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Hydrogeology of the Oyen area, Alberta

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HYDROGEOLOGY OF THE OYEN AREA, ALBERTA

ABSTRACT

The Belly River, Bearpaw, and Horseshoe Canyon Formations of Late Cretaceous age constitute the upper bedrock in the map area. The surficial deposits are generally quite thin (usually less than 50 ft or 15 m) with the exception of buried valley deposits which can be as much as 500 ft thick (150 m). Yields vary from 1 to 25 igpm (0.07 to 2 L/s) over most of the map area in both bedrock and surficial sediments; however, extensive pump testing of the Bulwark sandstones of the Bearpaw Formation in the northwestern corner of the map area has indicated a yield range of 25 to 500 igpm (2 to 40 L/s) in a small area.

Groundwater quality is generally poor, and areas of salt deposits are very common over all the map area.

INTRODUCTION

The map area is located in southeastern Alberta between longitudes 110° and 112° west and latitudes 51° and 52° north. This coincides with Tp. 23 to 35, R. 1 to 15, W. 4 Mer. of the Dominion land survey system. The main towns in the area are Hanna in the west (population 2539), Youngstown in the center (population 357), and Oyen in the southeast (population 978).

Short prairie grasses are the predominant vegetation and cover most of the uncultivated land. A few trees are found in coulees; shrubs grow near the few springs present in the map area.

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TOPOGRAPHY AND DRAINAGE

TOPOGRAPHY

The Oyen map area is generally flat, except for the east flank of the Hand Hills extending along its western edge. This feature rises to a maximum elevation of 2900 ft (880 m) and is a bedrock high composed of sandstones and shales of the Horseshoe Canyon Formation. From this high, the topography slopes gently to the east to a low of 2200 ft (680 m). The southern half of the map area is marked by many incised coulees. The northeast quadrant of the map area presents a different physiography due to the presence of contorted bedrock produced by glacial action. In some areas outcrops of the bedrock show faulting and folding. The outcrop located in Sec. 8, 9, 16 and 17, Tp. 31, R. 2, W. 4 Mer. is a particularly dramatic example.

DRAINAGE

The Red Deer River, which passes through the extreme southwestern corner of the map area, is the only major river in the area. Other rivers and streams are intermittent and streams are dry most of the year. No records of annual discharge are available for any river or stream other than the Red Deer River.

The map area can be divided into three drainage systems as follows: Two main systems, one to the north and one to the south, occupy 90 percent of the area, their common boundary following approximately an east-west line through the center of the map area. The third system drains the western ridge. The northern system (Sounding Creek) drains into the North Saskatchewan River. The two other systems drain into the Red Deer River.

CLIMATE

According to the Koeppen classification, most of the Oyen map area has a climate of middle latitude steppe (Bsk): semiarid and cold, with a mean annual temperature below 64.4°F (17.2°C), but with the mean temperature of the warmest month over 64.4°F (17.2°C).

The northwest corner of the map area has a humid, continental climate, with a warm summer (Dfa): a rain-snow climate with cold winters, the mean temperature of the coldest month below 26.6°F (-3.6°C) and the mean temperature of the warmest month over 50°F (10°C); precipitation throughout the year; a hot summer with a mean temperature of the warmest month over 71.6°F (22°C) (Atlas of Canada, 1957).

Precipitation in the map area ranges from less than 12 in (300 mm) in the southeast to more than 14 in (360 mm) in the northwest. Precipitation data in this area is scarce and incomplete. There are only two full scale weather stations within the area. These are shown on the meteorological side map, along with locations of rain-gauging stations.

VEGETATION

The most prominent natural vegetation of the map area is the short prairie grasses. Trees and bushes are found only where water is more abundant; that is, in coulees. Crops consist mainly of wheat, barley, oats, and flax.

GEOLOGY

Previous geological work in this area was done by Williams and Dyer (1930), Shaw and Harding (1954), Byrne and Farvolden (1959), Lines (1963), Campbell and Almadi (1964), Irish (1967), Nichols and Wyman (1969), Given and Wall (1971), McLean (1971), and Slater (1972).

BEDROCK TOPOGRAPHY

The bedrock topography map (Carlson, 1970) shows the presence of six main buried valleys which, from west to east, are:

(1) *The Hanna buried valley:* This buried valley trends roughly in a north-south direction along the western edge of the map area and reaches a maximum depth of 170 ft (50 m). Buried gravels are present. Some of these gravels were pump tested by Kunkle (1961) and have an estimated 20-year safe yield of 60 igpm (4.5 L/s).

(2) *The Cereal buried valley:* This buried valley also trends in a north-south direction; the maximum depth noted, 470 ft (140 m), was found in ARC testhole 8. Test drilling during the summer of 1972 revealed the presence of sands, clays, and gravels. The gravels are cemented and are not water-bearing. The sandy horizons are either dry or provide only minimal amounts of groundwater.

(3) *The Oyen buried valley:* A maximum depth of 250 ft (75 m) is reached in this buried valley. The occasional sands and gravels found in it are water-bearing in some areas.

(4) *The Sibbald buried valley:* This buried valley runs in a northwest-southeast direction and reaches a maximum depth of 340 ft (105 m). In one testhole, water-bearing sand was found at a depth of 35 to 50 ft (10 to 15 m); other minor sand and gravel lenses were found at greater depths.

(5) *The Monitor buried valley:* Situated in the north-central part of the area, this channel runs almost east-west and reaches a maximum depth of 150 ft (45 m). Yields from sediments in this valley are very poor.

(6) *The Sounding Creek buried valley:* This buried valley reaches a maximum depth of 250 ft (75 m). Sands or gravels or both within the valley are water-bearing but quantities are small.

Except in these buried valleys and in the southwestern portion of the map area, where drift composed of sands, clays, and gravels is between 50 and 150 ft (15 to 45 m) thick, the map area is only thinly covered with surficial sands, clays, and tills.

BEDROCK GEOLOGY

The Horseshoe Canyon, Bearpaw, and Belly River Formations, all of Late Cretaceous age, constitute the upper part of the bedrock in the map area.

The nonmarine Horseshoe Canyon Formation is found along the western edge of the map area.

> "The strata consist mainly of non-marine, light grey weathering, clayey sandstones, buff to grey weathering, silty shales and dark carbonaceous shales with minor amounts of thin, brown weathering, hard, calcareous sandstone, coal seams, thin beds of light grey, tufaceous sandstone, and thin bentonite beds .... The thickness of Edmonton strata underlying the map area ranges from zero to about 250 feet (75 m) along the western border." (Irish, 1967).

The marine Bearpaw Formation underlies the Horseshoe Canyon Formation and is found throughout most of the map area.

> "Exposed Bearpaw strata consist of interbedded, marine, light brown weathering, brown, silty shales and fine-grained, soft, shaly sandstones with two brown-weathering, concretionary ironstone zones up to 10 inches thick (25 cm). The shaly siltstone and shaly sandstone beds, about 50 feet thick (15 m), are estimated to be close to the base of the formation and

> underlie the typical grey shale of the Bearpaw Formation. The thickness of the formation in the map area ranges from zero along the valley of Sounding Creek to between 600 to 700 feet (180 to 210 m) in the western part of the area." (Irish, 1967).

The Bulwark sandstone members of the upper Bearpaw Formation are present in the northwest quarter of the map area. Three Bulwark sandstone members have been recognized (Hydrogeological Consultants Ltd., 1972) in a number of testholes in the vicinity of Kirkpatrick Lake. The upper sandstone member was found in 15 testholes; the middle sandstone was found in five of the testholes and in only three testholes was the lower sandstone found. This third sandstone seems to discontinue east of Kirkpatrick Lake.

The Belly River Formation outcrops in the northeastern corner of the map area along a narrow belt following Sounding Creek, and also subcrops in the extreme southeast corner of the map area.

> "The strata consist of interbedded, non-marine grey to pale grey sandstones and buff-coloured, sandy shales." (Irish, 1967).

HYDROGEOLOGY

Previous hydrogeological work was done in this and neighbouring areas by Golden (1946, 1947), Meneley (1959), Kunkle (1961, 1962), Le Breton (1963, 1969), Christiansen (1965), Currie (1968), and Vanden Berg and Lennox (1969).

Thousands of water wells have been drilled within the map area. For 1700 of these, water levels were available, and these were used to construct the water level maps. One map was constructed for drift aquifers and another for bedrock aquifers. Water levels for drift aquifers follow very closely the land surface topography. The water levels in the bedrock were drawn along the western and northern edges and in the center of the map area where data were available and where bedrock sediments are the main aquifer. These levels also reflect the land surface topography.

Flowing conditions are not common in the map area and generally are due to local conditions. Flowing shotholes or flowing wells are usually less than 100 ft (30 m) deep. Deeper wells do not flow. All the discharge points known are indicated on the main map.

Springs are scarce and located only in coulees and local depressions, most of them having flow rates of less than 1 igpm (<0.07 L/s) to a maximum of 5 igpm (0.4 L/s). Only one spring was found to have a flow rate of about 50 igpm (4 L/s). Springs in this area are usually associated with areas of sodium-sulfate salt deposits. These salts are common everywhere in the map area except the north-central part.

Wells shown on the main map are those for which it was possible to compute either an apparent transmissivity based on short pump or bail tests (95 percent of the wells) or a more reliable transmissivity based on long-term pump tests. Wells with long-term pump tests are few in the map area. Most are found along the north-center edge where extensive pump tests were conducted in a 140 sq mi (≈360 km^2)-area near Kirkpatrick Lake. The average expected yield of individual wells is indicated on the map. This value is based on calculations of the 20-year safe yield using the formula (Farvolden, 1961):

$$(1) \qquad Q_s20 = \frac{TH}{2110}$$

where:

Q_s20 = safe yield supplied from existing storage for 20 years, in igpm;

T = coefficient of transmissivity, in igpd/ft;

H = total available drawdown in feet. (For confined aquifers, H = depth to top of aquifer minus depth to static water level; for unconfined aquifers, H is rather arbitrarily taken at two thirds of the difference between static water level and the base of the aquifer.)

