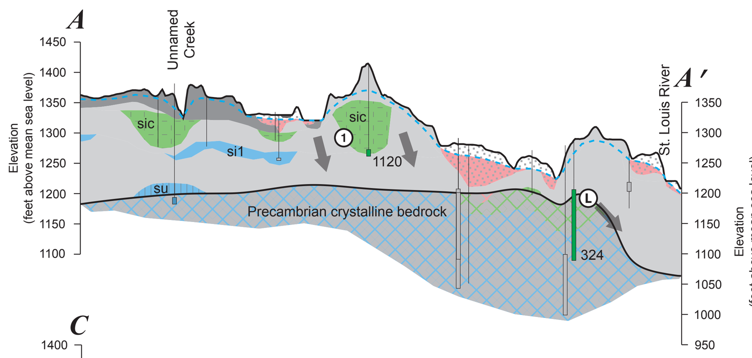
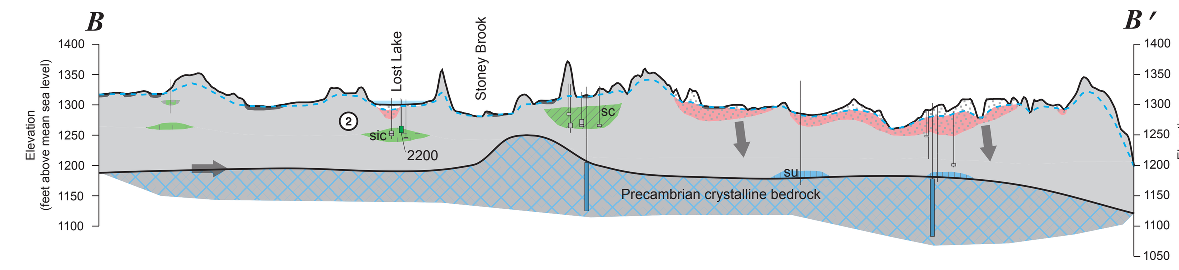


