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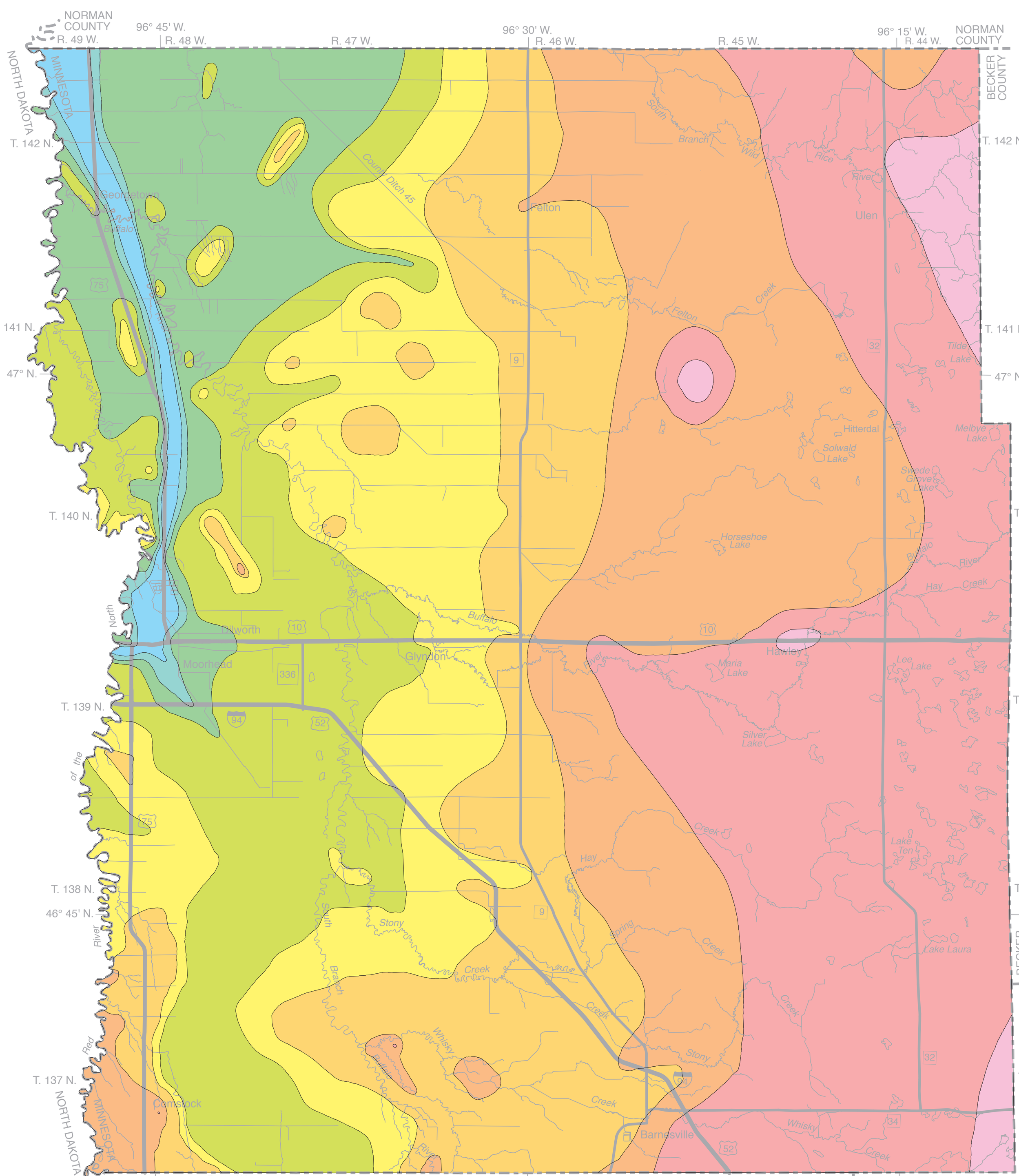
THE CLAY COUNTY BOARD OF COMMISSIONERS,
AND THE MINNESOTA DEPARTMENT OF NATURAL RESOURCES, DIVISION OF WATERS



Digital base modified from the Minnesota Department of Transportation BaseMap data; digital base annotation by the Minnesota Geological Survey.

Universal Transverse Mercator Projection, grid zone 15
1983 North American Datum

SCALE 1:200 000
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BEDROCK TOPOGRAPHY

By

Dale R. Setterholm

2014

EXPLANATION

The configuration of the bedrock surface was determined from records of water-wells, mineral exploration boreholes, and scientific drill holes (including holes drilled for this project). At a given location, the user should always take into account the density of available data, as illustrated on Plate 1, *Data-Base Map*, to assess the reliability of the map at that particular location. Those areas with a high density of bedrock control points are likely to have accurate interpretations of the bedrock elevation, whereas those areas with widely-spaced control points may be less reliable and provide an inappropriate level of detail for site-specific needs. The topography data were interpreted by a geologist and the contours were drafted at a 50-foot (15-meter) interval.

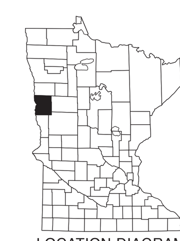
The bedrock surface is highest where it exceeds 850 feet (259 meters) above sea level in the northeast and southeast corners of the county. It is lowest in the northwest corner of the county where a valley eroded into the bedrock exits the county at less than 500 feet (152 meters) above mean sea level. The more than 350 feet (107 meters) of total relief on the bedrock surface is considerably less than the approximately 700 feet (213 meters) of relief on the present land surface of the county. The bedrock surface slopes from the east toward the west and is lowest in a narrow valley that is slightly east of the Red River in the northern half of the county and slightly west of the Red River to the south. That valley deepens to the north.