The coefficient of transmissivity was calculated from bail and pump test data using the formula (Todd, 1959, p. 94):

$$(2) \qquad T = \frac{264Q}{\Delta s}$$

where:

Q = pumping rate in igpm;

Δs = drawdown in ft/log cycle, the data being plotted on semilogarithmic paper.

Formula (2) was also used to calculate "Apparent Transmissivity" (Farvolden, 1961) from bail tests or short pump tests in which only the initial or static water level and the water level at the end of the test were known.

Yields in the Oyen map area are uniformly rather low. About 60 percent of the map area has a 20-year safe yield between 1 and 5 igpm (0.07 to 0.4 L/s). This yield range is found both in the drift and in the bedrock, more specifically in sands and gravels and in sandstone strata. About 30 percent of the area yields 5 to 25 igpm (0.4 to 2 L/s), from both the drift and bedrock. The remainder of the area shows yields of 25 to 500 igpm (2 to 40 L/s). These higher yields are from the Bulwark sandstone members of the Bearpaw Formation near Kirkpatrick Lake in the northwest corner of the map area, and from the sandstone strata of the Belly River Formation in the northeast.

Three sandstone horizons (called Bulwark sandstones) of the upper Bearpaw Formation are found in the northwest corner of the map area and are water-bearing. Extensive drilling and aquifer testing were conducted in particular by Hydrogeological Consultants Ltd. in 1972 to determine the extent, thickness, and hydraulic parameters of these three sandstone horizons. Groundwater from these various sandstones is withdrawn in the vicinity of Kirkpatrick Lake and Hamilton Lake area to the north for secondary recovery of oil. Aquifer testing conducted in 1972 by Hydrogeological Consultants Ltd. indicates that in the Kirkpatrick Lake area pumping in the upper sandstone aquifer affects water levels in the middle sandstone but "the response in zone 11 (middle sandstone) appears to be a short-term one, lasting only a few hours." Declining heads in the upper sandstone are due to pumping in the main water source wells. A few farm wells are completed in all three sandstone horizons in the immediate vicinity of Kirkpatrick Lake and the recommendation was made in a 1974 report by the Department of the Environment on the Hamilton Lake general area that in some of the water source wells, production should be cut by half; it was stated in this report that "lowering in farmer's water levels and production is caused by such pumping."

Sands and gravels are known to exist along the southern edge of the map area but had not shown much groundwater potential. Test drilling conducted during the summer of 1972 showed that these sands and gravels which extend over an area of about 30 mi (48 km) in length and about 6 mi (≈10 km) in width, are cemented and are either dry or have a Q_{20} of less than 1 igpm (<0.07 L/s). The cementation of the sand gravel zone is continuous except in one area about 1 mi (1.5 km) wide and 3 mi (5 km) long; this area is located in the one third eastern portion of the cemented sand and gravel zone. One farm well completed in this zone was pump tested and found to have a Q_{20} of 48 igpm (3.6 L/s).

HYDROCHEMISTRY

Hydrochemistry maps are presented for both drift and bedrock waters. The number of chemical analyses used to draw these maps were 639 for the bedrock and 575 for the drift. Data control points were quite evenly distributed as the data density map shows. The chemical analyses are from the Provincial Analyst, the Pollution Control Laboratory of Alberta Environment, and the Alberta Research Council Geochemistry Laboratory.

DRIFT WATERS

The total dissolved solids contents of drift waters range from 1000 mg/L to 5000 mg/L. Limited areas have waters with less than 1000 mg/L. These waters are found in zones of surficial sands. The increase in total dissolved solids contents seems to relate to the thinning of the drift: the higher the total dissolved solids content, the thinner the drift and the closer to surface the bedrock. The average total dissolved solids content in drift waters is 2000 mg/L.

Calcium-magnesium type waters are found in limited portions of the eastern part of the map area in both recharge and discharge areas. Groundwaters with sodium plus potassium constituting over 60 percent of total cations are present in the western part of the map area. Between the calcium-magnesium and sodium-potassium zones there is a transition area of mixed waters. The sodium-potassium waters are found where the Horseshoe Canyon Formation underlies thin drift deposits.

Bicarbonate type waters are found in small areas in the southeast and northwest part of the map area where total dissolved solids contents are less than 1000 mg/L or at other locations where the drift is thin.

Sulfate waters are present in the center of the map area where total dissolved solids contents are generally higher than 2000 mg/L.

Waters with chloride constituting over 60 percent of total anions are not found in the drift.

BEDROCK WATERS

Within the map area, except for the more transmissive Bulwark sandstones, the bedrock units yield waters with total dissolved contents greater than 1000 mg/L. Calcium-magnesium type waters are very seldom found in bedrock sediments. Bicarbonate makes up over 60 percent of the total anions in groundwaters of the Horseshoe Canyon Formation. Over 60 percent of total anions in groundwater in sandstone aquifers are sulfate. Bedrock waters usually have less than 60 percent of total anions as chlorides. However, waters from the Belly River Formation in the eastern part of the map area at depths of 600 to 900 ft (180 to 275 m) can have a chloride content up to 57 percent of total anions.

IRON, FLUORIDES, NITRATES, AND SALT DEPOSITS

Generally, both in the drift and in the bedrock, iron concentration is very high and in 90 percent of the wells is over 0.3 mg/L. Concentrations as high as 150 mg/L have also been measured.

Fluorides are not present in high concentrations. In 95 percent of the cases the fluoride content is less than 1 mg/L for bedrock waters and less than 0.5 mg/L in the case of drift waters.

Nitrates are more common and occur in higher concentrations in drift aquifers than in bedrock aquifers, but no real trend can be recognized.

Salt deposits on the surface are a very common feature over the entire map area, and can be quite thick in some cases. The analysis of one salt sample taken on the edge of a slough in the northeast corner of the map area showed the salt to be pure sodium-sulfate (99 percent purity according to the Alberta Research Council chemistry lab). A water sample taken from the same slough had a total dissolved solids content of over 300,000 mg/L with high concentrations of sodium, magnesium, sulfates, and chlorides (in decreasing order).

CONCLUSIONS

In the Oyen map area, the yields of aquifers are low (less than 25 igpm or 2 L/s) and groundwater quality is poor (total dissolved solids greater than 1000 mg/L) except in the Kirkpatrick Lake area where yields greater than 25 igpm (2 L/s) can be obtained and where total dissolved solids content is less than 1000 mg/L. Waters are generally of sodium sulfate type but are often a mixture of sodium sulfate and sodium bicarbonate types. The iron concentration is high almost everywhere, and groundwater commonly contains nitrates. Salt deposits are found on the surface over large portions of the map area.

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APPENDIX A

1. Carolside Testhole 1

Location: Lsd 5, Sec 31, Tp 25, R 11, W 4th Mer

Depth (feet)	Lithology
0-5	Till, very dark gray (5Y3/1): 10 percent fine, gray sand, 30 percent gray silt, 60 percent clay; gravel; gypsum, extra large crystals
5-10	Till, very dark grayish brown (2.5Y4/2): 10 percent fine, gray sand, 30 percent gray-brown silt, 60 percent clay
10-15	Till, very dark grayish brown (2.5Y4/2): 10 percent fine, gray sand, 30 percent gray-brown silt, 60 percent clay
15-20	Till, light brownish gray (2.5Y5/5/2): 10 percent gray sand, 35 percent gray-brown silt, 55 percent clay
20-25	Till, gray (5Y5/1): 10 percent fine, gray sand, 60 percent gray silt, 30 percent clay
25-30	Till, very dark gray (5Y3/1): 15 percent fine to medium, gray sand, 60 percent gray silt, 25 percent clay
30-35	Gravel and sand: gravel is from 3/4 inch to 1/4 inch in diameter; sand is medium to coarse, gray, some clay and silt
35-40	Sand and gravel: brown (10YR5/3), medium to coarse sand, fine gravel 1/4 inch; some white sand
40-45	Sand and gravel: medium to coarse, brown sand, fine to medium gravel 1/4 inch; iron stain
45-50	Sand and gravel: medium to coarse, brown sand, fine to coarse gravel
50-55	Till, olive gray (5Y4/2): 10 percent fine to medium, reddish brown sand, 20 percent gray silt, 70 percent clay; some gravel; iron stain in sand
55-60	Till, black (5Y2/1): 10 percent fine to medium sand, 15 percent gray silt, 75 percent black clay, some gravel; iron stained
60-65	Till, dark olive gray (5Y3/2): 5 percent fine, gray sand, 15 percent gray silt, 80 percent gray to brown clay; gravel
65-70	Till, olive gray (5Y4/5/2): 5 percent fine, gray sand, 55 percent gray silt, 40 percent gray clay
70-75	Till, olive gray (5Y4.5/2): 5 percent gray sand, 40 percent gray silt, 55 percent gray clay
75-80	As above
80-85	Silt, olive gray (5Y4.5/2): 25 percent gray clay
85-90	Silt, olive gray (5Y4.5/2): 15 percent gray clay

Carolside Testhole 1 (continued)

Location: Lsd 5, Sec 31, Tp 25, R 11, W 4th Mer

Depth (feet)	Lithology
90-95	Silt, olive gray (5Y4.5/2): 20 percent gray clay
95-100	Silt, olive gray (5Y4.5/2): 15 percent gray clay

