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GEOLOGY AND GROUNDWATER RESOURCES OF THE PEACE RIVER DISTRICT, NORTHWESTERN ALBERTA

by

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Geology and Groundwater Resources of the Peace River District, Northwestern Alberta

ABSTRACT

This report summarizes geological and groundwater studies carried out over 22,500 square miles of the Peace River region of Alberta between 1957 and 1963.

The bedrock strata with groundwater potential are all Cretaceous in age. The lowest exposed unit, the sandstones and shales forming the Peace River Formation, outcrops along the Peace River from Peace River town northward, and is easily recognizable in the subsurface on electric logs. The overlying Shaftesbury Formation, marine shales and silty shales, outcrops mainly along the Smoky and Peace Rivers in the east part of the region. This unit grades upward into the Dunvegan Formation—nonmarine sandstones and shales—which is exposed extensively along the Peace River in the west of the region and also on the Smoky River. The Dunvegan Formation thins from 600 feet in the northwest to less than 50 feet in the east and southeast, and the upper beds interfinger with the marine shales of the Kaskapau Formation. This unit thins from 1,500 feet on the Alberta-British Columbia boundary to less than 500 feet in the east and northeast of the region studied. The upper boundary of the Kaskapau is placed at the base of the Bad Heart Sandstone, a thin ferruginous quartzose to iron-rich oolitic sandstone up to 20 feet thick, discontinuously developed as north-west-trending lenses. Locally in the southwest part of the region the Cardium Sandstone is developed, lying some 200 feet below the Bad Heart Formation; this unit is absent from the north and east parts of the region.

The Puskwaskau Formation represents the marine shales present above the Bad Heart Formation, and the name Muskiki is applied to the shales between the Cardium and Bad Heart units. The Kaskapau-Puskwaskau succession, together forming the Smoky River Group, outcrops extensively over the prairie regions between the Peace River and the upland areas. The overlying beds constitute the nonmarine sandstones, shales, and coals of the Wapiti Formation, capping the Clear Hills in the north, the central Saddle and Birch Hills, and outcropping over most of the southern part of the region, where up to 4,000 feet of this unit are preserved.

Unconsolidated, post-Cretaceous sands and gravels are preserved in buried channels in the region, as near Beaverlodge and High Prairie, and these also form extensive beds between Fairview and Grimshaw. Typically these deposits are overlain by glacial deposits—till, outwash sands and gravels, and the lake silts and clays of the central Peace region.

Groundwater hydrologic data are sparse for the Peace River district. A number of transmissibilities, "apparent transmissibilities", and hydraulic conductivities have been calculated, some from the results of well-drillers' bail and pump tests, others from laboratory measurements, and a few from the results of carefully planned and executed aquifer tests. Most of these data are for sandstone, siltstone, or coal beds in the Wapiti Formation. Hydraulic conductivities for this formation generally range from about one to a few hundred gallons per day per square foot. Some extremely high

conductivities, however, were indicated in one or two instances. These are believed to originate in jointing or post-depositional fracturing. Values for other bedrock deposits are too few to allow the drawing of any firm conclusions regarding their hydraulic conductivities. Some fairly low conductivities were found for some of the surficial deposits. Alluvial-terrace and buried-channel deposits, however, generally formed the most permeable group of deposits, with conductivities ranging, with some exceptions, from about a hundred to more than a thousand gallons per day per square foot.

Available water-well information suggests that the Wapiti Formation provides the most suitable bedrock water supplies in the Peace River district. Typical yields range from 50 to 100 gallons per minute, but there is considerable variation within the district because of facies changes in the formation. Where it has been necessary to utilize other bedrock deposits, yields have not been found to exceed 10 gallons per minute. There are indications, however, that fairly substantial yields of up to 100 gallons per minute or more might be obtained from the Baytree Conglomerate or from the Cardium Formation. Waters from these deeper formations, however, tend to have a high dissolved-mineral content and may require treatment before they can be used for human consumption or industrial purposes. Waters in the Wapiti Formation range from fresh to slightly brackish, but are generally suitable for human consumption.

The best potential sources of large groundwater supplies in the Peace River district are the surficial-deposit aquifers. Of these, the buried-channel deposits appear to have the best potential for yielding large supplies. It is estimated that the deeply buried channel near High Prairie could yield well over 500 gallons per minute from a single properly constructed well. The course of this channel is as yet largely undetermined but similar yields might be available throughout its length. Buried sands and gravels near Fairview and Beaverlodge also have considerable, but lesser, potential. The Peace River district buried-channel system is, to a large extent, unknown and a complete evaluation of the district's groundwater resources will require a much more detailed knowledge of the system.

Alluvial-terrace deposits are the only other surficial-deposit aquifers potentially capable of providing large groundwater supplies. Whether or not they will live up to their potential depends to a great extent on whether or not there is a hydraulic connection between the terrace and the adjacent river. For a terrace adjacent to the Wapiti River south of Grande Prairie, the geologic situation looked favorable for induced infiltration, but attempts to produce water from the terrace and subsequent hydrologic tests demonstrated that a relatively impermeable barrier (presumably silt) in the bed or banks of the river, or both, prevented the infiltration of river water. Single-well yields for the terrace were therefore relatively low, averaging less than 100 gallons per minute. In addition, the quality of the water produced was poor. Other alluvial-terrace deposits along the Little Smoky, Smoky, and Peace Rivers, as well as along the Wapiti, appear to warrant further investigation but careful testing should precede any commitment to a production-well system.

Other surficial-deposit aquifers—aeolian, lacustrine, and till—are of minor importance, generally being adequate only for small domestic supplies. The aeolian deposits, however, can also be used to provide livestock requirements.

Waters from the surficial deposits are generally fresher than those from the bedrock aquifers. A few of the analyses available for buried-channel waters indicates these can be slightly brackish.

The bulletin includes an extensive chapter on the municipal water supplies of all the larger communities plus information on the supplies of some smaller communities relying on groundwater. Particular attention is given to the supplies for Beaverlodge, Fairview, Grande Prairie, and High Prairie, for which a great deal of geologic and hydrologic data have been gathered and analyzed.

INTRODUCTION

Purpose and Scope of Investigation

With the ever-increasing need for water in Alberta, individuals, municipalities, government and industry have carried out considerable exploration and testing for groundwater, and more attention has been paid to using quantitative methods in evaluating the occurrence, movement, and utilization of groundwater. In particular, an awareness and use of more recent techniques in groundwater hydrology—a science which has grown considerably in the last twenty years—have given impetus to a better understanding and evaluation of groundwater resources.

In recent years a considerable body of information pertinent to groundwater resources investigation has been gathered. Aided considerably by the tremendous growth of the oil and gas industry in Alberta, knowledge of the surface and subsurface geolgy has increased substantially. In addition, newer techniques used in geophysical exploration for groundwater, such as seismic refraction and resistivity surveys have added considerable data.

The Research Council of Alberta initiated in 1955 an extensive program to evaluate the groundwater resources of the Province of Alberta. This report describes the geology and groundwater resources of the Peace River district of northwestern Alberta and forms a part of the province-wide groundwater survey.

It is hoped that through this study, not only will detailed information be made available, but also existing supplies of this important resource will be utilized more efficiently, and the information herein will serve as a guide for future exploration and development of groundwater in the Peace River District.

Location, Access, and Extent of Area

The Peace River district, as defined for this report, lies between 116°00′ and 120°00′ west longitude and between 55°00′ and 57°00′ north latitude (Fig. 1). The total area comprises about 22,500 square miles.

The Peace River district, lying about 250 miles northwest of Edmonton, can be reached by Highway No. 43, a new all-weather paved road, and by a partially paved but mainly gravelled road, Highway No. 2, extending north from Edmonton and along the south shore of Lesser Slave Lake.

Rail service is provided to all the larger centers in the Peace River district by the Northern Alberta Railway Company. Regular air service is provided to the City of Grande Prairie by Canadian Pacific Airlines Limited and to the town of Peace River by Pacific Western Airlines Limited.

FIGURE 1. Index map.

Land-Survey System

The system of survey of lands used in the Province of Alberta is called the "Dominion Lands System". This system is used in most of Western Canada, and all locations given in this text and on the enclosed maps adhere to it. It is explained by the following excerpt from the "Schedule of Wells Drilled for Oil and Gas in 1962" (Alberta Oil and Gas Conservation Board, 1963, p. 4):

> Townships are six miles square, with road allowance in addition. A road allowance 66 feet wide is left on the east side of every section and either on the north or south side of each section, there being a road allowance on the south of the township, and every two miles northward. Sections are numbered as follows:
>
> | | | | | | |
> |---|---|---|---|---|---|
> | 31 | 32 | 33 | 34 | 35 | 36 |
> | 30 | 29 | 28 | 27 | 26 | 25 |
> | 19 | 20 | 21 | 22 | 23 | 24 |
> | 18 | 17 | 16 | 15 | 14 | 13 |
> | 7 | 8 | 9 | 10 | 11 | 12 |
> | 6 | 5 | 4 | 3 | 2 | 1 |
>
> Townships are numbered from the International Boundary northward. The east boundary of Alberta is the fourth principal meridian and it marks the 110th degree of longitude, west of Greenwich. The fifth meridian is at 114 degrees, and the sixth at 118 degrees west of Greenwich. Ranges are numbered westward from each initial meridian the last range abutting the next meridian being fractional. The north boundary of every township divisible by 4 is a base line, and sections along the base lines are a full mile wide. Going northward for 12 miles, each section narrows slightly until a correction line is reached, and going south each section widens slightly until the correction line is reached.
>
> Sections may be divided into 16 legal subdivisions and numbering of these subdivisions is prescribed as follows:
>
> | | | | |
> |---|---|---|---|
> | 13 | 14 | 15 | 16 |
> | 12 | 11 | 10 | 9 |
> | 5 | 6 | 7 | 8 |
> | 4 | 3 | 2 | 1 |

Sections, which have an area of 640 acres, can be divided into quarters of 160 acres each. Often less exact location designations are given, such as NE., NW., SE. and SW. quarters, particularly when describing farm locations.

Location designations are often abbreviated. For example "12-36-82-3-W6" is to be read as "legal subdivision 12 of section 36, township 82, range 3, west of the sixth meridian.

Physiography

The Peace River district is divisible into three categories of physiographic units. These are: (1) forested and rolling uplands and (2) broad, gently sloping prairies below the uplands, which are cut into by (3) deeply incised, steep-sided river valleys.

The most extensive uplands are the Clear and Whitemud Hills bordering the northwestern and central northern portions of the map-area which rise to altitudes of up to 2,700 feet in the east and to over 3,600 feet above sea level toward the west. This range of hills extends in an easterly direction for 60 miles from the British Columbia boundary almost to the town of Peace River.

On the eastern side of the Peace River district, east of the Peace River, is a lower range of subdued hills, constituting the southern extension of the Buffalo Head Hills.

In the west-central portion of the map-area, south of the Peace River, are the Saddle and Birch Hills, with elevations of up to 3,100 feet in the western portion and 2,600 feet in the eastern portion. These extend eastward from the British Columbia border for a distance of 60 miles.

In the southeastern portion of the map-area, the Sturgeon Heights, gentle uplands, occupy an area about 400 square miles and have elevations rarely exceeding 2,600 feet.

Two of the more prominent, better known hills close to settled and cultivated areas are Blueberry Hill and Saskatoon Hill. Blueberry Hill is a northward extension of the Saddle Hills occupying an area of about 144 square miles in Tps. 79 and 80, Rs. 9 and 10, W. 6th Mer. Saskatoon Hill (locally known as Saskatoon Mountain) has an area of about 10 square miles and lies in township 72, range 9, west of the sixth meridian. It rises 700 feet above the surrounding countryside and has a maximum elevation of slightly over 3,000 feet. It has a prominent southwesterly facing scarp that extends for 2½ miles and is an excellent point from which the view the Rocky Mountains, which lie about 80 miles to the southwest in British Columbia.

Broad gently sloping prairies are associated with the major drainage systems of the Peace River district and lie between the upland ranges of hills and the sharp, deeply incised river and stream valleys of the various drainage systems. These broad prairie areas probably are the floors of preglacial and glacial valleys and form the most favorable lands for cultivation in the Peace River district.

The largest prairie areas lie adjacent to the Peace River and the lesser ones are association with the Smoky, Little Smoky, and Wapiti Rivers.

The Peace River, from which the district obtains its name, has its origin in the Rocky Mountains 200 miles to the west in British Columbia. This mighty river enters Alberta from the west in Tp. 82, R. 13, W. 6th Mer. and winds through the central portion of the map-area. The average width of the deeply incised river valley is 1 to 2 miles at the top and the depth is from 500 to 900 feet below the upland prairie. The width of the river at water level is between ¼ and ½ mile. The upper parts of the river valley have in many places a hummocky appearance, caused by the slumping if the valley walls. In many portions of the river course, where no slumping has taken place, the river flows through steep-walled valleys along which bedrock is exposed.

The second largest river of the region is the Smoky River, which has its confluence with the Peace River near the town of Peace River. The Smoky River, which flows northeastward, has many of the characteristics of the Peace River, although on a smaller scale. It is incised to a depth of between 400 and 500 feet below the level of the prairie, and the valley flanks are hummocky—the result of the rapid erosion and slumping of the relatively incompetent materials through which the river has cut. In its lower reaches the Smoky River is ¼ to almost ⅓ mile wide at water level.

The Wapiti River, a tributary of the Smoky, has its origin in the Rocky Mountains in British Columbia, and enters the southwestern portion of the map-area in Tp. 69, R. 10, W. 6th Mer. The average width of the river valley is three quarters of a mile. The valley walls are generally steep sided and at the bottom the river is fairly narrow—from 400 to 500 feet wide. It joins the Smoky River in Tp. 71, R. 2, W. 6th Mer.

The Little Smoky River, which flows into the Smoky River in Tp. 77, R. 24, W. 5th Mer., is the major drainageway in the southeastern portion of the map-area. It, again, is deeply incised below the upland prairie with badly slumped and hummocky sides.

Many other small rivers and streams drain into the major rivers, and all are characterized by steep banks along which slumping has taken place—a reflection of the incompetence of the surficial deposits and bedrock strata. Many of the smaller tributary streams are seasonal in character and are often nearly dry in the summer months.

Many lakes, ponds, and sloughs are scattered throughout the Peace River district. These are the remnants of larger proglacial lakes that covered the main valleys between the uplands.

The largest lake in the Peace River district, extending far beyond the eastern edge of the map-area, is Lesser Slave Lake, lying in Tps. 74 and 75, W. 5th Mer. This lake extends eastward from the map-area another 50 miles, and varies in width from 12 to 20 miles.

The physical features are the result of both depositional and erosional processes. The advance and retreat of ice sheets resulted in erosion and modification of the preglacial topography even though it was, in general, probably similar to that of the landscape of today. The latest deposits of glacial materials were left in the preglacial valleys and depressions. Periglacial and postglacial processes then modified the area still further, smoothing and subduing the topography. Recent drainage has incised deeply into the glacial and the underlying bedrock deposits. Considerable sedimentation is taking place at present, filling in the lakes and sloughs.

Climate

The Peace River district of Alberta forms part of the northwestern portion of the forest and parkland region of Alberta. Its climate is typical of the Western Canada prairies, and is characterized by a moderately warm summer and a relatively cold winter.

The meteorological compilations in tables 1 and 2 are based on data supplied by the Meteorolgical Branch, Canada Department of Transport, for the meteorological stations at Beaverlodge, Grande Prairie, Fairview, Peace River and High Prairie. Table 1 gives the monthly and annual precipitation at the five recording stations. At these stations June and July are the months of greatest rainfall, and there is little difference in mean temperatures at the four stations for which data are available. Table 2 lists daily mean temperatures. A mean annual average temperatue of 35°F appears fairly representative for the area under study.

Table 3, based on a compilation by Dr. A. C. Carder, Dominion Experimental Farm at Beaverlodge, describes the frost conditions for selected localities in the Peace River district.

Table 1. Mean Monthly and Mean Annual Precipitation in Inches, 1921-1951

Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Beaverlodge	1.19	1.07	1.03	0.87	1.50	2.01	2.31	1.92	1.87	1.04	1.35	1.16	17.32
Grande Prairie	1.35	1.37	0.74	0.82	1.52	2.00	2.48	1.68	1.28	0.98	1.22	1.36	16.80
Fairview	1.23	1.30	0.98	1.01	1.40	2.31	2.26	1.96	1.49	1.15	1.41	1.42	17.92
Peace River	0.83	0.72	0.60	0.51	1.09	2.11	1.86	1.70	1.32	0.92	0.75	0.74	13.15
High Prairie	0.95	0.86	0.80	1.00	1.49	2.59	2.98	2.13	1.60	1.15	1.16	1.07	17.78

Table 2. Monthly and Annual Average Daily Mean Temperatures in Degrees Fahrenheit, 1921-1951

Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Beaverlodge	9.7	12.6	23.2	37.6	49.9	56.2	60.2	57.9	50.0	40.0	23.6	12.6	36.1
Grande Prairie	5.6	8.6	20.4	37.3	50.3	56.4	60.7	58.5	49.8	39.3	21.8	9.3	34.8
Fairview	4.7	8.1	20.2	36.7	49.9	56.4	60.2	58.1	49.6	38.5	20.2	7.4	34.2
Peace River	—	—	—	—	Not available		—	—	—	—	—	—	—
High Prairie	5.5	8.3	21.8	38.1	50.3	56.8	61.2	58.2	49.6	39.5	20.8	7.5	34.8

Table 3. Frost-Free Periods

Station	Location			Year 1962			Average frost-free period (days)	Years of record
	Tp.	R.	West of Mer.	Last spring frost	First fall frost	Frost-free period (days)		
Beaverlodge	72	10	6	June 5	Sept. 2	89	101	47
Goodfare	72	12	6	June 9	Sept. 2	85	56	13
Baldonnel, B.C.	83	17	6	June 10	Sept. 2	84	94	16
North Pine, B.C.	86	18	6	June 10	Sept. 2	84	96	10
Blueberry Mountain	80	8	6	June 9	Sept. 2	85	86	8
Wanham	78	3	6	July 5	Sept. 2	59	99	8
McLennan	77	19	5	May 7	Sept. 2	118	103	12
High Prairie	74	17	5	June 4	Sept. 2	90	85	11

Population and Industries

The Peace River district, as defined in this report, contains the greatest population concentration of Northern Alberta. It includes Local Improvement Districts Nos. 125, 126, 131, 132, 134, 138 and 139, County No. 1, and Municipal Districts Nos. 130, 133, 135 and 136. The residents are largely dependent for their livelihood upon agriculture, forest products, and supplying transport to the north. The exploration for and development of oil and natural gas bring many benefits to the area.

Grande Prairie is the largest community in the Peace River district and was incorporated as a city on January 1, 1958. Its population in 1964 had reached 10,365. It is the chief distribution center for areas on the south side of the Peace River and a trading center for a large farming area which specializes in the production of legumes, grasses, and grain. Local industries include forest-product plants, such as plywood plants and sawmills.

The chief distribution center for the northern part of the Peace River district is the town of Peace River, located below the confluence of the Smoky and Peace Rivers. The population of the town of Peace River in 1964 was 3,318.

High Prairie, 1964 population 2,305, serves the needs for the large farming area in the eastern portion of the district. It is located near the western edge of Lesser Slave Lake.

Grimshaw, 1964 population 1,515, located on the southern terminus of the Mackenzie Highway, serves as main distribution and trading center for the northern part of Alberta and parts of the Northwest Territories —Hay River and Yellowknife in particular.

Other communities with populations between 800 and 2,500 in the district are Beaverlodge, Fairview, Spirit River, McLennan, and Valleyview.

The Royal Commission on the Development of Northern Alberta (1958) estimated that by 1967 the population in this area would be 58,000 and by 1987 would be 121,000. By 1961, however, the population had risen to 61,300.

Industrial opportunity in this area will be concerned mainly with the development of the natural resources of the region and the major segments of growth will be in the processing of agricultural products, timber, oil, and natural gas.

Recent exploration for iron-rich deposits in the Clear Hills and Gordondale areas indicates the possibility of development of a large-scale mining and refining operation in the future.

Construction of the Pine Point branch of the Northern Alberta Railways, from Grimshaw north to Hay River, paralleling in many places the Mackenzie Highway, should encourage more agricultural settlement and development along its route, thus decreasing the cost of goods and services and again increasing the population in this area.

More comprehensive information on opportunities for industrial and resource development is given in the Royal Commission Report on the Development of Northern Alberta (1958).

Agriculture and Soils

Grain farming has been the most prevalent type of farming practiced in the Peace River district. Until about 1956, wheat was the principal crop grown, but in subsequent years there has been a considerable increase in the acreage sown to barley, oats and flax. At the same time, the production of seed crops—creeping red fescue, alfalfa, clover, and rape—has increased until it is now an important part of the agricultural economy of this area.

The livestock population is comparatively small, but the numbers of cattle and sheep are increasing steadily. Swine and poultry populations have fluctuated considerably in this area over the past twenty years.

Types of soils found in this area vary widely. The wide range can be attributed to variations in soil parent material (surface geologic materials), climate, vegetation, and topography (Odynsky *et al.*, 1956). The finest textured (heaviest) soils are found in former glacial lake basins. These soils are usually of a clay texture and in much of the area are saline to various degrees. In the highland areas, where till predominates as the parent material of the soil, the soils are most commonly clay loam in texture and exhibit some stoniness. Adjacent to the major stream courses the soils range in texture from coarse sand to silt loam and silty clay loam, the parent materials being mostly of alluvial origin.

The productive capacity of a soil, however, is not based entirely on the characteristics of the parent material, but depends to a large degree on the nature of the surface layers or horizons in the soil profile. Those soils having a relatively thick, dark-colored surface layer or horizon due to the accumulation of organic matter or humus are usually most fertile. In this area there are many gradations in the depth and darkness of the humus horizon, and the darkest-colored soils are found in the Grande Prairie, Beaverlodge, Rycroft, Falher, Fairview and Bonanza regions of the Peace River district (Odynsky and Newton, 1950; Odynsky *et al.*, 1956, 1961; Wyatt, 1935; Wyatt and Younge, 1930). In soil-classification terminology these soils are referred to as Dark Grey and Eluviated Black Soils.

However, Grey Wooded soils have the greatest areal extent in the Peace River district. These soils are found in both the highland and lowland areas, and are characterized by a very thin (less than two inches), dark-colored humus horizon which is underlain by a relatively thick leached layer. Soluble constitutents (plant food) have been removed from this layer by downward-percolating waters. The Grey Wooded soils are much less fertile than the Eluviated Black and Dark Grey soils, and require good management practices to ensure satisfactory cropping results.

Relatively immature soils (regosols) are found in a number of locations in the map-area. These soils usually occur on recent alluvial deposits on river flood plains and low terraces. One of the most extensive areas of such soil is situated in the High Prairie region (Odynsky *et al.*, 1952).

The soils developed on the aeolian sand deposits in the vicinity of the Wapiti River south of Grande Prairie and north of Culp along the Smoky River are for the most part characterized by brownish-colored, iron-enriched horizons below a thin humus surface horizon (Odynsky *et al.*, 1956; 1961). These soils, termed Acid Brown Wooded and Bisequa Grey Wooded soils, are of low inherent fertility and possess a low moisture-holding capacity.

Locally, throughout the map area, there are many low depressional areas in which the soils invariably show evidence of poor drainage. These soils, termed Gleysolic soils, have varying depths of peat at the surface and are usually underlain by a subsoil that is mottled and iron stained as the result of periodic wetting and drying. Associated with the Gleysolic soils are the organic soils which have more than 12 inches of peat at the surface. Generally two types of organic soils are recognized in this area: a fibrous peat that is developed from sedges, and a coarse peat derived principally from sphagnum moss. This latter type is often referred to as muskeg.

The soils of the area are generally fine textured and only slightly permeable to downward percolating water. These features, in combination with the low organic-matter content of many of the soils and long uniform topographic slopes, makes erosion by surface-water runoff a serious problem in some portions of the map area.

History and Land Settlement

The history and land settlement of the Peace River district is intimately linked with the growth of transportation—particularly with the development of roads and railways.

The "Peace River country", as it is often called, has a rich and varied heritage. Sir Alexander Mackenzie wintered in 1792-3 near the junction of the Smoky and Peace Rivers at what is now known as the Shaftesbury Settlement, near the town of Peace River, during his voyage of discovery to the Pacific Ocean. David Thompson—surveyor and mapper extraordinary—the "Klondikers of '98", and the "legendary Twelve-Foot Davis", who was said to have always had his door open and a hot meal on the stove for anyone, blazed the way into the Peace River district as it is known today.

Though white men have known the Peace River Country for over 170 years, its history of development is short. The fur traders of the Hudson's Bay and Northwest fur trading companies and the early explorers were the first to write of the potential for agricultural development in the Peace River district. It was not until the early 1900's that first settlement of Canada's "last frontier" began in earnest with the opening of the Edson Trail, carved through the swamp, muskeg, and forests from Edson to Grande Prairie. The first real major influx of settlers did not take place until the completion of the Edmonton, Dunvegan and British Columbia Railway (now the Northern Alberta Railways Company) in 1916 from Edmonton to Grande Prairie via the south shore of Lesser Slave Lake.

Thus started a steady growth of settlement and cultivation which has continued to this day. Although the railway provided access to the "outside", as Edmonton—300 miles to the southeast—was thought of, the day and overnight trip by rail was still quite an adventure, and up until World War II the Peace River country was fairly well isolated.

With the advent of World War II, change that has dominated the scene ever since commenced. Construction of the Alaska Highway, a "12-month miracle", initiated a rapid acceleration of growth of the region.

After the war a rapid series of events took place. The Mackenzie Highway was constructed from Grimshaw to Hay River to serve the expanding mining industry of the Northwest Territories. With the major discovery of oil in the province, and the consequent generation of funds for the provincial treasury, the provincial road grid system was expanded and an all-weather paved road, Highway No. 43—the "Whitecourt- Valleyview cutoff"—was built through muskeg and uninhabited forest land, shortening the trip to the Peace River country, and ending the necessity of making the trip along the sometimes muddy and hazardous gravel road—Highway No. 2, the old Athabasca Trail—which skirts the south shore of Lesser Slave Lake.

Today the larger communities in the Peace River district have modern facilities and comforts similar to those of the larger urban centres of the province, including telephone communications, radio and satellite television stations, and good access roads. However, it is still a young country and one of the few places in North America where homestead lands are available. In fact, the numbers of modern pioneer homesteaders have increased in the last few years and there is a considerable backlog of demand for agricultural lands as they are made available.

Describing the unique attractions of the Peace River Country are a few apt excerpts taken from MacGregor (1952, p. 15):

> One of the spells the Peace River Country casts over the visitor is in no wise wrought by any inherent quality, but is purely accidental. All other spells, such as beauty, richness, fertility, are hers. They, in all conscience, are enough to repay the visitor and hold his interest, and to make him her suitor forever. This one spell which magnifies all the others and creates a first impression out of due proportion is her inaccessibility. Is not the inaccessible always that for which we strive, casting away that which lies near at hand?
>
> Every traveller bound for the Peace River Country from the earliest times to the present, left or leaves behind him a fair and fertile country. In olden times he travelled down the Athabasca for many days and then up the Peace River, all the while in dismal spruce forest. When he finally reached the great prairies, the river valley opened out and the great hillsides came into view. In the open spaces on these vast park-like hillsides buffalo grazed in groups, with their yellow calves at their heels or tugging at their udders. In and out of the clumps of brush wandered bears innumerable. Up the hillside for a thousand feet shone the matchless beauty of the white Saskatoon flowers, and the air was fragrant with their scent and vibrant with the buzz of bees. It was a land flowing with milk and honey. He was quickened by the same feeling that The Promised Land stirred in Moses when he blessed Joseph saying; "Blessed of the Lord be his land, for the precious things of heaven, for the dew . . . and for the precious fruits brought forth by the sun . . . and for the precious things of the lasting hills . . . and for the precious things of earth and fulness thereof.

And again (p. 9):

> Great are the riches of the Peace River Country. In good black soil, gas and oil, coal and water power, timber and pulp wood it is physically rich. But it is in the high calibre, the clear timber and the staunch metal of its pioneers and their children that its greatest riches lie. Natural riches in a country tend to produce decadence in its people. This is not true of the Peace River country. There, the riches have had to be fought for and the battle is still being waged. The Peace is an invigorating country and vigorous are its people.

