STATE OF MINNESOTA
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF WATERS

COUNTY ATLAS SERIES
ATLAS C-13, PART B, PLATE 9 OF 10
Hydrogeologic Cross Sections

HYDROGEOLOGIC CROSS SECTIONS

By

James A. Berg

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EXPLANATION

Quaternary units (shown only on cross sections)

Confining units—low permeability

- ▤ Glacial Lake Grantsburg sediment—very high silt and clay content
- ■ Grantsburg and post-Automba phase Superior lobe till—high silt and clay content
- ▤ Glacial Lake Lind sediment—high silt and clay content
- ☐ Superior lobe till of the St. Croix, Automba, and older phases—contains more sand and less clay than the Grantsburg till and glacial lake sediment units

Aquifers—high permeability

- ▒ Sand or possible sand
- ▒ Sand with gravel, gravel, or possible gravel

Bedrock units (shown on index map and cross sections)

Sandstone aquifers

- Ꝑzu—Paleozoic sandstone, minor shale
- Ꝑmhn—Hinckley Sandstone
- Ꝑmfl—Fond du Lac Formation, sandstone and siltstone
  Ꝑmsu—Mesoproterozoic sandstone, siltstone, and minor shale

Volcanic rock aquifers

- ▩ Ꝑmmv—Minong volcanic sequence
  Ꝑmcb, Ꝑmcp—Basalt, Chengwatana Volcanic Group
  Ꝑmbu—Basalt, undifferentiated

Metamorphic rock aquifers

- ▩ Ꝑps—Metamorphosed graywacke
  Ꝑdam, Ꝑdms, Ꝑdmv—Denham Formation
  Amc—McGrath Gneiss