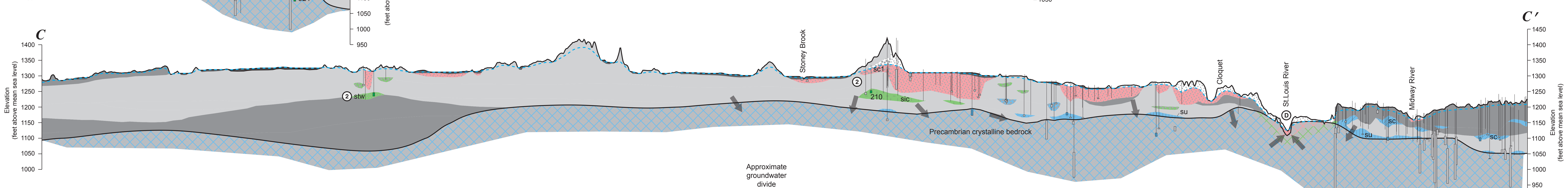


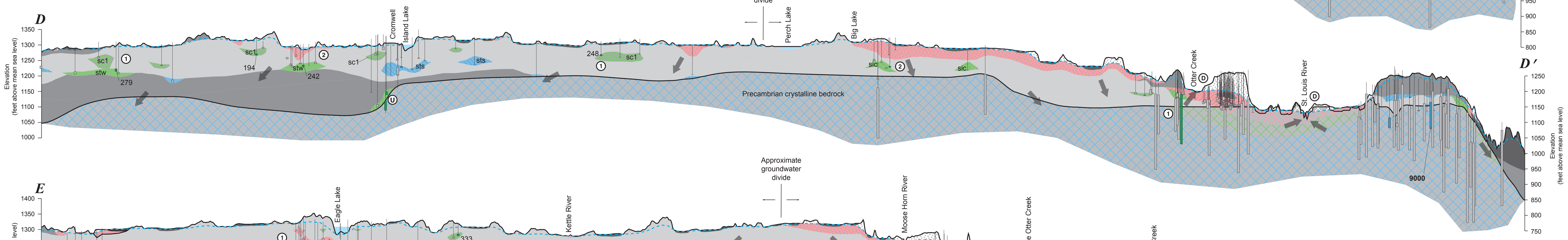
HYDROGEOLOGIC CROSS SECTIONS

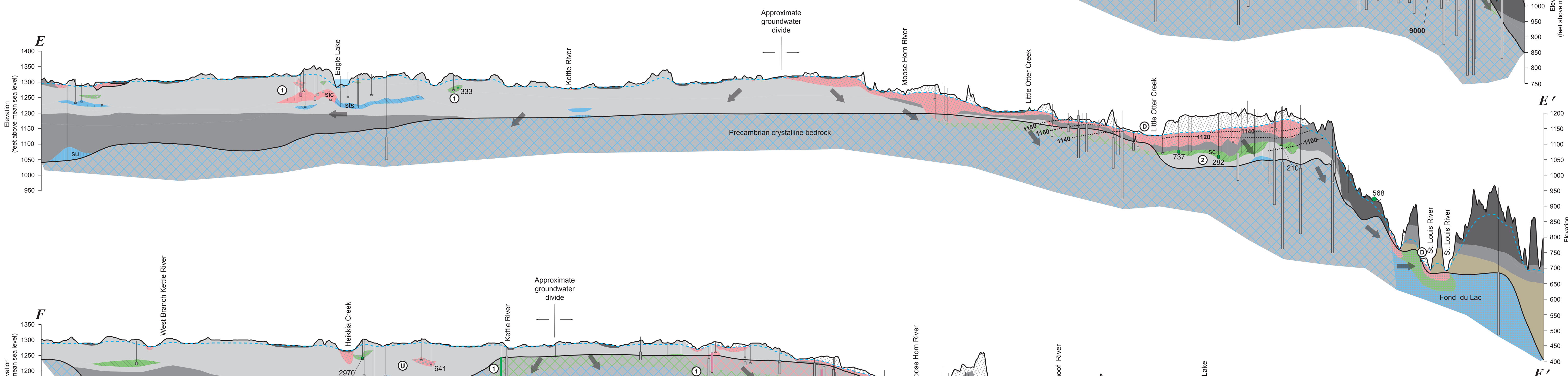
By

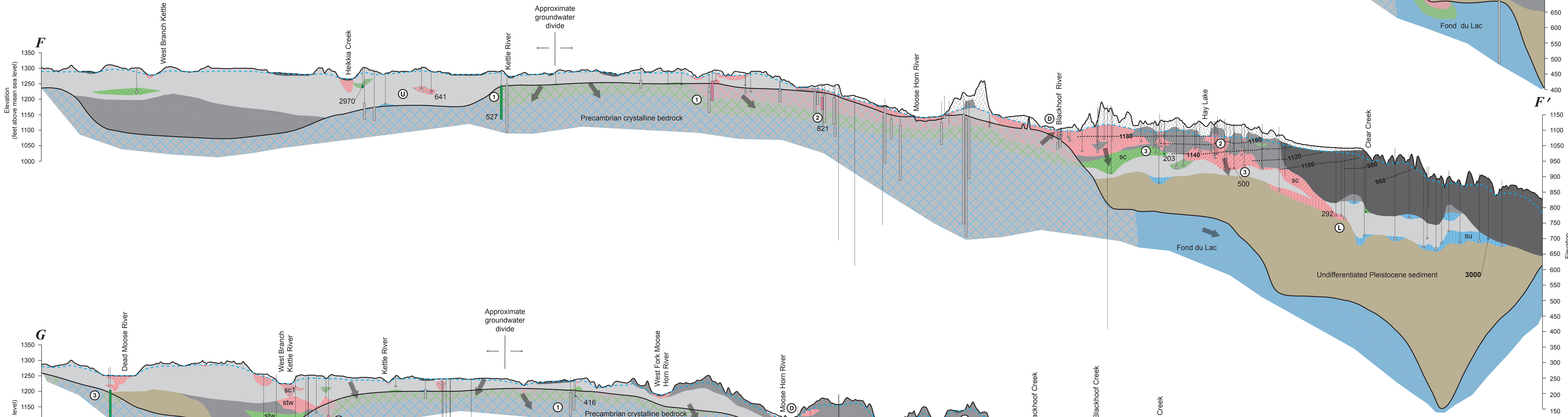
James A. Berg

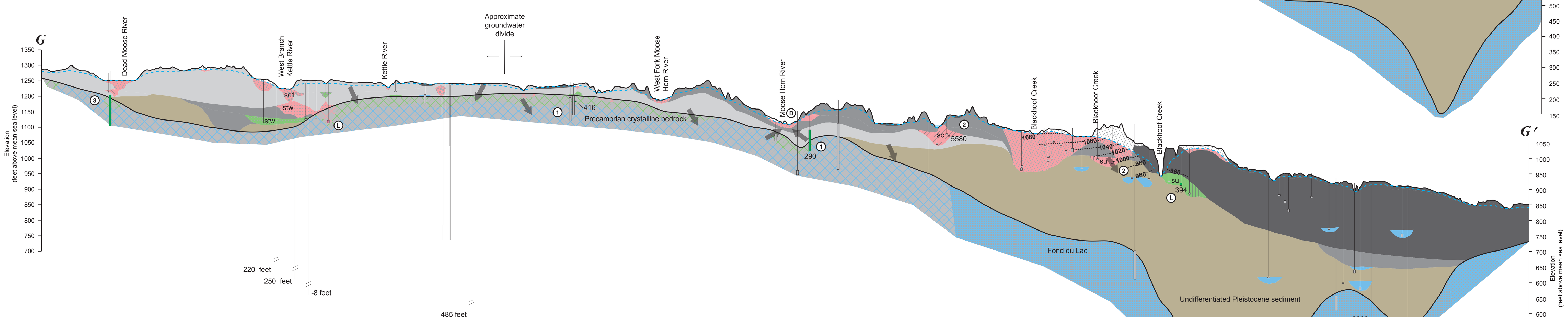
2011

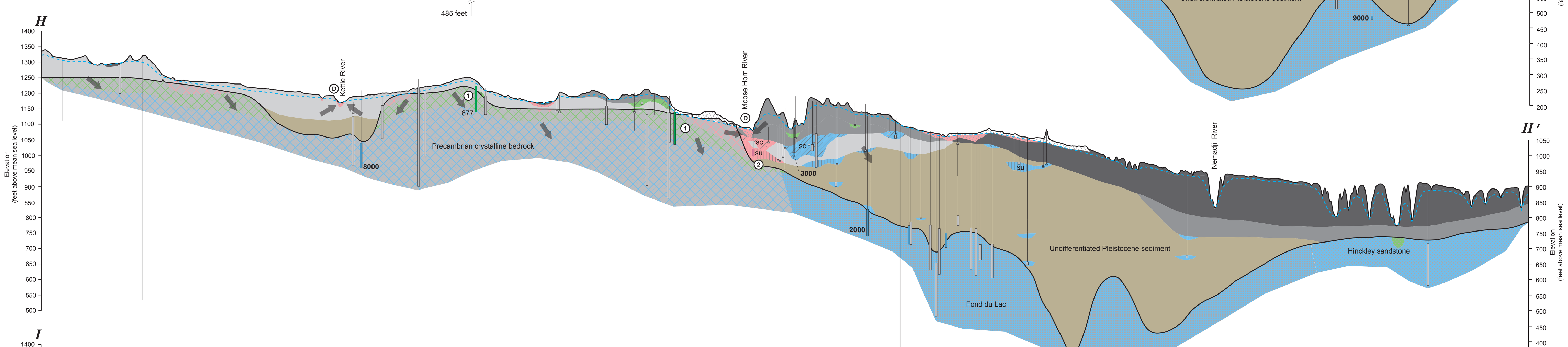


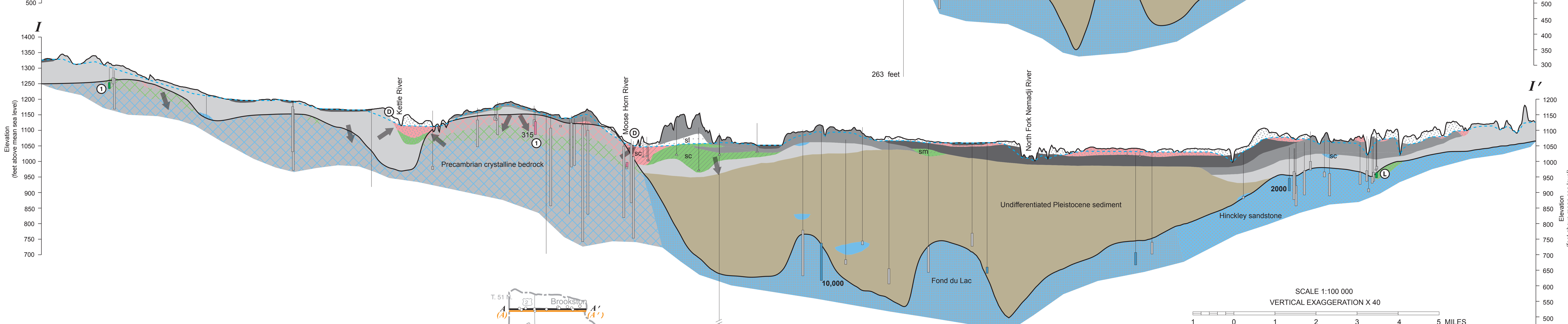












SCALE 1:100 000
VERTICAL EXAGGERATION X 40

1 0 1 2 3 4 5 MILES

1 0 1 2 3 4 5 6 7 8 9 KILOMETERS

INTRODUCTION

The nine hydrogeologic cross sections shown on this plate illustrate the horizontal and vertical extent of hydrogeologic units such as aquifers and aquitards, groundwater residence time, and general directions of groundwater flow. These cross sections were selected from a set of 53 regularly spaced, west-to-east cross sections. The cross sections were constructed using a combination of well data and information from the County Well Index (CWI), bedrock geology map (Plate 2), surficial geology map (Plate 3), and Quaternary stratigraphy (Plate 4) in Part A of this atlas. The well information for each cross section was projected onto the trace of the cross section from distances no greater than one-half kilometer. The locations of the nine cross sections in the study area are shown in Figure 1.