Previous Investigations

The earliest geological observations in the Peace River district were those recorded in the Geological Survey of Canada Reports of Progress by Selwyn (1877) and Dawson (1881). Other studies on the stratigraphy of the Cretaceous rock succession in the Peace River district have been carried out by McLearn (1918, 1919, 1926, 1944, 1945), McLearn and Kindle (1950), Allan (1922, 1928), Allan and Rutherford (1934), Allan and Carr (1946), Evans and Caley (1930), Crickmay (1944), Warren and Stelck (1940), and others. Gleddie (1954) presented a detailed discussion of the Upper Cretaceous stratigraphy in the Peace River region.

Geological investigations, with particular emphasis on surface and subsurface microfaunal associations and correlations, have been carried out by Stelck (1955), Stelck and Wall (1954, 1955), Warren and Stelck (1955), Stelck *et al.* (1958), and Wall (1960). McDonald (1957), Kidd (1959), Stott (1961a, 1961b), Green and Mellon (1962), and Burk (1963) have carried out further stratigraphic investigations of Cretaceous rock units using surface and subsurface information, a large part of the latter having become available through oil-exploration activities in the region.

Initial work carried out by Rutherford (1930) for the Research Council of Alberta outlined the basic groundwater potential of the many geological formations of the region. Later, in 1946, S. J. Kidd carried out for the Research Council a water-well survey through the area between townships 73 and 83, lying east of the Smoky River and west of range 21. Jones (1960, 1962b) carried out further groundwater investigations of a more local and detailed nature.

Study of the surficial deposits in different parts of the Peace River district of Alberta and adjacent areas of British Columbia has been carried out by Taylor (1958), Henderson (1959), and Mathews (1962). A detailed examination of the surficial deposits of the Beaverlodge area was carried out by Jones (unpublished M.Sc. thesis, Univ. Western Ontario, 1961).

The soils of the district have been almost completely mapped in recent years by the Alberta Soil Survey and, where pertinent to the groundwater studies, information from soil-survey reports has been incorporated in the text.

Fieldwork and Maps

Groundwater studies were carried out by the author from the spring of 1957 to the fall of 1963. Information on the water wells was obtained from municipalities, communities, and farmers, and from drillers' reports filed with Water Resources Branch, Alberta Department of Agriculture, Edmonton. Data collected during soils, surficial and bedrock geological mapping are used in the text where applicable to the groundwater studies. Other field information was collected by shallow digging, hand-auger boring, and the examination of road cuts and river sections. Considerable subsurface information has also been gathered from seismic shot-hole logs and from the examination of electric, gamma-ray, and lithologic logs obtained from wells drilled in the exploration for oil and gas.

Geophysical exploration programs have been carried out in many different localities by the Research Council of Alberta to aid the groundwater studies. A seismic survey of selected areas in the Beaverlodge district during the early part of the summer of 1958 was made to help in determining the extent of buried gravels (Jones, 1960). Gravity surveying was carried out in the vicinity of High Prairie during the summers of

1962 and 1963 in order to aid in the delineation of a deeply buried channel aquifer. Shallow hammer-seismic surveys have been carried out on certain alluvial terraces adjacent to the Smoky and Wapiti Rivers during the summer of 1961. Some electrical resistivity surveys were conducted in the vicinity of Hines Creek (1957) and Beaverlodge (1959).

Several test-drilling programs to determine the stratigraphic and sedimentologic nature of possible aquifers were completed during the years 1957 to 1963. In addition, pump tests to determine the hydrologic properties of aquifers have been carried out at selected points. Observation wells and automatic water-level recorders have been installed at several places in different aquifers to observe the water-level fluctuations due to seasonal and major climatic changes.

Much valuable information has also been obtained by the Research Council of Alberta by working with communities and industry in exploration and development programs for groundwater supplies in different parts of the district.

The studies of the groundwater and surficial and bedrock geology were aided by the use of aerial photographs obtained from the Alberta Department of Lands and Forests.

The base maps for this report were compiled from maps (scale: 1 inch to 4 miles) obtained from the Alberta Department of Lands and Forests in Edmonton. Topographic coverage has been compiled from maps on a scale of 1:40,000 and 1:50,000 of the National Topographic Series, obtained from the Canada Department of Mines and Technical Surveys, Ottawa.

Maps (scale: 1 inch to 4 miles), which are periodically revised, can be obtained from the Department of Lands and Forests in Edmonton. These maps show townships and main roads, oil-well site roads, locations of seismic trails, oil and gas pipelines, telephone lines, bridges, airstrips, and lookout towers. The maps covering the Peace River district are National Topographic Series sheets 84 C and D, and 83 M and N.

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The author would like to express his sincere appreciation for the excellent co-operation shown by municipal officials to the Research Council of Alberta in aiding collection of groundwater data. In addition, many farmers, water-well drillers, and oil companies provided much valuable information.

Excellent co-operation was received when the author was working with the consulting engineering firms of Stanley, Grimble, Roblin Ltd. and Strong, Lamb and Nelson Ltd., both of Edmonton, on many of the municipal groundwater-supply problems of the district.

The author is especially indebted to the staff of the Dominion Experimental Farm at Beaverlodge, who provided the use of their facilities on many occasions, and generously aided by supplying much information and by discussing many problems of the area.

F. W. Beairsto, formerly City Engineer of Grande Prairie, extended support and many courtesies during investigation of groundwater problems for the city of Grande Prairie.

The co-operation, enthusiasm, and many hours spent beyond those required by the drilling contractors engaged on test drilling and pumping-test research programs for the Research Council of Alberta are gratefully acknowledged. Mr. F. S. Gertsma of Hi-Rate Drilling Company Limited was particularly helpful in this respect. Mr. M. P. Curcio of Michele's Water-Soil Service, Edmonton, also took part in many enlightening discussions of well-drilling problems and, in his former capacity as secretary of the Alberta Water Well Drilling Association, aided materially in the preparation of the water-well specifications given in appendix C. It is emphasized that success of any groundwater program is in the last analysis dependent on a good water-well drilling contractor, and Alberta is fortunate in having some of the finest.

Gratitude is also expressed to colleagues at the Research Council of Alberta in the Groundwater, Geology, and Soils Divisions who assisted by supplying information and advice. Particular thanks are due to staff of the Soils Division who supplied data used in compiling Map 28. The author wishes to thank specifically the following people: G. M. Gabert carried out the original analyses of the Fairview and High Prairie test data and reported on the hydrologic aspects of the groundwater investigations for these municipalities. A. Vanden Berg prepared the section describing the application of soluble-sodium percentage and sodium-adsorption ratio to the determination of the suitability of waters for agricultural use. D. H. Lennox revised the section concerning Grande Prairie in the light of additional new data. Revision and recalculation of the Fairview and High Prairie test data were carried out by O. Tokarsky. Mr. Tokarsky also contributed materially to diagram preparation and to the chapter on utilization and development. The analysis of the High Prairie data for the buried-channel aquifer assumption was done by V. Carlson, using a digital-computer program devised by S. A. Bukhari. G. L. Nielsen carried out sample identifications for the Northern Alberta series of test holes and prepared the lithologic logs shown in appendix B.

Excellent field assistance was provided by G. M. Gabert during the summers of 1958 and 1959, by R. J. Clissold during the summers of 1962 and 1963, and also by R. J. Swanston in 1963.

The hospitality shown to the author on many occasions by residents of the Peace River Country has helped make the work thoroughly enjoyable and is gratefully appreciated.

GEOLOGY

Introduction

The Peace River district is underlain by a series of marine and non-marine sandstones, shales, and siltstones of Cretaceous age (Fig. 2). In general, the strata dip to the southwest into the Alberta syncline and thicken in the same direction, although some beds also thicken in a westerly or northwesterly direction towards the Alberta-British Columbia border. Dips are mainly of the order of a few feet per mile in the central and northern portions of the region, but they increase in the southwest portion of the map-area as the Foothills and Rocky Mountains are approached. The regional structure is relatively simple, although minor rolls of local importance are present locally in the central west and southwestern portions of the map-area. Electric-log cross sections illustrating the bedrock geologic structures and stratification are given in figures 3 to 8. Figure 9 is an index map for the cross sections.

Most of the Cretaceous strata are quite soft and tend to slump quite readily, the disturbed and slumped material commonly obscuring true bedrock outcrops; however, many exposures of bedrock are present along the river valleys of the area and along the upland margins.

Surficial deposits consisting of till, sands, gravels, and lacustrine silts and clays, cover most of the bedrock of the map-area with thicknesses

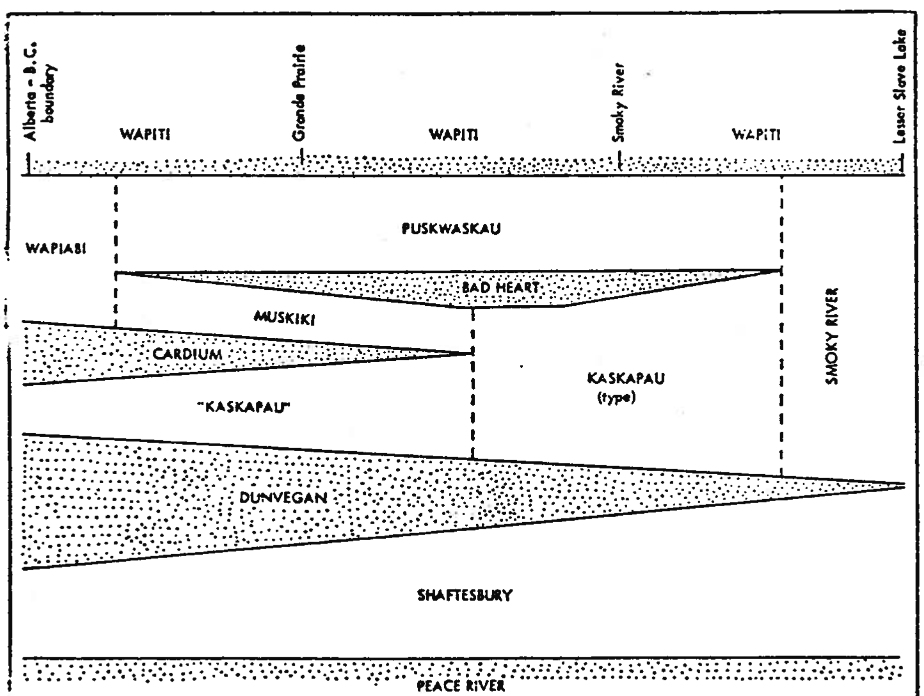

FIGURE 2. Diagrammatic representation of rock units.

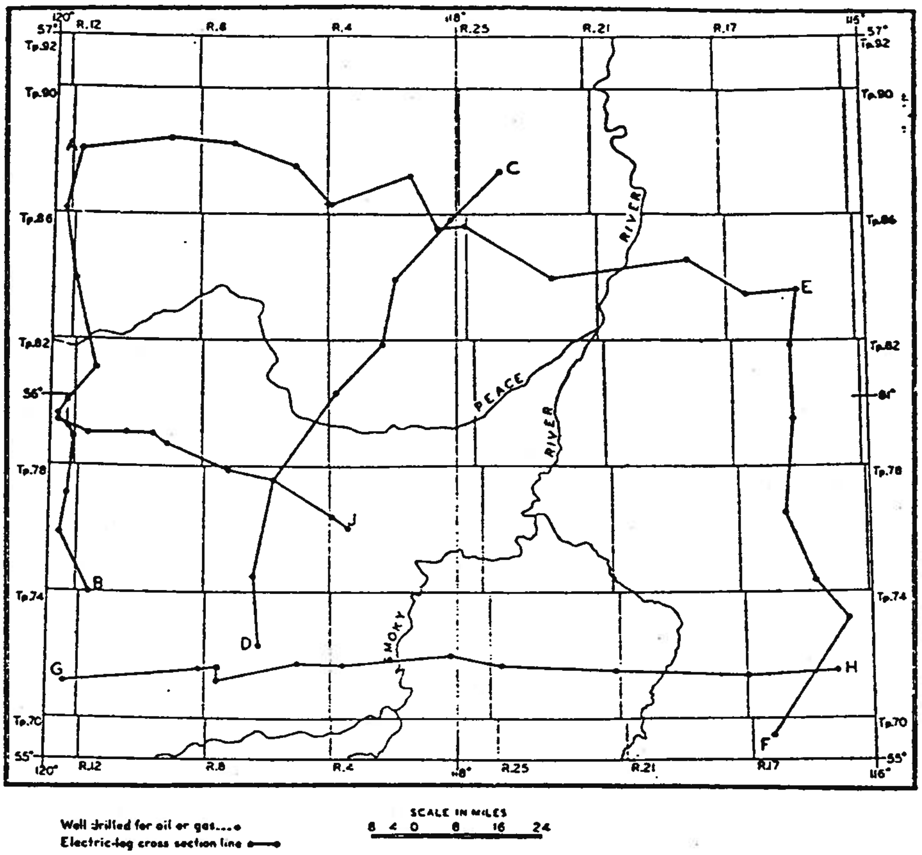

FIGURE 9. Index map, electric-log cross sections.

ranging from a few to several hundred feet. Generally the surficial deposits thin towards upland areas and are thickest in the valleys.

The distribution and extent of Cretaceous and surficial deposits are outlined on maps 27 and 28, respectively.

Cretaceous Strata

Peace River Formation

The lowermost Cretaceous strata exposed in the map-area are the sandstones and shales of the Peace River Formation (McConnell, 1893) which outcrop along the Peace River near water level from just south of Peace River town northward to beyond the edge of the map-area. This unit is recognizable in the subsurface from electric logs (Figs. 3-8) and extends eastward from the Alberta-British Columbia boundary to Lesser Slave Lake (Fig. 6).

The Peace River Formation, as redefined by Badgley (1952) and by a study group of the Alberta Society of Petroleum Geologists (Alberta Study Group, 1954) consists of three members: the Paddy Member—continental member of Wickenden (1951)—the Cadotte Member, and the Harmon Member, in descending order.

The Harmon Member consists of black to dark grey marine shale, and varies in thickness from 20 to 110 feet and averages about 60 feet.

The Cadotte Member consists mainly of fine-grained sandstone and siltstone, with varying amounts of shale. Its thickness varies from 40 to 170 feet, and the unit thins to the east and north of Peace River town.

The Paddy Member was established informally by Wickenden (1951) for the continental facies of massive sandstone and sand with local coaly beds at the top of the Peace River Formation. In outcrops the maximum thickness of the member, about 80 feet, is attained in Secs. 25 and 26, Tp. 85, R. 21, W. 5th Mer., but in subsurface sections thicknesses of up to 130 feet are attained (Alberta Study Group, 1954).

The sandstones of the Cadotte and Paddy Members form prominent cliffs for many miles along the Peace River north of Peace River town. Seven miles below the town a lens of easily crumbled, fairly clean, fine- to coarse-grained quartz sand is present in the Paddy Member. Crockford (1949) examined this body to evaluate its potential as glass sand; with reference to the origin of the sand body he commented as follows (*ibid.*, p. 12):

> Since the sandstone members of the Peace River formation thin somewhat from southwest to northeast, the source of the sediments lay somewhere west of the present site of the Rocky Mountains, and was probably the Selkirk Mountains. Rocks in the upper sandstone member of the Peace River formation were laid down close to a shoreline, as is attested by the presence in them of coaly beds. The fact that they underlie marine shales also shows that the sea was not far away. The lens of glass sand was probably deposited as part of a delta, for the sand in places is cross-bedded indicating strong current action. Futhermore, the glass sands feather out within a few miles, a feature to be expected in a delta. The sands in the lens are so high in silica that they must be a reworked sand deposit that was tapped by the stream and deposited as beneficiated sands.

The Peace River Formation is overlain by the Shaftesbury Formation. North and eastward from the map-area, the Peace River Formation equivalent is the Loon River Formation (Wickenden, 1951).

Shaftesbury Formation

The Shaftesbury Formation is composed of a series of marine shale and silty shale beds that overlie the Peace River Formation and underlie the Dunvegan Formation of the map-area.

Rocks of the Shaftesbury Formation outcrop mainly in the eastern portion of the map-area, along the Smoky and Peace Rivers. Originally Dawson (1881) applied the name Fort St. John to the shales below the Dunvegan Formation, but this name is now applied, as a group, to all strata between the Gething and Dunvegan Formations. McLearn and Henderson (1944) introduced the name Shaftesbury for the shales lying between the Dunvegan and Peace River Formations, the type area being along the Peace River valley between Dunvegan and the town of Peace River. Gleddie (1954) divided the Shaftesbury Formation into two members, the lower member comprised mainly of thinly bedded fissile shales with at least three fish-scale zones in the upper part and the upper member consisting of silty and sandy shales relatively free of fish scales.

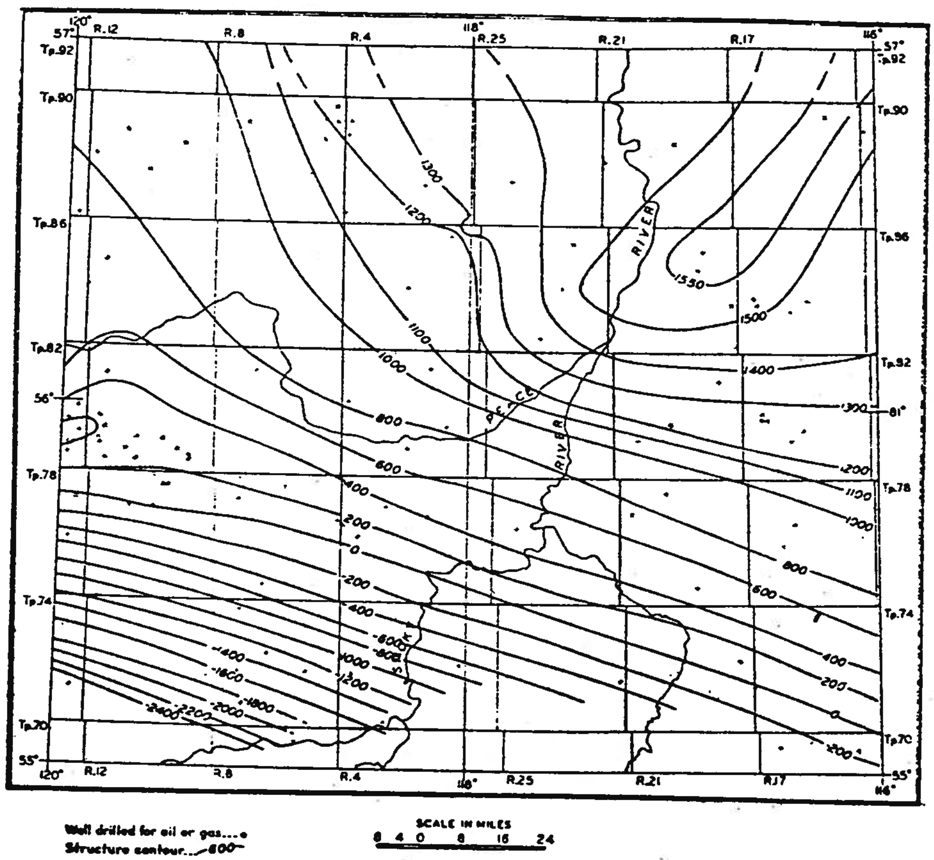

FIGURE 10. Structure at the base of the fish-scale zone.

Stelck, Wall and Wetter (1958, p. 13) placed the Lower-Upper Cretaceous boundary at the top of the fish-scale sand marker bed; however, for practical purposes the base of the fish-scale sand bed, an excellent subsurface marker on electric logs, is commonly used as the Lower-Upper Cretaceous boundary. This marker (Figs. 3-8), the structure on which is shown on figure 10, and which shows a readily recognizable persistent 'kick', is also generally used in separating the upper and lower members of the Shaftesbury Formation. Green and Mellon (1962) recognize a similar twofold division in the Shaftesbury Formation in the Chinchaga and Clear Hills areas, the southern part of which overlaps the north-western part of the map-area in this report. A more detailed map of the structure at the base of the fish-scale zone is available from the Alberta Oil and Gas Conservation Board.

The Shaftesbury Formation thins eastward and southward, as evidenced from figures 6 and 8. In the southwestern portion of the map-area the formation is 1,095 feet thick in McColl Cities Service Steeprock Creek No. 1 well (Lsd. 4, Sec. 10, Tp. 72, R. 13, W. 6th Mer.) and in the north-eastern portion in Stanolind East Peace River (Lsd. 1, Sec. 22, Tp. 84, R. 17, W. 5th Mer.) is 270 feet thick.

The uppermost part of the formation becomes silty to sandy, with minute carbonaceous fragments, and is transitional into the overlying non-marine Dunvegan Sandstone.

Dunvegan Formation

The Dunvegan Formation was named by Dawson (1881) for a group of mainly fresh-water sandstones and shales outcropping prominently on the north side of the Peace River (Fig. 11), at the site of former Fort Dunvegan, an old trading post and mission. The sandstones and shales of

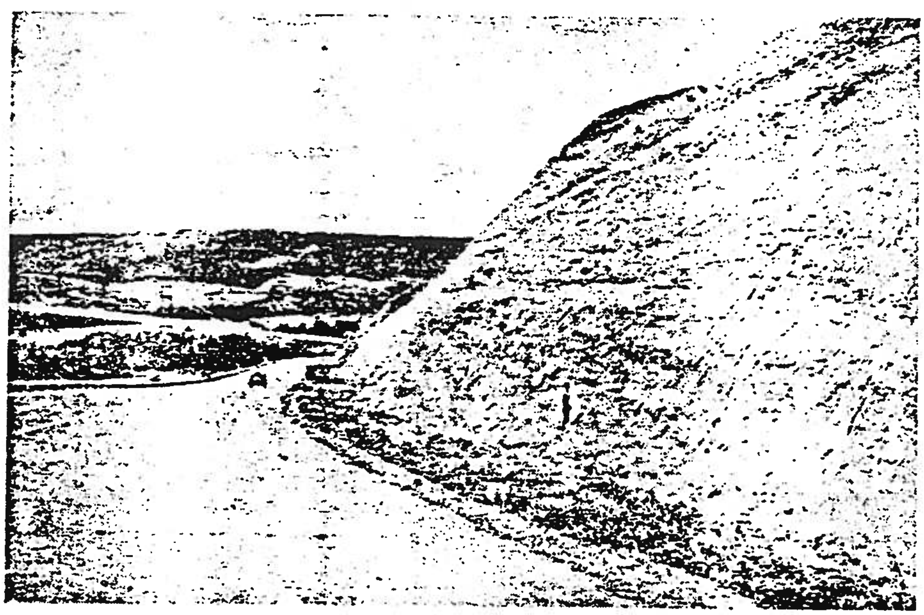

FIGURE 11. Type section of Dunvegan Formation.

the Dunvegan Formation outcrop along both sides of the Peace River from the Alberta-British Columbia border downstream to beyond Dunvegan Crossing and also on the Smoky River as far upstream as Watino.

Rutherford (1930, p. 19) gives the following description of these strata:

> The Dunvegan strata consist of an alternating series of sandstones and shales, with all gradations between these two types of strata. Some of the beds are over 50 feet thick. Sandstones are more prevalent in the middle part of the formation, while shales predominate in the upper and lower parts. The sandstones are usually fine-grained, crossbedded and massive, and light grey to buff in colour, with varying hardness. The harder phases are usually confined to the thicker massive sandstones and are dark green on fresh surfaces. During the erosion of these sandstones along valley outcrops, the harder phases often weather out as large spherical masses up to 10 feet in diameter, a feature common to Upper Cretaceous sandstones in many parts of the foothills of Alberta. These large blocks are not concretions, but appear to be centres which have undergone greater cementation. They are usually fine-grained in texture.

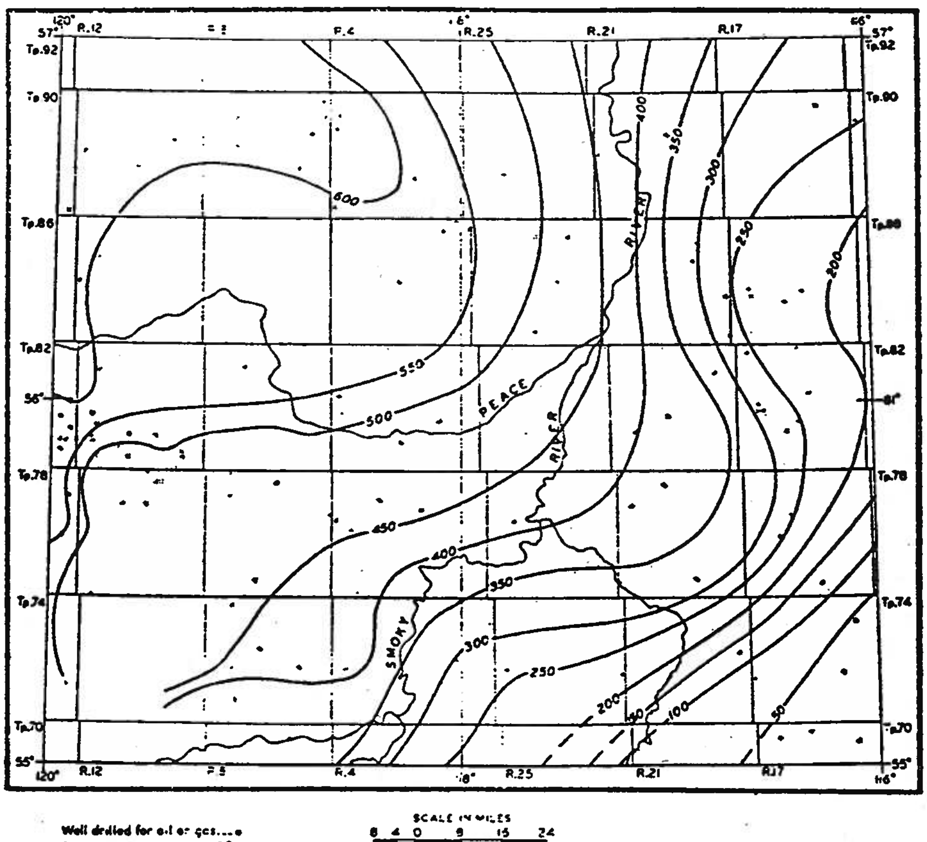

FIGURE 12. Isopachs of Dunvegan Formation.

> The shale phases vary from arenaceous siltstones to thin bedded dark grey shales. These siltstones alternate with sandstone layers and usually represent gradations between the thicker sandstone members. The thin bedded shales reach thicknesses in places of over 50 feet, especially in the upper part of the formation. Crystals of selenite (gypsum) occur frequently on the weathered surfaces of the shale outcrops.

In addition, some local coaly beds exist, and some brackish to marine phases (Gleddie, 1954).

In figure 12 the isopachs of the Dunvegan Formation show a fan-shaped wedge of strata thinning from the northwest to the southeast of the map-area. In the northwest portion of the map-area the thickness of the Dunvegan Formation is approximately 600 feet, whilst in the south-east portion it thins to 50 feet and less. Stelck and Wall (1955, p. 17) state:

> The Dunvegan sands in Alberta represent the outer margins of a delta built out as a broad apron skirting an upland centering on the southern Mackenzie mountains and the Cassiar mountains of northern British Columbia. A major river

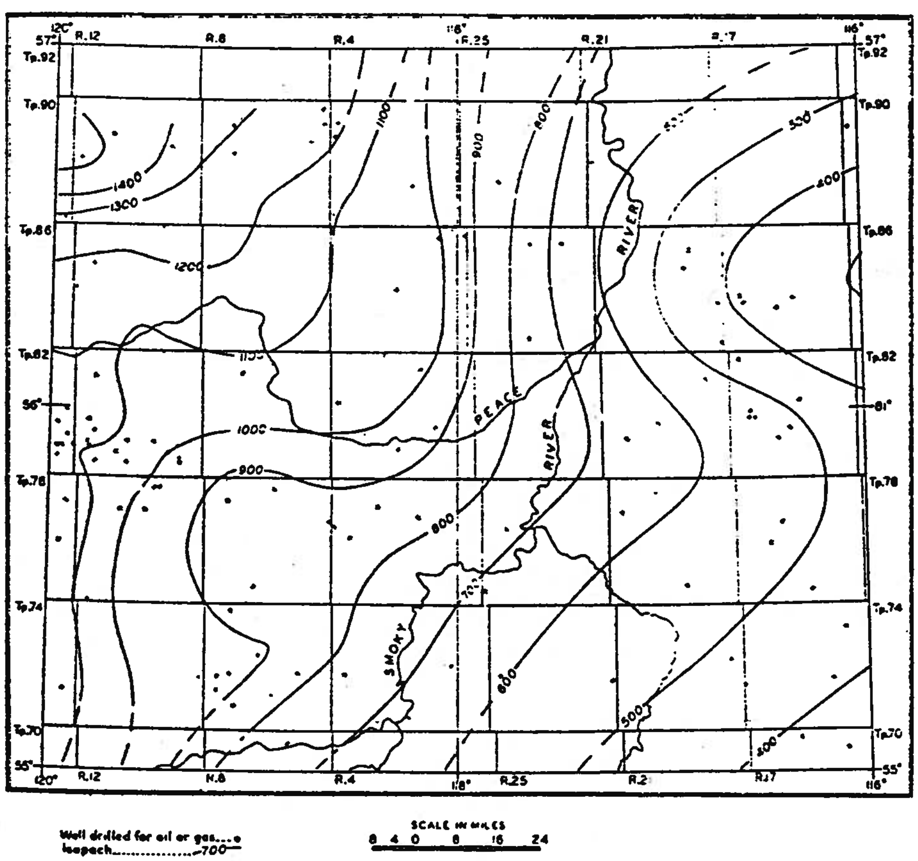

FIGURE 13. Isopachs of interval from base of fish-scale zone to top of Dunvegan Formation.

system, apparently draining through the general Liard plateau area, spilled arkosic beds into northeastern British Columbia with the more conglomeratic phases present northward toward the Liard Gap.

