STATE OF MINNESOTA
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF WATERS

HYDROGEOLOGIC CROSS SECTIONS

By

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INTRODUCTION

The nine hydrogeologic cross sections shown on this plate illustrate the horizontal and vertical extent of hydrogeologic units (aquifers and confining units), ground-water residence time, water table, and general ground-water flow directions. The cross sections shown on this plate were selected from a set of 39 regularly spaced, west-to-east cross sections. The cross sections were constructed using a combination of well data from the County Well Index (CWI), surface resistivity data, information from the surficial geology map of the Traverse-Grant Regional Hydrogeologic Assessment (in press), and information from Quaternary stratigraphy (Plate 4) and the bedrock topography map (Plate 2) of Part A. The well information for each cross section was projected onto the trace of the cross section from distances no greater than a half kilometer with a few exceptions.

PURPOSE AND METHOD OF CONSTRUCTING THE CROSS SECTIONS

The 39 cross sections were constructed to enable extrapolation of glacial stratigraphy from known areas to the rest of Pope County. The cross sections include the upper five stratigraphic units in the county (Upper Goose River, Lower Goose River, Otter Tail River, and Crow Wing River groups and Browerville Formation). Figure 1 depicts an oblique view of the county with three of those stratigraphic units separated below the land surface layer, which mostly consists of the Upper and Lower Goose River groups and sand and gravel outwash. The cross sections were also used as the primary tools for plotting and interpreting the three-dimensional distribution of surficial and buried sand deposits. The stratigraphic boundaries were correlated not only from west to east along the cross section by the conventional method of matching presumed stratigraphic unit tops, but also north to south by overlaying adjacent digitized cross sections with geographic information system (GIS) software to check for correlation discrepancies. The sand thickness information from each stratigraphic unit was then transferred to a map of the same scale, and the sand unit boundaries were drawn using geographical assumptions derived from a general understanding of the unit's depositional history and regional paleogeography. The sand unit boundaries on the cross sections on this plate were adjusted to match the boundaries of the maps on Plates 6 and 7.

The digital characteristics from the set of 39 cross sections were used to help create the aquifer maps shown in this atlas using a variety of GIS methods. As a GIS object, a curved line consists of many straight-line segments that are connected with small angular deviations in combinations sufficient to create the desired curved shape. The connections between these small straight-line segments (vertices) in a GIS cross section can contain information that can be used for three-dimensional mapping. This information (attributes) needed for the three-dimensional mapping process includes the three-dimensional coordinates of the vertex (x, y, and z) and its stratigraphic association. By using a custom extension (GIS tool), the three-dimensional coordinates for each stratigraphic surface were extracted from the set of 39 cross sections and interpolated using a spline-tension method. The resulting surfaces define the top and bottom elevations of the sand units and associated stratigraphic groups. The thickness maps shown on Plates 6 and 7 were derived by subtracting the appropriate surfaces.

HYDROGEOLOGIC FEATURES AND DATA

Relative hydraulic conductivity. The lithologic units (types of sediment) are shown on these cross sections with patterns and shades of gray to reflect broadly defined categories of inferred hydraulic conductivity. As such, the layers and other features of the cross sections are meant to represent hydrogeologic units. The cross-section explanation on this plate for the Quaternary units shows an inferred continuum of hydraulic conductivity, or the water-transmitting capacity of the hydrogeologic unit, from low to high. The till of the Goose River group (shown as the darkest gray) has the lowest average sand content (23 percent to 33 percent [Traverse-Grant Regional Hydrogeologic Assessment, in press]) and probably the lowest hydraulic conductivity. The Otter Tail River group and Browerville Formation (shown as the medium light and dark grays, respectively) are in the middle of the continuum (sand content from 43 percent to 48 percent). The Crow Wing River group till (shown as the lightest gray) is probably the most permeable with sand content ranging from 54 percent to 57 percent.

The sand and gravel aquifers (OT, CW, and BROW) are shown with stipple or line patterns on the cross sections and the reference maps (Figures 3a, 3b, and 3c) to the right. These patterns are provided to help the reader identify the aquifers on both the cross sections and the reference maps. The elevations above sea level for the top surface of the aquifers may help the reader identify an aquifer by depth or elevation at a specific location.

Ground-water residence time. The pink, green, and blue overlays shown on these cross sections represent the relative age of the ground water, also known as ground-water residence time. This is the approximate time that has elapsed since the water infiltrated the land surface to when it was pumped from the aquifer for this investigation. Ground-water residence time is closely related to the aquifer pollution sensitivity concept described on Plate 9. In general, short residence time suggests high pollution sensitivity, whereas long residence time suggests low sensitivity.

Tritium (^{3}H) is a naturally occurring isotope of hydrogen. Concentrations of this isotope in the atmosphere were greatly increased from 1953 through 1963 by above-ground detonation of hydrogen bombs (Alexander and Alexander, 1989). This isotope decays at a known rate, with a half-life of 12.43 years. Water samples with tritium concentrations of 10 or more tritium units (TU) are considered recent water (mostly recharged in the past 50 years, shown in pink). Concentrations of 1 TU or less are considered vintage water (recharged prior to 1953, shown in blue). Water samples with tritium concentrations greater than 1 TU and less than 10 TU are considered a mixture of recent and vintage and are referred to as mixed (shown in green).

Ground-water age for the vintage samples can be estimated with the carbon-14 (^{14}C) isotope. This isotope, which also occurs naturally, has a much longer half-life than tritium (5,730 years). Carbon-14 is used to estimate ground-water residence within a time span from about 100 years to 40,000 years.

HYDROGEOLOGY ILLUSTRATED BY THE CROSS SECTIONS

All of the aquifers shown on the cross sections that contain or are thought to contain ground-water tritium values greater than 1 TU (recent or mixed water) are marked with a code (1 through 4) indicating the types of recharge. A *1* indicates infiltration through a thin layer of overlying fine-grained material to an underlying aquifer. A *2* shows areas where ground water from an overlying surficial aquifer has recharged the underlying buried aquifer through leakage or a direct connection. Areas labeled with a *3* indicate ground-water leakage from the OT aquifer to the underlying CW aquifer. Areas labeled with a *4* indicate ground-water leakage through multiple aquifers and till. The other codes include *L* where lateral flow of ground water is suspected, *D* where ground-water discharge from buried aquifers probably occurs, *U* where the source of the recent or mixed ground water is unknown, and *S* where arsenic stratification occurs as defined by Figure 4, Plate 7. That figure provides a map summary of arsenic values from ground-water samples classified by aquifer. Where water samples were taken from wells near each other in the CW and BROW aquifers, higher arsenic concentrations typically were found in samples from the CW aquifer than in samples from the underlying BROW aquifers. These codes are also shown for comparison on the small-scale reference maps (Figures 3a–3c) of each buried aquifer at locations where residence time has been confirmed with tritium data. Figure 2 shows the distribution of the surficial aquifers in the county for comparison.

