably buried soils occur elsewhere within Qap3. Radiocarbon ages indicate that the fine-grained material at two sites accumulated over the last 10,000 years, that is, throughout the Holocene. In the borrow pit east of Valley (fig. 7), wood at a depth of 18.4 feet (5.6 m) yielded an age of 9640 ± 80 yr BP (Beta-132365), while wood from a depth of 22 feet (6.7 m) in core 11-B-99 yielded an age of 10,300 ± 60 yr BP (Beta-137807). In both cases, the wood is near the base of the fine-grained sediment, overlying coarse Platte River channel deposits.

Areas in Qap3 are subject to flooding but are farther from the active channel than Qap2 or Qap1. Thus, except for parts of Qap3 near flood channels, the flood hazard is somewhat less here than in areas of younger Platte River alluvium. The fine-grained cap on this part of the valley floor makes the land more productive for agriculture, but may provide a less suitable base for foundations, especially for large structures. Peats or highly organic rich soils in the subsurface can compress under load, causing uneven settlement. Where clays are present at the surface, shrink-swell action during wetting and drying cycles can damage structures. Archaeological sites or artifacts may occur within the fine-grained sediment in Qap3, and are particularly likely to be associated with the buried soils.

Qap3 (flood channels) Prominent single or multiple channels with associated alluvial ridges and small splays.

Two belts of single or multiple, moderately sinuous channels cross large areas of Qap3 in the Valley Qaudrangle, both trending from northwest to southeast (fig. 6). As with the flood channels in Qap2 (described above), some of these channels carry groundwater-fed base flow for much of the year, but they are probably shaped mainly by flow out of the Platte River during floods. Also, as with the Qap2 flood channels, those in Qap3 have associated alluvial ridges and small sand splays. Structures built adjacent to the flood channels are at risk if flows exceed the channel capacity. The northern part of the town of Valley is adjacent to one of the more prominent flood channels. Flood channels within Qap3 cross the southeastern portion of the Fremont East quadrangle, but their upstream connection to the Platte River has been obscured by road construction and urban development.

Qap3 (splay) Fan or "bird's foot" shaped, low relief area of sediment deposition from distributary channels

Large areas of Qap3 are covered with splays of fine sand or silt. The splays are elongate and somewhat similar in appearance to "bird's foot" deltas (fig. 6). Typically, small distributary channels branch off from a larger feeder channel and ultimately disappear into a smooth flood plain surface. During floods, water and sediment are distributed through this network and the sediment is ultimately deposited on the splays. Deposition probably occurs as sediment-laden water leaves the distributary channels and flows out into adjacent areas of shallow, ponded water. At the downstream margin of the splays, there is often a network of small channels that appear to collect water flowing off the splay, perhaps as the flood plain drains when the flood waters recede. Because the distributary channels are small and shallow, splays in Qap3 have a very smooth, low-relief surface, as compared to the flood channel belts. The splays tend to be areas with a particularly thick fine-grained cap of surficial sediment, but there are exceptions to this generalization.

Qap4 Platte River channel deposits, in the Todd Valley and beneath terraces (Pleistocene).

Medium-to-coarse sand and gravel

Sand and gravel deposited in former Platte River channel belts: Qap4 underlies loess and eolian sand beneath high terraces on both sides of the Platte River valley, and in the Todd Valley. The sand and gravel in Qap4 is Pleistocene, because it is partially or completely covered by Peoria Loess.

Qafb Flood basin clays and silts (Holocene and Pleistocene [?])

Clay and clayey silt, with lenses or thin beds of sand

Sediment deposited from ponded flood waters in extensive low-lying areas, or flood basins, near the margins of the Platte River valley: the sediment in each flood basin is probably from a mixture of sources, including the Platte River, Elkhorn River, Rawhide Creek, Clear Creek, and small drainages from the uplands on the west side of the Platte. Qafb is particularly extensive in the Fremont East quadrangle. The flood basins lack the flood channels, splay complexes, and relict braided channel patterns that characterize Qap3, and in addition, the surficial sediment in the flood basins generally has a higher clay content than sediments in Qap3. The typical sequence of sediments in Qafb includes 5-20 feet (1.5 to 6.1 m) of black or gray clay or very clayey silt with occasional thin sand beds, overlying a highly variable thickness of silts, clays, and sand and gravel, which in turn rest on Cretaceous sandstones, siltstones or claystones (typically described as “shale” in drillers’ logs). The total depth to bedrock is 25 to at least 90 feet (6.1 to 27 m), and it is often difficult to determine because the Dakota Group bedrock includes poorly consolidated silts, clays, and sands. In many areas of Qafb, particularly in the Arlington and northern Valley quadrangles, coarse sand and gravel do not occur above bedrock, or are present only in thin beds that cannot be correlated between nearby wells or test holes. In the Fremont East quadrangle, the central Valley quadrangle, and the Ashland East quadrangle, some flood basin deposits included in Qafb overlie a significant thickness (> 25 feet or 7.5 m) of coarse sand and gravel.

On air photos, many areas of Qafb display a complex pattern of small, highly sinuous former channels, similar to the historical anabranching channel of Rawhide Creek (fig.

8). Areas where this channel pattern can definitely be identified are mapped separately as **Qafb (sinuous channels)**. This is an important observation because sand bodies within the flood basin deposits may be related in part to sand transported as bedload in these sinuous channels. Local "sand spots" at the land surface appear to be associated with particularly prominent relict channels. The range of ages of the flood deposits contained in Qafb is uncertain. The surficial clays could have been deposited throughout the Holocene, and some Pleistocene fluvial sediment may be preserved in the subsurface.

The surficial clays in unit Qafb experience significant shrinking and swelling related to wetting and drying cycles, potentially causing damage to structures. Groundwater availability within unit Qafb for irrigation or domestic use is often limited and highly variable over short distances, although a few irrigation wells use water from locally thick beds of sand and gravel. For domestic use, deeper wells screened in Cretaceous sandstone may be the best option. Unit Qafb is an area of groundwater discharge during at least part of the year, because there are many local patches of saline soils, where salts in groundwater have been concentrated by evaporation. The saline soil patches are associated with sinuous channel patterns. Archaeological sites and artifacts may occur within Qafb, but most areas in this unit were probably too poorly drained in prehistoric times to have been the locations of settlements.

Qasg Undifferentiated Platte or Elkhorn River alluvium underlying surficial mapping units in the Platte River valley (Holocene and Pleistocene).

[stack map only]

Sand and gravel with local interbedded silt and clay

Within the Platte River valley, the surficial geologic mapping units described above overlie a variable thickness of alluvial sediment, which in turns directly overlies bedrock in most places. This valley fill is often thicker than the likely depth of Platte or Elkhorn river channel scour during floods, and therefore it was deposited at times when one or both of these rivers was more deeply entrenched than at present. Much of the valley fill is medium-to-coarse sand and gravel, although there is a significant amount of interbedded silt or clay in some places, particularly in areas farther from the present Platte channel. The source (Platte vs. Elkhorn) and age of these buried alluvial deposits cannot be determined from registered well logs, although some of them are clearly older than the early Holocene sediment in the lower part of unit Qap3. In the stack maps, all of the deeper valley fill is grouped into unit Qasg, with the typical *total subsurface thickness* of coarse sand and gravel added as a modifier.