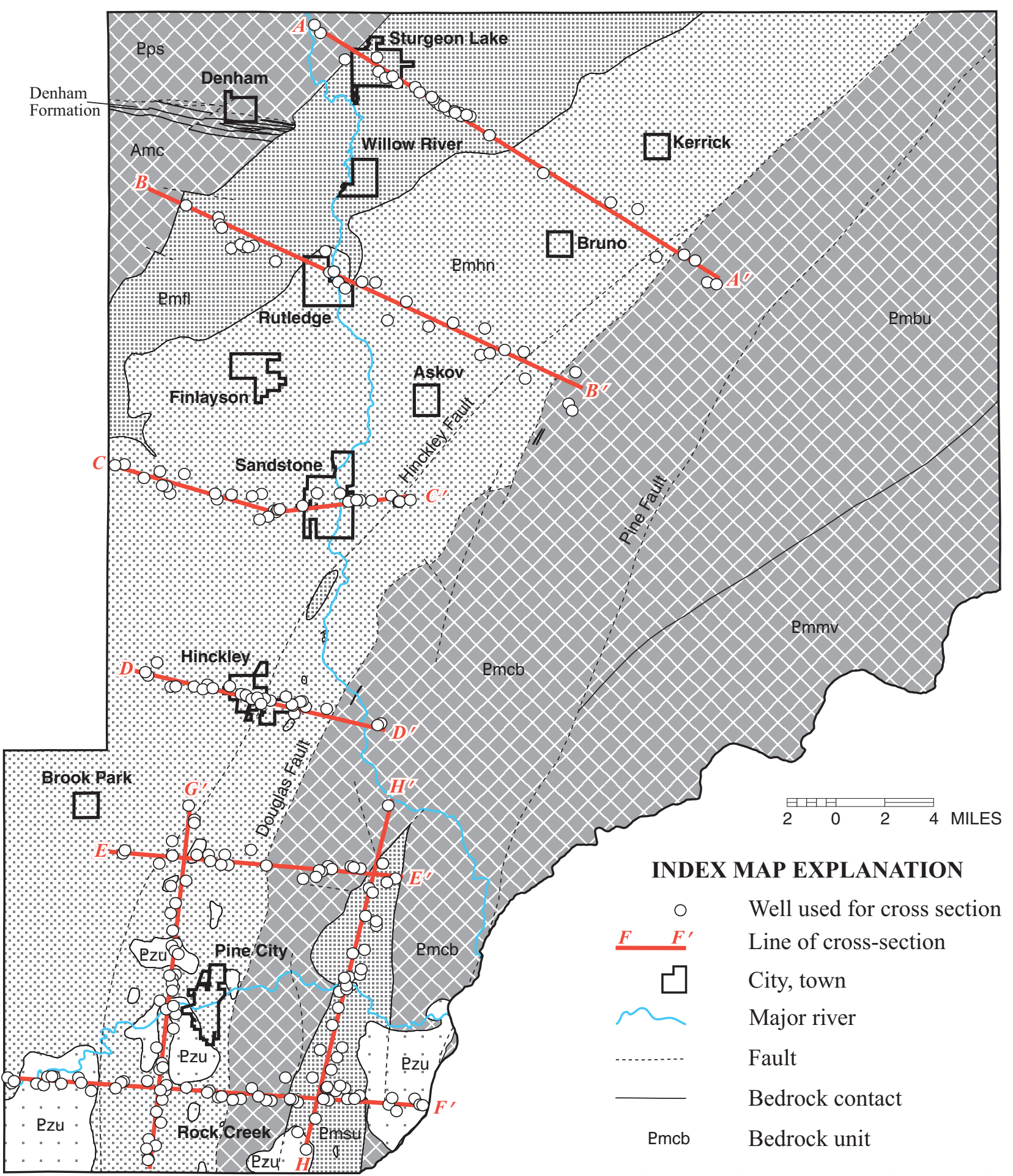
Cross-section symbols and labels

- ┈ Water table
- ─ Bedrock potentiometric surface
- ∿ Spring
- ← General direction of ground-water flow in bedrock
- ⊙ Ground-water flow out of the cross section
- D Fault—Approximately located; downthrown side
- U Fault—Approximately located; upthrown side
- ④ Label for featured area (see also Figure 3)

Tritium Age—Tritium age not shown for till or other very fine grained sediments. Unsaturated portions of aquifers have no tritium age indicated. Vertical rectangle indicates well screen or open hole of well. No vertical rectangle indicates no well screen or open hole data available.

- 🟥 Recent—Water entered the ground since 1953 (10 or more tritium units).
- 🟩 Mixed—Water is a mixture of recent and vintage waters (0.8 to less than 10 tritium units).
- 🟦 Vintage—Water entered the ground before 1953 (less than 0.8 tritium unit).
- ▯ Well not sampled for tritium.

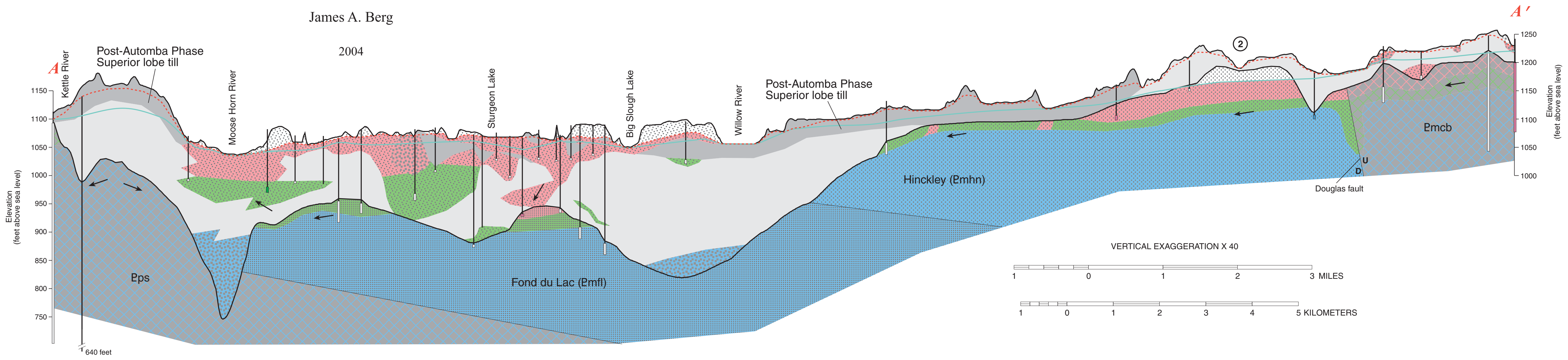
327 (B)	If shown, boron concentration equals or exceeds 95 parts per billion
0.024 (Sr/Mg)	If shown, strontium to magnesium ratio equals or exceeds 0.015
1740 (Cl/Br)	If shown, chloride to bromide ratio equals or exceeds 1000
4.5 (NO3)	If shown, nitrate-nitrogen concentration equals or exceeds 1 part per million
2400	If shown, ground-water age in years, estimated by carbon-14 isotope analysis
S1, S2, S3	Quaternary sand and gravel aquifers. See Plate 8, Figure 2.