The bedrock surface of Clay County is composed mostly of crystalline rocks, but in some places a clay-rich residuum that formed from weathering of those crystalline rocks is present. There are also a few small remnants of Cretaceous age sedimentary rocks as seen on the bedrock geology map.

The present elevation of the bedrock surface is dependent upon several factors, mainly the resistance of the underlying bedrock to weathering and erosion, but also bedrock structures such as faults and folds. Those rock types that are most resistant to erosion typically tend to occupy higher parts of the topography and less resistant rock types are associated with low areas. However, there is only a weak correlation between bedrock types and bedrock topography in Clay County. This may indicate that glacial dynamics were the dominant factor in shaping the bedrock surface, determining where erosion was focused.

- 851-900
- 801-850
- 751-800
- 701-750
- 651-700
- 601-650
- 551-600
- 501-550
- Less than 500

Elevation of the bedrock surface in feet above mean sea level



LOCATION DIAGRAM

DEPTH TO BEDROCK

By

Dale R. Setterholm

2014

EXPLANATION

The bedrock in Clay County is completely covered by glacial sediment that varies in thickness from slightly more than 100 feet to almost 700 feet (30 to 213 meters) thick.

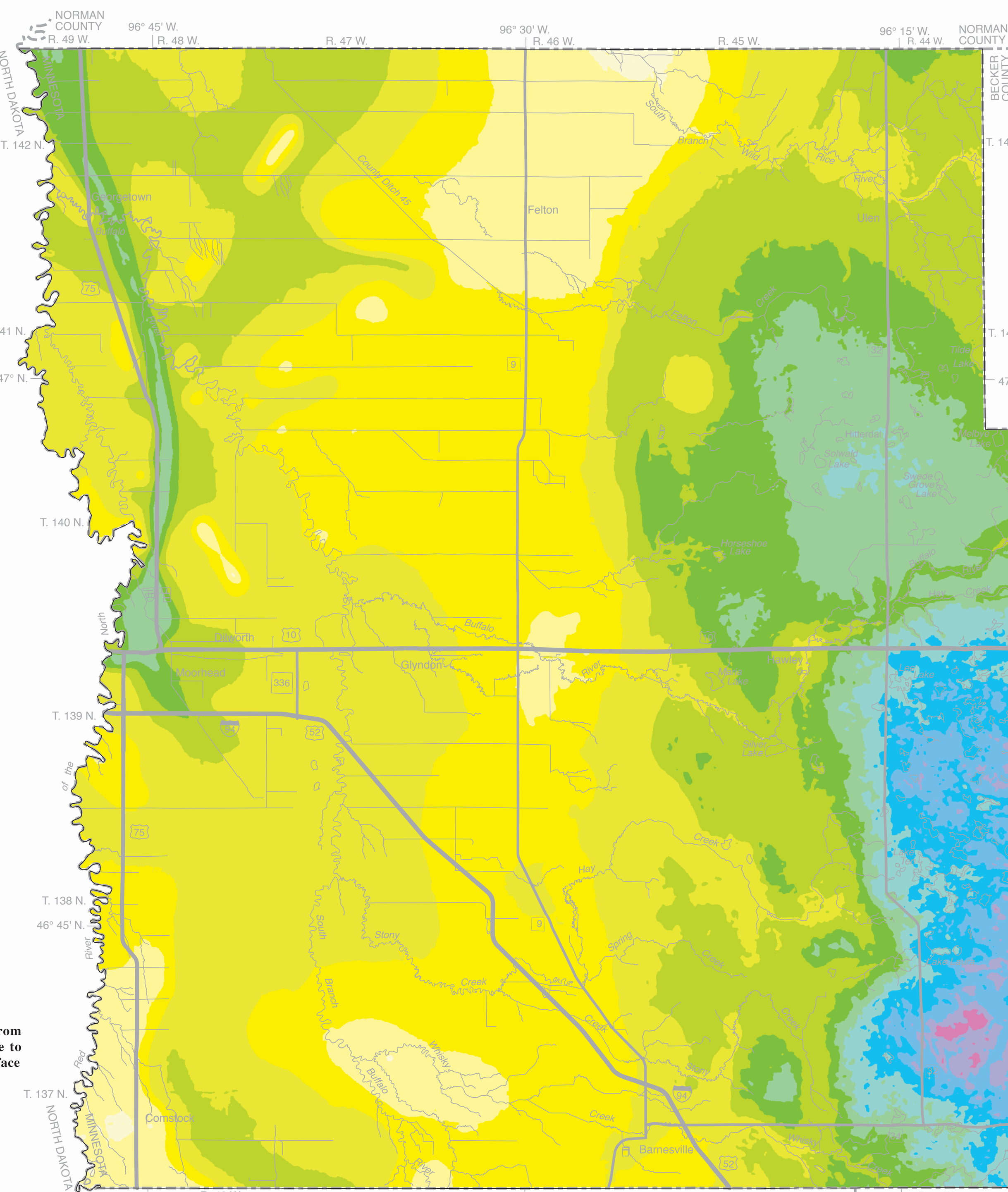
The thickness of the glacial sediment is equal to the depth from the land surface to the bedrock surface. To calculate that thickness at any place, the elevation of the bedrock surface was subtracted from the elevation of the land surface by digital methods. The resulting thicknesses were checked against measured glacial sediment thicknesses from drilling records, and fine-tuned where necessary. As with any map, it is important to observe the distribution of available data, seen on Plate 1, *Data-Base Map*, to comprehend the reliability of the derived map. These data should also be considered when working at site-specific scales. There are places where drift thickness varies over short distances, and mapping at this scale may not provide sufficient detail.