HYDROGEOLOGIC FEATURES AND DATA

Relative Hydraulic Conductivity

Layers shown in shades of gray on these cross sections represent till containing layers with varying sand content broadly defined in categories of inferred hydraulic conductivity. The Knife River and Wrenshall (offshore) members of the Barnum Formation, shown as the darkest gray, have the lowest average sand content, ranging from 3 percent to 12 percent (Part A, Plate 4), and they probably have the lowest hydraulic conductivities of the units shown. Other members of the Barnum Formation (Moose Lake and Lakewood tills), members of the Aitken Formation (Prairie Lake and Alborn tills), and pre-Wisconsinan till (W sequence, Winnipeg and Riding Mountain sources) are shown as medium gray, and are in the middle of the continuum with sand content ranging from 25 percent to 40 percent. The Cromwell Formation, including the Automba phase till; the Independence Formation till; Old Red till #1, #2, and #3; and a pre-Wisconsinan till (W sequence, Rainy source) are shown as the lightest gray, and are probably the most permeable of the till units with sand content ranging from 43 to 62 percent.

The surficial sand aquifers and the buried sand and gravel aquifers are shown with patterns on the cross sections. The patterns are provided to help the reader identify the aquifers on the cross sections; these patterns are not meant to convey any relative hydraulic conductivity information. Other unmapped buried sand and gravel aquifers are shown without a pattern. In a complex geologic setting such as the glacial sediments of this study area, not all of the buried sand and gravel aquifers can be associated with a particular stratigraphic interval and mapped; this is especially true of the smaller isolated occurrences. In addition, sand and gravel units that were mapped separately in Part A, Plate 5, including Quaternary geologic map units Qsw, Qsm, and Qsl are mostly surficial units and have been grouped together as the surficial sand aquifer (Figure 2).

Groundwater Residence Time

The pink, green, and blue colors shown on these cross sections represent the groundwater residence time. This is the estimated time that has elapsed since the water infiltrated the land surface to the time it was pumped from the aquifer for this investigation. Groundwater residence time is closely related to the aquifer pollution sensitivity described on Plate 10. In general, short residence time suggests high pollution sensitivity, whereas long residence time suggests low sensitivity.