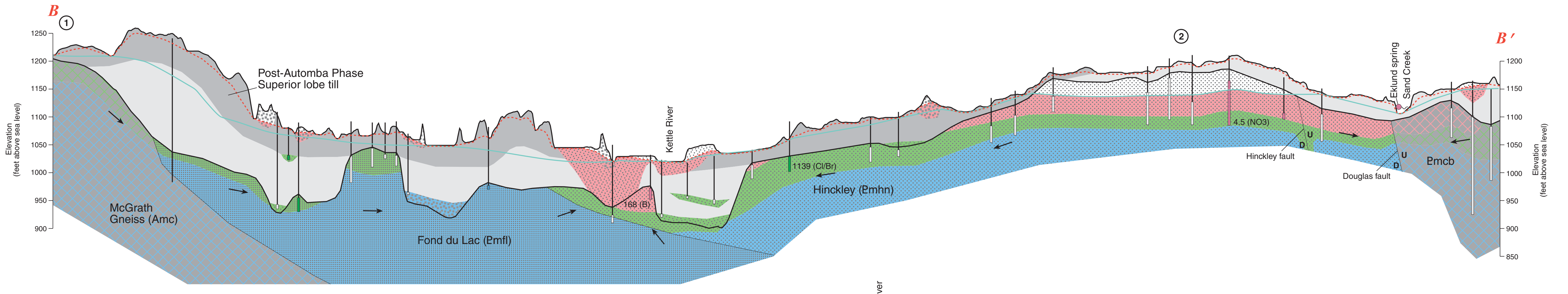


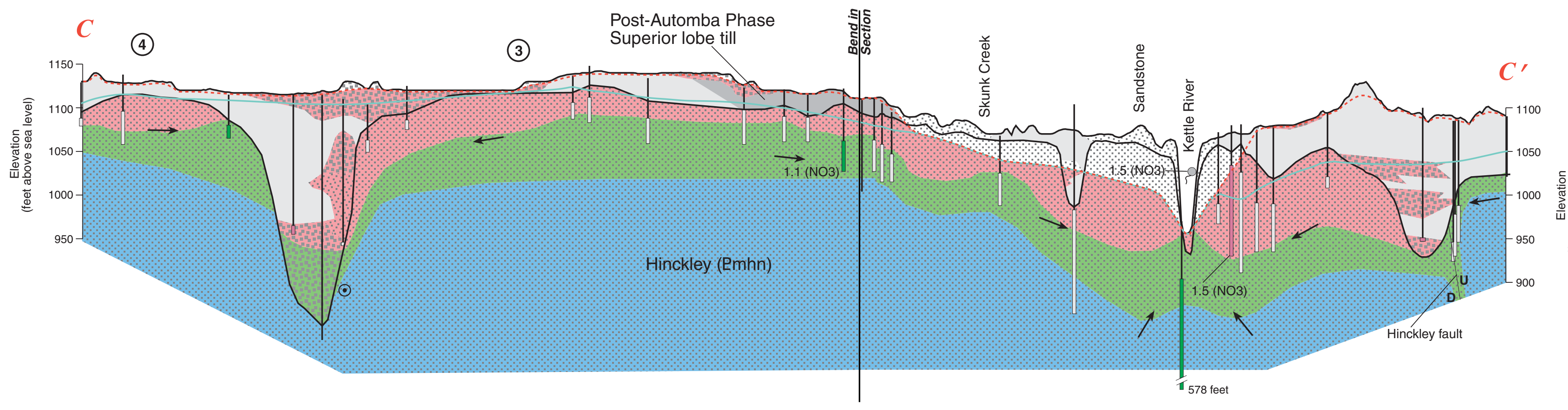
INDEX MAP EXPLANATION

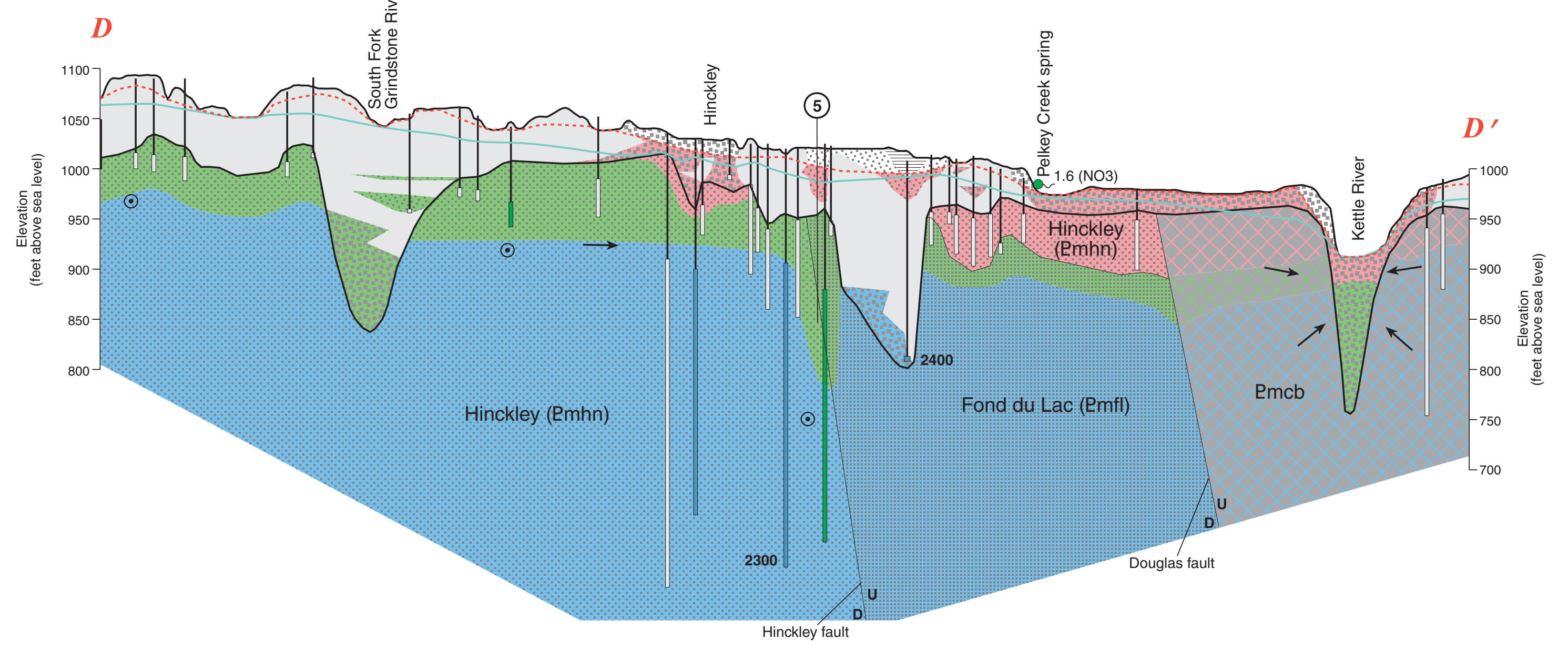
- ○ Well used for cross section
- F——F′ Line of cross-section
- ⌂ City, town
- ∿ Major river
- ┈ Fault
- ─ Bedrock contact
- Ꝑmcb Bedrock unit