Infiltration through thin, overlying, fine-grained layers (*1*) is typical for the OT aquifer (Figure 3a) with examples shown on the left side of C–C′, F–F′ between Outlet Creek and Steenerson Lake, and all the OT aquifer shown on cross section H–H′. Leakage from surficial aquifers (*2*) appears to be most common in the CW aquifer (Figure 3b). Examples of this type of recharge are shown on all cross sections, with CW aquifer occurrences particularly common on the right portions of cross-sections A–A′ through E–E′. Four confirmed examples are shown on Figure 3b: two of them are beneath the Belgrade-Glenwood sand plain in eastern Pope County, one is at Glacial Lakes State Park, and another is in western Pope County in the Chippewa River valley. Leakage from the OT aquifer to the CW aquifer (*3*) occurs at scattered locations in the western two-thirds of the county (Figure 3b) with confirmed examples shown on the left side of cross-section C–C′ west of the Little Chippewa River and on the right side of H–H′ in the Nilson Lake area. Infiltration through multiple aquifers and intervening fine-grained layers (*4*) is very common in eastern Pope County (Figure 3c) with the recharge from the surficial aquifer through the CW aquifer to the BROW aquifer as the usual occurrence. Examples of this type of recharge are shown on most of the cross sections with a confirmed occurrence shown on the middle portion of cross-section I–I′ in the Coates Lake area and two occurrences on E–E′: west of Starbuck in a sand and gravel aquifer in the older unmapped sand aquifer and on the right side of E–E′ west of the East Branch Chippewa River.

Examples of discharge (*D*) from the OT aquifer are shown near the left edge of cross-sections B–B′ and C–C′ (Chippewa River valley) and the left portion of H–H′ (unnamed creek). Discharge examples from the CW aquifer include the Glenwood area (cross-section C–C′) and the East Branch Chippewa River (center of I–I′). Probable BROW aquifer discharge examples are shown in the Long Beach area (center of cross-section C–C′), the Glenwood area (center of cross-section D-D′), and on the right portion of cross-section I–I' to an unnamed wetland area. Two examples of arsenic stratification (*S*) are shown on the center and right portions of cross section A–A′ at locations in the Reno Lake and Levan Lake areas, respectively.

SUMMARY

The OT aquifer in central and western Pope County is commonly recharged through direct surface leakage although some portions of the aquifer appear to be isolated (protected) from direct recharge. Recharge to the CW aquifer through surficial aquifers in eastern, central, and southwestern Pope County appears to be the most common mode of water infiltration. Ground-water leakage from the overlying OT aquifer to the CW aquifer represents another important recharge mode at scattered locations in the western two-thirds of the county. Ground-water leakage through multiple aquifers and fine-grained units is the dominant recharge mode for the generally deeper BROW aquifer. This type of recharge is especially common in eastern Pope County beneath the Belgrade-Glenwood sand plain.

Probable ground-water discharge locations from the buried aquifers include the Chippewa River in northwestern Pope County, Lake Minnewaska, East Branch Chippewa River, and several unnamed creeks and wetlands.

REFERENCE CITED

Alexander, S.C., and Alexander, E.C., Jr., 1989, Residence times of Minnesota groundwaters: Minnesota Academy of Sciences Journal, v.55, no.1, p. 48-52.

ACKNOWLEDGEMENTS

The author thanks Ken Harris, Alan Knaeble, and Bob Tipping of the Minnesota Geological Survey; Geoff Delin of the U.S. Geological Survey; Mike Trojan of the Minnesota Pollution Control Agency; Steve Lawrence of Pope County Environmental Services; Richard Soule of the Minnesota Department of Health; Cathy Villas-Horns of the Minnesota Department of Agriculture; Jan Falteisek, Nick Kroska, Jeanette Leete, Greg Massaro, Todd Petersen, Kathy Metzker, Tim Loesch, Brian Rongitsch, Andrea Bergman, and Sarah Tufford of the Minnesota Department of Natural Resources; and Scott Alexander of the University of Minnesota Department of Geology and Geophysics.

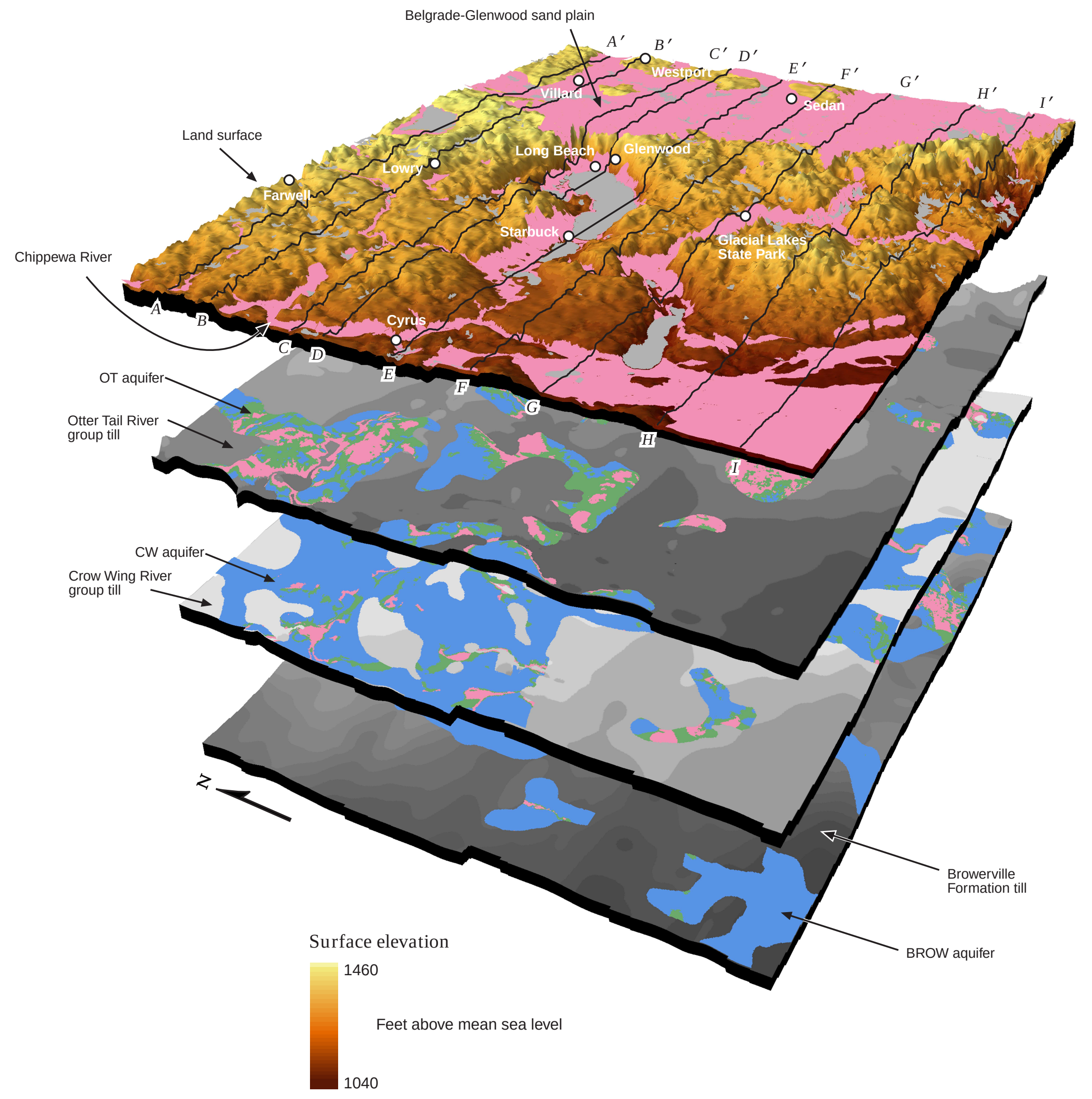
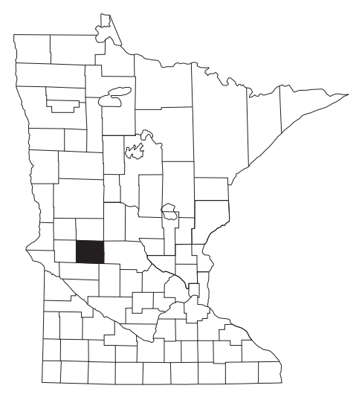