Continued uplift of the source area involved the upper reaches of the delta in the erosional cycle and the later sandy beds of the early Upper Cretaceous find their source, in part, in the reworked Dunvegan deltaic material. The implied tilting moved the late Cenomanian shoreline south-eastward and, consequently, the farthest southward expression of these "deltaic" Dunvegan deposits is considerably younger than the main arkosic beds of northeastern British Columbia. In offshore facies, only the latest Cenomanian beds appear in sandy phase, and the outermost latest margins of the "Dunvegan" delta carry marine(?) coal-seams interbedded with beds carrying oysters.

Isopachs of the interval from the base of the fish-scale marker to the top of the Dunvegan Formation (Fig. 13) show the general outline and distribution of these beds—further emphasizing the deltaic nature of this interval. The structure on the top of the Dunvegan Formation is shown in figure 14.

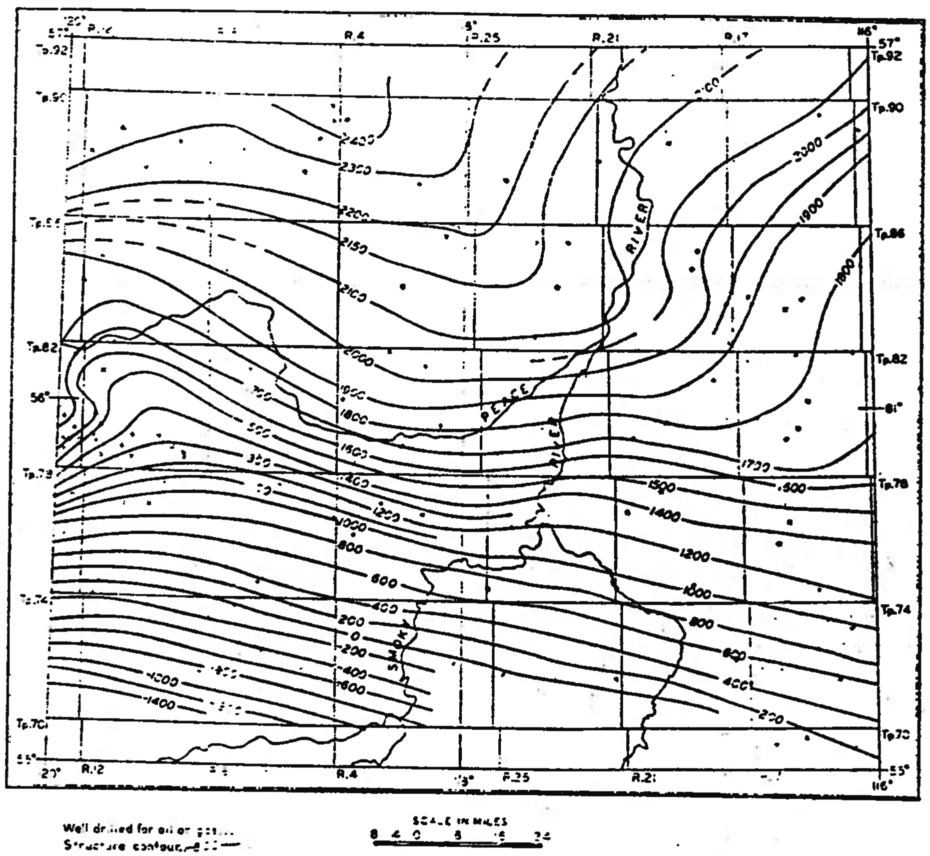

FIGURE 14. Structure at the top of the Dunvegan Formation.

In the electric-log cross sections (Figs. 3 to 8) the limited extent and discontinuity of the Dunvegan beds in the Peace River district can be seen. This phenomenon has been observed by Burk (1963) in adjacent areas to the south. Although marked discontinuity in individual sand units in the Dunvegan Formation is noted, some sands can be correlated, from the electric logs, for tens of miles, attesting to the large local areal extent of the deltaic sand bodies.

Smoky River Group

Dawson (1879) used the name "Smoky River" to describe a sequence of Upper Cretaceous marine shales exposed along the Smoky River. McLearn (1918) divided this formation into three members, an "Upper Shale", "Bad Heart Sandstone" and a "Lower Shale". Later, McLearn (1926) assigned the name "Kaskapau" to the lower shale, Gleddie (1954) named the three members in ascending order, the Kaskapau, Cardium and Wapiabi Formations, and raised the unit to group status. Stelck and Wall (1954) pointed out that the Bad Heart Sandstone was not part of the Cardium Formation, as suggested by Gleddie (1954), and raised it to formational status.

The Smoky River Group is conformable with the underlying Dunvegan Formation and the strata grade upward into the Wapiti Formation. Generally this group is equivalent to the upper part of the Colorado Group of the central and southern plains of Alberta. In the Pouce Coupe area the Smoky River Group is approximately 2,300 feet thick, thinning to about 1,200 feet on the Smoky River (see electric-log cross sections).

Kaskapau Formation

The Kaskapau Formation (Fig. 2), consisting predominantly of marine shales and silty shales, includes a basal transition zone which includes the Doe Creek, Pouce Coupe, and Howard Creek Sand Members.

The Kaskapau Formation has a thickness about 1,600 feet in the Pouce Coupe area of British Columbia near the Alberta border and thins eastward to Spirit River (Fig. 7) where it is approximately 1,000 feet thick (Gleddie, 1954). Farther east along the Smoky River about 500 feet are present.

Green and Mellon (1962) recognized between 200 and 400 feet of Kaskapau beds in the Clear Hills area of the northwestern portion of the map-area, indicating considerable thinning towards the north and east.

Doe Creek Member. The Doe Creek Sandstone Member of the Kaskapau Formation was first described by Warren and Stelck (1940). The type area for this sand is along the Doe Creek in the north half of Sec. 10, Tp. 81, R. 13, W. 6th Mer.

The Doe Creek Member has been recognized in the subsurface in the Pouce Coupe gas-field area of British Columbia and in adjacent areas in Alberta. This member consists of a group of three to four lenticular sands found within a 50-foot interval. At its type locality this unit consists of yellow fine-grained sandstone, argillaceous toward the base, approximately 6 feet in thickness, with the base of the sand about 225 feet above the base of the Kaskapau Formation and 75 feet below the base of the Pouce Coupe Member (Stelck and Wall, 1954).

The Doe Creek Member is of fairly limited extent and is confined mainly to the western part of the area, and although its equivalent has been recognized, from electric logs (Fig. 7), as extending almost as far east as Spirit River, it has almost completely shaled out in that direction. The sandstone appears to thicken slightly northward across the Peace River towards the Boundary Lake area of Alberta and British Columbia (Tps. 84 to 90, Rs. 12 and 13, W. 6th Mer.) (Fig. 3).

Pouce Coupe Member. The Pouce Coupe Sandstone Member of the Kaskapau Formation was first described by Warren and Stelck (1940). The type locality for this member is along the Pouce Coupe River near the mouth of Saskatoon Creek (Lsd. 13, Sec. 30, Tp. 79, R. 13, W. 6th Mer.) in British Columbia adjacent to the Alberta border.

The Pouce Coupe Member at its type locality consists of a yellow, massive, fine-grained, clean sandstone, approximately 30 feet thick, its top lying approximately 300 feet above the base of the Kaskapau Formation (Stelck and Wall, 1954). This sandstone can be traced in the subsurface north across the Peace River (Fig. 3) and to the west and central parts of the Clear Hills area, where a thick sandy zone is recognizable about 100 feet above the top of the Dunvegan (Green and Mellon, 1962). It ranges from 20 to 40 feet in thickness as indicated from electric logs in this area.

The Pouce Coupe Sandstone can also be traced eastward from its type locality (Fig. 7), where its equivalent can be recognized at Spirit River (Stelck and Wall, 1954).

This sand unit splits off the top of the Dunvegan Sandstone complex as a tongue interfingering with marine shales of the Kaskapau Formation, and thus may be expected to increase in thickness and coarseness to the north and west (Figs. 3, 8).

Howard Creek Member. The name "Howard Creek" was introduced by Stelck and Wall (1954) for a 14-foot bed of buff grey, fine- to medium-grained, partly glauconitic, marine shaly sandstone that outcrops northwest of the town of Spirit River on Howard Creek. This sandstone or its equivalent can be traced in the subsurface from the British Columbia boundary in the Pouce Coupe area east to Spirit River, where it lies 60 to 75 feet above the Pouce Coupe Member (Fig. 7).

Second White-Speckled Shale Horizon. A useful marker horizon in the Kaskapau Formation below the Cardium Formation and above the Dunvegan Formation is the Second White-Speckled Shale horizon, used in the subsurface electric-log correlation studies (Gleddie, 1954; Burk, 1963).

Cardium Formation

The Cardium Formation was named by Cairnes (1914) for the remarkably persistent, ridge-forming, sandy unit within the Alberta shales in the Foothills belt, and which extends from southwestern Alberta to northeastern British Columbia. Gleddie (1954) included the Bad Heart Sandstone of the Peace River district as part of the Cardium Formation, but Stelck (1955) demonstrated that these units are separate and identifiable formations in both subsurface and outcrop.

MacDonald (1957) used the well log of Baysel *et al.* Cutbank No. 1 well (Lsd. 6, Sec. 9, Tp. 64, R. 7, W. 6th Mer.) to illustrate the lithology of the Cardium Formation as it occurs in northwestern Alberta and described it (*ibid.*, p. 82) as follows:

> The Cardium at Cutbank No. 1 is 250 feet thick. The basal 90 feet of the formation consists of laminated silt and shale, very fine sand, and shale with numerous nodules and concretions of ironstone. In this well the main sand is of marine origin, and it reaches a thickness of 60 feet . . . . . The upper 100 feet of the Cardium formation consists of dark grey shale, which is in part coaly or carbonaceous, and some very fine-grained sandstone similar to the main sand.

MacDonald (1957) further states that an unconformity marked by a chert-pebble conglomerate generally lies at the top of the Cardium Sandstone in the area between the Pembina and the Peace Rivers and he believed that these chert pebbles mark the initial unconformable carpet of Wapiabi sediments transgressing upon the Cardium Formation.

The Cardium Formation is present in the subsurface in the southwestern part of the Peace River district (Burk, 1963) and outcrops to the west in the Dawson Creek area (Stott, 1961b). The zero-foot sandstone isolith extends northwestward from approximately township 70 and the sixth meridian (Burk, 1963) into the Gordondale area (Tp. 79, R. 10, W. 6th Mer.). In Research Council Gordondale Strat. Test No. 1 (Lsd. 12, Sec. 19, Tp. 79, R. 9, W. 6th Mer.) a silty to sandy shale interval was recorded about 200 feet below the Bad Heart Formation. Microfossils from the base of this interval include *Pseudoclavulina* sp., a form apparently restricted to an interval a short distance below the Cardium Formation in the Alberta foothills (J. H. Wall, pers. comm.).

Farther eastward, on the Smoky River, the interval of the Cardium Formation may be represented by a thin chert-pebble zone lying 60 to 70 feet below the Bad Heart Formation (J. H. Wall, pers. comm.). Northward, in the Clear Hills area, the Cardium Formation is absent also, and the equivalents have not been recognized, although Wall (pers. comm.) states the *Pseudoclavulina* sp. has been collected from samples from one testhole in that area.

Bad Heart Formation

McLearn (1918) originally described the Bad Heart Formation as a sandstone member of the Smoky River Formation. Gleddie (1954) considered the Bad Heart Sandstone a member of the Cardium Formation, but Stelck (1955) showed that it is stratigraphically higher than the Cardium Formation, and included it as a member of the Wapiabi Formation. Wall (1960), from studies in the Smoky River area, indicated that the Bad Heart Sandstone has a sharp contact with the overlying shales of the Puskwaskau Formation, but is gradational into the underlying silty shales of the Kaskapau Formation. Wall (1960) describes the Bad Heart as consisting of an upper massive, 8-foot thick, fine-grained, yellow-weathering, quartzose sandstone capped by a persistent ironstone layer, 1 to 2 feet thick, underlain by a variable amount of argillaceous sandstone approximately 20 feet thick. Burk (1963, Fig. 12) shows the subsurface distribution of this unit, as northwesterly-trending thin sand bodies.

In the Clear Hills area, in the northwestern portion of the map-area, the Bad Heart Formation is present as iron-rich deposits consisting of lenses of oolitic conglomeratic sandstone beds 10 to 20 feet thick trending in a northwesterly direction (Green and Mellon, 1962). Examination of well cuttings from a number of wells in the Clear Hills area and correlation with surface outcrops (Green and Mellon, 1962), indicate that in the western part of the Clear Hills the Bad Heart Sandstone proper is present, and that it becomes more ferruginous and oolitic eastwards, locally forming thick deposits in the Worsley and Swift Creek areas.

In the central portion of the map-area, thin ferruginous Bad Heart Sandstone beds outcrop south of Spirit River town. This unit extends westwards from Spirit River town to the Whitburn and Gordondale areas (Fig. 7), where oolitic and local conglomerate phases are present.

In summation, the Bad Heart Formation consists of a series of shoal-like bodies trending in a northwesterly direction.

Baytree Member

Stelck (1955) described the Baytree Conglomerate, at its type locality, 1 mile east and 2¼ miles south of Baytree Post Office (NW ¼ Sec. 25, Tp. 78, R. 13, W. 6th Mer.), as a massive, black chert and quartzite conglomerate, the lowermost part containing crossbedded lenses of coarse sandstone and fine conglomerate with sporadic coaly fragments, with pebbles as large as 2 or 3 inches being not uncommon. The thickness reported was approximately 50 feet.

This outcrop has now been partially destroyed by local mining of the unconsolidated conglomerate phases. Farther south and west, however, additional outcrops of the conglomerate can be found in Secs. 12 and 13, Tp. 78, R. 13, W. 6th Mer. along recently constructed oil- and gas-well access roads.

Some uncertainty exists as to whether the Baytree Conglomerate is the equivalent of the Bad Heart or of the Cardium Formation (Stelck, 1955; MacDonald, 1957; Burk, 1963). In the Dawson Creek map-area, immediately to the west, Stott (1961b) could not recognize the Bad Heart Formation east of the Kiskatinaw River to the Alberta-British Columbia boundary; extrapolation of Burk's (1963, Fig. 12) sandstone isoliths also suggests the absence of the Bad Heart Formation in the Pouce Coupe area. On the other hand, Stott (1961b) was able to trace the Cardium Formation from the Kiskatinaw River eastward to the Alberta-British Columbia boundary, and extrapolation of Burk's (1963, Fig. 11) sandstone isoliths of the Cardium Formation suggests that a substantial thickness of Cardium strata should be present in the area around Pouce Coupe and Baytree.

Correlation of the type of Baytree Conglomerate with the Cardium Formation would necessitate a rapid eastward shaling out of this unit to account for the Cardium-equivalent silty shale unit in the Gordondale area; such a rapid eastward facies change in the Cardium Formation is indicated by Burk (1963, Fig. 11).

Puskwaskau, Wapiabi, and Muskiki Formations

Wall (1960) gave the name Puskwaskau to those shale strata lying between the Bad Heart and Wapiti Formations. This name is applicable mainly in the Smoky River and northern parts of the map-area. In those parts of the map-area where the Bad Heart Formation is absent, the name Wapiabi is applicable to the strata between the Cardium and the Wapiti Formations. The strata, mainly marine shale, between the Cardium and Bad Heart Formations are designated as the Muskiki Formation (Stott, 1961a, 1963).

In the subsurface, southwest and southeast of the Smoky River, and south of the Peace River west of Spirit River, the Bad Heart and Cardium Formations separated by a shaly unit can be recognized (Figs. 3, 6). North and east of this area, the Cardium Formation is underlain by "Kaskapau Formation" beds (Fig. 2), the Bad Heart unit being absent.

In the Smoky River area, approximately 300 to 350 feet of marine shale beds of the Puskwaskau Formation are present (Wall, 1960). In the Clear Hills areas of the northwestern part of the map-area, Green and Mellon (1962) recognized 300 to 400 feet of Puskwaskau Formation: soft grey fissile shales of marine origin.

First White-Speckled Shale. The First White-Speckled Shale zone is a useful marker in the subsurface in the southern and eastern portions of the Peace River district. Smith (in Gleddie, 1954) recognized a speckled shale zone approximately 60 feet thick on the Smoky River in the Wapiabi (now Puskwaskau) Formation. Gleddie (1954) correlated this speckled zone with the upper "White Speckled Shale" zone of the Colorado Shales occurring in the southern plains.

In the northern and northwestern portion of the map-area, the First White-Speckled Shale zone appears to be absent.

Chinook Member. Gleddie (1954) gave the name "Chinook" to a littoral marine sandstone and sandy shale sequence about 75 feet thick, containing glauconite, and lying 90 to 100 feet below the Wapiti Formation on Fish Creek ½ mile above its junction with the Wapiti River. According to Smith (in Gleddie, 1954) the Chinook thins appreciably in an easterly direction to the Smoky River where it is only about 10 feet thick. Gleddie (1954) considered the Chinook as transitional into the overlying Wapiti Formation through a sandy and silty zone. The Chinook Member is recognizable on electric logs, and Workman (in Gleddie, 1954) correlated it with the top of the Milk River Formation of southern Alberta. Although Gleddie considered the Chinook Member a part of the Wapiti Formation in the present map-area, it must now be considered a member of the Puskwaskau Formation.

The Chinook equivalent has been recognized in the present map-area as far east as Grouard Mission (J. H. Wall, pers. comm.) at the west end of Lesser Slave Lake and is represented by a 12-foot glauconitic sandy-shale interval.

Wapiti Formation

The name "Wapiti" was first applied by G. M. Dawson (1881) to an Upper Cretaceous sequence of continental sandstones, shales, and thin coal seams exposed at the mouth of Big Mountain Creek, at its confluence with the Wapiti River, in Tp. 70, R. 5, W. 6th Mer. These beds underlie most of the settled areas in the southern part of the map-area and also cap the Clear Hills, in the northern part of the district. The upland areas in the central portion of the map-area, the Saddle and Birch Hills and Sturgeon Heights, are also capped by Wapiti strata.

The individual units within the Wapiti Formation are gradational in character, and commonly lens out within a mile or two when traced any distance along outcrop faces. Rutherford (1930, p. 31) gives the following description, typical of Wapiti Formation strata:

> Lithologically the Wapiti Formation consists of sandstones and shales of fresh-water deposition. The units vary in thickness from a few inches up to as much as 50 feet, the average thickness being more often 10 to 20 feet. All phases of gradation between sandstone and shale are common. The more massive sandstones are frequently cross-bedded and concretionary masses are common in eroded faces.
>
> Light grey to buff are the prevailing colors, and on the whole fine grained textures are most common. The shales are poorly stratified, a characteristic common to shales of fresh-water deposition.

Thin beds of greyish-green bentonite up to 6 inches in thickness are commonly found associated with some of the coal seams in the map-area. Occasionally thin beds of fresh-water limestone, never more than a foot or two thick, can be found.

A typical outcrop of Wapiti strata occurs in the southwest corner of Sec. 22, Tp. 70, R. 10, W. 6th Mer., along the Redwillow River (Jones, 1960). This section is probably part of 'Member B' of Allan and Carr (1946, p. 16):

Thickness (feet)	Top of Section
3.0	Recent alluvial silts and sands
20.0	Colluvium, a mixture of Recent and glacial pebbles, boulders and clay, resting on bedrock
5.8	Sandstone, yellowish grey-brown, salt and pepper, weathering light grey-buff, fine- to medium-grained feldspathic, reasonably well indurated and cemented, massive, shows bedding and cross-bedding, fractured in places
0.8	Shale, black, carbonaceous, with coal lenses
0.1	Bentonite, weathers white
1.0	Coal, black, well weathered, in thin bright and dull lenses

0.7	Shale, black, carbonaceous and coaly
0.7	Coal, hard, massive, fairly bright, with thick vitreous bands
1.0	Shale, black, carbonaceous
	Slump and colluvium, covering bedrock to river level

A more detailed description of the Wapiti Formation strata is given in appendix A from Research Council test and core holes Nos. 15, 16, 17 and 22, drilled in the Beaverlodge district in Tp. 71, R. 9, W. 6th Mer.

McLearn (1918) and Rutherford (1930) estimated 900 to 1,100 feet as the thickness of the Wapiti Formation overlying the Smoky River Shales (Puskwaskau Formation) along the Smoky River. South of the map-area, Evans and Caley (1930) estimated the thickness of the Wapiti Formation in the vicinity of the Cutbank River and Nose Mountain to be 1,100 feet. Allan and Carr (1946) indicated the maximum thickness of the Wapiti Formation to be 4,100 to 4,600 feet; more recent information from Baysel C.F.P. Regent Nose Mountain well (Lsd. 15, Sec. 20, Tp. 64, R. 11, W. 6th Mer.) shows a thickness of 5,380 feet for the Wapiti Formation. In the eastern part of the map-area, in the vicinity of Valleyview, 300 to 400 feet of Wapiti Formation are preserved. Wapiti Formation beds capping the southern portion of the Clear Hills probably attain a maximum thickness of 400 feet (Green and Mellon, 1962).

Rutherford (1930) considered the lower part of the Wapiti Formation to be equivalent to the Belly River Formation of the plains and foothills of southern Alberta. Allan and Rutherford (1934) recognized the Edmonton Formation west of the Smoky River as far as the Grande Prairie district and correlated it with the upper part of Wapiti Formation on the basis of lithologic similarity. According to Allan and Carr (1946), attempts at limiting the Wapiti Formation to those beds correlative with the Belly River of southern Alberta have been based entirely on lithologic evidence and no sure correlation is possible until more adequate studies of the nonmarine Upper Cretaceous strata have been undertaken in the Peace River district.

Rutherford (1930, p. 32) suggested that Tertiary strata might be present in the Peace River district. He stated:

> A relatively high, flat topped mesa occurs in the central part of township 72, range 8, west of the sixth meridian, a few miles east of Beaverlodge. This is known as 'Saskatoon Hill' which rises about 600 feet above the surrounding gentle sloped areas at the base. The shape of this hill is mesa-lake and about 150 feet of the underlying strata near the top are exposed in steep cliffs. These beds consisting of coarse cross-bedded sandstones and sandy shales are very similar in appearance to the Paskapoo Formation as developed elsewhere in Alberta.

Jones (1960) estimated that between 3,500 and 4,000 feet of Wapiti beds were originally present in the Beaverlodge district, and subsurface well data indicate that between 1,200 and 1,900 feet of Wapiti beds now remain, the remainder having been removed by erosion. The elevation of the top of the orginal Wapiti Formation was thus approximately 2,000 feet above the summit of Saskatoon Hill and therefore the beds capping Saskatoon Hill that Rutherford (1930) and Allan and Rutherford (1934) considered to be Tertiary are probably middle Wapiti in age.

Detailed examination of the lithology of sections of Wapiti sandstone cores in Research Council Northern Alberta test hole Nos. 20 (Lsd. 1, Sec. 14, Tp. 71, R. 10, W. 6th Mer.) and 22 (Lsd. 4, Sec. 13, Tp. 71, R. 9, W. 6th Mer.) reveals the following, reported by G. B. Mellon:

> The composition, determined from thin-section point-counts, and corresponding porosities and permeabilities (determined by Core Laboratories, Canada Ltd., Calgary) are shown in table 4.
>
> The detrital portions of the rocks are composed mainly of finely crystalline rock fragments (largely of volcanic origin), with accessory quartz, chert, and feldspars. Many of the softer rock fragments have been crushed and squeezed to form patches of interstitial "clay" matrix, which have filled much of the original intergranular pore space that undoubtedly was present prior to compaction and cementation. The remaining pore space has been partly or completely filled by finely crystalline authigenic clay cements, deposited from solutions subsequent to burial and compaction of the sandstones.
>
> Sample 117 is a fine-grained, well-sorted sandstone with seemingly high porosity (25 per cent) but with a hydraulic conductivity* of only 0.13 igpd/ft.[2] (imperial gallons per day per square foot) (8.8 millidarcys). The rock appears in

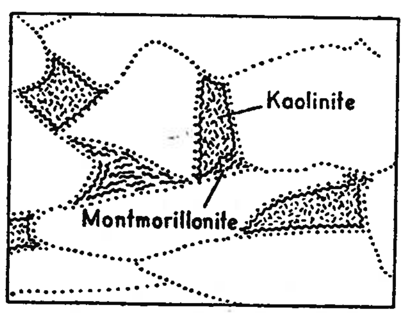

FIGURE 15. Schematic distribution of clay-mineral content in Wapiti sandstone sample 117.

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*The term "hydraulic conductivity" is used in place of "permeability" in order to distinguish a quantity depending not only on the geometric properties of the transmitting medium but also on the physical properties of the fluid being transmitted (hydraulic conductivity) from a quantity depending on geometric properties alone (permeability). This usage is in conformity with recent trends in soil science (U.S. Salinity Laboratory Staff, 1954) and groundwater hydrology (Hantush, 1961).

thin section to be completely cemented by finely crystalline clay aggregates, identified by optical and staining techniques as kaolinite and montmorillonite. Montmorillonite tends to form a fringe-like coating about the pore walls, whereas kaolinite fills the larger central areas (see Fig. 15). There are no visible void spaces, and the seemingly high porosity of the rock appears to be due to the capacity of the abundant clay matrix and cements (especially montmorillonite) to absorb water. In such a case, most of the water is "fixed" in the lattice of the clays, rather than distributed in pores, and the clays swell and effectively destroy the permeability of the sandstone, as was actually observed by putting a drop of water on an uncovered portion of the thin section.

Sample 199 is a coarse-grained, well-sorted sandstone containing scattered coaly partings. In thin section the rock appears to be only partly cemented, mainly by kaolinite, and many of the large intergranular pore spaces are partly or completely free of mineral matter. No montmorillonite was detected, and this, coupled with the presence of large uncemented voids, probably accounts for the high hydraulic conductivity (8.14 igpd/ft.², or 536 millidarcys) and porosity (34 per cent) of the rock.

Sample 431 is a coarse-grained sandstone containing several thin shaly laminae (matrix). This rock also appears to be completely cemented, mainly by kaolinite and chlorite. Staining tests show that montmorillonite is scarce or absent, and that the clayey constitutents do not swell when immersed in water. Thus, although the rock has about the same absorption capacity (23.5 per cent) as sample 117, the hydraulic conductivity (0.50 igpd/ft.², or 33 millidarcys) is considerably greater.

Table 4. Composition, Hydraulic Conductivities, and Porosities of Three Wapiti Sandstone Samples

Sample depth (feet)	Constituent percentages							Horizontal hydraulic conductivity (igpd/ft.²)	Porosity (per cent)
	quartz	chert	feld-spars	rock frag-ments	matrix	cements	voids		
117	15	1	16	36	9	23	—	0.13	25.1
199	9	10	6	49	9	9	8	8.14	34.2
431	17	8	11	34	16	13	—	0.50	23.5

As noted previously by Allan and Carr (1946) and Gleddie (1954), both invertebrate and vertebrate fossils occur throughout the Wapiti Formation, and plant remains are common. The invertebrates are generally small freshwater pelecypods and gastropods. Fragments of dinosaur bones have been found locally.