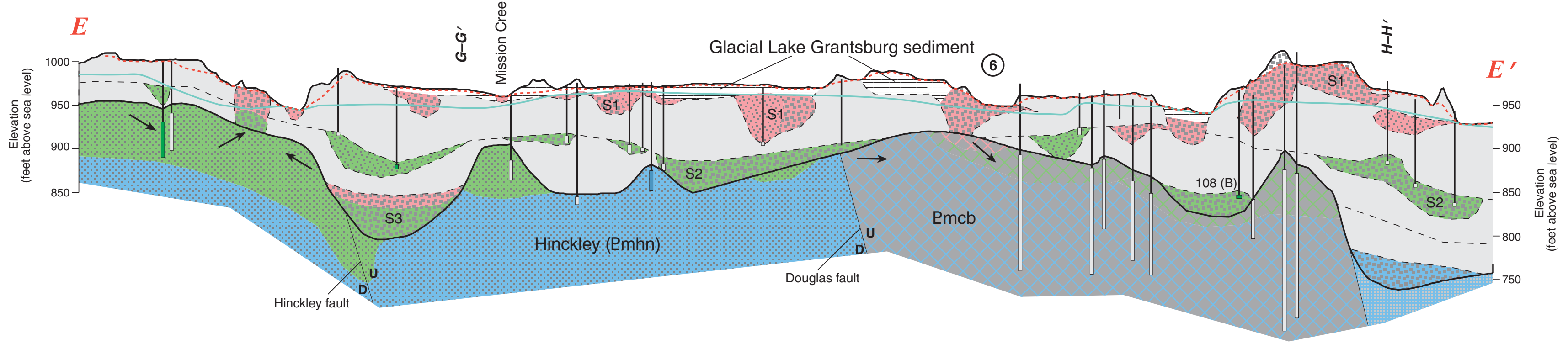
FIGURE 1. *Cross-section index map. The map displays the locations of cross sections and all wells shown on the cross sections for reference. The map also shows generalized bedrock units from Part A, Plate 2.*