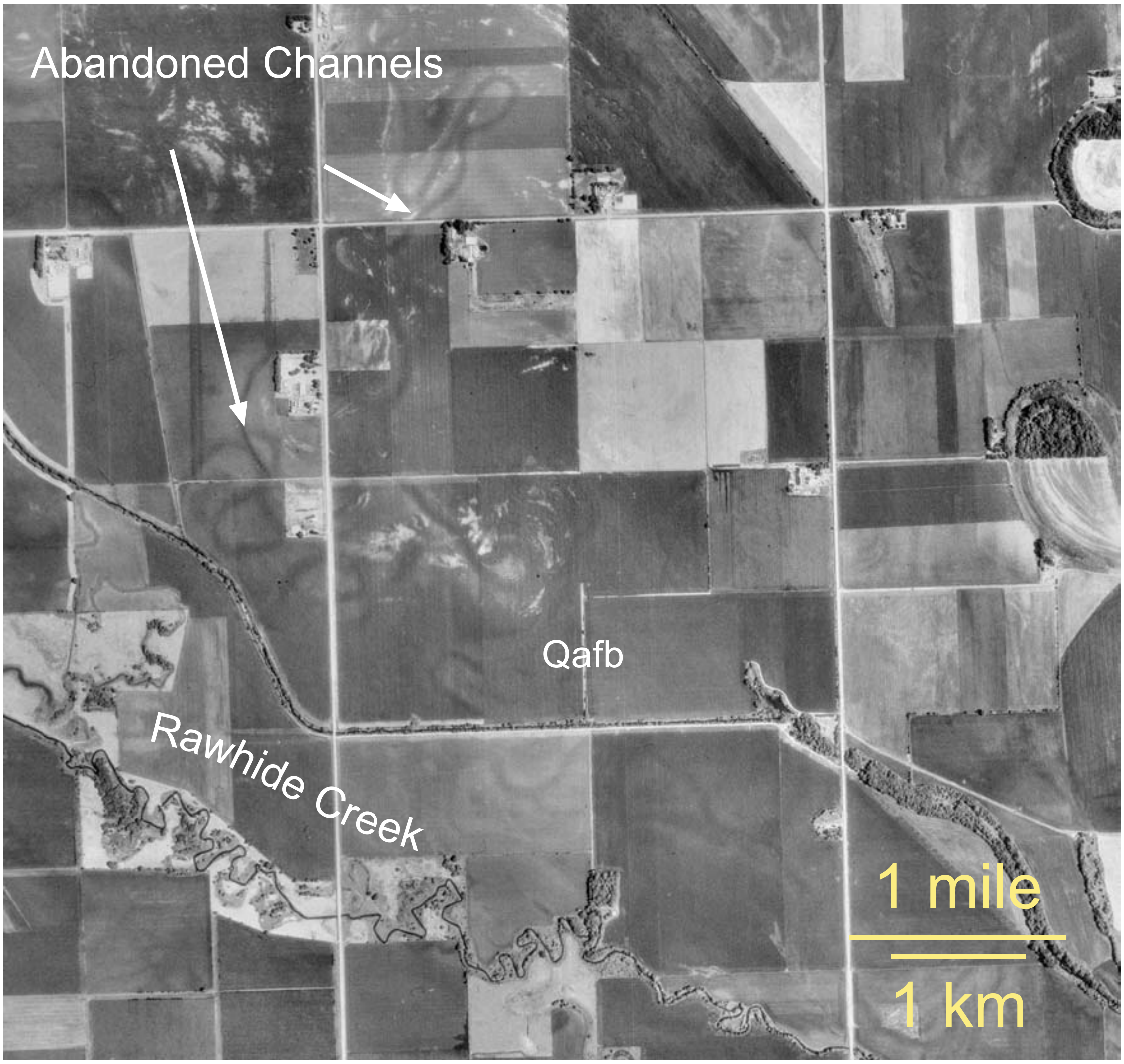


Figure 8. Representative area of Qafb in the Arlington Quadrangle, with abandoned channels of small sinuous streams. In this case, the channels were probably formed by predecessors of modern Rawhide Creek. Light patches associated with abandoned channels are either saline soils or small areas with sand at the surface.

Qabc1 Alluvium of Bell Creek, modern flood plain and low terraces (Holocene)

Silty clay and clayey silt with occasional sand beds

Alluvium beneath the modern flood plain of Bell Creek and discontinuous terraces that rise 5-10 feet (1.5 to 3 m) above the flood plain: soil survey data suggest that the surficial alluvium is predominantly black-to-grayish brown silty clay at least 5 feet (1.5 m) thick, with a surface veneer of lighter colored silt in many places. Stratification is prominent in some but not all stream cutbank exposures. Below the surficial silty clays, a few registered well logs suggest that silt and clay is interbedded with sand beds that are 5-20 feet (1.5 to 6.1 m) thick. The total thickness of Bell Creek alluvium is difficult to determine because stratified silt, clay, and sand of Qsg occur beneath the Bell Creek valley. Well logs do not provide enough information to distinguish Bell Creek alluvium from underlying till and Qsg sediments.

Most areas of Qabc1 are subject to a significant flood hazard. In addition, the high clay content of surficial sediment in this unit could cause damage to structures by shrinking and swelling during wetting and drying cycles. It is unlikely that the sand in the subsurface of Qabc1 can be commercially extracted because of the thickness of overlying silt and clay. Archaeological sites and artifacts may occur throughout Qabc1.

Qabc2 Alluvium of Bell Creek, high terraces, with possible Peoria Loess cover (Pleistocene or Holocene)

Clayey silt with occasional sand beds

Alluvium beneath one or more terraces that rise 10 to 30 feet (3 to 9.1 m) above the modern flood plain of Bell Creek: the terraces may be capped by at least 5 to 10 feet (1.5 to 3 m) of Peoria Loess. At least two terrace levels are present based on surface elevation, but differences in elevation might reflect different thicknesses of a loess cap, rather than two distinct fluvial surfaces. In a cutbank exposure, massive yellowish brown silt beneath the terrace surface graded downward into vaguely stratified silt. The silt was enriched in clay by soil development near the terrace surface, similar to upland soils formed in Peoria Loess. Well logs indicate that silt or clay is at least 20 feet (6.1 m) thick beneath the terrace surface, and in some places more than 50 feet (15 m) thick. Silt and clay with occasional sand beds occur at greater depth. If the massive silt at the top of the Bell Creek terraces is Peoria Loess, then the terraces are of late Pleistocene age. If this silt is alluvium, then the terraces could be early-middle Holocene, by analogy with terraces underlain by the Gunder Member of the DeForest Formation in southeastern Washington County, Nebraska (see description of unit Qa).

Most areas of Qabc2 are high enough above the active flood plain that flood hazards are minimal and are therefore favorable building sites. Much of the village of Arlington is on a terrace surface mapped as Qabc2. A few low terraces included in this unit may be inundated in extreme floods. If the terraces in Qabc2 are of Pleistocene age, then it is unlikely that the underlying sediment will contain archaeological sites or artifacts. Artifacts may be present if some of the terraces are Holocene, however.

Qa Alluvium of small streams (Holocene and late Pleistocene?).

Slightly to very clayey silt, overlying stratified sand and gravel in some areas

Alluvium in small stream valleys and in limited areas of the Platte River valley adjacent to Otoe, Rawhide, Clear, Wahoo, and Salt creeks: Sediments in Qa are mostly correlative with the DeForest Formation, as defined by Bettis (1990) in Iowa. Bettis (1990) distinguished three members of this formation, based on lithology. From oldest to youngest, these are the Gunder, Roberts Creek, and Camp Creek Members. The three members can often be distinguished locally in outcrops or cores, but it was not practical to map them separately in this study. These members are most readily distinguished in small, steep stream valleys.