FIGURE 1. *Exploded, three-dimensional oblique view of the uppermost glacial sediment layers.* This diagram depicts an oblique three-dimensional view of the county separated into four layers. The land surface layer and surficial aquifers are separated from the underlying three mapped aquifers and the underlying till associated with those aquifers. The lowest layer, BROW aquifer and Browerville Formation till, overlies about 50 feet to about 350 feet of older till. The aquifers are colored with the same color scheme used on the cross sections according to ground-water residence time.

The diagram is meant to illustrate three general concepts. The main purpose is to show the layered or stacked nature of the aquifers. Also by comparing the amount of pink and green in each aquifer (indicating recent and mixed water), a decrease in the amount of recent and mixed water becomes apparent; the decrease suggests less recent recharge to the deeper aquifers and greater protective cover. Finally, the relative elevations of the top of each till surface are shown by the darker shades of gray indicating the lower elevations on each layer. The lowest part of each surface, including the land surface, is in the southwestern portion of the county. The elevations generally increase toward the northeast.



LOCATION DIAGRAM

The DNR Information Center

Twin Cities: (651) 296-6157
Minnesota Toll Free: 1-888-646-6367
Telecommunication Device for the
Hearing Impaired (TDD): (651) 296-5484
TDD Minnesota Toll Free: 1-800-657-3929
DNR Web Site: http://www.dnr.state.mn.us

This information is available in an alternative format on request.

This map was compiled and generated using geographic information systems (GIS) technology. Digital data products, including chemistry and geophysical data, are available from DNR Waters at http://www.dnr.state.mn.us/waters.

This map was prepared from publicly available information only. Every reasonable effort has been made to ensure the accuracy of the factual data on which this map interpretation is based. However, the Department of Natural Resources does not warrant the accuracy, completeness, or any implied uses of these data. Users may wish to verify critical information; sources include both the references here and information on file in the offices of the Minnesota Geological Survey and the Minnesota Department of Natural Resources. Every effort has been made to ensure the interpretation shown conforms to sound geologic and cartographic principles. This map should not be used to establish legal title, boundaries, or locations of improvements.

Digital base composite:
Roads and county boundaries - Minnesota Department of Transportation GIS Statewide Base Map (source scale 1:24,000)
Hydrologic features - U.S. Geological Survey Digital Line Graphs (source scale 1:100,000)
Digital base annotation - Minnesota Geological Survey
Project data compiled from 2004 to 2005 at a scale of 1:100,000. Universal Transverse Mercator projection, grid zone 15, 1983 North American datum. Vertical datum is mean sea level.
GIS and cartography by Jim Berg and Greg Massaro. Edited by Nick Kroska.

EXPLANATION
Cross sections and figures

Symbols and labels

① Infiltration through a thin layer of overlying, fine-grained material to an underlying aquifer.
② Ground-water recharge from overlying surficial sand plain to buried aquifer.
③ Ground-water leakage from the OT aquifer to the underlying CW aquifer.
④ Ground-water leakage through multiple aquifers and fine-grained layers.
Ⓛ Lateral ground-water flow.
Ⓓ Ground-water discharge.
Ⓤ Unknown source of recent or mixed ground water.
Ⓢ Stratification of arsenic.

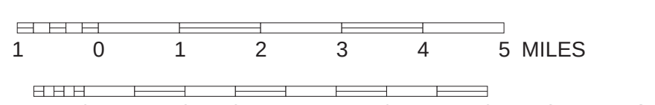
Color indicates tritium age. Vertical rectangle indicates well screen or open hole of well.

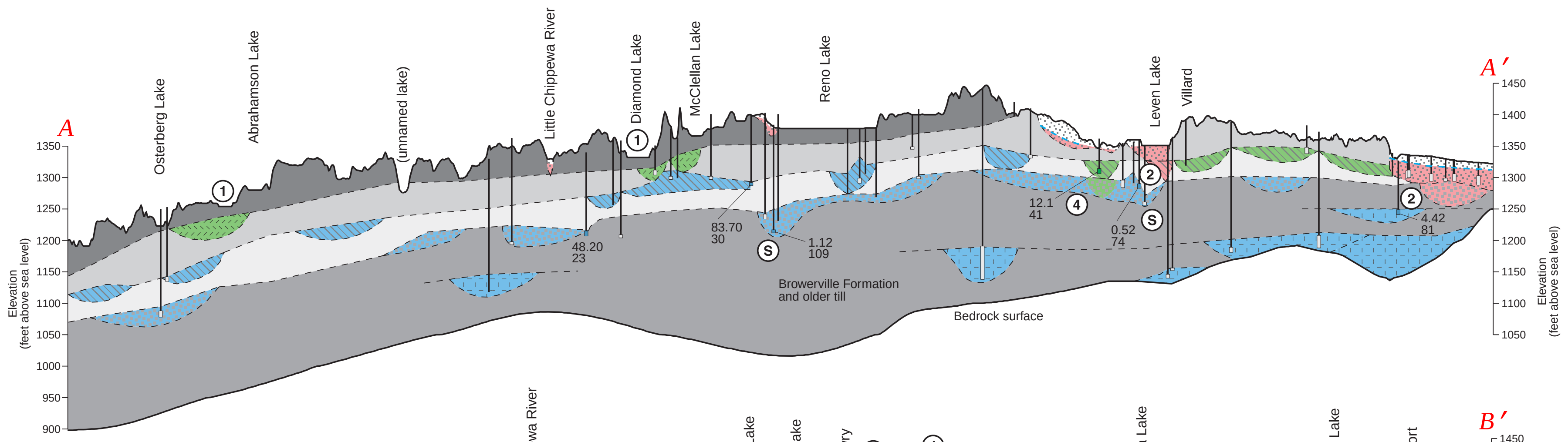
🟥	Recent—Water entered the ground since about 1953 (10 or more tritium units).
🟩	Mixed—Water is a mixture of recent and vintage waters (greater than 1 tritium unit to less than 10 tritium units).
🟦	Vintage—Water entered the ground before 1953 (less than or equal to 1 tritium unit).
▯	Well not sampled for tritium.
0.21 38	If shown, arsenic concentration in parts per billion (top) and chloride to bromide ratio (bottom).
2000	If shown, ground-water age in years, estimated by carbon-14 isotope analysis.
- - - -	Water table surface in surficial aquifer.
- - - -	Unit contact line.
←	General direction of ground-water flow.