2. Carolside Testhole 2

Location: Lsd 4, Sec 15, Tp 25, R 10, W 4th Mer

Depth (feet)	Lithology
0-5	Till, grayish brown (10YR5/2): 10 percent fine to medium sand, 15 percent clay, 75 percent silt
5-10	Till, light olive brown (2.5Y5/3): 10 percent fine to medium, light to dark brown sand, 75 percent light brown silt, 15 percent very light brown clay; the sand and silt are mainly quartz
10-15	Till, olive (5Y5/3): 5 percent fine, brown sand, 75 percent light and dark brown silt, 20 percent light brown clay; gypsum crystals
15-20	Till, olive (5Y5/3): gravel, 15 percent fine, brown sand, 60 percent brown silt, 25 percent light brown clay; coal fragments and gypsum crystals; iron stain
20-25	Till, olive (5Y5/3): 10 percent fine to medium sand, 80 percent fine, brown silt, 10 percent brown clay; iron-stained gravel
25-30	Till, olive (5Y5/3): 5 percent fine to medium, brown sand, 60 percent fine, brown silt, 35 percent brown clay; gravel; gypsum crystals
30-35	Till, olive (5Y5.5/3): gravel, 5 percent fine to medium, brown sand, 55 percent fine, brown silt, 35 percent brown clay
35-40	Till, olive (5Y5/3): 10 percent fine, brown sand, 65 percent brown silt, 25 percent clay; iron staining
40-45	Till, olive brown (2.5Y4/3.5): 25 percent light to dark sand, 60 percent light to dark silt, 15 percent light brown clay; gravel
45-50	Till, olive (5Y5/3): 15 percent brown sand, 75 percent brown silt, 10 percent light brown clay
50-55	Sand and silt, light olive gray (5Y6/2): 75 percent fine to medium, light to dark sand, 25 percent light brown, dark silt; gypsum crystals; iron staining
55-60	Sand and silt and gravel, dark grayish brown (2.5Y4.5/3): 5 percent gravel, 60 percent coarse to fine, light to dark sand, 30 percent brown silt, 5 percent clay; gypsum crystals; iron staining

Carolside Testhole 2 (continued)

Location: Lsd 4, Sec 15, Tp 25, R 10, W 4th Mer

Depth (feet)	Lithology
60-65	Till and gravel, grayish brown (2.5Y5/2): 60 percent fine to medium, brown sand, 35 percent silt, 5 percent clay, gravel; gypsum crystals
65-70	Sand and silt, pale olive (5Y6/3): 20 percent fine, brown sand, 80 percent brown silt; gypsum crystals
70-75	Silt, sandy, olive (5Y5/3): 50 to 10 percent sand
75-77	Silt, sandy, as above
77-80	Gravel and sand: fine gravel, coarse sand, light to dark, 2 mm to 2 cm
80-85	Gravel: fine, medium brown, 2 cm
85-90	Sand: coarse, light gray
90-95	Till, gray (5Y5/1): 5 percent gray sand, 70 percent gray silt, 25 percent clay
95-100	Till, gray (5Y5/1.5): 5 percent light sand, 65 percent gray silt, 30 percent clay; gypsum crystals
100-105	Till, gray (5Y5/1): 10 percent clear sand, 65 percent gray silt, 25 percent gray clay; coal fragments
105-110	Till, gray (5Y5/1): 10 percent clear sand, 65 percent gray silt, 25 percent gray clay
110-115	Till, gray (5Y5/1.5): 10 percent clear sand, 60 percent gray silt, 30 percent gray clay
115-120	Till, olive gray (5Y5/2): 5 to 10 percent gravel, 20 to 25 percent gray sand, 60 percent gray silt, 10 percent gray clay
120-125	No sample
125-130	Till, olive gray (5Y5/2): 5 to 10 percent fine gravel, 50 to 55 percent coarse to fine, light sand, 35 percent gray silt, 5 percent clay
130-135	Till, olive gray (5Y5/2): some medium to fine gravel; 5 to 10 percent clay; 10 to 15 percent silt
135-140	Till, gray (5Y5/1): coarse to fine (mostly medium); 10 to 15 percent gray silt; 5 to 10 percent clay; some fine gravel
140-145	Till, olive gray (5Y5/1): 5 to 10 percent fine, gray silt; 5 to 10 percent clay; some mica, gravel
145-150	Gravel and sand, gray (5Y5/1): fine gravel and coarse to fine, gray sand; 5 to 10 percent gray silt; 5 to 10 percent gray clay
150-155	Sand, olive gray (5Y5/2.5): fine to medium, 5 to 10 percent clay; coal fragments

Carolside Testhole 2 (continued)

Location: Lsd 4, Sec 15, Tp 25, R 10, W 4th Mer

Depth (feet)	Lithology
155-160	Till, olive gray (5Y4/2): 40 percent medium to fine, brown sand, 20 percent dark brown silt, 40 percent very dark brown clay
160-165	Till, dark olive gray (5Y3/2): gravel, 25 percent medium, gray sand, 50 percent dark gray silt, 25 percent gray clay
165-170	Silty clay, dark olive gray (5Y3/2): 20 percent silt; gravel
170-175	Silty clay, dark olive gray (5Y3/2): 20 percent silt
175-180	Silty clay, dark olive gray (5Y3/2): 20 percent silt; iron stain
180-185	Silty clay, dark olive gray (5Y3/2): 20 percent silt
185-195	Silty clay, gray (5Y5/1): 20 percent silt

3. Big Stone Testhole 3

Location: Lsd 15, Sec 9, Tp 24, R 9, W 4th Mer

Depth (feet)	Lithology
0-5	Till, olive gray (5Y4/2.5): 60 percent fine to medium, gray sand, 25 percent gray silt, 5 percent clay
5-10	Till, dark olive gray (5Y3/2): 60 percent fine to medium, gray sand, 25 percent gray silt, 15 percent clay
10-15	Till, olive gray (5Y5/2): 50 percent fine to medium, gray sand, 35 percent gray silt, 15 percent clay; iron stain; gypsum crystals
15-20	Till, olive gray (5Y5/2.5): 35 percent fine to medium, gray sand, 35 percent gray silt, 30 percent clay; coal fragments
20-25	Till, olive gray (5Y5.5/2): 35 percent fine to medium, gray sand, 45 percent gray silt, 20 percent clay
25-30	Sand and gravel: coarse to fine sand, gravel up to 1/2 inch
30-35	Same as above
35-40	Till, olive gray (5Y5.5/2): 30 percent fine to medium, gray sand, 45 percent gray silt, 25 percent clay
40-45	Till, olive gray (5Y5.5/2): 30 percent fine to medium, gray sand, 55 percent gray silt, 15 percent clay
45-50	Till, olive gray (5Y5/2): 25 percent fine to medium, gray sand, 60 percent gray silt, 15 percent clay

Big Stone Testhole 3 (continued)

Location: Lsd 15, Sec 9, Tp 24, R 9, W 4th Mer

Depth (feet)	Lithology
50-55	Till, olive gray (5Y5/2): 40 percent fine to medium, gray sand, 45 percent gray silt, 15 percent clay
55-60	Till, olive gray (5Y5/2.5): 30 percent fine to medium, gray sand, 55 percent gray silt, 15 percent clay
60-65	Till, olive gray (5Y5/2): 35 percent fine to medium, gray sand, 45 percent gray silt, 20 percent clay; iron stain
65-70	Till, olive gray (5Y5/2): 40 percent fine to medium, gray sand, 40 percent gray silt, 20 percent clay
70-75	Till, olive gray (5Y5/2): 50 percent fine to medium, gray sand, 35 percent gray silt, 15 percent clay
75-80	Till, olive gray (5Y5/2): 40 percent fine to medium, gray sand, 40 percent gray silt, 20 percent clay
80-85	Till, olive gray (5Y5/2): 35 percent fine to medium, gray sand, 45 percent gray silt, 20 percent clay; some iron stain
85-90	Till, olive gray (5Y5/2): 20 percent fine to medium, gray sand, 60 percent gray silt, 20 percent clay, gravel
90-95	Till, olive gray (5Y5/2): 15 percent fine, gray sand, 65 percent gray silt, 20 percent clay; a few medium sands through sample
95-100	Same as above
100-105	Till, dark gray (5Y4/1): 10 percent fine, gray sand, 70 percent gray silt, 20 percent clay; iron stain; fine gravel
105-110	Till, olive gray (5Y5/2): 10 percent fine, gray sand, 65 percent gray silt, 25 percent clay, gravel
110-115	Same as above
115-120	Same as above
120-125	Till, olive gray (5Y5/2): 20 percent fine to coarse, gray sand, 55 percent gray silt, 25 percent clay; gravel
125-130	Till, olive gray (5Y5/2): 15 percent fine, gray sand, 65 percent gray silt, 20 percent clay
130-135	Till, olive gray (5Y5/2): 10 percent fine, gray sand, 65 percent gray silt, 25 percent clay; coal fragments
135-140	Till, olive gray (5Y5/2): 10 percent fine, gray sand, 65 percent gray silt, 25 percent clay
140-145	Till, olive gray (5Y5/2): 10 percent fine, gray sand, 65 percent gray silt, 25 percent clay; gravel

Big Stone Testhole 3 (continued)

Location: Lsd 15, Sec 9, Tp 24, R 9, W 4th Mer

Depth (feet)	Lithology
145-150	Same as above
150-155	No sample
155-160	Sand, olive (5Y5/3): fine to medium (mostly fine); 5 percent clay
160-165	Sand, olive gray (5Y4/2): fine; 5 percent clay
165-170	Sand, very dark grayish brown (2.5Y3/2): fine, 15 percent silt, 15 percent clay
170-175	Sand, dark grayish brown (2.5Y4/2): fine, 20 percent silt, 15 percent clay; gravel
175-180	Till, grayish brown (2.5Y5/2): 60 percent fine, gray sand, 25 percent gray silt, 15 percent clay; gravel
180-185	Till, olive (5Y4/3): 10 percent medium to fine, gray sand, 75 percent gray silt, 15 percent clay; gravel
185-190	Till, olive (5Y4/3): 20 percent gray sand, 70 percent gray silt, 10 percent clay
190-195	Silt, olive gray (5Y5/2): 10 percent clay, 5 percent fine, gray sand
195-200	Till, grayish brown (2.5Y5/2): 25 percent medium to fine, gray sand, 60 percent silt, 15 percent clay; gravel
200-205	Till, gray (5Y6/1): 25 percent medium to fine, gray sand, 65 percent light gray silt, 10 percent clay; some coarse sand
205-210	Till, light olive gray (5Y6/2): 15 percent medium to fine, gray sand, 75 percent light gray silt, 10 percent clay
210-215	Till, gray (5Y5.5/1): 25 percent medium to fine, gray sand, 60 percent light gray silt, 15 percent clay; gravel
215-230	No sample; gravel at 228
230-235	Cemented gravel
235-240	Cemented gravel
240-245	Cemented gravel
245-247.5	Cemented gravel
247.5-250	Till, grayish brown (2.5Y5/2): 25 percent gravel, 20 percent fine to medium, light gray sand, 30 percent gray silt, 25 percent clay
250-255	Till, grayish brown (2.5Y5/2): 50 percent clay, 35 percent gray silt, 5 percent fine to medium, gray sand, 10 percent gravel; iron stain
255-260	Till, grayish brown (2.5Y5/2): 30 percent gravel, 5 percent fine, gray sand, 40 percent gray silt, 25 percent clay; iron staining