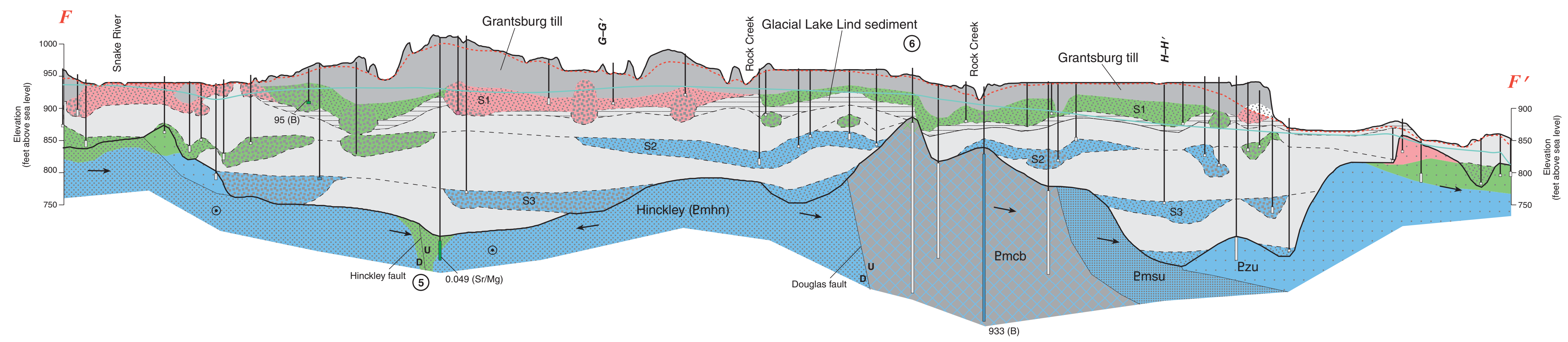


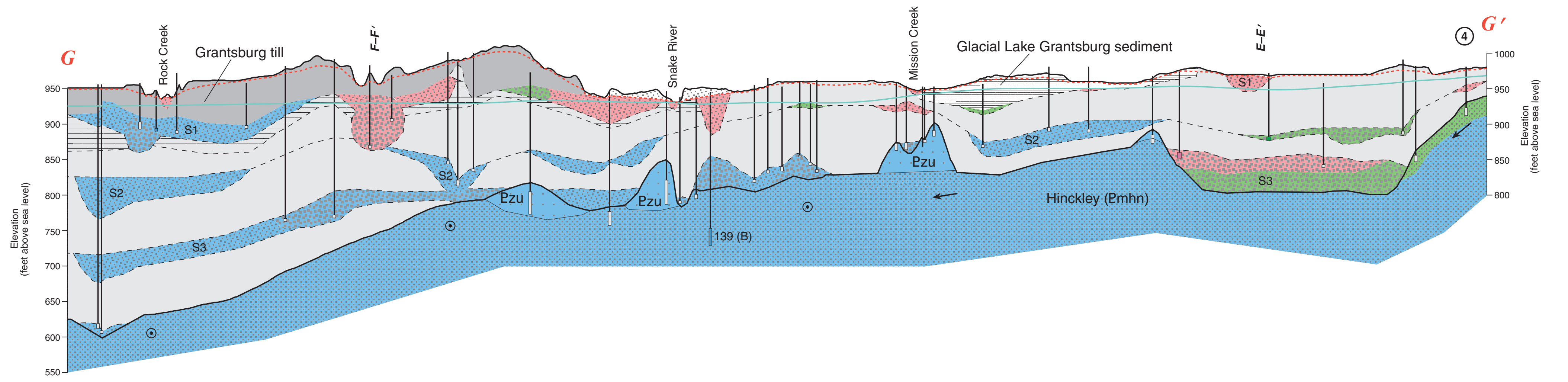












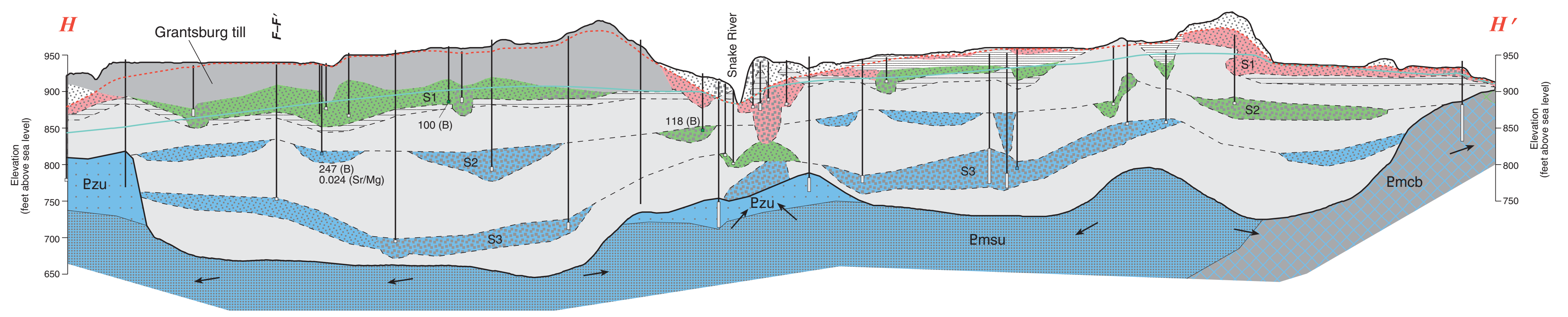


FIGURE 2. *Central, southern, northern, and northwestern areas. They are also delineated on the sensitivity map, Plate 10, Figure 4.*

INTRODUCTION

The eight 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 potentiometric surface profiles, and general ground-water flow directions. The locations of cross-section lines (Figure 1) were chosen to illustrate important hydrogeologic features and data for as much of Pine County as possible. Data were insufficient to construct cross sections in eastern Pine County. The cross sections were constructed using a combination of well data from the County Well Index (CWI); surface resistivity data; and information from the Bedrock Geologic Map and Sections (Plate 2), Surficial Geology (Plate 4), Quaternary Stratigraphy (Plate 5), and the Depth to Bedrock Map (Plate 6) of Part A. The well information for each cross section was projected onto the trace of the cross-section line from distances no greater than a mile. Cross-sections E–E′ through H–H′ and others not shown were used to map the sand and gravel aquifers in southern Pine County (Plate 8, Figure 2).

HYDROGEOLOGIC FEATURES AND DATA

Relative hydraulic conductivity. The lithologic units (types of sediment and rock) 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. Hydraulic conductivity, or the water-transmitting capacity of the hydrogeologic unit, is controlled by the porosity (open spaces) and permeability (a measure of how connected the open spaces are) within the unit. These factors mostly depend on the lithology and, for bedrock aquifers, the depth beneath the base of the glacial sediment (Runkel and others, 2003). In Pine County, most wells use the relatively shallow (less than 200 feet beneath the top of the bedrock) and fractured portions of the bedrock aquifers. The volcanic and metamorphic aquifers are shown with a crosshatch pattern to suggest a predominance of fracture porosity and permeability. The dark gray background of the pattern indicates the otherwise relative impermeability of the rocks. The sandstone aquifers are shown with the lighter dotted patterns to suggest intergranular porosity. However, in the shallow portions of these aquifers, fractures should be considered an important component of the unit's overall porosity and permeability.