In that setting, the upper part of the Gunder Member (the part typically seen in outcrops) is light yellowish-brown or gray, slightly to moderately clayey silt with a few lenses or thin strata of sand or gravel. In the upper part of many outcrops, this member is massive and closely resembles Peoria Loess. Faint-to-prominent stratification is common in the lower part of many outcrops, although it is not always present. Near the surface of the Gunder Member, it typically is darkened and clay-enriched by soil development, and the resulting moderately well-developed soil has distinct A and B horizons. Faint, slightly darker bands deeper within the Gunder Member probably represent brief periods of soil development during deposition of this unit. These dark bands, faint stratification, and occasional lenses of sand or charcoal are useful evidence in distinguishing the Gunder Member from the Peoria Loess in outcrop. The lower part of the Gunder Member may contain thick beds of sand, occasionally with some gravel. This portion of the Gunder Member is less commonly exposed, but is probably extensive in the subsurface. Total Gunder Member thickness ranges from a few feet to more than 20 feet (6.2 m). The Gunder Member in southwestern Iowa and southeastern Nebraska is early to middle Holocene in age (Bettis, 1990). Charcoal from the Gunder Member along Mill Creek, in southeastern Washington County, Nebraska, has a radiocarbon age of 6950 ± 50 yr B. P. (Beta-119109) at a depth of 15 feet (4.6 m) below the surface.

The Roberts Creek member is dark brown or black, moderately to very clayey silt (occasionally sandy silt or sandy clay). The dark color reflects high organic matter content. It is typically massive but displays weak stratification in some places. The Roberts Creek Member ranges in thickness from a few feet to more 10 feet (1 to more than 3.1 m). The Camp Creek Member overlies the Roberts Creek Member or is inset below it and is distinctly stratified, slightly to moderately clayey silt (occasionally sandy silt). Many of the strata are light-colored, and overall, the Camp Creek Member is lighter-colored and less organic-matter-rich than the Roberts Creek Member. Lenses or thin beds of sand and gravel are present in the Camp Creek member in some localities, where these grain sizes are available, for example, where there are till outcrops upstream.

Some “gravel” lenses consist entirely of calcium carbonate nodules reworked from the Peoria Loess. There is little significant soil formation at the top of the Camp Creek Member. The Camp Creek Member is less than 5 feet (1.5 m) thick in most places but may exceed 20 feet (6.2 m) in a few small valleys in the Omaha area. The Roberts Creek Member in southwestern Iowa and near Lincoln, Nebraska, is late Holocene, based on radiocarbon dating (Bettis, 1990; Mandel and Bettis, 1995), but no dates are available from the mapped area. The Camp Creek Member was deposited in the last 500 years, and particularly after initial European settlement in the 1850’s and 1860’s (Bettis, 1990; Mandel and Bettis, 1995).

It is difficult to distinguish the DeForest Formation members in wide, flat-floored larger stream valleys. In that setting, much of the alluvium is black, grayish brown, or gray, moderately to very clayey silt and silty clay, with some beds of sandy silt or clay. Sand and gravel is often, but not always, present near the base of the alluvium. Similar alluvium reaches thicknesses of at least 60 feet (18.5 m) in the valley of Big Papillion Creek, east of the Arlington Quadrangle, but is probably thinner in most of the present study area, and thins to only few feet near valley margins and in the smallest stream valleys. The alluvium in these wide, flat-floored valleys is presumed to be mostly of Holocene age, although no radiocarbon ages are available. Alluvium along Rawhide and Otoe creeks within the Platte River valley is broadly similar to stream alluvium in wide flat-floored valleys elsewhere in the mapped quadrangles. Rawhide Creek alluvium appears to contain more clay, and to have darker colors than alluvium along small streams in the uplands.

The Gunder Member has properties similar to the Peoria Loess, but in many cases it appears to have higher density (site-specific investigations will be necessary to confirm this). Where subsurface movement of contaminants is of interest, it is important to distinguish the Gunder Member from Peoria Loess. The stratification, buried soils and sand or gravel lenses that occasionally occur in the Gunder Member, but not in the Peoria Loess, probably have a significant impact on contaminant transport. Archeological sites and artifacts could potentially be present throughout the thickness of the Gunder Member, although Bettis (1990) reports that they are rare in the Gunder Member of southwestern Iowa. The physical properties of the Roberts Creek and Camp Creek members are highly variable, depending on texture and organic matter content. Few structures have been built in areas of Qa underlain by the Roberts Creek and Camp Creek members because of flood and erosion hazards. The relatively high organic matter content of the Roberts Creek member may affect the subsurface transport of some contaminants. Artifacts and archaeological sites may be present throughout the thickness of both Roberts Creek and Camp Creek members. Where the Camp Creek Member is thick, artifacts on the surface or at shallow depth are likely to be historic; older material will be found at or below the lower boundary of this member. The physical properties of the undifferentiated DeForest Formation alluvium in wide, flat-floored stream valleys are variable, depending on clay and organic matter content. This alluvium probably contains enough organic matter to affect contaminant transport. Although sand and gravel occurs within unit Qa in some areas, it is not commercially extracted because it is thin and patchy and deeply buried beneath fine-grained deposits.

Qa (clay surface)   Alluvium of small streams (Holocene and late Pleistocene?).

Silty clay, overlying clays, silts, fine sands, and in some areas, stratified sand and gravel

Qa (clay surface) has characteristics similar to Qa in wide, flat-floored stream valleys (described above), except that the upper 5 feet (1.5 m) or more of sediment is silty clay. This variant of the Qa unit is mapped on the flood plains of Salt Creek and Wahoo Creek in the Ashland East Quadrangle. Limited exposures indicate that gray or gray-brown colors predominate and multiple, weakly developed buried soils are present. Properties of Qa (clay surface) relevant to construction, hydrogeology, and archaeological site potential are similar to those of Qa, described above, with these exceptions: 1) areas of Qa (clay surface) will have greater shrink-swell potential; and 2) water flow and contaminant transport through Qa (clay surface) may be slower unless large cracks are present in the silty clay surface layer.

Qaf   Alluvial fan deposits (Holocene)

Silt and silty clay, locally sandy with occasional pebbles

Alluvium deposited on low-gradient fans, single or coalesced, at mouths of small drainages flowing off uplands and into the Platte River valley (fig. 3, right side): the fan sediments are primarily derived from erosion of Peoria Loess and glacial till upslope. Sediments in Qaf are predominantly silt, but contain some sand and/or pebbles where they are available in outcrops in the drainage basin that feeds the fan. The alluvial fan sediment is at least 20 feet (6.2 m) thick beneath the larger areas of Qaf, but thins to a few feet (< 1 m) toward the lower end of the fan. This sediment typically rests on alluvium of the Platte or Elkhorn rivers that predates formation of the fan. In many areas of unit Qaf a few feet (0.5 to 1 m) of light-colored sediment overlies a dark-colored buried soil. This represents acceleration of soil erosion when the uplands were originally cleared for agriculture. Other buried soil horizons occur at greater depth within the larger fans. Fans in the Ashland East quadrangle accumulated throughout the Holocene (Rolfe Mandel, personal communication, 2001). Structures built on unit Qaf could be affected by flash floods from the small, steep drainages that supply sediment to the fan. This hazard is most significant where structures are immediately adjacent to channels crossing the fan. Artifacts and archaelogical sites could occur throughout the alluvial fan sediment; in fact, alluvial fans are known to have particularly high archaelogical potential throughout the Midwest.

Qsw   Slopewash sediment, with underlying or intermixed Peoria Loess (Holocene and late Pleistocene?).