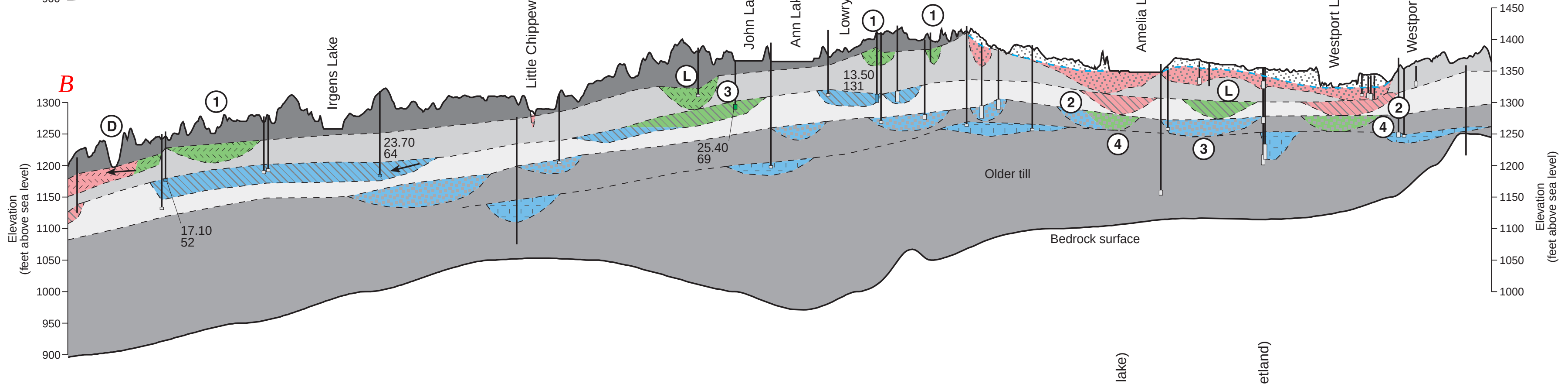
Geologic and hydrogeologic units

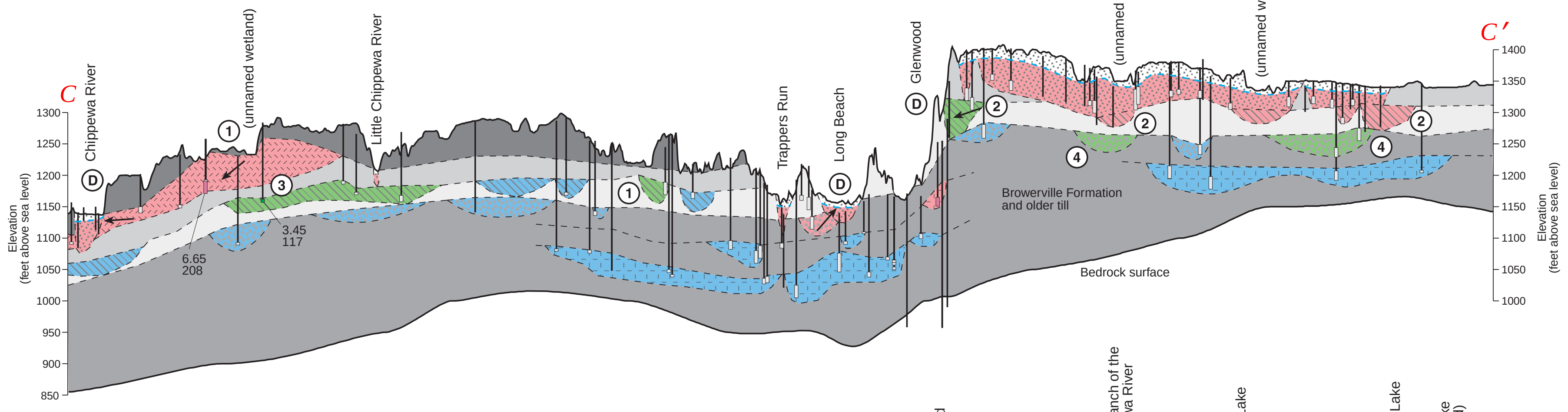
▨	Surficial sand and gravel (water-table aquifer). Uncolored where unsaturated.	▇	Upper and Lower Goose River groups. Dashed line is contact between groups.
▨	OT aquifer.	▇	Otter Tail River group.
▨	CW aquifer.	▇	Crow Wing River group.
▨	BROW aquifer.	▇	Browerville Formation and older till (lower part).
▨	Older sand aquifers.		