The strata of the Wapiti Formation are located on the east limb of the Alberta syncline. Studies based on information from structure-test holes and deep test-well electric logs indicate that the regional strike on the base of the Wapiti Formation is south 85 degrees west to due west and the dip is to the south at 44 to 55 feet per mile in the southern and southwestern portion of the map-area (Jones, 1960). Dips within the Wapiti Formation itself are much more gentle, being close to zero in the Clear Hills area and up to 15 to 20 feet per mile in the southern part, south of the Saddle and Birch Hills. Southwest of the map-area the strike of the Wapiti beds changes to a more northwesterly direction and dips become steeper toward the foothills.

Buried Channel Deposits

In the province, particularly in central and southern Alberta, deposits of sands and gravels which appear to have been laid down by old river systems have been found underlying surficial and recent deposits and overlying bedrock strata (Farvolden, 1963a, 1963b). In the Peace River district similar deposits have been found, the locations of which are outlined on figure 16.

Occurrence and Distribution

Buried deposits of sands and gravels outcrop in the Peace River region at several localities (Allan and Carr, 1946, p. 23; Rutherford, 1930, p. 34; Henderson, 1959, p. 64; and Jones, 1960, p. 11). Subsurface data, obtained from seismic shot-hole logs, oil company structure-test hole logs, water-well logs, and recent test holes drilled by the Research Council of Alberta, provide further information on the nature and distribution of these deposits in many areas of the Peace River district (see Fig. 16).

Jones (1960) describes a typical outcrop of these sand and gravel deposits occurring in a buried channel, herein named the Wembley Channel (Fig. 17), exposed along the west bank of the Beaverlodge River (SW. corner, Sec. 4, Tp. 71, R. 9, W. 6th Mer.). The strata are described as follows (Jones, 1960, p. 11):

Thickness (feet)	Top of Section
15	Silts and clays, varved and bedded, grey to greyish-brown, individual varves one-eighth inch to one foot thick
97	Till, grey-brown, boulders, pebbles and clay
20	Gravels, coarse, 2- to 6-inch yellow-white quartzite cobbles and pebbles, some chert pebbles with some minor lenses of coarse sand; face of gravel almost vertical in outcrop
1	Slump and colluvium to river level

Other exposures of the Wembley Channel in the Beaverlodge district (Jones, 1960) are located in the southeast corner of Sec. 30, Tp. 70, R. 9, W. 6th Mer., where a 5- to 10-foot bed of sand and gravel overlain by

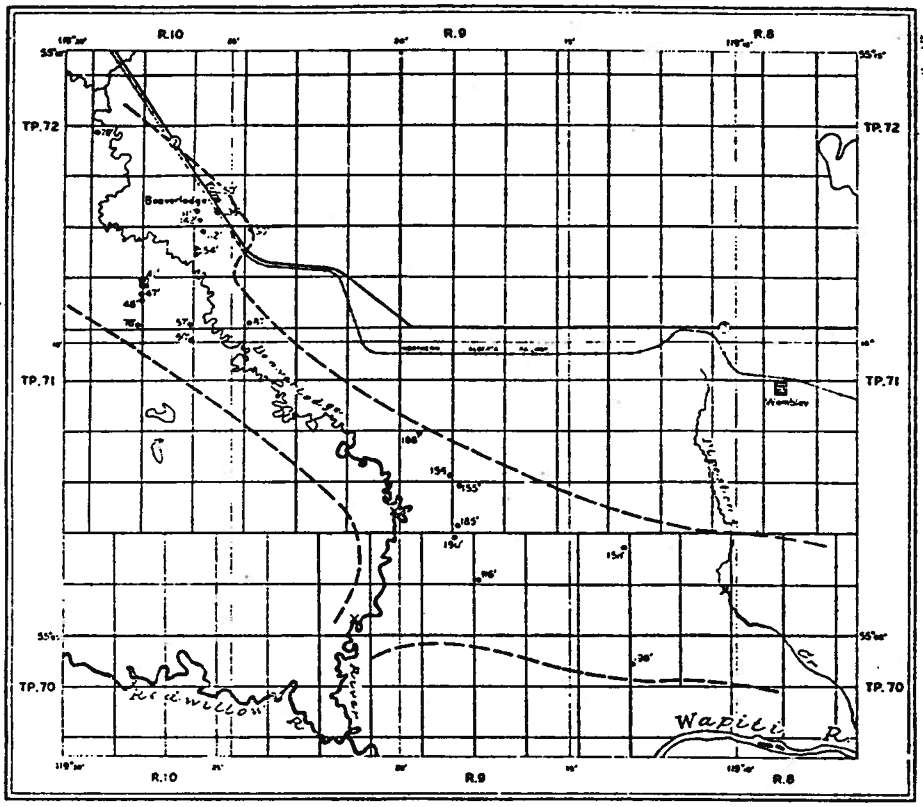

FIGURE 17. Wembley buried channel (– – –), showing water wells and test holes (●), depth to top of buried sand and gravel (47), and buried sand and gravel outcrops (x).

till rests on Wapiti Formation strata about 100 feet above the level of the Beaverlodge River, and in the northeast corner of Sec. 29, Tp. 70, R. 8, W. 6th Mer. along the bottom of Pipestone Creek, where 10 to 15 feet of similar gravels are found resting on bedrock.

A count of 507 pebbles from the outcrop along Pipestone Creek indicates the following rock types: quartzite, yellowish brown to brown, 56.8 per cent; sandstone, salt and pepper, 9.4 per cent; chert, grey and black, 30.2 per cent; limestone, fossiliferous, 1.8 per cent; clay ironstone, 1.4 per cent; coal, 0.2 per cent. The coarse, well-rounded and sorted nature of these essentially quartzite and chert gravels suggests that they were deposited by large rivers and streams. Granite, granite gneiss, and other rock types associated with glacial materials derived from the Canadian Shield are absent.

Along the Peace River, other outcrops of buried sands and gravels rest on bedrock and are overlain by surficial deposits. Near the mouth of the Montagneuse River, on the north bank about ¼ mile upstream from its junction with the Peace River (SW. corner, Sec. 6, Tp. 84, R. 6, W. 6th Mer.), a 15- to 20-foot bed of sand and gravel outcrops, overlain by surficial deposits and underlain by Dunvegan Formation strata.

Rutherford (1930, p. 34) also noticed thin beds of sand and gravel occurring along the Ksituan and Bad Heart Rivers, tributaries of the Peace and Smoky Rivers, respectively, overlying the bedrock and covered with glacial materials.

In the Watino area, Henderson (1959, p. 64) noted extensive coarse, well-bedded sands and gravels more than 20 feet thick, which outcrop laterally for several hundred feet on the east of the Smoky River, ½ mile below the mouth of the Little Smoky River, in Sec. 15, Tp. 77, R. 24, W. 5th Mer. These gravels are overlain by surficial deposits and underlain by bedrock, the base of the gravels being at an elevation of 1,400 feet, about 100 feet above the present Smoky River.

The data concerning locations, and depths of these buried-channel deposits in the Watino-Smoky River areas (Henderson, 1959) have been incorporated in figure 16. The major buried channel is referred to in this report as the Tangent Channel.

Test drilling by the Research Council of Alberta, Highway Research Division, in 1959 and 1960, in Sec. 7, Tp. 80, R. 4, W. 6th Mer.—south of the Dunvegan Bridge—revealed deeply buried coarse sands and gravels at depths of up to 600 feet below the land surface, with the elevation of the gravels being approximately 1,375 feet above sea level. A water well drilled in the same area (NE. ¼, Sec. 7, Tp. 79, R.4, W. 6th Mer.) reported gravel at a depth of 630 feet. Other test holes in the same area entered gravels at shallower depths. The tentative configuration of the channel in this area is presented in figure 16, based in part on this information.

In the Fairview-Whitelaw-Berwyn-Grimshaw areas much shallower buried sands and gravels (30 to 100 feet in depth) have been reported and are outlined in figure 16. Test-hole logs from this area are presented in Appendix A.

In the town of High Prairie (Tp. 74, R. 17, W. 5th Mer.) wells have been drilled which encountered buried sands and gravels in the interval approximately 545 to 588 feet below ground level. A well log is presented in appendix B of Research Council of Alberta Northern Alberta test hole No. 1 (Lsd. 16, Sec. 25, Tp. 74, R. 17, W. 5th Mer.), which encountered sand and gravel similar in type to that encountered in the town wells between 590 and 614 feet. The clean, medium- to coarse-grained sand

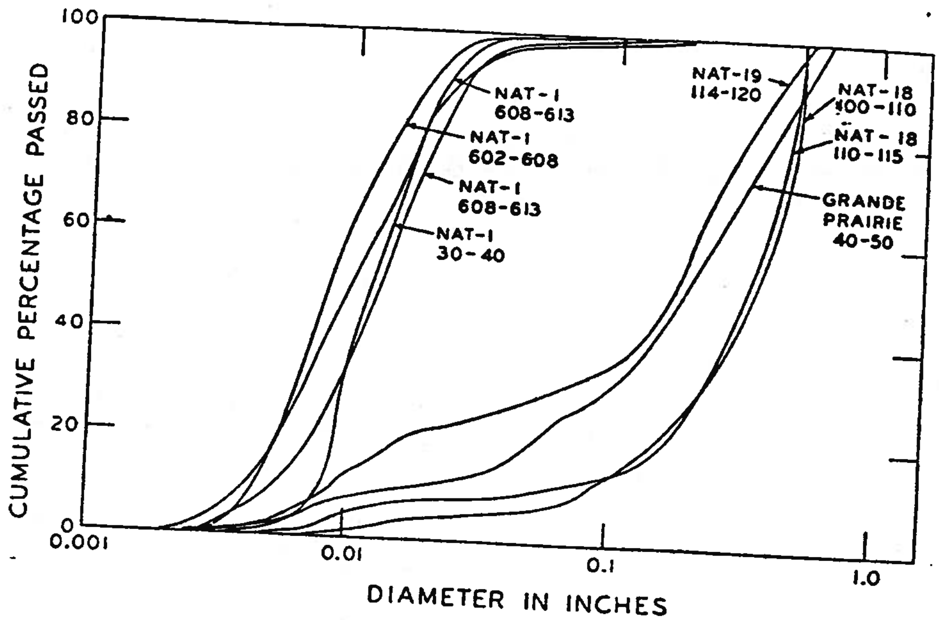

FIGURE 18. Mechanical analyses, surficial-deposit samples.

from the 578- to 583-foot interval in the 1962 High Prairie well and from the 608- to 613-foot interval in Research Council of Alberta test hole No. 1 consists of well-rounded quartz, feldspar, dark chert, many orange sandstone grains, scattered granite, gneiss, and coaly fragments. The nonopaque heavy-mineral fraction contains abundant hornblende and garnet, with common epidote and zircon, and scattered grains of staurolite, chlorite, tourmaline, rutile, and hypersthene (?) (pers. comm., G. B. Mellon). In addition it is quite uniform in grain size as evidenced from the mechanical analysis of the sand samples in figure 18. Thus this sand appears to be a typical glacial-outwash sand and different from other observed buried deposits of sands and gravels.

Similar deposits to those at High Prairie have been found in a test hole for a deep well drilled for the Northern Alberta Railroad at McLennan (Sec. 28, Tp. 77, R. 19, W. 5th Mer.) (see appendix A for log). It is possible that these two areas are connected by a deeply buried valley.

Origin of the Deposits

There are two possible origins for these buried-channel deposits of sands and gravels: they may (1) be deposits of a drainage system that was developed prior to Continental or Cordilleran glaciation; or (2) represent glacial or interglacial stream or river deposits, the source material being quartzites and cherts derived from Cordilleran drift that came from the Rocky Mountains to the west, and, in some instances, granitic and gneissic materials derived from till of the Continental glacier. Subsequent readvance of the last continental glacier came from the northeast, overrode the sands and gravels and covered them with till and associated deposits. No evidence to date has been found in the map-area of a Cordilleran till overlying these buried-channel deposits.

Henderson (1959, p. 66) believed that most of the buried sands and gravels in the vicinity of the Peace and Smoky Rivers could be attributed to a glaciofluvial origin, with deposition probably preceding the earliest invasion of Keewatin ice into the area, the gravels thus being older than the earliest continental till of the area, and hence of early Pleistocene age.

However, the hypothesis is favored that most of the buried sand and gravel deposits are preglacial. They are probably the northern equivalent of the Saskatchewan Gravels and Sands from central and southern Alberta described by Rutherford (1937) for which Rutherford (1937, p. 94) Warren (1939, p. 341) and, more recently, Farvolden (1963b) have suggested a preglacial origin. Subsequent post-Tertiary and postglacial uplift of the land surface, with consequent substantial down-cutting of the recent rivers and streams, has exposed the buried gravels below the covering of surficial materials. Farvolden (1963b, p. 69, Fig. 17) summarized the evolution of a system of bedrock channels in southern Alberta.

Although the deep buried-channel deposits at High Prairie contain fine sand in which Precambrian rocks are incorporated, it is believed that the main buried-channel features in the Peace River district are preglacial, and that the presence of Shield materials in the High Prairie deposits can be explained by reworking, during interglacial or immediately preglacial time, of ice-marginal outwash.

Surficial Deposits

Till, glaciolacustrine sands, silts and clays, and glaciofluvial sands and gravels of glacial and Recent ages cover most of the buried-channel deposits and the Cretaceous bedrock strata of the map-area. These deposits are generally thick in the valleys and thin considerably towards the highlands, becoming in many places near the crests of the hills only a few feet thick or absent. In Map 28 the distribution and general extent of these deposits are outlined.

Till Deposits

In the map-area, till—an unsorted mixture of sand, silt, clay and boulders—has its geomorphologic expression mainly as ground moraine, but also as hummocky moraines; it underlies most of the glaciolacustrine, aeolian, and other deposits. These till deposits are generally up to 600 feet thick in the valleys, as evidenced in the thick sections of till at High Prairie and elsewhere (Henderson, 1959; Jones, 1960).

Generally the tills in the Peace River district are more clayey than those in the Edmonton and east-central areas of Alberta. In the Beaverlodge district there is an average depth of oxidation of tills of 23 feet which is similar to that of central Alberta—20 feet (Bayrock, 1957, p. 16). The till color in the oxidized zone near the surface is yellowish brown, light and dark brown; in the unoxidized zone below, grey and dark grey predominates, but some unoxidized tills have a marked bluish cast.

Glaciolacustrine Deposits

A good portion of the map area (Map 28) is covered by a layer of lacustrine sand, silt, and clay that was laid down in proglacial lakes that covered the area. Most of these lacustrine deposits are bedded and most should perhaps be called "varved", consisting as they do of alternating light and dark laminae. These deposits are important in that they form the parent materials of some of the best soils in the Peace River district.

In the Beaverlodge district, as well as elsewhere in the Peace River district (Henderson, 1959), a good portion of the glaciolacustrine deposits consists of thin varves, although varves up to a foot or more in thickness have been measured.

Usually microscopic fossils are not found in typical varved sediments in fresh water, except for land plants or pollen grains that may have blown into the glacial lakes. An explanation, which is probably true for most of the Peace River district map-area, has been given by Jones in his M.Sc. dissertation (Univ. Western Ontario, 1961) to account for the lack of animals with conspicuous skeletons in varves in the Beaverlodge district:

(1) the continuous sedimentation in the glacial lakes prevented the development of a flora on which animals could feed,

(2) the low temperature and high turbidity of the glacial lakes made the waters unsuitable for fauna and flora, and

(3) the time of existence may have been too short for colonization to take place.

Most of the varved deposits were laid down probably in large cold proglacial lakes; however, it should be noted that in the later lake stages, when silty (unvarved) sediments were deposited in areas adjacent to the present-day Peace River, the lake waters supported a shallow-water microfauna. This fauna was found by the writer and others during the 1960 field season.

A detailed description of the structure and features of varve deposits in the Beaverlodge district of the map-area has been given by Jones (unpublished M.Sc. thesis, Univ. Western Ontario, 1961). These varve deposits have been classified into four types: (1) ice-marginal varve deposits, (2) transition-zone varve deposits, (3) basin-center varve deposits, and (4) drainage varve deposits.

Beaches

Glacial beach deposits of sand and gravel are developed in many areas in the Peace River district and have been described by Henderson (1959). Some of these deposits in the Peace River district are outlined on Map 28.

Glaciofluvial Deposits

Glaciofluvial outwash deposits consisting mainly of gravel, sand, silt, and some clay have been deposited by large rivers and streams that drained the glacial lakes of the map-area. They have been described in detail by Jones (unpublished M.Sc. thesis, Univ. Western Ontario, 1961) in the Beaverlodge district, and by Henderson (1959) in the Smoky River, Watino, and Sturgeon Heights areas. These generally permeable deposits are found in large areas near and adjacent to most of the present rivers such as the Wapiti, Smoky, Little Smoky, and Peace Rivers. Their general distribution and areal extent are shown on Map 28.

Pleistocene Terraces

Paired terraces, consisting of sand and gravel, have been noted by Jones (1960) along the Wapiti River in the Beaverlodge district and by Henderson (1959) along the Wapiti River south of Grande Prairie.

Stream Trenches

Till-filled meltwater channels—stream trenches—are not common in the Peace River district, although Jones (*ibid.*) recognized some in the Beaverlodge district, and Henderson (1959) recognized meltwater channels in the Sturgeon Lake map-area. These features are generally much commoner in eastern and central Alberta (Gravenor and Bayrock, 1956). Further detailed study of air photographs of the Peace River district may outline their over-all extent.

Other Glacial Deposits

Other glacial deposits are rather uncommon in the Peace River district, though common elsewhere in Alberta; these include kames, eskers, till, and silt mounds, as has been mentioned by Henderson (1959).

Recent Deposits

Alluvial-Terrace Deposits

Recent alluvial terraces of silt, sand, and gravel are found at present river levels along the drainage courses of the map-area (Map 28). There are large terraces along the Wapiti, Smoky, Little Smoky, and Peace Rivers. Particularly large alluvial terraces are found along the Smoky River at Watino, and along the Peace River at Shaftesbury Settlement.

Recent Bottomland Deposits

Recent bottomland deposits of silt and clay are encountered along the rivers and streams, around lake shores, and in small closed depressions where ponds or sloughs exist or existed previously. Sedimentation into many of these lakes and sloughs appears to have been continuous from the time of large glacial lakes to that of the present remnant ones.

Slump and Colluvial Deposits

Most of the steep slopes in the map-area are covered with a veneer of colluvium. In many places glaciolacustrine or other deposits have been eroded from higher elevations exposing the underlying till or bedrock. The eroded materials are deposited at the slope bases in topographic lows, or where the slope of the land surface is less than two or three degrees.

Along the rivers and streams, slump and landslide deposits in many places cover and obscure the bedrock and other deposits with a veneer of colluvium.

Recent slopewash and gullying are quite common in the Peace River district, particularly in areas near topographic highs that are underlain by glaciolacustrine deposits. The construction of country access roads in the map-area has facilitated the ready erosion of these deposits and extensive gullying has taken place where the slope exceeds two or three degrees and the road allowances run downslope. Eventually the lower portions of the road ditches become filled with recent slope- or sheet-wash deposits.

Both the formation of soil and the general erosion processes since the end of Pleistocene time have tended to destroy the original depositional structures of the upper 1 or 2 feet of surficial materials, commonly making them difficult to identify.

In areas where large deep buried channels intersect present rivers and streams, excessive active slumping tends to occur, and these very badly slumped areas can commonly be used as indicators of the presence of buried channels.

Recent Lacustrine and Beach Deposits

Recent poorly developed beach deposits of sand, silt, and coarse cobbles and pebbles can be found along the larger lakes of the map-area. Better-sorted deposits are found along the eastern margins of the lakes, possibly due to the prevailing westerly wind direction.

Aeolian Deposits

Large areas of aeolian deposits of sand and silt are found adjacent to most of the major rivers and streams of the map-area. These aeolian deposits are generally developed on the surface of large areas of glacial-outwash sands and gravels. Some thin aeolian deposits have been found over glaciolacustrine and till deposits. Usually, present vegetation has stabilized dune formation, and only where man has removed this protective cover do blowouts and movement of sand now take place. In most instances the sand has not been driven far beyond its area of original deposition.

In the district, large hairpin-shaped dunes with horns that extend for more than a mile in a westerly direction have been recognized. These vary in height from 5 to 30 feet and are up to ¼ mile wide. They have been described by Henderson (1959) in areas adjacent to the Smoky and Little Smoky Rivers, and Jones has described them in that part of the Beaverlodge district adjacent to the Wapiti River (Tp. 70, Rs. 9 and 10, W. 6th Mer.; Tp. 69, Rs. 8 and 9, W. 6th Mer.).

Odynsky (1958) has described their orientation and genesis in detail. Generally these dunes are aligned in an east-west direction indicating that the dominant prevailing wind direction was from the west at the time of their formation—a similar wind direction to that prevailing today.

HYDROLOGY

Terminology, Methods, and Usage

The fundamental properties that determine whether or not successful water wells may be constructed in earth materials relate to the abilities of these materials to store and transmit water readily. Any geologic deposit from which water can be withdrawn successfully is called an *aquifer*. The ability of an aquifer to store and transmit water depends primarily on two or its properties—its porosity and its hydraulic conductivity*. *Porosity* is the percentage of pore space or void in a given volume of rock or soil, while *hydraulic conductivity*, defined as the rate of flow of water in gallons per day through a cross-sectional area of 1 square foot under unit hydraulic gradient, is a measure of the ability of a rock or soil to transmit water. In Canada the units of hydraulic conductivity are imperial gallons per day per square foot (igpd/ft^2). The most common types of earth materials and their hydrologic characteristics are briefly summarized below.

(1) Clean well-sorted sands and gravels usually transmit water the best and as a consequence it is common to search for them when large-capacity wells are required.

(2) Consolidated sandstones have a much lesser ability to transmit water than most sands and gravels. Their hydraulic conductivities depend upon the degree of cementation. All gradations exist from clean well-sorted sandstones with fair to medium production of groundwater to silty and shaly sandstones with little or no production.

(3) Some cemented sandstones are sufficiently fractured and creviced to have enough conductivity to be an aquifer. Similarly, some well-fractured coal seams are good aquifers.

In figure 19, adapted from Todd (1959), the hydraulic conductivities of different earth materials are shown.

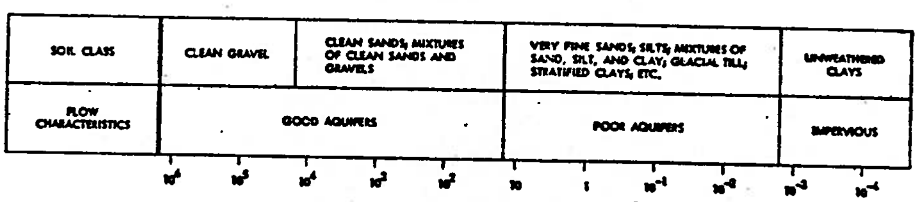

FIGURE 19. Hydraulic conductivities of earth materials.

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*The term "hydraulic conductivity" is used in place of "permeability" in order to distinguish a quantity depending not only on the geometric properties of the transmitting medium but also on the physical properties of the fluid being transmitted (hydraulic conductivity) from a quantity depending on geometric properties alone (permeability). This usage is in conformity with recent trends in soil science (U.S. Salinity Laboratory Staff, 1954) and groundwater hydrology (Hantush, 1961).

The hydrological characteristics of an aquifer in groundwater studies are commonly expressed in terms of the coefficients of transmissibility and storage. The coefficient of *transmissibility* of an aquifer is defined as the rate of flow of water in gallons per day through a vertical strip of the aquifer 1 foot wide under unit hydraulic gradient (Ferris *et al.*, 1962). Stated in another way, the transmissibility is the product of the thickness and hydraulic conductivity of the aquifer. In Canada the units of transmissibility are imperial gallons per day per foot (igpd/ft.). The *coefficient of storage* is defined as the amount of water, in cubic feet, that will be released from storage in a vertical column of an aquifer with a height equal to the thickness of the saturated portion of the aquifer divided by the product of the cross-sectional area of the column and the change in head causing the release of water from storage (Ferris *et al.*, 1962).

These constants may be determined from an analysis of aquifer pumping test data. The pumping-test data can also be used to determine the location and effect of hydrologic boundaries that affect groundwater movement. Observations of the changing water level in a pumping well alone are sufficient for the calculation of the coefficient of transmissibility, but one or more observation wells are required if the coefficient of storage is to be calculated. The number of observation wells selected is dependent upon the complexity of the hydrologic situation. In general, this number increases along with the number of known local hydrologic boundaries that may have an effect on the pump test. Such boundaries include both lateral and vertical changes in hydraulic conductivity within an aquifer and boundaries between an aquifer and any body of water, such as a lake or river, serving as a source of recharge.

Two types of aquifers are recognized: the water-table or unconfined aquifer and the artesian or confined aquifer.

Water-Table or Unconfined Aquifers

Groundwater is said to be under water-table or unconfined conditions if there is no impermeable confining bed between the aquifer and the land surface and if the upper surface of the contained water is at atmospheric pressure. Where the water table intersects the surface of the land groundwater is discharged through springs. The water table does not remain constant but fluctuates depending upon the amount of groundwater gained or lost due to changes in the relationship between recharge and discharge. A *perched water-table* condition results when water accumulates over impermeable strata lying above the general water table. In the Peace River district the most common water-table aquifers are the sands and gravels in alluvial terraces adjacent to rivers and streams in which the water table fluctuates with changes in river or stream flow. Other unconfined aquifers are glacial outwash sands and gravels and dune sands. The storage coefficient of most unconfined aquifers commonly lies in the range 0.05 to 0.30.

Artesian or Confined Aquifers

Where an aquifer, such as a sandstone bed, is overlain by less permeable strata, such as shale, the water in the sandstone may be confined and under pressure. In such a case the water level in a well drilled into it rises above the top of the aquifer and the well and the aquifer are termed *artesian*. The amount of rise is known as the *head*. If the pressure is sufficient to make the water rise above the ground level, the well is called a *flowing artesian well*. In the Peace River district confined aquifers are limited to the sandstone and coal beds in the Cretaceous formations and to the buried sand and gravel deposits. For artesian conditions the values of the storage coefficient lies somewhat between 1.0×10^{-3} and 1.0×10^{-4}. Most commonly a storage coefficient of about 5.0×10^{-4} can be taken to be representative of Alberta Cretaceous and Tertiary confined aquifers.

Analysis of Pumping-Test Data

The *nonequilibrium formula* (Theis, 1935) expressing the drawdown in the vicinity of a pumping well may be used to calculate the coefficients of transmissibility and storage. It is not generally suitable for the analysis of water-level variations in the pumping well but is applicable to those in any observation well. The formula is based on certain assumptions: (1) the aquifer is homogeneous and isotropic; (2) the aquifer has infinite areal extent; (3) the discharge well penetrates and receives water from the entire thickness of the aquifer; (4) water taken from storage in the aquifer is discharged instantaneously with a decline in head; (5) the coefficient of transmissibility is constant at all times and at all places; and (6) the diameter of the well is infinitely small. The use of the Theis nonequilibrium formula is described by Todd (1959) and by Ferris *et al.* (1962).

Strictly, the Theis equation and equations derived from it are not applicable if there is natural recharge to the aquifer. Generally, in Alberta, however, natural recharge contributes so little to storage during the period of the usual pump test that the Theis equation may be used to deduce the aquifer constants of true artesian aquifers. When this is the case, the fact that natural recharge may become a significant factor during the production life of a well merely represents a safety factor of undetermined magnitude in the calculation of the safe pumping rate for this period.

The *modified Theis equation* developed by Jacob (1950) is derived from the Theis nonequilibrium equation. This equation is useful in analyzing the drawdown measurements in a pumping well, and, in certain cases, the measurements in observation wells. Only the transmissibility may be determined from this formula. The modified formula is applicable only under certain limiting conditions and an analogous formula, good under the same conditions, may be used to determine the storage coefficient (Ferris *et al.*, 1962) from the drawdown observations in an observation well.

The *Theis recovery formula* (Ferris *et al.*, 1962) is similar to the modified Theis equation and is used to analyze the recovery measurements in a pumped well. It may be used for the determination of transmissibility.