Slightly to moderately clayey silt, with significant sand or pebble content in some localities

Sediment deposited mainly by slopewash: occurs on concave lower slopes, in drainageways, and on alluvial fans too small or indistinct to map separately. Sand and pebbles occasionally occur within this unit when glacial till or sand and gravel crop out on the slopes above. The lower part of this unit is light yellowish brown or gray and commonly contains brown, yellow, and gray mottles. The upper part is brown or dark brown because of soil formation. The dark brown surface layer (the soil A horizon) thickens downslope and into the center of drainageways, where it is several feet (ca. 1 m) thick. Drainageways in which Qsw is mapped, rather than Qa, are at the upper end of the drainage network and often lack distinct stream channels. Areas mapped as Qa are expected to contain sediment with typical characteristics of alluvium, such as distinct stratification to depths greater than a few feet, as well as distinct former channels now infilled with younger sediment. These characteristics are usually lacking in areas mapped as Qsw, except for a distinct light-colored upper stratum less than 3 feet (1 m) thick, which represents deposits of recently eroded soil. Most areas of this unit probably include some Peoria Loess directly deposited by the wind, but this primary loess is overlain and/or mixed with sediment moved downslope by other processes. These processes include rainsplash, sheet wash, flow in small rills and gullies, and possibly soil creep or other types of mass movement. The thickness of the dark brown surface horizon indicates that this downslope sediment movement was generally slow and soil development kept pace with it. It is difficult to clearly distinguish deeper, lighter-colored layers of slopewash sediment from primary loess (deposited directly by the wind), because the slopewash deposits are largely made up of reworked Peoria Loess. The total thickness of this unit varies from less than 1 foot to more than 15 feet (0.3 to 4.6 m), and increases down slope and into drainageways. In many places this unit grades laterally into the alluvium of Qa, suggesting contemporaneous deposition during the Holocene. Slope erosion undoubtedly also occurred as the Peoria Loess was being deposited, so some of the slopewash sediment is probably late Pleistocene in age.

Areas of Qsw in which mottles or gray colors are common below the surface soil may not be good building sites because of poor drainage. Archaeological sites or artifacts may be shallowly buried in Qsw, because of ongoing deposition of sediment from higher on the slope.

Qc Colluvium at the foot of the Platte/Elkhorn valley wall (Pleistocene and Holocene?)

Heterogeneous sand and silt with some larger rock fragments

Massive silt, stratified sediment, and diamicton deposited at the foot of slopes by a combination of mass wasting processes (e.g. slumps) and slopewash. This unit is only mapped in a few small areas where it is known to be present because of a large exposure. It is likely that similar colluvium occurs elsewhere along the Platte valley walls but is not exposed. The colluvium in this unit is derived partly from Peoria Loess, and partly from older loess, glacial till, and/or Dakota sandstone. Mass movement processes are evident in the main outcrop because block failure planes are exposed. Slopewash is also demonstrated by crudely stratified material at the base of the slope as well as in apparent small gully fills. The older parts of this unit may predate Peoria Loess deposition, but mass wasting also reworked Peoria Loess and large landslides have occurred in recent times in a few places along the valley wall. The material in Qc is too heterogeneous to allow generalizations about limitations or potentials for specific land uses. The presence of Qc does suggest a possible landslide hazard, but confirming this requires site-specific investigation. It is unlikely that archaeological sites or artifacts occur in most areas of Qc.

Qlp Peoria Loess (late Pleistocene).

Slightly to moderately clayey silt

Massive or occasionally faintly laminated silt mantling uplands throughout the Arlington, Valley, and Wann quadrangles: Peoria Loess is interpreted as a deposit of wind-blown dust, although it may include some sediment that has been reworked down slopes by water or gravity. Peoria Loess is light yellowish brown or gray, except in the upper few feet, which are very dark brown to brown because of soil development. Brown, orange, and gray mottles are common below the surface soil profile. Hard concretions of calcium carbonate are present at some localities, but otherwise, Peoria Loess contains little material coarser than 0.1 mm diameter. Peoria Loess is generally calcareous below the surface soil profile, because of calcite and dolomite grains in the original loess deposit. Shells of land snails are also common in this unit where it is calcareous.

Within a local area, the thickest Peoria Loess is on wide, gently sloping ridgetops. Peoria Loess in this landscape position is about 25-35 feet (7.6 to 10.7 m) thick in the uplands of the mapped quadrangles. The thinnest Peoria Loess in a local area is at the downhill edge of areas included in Qlp, bordering Qsw, Ql, or Qt (fig. 1). A similar pattern is observed in the eastern parts of the Valley and Wann quadrangles. On parts of the hill slopes forming the bluff line at the edge of the Platte River valley, Peoria Loess has been completely removed by erosion and the underlying Ql, Qt, or Qsg units occur at the land surface (areas in which the older loess deposits of the Ql unit crop out are too small to show on these maps). East of the Platte Valley, there is systematic regional variation in the thickness of Peoria Loess on stable upland summits that have experienced little erosion since the loess was deposited (fig. 9). The greatest thickness, 60-70 feet (18-21 m) occurs on gently sloping ridge tops near the Missouri River valley, and Peoria Loess thickness decreases westward to around 30 feet (9.1 m) near the valley of Big Papillion Creek, and then remains in that range or increases slightly in thickness (to about 33 feet, or 10 m) westward to the Platte Valley. Areas mapped as Qlp probably include many small outcrops of Ql or Qt, that were not detected because of vegetation cover. Most of these outcrops occur near the downhill edge of areas mapped as Qlp.