Groundwater residence time can be estimated by the level of tritium (^3H) that is present in the groundwater. Tritium is a naturally occurring isotope of hydrogen, and 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 since the tritium concentrations indicate that the aquifers have been mostly recharged during the past 50 years (shown in pink). Water samples with concentrations of 1 TU or less were recharged prior to 1953 and are considered vintage water (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 waters and are referred to as mixed water (shown in green). Groundwater residence time for the vintage samples can also be estimated with the carbon-14 (^{14}C) isotope. This isotope, which also occurs naturally, has a much longer half-life than tritium (5730 years). Carbon-14 is used to estimate groundwater residence time between a range of time from about 100 years to 40,000 years.

HYDROGEOLOGY ILLUSTRATED BY THE CROSS SECTIONS

Codes are placed on the cross sections to highlight different groundwater conditions. Codes ① through ③ indicate the type of recharge for many of the aquifers that contain or are interpreted to contain groundwater tritium concentrations greater than 1 TU, which indicate recent or mixed water. These codes also appear on Plate 10, Figures 3 through 8. Code ① indicates infiltration through a thin layer of overlying fine-grained material to an underlying aquifer. Code ② shows areas where groundwater from an overlying surficial aquifer has recharged the underlying buried aquifer through leakage or a direct connection. Areas labeled code ③ indicate groundwater leakage from an overlying buried aquifer to an underlying buried aquifer. Code Ⓓ indicates an area where groundwater discharge from buried aquifers to surface-water bodies probably occurs. Code Ⓛ indicates where lateral flow of groundwater is suspected, and code Ⓤ indicates where the source of the recent or mixed groundwater is unknown.

Recharge by Infiltration through Thin, Fine-Grained Layers and Surficial Sand

Since sandy surficial materials and shallow bedrock conditions are fairly common in the study area, infiltration conditions ① and ② are widespread. Examples of both these conditions are shown on all the cross sections. A major groundwater flow divide exists in the central portion of the county with a southwest to northeast trend. The crest of this divide is shown on cross sections D–D′ through G–G′. West of this divide, where surficial sand and gravel deposits are relatively limited, infiltration through thin fine-grained layers, condition ①, is common. Occurrences are shown on the western portion of cross sections A–A′, D–D′, and E–E′ where buried sand and gravel aquifers are covered by a relatively thin (approximately 20 feet or less) layer of sandy glacial till. Similar situations are shown for the crystalline bedrock aquifer on the central and western portions of cross sections F–F′, G–G′, H–H′, and I–I′.

East of the groundwater divide infiltration through the surficial sand aquifer into underlying buried sand and gravel aquifers, condition ②, is common, although some occur west of the divide, such as the example shown on the western portion of cross section B–B′ and the central portion of cross section H–H′. Examples from the eastern side of the divide are shown on the central and eastern portions of cross sections D–D′, E–E′, F–F′, and G–G′.

Both conditions ① and ② are the dominant recharge mechanism for the crystalline bedrock aquifer with extensive areas of recent or mixed groundwater in this aquifer shown on cross sections D–D′ through I–I′. These conditions are prevalent to a lesser extent for the buried sand and gravel aquifers shown on the central and eastern portions of cross sections F–F′ through I–I′.

Recharge by Leakage through Adjacent and Multiple Aquifers

Condition ③ is somewhat rare due to the relative thinness of glacial sediment in the study area, with the exception of the southeastern portion of Carlton County. Even in the southeastern part of the county this condition is uncommon; the occurrence of buried sand and gravel aquifer lenses tends to be rare. However, two examples of this condition are shown on the eastern portion of cross section F–F′ where mixed and recent water has infiltrated through the surficial sand and an underlying adjacent buried aquifer into an even deeper buried aquifer. Another example of this condition is shown on the western portion of cross section G–G′ where mixed water was detected in the crystalline bedrock aquifer; water appears to be infiltrating from the surficial sand aquifer to the bedrock through an intervening hydraulically connected aquifer.

Discharge to Surface Water Bodies

Discharge or probable discharge of groundwater to surface water bodies, condition Ⓓ, is common for many of the streams in the study area. Groundwater discharge to the St. Louis River from the crystalline bedrock and Fond du Lac aquifers is shown on the eastern portions of cross sections C–C′ through E–E′. Groundwater discharge to the Moose Horn River from a thin surficial sand aquifer with probable connections through the crystalline bedrock aquifer is shown on cross sections G–G′ through I–I′. Groundwater discharge to the Kettle River in the southwestern portion of Carlton County is shown on the western portions of cross sections H–H′ and I–I′.