The unmodified and modified Theis equations and the Theis recovery formula are always used on the assumption that there is no significant leakage of water into the aquifer and from the overlying or underlying beds. If there is significant leakage, the analytical method for a *leaky-artesian aquifer* (Walton, 1960, 1962) must be used. This method is based on a formula developed by Hantush and Jacob (1955). Still other methods must be used when analyzing drawdown results obtained during the testing of water-table aquifers. Suggested methods vary and selection commonly depends on the conditions and duration of the test. The water-table case has been discussed by Boulton (1954a, 1954b), Butler (1957), Ferris *et al.*, (1962), and Walton (1962).

All of the methods cited above can be used only to describe conditions in aquifers that are infinitely large in areal extent. Such aquifers are never met with in nature, although it is possible in some instances to proceed with the analysis on the assumption that the real aquifer is infinite. Generally, however, the effects of aquifer boundaries must be taken into account. A real aquifer bounded laterally by relatively impermeable materials, or by bodies of water providing recharge, or by both, can generally be replaced for the purposes of analysis by an infinite aquifer in which there are a number of image wells in addition to the real pumping well (Ferris *et al.*, 1962; Walton, 1962). The image wells may either pump water into or remove water from the aquifer depending on the nature of the boundaries, and their pumping rates will be the same as that of the real pumping well. Once the real hydrologic system of a real pumping well in a bounded aquifer has been converted to the equivalent infinite-aquifer system with the real pumping well and a number of image wells, it is possible to use the standard methods of analysis for nonleaky or leaky artesian or for water-table aquifers. As the number of hydrologic boundaries becomes large, however, a very large and possibly infinite number of image wells may be generated. Digital-computer programs have been developed to handle some of these complex cases (Walton and Neil, 1960).

It has been intimated that the methods referred to above are limited in their application to the analysis of drawdown data in the case of the pumping well. This is because drawdown in the pumping well has two principal components: that due to "formation loss" and that due to "well loss". *Formation loss* is the drawdown caused by laminar flow of water through the aquifer towards the well and is described by the appropriate nonleaky or leaky artesian, or water-table formula. *Well loss* is that additional loss of head that is observed at the well and very close to it partly because the inflowing water may have attained a velocity at which its flow has become turbulent rather than laminar and partly because of the head losses within the well itself. Jacob (1946), Rorabaugh (1953), and Lennox (1966) describe methods that may be used to determine the magnitude of well loss over a range of pumping rates.

Estimation of Safe Production Rates

Estimation of the amount of water that can be produced safely over a given period of time from a well depends on estimates of formation loss and well loss for a number of pumping rates for the desired period. If good pump- and recovery-test data are available, and if the locations of hydrologic boundaries are accurately known, the appropriate drawdown formulae may be used to predict the formation losses at the pumping well. Well-loss predictions can be based on Jacob's (1946), Rorabaugh's (1953), or Lennox's (1966) methods. Commonly, predictions are required not only for a single well but for groups of wells and, in such cases, interference among wells must also be considered. Well spacing and production rates must be chosen so that the most efficient utilization of the groundwater resources will result. If the aquifer is extensive and a complex well field is to be designed to supply a single consumer or municipality the capital costs for well and pump installations and pipelines and the operating costs for pumping water are also important factors. Theis (1941, 1963) and Hantush (1961) have considered this problem.

The desirable length for the safe production period commonly depends on the purpose for which the groundwater is required. The safe production period for municipal supplies in Alberta is customarily 20 years. Water-supply wells for oil-field pressure maintenance, on the other hand, can have periods ranging from 5 to 40 years, depending upon the situation.

If hydrologic information is limited, more approximate methods must be used to estimate safe production rates. This situation would arise in the case of a test conducted without observation wells in an aquifer in which there were no nearby producing wells. Such tests are common for domestic and farm wells. The equation below has been found to be useful in making estimates of the safe production rate for a 20-year period. It is derived from the modified nonequilibrium equation (Jacob, 1950) by stipulating that it takes seven log cycles of time after the first minute (roughly 20 years) to draw the well down from its nonpumping level to the top of the aquifer.

$$Q_s = \frac{TH}{1848}$$

where Q_s = safe production rate in gallons* per minute,
H = total available drawdown in feet, and
T = transmissibility in gallons* per day per foot.

This method of computation may be used only for a single well. It does not take into account well loss, interference between wells, or the storage coefficient, and thus at best can serve only as a useful guide. Commonly, but not always, a safety factor of 0.7 is used in determining the final safe rate. Its use depends on the type of available data and the purpose for which the well might be used.

Observed Transmissibilities

The few observed transmissibility values for the Peace River district are presented in table 5. Some are derived from water-well drillers' bail- and pumping-test data, others from more detailed tests conducted by groundwater geologists or engineers. In some cases the well driller's pumping-test data consisted only of the total drawdown during the test, the length of the test, and the pumping rate. An accurate transmissibility cannot be derived from such data and it is best to call the value obtained an *"apparent transmissibility"* in order to distinguish it from more reliable values (Farvolden, 1961b, p. 9). If there are sufficient data of this type it is possible to subdivide a study area into smaller areas with differing groundwater potentials on the basis of the measured apparent transmissibilities (Farvolden, 1961b, p. 10).

The few transmissibility values listed in table 5 are inadequate for the mapping of more or less favorable areas for groundwater development. As the search for groundwater in the Peace River district progresses and more proper aquifer tests are carried out, this will eventually no longer hold true and it should be possible to obtain a good picture of groundwater possibilities from a map of transmissibility values.

Laboratory Measurements of Hydraulic Conductivity and Porosity

Samples and cores were collected from different Cretaceous rock units in the Peace River district to be analyzed for hydraulic conductivity and porosity. Both vertical and horizontal conductivities were measured to obtain some idea of the hydrologic anisotropy. Since transmissibility is the product

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*Imperial gallons are used throughout this bulletin.

Table 5. Apparent Transmissibilities and Hydraulic Conductivities from Drillers' Logs

Lsd. or ¼	Sec.	Tp.	R.	West of Mer.	Aquifer*	Thickness (feet)	Transmissibility (igpd/ft)	Hydraulic conductivity (igpd/ft²)	Remarks
NW	15	70	22	5	coal	2	188	94	
NW	15	70	22	5	ss	8	88	11	
NE	15	70	22	5	ss	30	30	1	
NE	15	70	22	5		9	132	15	
SE	21	70	22	5	coal	3	188	63	
SE	21	70	22	5	coal	1	188	188	
SW	22	70	22	5	coal	2	70	35	
SW	22	70	22	5	coal	2	66	33	
NW	23	70	22	5	coal?	1	66	66	
13	9	70	10	6	ss	9	18	2	
	28	70	10	6	ss	5	220	44	
SW	28	70	10	6	ss		21		
SE	33	70	10	6	ss		21		
		71	6	6	ss	3	420	140	
	26	71	6	6	ss	8	132	17	
		71	6	6	ss	7	96	14	
1	25	71	8	6	ss	3	11	4	
	28	71	10	6	ss	5	220	44	
NE	36	71	10	6		2	7,700	3,850	Bail test
NW	8	71	11	6	ss	1	32	32?	
NE	20	72	7	6			1,500		Flowing-well pressure recovery
SW	21	72	7	6			300		Flowing-well pressure recovery
16	30	72	21	5	ss	10	35	3.5	
	10	72	3	6	surf. sd		121		

NE	26	72	4	6	ss		200		
	25	72	6	6	ss	7	45	6	
	12	73	2	6	ss	15	189	13	
7	27	73	3	6	ss		141		
2	30	73	3	6		20			
	24	73	6	6	ss	10	57	6	
NE	19	73	10	6			60		Flowing-well pressure recovery
NW	20	73	10	6			160		Flowing-well pressure recovery
16	35	73	10	6	ss	7	70	10	
SW	1	73	11	6			40		Flowing-well pressure recovery
NW	11	73	11	6			105		Flowing-well pressure recovery
	13	73	11	6	ss		47		
SW	13	73	11	6			360		Flowing-well pressure recovery
4	13	73	11	6	ss	22	33	1.5	
SW	23	73	11	6			990		Flowing-well pressure recovery
SW	26	73	11	6			40		Flowing-well pressure recovery
14	12	73	12	6	ss	18	75	4	
10	11	73	13	6	ss	8	62	8	
	11	73	13	6	ss	3	42	14	
	11	73	13	6	ss	3	158	53	
	11	73	13	6		10	264	26	
NW	11	73	13	6		3	210	70	
2	4	74	3	6	coal or ss		146		
SW	7	74	7	6			400		Flowing-well pressure recovery
SE16	8	74	8	6	surf. sd & gr	3	176	59	
12	10	74	8	6	ss	21+	74	3	
SE1	14	74	8	6	ss		146		
SW4	6	74	9	6	ss	4	39	10	
SE16	24	74	9	6	surf. sd & gr	5	18	4	
NE10	10	74	10	6	ss	3	264	88	
NW13	12	74	10	6	ss	2	48	24	

Table 5 (cont'd)

Lsd. or ¼	Sec.	Tp.	R.	West of Mer.	Aquifer*	Thickness (feet)	Transmissibility (igpd/ft)	Hydraulic conductivity (igpd/ft²)	Remarks
SW	36	74	10	6			11,300		Flowing-well pressure recovery
SW	4	74	11	6			high		Flowing-well pressure recovery
SW4	5	74	11	6	ss	2	300	150	
SE	5	74	11	6			1500		Flowing-well pressure recovery
SE	7	75	2	6	ss	10	680	68	
NE	9	75	2	6	ss		210		
4	17	75	2	6	coal	1	55	55	
	18	75	2	6	surf. sd	20	127	6	
	18	75	2	6	coal		11		
1	30	75	5	6	ss		8		
4	18	76	5	6	ss		292	49	
13	18	76	5	6	ss		46		
NW4	2	82	24	5	Dunvegan ss	1	105	105	
NE	32	82	25	5	surf. sd & gr		2,640		
NW	7	83	23	5	surf. sd & gr	1	1,920	1,920	
SE	6	87	25	5	surf. sd & gr	37	440	12	
12	30	87	7	5	surf. sd	20	53	3	

*Unless otherwise indicated, all aquifers are in the Wapiti Formation.

Abbreviations: ss—sandstone; sd—sand; gr—gravel; surf.—surficial of aquifer thickness and hydraulic conductivity it was possible in some cases to calculate transmissibility value from the laboratory measurement and the observed aquifer thickness. This value could then be compared with the transmissibility obtained from pump-test data.

If the aquifer materials are unconsolidated, an approximation to the hydraulic conductivity can commonly be obtained from the results of a mechanical analysis by using a formula proposed by Hazen (1893). With certain simplifications the formula may be written:

$$K = CD^2_{10}$$

where K = hydraulic conductivity in igpd/ft²,

D_{10} = effective grain size of the material in inches—defined by Hazen as the diameter such that 10 per cent of the material is of smaller grain size and 90 per cent of larger—and

C = a constant depending on the material; it ranges from 5×10^6 to about 15×10^3 and is assumed to be 10^7 in this bulletin.

The mechanical analyses of a number of unconsolidated Cretaceous sandstones are shown in figure 20.

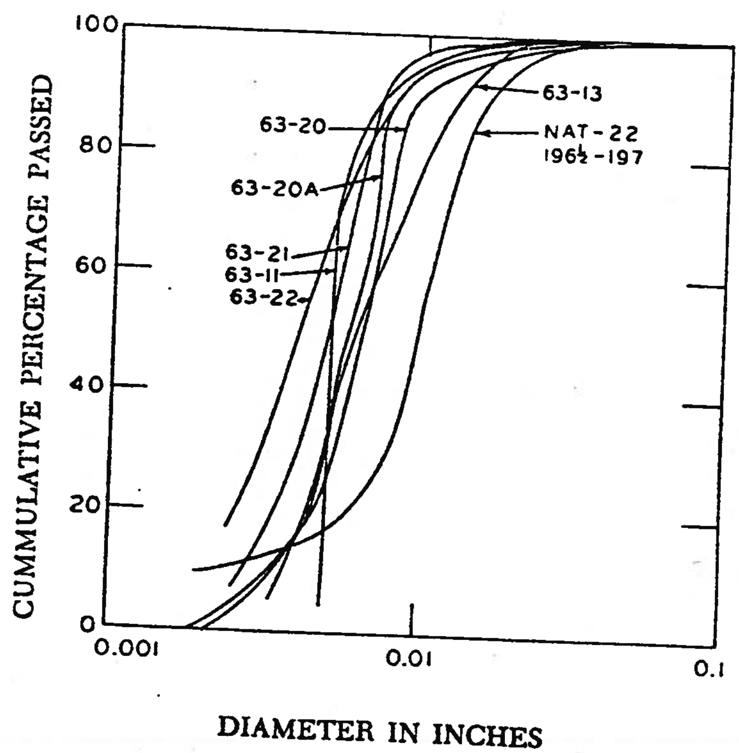

FIGURE 20. Mechanical analyses, unconsolidated-bedrock samples.

Table 6 and table 7 present the results of laboratory measurements of porosity and hydraulic conductivity, the former for a number of Cretaceous sandstones and the Baytree Conglomerate, the latter for a number of samples from varying depths in Research Council Northern Alberta test hole No. 20, penetrating the Wapiti Formation at a location south of Beaverlodge. Table 8 gives conductivities calculated on the basis of equation (2) for a number of unconsolidated-bedrock and surficial-deposit samples.

Movement of Groundwater and Piezometric Surface

According to Meinzer (1923, p. 38): "The piezometric surface of an aquifer is an imaginary surface that everywhere coincides with the static ('nonpumping') level of the water in the aquifer. It is the surface to which the water from a given aquifer will rise under its full head." To construct a piezometric surface map then clearly requires that all data and wells must relate to the same aquifer. Such certainty of relationship cannot be determined for wells in the thick nonmarine successions in Alberta. Figure 21 is based on water levels in wells known to be completed in several different aquifers in the Beaverlodge area, and is not, as was stated previously (Jones, 1960, p. 20), a map of the piezometric surface. Rather it shows the nonpumping water levels of the Beaverlodge area for the summer of 1958, the contours joining points at which the same water level exists.

The movement of groundwaters is from zones of high potential or head to zones of low potential; groundwater movement will, with time, influence the nonpumping water levels and so change the appearance of the map. The water levels will also be influenced by other factors, such as seasonal climatic changes, man-made changes such as manipulation of plant and forest cover, and removal of water from aquifers by means of well withdrawals.

Near the town of Beaverlodge the 2,300-foot contour bends slightly off the regular upstream trend of the piezometric surface, an example of a cone of depression produced by a greater local withdrawal of groundwater.

Maximum fluid potentials are observed under topographically high areas, as has been found to be true elsewhere in Alberta (Farvolden, 1961b; Le Breton, 1963a, 1963b, 1963c; Tóth, 1962, 1963). The general movement of the groundwater therefore appears to be controlled by local topography, the movement being from recharge areas in the highlands to discharge areas in the lowlands. Tóth (1963) has developed a two-dimensional mathematical model that shows the part that local topography

Table 6. Porosities and Hydraulic Conductivities of Outcrop Samples of Unconsolidated Cretaceous Deposits

¼	Sec.	Tp.	R.	West of Mer.	Rock unit	Lithology	Porosity (per cent)	Hydraulic conductivity (igpd/ft²) Horizontal	Vertical
SE	22	70	6	6	Wapiti	Sandstone: salt and pepper, medium grained, angular, medium sorting, kaolin cement, low framework to filler ratio, moderately hard	24.7	.29	.21
SW	11	70	8	6	Wapiti	Sandstone: salt and pepper, medium grained, well rounded, medium sorting, medium sphericity, calcareous, kaolin cement, well indurated, slightly micaceous	11.2	.0116	.00228
NE	11	70	8	6	Wapiti	Sandstone: salt and pepper, very fine, well sorted, well rounded, calcareous, slightly kaolinitic, well indurated	17.9	.0116	.00865
NE	24	70	11	6	Wapiti	Sandstone: salt and pepper, very fine, well sorted, well rounded, calcareous, kaolin cement, very hard, particles slightly alignel	12.6	.00516	.00228
NE	14	78	13	6	Baytree	Conglomerate: dark grey, salt and pepper, mainly quartzite and chert granules about 3 mm. in diameter, subrounded, to well rounded, poorly indurated in part, excellent porosity, hematite cement	15.2	80.8	77.4
SE	30	70	13	6	Pouce Coupe	Sandstone: white, fine, almost entirely quartz, few chert and shale fragments well rounded, medium to good sphericity, well sorted, poorly indurated, almost no matrix, good porosity	28.3	20.0	20.5
	31	82	13	6	Dunvegan	Sandstone: salt and pepper, very fine, mainly quartz, some feldspar and chert grains, well sorted, slightly calcareous, kaolin cement, soft	24.3	.111	.07

Table 7. Porosities and Hydraulic Conductivities of Wapiti Formation Samples from a Test Hole near Beaverlodge

(Lsd. 1, Sec. 14, Tp. 71, R. 10, W. 6th Mer.)

Depth (feet)	Lithology	Porosity (per cent)	Hydraulic conductivity (igpd/ft²)	
			Horizontal	Vertical
117.0-117.3	Sandstone: salt and pepper, fine grained, subrounded, medium sorting, medium sphericity, slightly calcareous, kaolin cement, slightly micaceous, bluish grey	25.1	.134	.099
122	Sandstone: salt and pepper, medium grained, bluish grey, subangular to subrounded, medium sorting, medium sphericity, calcareous, kaolin cement	18.8	.038	.021
161	Sandstone: salt and pepper, dark grey, slightly banded, very fine grained, angular, poorly sorted, slightly micaceous, soft, argillaceous, few small well-rounded shale fragments	20.9	.0274	.0244
167.5	Siltstone: salt and pepper, subrounded, medium sphericity, hard, kaolin cement	18.8	.0563	.00152
191.3	Sandstone: salt and pepper, medium grained, subrounded, medium sorted, calcareous, some green tourmaline particles	12.5	.00152	.00152
193.6	Sandstone: salt and pepper, medium to coarse grained, medium sorted, very calcareous, kaolin cement, green tourmaline grains, trace coal	12.2	.00304	.00304
199.4-199.7	Sandstone: salt and pepper, medium to coarse grained, well sorted, very calcareous, kaolin cement, green tourmaline grains, thin coal partings	34.2	8.15	3.98
223.5-223.8	Sandstone: salt and pepper, medium grained, subangular, medium sphericity, medium sorted, kaolin cement, abundant thin dark carbonaceous bands at 5° dip, cross-bedded	22.6	.00628	.00304

227.0-227.4	Sandstone: salt and pepper, medium grained, subrounded, well sorted, good sphericity, slightly calcareous, kaolin cement	25.5	.0289	.021
365.3-365.5	Sandstone: salt and pepper, very fine grained, well sorted, subrounded, medium sphericity, slightly calcareous, micaceous, feldspar common	19.4	.00304	.00152
425.8-426.0	Siltstone: light grey, medium sorted, well rounded, good sphericity, slight micaceous, fragments of plant fossils abundant Sandstone: as in previous sample, interbedded with siltstone	24.6	.101	.0547
431.4-431.5	Sandstone: salt and pepper, very fine to medium grained, well sorted, subrounded, medium sphericity, kaolin cement, trace coal, crossbedding at 10° dip	23.5	.0502	.0334

Table 8. Hydraulic-Conductivity Estimates for Selected Unconsolidated-Bedrock and Surficial-Deposit Samples

(as calculated from Hazen's formula)

Northern Alberta test hole (NAT) No. or Sample No.	Lsd.	Sec.	Tp.	R.	West of Mer.	Sample depth (feet)	Description	Effective size (inches)	Hydraulic conductivity (igpd/ft^2)
NAT-1	16	25	74	17	5	20-30	Lacustrine sand	0.008	625
NAT-1	16	25	74	17	5	602-608	Outwash sand, buried channel	0.0045	178
NAT-1	16	25	74	17	5	608	Outwash sand, buried channel	0.0052	273
NAT-18	14	3	72	10	6	96-100	Sand and gravel, buried channel	0.035	1190
NAT-22	4	13	71	9	6	196.5-197	Unconsolidated sandstone, Wapiti Formation	0.0028	80
63-20A	7	9	86	23	5		Unconsolidated sandstone, Dunvegan Formation	0.0035	123

may play in controlling near-surface groundwater motion. Although the model is necessarily simplified in order to make the analysis possible, there is no doubt that its predictions are generally in agreement with field observations of near-surface flow patterns in Alberta. Anisotropy and inhomogeneity may serve to distort Tóth's basic picture, however, and regional geologic controls probably remain important for extensive deeper-lying aquifers.

Vertical Head Changes

Head changes that take place with increasing depth are generally as follows: for wells drilled on or near topographic highs, the available head decreases with depth; for wells drilled in topographic lows, the head increases with depth. Farvolden (1961b, p. 16) has discussed this phenomenon in the Pembina district, and Meyboom (1961) in the Calgary district.

Thieving between aquifers (Bennett and Patten, 1960) can give rise to distortions of the normal fluid-potential distribution. If a well is completed in such a way that there is a connection through the well between two or more water-bearing zones, flow will take place in the well from zone to zone until the pressures within the various zones become equalized. The head in such a well may seem anomalous by comparison with those in nearby wells deriving their water from a single zone.

Groundwater Recharge

In any aquifer the amount of groundwater that can be permanently produced without taking water from storage and causing an over-all decline of water levels in the aquifer is that amount of water that enters the aquifer as natural recharge. The source of groundwater is rain and snow that falls on the land surface. Most of this water runs off the land and is eventually returned to the atmosphere by evaporation and transpiration. A portion, however, percolates downward through many different kinds of earth materials and reaches the zone of saturation, thus recharging the groundwater reservoir.

During the winter months the ground in Alberta is frozen so that precipitation cannot enter the ground. The average frost-free period in the Peace River district is approximately 132 days at 28°F or higher. Thus the period in which water can penetrate the ground and recharge the groundwater reservoir is probably from late spring (beginning of May) to early fall (October), a period of approximately 5 months.

Farvolden (1963, p. 99) suggests a similar period of frozen-ground conditions for the Edmonton area, where the climate is similar to that of the Peace River district. In the Edmonton area (Farvolden, 1963, p. 104) the rate of recharge to the groundwater reservoir over a small basin was calculated to be 0.031 feet per year or about 2 per cent of the annual precipitation; since the climates of the two areas are quite similar, it is considered that the same order of magnitude of groundwater recharge should apply to the Peace River district. This amount of recharge is quite low in terms of that of other areas where the climate is less severe, and Farvolden (1963, p. 105) ascribes this low rate to the following factors:

(1) a low average annual precipitation,

(2) a long period during the winter in which no recharge can occur,

(3) slow melting of the ground frost in the spring which prevents recharge during spring runoff,

(4) high evapotranspiration rates during the summer when recharge can take place, and

(5) relatively impermeable surface materials.

Natural Groundwater Discharge

Springs are areas of natural groundwater discharge; many of the beter-known springs in the Peace River district are shown on figure 22. There are many natural seeps and springs where the rivers have downcut through aquifers and have exposed them with the result that groundwater drains naturally into these zones of lower pressure.

Most exposed Cretaceous bedrock aquifers, because of their low permeability, develop springs that do not flow much over a few gallons per minute (gpm). However, a few large natural springs are known which flow over 50 gpm. These springs have their origin in more permeable aquifers; such are the springs at Grimshaw and Whitelaw, which flow from buried sand and gravel aquifers that intersect the land surface. These springs, especially during early settlement in the Peace River district, were often watering points. The spring at Grimshaw is used now as the municipal water supply, as is outlined in the chapter on utilization and development.

Groundwater Temperatures

One of the advantages of groundwater over surface water is a constant or more nearly uniform temperature. Surface water is subject to the extreme seasonal temperature fluctuations observed at the earth's surface. The subsurface is also affected by seasonal temperature variations but their magnitude is generally much less and decreases rapidly with increasing depth. A simple calculation based on a formula given by Jakosky (1957, p. 979) indicates the range of annual temperature variation at a depth of 5 feet is approximately half that at the surface. At about 50 feet the temperature variation is generally negligible. Groundwaters in alluvial terraces hydrologically connected to major rivers undergo additional temperature changes because of the inflow and outflow of surface waters.

Of groundwaters obtained from the bedrock and buried sand and gravel aquifers, a temperature range between 39°F to 42°F appears to be fairly representative for the Peace River district up to a depth of 600 feet. This temperature is approximately 4° to 7°F warmer than the annual average surface temperature of the region.

Waters obtained by induced infiltration show a greater seasonal temperature variation than would the groundwaters in the same deposits if no water were being removed from them. The variation is, however, less than that for the surface water in the adjacent river or lake. There will be a time lag between the observed maximum for the surface water and that for the groundwater. The relative range in the groundwater temperature variation and the magnitude of the time lag will both be influenced by the pumping rate and the distance from the surface body.

Temperature fluctuations lead to significant variations in the coefficient of viscosity and thus to corresponding variations in the transmissibility. As a result pumping rates may have to be reduced when temperatures are low and viscosities high. Meyboom (1961) in a study of the temperature of water obtained by induced infiltration from the Elbow River in Calgary, indicated that during the month of August the surface-water temperature reach a maximum of 60°F. The maximum temperature of the induced infiltrated water was recorded in the last week of October or early November, indicating a lag of nearly three months between the dates of maximum temperatures of the two waters. Meyboom's figure 12 (1961, p. 38) represents graphically the comparison of the surface-water temperature and that of the induced infiltrated water at Calgary.

Kazmann (1948) outlines some of the complex factors relating surface- and infiltrated-water temperature fluctuations. These are:

(1) the mixing of groundwater with infiltrated river waters when pumping is initially started;

(2) the admixture of river waters of different temperatures while en-route to the collector;

(3) the heat storage of the aquifer and underlying rocks; and

(4) the conduction of heat upward to the surface and laterally within the aquifer due to temperature gradients.

Thus for water produced by induced infiltration, the range in temperature is always less than that for the water in the adjacent river.

Bedrock Aquifers

Peace River Formation

The Peace River Formation underlies most of the district at considerable depth, and electric logs indicate that the sandstones possess good porosity and permeability in many areas.

West of the town of Peace River the Peace River Formation is too deeply buried to be of much interest as an aquifer. In the vicinity of Peace River town, where the sandstones are exposed and cut through by the Peace River (Map 27), some wells adjacent to the river obtain water from this sandstone. Immediately to the east and north of the town the formation could be an aquifer, but the water is probably chemically unsuitable. Saline water from the Peace River Formation could possibly be utilized for pressure maintenance for secondary recovery for oil wells where other sources of water are not available. It is not expected that the Peace River Formation will be utilized as an aquifer for domestic, municipal, and industrial water supplies. Characteristics of the Peace River Formation and other aquifers are summarized in table 9.

Dunvegan Formation

The Dunvegan Formation is of wide areal extent in the Peace River region (Map 27). Its net total thickness is greatest in the northwestern portion of the map-area (approximately 600 feet) and it thins rapidly to the east and southeast. Individual sandstone and siltstone zones reach thicknesses of up to 80 feet, and may be fairly extensive, but this unit is on the whole quite fine grained and silty, making well completion difficult. South of the Peace River the Dunvegan Formation aquifers become very fine grained. Generally, the water is of poor quality. In areas around Grimshaw and to the north, where the Dunvegan Formation is the subcrop, suitable supplies of groundwater may be found for domestic and livestock purposes. Yields are expected to be quite low—in the order of a few gallons per minute.