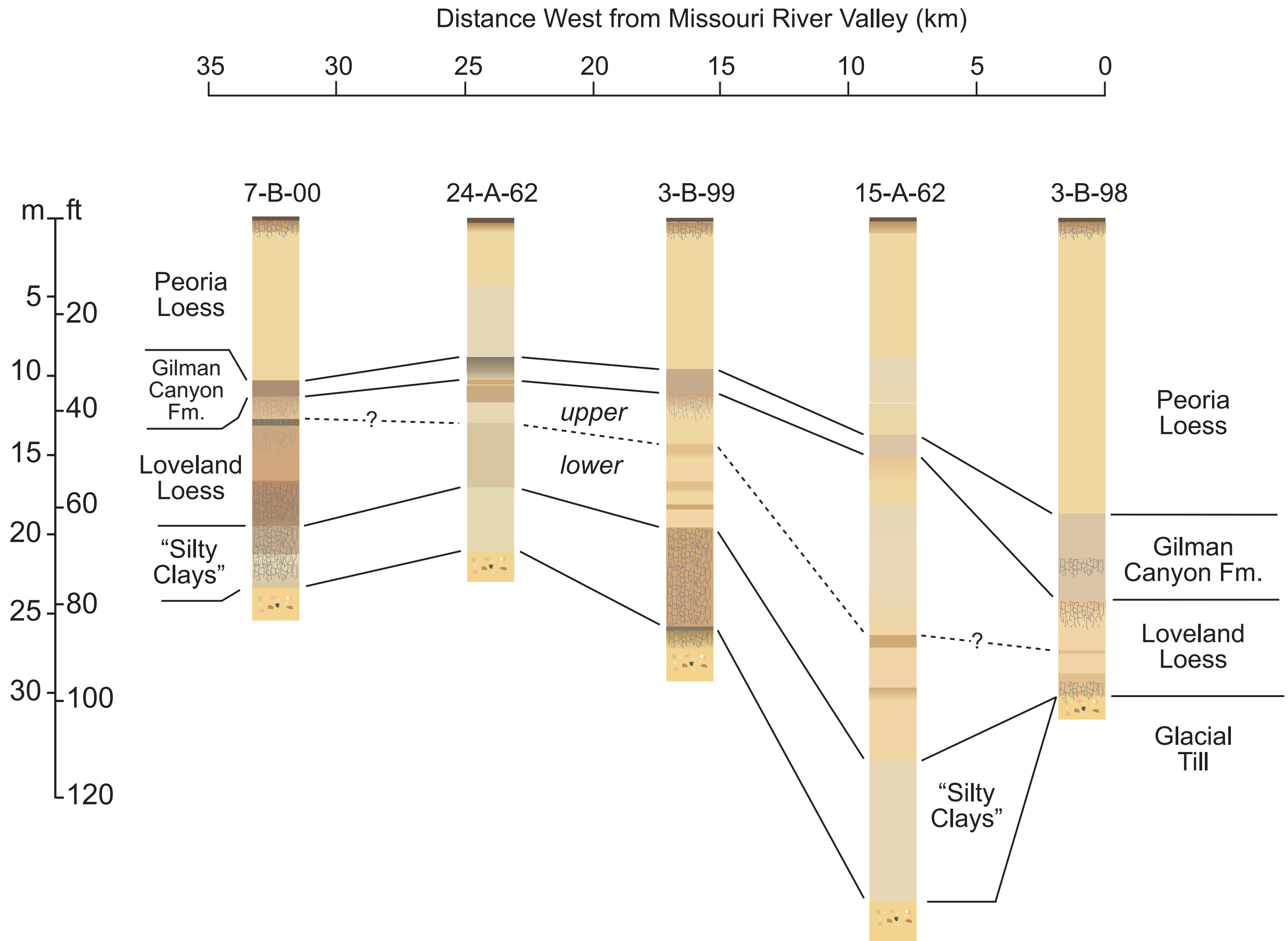


Figure 9 (continues on following page). Loess stratigraphy in upland cores ("-B-") and rotary drill holes ("-A-") between Fort Calhoun and Arlington, Nebraska, including part of the Arlington and Fremont West quadrangles. These test holes were selected to form two transects from the Missouri River valley westward to the Platte valley. These columns represent maximum thickness of each stratigraphic unit in a local area, as found beneath wide, nearly-level upland ridge tops. All units will be thinner, and some may be absent, on slopes. The colors used in each column approximate the moist colors of the various loess units and surface or buried soils formed in them. Blocky pattern in cores shows zones with well-preserved soil structure. In the surficial geologic and stack maps, Peoria Loess is unit Qlp, and the Gilman Canyon Formation, Loveland Loess, and "silty clays" are all included in unit Ql.

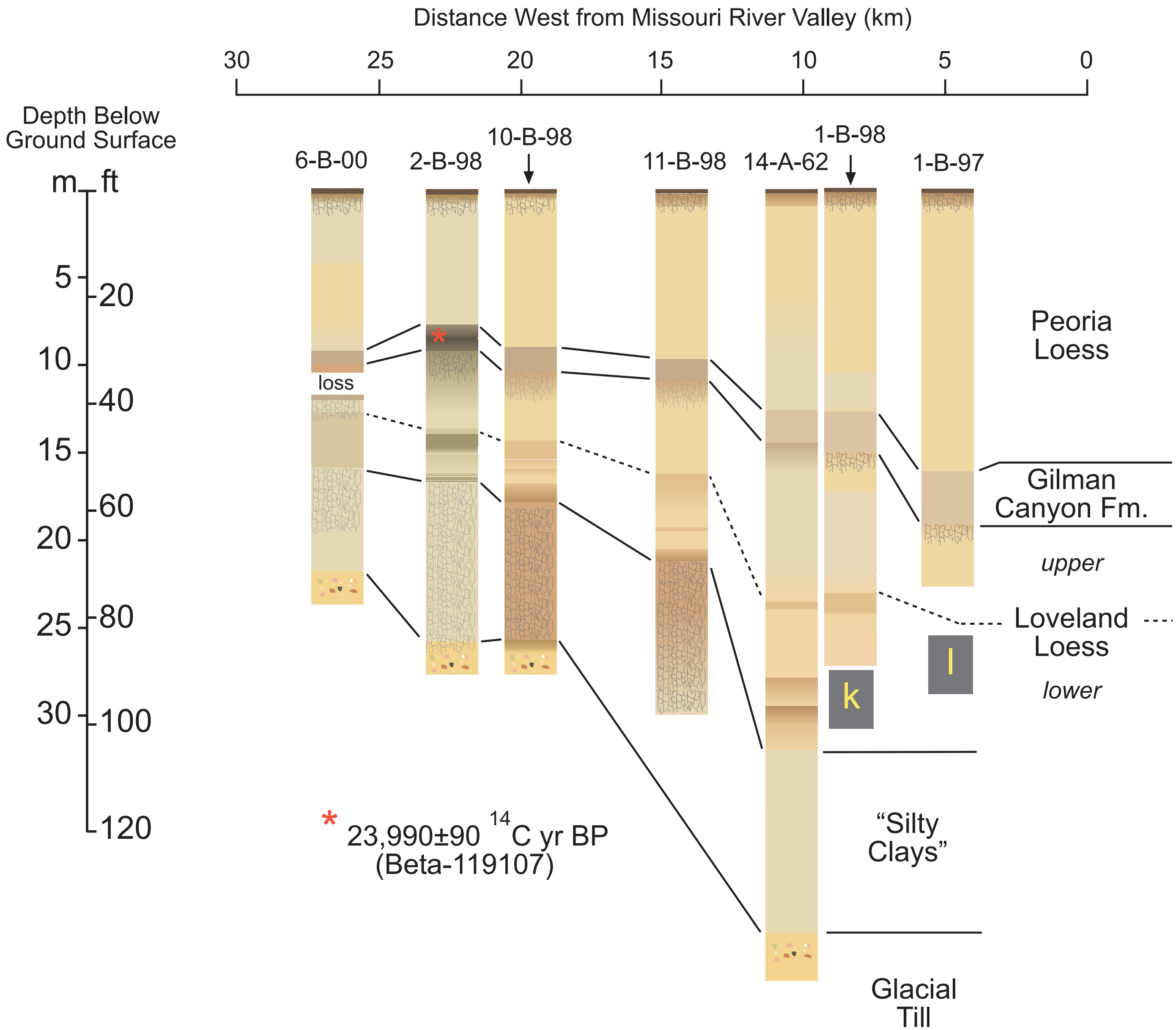


Figure 9 [continued from previous page].

Peoria Loess is the uppermost of a sequence of loess deposits consistently observed in the eastern Nebraska (fig. 9). It is also a widespread stratigraphic unit throughout the central U. S. and is now referred to as the Peoria Silt in some states (Leigh and Knox, 1994; Hansel and Johnson, 1996). The basal part of the Peoria Loess dates to between 25,000 and 20,000 yr B. P. (years before present) at Loveland, Iowa (Forman and others, 1992). The end of Peoria Loess deposition is not dated in the Omaha area, but deposition had ended by about 10,500 yr B. P. in central Nebraska (Maat and Johnson, 1996), and ended as early as 14,000 yr B. P. in central Iowa (Ruhe, 1969). Miller (1964) suggested that a younger loess deposit (Bignell Loess) is also present in and around Omaha, but the present investigation produced no evidence of a significant thickness of Bignell Loess in this area. Some dust was undoubtedly blown from the Missouri and Platte river flood plains to the surrounding uplands after the end of Peoria Loess deposition, but not enough to produce a distinct loess deposit.

Most previous workers have assumed that the primary source of Peoria Loess near Omaha was the Missouri River flood plain, with a secondary contribution from the Platte or Elkhorn River flood plains to the west (Miller, 1964). The local decrease in Peoria Loess thickness with distance from the Missouri River indicates that the flood plain of that river was a major source (fig. 9). From a broader perspective, however, larger-scale thickness trends indicate that much of the Peoria Loess in eastern Nebraska was probably transported southeastward from the area presently occupied by the Nebraska Sand Hills (Mason, 2001). Local thickening near the Platte Valley suggests that the Platte River flood plain may have been a secondary source.