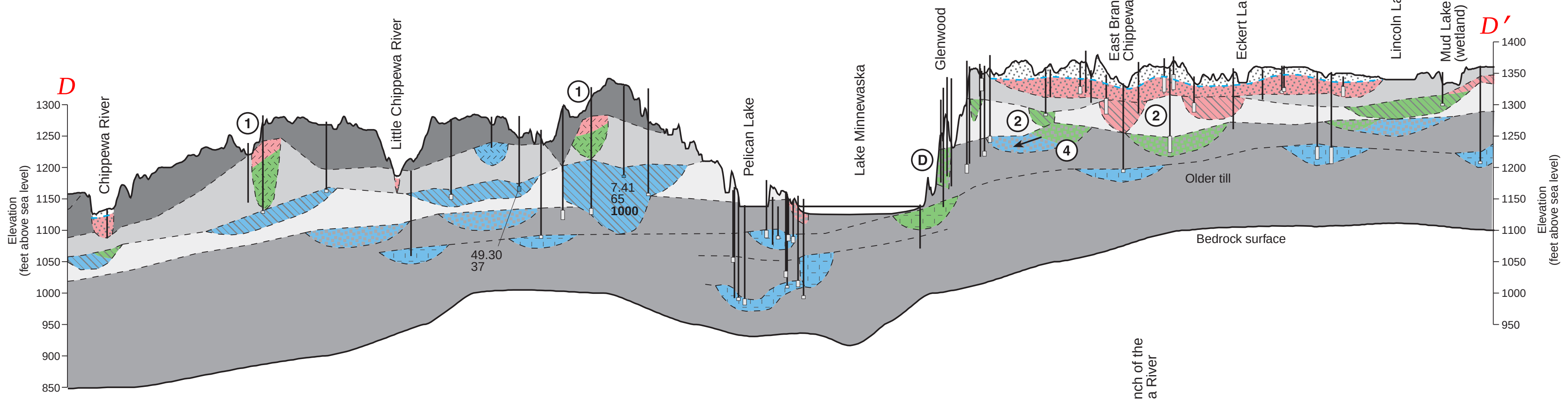
VERTICAL EXAGGERATION X 70

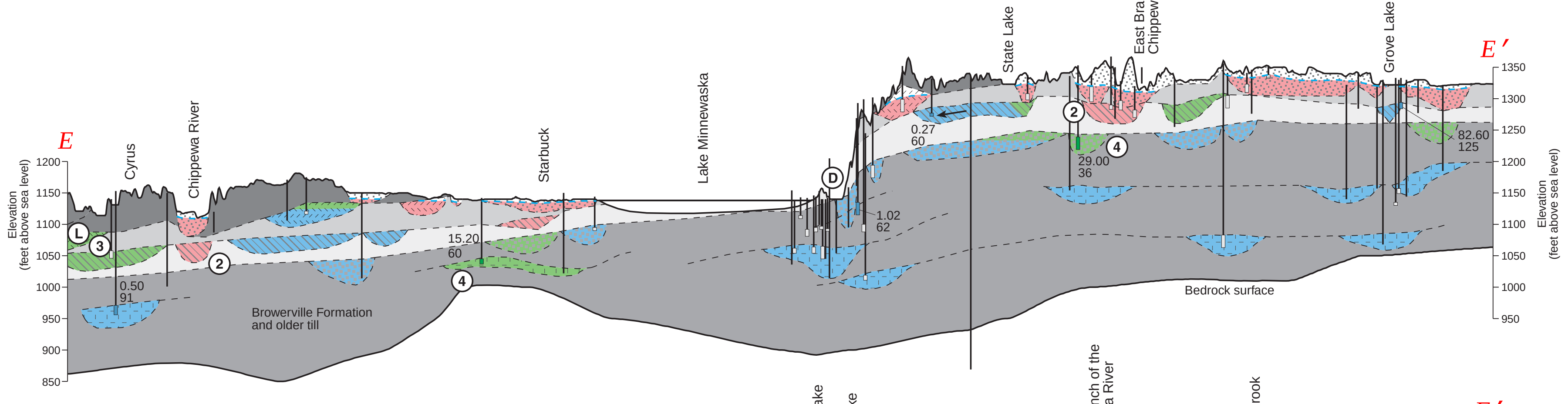


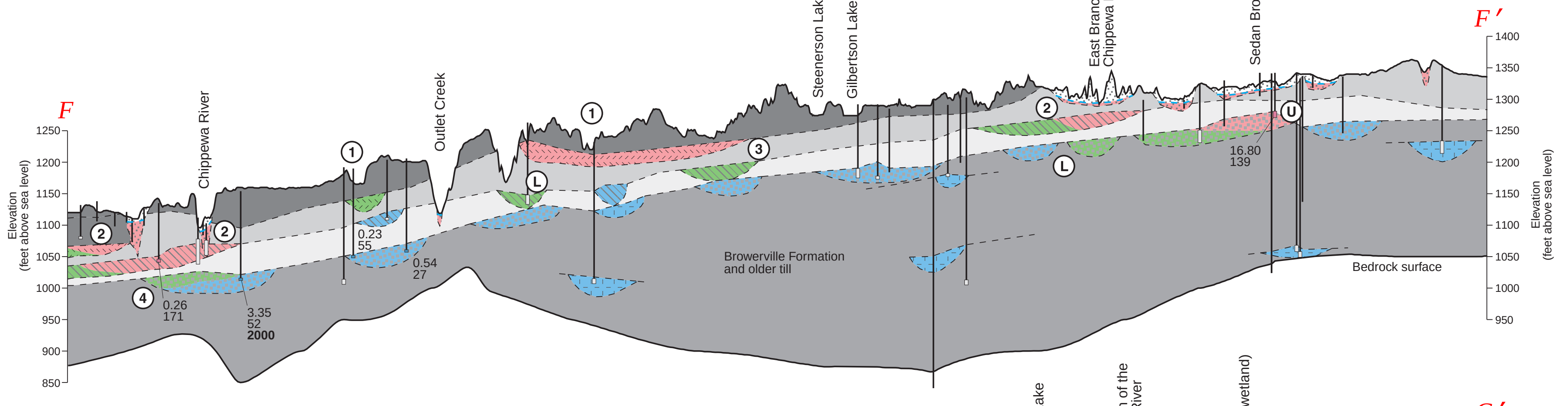


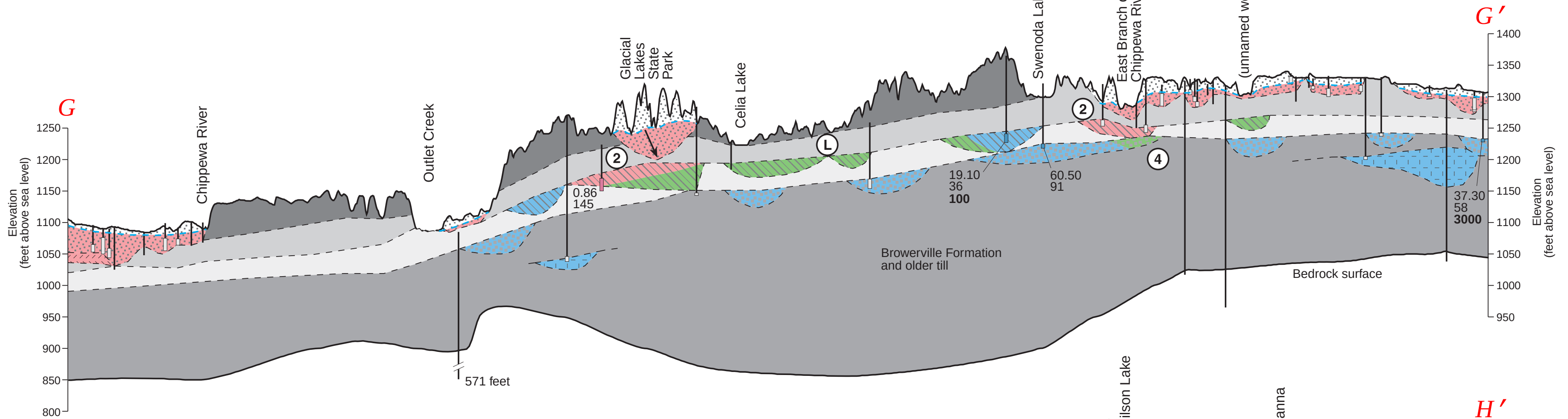