Table 9. Aquifer Characteristics,

Rock Unit	Description	Location
Alluvial-terrace deposits	Sand and gravel deposits 15 to 40 feet thick. Average thickness 15 to 25 feet along Smoky and Wapiti Rivers. Thicker terraces may be present along Peace River	Adjacent to rivers and streams
Aeolian deposits	Sand 5 to 30 feet thick	Associated largely with upland areas adjacent to major drainage-ways
Lacustrine deposits	Sand, silt, and clay 1 to 30 feet thick	Large lowland prairie areas
Till deposits	Clay, silt, sand and boulders up to 600 feet thick	Large upland areas, prairies, and as preglacial valley fill
Buried-channel deposits	Sand, sand and gravel, 20 to 50 feet thick	Fairview-Grimshaw area, High Prairie-McLennan. Beaverlodge area
Wapiti Formation	Sandstone, siltstone, and coal. Sandstone beds few feet up to 40 feet thick	Southern portion of district
Bad Heart Formation	Sandstone, siltstone, and conglomerate, 0 to 20 feet thick, thickness varies from area to area	South-central and western portion of district. Silts up towards east
Baytree Member	Conglomerates and grit capping up to 50 feet thick on hills near Alberta-B.C. border. Infiltration area	Western and southern portion near Alberta-B.C. border. Of limited areal extent
Cardium Formation	Sandstone, siltstone, and conglomerate up to 70 feet thick	Western and southern portion of district—found at depth
Pouce Coupe Member	Sandstone and siltstone up to 50 feet thick	Western and northwestern portion of district
Dunvegan Formation	Sandstone, siltstone, some beds up to 80 feet thick	Northern and north-central portion of district. Subcrop in area north of Grimshaw. Quite deep in some areas
Peace River Formation	Sandstone up to 100 feet thick	Northern portion of map-area. Quite deep in most areas

Peace River District

Permeability	Groundwater Potential	Well Yield
Medium	Domestic, municipal and industrial	Perhaps up to 200 igpm from wells and larger amounts from infiltration galleries
Low	Suitable for domestic and stock supplies	Up to 5 to 10 igpm
Very low	In places suitable for domestic and stock supplies (shallow wells)	Very small. Much less than a gallon per minute
Very low	In places suitable for domestic and stock supplies (shallow seepage wells)	Few gallons per day
Medium-high	Suitable for domestic, municipal and industrial supplies	Up to 1,000 igpm or more
Low-medium	Suitable for domestic, municipal, and possibly light industrial supplies	5 to 100 igpm
Low	Possibly suitable for domestic and stock purposes	1 to 10 igpm
Medium	Possibly suitable for domestic and stock purposes	Yield unknown—could be locally quite high
Low-medium	Possibly suitable for municipal and industrial purposes after treatment	Yield unknown—could be high, 100 igpm or more
Low	Possibly suitable for domestic and municipal purposes	1 to 10 igpm(?)
Low	Possibly suitable for domestic and stock purposes in areas north of Grimshaw and north of the Peace River	Low yields, a few gallons per minute
Low-medium	Possibly suitable for domestic and livestock supplies. Quite saline—would require desalinization	Indication of fair permeability from electric logs. May be used in some areas in future

Pouce Coupe Member

The Pouce Coupe Member of the Kaskapau Formation is found in the northwestern portion of the map-area. It may be suitable as an aquifer along the Alberta-British Columbia border in Tp. 80, Rs. 12 and 13, W. 6th Mer. and in the northwestern part of the Peace River district in the vicinity of Worsley, as in Sec. 15, Tp. 87, R. 7, W. 6th Mer. where water wells have been drilled into sandstone beds that appear to be the Pouce Coupe unit (Map 27). As the Pouce Coupe Sandstone in this part of northwestern Alberta is commonly 40 feet thick or more, it may prove to be of value as an aquifer, although the water quality is suitable principally for livestock only. Due to the fine-grained and silty nature of the beds, the expected yields in this area are of the order of a few gallons per minute and well-completion difficulties can be expected.

Cardium Formation

This sandstone and siltstone aquifer is quite extensive in the western and southern portions of the map-area, but is not used extensively as a groundwater source except in the Tupper Creek area (Tps. 77 and 78, Rs. 12 and 13, W. 6th Mer.) close to the British Columbia border. Farther east and south the Cardium Sandstone underlies the settled areas in the Beaverlodge-Grande Prairie district at depths approximately 1,600 to 2,000 feet below the land surface. Although the water in it becomes brackish and saline at depth away from its outcrop area, the Cardium Sandstone interval may prove useful in the future, especially if water for pressure maintenance in secondary-recovery operations is required. The Cardium Sandstone appears to be fairly thick in places (40 to 100 feet) (Burk, 1963) and appears, from electric-log examination, both porous and permeable. If the water is desalinized, this aquifer could be utilized for municipal and some industrial purposes.

Bad Heart Formation

The Bad Heart Formation, consisting of low-permeability siltstone, sandstone, and conglomerate, is not a very good aquifer in most areas although locally in the Peoria district it provides some water—up to a few gallons per minute.

Baytree Conglomerate

In the central western part of the Peace River district near the British Columbia boundary, the Baytree Conglomerate which caps the hills south of Gordondale may be a good aquifer at depth farther south, where it is quite permeable (see table 6), allowing ready filtration of precipitation and providing recharge to the groundwater reservoir. Extensive development of wells in this area is not foreseen and probably the Baytree will receive little use.

Wapiti Formation

The uppermost bedrock aquifers are in the Wapiti Formation which extends through most of the southern portion of the Peace River district (Map 27).

The units that comprise the aquifers consist mainly of sandstone, siltstone, and coal. The sandstone aquifers range from fine-grained, well-cemented sandstones with low hydraulic conductivity to relatively unconsolidated, medium-grained sandstones with a higher conductivity. In addition some coal seams are aquifers. Both intergranular and fracture permeability exist in the sandstones and fracture permeability exists in the coal seams.

Generally the intergranular hydraulic conductivity of the relatively unconsolidated sandstones of the Wapiti Formation, as determined from apparent-transmissibility values, ranges from a few to over 100 igpd/ft^2 (Table 5). Some very high transmissibility values have been measured; for example, a sandstone aquifer approximately 2 feet thick in a Research Council of Alberta observation well located at the Beaverlodge Experimental Farm (SE. ¼, Sec. 36, Tp. 71, R. 10, W. 6th Mer.) had an abnormally high transmissibility of 7,700 igpd/ft. Several other abnormally high transmissibility values have been recorded from pressure-recovery tests of flowing wells and they are also given in table 5.

The abnormally high values of transmissibility and the consequent relative ease of obtaining water from the Wapiti Formation, particularly in the Beaverlodge and Grande Prairie areas, has to be ascribed in part to some cause other than intergranular permeability. The very high permeabilities of some of the Wapiti Formation sandstone beds could be caused by original joint and bedding planes or by post-depositional fracturing due in part to tectonism, as the Wapiti Formation is close to the foothills belt. Possibly superincumbent loading and unloading of the relatively competent Wapiti Formation by either continental or Cordilleran glaciation, or both, could also have led to brittle failure and subsequent fracturing of the Wapiti Formation sandstone beds.

Structure test-hole, core-hole, water-well, and electric-log information show that the Wapiti Formation thickens and becomes more arenaceous as the Alberta-British Columbia border is approached across the southern portion of the Peace River district. Little difficulty is experienced in obtaining water wells west of the city of Grande Prairie in this formation. Yields for individual wells of up to 60 igpm have been found in the Valhalla-Hythe district, and yields of 5 to 10 igpm are common.

East and north from Grande Prairie the Wapiti Formation thins and becomes more shaly. It is more difficult to obtain water supplies of much more than 5 igpm in the Bezanson-Sturgeon Heights-Valleyview areas, although fairly good coal and sandstone aquifers are found in the immediate vicinity of Valleyview (see section on Valleyview municipal supply).

Individual sandstone zones in the Wapiti Formation are commonly irregular in distribution and change rapidly with depth and direction, a common feature of continental beds. Locally some sandstone beds, such as those at Wembley (Appendix A), are well developed and extensive.

In the Hythe-Demmitt area, flowing artesian wells are common, the water being derived from a small artesian basin in sandstones of the Wapiti Formation.

The thickness of individual sandstone beds commonly approaches 40 to 50 feet and they commonly are quite permeable and porous. Where there is sufficient head, it should not be too difficult to develop water wells with yields of up to 60 igpm or more.

Generally the low yields of wells presently completed in the Wapiti Formation are due either to poor well-completion and development practice or to the modest demands imposed by most domestic and agricultural needs. For most domestic and stock purposes a few gallons per minute is sufficient.

The distribution of water wells in the Wapiti Formation has been indicated by Jones (1960, 1962a).

In summation, water suitable for most domestic and livestock requirements can be produced at rates of up to 60 igpm from aquifers in the Wapiti Formation without too much difficulty. In the western portion of the map-area, from Beaverlodge west to the British Columbia border, water in amounts suitable for small municipalities and light industry should not be difficult to obtain.

Surficial-Deposit Aquifers

The best potential sources of large groundwater supplies for domestic, municipal, and industrial use appear to be aquifers in surficial deposits. Characteristics of the surficial-deposit aquifers are also summarized in table 9.

Alluvial-Terrace Deposits

Large supplies of groundwater may possibly be obtained from sands and gravels in deposits in alluvial terraces adjacent to the major rivers of the Peace River district (Map 28) but the potential of these terraces is generally unknown.

The only terrace deposits in the Peace River district that have been properly evaluated are adjacent to the Wapiti River to the south of Grande Prairie. An extensive test-drilling and aquifer-testing program has been conducted for these terraces, and a series of production wells constructed in the terrace deposits, unfortunately before the testing phase was complete. The terrace supply has been used for two years, but is now considered unsuitable as there is essentially no hydraulic connection between the terrace sands and gravels and the river, and because the terrace is subject to flooding. Details of the testing and production history are given in the chapter on municipal supply. They illustrate the importance of thorough testing of any water-bearing deposits before the installation of any permanent supply system.

The difficulties experienced at the Wapiti River site may not be typical of similar sites in the Peace River district. Other terraces that will bear investigation are found along the Peace River, especially in the vicinity of Peace River town, and along the Little Smoky River near Valleyview. Other promising sites are evident on Map 28 and each is worthy of a careful testing program designed to prove its potential.

Aeolian Deposits

In the areas of aeolian sand deposits (Map 28) shallow wells can generally be developed to supply water for domestic and stock purposes. Yields of water are usually quite low—in the order of a few gallons per minute—as these deposits are usually thin (up to 30 feet). These are water-table aquifers and respond readily to seasonal fluctuations in precipitation.

Lacustrine Deposits

Lacustrine deposits, consisting largely of clay, cover large areas of the Peace River district. In some areas, the vicinity of High Prairie for example, deposits of silt and sand are commonly found (see log for Northern Alberta test hole No. 1, Appendix B) in which wells with low yields can be developed (1-2 gpm). In many places seepage wells are dug which obtain a few gallons of water per day.

Generally, however, lacustrine deposits do not provide sufficient water for domestic or stock purposes as they are usually quite impermeable.

Till Deposits

Till deposits, consisting of clay, silt, sand and boulders, are impermeable, and hence are usually not suitable for the development of wells, with the possible exception of dug wells from which a few gallons of water per day may be obtained by seepage.

Buried-Channel Deposits

Several areas of the Peace River district are underlain by permeable deposits of sand and gravel, which may be either of glacial or preglacial origin (Fig. 16). The thicknesses of these deposits may be 30 feet or more and their depths vary from 600 feet below the land surface, as at High Prairie, to 20 to 30 feet, as at Fairview and Grimshaw. Buried-channel deposits appear to have the best potential in the Peace River district for yielding large supplies of groundwater for domestic, municipal and industrial purposes wherever they are water-saturated, sufficiently permeable, and have a large area extent. The aquifer at the Town of High Prairie, as described in the chapter on utilization and development, has potential yields in excess of 1,000 igpm. Similarly, the buried sand and gravel aquifers at Fairview and Beaverlodge have considerable potential for the development of productive well fields. The deep-lying gravels in the vicinity of the Peace River at Dunvegan, on the other hand, do not appear to be water-bearing.

Figure 16 outlines areas known to contain buried sands and gravels at depth. The High Prairie-McLennan buried-channel system appears at present to have the greatest potential for increased development and use of groundwater, due to the large amount of available drawdown.

Further exploration in the delineation of these buried-channel aquifers should be undertaken in order to promote the development of large supplies of groundwater.

Water-Level Records

Observation wells have been installed in several aquifers in the Peace River district in order to observe water-level fluctuations and their relation to climatic fluctuations and water use. Sufficient data are not yet available, however, for any conclusions to be drawn regarding changes in the water levels and their causes. Data concerning the observation-well installations in the Peace River district are given in table 10.

Flowing Seismic Shot Holes

In the province of Alberta records are kept of seismic shot holes drilled in the search for oil and natural gas from which water flowed. Locations of flowing seismic shot holes are presented on figure 22 as an aid in the search for groundwater in the Peace River district.

Table 10. Observation Wells, Peace River District

Name	Lsd. or ¼	Sec.	Tp.	R.	W. of Mer.	Aquifer Materials	Installed	Removed	Permanent or Temporary
Beaverlodge—experimental farm	NE.	36	71	10	6	Wapiti Formation sandstones	July 1959	——	Perm.
Enilda	1	5	75	15	5	Lacustrine silt	Aug. 1965	——	Perm.
Grande Prairie—treatment plant	10	24	70	6	6	Alluvial gravel	Sept. 1963	June 1965	——
Grande Prairie—Wapiti River	3	23	70	6	6	Alluvial gravel	Feb. 1961	May 1965	——
Grimshaw	7	29	83	23	5	Preglacial terrace gravels	Aug. 1963	June 1965	——
Grishaw A35-1	9	35	83	24	5	Preglacial terrace gravels	Aug. 1965	——	Temp.
Grimshaw—Karpiak	10	16	84	24	5	Preglacial terrace gravels	Sept. 1965	——	Temp.
Grimshaw—Kerndale	4	13	83	25	5	Preglacial terrace gravels	Aug. 1965	——	Temp.
Grimshaw—Lac Cardinal Provincial Park	10	22	83	24	5	Preglacial terrace sands	Aug. 1965	——	Temp.
Grimshaw—Mercier	5	29	83	23	5	Preglacial terrace gravels	Sept. 1965	——	Temp.
Grimshaw—new spring	7	29	83	23	5	Preglacial terrace gravels	June 1965	——	Perm.
Lac Cardinal	5	16	83	24	5	Lake-level recorder	Oct. 1965	——	Temp.

CHEMICAL QUALITY OF GROUNDWATER

The chemical quality of groundwater shows considerable variation throughout the Peace River district and depends on the type of material the groundwater has encountered in its migration to the aquifers. It has been noted by Foster and Farvolden (1958), Jones (1960), and Le Breton and Jones (1962) that hard waters generally occur in glacial and recent deposits and soft water in the bedrock. Fresh water percolating downward through the glacial materials picks up calcium and magnesium. Where these hard waters enter bedrock containing a high content of the clay mineral montmorillonite, the calcium and magnesium are exchanged for sodium and water becomes softer. As a consequence of this base exchange, as the process is called, many wells are drilled through glacial deposits containing hard water in search of softer water in the bedrock.

Cormparison of the chemical properties of bedrock and drift gound-waters in Alberta (Le Breton and Jones, 1962) indicates that bedrock waters are generally lower in sulfates and iron than waters from surficial deposits. The total dissolved solids contents in groundwaters from both bedrock and surficial aquifers, however, remain similar because, although there is a reduction in sulfates and hardness in bedrock waters, there is a corresponding increase in the sodium alkalinity.

Chemical Constituents and Classification of Groundwater

The amounts of the various dissolved constituents in waters analysed by the Provincial Analyst are usually expressed as parts per million (ppm). The amounts may also be expressed as equivalents per million (Hem, 1959, p. 32), a form that is particularly useful in hydrogeological studies. From a water analysis expressed in epm, the soluble-sodium percentage (SSP) and the sodium-absorption ratio (SAR) can both be derived (U.S. Salinity Laboratory Staff, 1954, p. 156). These two derived quantities are of great value in assessing the quality of irrigation waters. The epm values may also be used in the comparison of calculated total solids with reported total solids as a check for gross errors in the analyses (Hem, 1959).

The chemical constituents of Alberta groundwaters reported routinely or on request by the Provincial Analyst are listed in the paragraphs below, together with their significance and the permissible upper concentration limits suggested by the Division of Sanitary Engineering of the Provincial Department of Health, where these are applicable. These upper limits serve only as guides and each case is judged on its own merits.

Total Solids

The total-solids content is determined from the weight of the residual material after drying and heating of a known quantity of water sample. The upper limit for total solids, as outlined in provincial health standards for Alberta, lies between 1,000 and 2,000 ppm. Water may be satisfactory from the standpoint of total-solids concentration, but unsatisfactory because the concentration of a particular constituent is excessive.

Hardness

The hardness of water is dependent on the concentration of calcium and magnesium sulfates or bicarbonates. Hardness is of two types—temporary and permanent. The temporary hardness is caused by the bicarbonates of calcium and magnesium which precipitate on boiling. Permanent hardness is caused by the sulfates of calcium and magnesium, which cannot be removed by boiling. Temporary and permanent hardness are not distinguished in most water analyses, where they are usually expressed in terms of ppm of calcium carbonate.

Sulfates

The sulfates referred to in most Alberta water analyses are those of calcium, magnesium and sodium. Magnesium sulfate (commonly known as "Epsom salts") if present in large amounts has a pronounced laxative effect on persons unaccustomed to it. In Alberta analyses, sulfates are expressed as ppm sulfite. According to Alberta provincial health standards, the usual maximum permissible amount for public supplies is 500 ppm. Occasionally amounts of up to 700 ppm are tolerated in certain areas where no other water source is available.

Chlorides

Chlorides are generally found in all waters. In analyses by the Provincial Analyst they are generally expressed as ppm Cl and the suggested permissible upper limit, acording to Alberta provincial health standards, is 500 ppm. Occasionally amounts of up to 700 ppm are allowed in cases where no alternative water source is available. If, however, the chlorides are principally NaCl, concentrations as low as 400 ppm may be sufficient to counteract the beneficial effects of salt-free diets.

Alkalinity

Alkalinity generally represents the content in ppm of carbonates, bicarbonates, and, rarely, hydroxides. The nature of the alkalinity is shown by listing the most abundant compound or compounds giving rise to alkalinity, such as calcium or sodium bicarbonate. In Alberta alkalinity is expressed as ppm carbonate.

Iron

An excessive amount of iron in a water supply stains clothing and plumbing fixtures, and often causes bad tastes and odors. If in the form of iron sulfate it will corrode ferrous metals and brass. Although iron is present in most waters, an amount in excess of 0.3 ppm is objectionable.

Nitrates and Nitrites

Nitrates and nitrites indicate the presence of organic matter in the water and if present in large quantities may indicate that the water supply is being contaminated by organic wastes. In Alberta water analyses, nitrates and nitrites (nitrites are rare) are expressed in ppm nitrogen. According to Alberta provincial health standards amounts greater than 10 ppm are excessive. Where the nitrate is excessive the water is dangerous when used for infant feeding.

Fluorides

Fluorides are commonly found in natural waters and are desirable for the prevention of dental caries. The suggested upper limit for naturally occurring fluorides is 1.5 ppm. When fluorides are added to natural waters the suggested upper limit is 1.0 ppm.

Table 11 is based on a table prepared by the United States Public Health Service (U.S. Public Health Service, 1961) listing suggested upper limits that should not be exceeded where other more suitable supplies are or can be made available. Limits for a number of constituents generally found only in small or trace amounts are given in the table in addition to those for some of the constituents already discussed.

Table 11. Suggested Upper Limits for Concentrations of Various Groundwater Constituents

(based on U.S. Public Health Service, 1961)

Constituent	Concentration (ppm)
Arsenic (As)	0.01
Chloride (Cl)	250.0
Copper (Cu)	1.0
Cyanide (CN)	0.01
Fluoride (F)	1.7
Iron (Fe)	0.3
Manganese (Mn)	0.05
Nitrate (N)	10.0
Sulfate (SO_3)	240.0
Zinc (Zn)	5.0
Total dissolved solids	500.

Classification of Mineralized Waters

Table 12 gives Faust's (1962) classification of mineralized waters on the bases of dissolved-solids concentration.

Table 12. Classification of Mineralized Waters
(after Faust, 1962)

Description of waters	Concentration of dissolved solids (ppm)
Fresh	under 1,000
Slightly brackish	1,000 - 3,000
Moderately brackish	3,000 - 10,000
Highly brackish	10,000 - 33,000
Sea water	33,000 - 36,000
Brine	Over 36,000

Quality of Peace River District Groundwaters

Tables 13 and 14 give the available chemical analyses for groundwaters from aquifers in the Peace River district. The original figures quoted by the Provincial Analyst (Table 13) and the calculated epm figures (Table 14) are both listed.

No data are given for groundwaters from the Peace River Formation, but reports indicate that these waters are, at least in some areas, very high in total solids and probably highly brackish. In such areas total solids are known to range between 20,000 and 30,000 ppm. In other areas, however, the total-solids content may range between 3,000 and 7,000 ppm.

Two analyses of waters from the Dunvegan Formation are given in table 13. Both analyses put the waters in the moderately brackish category and there is a suggestion that brackishness may increase to the south of the Peace River. In that area water from the Dunvegan Formation is unsatisfactory for domestic, municipal, and industrial use.

One analysis is available of water from the Pouce Coupe Member of the Kaskapau Formation. The water is only slightly brackish. A single analysis of Bad Heart Formation water indicates this water to be fresh.

Table 13 Chemical Analyses in Parts per Million of Peace River District Groundwater

No.	Source	Sec.	Tp.	R.	West of Mer.	Aquifer*	Total solids	Ignition loss	Hardness	Sulphates§	Chlorides§	Alkalinity	Nature of Alkalinity	Nitrites§	Nitrates§	Iron	Soda§
1	Valleyview Well	15	70	22	5	W	594	24	15	40	2	475	Bicarb Ca, Mg, Na	0	0	1.2	34.2
2	Wembley Well	15	71	8	6	W	1790	100	20	586	16	600	Bicarb Ca, Mg, Na	0	0	0.4	43.04
3	Observation Well	36	71	10	6	W	2116	64	30	616	4	915	Bicarb Ca, Mg, Na	0	0	5.0	65.67
4	Bezanson Well	10	72	3	6	W	870	70	0	17	23	690	Bicarb Na	0	0	0.7	51.2
5	Clairmont Well	25	72	6	6	W	1232	32	15	166	5	855	Bicarb, Ca, Mg, Na	tr	tr	0.4	62.3
6	Farm Well	20	72	7	6	W	960	130	160	22	14	800	Bicarb Ca, Mg, Na	tr	0.5	0.5	47.49
7	Farm Well	21	72	7	6	W	930	108	140	2	11	820	Bicarb Ca, Mg, Na	0	0	0.2	
8	Beaverlodge Well	2	72	10	6	W	1244	100	0	75	18	925	Bicarb Na	0	0	0.2	68.2
9	Sexsmith Well	25	73	6	6	W	922	26	10	95	4	685	Bicarb Ca, Mg, Na	0	0	0.4	50.1
10	Hythe Hotel Well	13	73	11	6	W	728	26	20	54	8	570	Bicarb Na	0	0	0.2	40.8
11	Hythe Campsite Well	24	73	11	6	W	890	112	190	81	5	680	Bicarb Ca, Mg, Na	0	0	1.0	36.3
12	Teepee Creek Well	5	74	3	6	W	1536	264	290	163	6	1055	Bicarb Ca, Mg, Na	0	0	0.7	56.8
13	Buffalo Lakes Well	4	74	7	6	W	1230	28	155	256	6	770	Bicarb Ca, Mg, Na	tr	1.2	0.8	45.63
14	Farm Well	8	74	8	6	W	1228	148	240	208	12	765	Bicarb Ca, Mg, Na	0	0	0.7	38.90
16	La Glace Well	15	74	8	6	W	684	16	20	38	0	575	Bicarb Ca, Mg, Na	tr	1.2	0.2	41.18
16	Demmitt Well	25	74	13	6	W	824	112	220	160	2	505	Bicarb Ca, Mg	0	0	0.2	21.1
17	Hythe Well	27	74	13	6	W	608	34	50	63	2	480	Bicarb Ca, Mg, Na	0	0	0.4	31.9
18	Woking Hotel Well	19	76	5	6	W	2710	168	355	970	45	875	Bicarb Ca, Mg, Na	tr	1.5	1.7	38.6
19	Belloy Spring	21	77	2	6	W	1036	244	455	283	0	490	Bicarb Ca, Mg, Na	tr	tr	tr	
20	Spirit River Well	22	78	6	6	D	5724	222	80	1780	308	1785	Bicarb Na, Ca	0	0	30	
21	Hines Creek Well	32	83	4	6	D	4148	170	85	1953	22	490	Bicarb Na	0	0	1.6	30
22	Bad Heart Well	19	75	2	6	B	872	36	20	72	18	650	Bicarb Na	tr	tr		46.8

23	Worsley-Shell Gas Plant Well	15	87	7	6	P	2636	124	125	1103	20	555	Bicarb Ca, Mg, Na	0	0	tr	
24	Grovedale Bridge Test Well	23	70	6	6	T	844	232	380	100	3	585	Bicarb Ca, Mg, Na	0	0	4.5	
25	Grande Prairie Test Well	24	70	6	6	T	432	150	295	17	1	375	Bicarb Ca, Mg, Na	0	0	5	
26	Grande Prairie City Well	24	70	6	6	T	224	124	165	tr	0	165	Bicarb Ca, Mg	tr	tr	3.6	
27	Wembley Test Well	12	70	8	6	T	346	124	230	32	3	260	Bicarb Ca, Mg, Na	0	0	1.2	
28	Watino Test Well	34	77	24	5	T	1164	220	705	425	17	290	Bicarb Ca, Mg	0	0	3.1	
29	Watino Village Well	34	77	24	5	T	1000	238	470	273	2	480	Bicarb Ca, Mg	0.1	0.1	0.2	
30	Farm Well	28	71	10	6	BG	1554	230	425	508	0	600	Bicarb Ca, Mg, Na	0	0	1.5	
31	Test Well	28	71	10	6	BG	1184	176	345	370	0	495	Bicarb Ca, Mg, Na	0	0	1.2	11.13
32	Test Well	35	71	10	6	BG	1176	112	180	235	1	695	Bicarb Ca, Mg, Na	0	0	1.0	38.21
33	Beaverlodge Well	2	72	10	6	BG	1358	70	195	315	3	775	Bicarb Ca, Mg, Na	0	0	1.4	43.0
34	High Prairie Well	25	74	17	5	BG	710	188	185	0	117.3	397	Bicarb Ca, Mg, Na	0	0	5.0	
35	Farm Well	7	74	7	6	BG	668	110	320	76	0	550	Bicarb Ca, Mg, Na	0	0	1.8	17.07
36	Berwyn Well	31	82	24	5	BG	478	174	330	116	4	165	Bicarb Ca, Mg	tr	0.7	0.8	
37	Whitelaw Spring	15	82	1	6	BG	396	112	285	94	2	205	Bicarb Ca, Mg	tr	0.64	0.2	
38	Fairview Spring	26	82	2	6	BG	528	152	350	183	1	90	Bicarb Ca, Mg	0	0	1	
39	Fairview Well	27	82	2	6	BG	580	184	425	188	3	105	Bicarb Ca, Mg	0	0	2	
40	Peace River Spring	32	83	21	5	BG	1332	234	120	140	57	77	Bicarb Ca, Mg, Na	0.1	0.2		
41	Grimshaw Spring	21	83	23	5	BG	432	124	290	112	tr	195	Bicarb Ca, Mg	tr	tr	0.8	
42	Farm Well	13	84	12	6	BG	1604	204	510	703	5	390	Bicarb Ca, Mg	0	0	2.6	

*B=Bad Heart Formation, G=buried sand and gravel, D=Dunvegan Formation, P=Pouce Coupe Member, Kaskapau Formation, T=alluvial-terrace sand and gravel, W=Wapiti Formation

§tr=trace

†gpg (grains per gallon)=14.3 ppm

Table 14. Chemical Analyses in Equivalents Per Million of Peace River District Groundwaters