The glacial thickness map is more detailed than the drill hole data support. This is an artifact of the digital process of subtracting the smooth and generalized elevations of the bedrock surface from the highly detailed elevations of the land surface.

The thickest glacial sediment occurs in the southeastern part of the county where the land surface is the highest. That thickness is caused by the great accumulation of glacial debris in the Alexandria Moraine. The thinnest glacial cover is in north-central Clay County, where the low-lying glacial Lake Agassiz Plain overlies relatively high bedrock.

- 101-150
- 151-200
- 201-250
- 251-300
- 301-350
- 351-400
- 401-450
- 451-500
- 501-550
- 551-600
- 601-650
- 651-700

Depth in feet from the land surface to the bedrock surface



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Every reasonable effort has been made to ensure the accuracy of the factual data on which this map interpretation is based; however, the Minnesota Geological Survey does not warrant or guarantee that there are no errors. Users may wish to verify critical information; sources include both the references listed here and information on file at the offices of the Minnesota Geological Survey in St. Paul. In addition, effort has been made to ensure that the interpretation conforms to sound geologic and cartographic principles. No claim is made that the interpretation shown is rigorously correct, however, and it should not be used to guide engineering-scale decisions without site-specific verification.

Edited by Lori Robinson

SAND DISTRIBUTION MODEL

By

Angela S. Gowan

2014

Surficial sand and gravel	ha, wls. wlg
Sherack Formation	sl
Poplar River Formation	*prf*
Brenna Formation	bl
Red Lake Falls Formation	ro & roc
	rpt
	rlt
	rgs
Goose River Formation	grb, gro, grc, *gss & gsg*
	gst
	gds & gdg
	gdt
New Ulm Formation (1)	*nhl*
	nhs & nhg
	nht
Otter Tail River Formation	*olu*
	osu & ogu
	otu
	ons
	ont
New Ulm Formation (2)	*nvs & nvg*
	nvt
	dgs & dgg
Gardar Formation	*dgt*
Buffalo River Formation	*brl*
	brs
	brt
Hewitt Formation	*hl (1)*
	hs & hg (1)
	ht (1)
	hl (2)
	hs & hg (2)
	ht (2)
	hl (3)
	hs & hg (3)
	ht (3)
	hl (4)
	hs & hg (4)
	ht (4)
Browerville Formation	*bvs & bvg*
	bvt
Gervais Formation	*gvt*
"x" tills	*x1l*
	x1s
	x1t
	x2s
	x2t
	x2s
	x3t
Unknown	*qsu (1)*
	qtu (1)
	qsu (2)
	qtu (2)
	qu

Figure 1. Stratigraphic position of sand and gravel bodies modelled herein; see Plate 4, *Quaternary Stratigraphy*, for complete unit descriptions. The name designations of sand and gravel bodies depicted are associated with their underlying till (except for those at the land surface and those that intersect the lowermost unknown units). Bear in mind, however, that sand and till units may be an admixture of material from immediately above or below the actual named unit, especially where a stratigraphic unit is absent on the cross section. Multiple depositions of the same unit are numbered sequentially.

INTRODUCTION

The Quaternary sand and gravel deposits of Minnesota are products of a long and complex history of multiple glacial events that makes mapping of these potential aquifers difficult. However, establishing the location and characteristics of sand and gravel aquifers is an essential step toward their wise use and protection. In Clay County, this project employed a process that combined the understanding of a geologist with the data-handling ability of a geographic information system (GIS) to create three-dimensional models showing the distribution of Quaternary sand and gravel deposits that may be aquifers. The geologist interpreted the three-dimensional models and related aquifers to the glacial events that formed them. Although the models and interpretations are based on the best available data, they are unavoidably incomplete due to a lack of data in some areas (see Plate 1, *Data-Base Map*).

Sand and gravel distribution at the land surface is mapped by a geologist from exposures, shallow drill holes, soil maps, and landforms. In contrast, interpreting sand distribution in the subsurface relies primarily on well records, scientific drill core, and drill cuttings. Each well record or drill log is an interpretation of the vertical sequence of earth materials at one location. It falls to the geologist to assess the accuracy of these interpretations and use them to predict what materials occur in the areas between wells or at depths not penetrated by the wells. That prediction is based on an assessment of the available data and an understanding of the glacial history and processes that created the glacial sediment. The distribution of data greatly affects the resolution and accuracy of our models. For example, if the wells are widely spaced, they will not intersect deposits of limited extent and cannot support accurate mapping of those features. In a similar manner, bodies of sand and gravel that occur deep in the subsurface are typically not intersected by many wells because shallower bodies of sand and gravel are adequate to supply water and there is no need to continue drilling.

The unconsolidated Quaternary sediments that overlie the bedrock in Clay County vary greatly in character and thickness. These deposits are largely the result of many distinct glacial ice advances during the Pleistocene Epoch (Plate 3, *Surficial Geology*). Most of the aquifers within Clay County consist of sand and gravel beds laid down by meltwater that flowed from these glaciers. Unsorted sediment deposited directly from the ice, termed "till," and fine-grained clay- and silt-rich bedded sediment deposited in ponded meltwater in front of the glaciers, form confining layers that may enclose the aquifers. The till layers left by each ice sheet tend to be more laterally persistent than the sand layers because they are more cohesive and were deposited by ice that typically spread across the entire county, whereas meltwater streams that deposited the sand and gravel were generally restricted to drainages at lower elevations of the evolving landscape and the deposits were easier to erode. To further confuse things, sand and gravel may be deposited by both the advance and retreat of glaciers. Thus, till from an ice advance may bury its own sand and gravel, as well as material deposited during a previous glacial event. By convention, the name designations of sand and gravel bodies depicted in this report are associated with their underlying till (except for those at the land surface and those that intersect the lowermost poorly known units).