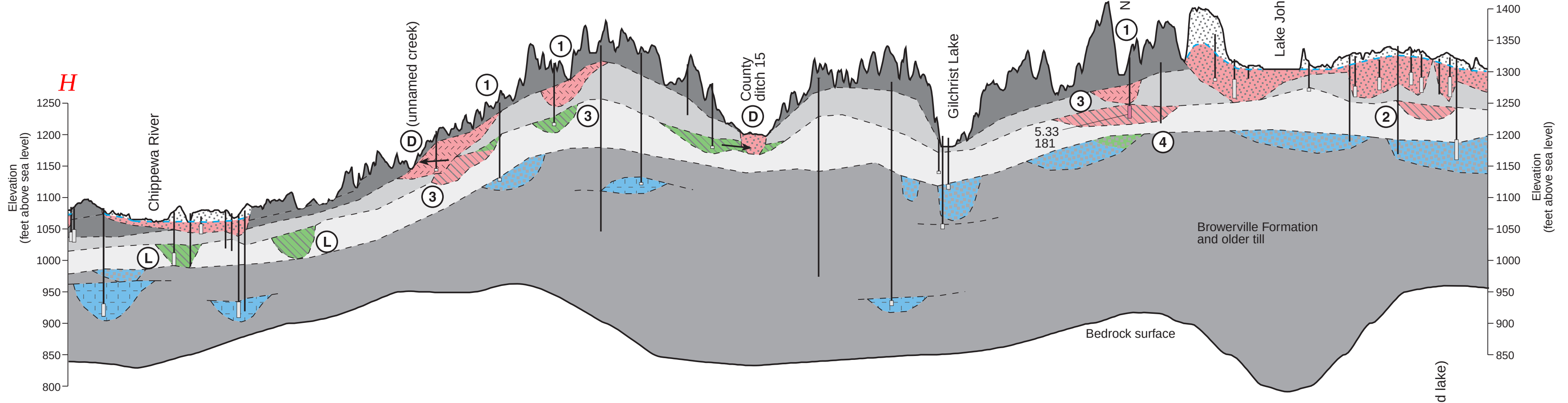


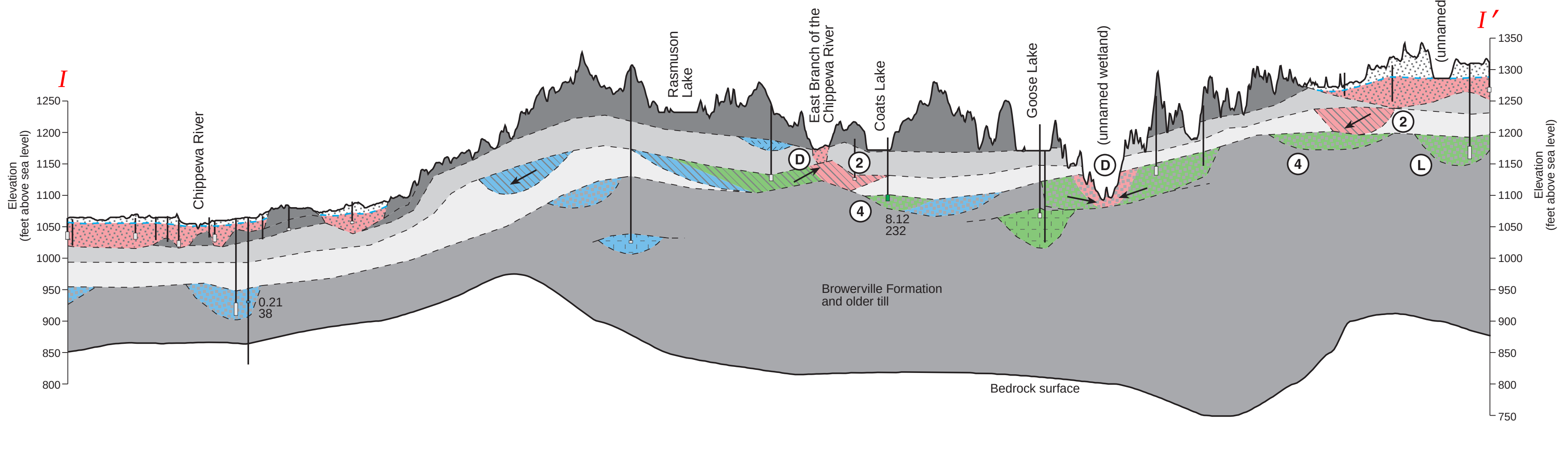












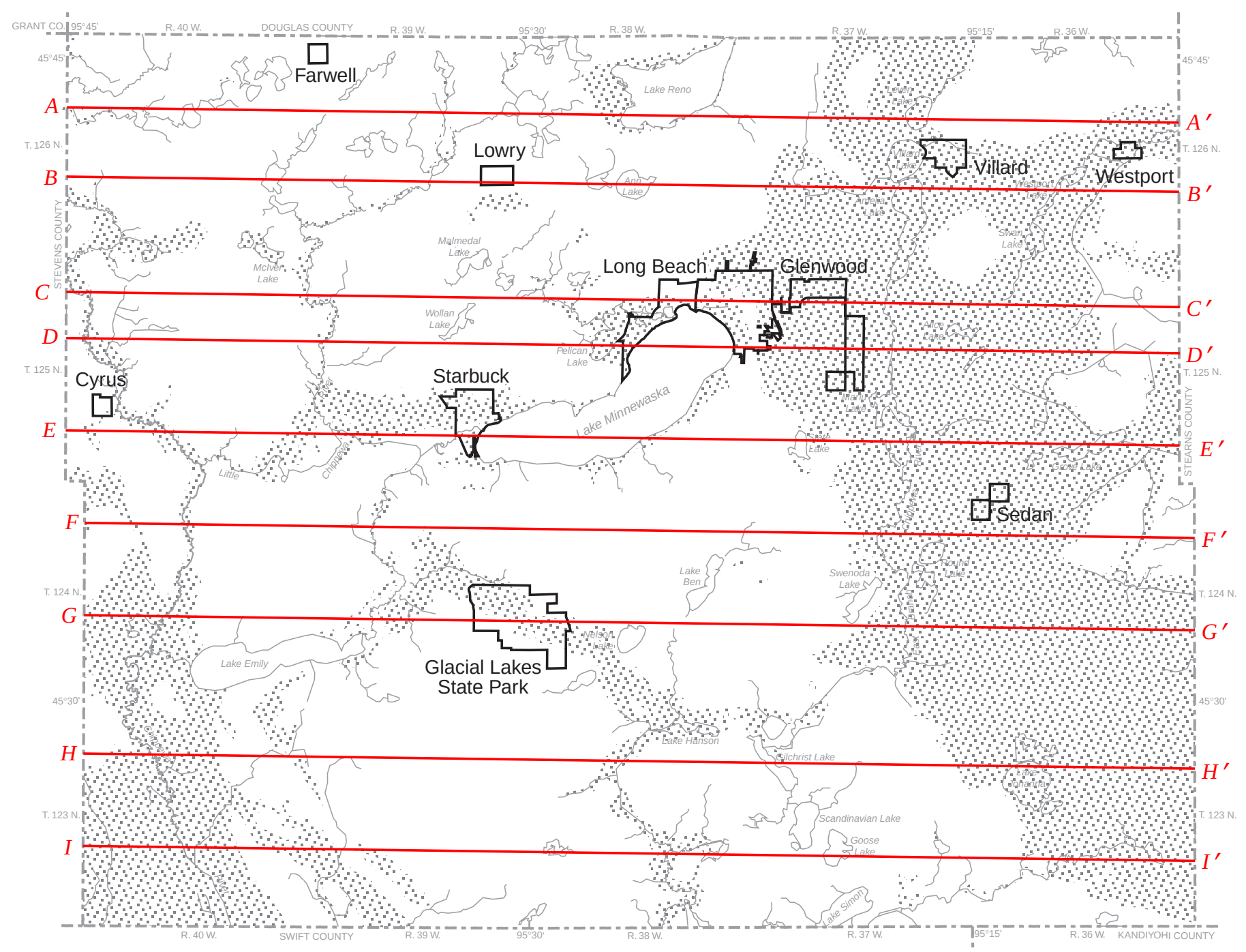
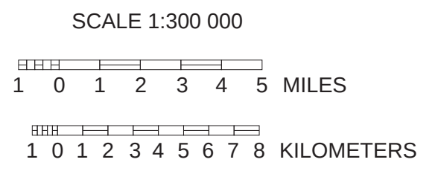