The cross-section explanation on this plate for the Quaternary units shows an inferred continuum of hydraulic conductivity from low to high. The relative average proportions of sand, silt, and clay (matrix texture) shown on Part A, Plate 5, Table 1 were key for ranking the geologic units in this continuum. For instance, the fine-grained deposits of the glacial Lake Grantsburg units contain the highest proportion of clay content (56 percent) to sand content (10 percent), which probably makes them some of the best confining units. The Superior lobe till of the St. Croix and Automba phases has the lowest proportion of clay (12 percent) to sand (62 percent). Those proportions probably make these till units some of the poorest confining layers in the county. The relative confining and protective properties of these units were also used to devise a pollution sensitivity model for the county (Plate 10).

Ground-water residence time. The pink, green, and blue overlays shown on these cross sections represent the age of the ground water, also known as ground-water residence time. This is the approximate time that has elapsed from when 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 sensitivity concept described on Plate 10. 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 aboveground 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 concentrations of tritium greater than 10 tritium units (TU) are considered recent water (mostly recharged in the past 50 years, shown in pink). Concentrations less than the detection limit (0.8 TU) are considered vintage water (recharged prior to 1953, shown in blue). Concentrations between these two limits 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 200 years to 40,000 years.

HYDROGEOLOGY ILLUSTRATED BY THE CROSS SECTIONS

Central and northwestern areas. In these two areas (Figure 2), which encompass approximately half the county, protective layers of glacial sediment only thinly cover the bedrock aquifers (labels 1–4 on the cross sections and Figure 3). The right side of cross-sections A–A′ and B–B′ and all of C–C′ and D–D′ are in these areas. In the central area, the bedrock aquifers consist mostly of the Hinckley sandstone aquifer to the northwest and the volcanic rock aquifer to the southeast. Smaller areas with similar thin glacial sediment and recent recharge characteristics exist in the northwestern portion of the county (left side of A–A′ and B–B′) and along the St. Croix River (right side F–F′).

The shallow portions of bedrock aquifers in these areas (no greater than approximately 100 feet deep) contain mostly recent and mixed water. Anthropogenic indicators of elevated nitrate values and chloride to bromide ratios shown on B–B′, C–C′, and D–D′ and described on Plate 8 are evidence of recent recharge to ground water. Two City of Hinckley wells (D–D′) were constructed in a manner that sealed off the zone with detectable tritium. The open-hole portion of one of these wells is deep enough to extract vintage water with a carbon-14 age of 2300 years. Another deep well east of the City of Hinckley wells (D–D′, label 5) was drilled through and completed across the Hinckley fault. Although the construction of this well is similar to the City of Hinckley wells, the ground-water sample from this well had a mixed tritium value, which suggests that the Hinckley fault is an active ground-water flow zone. Evidence of ground-water movement along this fault is shown by another mixed tritium value in a sample from a well near the fault, 17 miles to the southwest (left side of F–F′). The extent of this flow zone along the Hinckley fault is not known.

Unsaturated conditions in the upper portion of the Hinckley Sandstone are shown on the right side of cross-sections A–A′, B–B′, and C–C′. These unsaturated zones are part of a broad area of unsaturated conditions in the Hinckley Sandstone that exist from just west of the City of Sandstone to just southeast of Kerrick (Figure 3c, Plate 10). East of the Kettle River, this unsaturated area matches the distribution of known sinkholes and may be related to karst conditions. Sinkhole formation, for instance, requires turbulent (fast) water flow through existing surface sediment pathways and bedrock fractures (Part A, Plate 6). Infiltrating surface water can generally drain more rapidly though unsaturated bedrock. Ground water will rapidly move from the high-permeability, elevated portions of aquifers, leaving those zones unsaturated. The unsaturated Hinckley Sandstone may also be indirect evidence of karsted, highly permeable subsurface conditions where sinkhole mapping has not been completed.

Southern area. The southern portion of the county (Figure 2) is characterized by a relatively thick layer of glacial sediment, which includes a series of layered aquifers (Plate 8, Figure 2). The bedrock aquifers underlying this glacial sediment are the Hinckley sandstone, volcanic rock, and unidentified Paleozoic and Mesoproterozoic sandstone units (E–E′, F–F′, G–G′, and H–H′). Cross-section E–E′ represents a transitional area between the thin glacial sediment area to the north and the thicker glacial sediment area to the south. Water samples from wells in the bedrock aquifers within this transitional area shared some characteristics of the north and south areas. Vintage tritium values were typical for most of the water samples from bedrock aquifers in the southern area.