Glacial ice and meltwater not only deposited sediments, but also eroded older, underlying sediments, creating a very disturbed "layer cake" stratigraphy (Fig. 1). A new layer of sand or till could fill a void eroded into an older layer, or could completely displace an older layer, given sufficient erosion. The net effect of this depositional and erosional activity in Clay County is that sand and gravel bodies that provide water to wells tend to be discontinuous. Even over relatively short distances in most directions, the extent and thickness of any given aquifer is difficult to predict. In order to create a valid geologic model of the subsurface, 61 closely spaced (0.6 mile [1 kilometer]) cross-section lines were generated in a west–east direction (Plate 4, Fig. 1). Along these lines, water-well records and records of scientific and engineering test holes (Plate 1, *Data-Base Map*) were used by a geologist to identify contacts between till units in the subsurface. Final interpretations along five of these cross sections are shown on Plate 4, *Quaternary Stratigraphy*.

Till is generally described as "clay" by well drillers. Although sand and gravel can occur within a till, more extensive deposits occur at the contacts between till sheets. Where two clay (till) layers related to different depositional events are not separated by a sand and gravel layer, their contact may be recognized by a change in the driller's description of the clay's texture, density, or color. Using the available data, contact lines were drawn along each cross section, with each line representing the base of a unit of sand and gravel or till. GIS software was used to extract elevation values from vertices along each unit line, and convert those into a raster elevation surface showing the distribution of the unit over the county. The till and sand surfaces were iteratively modified until the geologist was confident that they adequately represented the stratigraphic interpretation for the majority of water-well data. When the till and sand surface rasters representing the base of each unit were final, they were processed through GIS raster calculations to create top and bottom surfaces for each geologic unit and a thickness for each sand unit. The result is a three-dimensional geologic model of tills and sands for the county. The more extensive sands portrayed by the geologic model are shown in Figures 2 through 8. Note that contours showing thickness of sand and gravel units may not close within the outline of each unit. This is an artifact of the GIS processing of surfaces. The figures show sand units ranging from the youngest sands at the land surface to buried, progressively older sands (Fig. 1). Where saturated, these sand bodies are aquifers. Their capacities for water yield depend on their extent and thickness, as well as factors such as sediment coarseness, degree of sorting, consolidation, and potential for recharge. In many places two or more of these sand units form a single aquifer where they are juxtaposed with no intervening till layer.

The geologic model images should be considered probability maps for the occurrence and approximate thickness of major sand bodies. The model does not guarantee sand and gravel will be found at all places shown, nor does it preclude them from being found in areas where they are not shown. Sands that were too thin or did not extend to neighboring cross sections commonly did not survive the processing that created the multiple surfaces. Because wells typically do not penetrate the complete thickness of sand layers, drillers' logs commonly under report sand-body thickness. As a result, some of the sands shown on the cross sections (Plate 4; but not necessarily on the final sand distribution figures) may be thicker and more widespread than portrayed. At increasing depths in the stratigraphic section, data availability diminishes and delineated sand bodies could be more or less discontinuous than shown. In many parts of Clay County water wells do not extend through the full thickness of the Quaternary deposits. The cross sections indicate that the characteristics of deeper Pleistocene deposits cannot be differentiated in many places. However, where deep drill holes occur, thicker sands are commonly present. Additional sand bodies, or extensions of those mapped, are undoubtedly present in these undifferentiated parts of the Pleistocene section. In spite of these limitations, the geologic model provides a realistic interpretation of where and what kind of geologic units would be encountered in the subsurface of Clay County. However, given the limits of the data, as noted above, the model should be used as a guide and should not preclude further site-specific investigations or inspection of individual well logs.

CONTOURS FOR FIGURES 2 THROUGH 7

Thickness of a sand and gravel unit contoured at 20 foot (6 meter) intervals.

- 20
- 40
- 60
- 80
- 100
- 120
- 140 and greater

Note: Two features on the sand models are largely an artifact of digital processing: contour lines do not close at the edges of some mapped areas; and some units display pronounced east–west linearity.

DEPTH FOR FIGURES 2 THROUGH 7

- 0–50
- 51–100
- 101–150
- 151–200
- 201–250
- 251–300
- 301–350
- 351–400

Depth in feet from the land surface to the top of a sand and gravel unit.