FIGURE 2. *Extent of surficial aquifers. See Plate 6 for more information.*



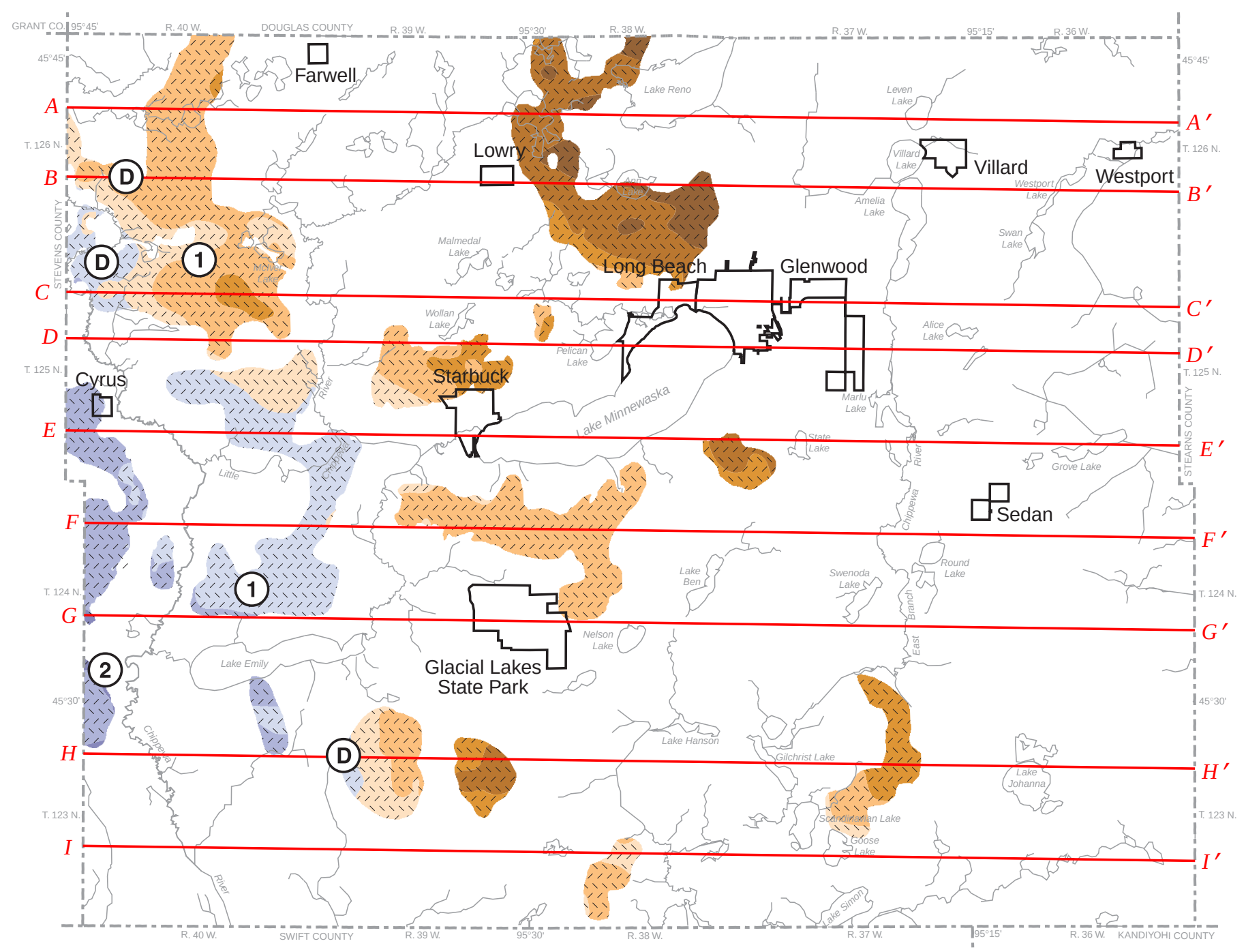


FIGURE 3a. *Aquifer conditions and elevation of the top of the OT aquifer. See also Plate 7, Figure 3a.*