The Surficial Geology map (Part A, Plate 4) shows extensive sand and gravel deposits of eskers across much of the county. Eskers are long, narrow glacial deposits that usually contain high percentages of gravel. Limited surface resistivity surveys conducted for this project showed that these deposits can be detected in the shallow subsurface. Based on this evidence, most of the gravel deposits of the S1 aquifer (Plate 8, Figure 2a) have been shown with cross-sectional geometry typical of an esker. These types of deposits may have also been common features of the preceding glaciations; however, the data density for these deeper deposits was inadequate to show the gravel deposits in this manner. Esker deposits are important local recharge features for aquifers (E–E′ right side; label 6; and Plate 8, Figure 2a), local discharge areas (E–E′ left side), and preferential pathways for lateral ground-water flow.

A recent tritium value for a water sample from a buried S1 esker deposit shown on cross-section F–F′ (near intersection with cross-section G–G′) is evidence of local recharge for some of the S1 aquifer. The lateral continuity of the southern portion of the S1 aquifer is also evident on F–F′. The sandy sediments of this unit were deposited in a glacial lake setting (glacial Lake Lind) that was deepest in the southern portion of the county. The northern edge of the main protective layer (Grantsburg till) overlying the S1 unit is shown in the central portions of G–G′ and H–H′ near the Snake River. The S1 aquifer north of the Grantsburg till (right sides of G–G′ and H–H′) comprises thin surficial deposits, is less protected, and consequently is not used as much for domestic water supplies. On E–E′, the S1 aquifer is covered only sporadically by relatively thin layers of clayey glacial Lake Grantsburg sediments.

North of E–E′ is an important recharge area for the buried Quaternary aquifers to the south (Plate 8, Figures 2b and 2c). The recent and mixed tritium values of ground-water samples from a buried sand S3 aquifer (right side of G–G′) are evidence of rapid ground-water movement through buried valley or esker deposits from a surficial source 2 or 3 miles to the north. The S3 buried valley aquifer on the left side of E–E′, also shown with a recent tritium value, connects the S3 buried sand aquifer on G–G′ to the shallower recharge areas to the north.

Occurrences of chemical constituents indicative of ground water that has passed through basalt rock provide other insights into the deeper ground-water movements in this area. On H–H′ (left side), elevated values of boron and strontium to magnesium (Sr/Mg) were found in water samples from both the S1 and S2 aquifers. These samples were collected from wells downgradient from a ridge of volcanic rock that is shown on cross-sections E–E′ and F–F′ (label 6). The presence of these chemical constituents is evidence that ground water moving through the volcanic ridge discharges water to the S1 and S2 aquifers. Elevated Sr/Mg values in samples from the Hinckley sandstone aquifer near the Hinckley fault (left side of F–F′, label 5) also indicates ground water that has moved from a basalt rock source.

Northern area. This area is shown on the left sides of A–A′ and B–B′. Similar to the southern area, this northern area has a relatively thick layer of glacial sediment that contains important Quaternary sand and gravel aquifers. Also similar to the southern area, the uppermost till unit is clay rich (post-Automba phase Superior lobe till). The thickness of this unit as shown on the cross sections has been estimated since it is the same color as the underlying till layer and cannot be distinguished based on color differences listed on drillers' logs. Unlike the southern area, the bedrock aquifer in the northern area consists mostly of the Fond du Lac aquifer. In addition, the northern area has thick surficial sand and gravel deposits that in places extend to the bedrock. Therefore, portions of the bedrock aquifer receive recent recharge as shown by the recent and mixed tritium values in water samples from wells on both A–A′ and B–B′. An elevated boron concentration (168 parts per billion) in a water sample from a well in the Hinckley sandstone aquifer (center of B–B′) is evidence of ground-water upwelling created by the Kettle River as a major ground-water discharge feature.

REFERENCES CITED

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Runkel, A.C.; Tipping, R.G.; Alexander, E.C., Jr.; Green, J.A.; Mossler, J.H.; and Alexander, S.C., 2003, Hydrogeology of the Paleozoic bedrock in southeastern Minnesota: Minnesota Geological Survey, Report of Investigations 61, p.17.