SCALE 1:300 000
10 MILES
10 KILOMETERS

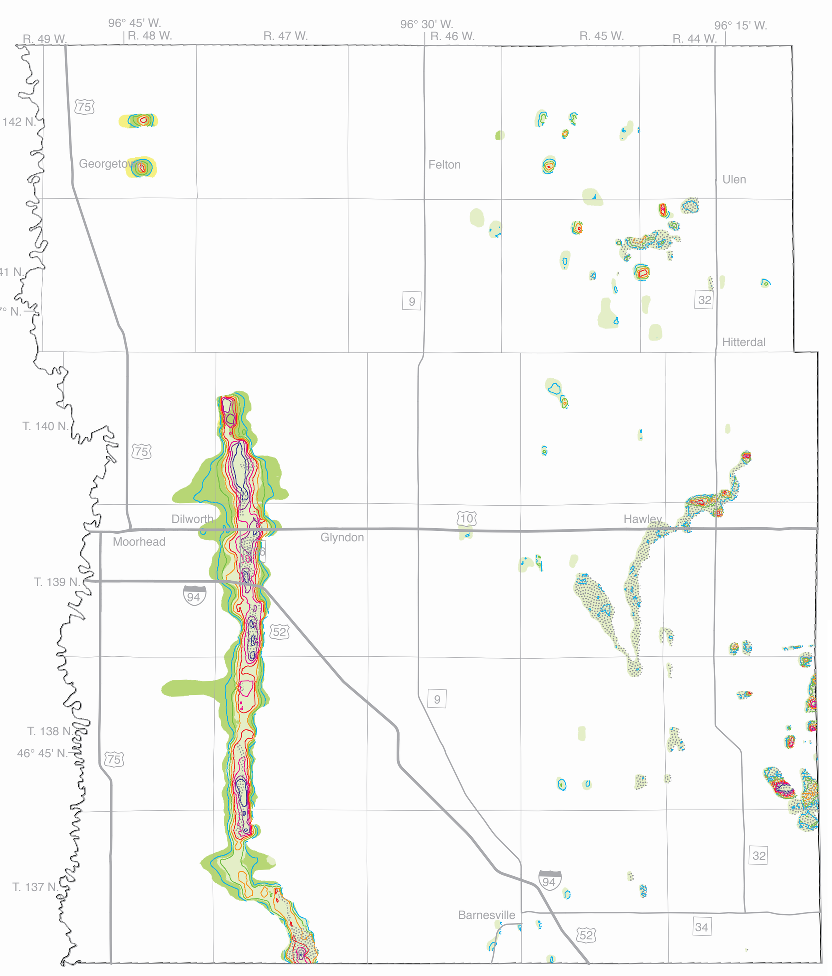


Figure 2. ro, roc, rgs, and grb sand and gravel—Model-generated map of the extent, depth from the surface, and thickness of sand bodies that commonly lie stratigraphically immediately above unit rpt or rlt, but in places may overlie older units. Portions of this unit occur at the surface and are shown by a pattern overlay. These bodies consist of silt to sand and gravel laid down as outwash and stream deposits by meltwater during the last retreat of the Red River lobe from Clay County. They occur in discontinuous lenses and in stream-forms, most notably the Buffalo aquifer.

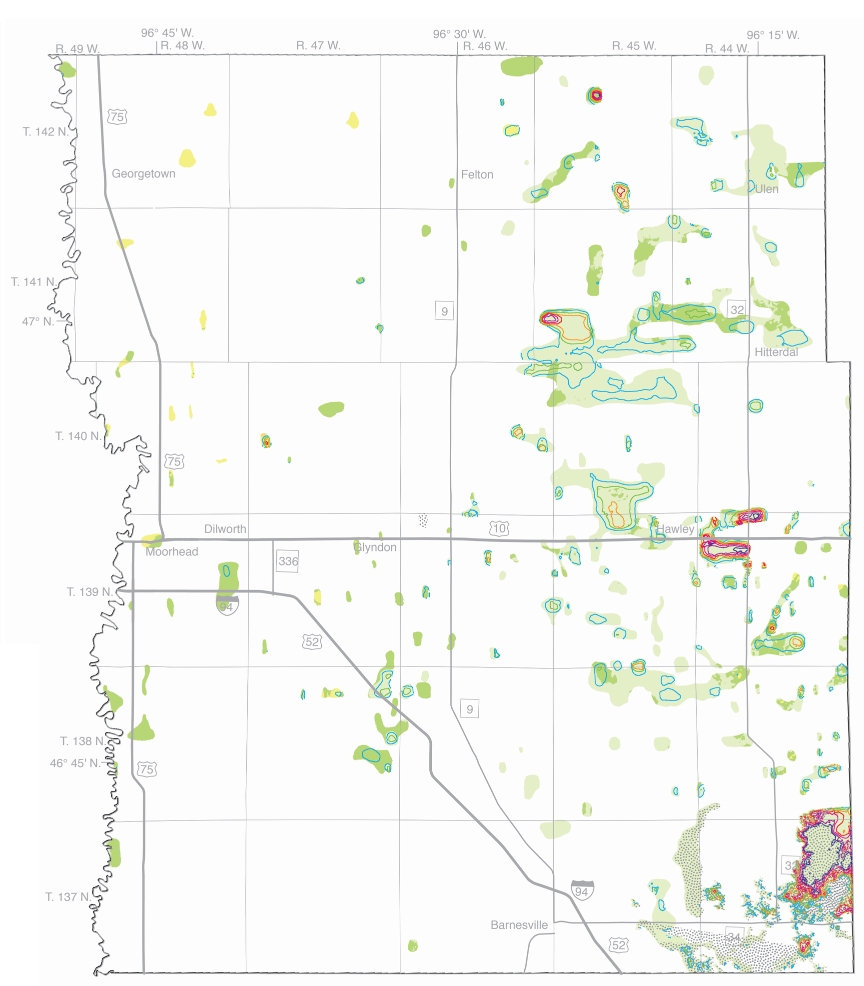


Figure 3. *gro, grc, gss, gsg, gds,* and *gdg* sand and gravel—Model-generated map of the extent, depth from the surface, and thickness of sand bodies that commonly lie stratigraphically immediately above till units *gst* or *gdt*, but in places may overlie older units. Portions of this unit occur at the surface and are shown by a pattern overlay. Units *gss* and *gsg* consist of mostly proglacial sediment deposited by meltwater at the margin of the retreating Bigstone II phase of the Red River lobe (Plate 3, Fig. 3B). Units *gds* and *gdg* were deposited by meltwater from the receding Bigstone I phase of the Red River lobe (Plate 3, Fig. 3C).