Big Stone Testhole 3 (continued)

Location: Lsd 15, Sec 9, Tp 24, R 9, W 4th Mer

Depth (feet)	Lithology
260-265	Sandstone, light gray (5Y6/1): fine, soft
265-270	Sand and clay, gray (5Y5/1): fine
270-275	Sandstone, light gray (5Y6/1): fine, medium hard
275-280	Sand and clay, dark gray (5Y4/1): fine
280-285	Silt and clay, dark gray (5Y4/1)
285-290	Sand and clay, olive gray (5Y5/2): fine
290-295	Sand and clay, olive gray (5Y5/2): fine to medium
295-300	Sand and clay, light gray (5Y6/1): fine to medium to coarse; coal fragments
300-305	Sand, grayish brown (2.5Y5/2): fine, 20 percent clay
305-310	Sand, clay, light gray (5Y6/1): fine to medium
310-320	Shale, black (10YR2/1)

4. Cicon Testhole 5

Location: Lsd 4, Sec 11, Tp 24, R 8, W 4th Mer

Depth (feet)	Lithology
0-5	Till, olive (5Y4/3): 5 to 10 percent fine to medium, gray-brown sand, 45 to 50 percent gray silt, 45 percent clay
5-10	Till, olive (5Y4/3): 5 to 10 percent fine to medium, gray sand, 50 to 55 percent gray silt, 40 to 45 percent clay
10-15	Till, olive (5Y5.5/3): 10 percent fine, gray sand, 50 percent gray silt, 40 percent clay; coal fragments; iron stain; gypsum crystals
15-20	Till, olive (5Y5.5/3): 5 percent fine, gray sand, 50 percent gray silt, 45 percent clay
20-25	Till, olive (5Y5/3): 5 percent fine, gray sand, 50 percent gray silt, 45 percent clay; gypsum crystals
25-30	Till, olive (5Y5/3): 10 percent fine, gray-brown sand, 45 percent gray-brown silt, 45 percent clay; gypsum crystals
30-35	Till, pale olive (5Y6/3): 10 percent fine to medium, gray-brown sand, 35 percent gray silt, 55 percent clay; gypsum crystals; coal fragments
35-40	Till, pale olive (5Y6/3): 25 percent fine to medium, gray and brown sand, 45 percent gray silt, 30 percent clay
40-45	Till, pale olive (5Y6/3): 30 percent fine, gray and brown sand, 50 percent gray silt, 20 percent clay

Cicon Testhole 5 (continued)

Location: Lsd 4, Sec 11, Tp 24, R 8, W 4th Mer

Depth (feet)	Lithology
45-50	Till, pale olive (5Y5/3): 35 percent fine, gray and brown sand, 50 percent gray silt, 15 percent clay; gypsum crystals
50-55	Till, pale olive (5Y5/3): 40 percent fine, gray and brown sand, 50 percent gray silt, 10 percent clay; gypsum crystals
55-60	Sand, olive (5Y5/3): fine, subangular, gray to brown, 5 percent clay
60-65	Till, olive (5Y5/3): 25 percent gravel (pea size), 40 percent fine to medium sand, 25 percent gray silt, 10 percent clay
65-70	Sand, pale olive (5Y5/3): fine to medium, gray and brown sand, 5 percent clay
70-75	Till, olive (5Y5/3): 15 percent gravel (pea size), 45 percent fine to medium, gray-brown sand, 35 percent gray silt, 5 percent clay
75-80	Sand, light brownish gray (2.5Y6/2): fine to medium, 5 to 10 percent clay; gravel; pebbles
80-85	Sand, pale olive (5Y6/3): fine to coarse, 10 to 15 percent gray silt, 5 to 10 percent clay; gravel; pebbles
85-90	Sand, light brownish gray (2.5Y6/2): fine to coarse, 5 to 10 percent clay; gravel; pebbles; iron stain
90-95	Same as above
95-100	Sand, light brownish gray (2.5Y6/2): fine to medium; gypsum crystals
100-105	Silt, light brownish gray (2.5Y6/2): 5 to 10 percent clay, 5 percent very fine sand
105-110	Same as above
110-115	Silt, light gray (2.5Y7/2): 10 percent fine, gray-brown sand, 15 percent clay
115-120	Sand, light brownish gray (2.5Y6/2): fine to medium, some coarse, 5 percent silt, 5 percent clay; some gravel (5 percent)
120-125	Sand, light brownish gray (2.5Y6/2): fine to medium, 5 percent clay, 10 percent silt, 5 percent gravel
125-130	Silt, pale olive (5Y6/3): 5 percent fine sand, 25 percent clay
130-135	Till, pale olive (5Y6/3): 10 percent fine, gray sand, 65 percent gray silt, 25 percent clay; gravel
135-140	Same as above
140-145	Till, pale olive (5Y6/3): 15 percent fine, gray sand, 65 percent gray silt, 20 percent clay
145-150	Till, pale olive (5Y6/3): 10 percent fine, gray sand, 70 percent gray silt, 20 percent clay

Cicon Testhole 5 (continued)

Location: Lsd 4, Sec 11, Tp 24, R 8, W 4th Mer

Depth (feet)	Lithology
150-155	Silt, pale olive (5Y6/3): 5 percent fine, gray sand, 20 percent clay
155-160	Sand, light gray (5Y7/2): fine to medium, subangular; some gravel
160-165	Gravel and sand: gravel is slightly cemented
165-170	Coarse gravel and medium to fine gray sand: 10 percent sand
170-175	Gravel and sand, 50 percent; 50 percent fine to medium, gray sand, some coarse
175-180	Till: 50 percent gravel, 45 percent fine to medium, gray sand, 5 percent silt
180-185	Gravel, slightly cemented

5. Krause Testhole 6

Location: Lsd 16, Sec 2, Tp 24, R 7, W 4th Mer

Depth (feet)	Lithology
0-5	Clay, black (5Y2/1): very hard; 15 percent light gray silt
5-10	Till, dark grayish brown (2.5Y4/2): 15 percent fine to medium, reddish brown sand, 35 percent gray and brown silt, 50 percent clay
10-15	Till, very dark grayish brown (2.5Y3/2): 25 percent fine, grayish brown sand, 50 percent brown silt, 25 percent clay
15-20	Till, very dark grayish brown (2.5Y3/2): 20 percent fine to medium, grayish brown sand, 50 percent dark brown silt, 30 percent clay; gypsum crystals
20-25	Till, olive (5Y4/3): 25 percent fine, grayish brown sand, 60 percent dark brown silt, 15 percent clay; gypsum crystals
25-30	Till, olive (5Y4/3): 20 percent fine to medium, grayish brown sand, 65 percent dark brown silt, 15 percent clay
30-35	Sand, light brownish gray (2.5Y6/2): fine to coarse, well rounded; some gravel
35-37.5	Till, olive (5Y5/3): 35 percent fine to coarse, gray and brown sand, 45 percent gray silt, 15 percent clay, 5 percent gravel
37.5-45	Sand, light brownish gray (2.5Y6/2): fine to coarse, subrounded; some gravel

Krause Testhole 6 (continued)

Location: Lsd 16, Sec 2, Tp 24, R 7, W 4th Mer

Depth (feet)	Lithology
45-50	Same as above
50-55	Till, dark grayish brown (2.5Y4.5/2): 15 percent fine to medium, gray sand, 60 percent silt, 25 percent clay
55-60	Sand, grayish brown (10YR5/2): fine to medium, subrounded
60-65	Same as above and some gravel
65-70	Till, very dark grayish brown (2.5Y3/2): 65 percent fine to medium, gray-brown sand, 20 percent gray-brown silt, 15 percent clay
70-75	Till, very dark grayish brown (2.5Y3/2): 65 percent fine to coarse, gray-brown sand, 15 percent gray-brown silt, 20 percent clay
75-80	Sand and gravel: coarse, brownish, subrounded sand and fine gravel
80-85	Sand, grayish brown (2.5Y5/2): medium to coarse, subrounded; some gravel
85-90	Till, dark olive gray (5Y3/2): 10 percent fine to medium, gray sand, 50 percent gray silt, 40 percent clay; some gravel
90-95	Sand, dark grayish brown (2.5Y4/2): coarse, gray and brown sand, fine, brown sand with clay
95-100	Sand, grayish brown (10YR5/2): medium to coarse, gray and brown sand, 10 percent silt
100-105	Same as above
105-110	Till, grayish brown (2.5Y5/2): 30 percent fine to coarse, gray-brown sand, 40 percent gray silt, 30 percent clay
110-115	Till, olive (5Y4.5/3): 40 percent fine to medium, gray-brown sand, 45 percent gray silt, 15 percent clay; some gravel pebbles
115-120	Till, olive gray (5Y4/2): 25 percent fine to coarse, gray-brown sand, 25 percent gray silt, 50 percent clay; some gravel pebbles
120-125	Same as above
125-130	Sand, grayish brown (2.5Y5/2): medium to coarse, 15 percent silt, 15 percent clay; some gravel pebbles
130-135	Sand, grayish brown (2.5Y5/2): medium to coarse, 15 percent gray silt, 15 percent clay; some gravel
135-140	Till, olive (5Y5/3): 20 percent fine, gray sand, 55 percent gray silt, 25 percent clay
140-145	Till, olive (5Y5/3): 5 percent fine gravel, 20 percent fine to medium to coarse, gray-brown sand, 55 percent gray silt, 20 percent clay

Krause Testhole 6 (continued)