Lateral Groundwater Movement

Lateral groundwater movement, condition Ⓛ, is pervasive in most aquifer settings. The following examples are limited to locations where recent surface-water infiltration was detected, evidenced by recent or mixed water, but the apparent recharge location was upgradient from the well location. Recent water occurrence in the su aquifer shown on the eastern portion of cross section F—F′ is one example of lateral groundwater movement. At this location, vertical infiltration through the thick overlying clay-rich till seems unlikely. Since there is ample evidence upgradient of recent water infiltration, a groundwater flow pathway from the Hay Lake area to that portion of the su aquifer seems likely. Two other examples of likely lateral groundwater movement are shown on the eastern and western portions of cross section G–G′. In the eastern example, mixed water in the su aquifer appears to have traveled from the Blackhoof River valley located laterally to the west. In the western example, recent water in the bedrock aquifer east of the West Branch Kettle River valley may have moved laterally from that valley through the buried sc1 and stw aquifers.

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.

CROSS-SECTION EXPLANATION

Tritium age

Darker color in small vertical rectangle (well screen symbol) indicates tritium age of water sampled in well. Lighter color indicates tritium age of water in aquifer.

- Recent—Water entered the ground since about 1953 (10 or more tritium units [TU]).
- Mixed—Water is a mixture of recent and vintage waters (greater than 1 TU to less than 10 TU).
- Vintage—Water entered the ground before 1953 (less than or equal to 1 TU).
- Well not sampled for tritium.

Symbols and labels

- Groundwater sample from spring collected for chemical analysis; color indicates tritium age.
- 300 — If shown, chloride to bromide ratio greater than 190.
- **2000** — If shown, groundwater age in years, estimated by carbon-14 (^{14}C) isotope analysis.
- General direction of groundwater flow.
- 1250 — Approximate equipotential contour. Contour interval 20 feet.
- Water table.
- Land or bedrock surface.
- Lake.

Groundwater conditions

① Infiltration through a thin layer of overlying, fine-grained material to an underlying aquifer.
② Groundwater recharge from overlying surficial aquifer to buried aquifer.
③ Groundwater leakage from an overlying buried aquifer to an underlying buried aquifer.
Ⓓ Groundwater discharge from a buried aquifer to surface-water body.
Ⓛ Lateral groundwater flow.
Ⓤ Unknown source of recent or mixed groundwater.

Aquifers - grouped by stratigraphy and lithology

Surficial sand aquifer; generally high hydraulic conductivity.
- Surficial sand and gravel

Buried sand and gravel aquifers; generally high hydraulic conductivity.
- sm
- sl
- sc
- sc1
- sic
- sts
- stw
- su
- other sand and gravel aquifers of uncertain extent.

Sedimentary bedrock aquifers; generally lower hydraulic conductivity.
- Hinckley sandstone
- Fond du Lac

Crystalline bedrock, low hydraulic conductivity aquifer or aquitard, depending on location.
- Precambrian crystalline bedrock

Aquitards - grouped by texture ranging from highest sand content (light gray) to lowest sand content (dark gray). Percent sand content indicates relative hydraulic conductivity (see Plate 4, Table 1).

Percent sand	Geologic units (geologic map unit, Plate 4)
40 - 60	Cromwell Formation till (Qc). Independence Formation till (Qit). Old Red till, #1, 2, and 3 (Qts). Pre-Wisconsinan, W-sequence till, Rainy source (Qtr).
20 - 40	Barnum Formation till. Moose Lake member (Qm). Lakewood member (Ql). Aitkin formation till (Qa). Pre-Wisconsinan W-sequence till, Winnipeg source (Qtw). W-sequence till, Riding Mountain source (Qtm).
0 - 20	Barnum Formation till. Knife River member (Qkt). Wrenshall member, off shore (Qwf). Peat and other organic sediments (Qhp) (texture described on Plate 3).
	Undifferentiated Pleistocene sediment (Qu). Texture and relative hydraulic conductivity unknown.