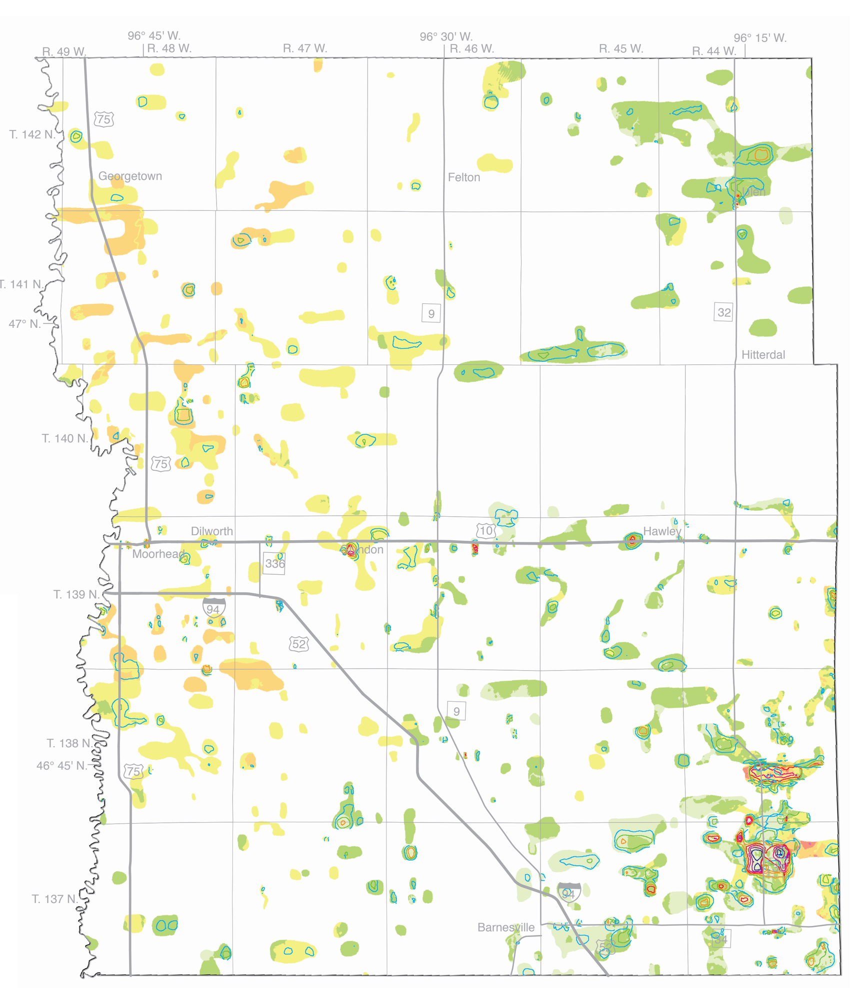


Figure 4. *nhs, nhg, osu, ogu, ons, nvs, nvg, dgs, dgg,* and *brs* sand and gravel—Model-generated map of the extent, depth from the surface, and thickness of sand bodies that commonly lie stratigraphically immediately above till units *nht, otu, ont, nvt, dgt,* and *brt*, but in places may overlie older units. Deposited by meltwater of the receding Des Moines lobe and Rainy/Winnipeg and Riding Mountain provenance ice.