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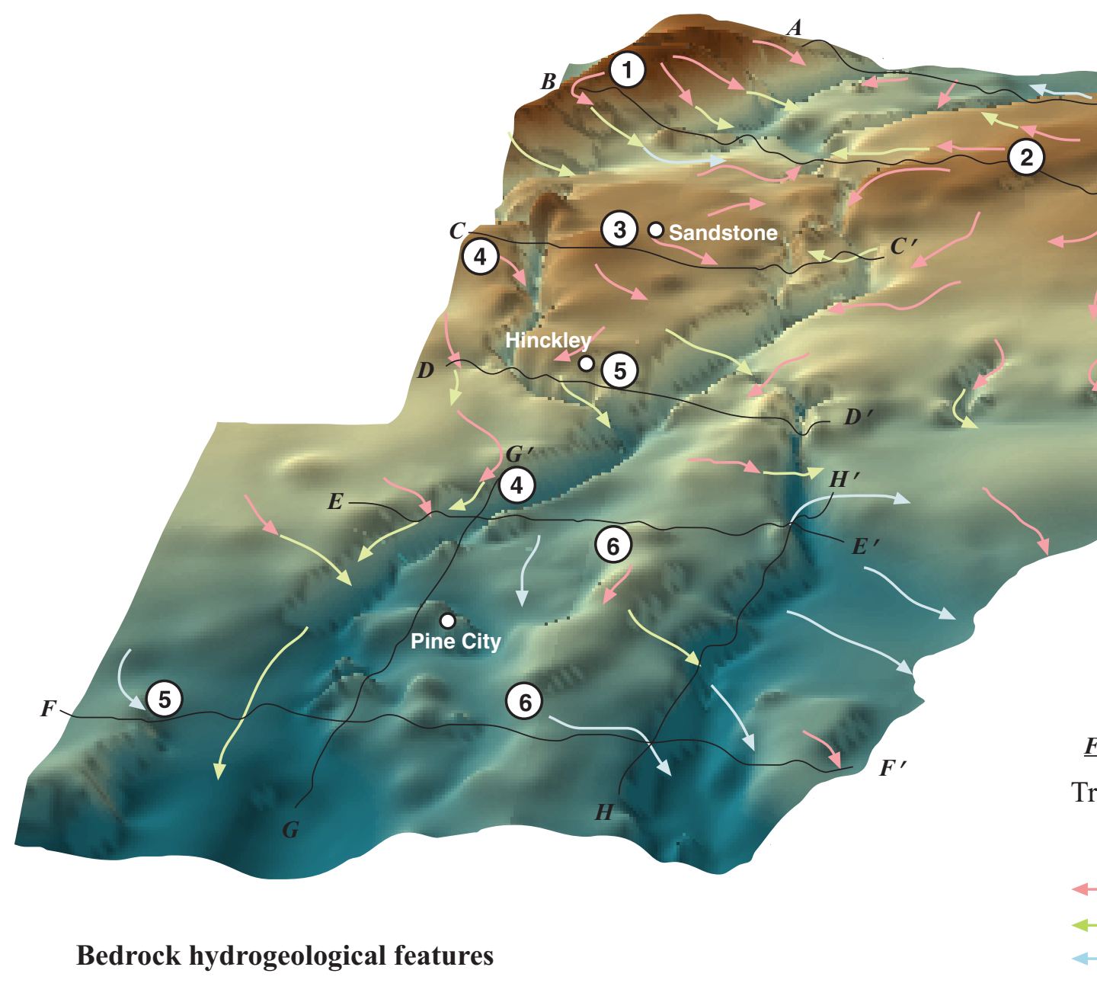


Bedrock hydrogeological features

- ① ③ ④ Thin drift: important bedrock recharge area
- ② Thin drift: important bedrock recharge area, sinkholes common
- ⑤ Hinckley fault: fracture porosity, zone of preferential lateral and vertical ground-water flow
- ⑥ Volcanic rock ridge: bedrock recharge area

FIGURE EXPLANATION

- ○ Selected town or city
- ① Label for featured area
- F——F′ Line of cross-section

Tritium age and ground-water flow—Arrow is colored according to tritium age and indicates the general direction of ground-water flow in bedrock.

- 🟥 Recent
- 🟩 Mixed
- 🟦 Vintage

Bedrock surface elevation

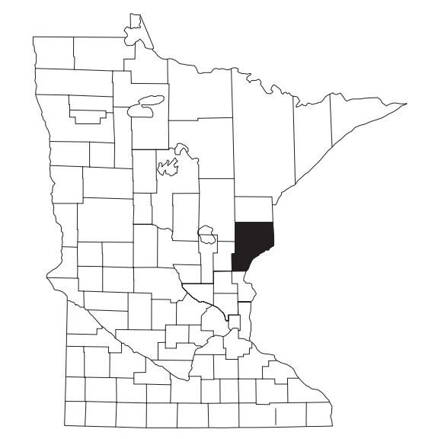
1290

Bedrock surface—Feet above mean sea level

610

FIGURE 3. *Ground-water flow paths in bedrock aquifers on a three-dimensional perspective of bedrock topography. The arrows, colored by residence time characteristics, represent the ground-water flow paths in the bedrock aquifers. The traces of the cross sections overlain at land surface elevations are shown for comparison.*

Important bedrock hydrogeological features are marked by numbered circles and include the following. Major recharge to bedrock aquifers occurs in the following areas: (1) northwestern corner of the county, (2) from Sandstone to Kerrick in the bedrock high area trending northeast to southwest, and bedrock high areas west of (3) Sandstone and (4) Hinckley. Mixed tritium conditions were found in ground-water samples from (5) the Hinckley fault, which suggests that the fault acts as a zone of preferential ground-water flow. The highest portions of (6) the buried volcanic ridge receive recent recharge. Ground water from that buried ridge containing chemical constituents leached from basalt moves laterally and downward into hydraulically connected buried sand and gravel aquifers.



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://dnr.state.mn.us/waters.

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 2001 to 2003 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.

GEOLOGIC ATLAS OF PINE COUNTY, MINNESOTA