Location: Lsd 16, Sec 2, Tp 24, R 7, W 4th Mer

Depth (feet)	Lithology
145-150	Till, olive (5Y5/3): 15 percent fine, gray sand, 65 percent gray silt, 20 percent clay
150-155	Same as above
155-160	Till, olive (5Y5/3): 10 percent fine, gray sand, 55 percent gray silt, 25 percent clay
160-165	Same as above
165-170	Same as above
170-175	Silt, olive (5Y5/3): 25 percent clay
175-180	Same as above
180-185	Till, olive (5Y5/3): 60 percent fine to medium, gray and brown sand, 30 percent gray silt, 10 percent clay
185-190	Sand, grayish brown (2.5Y5/2): fine to medium to coarse; some gravel; 5 to 10 percent clay and silt
190-195	Same as above
195-200	Sand, grayish brown (2.5Y5/2): fine to coarse; some gravel; iron stain
200-205	Sand, grayish brown (2.5Y5/2): coarse with some medium, subrounded; some gravel
205-210	Sand, grayish brown (2.5Y5.5/2): fine to coarse, rounded; 5 percent gray silt and clay
210-215	Same as above
215-220	Till, light brownish gray (2.5Y6/2): 40 percent coarse, white, brown and black sand, 40 percent gray silt, 20 percent clay
220-238	No sample
238-240	Sand and clay, grayish brown (2.5Y5/2): 65 percent fine to coarse, subrounded, gray sand, 35 percent clay
240-245	Same as above
245-250	Sand and clay, grayish brown (2.5Y5/2): 40 percent fine to coarse, gray sand, 65 percent clay
250-300	No sample
300-305	Sand, dark grayish brown (10YR4/2): fine to medium, 10 percent clay; iron stain
305-310	Same as above
310-315	Clay, dark olive gray (5Y3/2): very hard, looks like shale

6. Krause Testhole 6C

Location: Lsd 16, Sec 2, Tp 24, R 7, W 4th Mer

Depth (feet)	Lithology
0-5	Silt, olive (5Y5/3): 30 percent clay
5-10	Till, olive (5Y5/3): 10 percent fine, gray and brown sand, 65 percent grayish brown silt, 25 percent clay; gravel pebbles; iron stain
10-15	Same as above
15-20	Till, olive (5Y5/3): 10 percent fine, gray and brown sand, 70 percent grayish brown silt, 20 percent clay; gypsum crystals; iron stain
20-25	Till, olive (5Y5/3): 15 percent fine, brownish gray sand, 70 percent grayish brown silt, 15 percent clay
25-30	Till, grayish brown (2.5Y6/2): 15 percent fine, brownish gray sand, 65 percent grayish brown silt, 20 percent clay; some coarse gravel
30-35	Same as above
35-40	Till, dark grayish brown (10YR4/1): 10 percent fine, brown sand, 65 percent brown silt, 25 percent clay
40-45	Same as above plus gravel pebbles and gypsum crystals
45-50	Till, dark gray (10YR4/1): 10 percent fine to medium, gray sand, 65 percent gray silt, 25 percent clay; gravel
50-55	Same as above
55-60	Till, dark gray (10YR4/1): 15 percent fine to medium, gray sand, 60 percent gray silt, 20 percent clay; gravel
60-65	Same as above
65-70	Same as above
70-75	Till, dark gray (10YR4/1): 20 percent fine to medium, gray sand, 60 percent gray silt, 15 percent clay
75-80	Same as above
80-85	Till, olive gray (5Y5/1.5): 30 percent fine, gray sand, 50 percent gray silt, 20 percent clay
85-90	Sand, light gray (10YR6.5/2): very fine, grading into silt, 10 percent clay
90-95	Same as above
95-100	Sand, light gray (10YR6.5/2): fine sand, grading into silt
100-105	Till, black (10YR2/1): 10 percent fine, light gray sand, 65 percent dark gray silt, 25 percent clay

Krause Testhole 6C (continued)

Location: Lsd 16, Sec 2, Tp 24, R 7, W 4th Mer

Depth (feet)	Lithology
105-110	Till, grayish brown (2.5Y5/2): 15 percent fine, light gray sand, 60 percent dark gray silt, 25 percent clay; gravel pebbles
110-115	Till, grayish brown (2.5Y5/2): 10 percent fine, gray and brown sand, 50 percent dark gray silt, 40 percent clay
115-120	Till, grayish brown (2.5Y5/2): 10 percent fine to medium, gray and brown sand, 60 percent dark gray silt, 30 percent clay; some iron stain; gypsum crystals
120-125	Till, gray (5Y5/1): 45 percent fine to medium, gray and brown sand, 40 percent gray silt, 15 percent clay
125-130	Till, olive (5Y5/3): 10 percent fine, brownish gray sand, 65 percent grayish brown silt, 25 percent clay
130-135	Same as above
135-140	Till, olive (5Y5.5/3): 30 percent fine, gray sand, 55 percent gray brown silt, 15 percent clay
140-145	Till, olive (5Y5.5/3): 15 percent fine, gray sand, 65 percent gray-brown silt, 20 percent clay
145-150	Till, olive (5Y5.5/3): 15 percent fine, gray sand, 70 percent gray and brown silt, 15 percent clay; gravel pebbles
150-155	Same as above
155-160	Till, olive (5Y5.5/3): 25 percent fine, gray and brown sand, 60 percent gray and brown silt, 15 percent clay
160-165	Same as above
165-170	Till, olive (5Y5.5/3): 30 percent fine to medium, gray and brown sand, 55 percent grayish brown silt, 15 percent clay; gravel pebbles
170-175	Same as above
175-180	Same as above
180-185	Till, olive (5Y5.5/3): 15 percent fine to medium, grayish sand, 70 percent grayish silt, 15 percent clay
185-190	Same as above
190-195	Till, olive (5Y5.5/3): 10 percent fine to medium, grayish sand, 65 percent grayish silt, 25 percent clay
195-200	Same as above
200-205	Same as above
205-210	Till, olive (5Y5.5/3): 5 percent fine to medium, gray sand, 70 percent grayish silt, 25 percent clay; gravel pebbles

Krause Testhole 6C (continued)

Location: Lsd 16, Sec 2, Tp 24, R 7, W 4th Mer

Depth (feet)	Lithology
210-215	Silt, olive (5Y5/3): 5 percent fine, gray sand, 10 percent clay
215-220	Same as above
220-225	Silt, olive (5Y5/3): 10 percent fine to medium, gray sand, 15 percent clay; gravel pebbles
225-235	Till, olive gray (5Y4/2): 10 percent fine to medium, gray sand, 60 percent gray silt, 30 percent clay; gravel pebbles
235-240	Till, gray (5Y4/2): 15 percent fine, gray sand, 60 percent gray silt, 25 percent clay
240-245	Till, gray (5Y4/2): 20 percent fine to coarse, gray sand, 60 percent gray silt, 20 percent clay; some fine gravel pebbles
245-250	Till, olive (5Y5/3): 10 percent fine to coarse, gray sand, 70 percent gray silt, 20 percent clay
250-255	Same as above
255-260	Till, olive (5Y4/3): 20 percent fine, gray sand, 60 percent gray silt, 20 percent clay; fine gravel pebbles
260-265	Same as above
265-270	Silt, light yellowish brown (2.5Y6/3): 5 percent fine, gray sand, 15 percent clay
270-275	Silt, grayish brown (2.5Y5/2): 5 percent gray sand; clay; iron stain
275-280	Silt, olive (5Y5/3.5): 5 percent gray sand, 15 percent clay
280-285	Till, olive gray (5Y5/2.5): 30 percent fine to medium, gray and brown sand, 50 percent gray silt, 20 percent clay; some fine gravel
285-290	Same as above
290-295	Till, olive (5Y5/3): 25 percent fine to coarse, gray and brown sand, 50 percent gray silt, 25 percent clay
295-300	Same as above
300-305	Till, olive (5Y5/3): 20 percent fine to coarse, gray sand, 50 percent gray silt, 30 percent clay
305-310	Silt, light brownish gray (2.5Y6/2): 5 percent medium, gray and brown sand, 15 percent clay
310-315	Same as above
315-320	Silt, light brownish gray (2.5Y6/2): 10 percent fine to medium, gray and brown sand, 10 percent clay

Krause Testhole 6C (continued)

Location: Lsd 16, Sec 2, Tp 24, R 7, W 4th Mer

Depth (feet)	Lithology
320-325	Cemented gravel
325-330	As above
330-340	As above
340-345	Gravel; till, grayish brown (2.5Y5.5/2): 5 percent fine, gray and brown sand, 30 percent gray and brown silt, 65 percent clay
345-380	Clay, black (5Y2/2): very hard, shaley looking
380-385	Clay as above with coal fragments
385-394	Sandstone, light gray (2.5Y7.2/0): very fine-grained, clayey; iron stain

7. Holiday Testhole 7

Location: Lsd 13, Sec 4, Tp 24, R 6, W 4th Mer

Depth (feet)	Lithology
0-5	Till, grayish brown (2.5Y5/2): 40 percent fine to medium, gray sand, 40 percent gray silt, 20 percent clay; iron stain
5-10	Till, grayish brown (2.5Y5/2.5): 45 percent fine to medium, gray and brown sand, 40 percent gray silt, 15 percent clay; iron stain
10-15	Till, grayish brown (2.5Y5/2.5): 40 percent fine to medium, gray and brown sand, 40 percent gray silt, 20 percent clay; gravel pebbles; iron stain
15-20	Till, grayish brown (2.5Y4.5/2): 30 percent fine to medium, gray and brown sand, 10 percent gray silt, 30 percent clay; iron stain
20-25	Till, dark grayish brown (2.5Y4/2): 30 percent fine, gray and brown sand, 30 percent gray silt, 40 percent clay; iron stain
25-33	Same as above
33-35	Sand, light brownish gray (2.5Y6/2): fine to coarse, rounded, 5 percent clay; some gravel up to 1/4 inch in diameter; iron stain
35-40	Same as above
40-45	Sand, light brownish gray (2.5Y6/2): fine to medium, rounded, 5 percent clay; iron stain; some fine gravel
45-50	Till, grayish brown (2.5Y5/2): 20 percent fine, gray sand, 40 percent gray and brown silt, 70 percent clay

Holiday Testhole 7 (continued)