Peoria Loess has distinctive properties that can affect most types of construction (Benak, 1967; Handy, 1973; Lutenegger and Hallberg, 1988). These properties of Peoria Loess are variable from place to place, and a site-specific geotechnical investigation is necessary to determine whether any of the following generalizations apply at a particular location. Dry Peoria Loess will often stand in a steep face (> 70° slope) for many years (Lohnes and Handy, 1968), but wet loess has much lower strength. Peoria Loess in the Omaha area is often considered to have inadequate bearing capacity for large structures, at its natural density, based on geotechnical tests and past experience. Because of this limitation, special construction techniques are often required when large structures are built in areas of thick Peoria Loess. Some dry, low-density Peoria Loess in the Omaha area will collapse, or consolidate rapidly, when wetted (Handy, 1973). Low density is typically found in thick, well-drained deposits of Peoria Loess near the Missouri River valley but could also occur close to the Platte River valley. Collapsible zones occur within thinner Peoria Loess as well (Lutenegger and Hallberg, 1988). Handy (1973) describes a simple criterion for collapsibility: in collapsible loess the saturation moisture content typically exceeds the liquid limit. Peoria Loess is highly erodible where it is not protected by vegetation, and erosion of exposed loess will cause rapid siltation in downstream reservoirs or flood plains. Deep gullies can develop rapidly at construction sites or in agricultural fields if adequate erosion control practices are not followed. Slumps and other types of slope failure occur within Peoria Loess in some localities, particularly where steep slopes are undercut by streams, although many steep slopes underlain by Peoria Loess are stable and do not experience any significant mass movement. Undisputed human artifacts have not been found deeply buried within Peoria Loess in Nebraska, although they could be present given increasing documentation of human presence in North America during at least the last phase of Peoria Loess deposition.

Qes Eolian sand in the Todd Valley (late Pleistocene).

Fine-to-medium sand, well-sorted

Sand interpreted as a wind-blown deposit: Qes overlies Platte River fluvial sand and gravel (Qap4) and generally covered by Peoria Loess. This interpretation is based on the topography of the Todd Valley surface, which resembles a field of low sand dunes or a hummocky eolian sand sheet, now mantled by Peoria Loess. The absence of Gilman Canyon Formation or older loess overlying this sand suggests that it was deposited at the same time as the initial increment of Peoria Loess on adjacent uplands, and thus the sand is of late Pleistocene age.

Note: Qes is not distinguished from underlying Qap4 in the current versions of surficial and stack maps included with this report.

Ql Gilman Canyon Formation, Loveland Loess, and older unnamed loess deposits (middle to late Pleistocene).

[stack map only]

Moderately to very clayey silt and silty clay

Silt and clay interpreted as wind-blown dust deposits, but often highly altered by soil formation and weathering after deposition: this unit includes all loess deposits older than Peoria Loess, including from youngest to oldest, the Gilman Canyon Formation, Loveland Loess, and one or more unnamed units (fig. 9). In the quadrangles included in this study, outcrops of Ql are too small to show on the maps, but their occurrence can be predicted from slope position (fig. 3). Ql is an important component of stack map units, however.

The Gilman Canyon Formation is moderately clayey silt and is grayish brown with a redder hue than overlying Peoria Loess (hue of 10YR rather than 2.5Y in the Munsell color system). This unit displays weak granular or blocky soil structure at many localities. The Gilman Canyon Formation is 18 feet (5.5 m) thick at one site east of the present study area, near the Missouri River at Fort Calhoun, but in the quadrangles include in this report this loess unit is only 2-5 feet (0.6-1.5 m) thick. The contact between the Gilman Canyon Formation and underlying Loveland Loess is gradational because soil development continued as the initial increment of Gilman Canyon Formation loess was deposited. In many older descriptions of stratigraphy in the Omaha area, the Gilman Canyon Formation was considered to be part of the soil formed in the upper part of the Loveland Loess and was not recognized as a separate loess deposit. The Gilman

Canyon Formation is stratigraphically equivalent to the Pisgah Formation in Iowa (Forman and others, 1992) and the Roxana Silt in Illinois, Wisconsin, and Minnesota (Hansel and Johnson, 1996; Leigh and Knox, 1994; Mason and others, 1994). Deposition of the Gilman Canyon Formation in the Omaha area began before 35,000 yr B. P. and continued until some time between 25,000 and 20,000 yr B. P., based on the available radiocarbon ages. Mandel and Bettis (1995) reported a radiocarbon age of 25,340 ± 260 yr B. P. (CAMS-10190) from just below the top of the Gilman Canyon Formation in Bellevue, Nebraska. The Gilman Canyon Formation has also been radiocarbon dated near Winslow, Nebraska, 12 miles (20 km) northwest of the Arlington quadrangle, where organic matter in the upper part of this formation has an age of 23,000 ± 600 years B. P., and organic matter in the lower part has an age of 31,400 +1800, -1500 yr B. P. (Souders and others, 1971). In this investigation, an age of 24,010 ± 90 yr B. P. (Beta-119107) was obtained from wood at a depth of 2 feet (0.6 m) below the top of the Gilman Canyon Formation in the Arlington Quadrangle (Conservation and Survey Division Test Hole 2-B-98, fig. 9). Thermoluminescence and radiocarbon ages reported by Forman and others (1992) indicate that the Pisgah Formation was deposited between about 35,000 and 23,000 years B.P. at Loveland, Iowa; this is probably a good approximation of the age of the stratigraphically equivalent Gilman Canyon Formation across the Missouri in the Omaha area.

Loveland Loess is moderately to very clayey silt. In intact cores collected on wide, nearly level ridgetops in the Arlington Quadrangle, Loveland Loess is 20 to 25 feet (6.1 to 7.6 m) thick. Greater thicknesses occur between the Arlington Quadrangle and the Missouri River valley. For example, in two mud-rotary test holes near Fort Calhoun, Nebraska, (14-A-62 and 15-A-62, fig. 9), Loveland Loess may be up to 60 feet (18.3 m) thick. In contrast, only a few feet (ca. 1 m) of Loveland Loess were present beneath a ridgetop at one site in the eastern part of the Wann Quadrangle (CSD core 12-B-99, SW 1/4 Section 11, T14N R10E). More work is needed to characterize Loveland Loess thickness south of the Arlington Quadrangle. This unit is always much thinner in outcrops on slopes than on adjacent ridgetops. Where Loveland Loess is thick it contains three distinct zones. The three zones vary widely in thickness. The upper zone was highly altered by soil formation and weathering during both the last interglacial period and a significant portion of the last glacial period, before it was deeply buried by deposition of the Gilman Canyon Formation and Peoria Loess. Effects of this prolonged period of soil formation include the accumulation of clay, development of a redder color, and development of blocky structure. The soil formed in the upper Loveland Loess is considered correlative with the Sangamon Geosol (or Sangamon Soil) of the midwestern U. S. (Follmer, 1983). The middle zone of the Loveland Loess contains less clay, has a yellower color, and in some cases closely resembles Peoria Loess. The lowest zone of the Loveland Loess is often slightly darker and firmer, and has a slightly redder hue than the middle zone. These differences between middle and lower Loveland Loess could reflect different sediment sources. In many cases, one to three distinct darker bands occur within the lowest zone, possibly representing brief periods of soil development because of slower loess deposition. In one core collected near the center of a wide ridgetop in the Arlington Quadrangle (CSD core 2-B-98, fig. 9), all three zones of the Loveland Loess had gray, rather than brown or yellow, colors, probably because of long-term saturation. This condition may be common in similar topographic settings. No calcareous Loveland Loess was identified in this study, although a few large carbonate nodules are present locally. Thermoluminescence dating at the paratype section of the Loveland Loess in Iowa indicates that it was deposited 135,000 ± 20,000 years before present during the Illinoian glacial period (Forman and others, 1992). The main source of Loveland Loess may have been the Missouri River valley, but this cannot be confirmed without more study of grain size and thickness trends.