No.	Sec.	Tp.	R.	West of Mer.	Calculated total solids	Cations: Ca+Mg	Cations: Na+K	Cations: Sum	Anions: SO_4	Anions: Cl	Anions: CO_3+ HCO_3	Anions: NO_3	SAR*	SSP† (per cent)
1	15	70	22	5	21.1	0.3	10.3	10.6	1.0	0.1	9.5	0.0	26.4	97
2	15	71	8	6	54.2	0.4	26.7	27.1	14.7	0.5	12.0	0.0	59.7	99
3	36	71	10	6	67.6	0.6	33.2	33.8	15.4	0.1	18.3	0.0	60.6	98
4	10	72	3	6	29.7	0.0	14.9	14.9	0.4	0.6	13.8	0.0	—	100
5	25	72	6	6	42.9	0.3	21.1	21.4	4.1	0.1	17.1	0.0	54.4	98
6	20	72	7	6	34.0	3.2	13.8	17.0	0.6	0.4	16.0	0.0	10.8	81
7	21	72	7	6	33.6	2.8	14.0	16.8	0.1	0.3	16.4	0.0	11.7	83
8	2	72	10	6	41.8	0.0	20.9	20.9	1.9	0.5	18.5	0.0	—	100
9	25	73	6	6	32.3	0.2	16.0	16.2	2.4	0.1	13.7	0.0	50.5	99
10	13	73	11	6	25.9	0.4	12.6	13.0	1.4	0.2	11.4	0.0	28.1	97
11	24	73	11	6	31.5	3.8	12.0	15.8	2.0	0.1	13.6	0.0	8.7	76
12	5	74	3	6	50.7	5.8	19.5	25.3	4.1	0.2	21.1	0.0	11.4	77
13	4	74	7	6	44.1	3.1	19.0	22.1	6.4	0.2	15.4	0.1	15.2	86
14	8	74	8	6	41.7	4.8	16.0	20.8	5.2	0.3	15.3	0.0	10.3	77
15	15	74	8	6	25.1	0.4	12.1	12.5	1.0	0.0	11.5	0.1	27	97
16	25	74	13	6	28.3	4.4	9.8	14.2	4.0	0.1	10.1	0.0	6.6	69
17	27	74	13	6	22.5	1.0	10.2	11.2	1.6	0.1	9.6	0.0	14.4	91
18	19	76	5	6	86.1	7.1	35.9	43.0	24.3	1.3	17.5	0.1	19.0	83
19	21	77	2	6	33.8	9.1	7.8	16.9	7.1	0.0	9.8	0.0	3.6	46

20	22	78	6	6	177.8	1.6	87.3	88.9	44.5	8.7	35.7	0.0	97.5	98
21	32	83	4	6	118.5	1.7	57.5	59.2	48.8	0.6	9.8	0.0	62.4	97
22	19	75	2	6	30.6	0.4	14.9	15.3	1.8	0.5	13.0	0.0	33.3	97
23	15	87	7	6	78.6	2.5	36.8	39.3	27.6	0.6	11.1	0.0	32.9	94
24	23	70	6	6	28.6	7.6	6.7	14.3	2.5	0.1	11.7	0.0	3.4	47
25	24	70	6	6	15.9	5.9	2.1	8.0	0.4	0.0	7.5	0.0	1.2	26
26	24	70	6	6	6.6	3.3	0.0	3.3	0.0	0.0	3.3	0.0	0.0	0
27	12	70	8	6	10.8	4.6	0.8	5.4	0.1	0.1	5.2	0.0	0.5	15
28	34	77	24	5	33.8	14.1	2.8	16.9	10.6	0.5	5.8	0.0	1.1	17
29	34	77	24	5	33.0	9.4	7.1	16.5	6.8	0.1	9.6	0.0	3.3	43
30	28	71	10	6	49.4	8.5	16.2	24.7	12.7	0.0	12.0	0.0	7.9	66
31	28	71	10	6	38.4	6.9	12.3	19.2	9.3	0.0	9.9	0.0	6.6	64
32	35	71	10	6	39.6	3.6	16.2	19.8	5.9	0.0	13.9	0.0	12.0	82
33	2	72	10	6	46.9	3.9	19.6	23.5	7.9	0.1	15.5	0.0	14.0	83
34	25	74	17	5	22.5	3.7	7.5	11.2	0.0	3.3	7.9	0.0	5.5	67
35	7	74	7	6	25.8	6.4	6.5	12.9	1.9	0.0	11.0	0.0	3.6	50
36	31	82	24	5	12.4	6.2	0.2	6.4	2.9	0.1	3.3	0.1	0.1	4
37	15	82	1	6	13.0	5.7	0.9	6.6	2.4	0.1	4.1	0.0	0.5	13
38	26	82	2	6	13.4	7.0	0.0	7.0	4.6	0.0	1.8	0.0	0.3	9
39	27	82	2	6	15.4	8.5	0.0	8.5	4.7	0.1	2.1	0.0	0.8	23
40	32	83	21	5	41.0	2.4	18.1	20.5	3.5	1.6	15.4	0.0	16.5	88
41	21	83	23	5	13.4	5.8	0.9	6.7	2.8	0.0	3.9	0.0	0.53	13
42	13	84	12	6	51.0	10.2	15.3	25.5	17.6	0.1	7.8	0.0	6.7	60

*Sodium-absorption ratio

†Soluble-sodium percentage

Analyses are presented for 19 water samples from the Wapiti Formation. These waters are about evenly divided between the fresh and slightly brackish categories, 10 falling in the first category and 9 in the second. Generally, the water in this formation decreases in total solids and improves in over-all quality from east to west, a trend consistent with its sedimentologic history.

There are 6 analyses for alluvial-terrace aquifers and 13 for buried sand and gravel aquifers. In both cases waters are fresh or slightly brackish, the majority of analyses falling in the former category.

Although the figures are not too significant statistically, they do indicate the relative quality of water that may be expected and the opportunity for amelioration of some of the groundwaters if they are to be used for domestic, municipal and industrial purposes.

Quality of Water Obtained by Induced Infiltration

Large supplies of water can commonly be obtained by induced infiltration into alluvial-terrace aquifers adjacent to large rivers (Kazmann, 1948; Klaer, 1953). Infiltration through the terrace deposits leads to the removal of turbidity, organic matter, and pathogenic bacteria (Klaer, 1960) and a consequent substantial reduction in capital and operating costs by comparison with direct use of the surface water.

The water initially produced from a well in an alluvial-terrace aquifer adjacent to a river generally is higher in dissolved solids than the nearby surface water. If water can be induced to move from the river toward the well, water quality will tend to approach that of the river (Klaer, 1953). Noring (1954) indicates that water infiltrating into the river banks contains free oxygen and oxidizable organic substances, from which carbon dioxide is formed. The carbon dioxide then combines with the water to form carbonic acid which dissolves calcium and magnesium carbonate from the gravel, increasing the carbonate hardness. The carbonic acid also dissolves iron and manganese. All these processes lead to a higher dissolved-solids content for the waters in the alluvial deposits than for the surface water. Relatively rapid flushing of the aquifer due to pumping allows less time for these processes and the water quality improves.

At certain periods of the year, rivers and streams commonly provide recharge of surface waters to adjacent areas of unconsolidated materials such as alluvial terraces (Todd, 1959). At other times the terraces themselves provide a source of recharge of water to the streams. Thus seasonal differences in the chemical quality of river waters and of waters from adjacent alluvial terraces can be expected. Meyboom (1961) has described this situation for the Elbow and Bow Rivers at Calgary, where river water enters gravel banks during influent stages and undergoes chemical changes that produce water of a greater hardness. This phenomenon has also been observed along the Rhine River (Noring, 1954).

Brackish-Water Resources

Considerable research has been undertaken in the United States, particularly by the Office of Saline Water, on the utilization of saline and brackish water resources. Faust (1962) outlines some of the purifying processes used and their applicability to waters of differing salinity. Of particular note are studies on utilization of slightly brackish and brackish water purified by electrolysis methods. Possibly some of these methods could be used in obtaining suitable water supplies in certain areas of the Peace River district where no surface waters are available and where aquifers contain slightly to moderately brackish water. For example, in certain areas, groundwaters from the Peace River Formation contain dissolved solids in quantities ranging from 3,000 to 7,000 ppm, and these waters could be utilized. Waters from aquifers in the Pouce Coupe Member and the Dunvegan Formation could be also utilized. In the southern part of the map area, the Cardium Formation has indications of fairly good permeability, although the water is high in dissolved solids. Utilization of all these waters may be possible if future need arises and if desalinization should prove economically feasible.

Suitability of Groundwaters for Irrigation

The suitability of waters for irrigation depends on a number of characteristics, among which the most important seem to be (1) the total concentration of soluble salts, (2) the relative proportion of sodium to other cations, (3) the concentration of boron or other elements that may be toxic, and (4), under some conditions, the bicarbonate concentration as related to the concentration of calcium and magnesium (U.S. Salinity Laboratory Staff, 1954). Information concerning total-solids content and concentrations of the major cations is given in table 14, but, in general, there are no data on boron and other toxic elements in Alberta groundwaters. Nevertheless some indication of the suitability of the water for irrigation may be obtained from a comparison of the figure for total dissolved solids and the soluble-sodium percentage, both of which are given in table 14. The soluble-sodium percentage is calculated from the equation:

$$SSP = \frac{Na^{+} + K^{+}}{Ca^{++} + Mg^{++} + Na^{+} + K^{+}}$$

where the ionic concentrations are expressed in equivalents per million.

The following table, adapted from one prepared by Wilcox (1955), illustrates the classification of waters for irrigation purposes on the basis of total solids and soluble-sodium percentage. The classification assumes average soil conditions.

Table 15. Quality Classification of Water for Irrigation

SSP (per cent)	Calculated total solids (epm)	Water class
<20	<2.5	Excellent
20-40	2.5- 7.5	Good
40-60	7.5-20.0	Permissible
60-80	20.0-30.0	Doubtful
>80	>30.0	Unsuitable

In applying table 15 the water is classified in accordance with the factor giving the worse rating. For example, in the case of sample No. 19 in table 14 for which the SSP rating is "permissible" and that total-solids rating "unsuitable", the water would be judged unsuitable for irrigation. Simiarly, in the case of sample No. 25, for which the corresponding ratings are "good" and "permissible", the use of water for irrigation purposes would be judged permissible.

The precise evaluation of groundwaters for use in irrigation should be done only by a qualified professional, such as a district agriculturist, because of the many factors that influence suitability. In such an evaluation, the sodium-absorption ratio, also given in table 14, is a more suitable indicator than the soluble-sodium percentage (U.S. Salinity Laboratory Staff, 1954). The sodium-absorption ratio expresses the relative activity of sodium ions in exchange reactions with the soil and is calculated from the equation:

$$SAR = \frac{Na^{+}}{\sqrt{Ca^{++} + Mg^{++}/2}}$$

where the ionic concentrations are expressed in equivalents per million.

An examination of table 14 indicates that the suitability of the groundwater supplies in much of the Peace River district for irrigation practices is limited, particularly in the case of highly mineralized bedrock waters. Waters from the alluvial-terrace and buried sand and gravel aquifers are considerably more suitable.

WELL COMPLETION AND DEVELOPMENT

In order to utilize an aquifer successfully, proper well-design and completion practices have to be carried out. Proper well design in the case of unconsolidated aquifers necessitates an understanding of the nature and gradation of the particle sizes of the aquifer materials as determined from sieve (mechanical) analysis. Most wells need adequate development before they can be put into production. Development may involve: (1) bailing, (2) surging, (3) acidizing, (4) use of detergents, (5) hydraulic fracturing, (6) screening, and (7) screening and sand or gravel packing.

Most cases of well failure can be attributed to faulty development procedures and well-completion practices.

Common Well-Completion Methods

A well may be completed either in such a way that it draws water from only one aquifer or, alternately, so that it draws water from two or more aquifers. The latter case is known as a multiple completion. What is known as an "open-hole completion", the simplest available, is made where the mechanical constituents of the aquifer are sufficiently competent to stand by themselves so that there is no danger of them collapsing or running in the hole. Usually the casing is run to the top of the aquifer and set in place. A "screen, or screens and sand- or gravel-pack completion" is usually made where the aquifer constituents are not competent to stand by themselves. This situation applies to the majority surficial-deposit aquifers and to a good proportion of the bedrock aquifers in the Peace River district. To develop this kind of aquifer a screen or combination of a screen and sand or gravel pack has to be installed (Farvolden, 1961a). The size and type of screen is usually determined by particle-size analyses (mechanical analyses) of representative samples of the water-bearing formation. From certain criteria derived from the sieve analysis a screen, or a combination of a screen and selected sizes of sand or gravel, may be chosen that will hold back a certain proportion of the aquifer constituents (Ahrens, 1957).

Screen and Sand- or Gravel-Pack Selection

Figures 18 and 20 show examples of sieve analyses of materials from surficial-deposit and bedrock aquifers, respectively, in the Peace River district. The points on the curve are known as per-cent sizes and, for any given point, the ordinate gives the percentage by weight of the sample smaller than the size indicated by the abscissa. Of particular importance are the 10 and 60 per-cent sizes, which the used in defining the "effective size" and the "uniformity coefficient", two parameters commonly used in describing a sample's size characteristics (Ahrens, 1957).

The *effective size* is defined as the 10 per-cent size and is supposed to be indicative of the permeability of the material.

The *uniformity coefficient* is defined as the ratio of the diameter of the 60 per-cent size to that of the 10 per-cent size. It is a measure of the uniformity of the material and is usually only significant for materials that are well graded. If it is less than 3.0, a uniformly grained material is indicated; if greater than 3.0, a graded material is indicated.

The effective size and the uniformity coefficient are used to determine whether or not a sand or gravel pack is required and, if so, what type is to be used (Ahrens, 1957). Conditions justifying the use of a pack are, according to Ahrens (1957):

(1) in poor aquifers consisting of fine-grained materials from which the maximum yield is required, to permit the use of larger slot sizes (screen openings) and a correspondingly greater percentage of open area in order to obtain a more efficient well;

(2) to stabilize well-graded aquifer sands with a large percentage of fines in order to avoid sand pumping; and

(3) occassionally in deep-lying aquifers to improve well efficiency where increased yield will justify the cost of a pack in an underreamed section of the hole in the aquifer, but would not justify the cost of drilling a larger-diameter hole to and through the aquifer.

Ahrens (1957) also lists criteria for designing uniformly graded and graded packs, the criteria being based on the characteristics of the sieve-analysis curves. Pack material may be obtained locally from nearby gravel pits but some screening is generally required and this type of material may not be satisfactory for all applications. Where gravel or other suitable natural materials are not available, crushed stone may be substituted, but its efficiency in a pack is believed to be somewhat less than that of a natural material (Ahrens, 1957). A uniformly grained pack may be essential for a satisfactory well design and, in such a case, specially prepared products are available. Typical of these are the sand pack materials available from Cardium Supply Limited. Data on some of the available sizes are given in table 16.

Generally (Ahrens, 1957), the packs should not contain particles greater than ½ inch in diameter and the particles should be relatively well rounded, with less than 10 per cent being flat or platy and less than 5 per cent soft or earthy. The thickness of artificial packs should range from 4 to 9 inches.

Table 16. Sieve Analyses and Recommended Maximum Screen-slot Openings for Commercial Sand Packs

Standard commercial sand-pack size No.*	Sieve analysis			Maximum screen-slot size No.* to retain about 90 per cent of pack
	U.S. mesh No.	Mesh opening (inches)	Cumulative Per cent sand retained	
10-20	16	0.0468	10.5	30
	20	0.0331	90.0	
	30	0.0234	99.8	
	40	0.0166	100.0	
20-40	20	0.0331	4.0	16
	30	0.0234	48.7	
	40	0.0166	96.0	
	50	0.0117	100.0	
40-60	20	0.0331	0.0	12
	30	0.0234	1.4	
	40	0.0166	40.0	
	50	0.0117	88.8	
	70	0.0083	99.0	
	100	0.0059	99.9	
	140	0.0041	100.0	

*The commercial sand-pack size number refers to a range in U.S. mesh numbers; the screen-slot size number to the slot opening in thousandths of an inch.

Well-Screen Slot Size

Selection of a suitable screen is also governed by the results of the sieve or mechanical analysis. Ahrens (1957) lists the criteria to be applied in the determination of the largest slot size that will ensure a stable well. Where screens are used with sand or gravel packs the slot size selected should retain 90 per cent or more of the pack materials. Table 16 lists the maximum screen-slot sizes for the commercially available uniformly graded pack materials.

Sieve Analyses of Peace River Aquifer Materials

In figures 18 and 20 are examples of sieve analyses of surficial-deposit and bedrock aquifer materials in the Peace River district. As can be seen from these analyses most of the unconsolidated-sandstone bedrock aquifers have a low uniformity coefficient, generally less than 2.0, and a small effective size, indicating (Ahrens, 1957) that successful completion and development of wells in aquifers of this nature generally require the installation of a well screen and a uniformly graded sand pack to obtain the best efficiency and water production. Aquifer characteristics for screen and gravel-pack selection are indicated in table 17. Little attention has been paid in the district in the past to the use and careful selection of well screens and, as a result, there have been many silting and sanding problems. Due consideration should be given to obtaining professional advice when difficult aquifer conditions are encountered, as many difficulties can often be avoided through following proper well-completion and design procedures.

Completion Practices to Avoid

When completing water wells it is best to avoid using slotted casing to obtain water from an aquifer; the well efficiency is reduced considerably and if the aquifer is unconsolidated and contains fine sand the sand will commonly run into the bore hole, causing plugging and damaging pumps.

Ahrens (1957), commenting on the use of well screens and perforated casing, states that the efficiency of wells falls rapidly as the open area decreases below 15 per cent. Most well screens have open areas ranging between 15 and 25 per cent. These figures cannot be approached by perforated casing, which is generally prepared by cutting with an acetylene torch or with a hacksaw blade. The size and number of performations in well casing are limited because perforating weakens the casing, making it susceptible to corrosion and shortening well life. Perforated casing requires larger-diameter wells to obtain the desired amount of water and leads to an increase in drilling costs.

Similarly, cementing of casing across an aquifer and then perforating the casing is not efficient. The cement is liable to seal off the aquifer and reduce the effective permeability of the formation; later perforating will thus not be of much value and the efficiency is liable to be even less than that obtained by using slotted casing alone.

Groundwater Testing and Development Program

For most municipal and industrial groundwater-development programs it is desirable that the services of a qualified groundwater consultant be obtained to supplement those of the well-drilling contractor, who may not be equipped to carry out a complete hydrogeological investigation. For most domestic and stock water supplies relying upon a competent well-drilling contractor is usually satisfactory. Jones (1963) has outlined considerable information useful for obtaining groundwater supplies.

A program to evaluate and develop groundwater supplies for municipal and industrial use can be carried out in three phases.

The first phase is the collection and examination of available geologic and hydrologic data. The purpose of this phase is the location of possible

Table 17. Examples of Screen and Gravel-Pack Selection for Peace River District Aquifers

Northern Alberta test hole (NAT) No. or sample No.	Lsd.	sec.	Tp.	R.	West of Mer.	Aquifer	Depth Interval (feet)	Uniformity Coefficient	Effective Size (Inches)	Type of Completion and Remarks
63-13	SW. cor.	25	70	6	6	Recent sand dune	Outcrop	1.95	.0037	Uniform grained sand, requires a uniform gravel pack and a well screen for a successful completion
NAT-1	16	25	74	17	5	Sand lens in till	30-40	1.8	.0078	Uniform grained sand, requires a uniform graded pack and well screen for maximum efficiency; a No. 12 slot-size screen could be used without a pack, where efficiency not important
NAT-18	14	3	72	10	6	Wembley buried channel	96-100	5.2	.035	A graded sand and gravel, can be screened without use of a pack; a No. 150 slot-size screen would be satisfactory
							100-110	7.0	.05	A graded sand and gravel, can be screened without use of a pack; a No .150 to 200 slot-size screen would be satisfactory
NAT-1	16	25	74	17	5	High Prairie buried channel	602-608	2.0	.0044	Uniform grained sand, a graded pack and a well screen is required for maximum efficiency; a No. 10 slot-size screen could possibly be used without a pack
							608-613	3.0	.0053	Uniform grained sand, a graded pack and a well screen is required for maximum efficiency; a No .12 slot-size screen could possibly be used without a pack where high yields not important
NAT-22	4	13	71	9	6	Wapiti Formation	196.5-197	3.8	.0028	Slightly graded sand, requires a graded pack and screen for maximum efficiency; where efficiency is not required, a No. 10 slot-size screen could be used without pack
63-11	4	16	80	4	6	Dunvegan Formation	Outcrop	1.4	.0033	Uniform grained sand, requires a uniform grained pack and a well screen
63-20A	7	9	86	23	5		Outcrop	1.9	.0034	Uniform grained sand, requires a uniform grained pack with a well screen, a No. 30 slot-size screen and No. 10-20 Cardium sand pack could be used.
63-21	12	29	65	25	5		Outcrop	2.1	.0026	Uniform grained sand, requires a uniform gravel pack and a well screen for a successful completion
63-22	4	18	84	23	5		Outcrop	2.5	.0019	Uniform graine dsand, requires a uniform gravel pack and a well screen for a successful completion

aquifers and the preliminary assessment of their potential. Data that should be gathered include:

(1) Geological Survey of Canada reports and maps, especially those dealing with surficial deposits and near-surface bedrock formations;

(2) Research Council of Alberta reports and maps on geology, groundwater and soils;

(3) local air photographs and interpretations of these photographs;

(4) water-well records on municipal, provincial, federal, and local well-contractors' files;

(5) structure test-hole logs available as a result of local exploration for oil and gas;

(6) electric logs from oil and gas exploration;

(7) flowing seismic shot-hole reports;

(8) chemical-quality data from municipal files and groundwater reports;

(9) records of groundwater temperature, especially if water is to be used for cooling purposes; and

(10) records of water use and possible future needs.

If the available water-well records are incomplete, it will be necessary to make a field survey of the wells in the area of interest and a number of these wells may be sampled for water quality. This last procedure is advisable in any case if water-quality data are sparse.

On the basis of the information obtained, geological maps and cross sections may be prepared indicating possible aquifer sites, aquifer isopachs, structure contours and other features of interest. In addition, recommendations may be made concerning the economic feasibility of various alternate sources of water, including surface sources. The recommendations will take into consideration such factors as pipeline and pumping costs and costs of water treatment. Finally, if a groundwater source is judged to be most suitable ,the cost and nature of the groundwater-test program will be outlined.

The second phase of the program involves groundwater testing and exploration. It should include:

(1) drilling of test holes in selected locations to determine the thickness and extent of the local aquifers;

(2) electric logging of all test holes as a check on the lithologic logs and for the more accurate determination of aquifer depth and thickness;

(3) preliminary bail testing of promising aquifers to obtain a general indication of potential;

(4) drilling and completing of selected holes as test wells, the selection to be made on the basis of previous test-drilling results;

(5) pump testing of these wells to determine the hydrologic characteristics of the aquifer and thus its potential as a water supply; and

(6) finally, the preparation of specifications for production wells based on the accumulated geological and hydrological knowledge.

It may sometimes be possible to combine steps (5) and (6) so that the pump test is carried out on the production well. Supervision of all testing should be carried out by someone thoroughly familiar with groundwater hydrology and test drilling.

The third phase is the installation of the production well or wells and their evaluation. Included in this phase are:

(1) installation, if not carried out in the second phase, as suggested above;

(2) a final pumping test to confirm the previous test on the test well and a step-drawdown test to determine the characteristics of the well; and

(3) a final report on the project containing all the basic data gathered during all three phases, the details of well construction, pumping equipment and pump housings, predicted yields, and recommendations for the future.

Although individual programs may vary in detail from that suggested above, it should form the basis of any sound and well-executed groundwater program. It is hoped that it will serve as a useful guide to municipalities and industries in the Peace River district and elsewhere who are considering groundwater as a source of water supply.

Well Construction Standards

For most municipal and industrial groundwater supplies, construction standards will be handled by the authority supervising the groundwater-test program, who will be aware of good well-construction standards and municipal and provincial ordinances relating to them.

For domestic and stock water supplies the person requiring water-well drilling services usually has to rely on the local well contractors, many of whom are known for good standards of workmanship. However, there have been occasional complaints of poor workmanship, contamination of wells, sand problems, and so on, from the public at large. The suggested minimum specifications given in appendix C should serve as a useful guide for the person considering the construction of a water well in the Peace River district and elsewhere. These specifications and standards have been drawn up by the Research Council of Alberta in consultation with the Alberta Water Well Drilling Association and various government departments by whom they have been used. They are voluntarily accepted by most of the better water-well drillers in the province and are considered to represent minimal construction standards for small domestic and stock groundwater supplies. In addition to these standards, the well contractor has to comply with provincial and local municipal ordinances regarding the sanitary aspects of well completions.

In addition to the minimum specifications and standards, suggested examples of bid forms and contract documents are given in appendices D and E to serve as guides in case several well contractors are to be contacted regarding the pricing for the work.

UTILIZATION AND DEVELOPMENT

Introduction

Within the last few years, with the increase in water consumption and growth of communities in the Peace River district, the value of adequate supplies of good-quality water has been realized A recent event, in some cases, has been the consideration of the relative importance of various alternate sources of water, and a trend has developed which is leading towards the integration of groundwater and surface-water supplies and, in some cases, to switching from existing sources of surface water if the groundwater supplies show an economic advantage

In the map-area groundwater is utilized mainly for domestic, livestock, and municipal purposes. Figure 23 shows the locations and types of water wells in the Peace River district to the end of March, 1964. There are very few commercial or industrial establishments that have their own groundwater supplies, and most obtain their water directly from the municipality in which they are located. Thus to encourage industries, especially those that require large supplies of good-quality water, to locate in a municipality it appears that the onus of finding such supplies will rest on the municipality.

Generally the selection of a groundwater rather than a surface-water supply has been on the basis of one or more of the following advantages (Thomas, 1955):

(1) groundwater may be reached within a few hundred feet of the place where it is to be used, and on the same property, whereas surface water may require pipelines and rights-of-way over stretches of several miles;

(2) groundwater may be available for use in areas where the water in streams and lakes has already been appropriated by other users;

(3) yield from wells and springs generally fluctuates less than stream flow in alternating wet and dry periods; and

(4) groundwater is more uniform in temperature and soluble mineral load than surface water, and is generally free of turbidity and bacterial pollution.

Generally, the capital and operating costs for a groundwater supply are much less than those for an equivalent volume of water obtained from a surface-water supply. Thus many communities that do not have a satisfactory surface-water or groundwater supply nearby should be able to go farther away to obtain a groundwater supply than for a comparable surface-water source.

Domestic and Livestock Water Supplies

Most rural domestic and livestock requirements for groundwater in the map-area are seldom much over 5 igpm. At present there is little water required for irrigation, except in certain areas adjacent to the Peace and Smoky Rivers, where some market gardening is carried out at the Shaftesbury Settlement and at Watino respectively. At present most irrigation water is obtained from these rivers.

Per capita consumption of water for domestic use in rural households has been estimated by Anderson (1959) at 35 imperial gallons per day (igpd). The average consumption of water by livestock has been estimated by Anderson (1959) to be 25 to 35 igpd for each milk-producing cow, 12 igpd for each steer or dry cow, 10 igpd for each horse, 2 igpd for each hog, 1½ igpd for each sheep and 4 igpd for every 100 chickens.

Municipal and Industrial Water Supplies

Many factors have to be considered if groundwater supplies are going to be used by municipalities and industry. It is of importance to know, for instance, whether more than one well will be required; at what rate can the well be safely pumped; whether the well will be taking more water out of the ground than is being replaced; how long the well will last; and what is the temperature and quality of the groundwater. In order to answer some of these questions, the following outline of municipal groundwater supplies has been prepared so that municipal officers, engineers, well contractors, and other people will know the basic data currently available and will be able to evaluate the groundwater resources and plan soundly for their use.

In estimating the water requirements for most small urban municipalities of 1,000 people or less, a per capita water consumption of 50 igpd is normally used. In larger centers the water requirements are usually much more diversified because of local industrial requirements, so that special detailed studies on per capita water consumption have to be carried out. As the population of a community increases there is a corresponding increase in per capita consumption of water, so that consumption estimates must be revised periodically.

Available water-production and use data are given in the sections to follow for municipalities in the map-area having groundwater supplies. The available data on water quality for these municipalities are presented in tables 13 and 14.

Beaverlodge

Location, Population, and Water Supply. The town of Beaverlodge is located in Sec. 2, Tp. 72, R. 10, W. 6th Mer. in the southwestern portion of the report area. According to the Alberta Bureau of Statistics the population was 331 in 1941, 443 in 1946, 514 in 1951, 768 in 1956, and 897 in 1961. The 1963 population (Secretary-Treasurer, personal communication) was 1,057.

Water is supplied to the town from two wells. One well (Howey well) was drilled in 1951 by Western Water Wells to a depth of 232 feet. The second (Oszust well) was drilled in 1954, also by Western Water Wells of Calgary, to a depth of 150 feet. The Oszust well is pumped at approximately 20 igpm and the Howey well at approximately 30 igpm. The original logs of the two wells are given in appendix A. Some sand and silt appear to come into the Howey well with hard pumping and it has to be cleaned out periodically .