Base modified from Minnesota Geological Survey, Carlton County Geologic Atlas, Part A, 2009.
Project data compiled from 2009 to 2010 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, Greg Massaro, and Shana Pascal. Edited by Neil Cunningham.

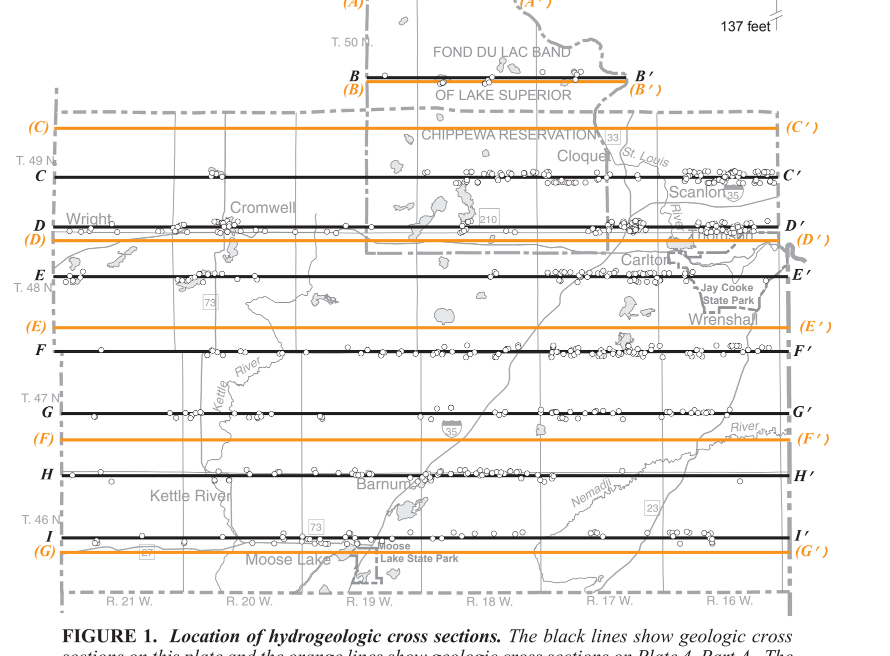


FIGURE 1. ***Location of hydrogeologic cross sections.*** *The black lines show geologic cross sections on this plate and the orange lines show geologic cross sections on Plate 4, Part A. The small open circles indicate the locations of wells displayed on the hydrogeologic cross sections shown on this plate.*

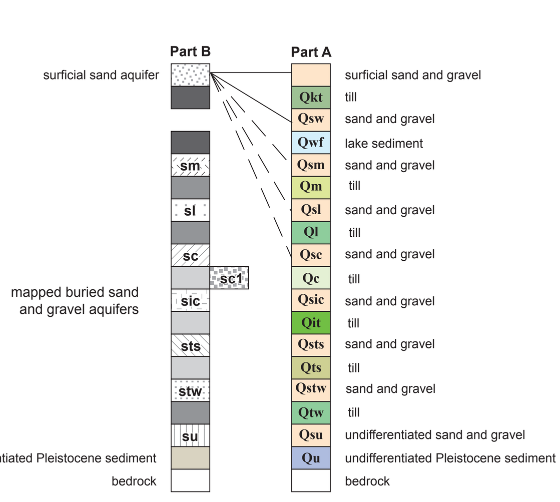
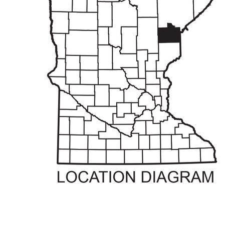


FIGURE 2. ***Hydrostratigraphy of Quaternary unconsolidated sediments (Part B) compared to the Quaternary lithostratigraphy (Part A).*** *The purpose of the Part B maps and cross sections is to build on the geologic framework and GIS map elements to describe the hydrogeology of the subsurface. Some mapped units of Part A comprise both surficial sand and buried sand and gravel sediments. Therefore, the surficial portions of some of the Part A mapped units (Qsw, Qsm, Qsl, and Qsc) were included with the Part B surficial sand aquifer. The buried sand and gravel portions of these units were included in the corresponding buried sand and gravel aquifer.*



LOCATION DIAGRAM