Clayey silts and silty clays from 20 to 30 feet (6-9 m) thick occur beneath Loveland Loess under ridgetops and gentle slopes in the rolling uplands, although they are rarely observed in outcrop. These deposits were observed in one outcrop in the Valley Quadrangle and in upland test holes in the Fremont East, Arlington, and Ashland East quadrangles, but were not found at one ridgetop test hole site in the Wann Quadrangle (CSD Core 12-B-99). More work is needed to characterize their extent throughout the uplands bordering the lower Platte valley. The silts and clays beneath Loveland Loess are either reddish brown or gray in color and typically have blocky soil structure throughout. In some cases, two or more distinct soil profiles can be identified within these clayey silts and silty clays. These clays and clayey silts appear to drape the topography of the underlying glacial till surface, and they are interpreted as predominantly loess that has been altered by weathering and soil development. They could also include sediment deposited by slopewash in closed depressions on the glacial till surface. These clayey silts and silty clays probably represent multiple thin increments of sediment deposited periodically over a long period of time. Extensive soil development occurred after each episode of sedimentation, but the resulting soil profiles overlap each other too closely to be distinguished. The clayey silts and silty clays are pre-Illinoian, on the basis of their position beneath Loveland Loess.

The mechanical properties of older loess deposits are highly variable, depending on texture, degree of compaction, clay content, and other factors. Most loess deposits older than Peoria Loess have higher density than that unit. Where Loveland Loess is thick, the less weathered, yellower part of it, below the Sangamon Soil and above the basal dark zone, may have low density and bearing capacity similar to the Peoria Loess. This behavior is suggested by blow counts in Nebraska Department of Roads borings, in which counts from the lower part of thick Loveland Loess are similar to those from Peoria Loess. The Gilman Canyon Formation also is only slightly denser than Peoria Loess in some areas. The silty clays and clayey silts beneath Loveland Loess are quite dense and may have high bearing capacity similar to glacial till. It is commonly believed that a perched saturated zone forms in lower Peoria Loess because of the low permeability of the upper Loveland Loess. This may be true in some cases, but saturated conditions in the pre-Loveland silts and clays below Peoria Loess are not be easily recognized because the hydraulic conductivity of these units is low and seepage into test holes or excavations is very slow. None of the loess deposits below Peoria Loess would be expected to contain human artifacts because they predate any widely recognized human inhabitation of North America.

Qt Glacial till and associated inclusions of sorted sediment (Pleistocene or late Pliocene?).

Silty to sandy clay with rock fragments ranging from granule to boulder size, with lenses and beds of sorted sand (or occasionally silt or clay)

Predominantly dense, massive *diamicton* (a poorly sorted sediment containing material from clay to boulder size) interpreted to be the deposits left by past advances of a continental ice sheet into what is now the Midwestern U. S.: this diamicton includes rock fragments that must have been transported from the Canadian Shield and surrounding areas to the north and northeast of Nebraska. The material in Qt has generally been described as *glacial till*, rather than diamicton, by previous researchers in Nebraska (Reed and Dreeszen, 1965), and that term is used in a similar broad sense on these maps. Some glacial geologists prefer to use the word *till* only for sediment deposited directly from the base of a glacier (Benn and Evans, 1998, p. 379-380), which may not be true of all till included in the Qt unit.

The total thickness of glacial till ranges from a few feet to at least 200 feet (1 to at least 62 m) in the region covered by this report. Thinner till occurs beneath ridge tops in other parts of these quadrangles, particularly where thick deposits of sand and gravel and other sorted sediment (Qsg) are present beneath the till. Both oxidized and unoxidized glacial till occur in the subsurface and in outcrops. The oxidized till is light yellowish brown to light grayish brown, and usually contains large fractures commonly filled with calcium carbonate. The unoxidized till is dark gray. Associated sorted sediments are predominantly sand that occurs as thin beds or irregularly shaped masses within the till. Similar masses of silt and clay have also been observed. These inclusions are common at some localities and rare or absent at others. The glacial till is homogeneous (except for the sand or silt inclusions) and unstratified in outcrops.

The high density and homogeneity of much of the glacial till in eastern Nebraska suggests deposition directly from the base of an ice sheet. Some of the glacial diamicton in this area that has lower density and is less homogeneous may have initially accumulated as superglacial debris on the surface of the ice sheet and been reworked by gravity or water. Typical superglacial sediment as described by researchers in other areas (Johnson and Menzies, 1996) is rare in eastern Nebraska, however. The difference in color between oxidized and unoxidized tills is the result of weathering after deposition. Oxygen-rich water passing through the till over time results in formation of iron hydroxides that give the oxidized till its brown or yellow color. The inclusions of sorted sediment could have originated in several ways. The ice sheet could have eroded intact masses of sorted sand or silt and then redeposited them along with surrounding till. Some sorted sediment could also have been deposited by flowing water in tunnels within or at the base of the ice sheet.

The glacial till in the Omaha area is the result of several glaciations in the early and middle Pleistocene and possibly the late Pliocene, on the basis of stratigraphic relationships between tills and dated tephras, as well as paleomagnetic evidence

(Boellstorff, 1978a; 1978b). At any particular site in the Omaha area, there is rarely evidence for more than one glaciation, for example, two tills separated by a well-developed interglacial soil. This absence of evidence for multiple glaciations is presumably because deposits of older glaciations were eroded, both by flowing water during interglacials and by the ice sheet itself during the most recent glaciations. Much glacial till shown on the surficial geology map and occurring in the subsurface in the mapped quadrangles would probably have been included in the Cedar Bluffs or Nickerson tills of Reed and Dreeszen (1965), both considered to be of Kansan age. Shimek (1909) originally described "Nebraskan" till near Florence, east of the Arlington quadrangle, but the section he described is not clearly identifiable at present. Boellstorff (1978a) recommended that the terms "Kansan" and "Nebraskan" be dropped, as they had been applied inconsistently to tills of widely varying age. That recommendation is followed here. Boellstorff (1978b) identified several different informal till lithologic units, which can be distinguished using a combination of pebble lithology, position relative to dated volcanic ash deposits, and remanent magnetism. No attempt has been made to distinguish between these units in this study because of insufficient data. Sandy till was consistently found overlying till with low sand content at widely scattered locations in southern Washington County, including the northeastern Arlington quadrangle, but the regional significance of this observation is uncertain.

Because of its high density, the glacial till in the Omaha area provides better structural support than overlying loess deposits, particularly Peoria Loess. The high clay content of the till makes it prone to shrinkage and swelling where it is near the surface, unconfined and exposed to wetting and drying cycles. Because the till has low hydraulic conductivity, it can impede drainage where it is near the surface, potentially causing problems such as wet basements or malfunctioning septic system drain fields. In some deep excavations, it has been observed that water flows from sand lenses or beds within the till, sometimes at high enough rates to cause drainage problems in the excavation. Archaeological sites should not be present in undisturbed till or associated sorted sediment, because of its early to middle Pleistocene age.

Qsg Fluvial and lacustrine sediment in the subsurface beneath uplands (Pleistocene or Pliocene?)