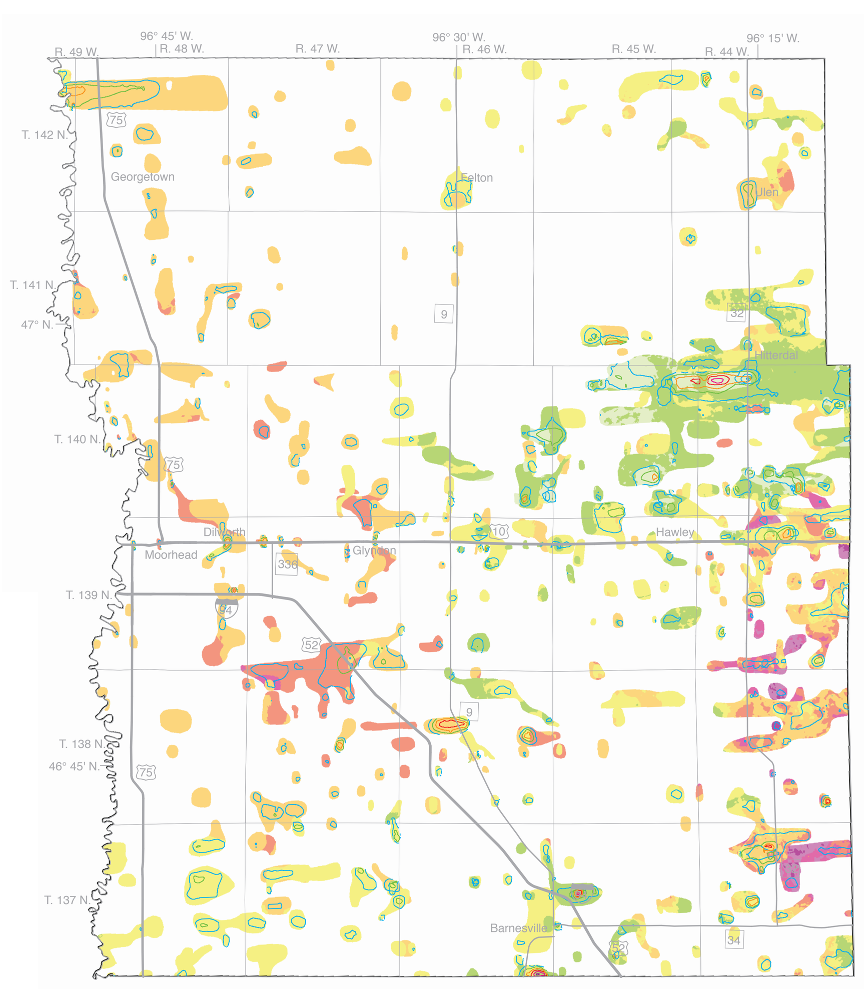


Figure 5. *hs (1), hg (1), hs (2), hg (2), hs (3), hg (3), hs (4),* and *hg (4)* sand and gravel—Model-generated map of the extent, depth from the surface, and thickness of sand bodies that commonly lie stratigraphically immediately above till units *ht (1), ht (2), ht (3),* and *ht (4)*, but in places may overlie older units. Deposited by meltwater of the last episode of receding Rainy provenance ice. Multiple depositions of the same unit are numbered sequentially.

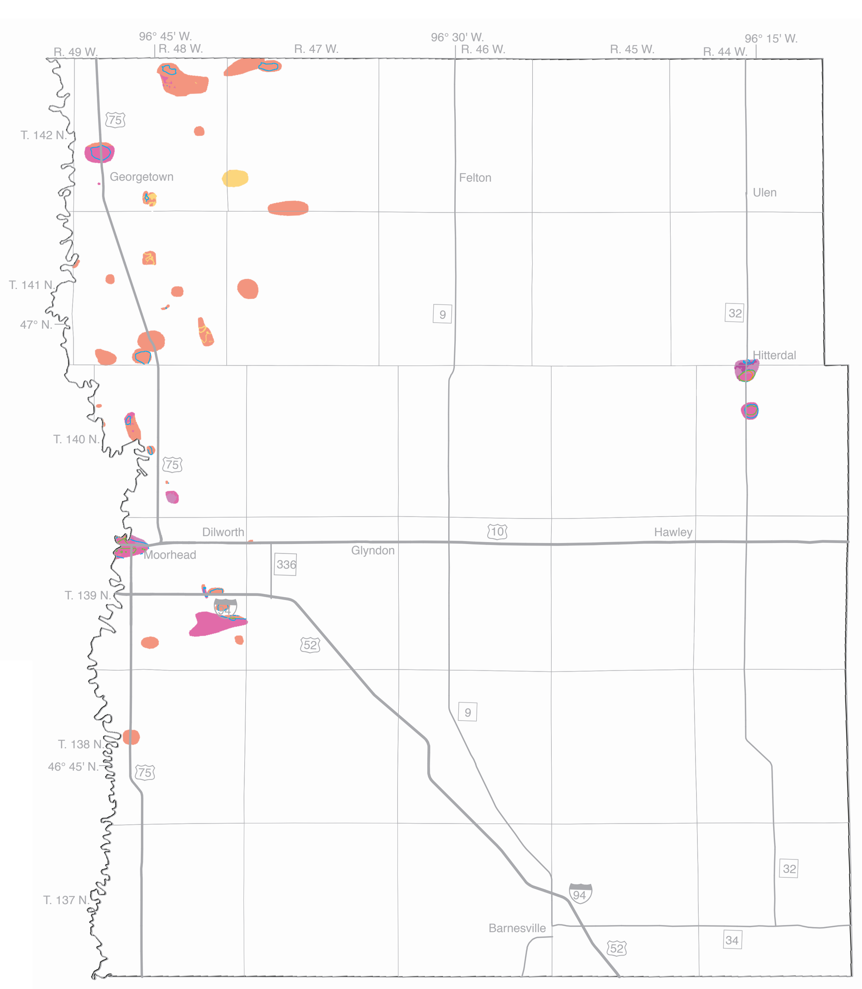


Figure 6. *bvs, bvg, x1s, x2s,* and *x3s* sand and gravel—Model-generated map of the extent, depth from the surface, and thickness of sand bodies that commonly lie stratigraphically immediately above till units *bvt, x1t, x2t,* and *x3t*. Deposited by meltwater of receding Winnipeg/Rainy (twice) and Rainy provenance ice.