Location: Lsd 13, Sec 4, Tp 24, R 6, W 4th Mer

Depth (feet)	Lithology
50-55	Till, light brownish gray (2.5Y6/1): 65 percent fine, gray sand, 15 percent gray silt, 20 percent clay; gravel pebbles
55-60	Till, grayish brown (2.5Y5/2): 65 percent fine, gray sand, 20 percent gray and brown silt, 15 percent clay
60-65	Same as above
65-70	Till, olive gray (5Y5/1.5): 60 percent fine, gray sand, 20 percent gray silt, 20 percent clay
70-75	Till, gray (5Y5.5/1): 50 percent fine, gray sand, 30 percent gray silt, 20 percent clay; gravel pebbles
75-80	Till, olive gray (5Y5/1.5): 30 percent fine, gray sand, 50 percent gray silt, 20 percent clay; a few grains of coarse sand
80-85	Till, gray (5Y5.5/1): 40 percent fine, gray sand, 40 percent gray silt, 20 percent clay
85-90	Sand, grayish brown (2.5Y5/2): medium, subrounded, quartz; some coal fragments
90-95	Same as above
95-100	Sand, grayish brown (2.5Y5/2): fine to medium, subrounded to rounded, quartz
100-105	Till, gray (4Y5/1.5): 30 percent fine to medium, gray, quartz sand, 35 percent gray silt, 35 percent clay; gravel pebbles
105-110	Till, pale olive (5Y6/3): 15 percent fine to medium, gray, quartz sand, 50 percent gray-brown silt, 35 percent clay; iron stain
110-115	Same as above and gravel pebbles
115-120	Till, pale olive (5Y6/3): 10 percent fine to medium, gray, quartz sand, 60 percent gray-brown silt, 30 percent clay; iron stain
120-125	Till, light gray (5Y6.5/1.5): 5 percent fine to medium, gray sand, 70 percent gray-brown silt, 25 percent clay; iron stain
125-130	Silt, light gray (4Y6.5/2): 5 percent fine to medium, gray sand (mostly fine), 20 percent clay; iron stain
130-135	Same as above
135-140	Same as above
140-145	Silt, light gray (4Y6/2): 20 percent clay; iron stain
145-150	Till, pale olive (5Y6/3): 10 percent fine, gray sand, 70 percent gray-brown silt, 20 percent clay; iron stain

Holiday Testhole 7 (continued)

Location: Lsd 13, Sec 4, Tp 24, R 6, W 4th Mer

Depth (feet)	Lithology
150-155	Till, pale olive (5Y6/3): 10 percent fine, gray sand, 65 percent gray-brown silt, 25 percent clay
155-160	Till, light brownish gray (2.5Y6/3): 30 percent fine to medium, gray-brown sand, 40 percent gray-brown silt, 30 percent clay; gravel pebbles
160-165	Silt, pale olive (5Y6/3): 25 percent clay
165-170	Same as above
170-175	Silt, pale olive (5Y6/3): 20 percent clay; coal fragments; a few grains of coarse sand
175-180	Silt, pale olive (5Y6/2.5): 25 percent clay; iron stain
180-185	Silt, pale olive (5Y6/3): 30 percent clay; iron stain; coal fragments
185-190	Same as above
190-195	Till, light brownish gray (2.5Y6.5/2): 35 percent clay
195-200	Till, light brownish gray (2.5Y6.5/2): 55 percent clay, 45 percent gray-brown silt
200-205	Same as above
205-210	Till, light gray (2.5Y7/2): 40 percent gray-brown silt, 60 percent clay
210-216	Same as above
216-220	Gravel: coarse, rounded, 1/2 inch diameter; not cemented
220-225	Gravel: 1/4 inch diameter; slightly cemented
225-230	Gravel: same as above
230-235	Gravel: highly cemented
235-241	Same as above
241-250	Till, light brownish gray (2.5Y6/2): 40 percent gray-brown silt, 60 percent clay
250-255	Same as above
255-260	Till, light brownish gray (2.5Y6/2): 20 percent fine to medium, gray-brown sand, 35 percent gray-brown silt, 45 percent clay
260-265	Till, light grayish brown (2.5Y5.5/2): 35 percent fine to medium, gray-brown sand, 35 percent gray-brown silt, 30 percent clay; iron stain
265-270	Same as above

Holiday Testhole 7 (continued)

Location: Lsd 13, Sec 4, Tp 24, R 6, W 4th Mer

Depth (feet)	Lithology
270-275	No sample
275-280	Sandstone, light gray (2.5Y6.5/1): fine-grained, bentonitic
280-285	Same as above
285-290	Sandstone, light gray (2.5Y6/1): fine-grained, bentonitic; iron stained; some coarse grains in sandstone
290-295	Shale, black (10YR2/1): soft, burnt
295-298	Sandstone, light gray (5Y6/1): fine-grained, bentonitic

8. Holiday Testhole 8

Location: Lsd 16, Sec 31, Tp 23, R 5, W 4th Mer

Depth (feet)	Lithology
0-5	Till, light brownish gray (2.5Y6/2): 30 percent fine to medium, rounded sand, 45 percent gray-brown silt, 15 percent clay, 10 percent gravel pebbles; iron stain
5-10	Till, light brownish gray (2.5Y6/2): 20 percent fine to medium, gray sand, 60 percent gray-brown silt, 20 percent clay; iron stain; gypsum crystals, no gravel
10-15	Till, olive (5Y5/3): 20 percent fine to medium, gray sand, 60 percent gray-brown silt, 20 percent clay; gravel pebbles; iron stain
15-20	Same as above
20-25	Till, olive gray (5Y5/2): 15 percent fine to medium, gray sand, 55 percent gray-brown silt, 30 percent clay; gravel pebbles
25-30	Till, grayish brown (4Y5/2): 15 percent fine to medium, light and dark gray sand, 60 percent gray-brown silt, 25 percent clay; gypsum crystals
30-35	Till, olive gray (5Y5/2): 10 percent fine to coarse, light to dark gray sand, 70 percent gray and brown silt, 20 percent clay; iron stain; gravel pebbles
35-40	Same as above
40-45	Till, light brownish gray (2.5Y6/2): 15 percent fine to medium, light and dark gray sand, 55 percent gray-brown silt, 30 percent clay; gravel pebbles

Holiday Testhole 8 (continued)

Location: Lsd 16, Sec 31, Tp 23, R 5, W 4th Mer

Depth (feet)	Lithology
45-50	Till, light brown gray (2.5Y6/2): 5 percent fine to medium, gray sand, 55 percent gray-brown silt, 40 percent clay; iron stain
50-55	Same as above
55-60	Till, olive gray (5Y5/2): 10 percent fine to coarse, gray sand, 45 percent gray-brown silt, 45 percent clay; iron stain; gypsum crystals
60-65	Same as above
65-70	Till, grayish brown (2.5Y5.5/2): 15 percent fine to medium, light and dark gray sand, 70 percent gray-brown silt, 15 percent clay; iron stain; gravel pebbles
70-75	Same as above
75-80	Same as above
80-85	Silt, grayish brown (2.5Y5.5/2): 5 percent fine, gray sand, 15 percent clay
85-90	Silt, grayish brown (2.5Y5.5/2): 5 percent fine, dark and light gray sand, 15 percent clay; gravel pebbles
90-95	Same as above
95-100	Silt, olive gray (5Y5/2): 10 percent fine to medium, gray sand, 10 percent clay
100-105	Same as above and iron stain
105-110	Silt, gray (5Y5/1.5): 10 percent fine to medium, gray sand, 15 percent clay
110-115	Same as above
115-120	Till, grayish brown (2.5Y5/1.5): 10 percent fine, gray sand, 70 percent gray-brown silt, 20 percent clay; gravel pebbles
120-125	Till, light brownish gray (2.5Y6/2): 15 percent fine, gray sand, 70 percent gray-brown silt, 20 percent clay
125-130	Silt, light brownish gray (2.5Y6/2): 5 percent fine, gray sand, 10 percent clay
130-135	Same as above
135-140	Silt, grayish brown (2.5Y5.5/1.5): 5 percent fine, gray sand, 10 percent clay; iron stain
140-145	Silt, pale olive (5Y6/3): 5 percent fine, gray sand, 5 to 10 percent clay; iron stain
145-150	Same as above

Holiday Testhole 8 (continued)

Location: Lsd 16, Sec 31, Tp 23, R 5, W 4th Mer

Depth (feet)	Lithology
150-155	Till, light brownish gray (2.5Y6/2): 5 percent fine, gray sand, 15 percent clay; iron stain; gravel pebbles
155-160	Till, light brownish gray (2.5Y6/2): 5 percent fine, gray sand, 25 percent clay; iron stain
160-165	Same as above
165-170	Till, light brownish gray (2.5Y6/2): 30 percent clay; iron stain
170-175	Till, light brownish gray (2.5Y6/2): 5 percent fine, gray sand, 30 percent clay; iron stain
175-180	Till, light brownish gray (2.5Y6/2): 5 percent fine, gray sand, 25 percent clay; iron stain
180-185	Same as above
185-190	Till, light brownish gray (2.5Y6/2): 5 percent fine, gray sand, 65 percent silt, 30 percent clay; iron stain
190-195	Till, light brownish gray (2.5Y6/2): 10 percent fine, gray sand, 60 percent silt, 30 percent clay; iron stain
195-200	Same as above
200-205	Till, light brownish gray (2.5Y6/2): 10 percent fine, gray sand, 60 percent gray-brown silt, 30 percent clay; iron stain
205-210	Same as above
210-215	Till, light brownish gray (2.5Y6/2): 5 percent fine, gray sand, 60 percent gray-brown silt, 35 percent clay; iron stain; gravel pebbles
215-220	Same as above
220-225	Till, light brownish gray (2.5Y6/2): 15 percent fine to medium, gray sand, 60 percent gray-brown silt, 25 percent clay; iron stain
225-230	Same as above plus gravel
230-235	Till, light brownish gray (2.5Y6/2): 30 percent fine to medium, gray sand, 35 percent gray-brown silt, 15 percent clay, 20 percent fine gravel; gypsum crystals
235-240	Till, light brownish gray (2.5Y6/2): 10 percent fine to medium, gray sand, 65 percent gray-brown silt, 15 percent clay, 10 percent fine gravel; iron stain
240-245	Till, light brownish gray (2.5Y6/2): 10 percent fine to medium, gray sand, 70 percent gray-brown silt, 20 percent clay; gravel pebbles