Sand, gravel, and silt

Thick, extensive deposits of sorted sediment in the subsurface beneath uplands: this unit usually occurs between glacial till and bedrock. The only known outcrops in the mapped quadrangles are in the northwest corner of the Wann Quadrangle and in one small area of the Ashland East Quadrangle. Older till or silts underlie or possibly occur within these deposits in a few areas. Registered well logs and several Conservation and Survey Division test holes penetrate these deposits, and the consistent stratigraphy and sedimentology suggest that they are laterally continuous over areas of several square miles in the central and eastern Arlington Quadrangle and the southern and eastern Ashland East Quadrangle. In the stack map, Qsg has been mapped only in areas near registered wells or test holes in which it is clearly present. As a result, this unit may be more extensive than shown on the stack map. One or more medium or coarse sand beds are always present in Qsg where it is indicated on the stack maps, but this unit also contains interbedded fine sand, silt, and clay. In the northeastern Arlington Quadrangle, these finer beds make up much of the upper 30 to 115 feet (9 to 35 m) of Qsg, or even most of the thickness of the unit in a small part of this quadrangle (shown on stack map). The silt and clay beds have distinct lamination in samples from several CSD test holes. The medium and coarse sand or gravel beds within Qsg usually have a total thickness of 30 to 80 feet (9 to 25 m), although the exact thickness at any given point is difficult to predict even from nearby wells or test holes. At many sites, two or more beds of coarse sand and gravel are separated by layers of silt or clay. The coarse sand and gravel has a distinctive yellowish-green color in fresh drill cuttings and contains abundant well-rounded quartz sand grains and pebbles. The small outcrops of Qsg in the Wann and Ashland East quadrangles are of fine or medium sand. Coarser sand and gravel may be present at greater depth but there is insufficient subsurface data to determine this.

The sediments included in unit Qsg are of middle Pleistocene age or older, based on their stratigraphic position underlying pre-Illinoian glacial till. The gravels in Qsg include pebbles probably transported from the Canadian Shield by glacial ice, and therefore post-date the earliest continental glaciation, which occurred in the late Pliocene (Boellstorff, 1978b). The coarse sand and gravel in this unit could have been deposited by non-glacial streams reworking older glacial deposits but is more likely a once-extensive accumulation of outwash at the margin of an ice sheet. The finer-grained components of this unit may also be stream deposits but are more likely to have been deposited in lakes formed when the ice sheet dammed existing stream valleys. If so, the finer-grained silts and clays were probably deposited in deeper water and the sands either accumulated nearer the shore or were carried into deeper water by occasional sediment flows down the bed of the lake. Similar sediment in the area around Lincoln, Nebraska, clearly formed in ice-marginal lakes, but the sediments of Qsg in the Arlington Quadrangle are not adequately exposed to allow any definite conclusions on their origin. In some cases Qsg appears to be located in lows in the bedrock surface ("paleovalleys"), but there are also bedrock lows that do not contain these sorted sediments. Where the sorted sediment of Qsg is absent, it may originally have been present but was later eroded by streams or by an ice sheet advancing over it.

The coarse sand and gravel in Qsg forms an aquifer that is an important source of water in southern Washington County. It is currently used for domestic wells, a few irrigation wells, and a few high-capacity wells serving housing developments. This aquifer is at least partially confined beneath fine-grained till, loess, and alluvium. The fine-grained deposits overlying Qsg will not always limit the rate of contaminant movement to this aquifer, however. Potentially rapid contaminant pathways to the aquifer include fractures in the till where it is thin, or poorly constructed wells. Qsg will not contain archaelogical artifacts because of its age.

Kdss Sandstone of the Dakota Group (Cretaceous).

Sandstone outcrops are mapped in a few areas, mainly in the Ashland East Quadrangle. Shallow bedrock, including mudrocks as well as sandstone, may also be encountered in areas adjacent to the mapped outcrops. The Dakota Group as defined historically in Nebraska is equivalent to the Dakota Formation of Iowa (Witzke and Ludvigson, 1994). Sandstone at a shallow depth will impose severe limitations on excavations for basements and on installation of effective septic system drain fields.

Fill Includes all types of artificial fill. Examples include natural earth materials (silt, sand, gravel, and crushed rock) that have been moved and often compacted during construction projects, as well as construction debris and trash. Small areas of artificial fill occur throughout the mapped quadrangles, for example in road beds and around buildings. Only the larger and more easily delineated areas of fill are shown on this map. These areas mainly include the Douglas County Landfill in the southeastern Arlington Quadrangle, earth-fill dams and a few large road fills (particularly the bed of Interstate 80 and several railroads in the Platte Valley). Fill resulting from sand and gravel mining and associated housing development is included in the "Pits" unit.

Water Only larger water bodies are shown; these are mainly the channels of the Platte and Elkhorn rivers, artificial excavations in the alluvial valley, oxbow lakes, and large farm ponds. Many smaller farm ponds are not shown on the map.

Pits Areas disturbed by large, long-term excavations, usually mining operations. Used mainly for 1) sand and gravel pits in the Platte River valley, including formerly active pits now converted to housing developments, and 2) limestone quarries in the southern part of the Ashland East Quadrangle. Areas mapped as "Pits" include all lands believed to have been disturbed by mining operations, including pits that have been backfilled as well as spoil piles and areas reshaped for housing development. The actual excavations in many cases have now been filled with water and are mapped as such.

EXPLANATION OF STACK MAP UNITS

Stack map units represent, in broad terms, the vertical sequence of sediment down to Cretaceous or Pennsylvanian bedrock. These map units are defined using a sequence of the units used on the surficial geologic map, as well a few additional units not mapped at the surface. Where a unit may or may not be present in the subsurface, it is contained in brackets. For example:

Stack Unit: Qlp/Ql/Qt/Qsg

Represents the following sequence of materials (from surface downward):

1) Peoria Loess;
2) Gilman Canyon Formation, Loveland Loess, and older loess;
3) glacial till, interbedded with discontinous beds of sand and occasionally gravel, and locally, silts and clays.
4) thick, laterally extensive sorted sediments, typically consisting of interbedded silt, clay, fine sand, and medium-to-coarse sand and gravel.

Stack Unit: Qsw/[Qlp]/[Ql]/Qt

Represents the following sequence of materials (from surface downward):
1) slopewash sediment, possibly including some primary Peoria Loess;
2) *[may not be present]* Peoria Loess;
3) *[may not be present]* Gilman Canyon Formation, Loveland Loess, and older loess deposits;
4) glacial till, interbedded with or overlying discontinous beds of sand and occasionally gravel and locally silts and clays.

In the Platte River valley, the unit Qasg is used to represent a variety of subsurface alluvial sediment. In many cases, the boundary between the surficial unit (e.g. Qap1) and the underlying Qasg is indefinite. Thus, the following convention is used to map subsurface sand and gravel thickness, which is important for many practical applications of these maps. The modifier attached to Qasg in stack map units indicates the estimated *total thickness* of medium-to-coarse sand and gravel, from the surface down to bedrock.

For example, in stack unit Qap1/Qasg (40-100 feet), there is an estimated total thickness of 40 to 100 feet of medium to coarse sand and gravel above bedrock. This sand and gravel may be a single continuous unit, or it may be in two or more beds separated by layers of silt or clay.

The stack units should be regarded as approximations of stratigraphy that is often complex in detail. For example, thin beds of sorted sediment are common within a vertical sequence of glacial tills, but both the tills and the minor included sorted sediment are represented simply by "Qt" in the stack unit. Stratigraphy will diverge most significantly from the sequence represented by the stack unit on slopes at the edges of stream valleys, where some units have been removed by erosion.

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