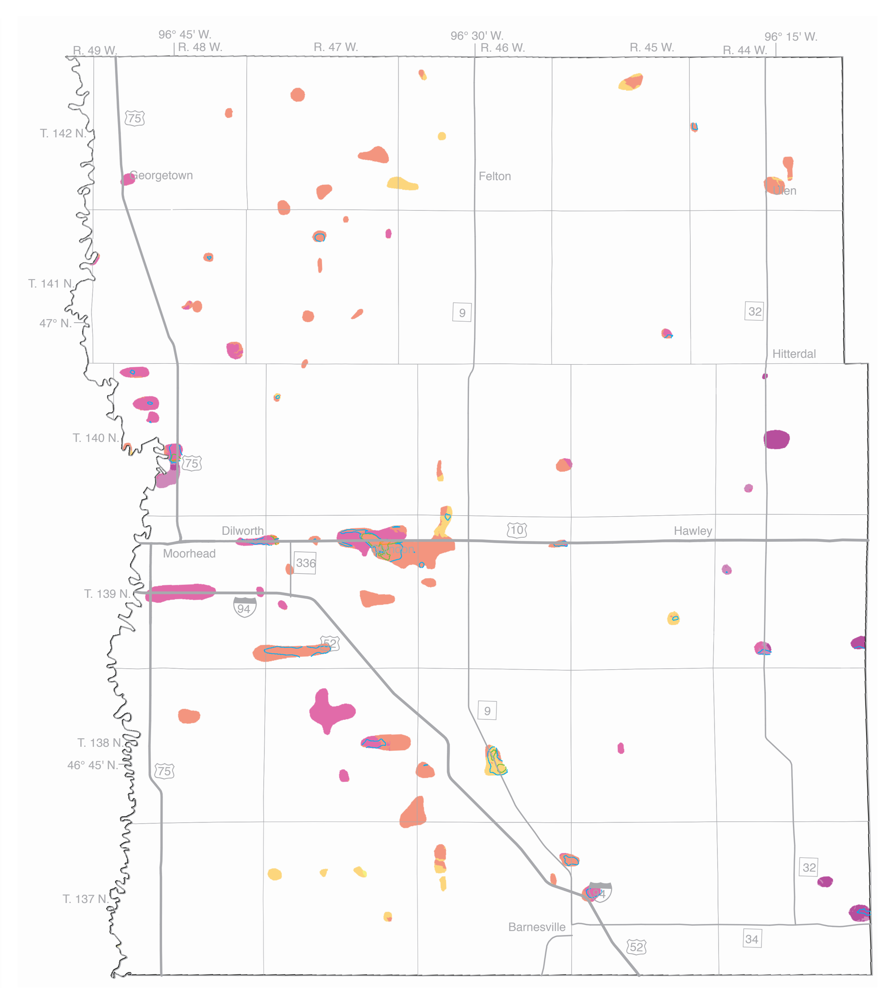
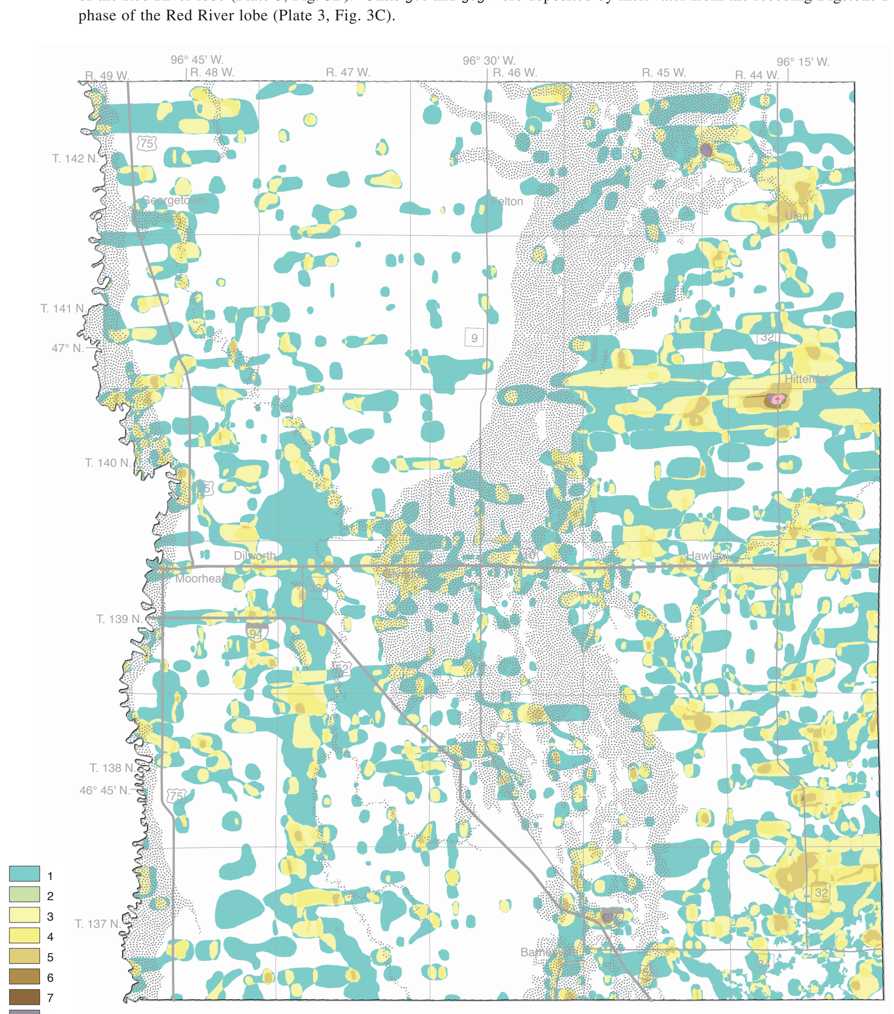


Figure 7. *qsu (1)* and *qsu (2)* sand and gravel—Model-generated map of the extent, depth from the surface, and thickness of sand bodies stratigraphically at the top of units *qtu (1), qtu (2),* and *qu*.



- 1
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9
- 10
- 11

Number of sand bodies

Figure 8. Sand unit stack—Model-generated map of the extent and number of Pleistocene sand units (as defined in the model) encountered between the ground surface and bedrock. Note that overlying sand units are not necessarily interconnected. Patterned area includes surficial alluvium and glacial Lake Agassiz beach deposits (units ha, wls, and wlg).