Holiday Testhole 8 (continued)

Location: Lsd 16, Sec 31, Tp 23, R 5, W 4th Mer

Depth (feet)	Lithology
245-250	Till, light brownish gray (2.5Y6/2): 20 percent fine to medium, gray sand, 70 percent gray-brown silt, 10 percent clay; fine gravel pebbles
250-255	Till, light brownish gray (5.5Y6/2): 20 percent fine to medium, light gray, quartz sand, 70 percent gray-brown silt, 10 percent clay
255-260	Silt, light brownish gray (2.5Y6/2): 10 percent fine to medium, gray sand, 15 percent clay; gravel pebbles
260-265	Same as above
265-270	Silt, light brownish gray (2.5Y6/2): 10 percent fine to medium, gray sand, 15 percent clay; iron stain
270-275	Same as above
275-280	Silt, light brownish gray (2.5Y6/2): 5 percent fine to medium, gray, quartz sand, 20 percent clay; iron stain; coal fragments; gravel pebbles
280-285	Silt, light brownish gray (2.5Y6/2): 10 percent fine to medium, gray sand, 10 percent clay; coal fragments
285-290	Silt, light brownish gray (2.5Y6/2): 15 percent fine to medium, gray sand, 10 percent clay; coal fragments
290-295	Same as above
295-300	Silt, light brownish gray (2.5Y6/2): 5 percent fine to medium, gray sand, 15 percent clay; gravel pebbles
300-305	Silt, light brownish gray (2.5Y6/2): 5 percent fine to medium, gray sand, 20 percent clay
305-310	Same as above
310-315	Till, light brownish gray (3.5Y6/2): 10 percent fine to medium, gray sand, 70 percent gray-brown silt, 20 percent clay; gravel pebbles
315-320	Same as above
320-325	Till, light brownish gray (2.5Y6/2): 10 percent fine to medium, gray sand, 65 percent gray-brown silt, 25 percent clay
325-330	Same as above
330-335	Till, light brownish gray (2.5Y6/2): 5 percent fine to medium, gray sand, 65 percent gray-brown silt, 30 percent clay; iron stain
335-340	Till, light brownish gray (2.5Y6/2): 5 percent fine to medium, gray sand, 65 percent gray-brown silt, 30 percent clay; iron stain
340-345	Till, light brownish gray (2.5Y6/2): 5 percent fine to medium, gray sand, 60 percent gray-brown silt, 35 percent clay; iron stain

Holiday Testhole 8 (continued)

Location: Lsd 16, Sec 31, Tp 23, R 5, W 4th Mer

Depth (feet)	Lithology
345-350	Same as above
350-355	Till, light brownish gray (2.5Y6/2): 65 percent gray-brown silt, 35 percent clay
355-360	Same as above
360-365	Till, light brownish gray (2.5Y6/2): 5 percent fine to medium, gray sand, 60 percent gray-brown silt, 35 percent clay
365-370	No sample
370-375	Till, light brownish gray (2.5Y6/2): 10 percent fine to medium, gray sand, 60 percent gray-brown silt, 30 percent clay; iron stain; coal fragments
375-380	Till, light gray (2.5Y6/1): 10 percent fine to medium, gray sand, 45 percent gray-brown silt, 45 percent clay
380-385	Till, light gray (2.5Y6/1.5): 10 percent fine to medium, gray sand, 50 percent gray-brown silt, 40 percent clay; iron stain
385-390	Same as above
390-395	Same as above
395-400	Till, light gray (2.5Y6/1.5): 5 percent fine to medium, gray sand, 60 percent gray-brown silt, 35 percent clay
400-405	Same as above
405-410	Till, light gray (2.5Y6/1.5): 65 percent gray-brown silt, 35 percent clay
410-415	Same as above
415-420	Till, light brownish gray (2.5Y6/2): 55 percent gray-brown silt, 45 percent clay
420-425	Till, light gray (2.5Y6/1): 50 percent gray-brown silt, 50 percent clay
425-430	Same as above
430-435	Till, light gray (2.5Y6/L): 60 percent gray-brown silt, 40 percent clay
435-440	Sand, light brownish gray (2.5Y6/2): fine to coarse, rounded, color of sand grains varies from black to white, 20 percent silt, 10 percent clay; gravel

Holiday Testhole 8 (continued)

Location: Lsd 16, Sec 31, Tp 23, R 5, W 4th Mer

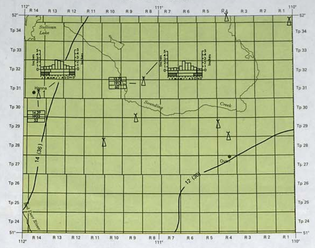
Depth (feet)	Lithology
440-445	Siltstone, light gray (2.5Y6/1): iron stain
445-450	Same as above
450-455	No sample
455-460	Siltstone, light gray (2.5Y6/0)
460-470	Coring
470-485	No sample

Alberta Research Council

METEOROLOGY

LEGEND

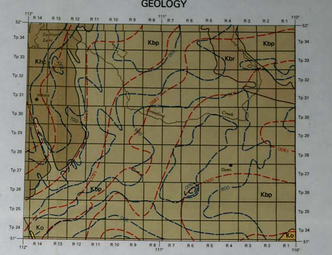
Isohyet, mean annual precipitation in inches (cm) 14 (36)
Mean annual precipitation in inches (cm):
less than 15 inches (38 cm):
Meteorological station
Standard rain gauge
Precipitation data:
Mean annual precipitation estimated in inches
Year of commencement of observations
Number of years in average
Mean monthly precipitation
Period when surface is usually snow-covered
Period with mean daily temperatures below freezing

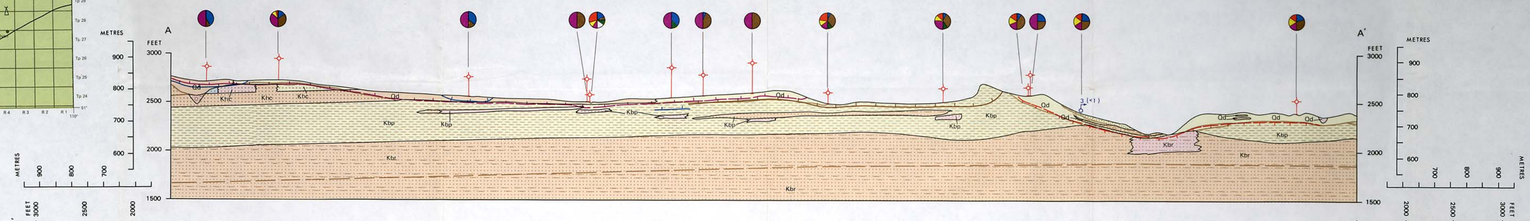


GEOLOGY

LEGEND

Horseshoe Canyon Formation: *gray feldspathic, clayey sandstone; gray bentonitic mudstone and carbonaceous shale; concretionary ironstone beds, scattered coal; subbituminous bed of variable thickness, minor limestone beds; mainly nonmarine*
Bearpaw Formation: *dark gray blocky shale and silty shale; greenish glauconitic and gray clayey sandstone; thin concretionary ironstone and bentonite beds; marine*
Belly River Formation: *grey to greenish gray, thick-bedded feldspathic sandstone; gray clayey siltsone, mudstone; concretionary ironstone beds; nonmarine*
Oldman Formation: *pale gray, thick-bedded, medium-to coarse-grained, feldspathic sandstone; gray clayey siltsone, mudstone; dark gray and brown carbonaceous shale; ironstone concretionary beds; nonmarine*
Structure contour on the base of the Oldman Formation 1100
Structure contour of the top of the First White Specks zone 600





MAIN MAP LEGEND

Topography
Surface contours and elevation in feet (interval 100 feet) 3000

Geology
Geological boundary
Buried valley boundary

QUATERNARY
Qd Unconsolidated deposits

CRETACEOUS
Khc Horseshoe Canyon Formation
Kbp Bearpaw Formation
Kbr Belly River Formation
Top of Basal Oldman Sandstone

Lithology
Gravel
Sand and gravel
Sand
Sandstone
Clay
Shale
Coal

Hydrography
Lake or slough, perennial
Lake or slough, seasonal
Saline lake
Marsh, muskeg
Area inundated during floods
Stream, perennial
Stream, intermittent
Surface water divide

Hydrogeology
Spring, flow rate unknown
Spring, flow rate in igpm (lisec)
Nonpumping water level contour in the bedrock (elevation in feet followed by metres in brackets) 2500 (760)
Direction of groundwater flow

Groundwater Probability†
Range of average expected yield of wells in imperial gallons per minute (lisec)
Probable: estimated from quantitative information (pump tests, bail tests, etc.)
Possible: estimated from qualitative information (flow regime, lithology, etc.)

100-500	(8-38)
25-100	(2-8)
5- 25	(0.4-2)
1- 5	(0.1-0.4)
<1	(<0.1)

Yield area boundary

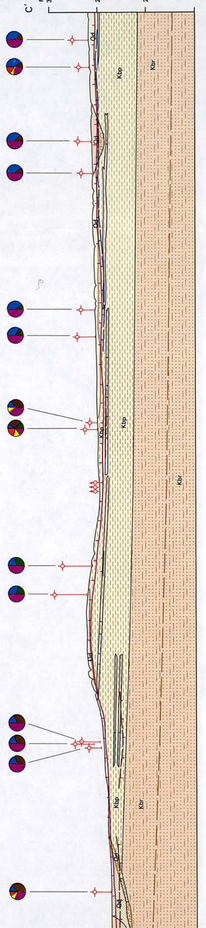
† The calculated average expected yields are predictions based on the best data available at the time of compilation. Due to data shortcomings and special conditions, local discrepancies between predicted and actual yields are inevitable. Multiaquifer completion may be necessary to obtain the yield indicated.