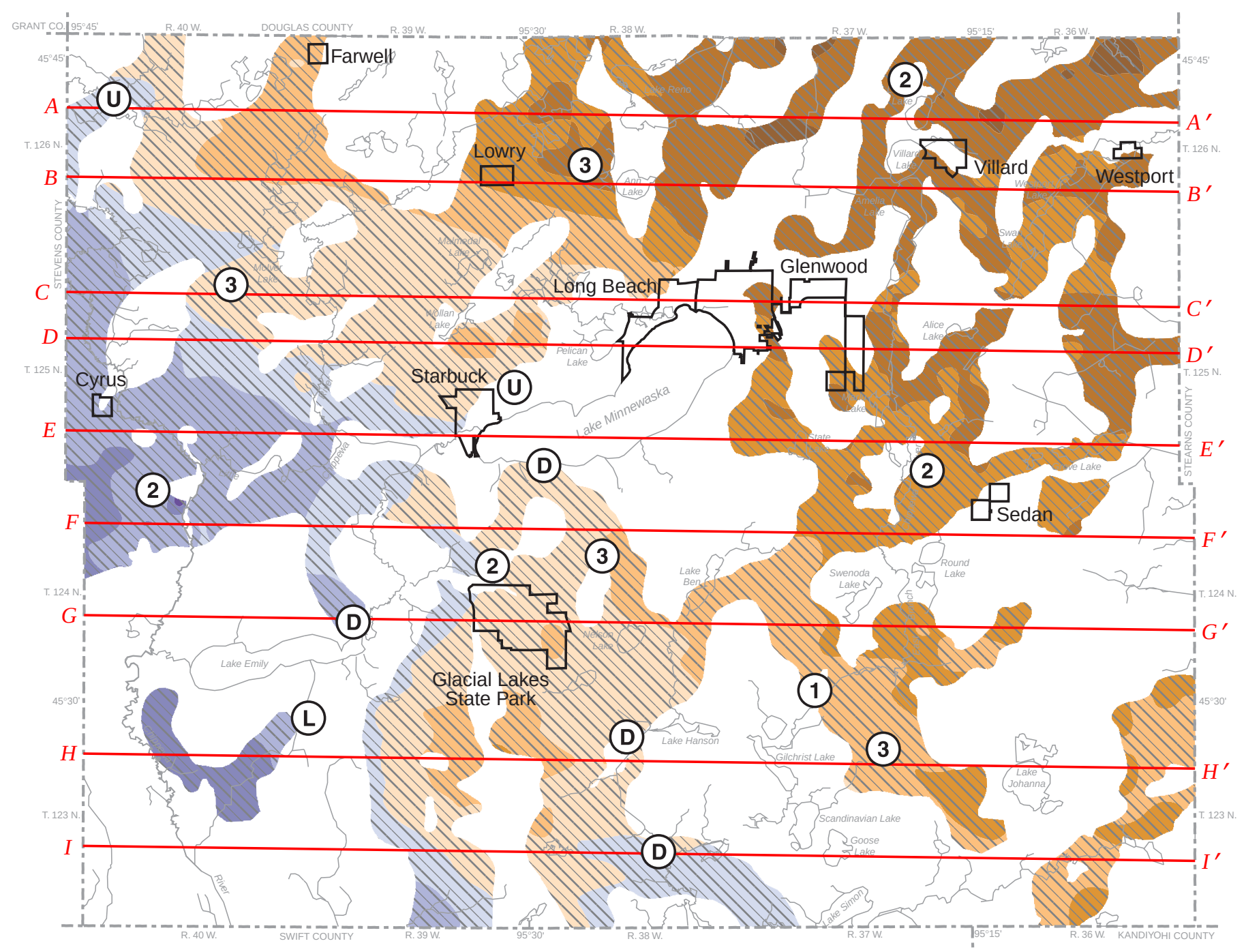


FIGURE 3b. *Aquifer conditions and elevation of the top of the CW aquifer. See also Plate 7, Figure 3b.*

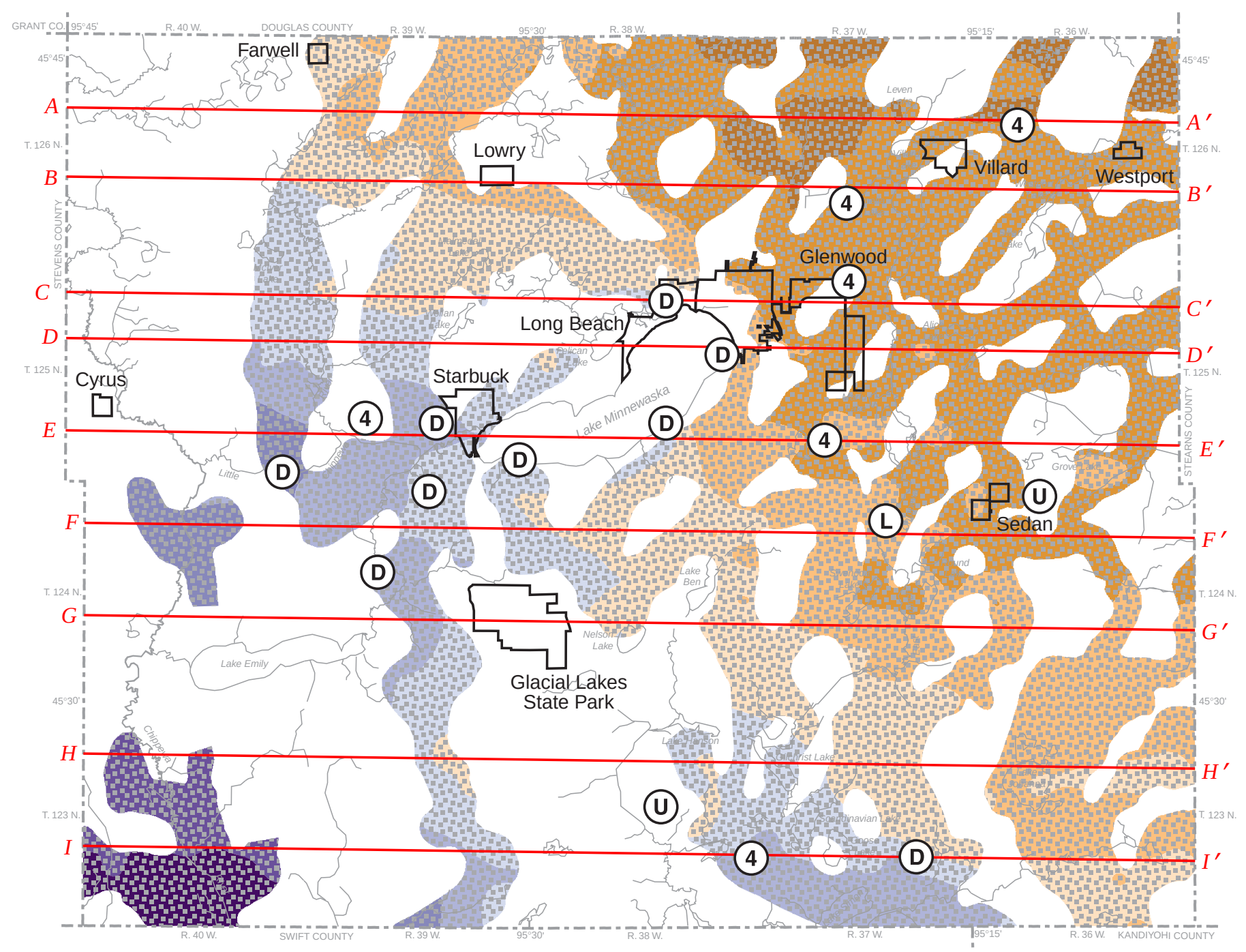


FIGURE 3c. *Aquifer conditions and elevation of the top of the BROW aquifer. See also Plate 7, Figure 3c.*

EXPLANATION

Elevation of the top of the buried aquifers
(feet above mean sea level)

🟫	1350–1400	⬜	1100–1150
🟫	1300–1350	🟪	1050–1100
🟧	1250–1300	🟪	1000–1050
🟧	1200–1250	🟪	950–1000
🟧	1150–1200	🟪	900–950

☐ Data insufficient or deposit not present

GEOLOGIC ATLAS OF POPE COUNTY, MINNESOTA