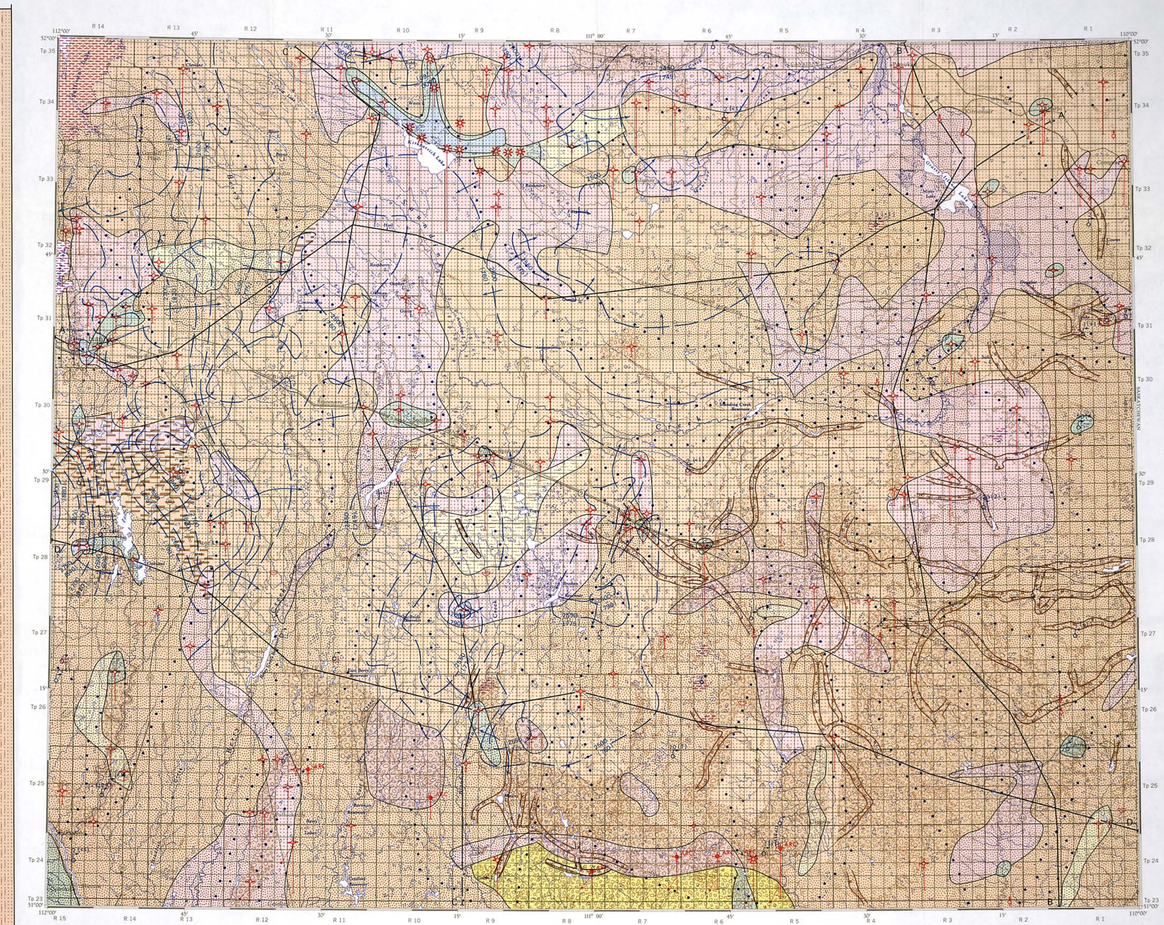
Wells and Other Artificial Works
Depth Scale: 0, 100, 200, 300, 400 FEET — Depth to water — Depth of well or seismic shot hole
Water well, nonflowing
Water well, nonproducing
Recharge well
Water well, 20-year safe yield calculated from a good bail test or a short pump test
Water well, 20-year safe yield calculated from a pump test of sufficient length to reflect regional hydraulic conditions
Locations of Alberta Research Council test well ..... ABC
Shothole, flowing
Other testholes (oil-well, gas-well etc.)
Spring catchment
Storage reservoir for surface water
Line of hydrogeological profile ..... A A'

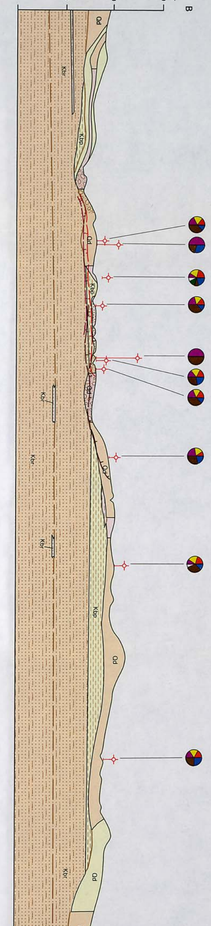
Hydrochemistry
Cations: Calcium, Magnesium, Sodium + potassium; Anions: Carbonate + bicarbonate, Sulfate, Chloride, Nitrate; 50% 50% 100%
Note: When the yellow Mg pie sector is absent, Ca + Mg are represented as a unit by the red pie sector.

Isogram along which calcium + magnesium constitute 60 percent of total cations*; teeth indicate direction of lesser calcium + magnesium content, defined:
Isogram along which sodium + potassium constitute 60 percent of total cations*; teeth indicate direction of lesser sodium + potassium content, defined:
Isogram along which carbonate + bicarbonate constitute 60 percent of total anions*; teeth indicate direction of lesser carbonate + bicarbonate content, defined:
Isogram along which sulfate constitutes 60 percent of total anions*; teeth indicate direction of lesser sulfate content, defined:
Isogram along which chloride constitutes 60 percent of total anions*; teeth indicate direction of lesser chloride content, defined:

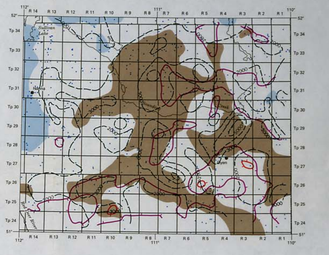
* determined on equivalents per million basis



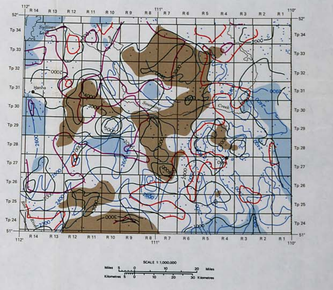




HYDROCHEMISTRY: BEDROCK



HYDROCHEMISTRY: DRIFT

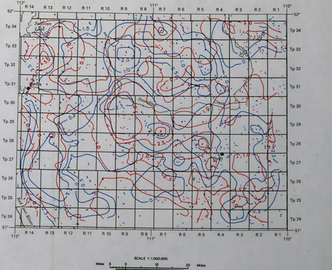


LEGEND

Data control point marking the location of a spring or well with a chemical analysis
Total dissolved solids in parts per million, defined: 3000
Nonpumping water level contour in the drift (elevation in feet) 3000
Carbonate + bicarbonate constituting over 60 percent of total anions* .....
Sulfate constituting over 60 percent of total anions* .....
Isogram along which calcium + magnesium constitute 60 percent of total cations*; teeth indicate direction of lesser calcium + magnesium content, defined:
Isogram along which sodium + potassium constitute 60 percent of total cations*; teeth indicate direction of lesser sodium + potassium content, defined:

* determined on equivalents per million basis

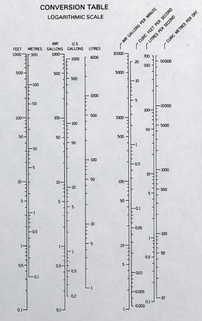
IRON: DRIFT AND BEDROCK



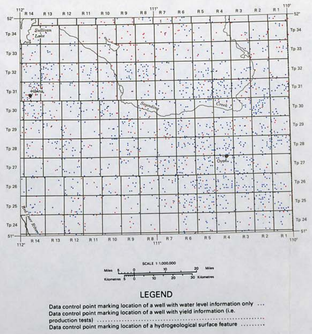
LEGEND

Data control point marking location of a well or surface feature in the drift
Data control point marking location of a well in the bedrock
Total iron content in the drift, in parts per million: defined 1.0
Total iron content in the bedrock, in parts per million: defined 2.5

CONVERSION TABLE
LOGARITHMIC SCALE

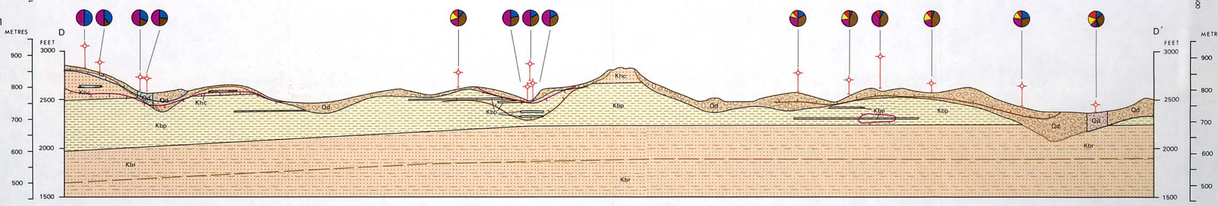


DATA DENSITY



LEGEND

Data control point marking location of a well with water level information only
Data control point marking location of a well with yield information (i.e. production tests)
Data control point marking location of a hydrogeological surface feature



SCALE 1:250,000

All elevations in feet above mean sea level.

Vertical exaggeration of the hydrogeological profiles is approximately 40X.

An expanded legend and explanatory notes (Report 72-12) for use with this hydrogeological map series is available from Alberta Research Council, Edmonton, Canada.

Map to accompany Report 78-2.

Hydrogeology by D.M. Borneuf.

Drafted by J.K. Matthie

Cartographic editing by A.R. Campbell.

HYDROGEOLOGICAL MAP
OYEN
ALBERTA
NTS 72-M

Base map provided by Surveys and Mapping Branch, Department of Energy, Mines and Resources, Ottawa, modified by Surveys Branch, Alberta Transportation, Edmonton.

Published 1978