Geology and Hydrology. A reinterpretation of the original driller's log for the Howey well indicates that it obtains its water from sandstones of the Wapiti Formation in the interval between 161 and 232 feet. The Oszust well obtains its water from the Wembley Channel, containing sands and gravels above the bedrock in the interval from 135 to 140 feet.

The buried channel aquifer has been outlined by geologic and seismic surveys and by test drilling carried out in 1959 (Jones, 1960). It roughly follows the course of the Beaverlodge River and has a width of about 3½ miles in the vicinity of the town of Beaverlodge. The town is located on the northern boundary of the channel (Fig. 17). Recent test drilling in the summer of 1963 (Northern Alberta test holes Nos. 15 to 22) has indicated buried sands and gravels close to the western edge of the town. Lithologic and electric logs for most of these holes are given in Appendix B. The mechanical analysis of the buried sands and gravels is presented in figure 18.

There have been no pumping tests run on the wells in the town of Beaverlodge adequate for the determination of the hydrologic characteristics of the aquifers. Existing pumping tests are summarized as follows:

In the Howey well the original nonpumping or static level was 79 feet. After pumping for a period of 48 hours at a rate of 45 igpm the water level appeared to have stabilized at a depth of 89 feet. This well had a recommended pumping rate of 50 igpm but the rate was later reduced because of the fine sand and silt coming into the well.

The Oszust well produced at a rate of 41 igpm during a 48-hour pumping test. The original nonpumping level was 68 feet and the water level appeared to have stabilized at 83.6 feet. The production rate of the well is now approximately 20 igpm.

Jones (1960) estimated that the volume rate of flow was approximately 9.7×10^5 igpd in the Wembley Channel. The present withdrawal of water from the channel is approximately 7.5×10^4 igpd and there is, therefore, ample scope for the exploration for and development of additional buried-channel supplies in this area. Results of a pumping test in the channel south of Beaverlodge indicated that yields of up to 60 igpm (Jones, 1960) might be developed by a properly completed well.

The bedrock Wapiti Formation has excellent thick sandstone aquifers which have not been thoroughly tested at Beaverlodge. Properly completed wells in these sandstones might yield amounts similar to those obtainable from the buried-channel deposits.

Treatment, Storage, and Distribution. Until 1962 the town of Beaverlodge had only a 52,000-gallon reservoir located north of the town. In that year an additional 150,000-gallon underground reservoir was added. The water is not treated at present. The water quality of the two wells is different and the chemical analyses are presented in the section on water quality (Tables 13 and 14). The water obtained from the buried sands and gravels of the Oszust well is considerably harder than the water obtained from the Howey bedrock well. The bedrock well is considerably higher in soda and is softer.

In 1963 there were approximately 270 water services in Beaverlodge, most of them unmetered. Large institutions (e.g. hospitals and schools) are charged $20.00 for the first 20,000 gallons and $0.50 per thousand gallons for additional water; other metered services are charged $1.00 per 1,000 gallons and unmetered services are charged a flat $3.50 per month.

In 1958 the town had an average consumption of 25,000 igpd. This figure increased to approximately 32,000 igpd by 1960, and in 1963 the water consumption was 43,000 igpd, indicating a daily per capital consumption of approximately 40 gallons.

Recommendations and Conclusions. During 1963 some difficulty appears to have been experienced in maintaining production at both the Howey and Oszust wells. Occasionally the Howey well, when pumped at higher rates, produces some silt and sand. The Oszust well appears to be experiencing a decline in yield that could be due either to deterioration of the well or to a decline in the water level in the aquifer. Neither well is ideally constructed, both having slotted casing, possibly encrusted and corroded with age, installed opposite the water-bearing zones. Slotted casing, whether corroded or not, is, in any case, an inefficient way to obtain water, especially if higher rates of sustained pumping are required.

If corrosion is a problem, a competent well driller could rehabilitate the wells by acidizing, surging, and cleaning. A step-drawdown test should then be run to determine their actual capacity after rehabilitation, in order that they are not subsequently overpumped.

It may transpire that the Howey and Oszust wells, even after rehabilitation, will be unable to produce in sufficient quantity to satisfy the needs of the town. A testing program to increase the water supply would then be in order. It is suggested for such a program that at least one test hole be drilled to a depth of 400 feet, sampled carefully and electrologged. The samples will enable the selection of well screens with correct slot openings. The electric log will enable the tops and bottoms of the water-bearing zones to be distinguished more readily and will aid in the correct positioning of well screens.

There should be at least one observation well close to the new production well and drilled into the same aquifer, and a pumping test should be carried out to evaluate the coefficients of transmissibility and storage in order to predict the safe pumping rate of the well and the long-term yield of the aquifer. The new well could be put adjacent to one of the existing wells in order to reduce the cost of transmitting water to the distribution system by utilizing the supply lines that are already laid down. The yield of the new well should be superior to that of old well because of the use of better construction and development techniques. The old well could be retained as an observation or standby well. Consideration should be given to proper well spacings in order that production will not be reduced as a result of interference between wells.

Beaverlodge is one of the areas in the Peace River district that has excellent groundwater resources and ample opportunity to carry out a sound and orderly development program of benefit to the whole community. With these resources it should be possible to produce water at reasonable rates and, perhaps, to support some light industry as well.

Berwyn

The village of Berwyn is located in Sec. 31, Tp. 82, R. 24, W. 5th Mer. According to the Alberta Bureau of Statistics the population was 206 in 1941, 308 in 1946, 288 in 1951, 342 in 1956 and 347 in 1961.

The village is served by two wells which obtain water from buried sands and gravels at depths between 100 and 120 feet. Well No. 1 approximately 25 years old, has 4-inch diameter casing to a depth of 114 feet, Well No. 2 has 8-inch diameter casing to a depth of 120 feet. This well is approximately 30 years old. Both wells appear to be finished as open holes and have submersible pumps, capable of producing approximately 15 igpm each. The depth to the nonpumping or static water level is approximately 55 feet. There are no detailed lithologic logs or other information available for the wells.

These wells are finished in buried sands and gravels similar to those found near Fairview and Grimshaw. These buried sands and gravels appear to have the potential for yielding water far in excess of the present withdrawals at Berwyn. No pumping tests have been run on the existing wells at Berwyn to determine the coefficients of transmissibility and storage.

The water quality at Berwyn is reasonably good, although the water is quite hard (Tables 13 and 14). It contains some iron and some trouble is experienced with corrosion of water pipes. The water is treated with lime and soda ash.

Water storage is provided by a 40,000-gallon elevated tower.

In 1957, the village had 60 services and these increased to approximately 110 in 1962. The water consumption average about 10,000 igpd in 1957 and had increased to approximately 40,000 igpd in 1961.

The water services are unmetered and a flat $4.00 per month is charged for water.

Berwyn is located in the area between Fairview and Grimshay where the chances are quite favorable for obtaining groundwater supplies from buried sands and gravels. If the need for additional water should arise it is recommended that a constant-rate pumping test be carried out on the existing wells, using one well as the pumping well and the other as the observation well, to determine the local coefficients of transmissibility and storage, the long-term safe pumping rates for the existing wells, and the potential long-term yield of the aquifer. In addition a step-drawdown test should be carried out to evaluate the efficiency of the existing wells. It may be possible to improve their performance by suitable treatment but if a new well should be required it should be properly constructed and developed. Test holes should be carefully sampled and have electric logs run on them to aid in the well design. Berwyn should experience a minimum of difficulty in increasing its present water supply.

Bezanson

The unincorporated village is located in Sec. 10, Tp. 72, R. 3, W. 6th Mer. The population as given by the Alberta Bureau of Statistics was 65 in 1951, 73 in 1956, and 68 in 1961.

Water is supplied from a well 532 feet deep. drilled in 1959. The reported depth to the non-pumping or static level was 180 feet. The yield is approximately 2 to 3 igpm and appears to be adequate to supply the needs of the community and local school. The well is completed in sandstones and shales of the Wapiti Formation. The water is soft, quite high in soda, and contains some iron (Tables 13 and 14).

Bluesky

The unincorporated village of Bluesky is located in Tp. 81, R. 2, W. 6th Mer. According to the Alberta Bureau of Statistics the population was 105 in 1956 and 108 in 1961.

There is no central distribution system for water. Individual homeowners are responsible for their own water supply. Water is obtained from a large dugout close to the community and also from a dug well approximately 50 feet in depth. This well was reported to contain considerable sand and its water was not used for drinking purposes.

The geologic situation in the immediate area is favorable for finding groundwater supplies in buried sands and gravels at depths similar to those found at Fairview and Grimshaw. To obtain suitable water in Bluesky will require proper testing and development, but not too much difficulty should be experienced. The town of Fairview is obtaining water of very good quality from wells in a buried sand and gravel aquifer 4 miles north of Bluesky. These wells are capable of yielding up to 200 igpm.

Brownvale

The village of Brownvale is located in Sec. 19, Tp. 82, R. 25, W. 5th Mer. The population was 140 in 1951, 177 in 1956, and 237 in 1961 according to the Alberta Bureau of Statistics.

Brownvale has no central water-distribution system and obtains water from individual wells and surface-water dugouts. No difficulty should be experienced in obtaining a suitable supply of groundwater from buried sands and gravels that are present in the vicinity. Thorough testing will have to be carried out, however, to evaluate the aquifer potential, as little detailed information is available at present.

The expected water quality is similar to that at Berwyn, Whitelaw, and Grimshaw (Tables 13 and 14).

Clairmont

The unincorporated village of Clairmont is located in Sec. 25, Tp. 72, R. 6, W. 6th Mer. The population, according to the Alberta Bureau of Statistics, was 71 in 1951, 164 in 1956, 292 in 1961.

Clairmont obtains its water from four wells between 155 and 255 feet deep. No detailed information is available on the wells except that the water comes from sandstones of the Wapiti Formation. The supply appears to be adequate at the present time. There is no central distribution system. The water is quite soft, high in soda, and contains some iron (Tables 13 and 14). The village is growing in size and in the near future may require a central distribution system for water. Careful drilling and testing of new wells will have to be undertaken to evaluate the long-term safe well yield of the Wapiti Formation beds at Clairmont to determine whether it is adequate to supply a distribution system. The prospects however seem quite good, as the nearby larger village of Sexsmith has no difficulty in obtaining groundwater from the Wapiti Formation. A test hole for a new well should be carefully sampled and electrologged to ensure the best well design.

Fairview

Location, Population, and Water Supply. The town of Fairview is located in Tp. 81, R. 3, W. 6th Mer. The population according to the Alberta Bureau of Statistics was 432 in 1941, 487 in 1946, 929 in 1951, 1,260 in 1956, and 1,506 in 1961. The 1963 population is estimated to be slightly in excess of 1,600.

The town of Fairview has been using surface water treated in a plant constructed in 1956. This water-treatment plant has a maximum capacity of 200 igpm with 23,000 gallons of inside storage. Adjacent to the plant is a 6-million gallon, outside, surface-water reservoir. The water supply for Fairview is dependent upon local rainfall and runoff. Surface water is collected in a series of sloughs in a 5-mile radius north and east of the town and is brought into town by a series of ditches. In the fall the water is pumped from one slough to another and into the main reservoir to provide enough water in storage to carry the town over the winter. With increase in water demand during the last few years the surface-water supplies have become quite low, especially in late winter. In the fall of 1961 the town approached the Research Council of Alberta for aid in obtaining a groundwater supply, either to augment or to replace their surface supply. From studies of the local geology and information on file at the Research Council the subsurface conditions seemed favorable for the finding of water-bearing sands and gravels.

An extensive test program was initiated in the fall of 1961, under the supervision of the Research Council of Alberta, to locate a groundwater supply. After several months of testing, during which 22 test holes were drilled, a buried sand and gravel aquifer, in which wells with capacities of up to 200 igpm each could be developed, was located 8 miles northeast of the town. A plebiscite was held for the ratepayers in early 1963 and it was decided to build a pipeline to this groundwater source. Additional exploration and testing of the groundwater supply was carried out in the summer of 1963 by Strong, Lamb and Nelson Ltd. of Edmonton, consulting engineers for the town, who constructed a larger supply well and carried out an extended pumping test to evaluate further the hydrologic characteristics of the aquifer and its ultimate yield. Construction of the 8-mile pipeline and pumping facilities was commenced in October 1963. The water will be brought to the existing water-treatment plant for distribution. The existing surface-water sources will be left on standby to use in case of emergencies. There are now two production wells at the new site.

Geology and Hydrology. The 1961 drilling program to trace the extent of buried gravels commenced close to town, along and within the vicinity of the existing system of ditches and canals bringing surface water to the town. Sands and gravels buried beneath about 35 to 45 feet of till and ranging in thickness from 33 to 53 feet were found in test holes 14, 15, and 16 (Fig. 24) but were dry in all three cases. It may be conjectured that these deposits outcrop or come near to the surface within a few miles to the south and southwest of Fairview and are drained there by a number of intermittent streams originating at these locations. Test holes 8 to 13 (Fig. 24) put down at sites some 4 to 6 miles to the northeast of Fairview, generally encountered permeable materials at the surface, in most cases gravel or sandy gravel. In test hole No. 9, however, 20 feet of silt were found at the surface and in test hole No. 10, 15 feet of sand and silt. Thicknesses of permeable deposits in the other holes ranged from 3 to 20 feet and in all cases the deposits were dry.

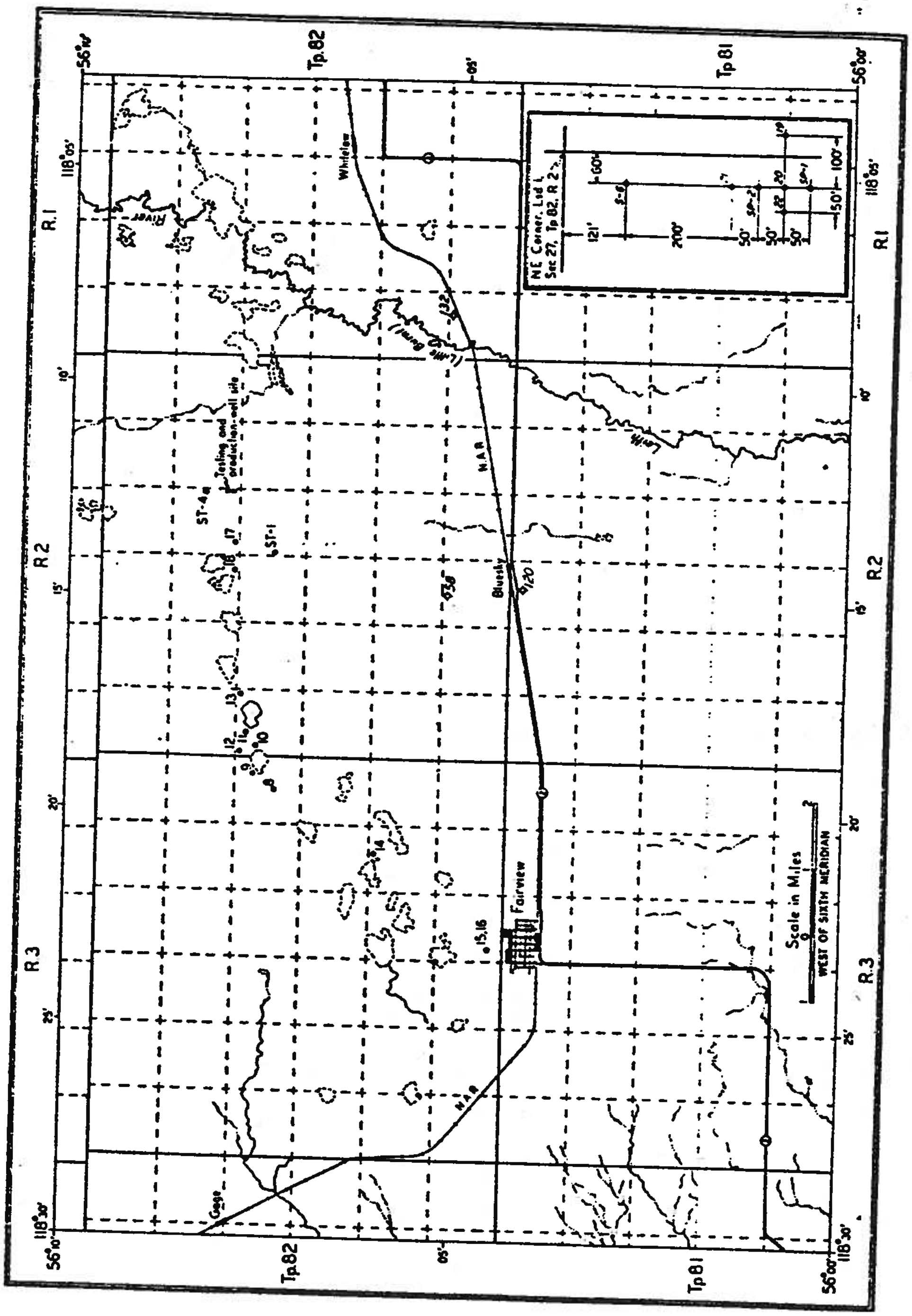

FIGURE 24. Test-hole and well locations, Fairview area.

The first test hole in the series penetrating permeable water-bearing deposits was No. 17, about 7½ miles to the northeast of Fairview (Fig 24). With this success, five more holes (Nos. 18 to 22) were drilled in the same general area and unconsolidated water-bearing sands and gravels were again encountered in all except No. 18. Aquifer thicknesses averaging slightly greater than 30 feet were observed in holes 19 to 22 and this area was selected as a test site. The sands and gravels here overlie the Kaskapau Formation at a depth of about 60 feet and the evidence from hole No. 18 suggests that a barrier boundary exists somewhere between ¾ and 1½ miles west of the test site. Driller's logs for holes 17 to 22 are given in appendix A.

In December 1961 hole No. 20 was completed as a pumping well for testing purposes. Construction details are given in appendix A. Holes 19, 21, and 22 were completed as observation wells. The pump test was conducted in February 1962, the pumping rate being 180 igpm and the length of the test 54 hours. Subsequently a 3-hour step-drawdown test was conducted to evaluate the efficiency of the well and the well was subsequently put into production as town well No. 1.

The pumping-test data were analyzed using the leaky-aquifer method described by Walton (1960, 1962) and based on Hantush and Jacob's formula (1955). The average calculated value for the transmissibility was 2.2×10^{-4} igpd/ft and the average calculated storage coefficient was 1.4×10^{-4}. This method also yields a value for the vertical permeability of the confining bed overlying the aquifer from which water is induced to flow into the aquifer when the hydraulic pressure is reduced due to pumping. The average calculated vertical permeability was 5.5×10^{-2} igpd/ft².

In 1963 further test drilling was conducted by Strong, Lamb and Nelson Ltd. Two new test-hole locations (ST-1 and ST-4, Fig. 24) were selected and sands and gravels were found in both. The results for ST-4 indicated the aquifer pinches out toward the north. Two possible pumping-well sites (SP-1 and SP-2) were then selected at the original test site and good sand and gravel thicknesses were found in both. SP-2 was selected as the pumping well and was completed as a 10-inch well with 15 feet of well screen. This well became town well No. 2. The test was conducted in the late summer of 1963 with seven observation wells. The wells involved in the test were numbered 1 to 8 for convenience, these numbers corresponding to the numbers 22, 20, 19, SP-2, 21, S-6, 17, and ST-4 respectively on figure 24. No log or drilling record can be located for S-6.

The results of the 1963 test confirmed those obtained from the 1961. test. The average calculated transmissibility, storage coefficient, and vertical hydraulic conductivity were 2.08×10^4 igpd/ft, 1.3×10^{-4}, and 5.5×10^{-2} igpd/ft² respectively.

No step-drawdown test data are available for the second production well. However, step-drawdown results from town well No. 1 indicate, according to criteria discussed by Rorabaugh (1953), that flow in the vicinity of both production wells is probably laminar, at least for rates of up to 184 igpm. Turbulent-flow well losses should be even less noticeable for the larger-diameter, better-developed second production well.

Estimated Safe production. The available geologic and hydrologic data suggest that the calculation of long-term safe yields for the Fairview aquifer must involve consideration of the effects of a single discharge or barrier boundary and of leakage. Preliminary calculations show that the leakage effect predominates and that of the boundary may be neglected. Well losses could not be accurately determined. An undoubtedly pessimistic estimate of their magnitude was provided by assuming the onset of turbulent flow in the vicinty of the production well to take place at a flow rate of 184 igpm. In addition it was assumed that the effective well radius was 1 foot and the s_w, the drawdown at the pumping well, could be expressed by the equation:

$$s_w = BQ + C'Q \qquad (3)$$

for flow rates up to and including 184 igpm, and by the equation:

$$s_w = BQ + CQ^2 \qquad (4)$$

for flow rates exceeding 184 igpm. This is a useful method of estimating well loss for pumping rates in excess of test rates, if the step-drawdown test has provided no information on the onset of turbulent flow (Lennox, 1966). A safety factor is thereby introduced.

In equations (3) and (4), C and C′ are constants to be determined from the results of the step-drawdown test and B is a function of time (Rorabaugh, 1953). The magnitude of the formation loss at the effective well radius is expressed by BQ and, properly speaking, in the case of the Fairview aquifer, is given by the leaky-aquifer formula (Hantush and Jacob, 1955). For the assumed effective well radius of 1 foot, however, Theis's nonleaky-aquifer formula (Theis, 1935) is much more convenient to use and results in only a small overestimate of the drawdown.

Twenty-year drawdowns were calculated for various pumping rates and for both a single well and for a linear array of three pumping wells at 1,000-foot intervals. In the latter case the drawdown was determined at the central well and the leaky-aquifer tables (Walton, 1962) were used in calculating the interference effects due to the other two wells. Transmissibility, storage coefficient, and vertical permeability of the confining bed were assumed to be 2.1×10^4, 1.3×10^{-4}, and 5.5×10^{-2} respectively.

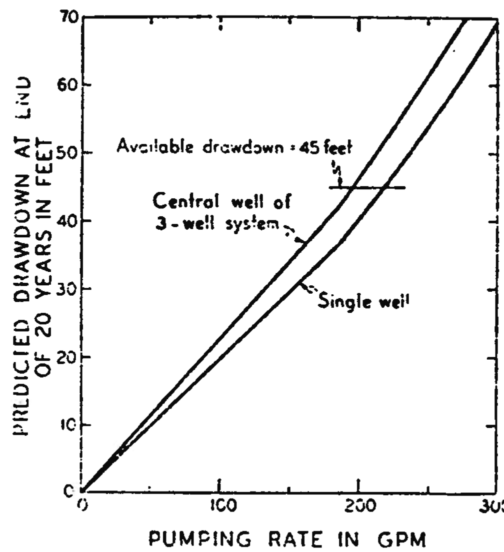

FIGURE 25. Twenty-year drawdowns, Fairview aquifer.

The results of the calculations are shown in figure 25. The available drawdown being 45 feet, the maximum safe 20-year pumping rates are 217 and 196 igpm for the single well and the central well of the three-well system, respectively. The combined maximum safe 20-year pumping rate for the three-well system is, therefore, 588 igpm.

In a leaky-aquifer situation water levels in the aquifer become stabilized, except in the vicinity of the pumping well, and most of the production is supplied by leakage. For a shallow aquifer, such as the Fairview aquifer, production will eventually have to be supplied mainly by natural recharge to the overlying leaky beds, that is by that proportion of the annual precipitation that goes to replenish the groundwater reservoir. From investigations in other parts of the province (Farvolden, 1963c; Le Breton, 1963c; Meyboom, 1961) this proportion appears to range from 1 to 3 per cent and it is of interest to determine, by assuming an average percentage recharge, whether the natural rate of recharge over the area of the cone of depression is of the same order of magnitude as the 20-year safe production rates calculated above. If it is appreciably less some difficulty might be experienced with dewatering of the aquifer and of the confining beds with premature failure of the well or well system.

Since water levels stabilize early, the cone of depression also stabilizes early and, if it is assumed that its vertical radius is that radius at which the drawdown is no longer measurable (0.005 feet or less), the vertical radius can be calculated to be 3.8 miles and the surface area of the cone of depression to be 45 square miles. The annual precipitation in the Fairview area is about 15½ inches and, on the assumption that 2 per cent of this recharges the groundwater reservoir, annual groundwater recharge is then about 0.026 feet, or about 9 igpm per square mile. Over an area of 45 square miles the natural recharge is then slightly over 400 igpm, a figure comparable to the calculated maximum safe 20-year pumping rates. It appears, therefore, that there should be no serious difficulty with dewatering, either at the present production rates of approximately 70 igpm, or at the calculated safe 20-year pumping rates.

Treatment and Distribution. The water quality appears to be quite good, although the water is hard (Tables 13 and 14). Some treatment to remove a slight excess of iron may be required.

Fairview has approximately 350 services at present. The rate charged to the consumer is a minimum of $4.00 per service per month. Average daily consumption in 1963 was estimated at approximately 70 igpm or about 100,000 igpd.

Recommendations and Conclusions. It appears that Fairview is fortunate in having found an excellent supply of good-quality groundwater that should be more than adequate for several years to come. In addition, the supply can readily be expanded with the addition of more wells. With this water supply the town should be in a position to encourage industry to establish in Fairview.

Falher

The town of Falher is located in Sec. 8, Tp. 78, R. 21, W. 5th Mer. The population as given by the Alberta Bureau of Statistics was 575 in 1951, 802 in 1956, and 741 in 1961.

Groundwater possibilities in and near the town of Falher are quite unfavorable. Smoky River shales are the underlying bedrock and extend to depths of about 600 feet. Wells drilled prior to 1930 obtained small supplies of very hard water at depths to 400 feet (Rutherford, 1930). Water below 600 feet from the upper part of the Dunvegan Formation was soft and high in total solids, making it unsuitable for drinking.

A surface water supply is used at present to supply approximately 190 services.

Grande Prairie

Location, Population, and Water Supply. The city of Grande Prairie is located in Tp. 71, R. 6, W. 6th Mer. The population according to the Alberta Bureau of Statistics was 1,724 in 1941, 2,267 in 1946, 2,664 in 1951, 6,302 in 1956, 8,352 in 1961 and in January 1963 was estimated to be 9,680.

Prior to 1946 the city of Grande Prairie was served by four closely spaced wells located in the city center approximately 1,000 feet apart which obtained water from sandstones of the Wapiti Formation at depths ranging from 180 to 500 feet. These wells were pumped intermittently at about 20 igpm each. The water was fairly soft, but high in soda.

Since the well supply was not sufficient, a 210-million gallon reservoir was built in 1946 to store a surface supply obtained from Bear Lake located about 7 miles to the northwest of the city. The reservoir property including the immediate drainage area comprised some 109 acres. At this site a treatment plant was constructed and a 100,000-gallon underground reservoir was provided. The water was delivered from sedimentation tanks and filters at Bear River to the elevated storage tank and pumping station located on the same site as the old town hall.

The capacity of the water system in 1949 was approximately 55,000 igpd, serving 340 services. By 1955 the system had increased to serve 800 connections supplying about 50 per cent of the built-up area of the town.

In 1955 a new filtration plant with a capacity of 370 gpm was added to the old one. The plant was operating at maximum capacity in July 1958 and was treating about 500,000 igpd. Average daily water consumption in 1958 was approximately 250,000 gallons.

The storage capacity for treated water was not considered adequate and the water pressure was low in some parts of the town. Therefore in 1959 a 750,000-gallon storage reservoir was built in the north end of town near the hospital.

Considerable difficulty was experienced in treating the surface water obtained from Bear Lake due to a considerable buildup of algae in the reservoir at certain times of the year, particularly during periods of west winds and low water. In addition the reservoir showed some tendency to silt up. The algae were combatted by using copper sulfate. Operating and chemical costs for treating the surface water were very high and therefore some consideration was given to obtaining alternate sources of water for the city.

In 1960, the Research Council of Alberta, as part of a program to evaluate the groundwater potential of alluvial-terrace aquifers adjacent to the major drainageways in the Peace River district, carried out a drilling and aquifer-testing program on an alluvial terrace on the south side of the Wapiti River near Grovedale Bridge 9 miles south of Grande Prairie. (Fig. 26). Four wells were involved in the aquifer test, which lasted about 26 hours. A representative log is given in appendix A. From this exploratory study it seemed that the hydraulic conductivity of the sands and gravels in the alluvial terrace was such that large amounts of water might be obtained by induced infiltration from the Wapiti River, either by a series of closely spaced conventional water wells or by infiltration galleries.

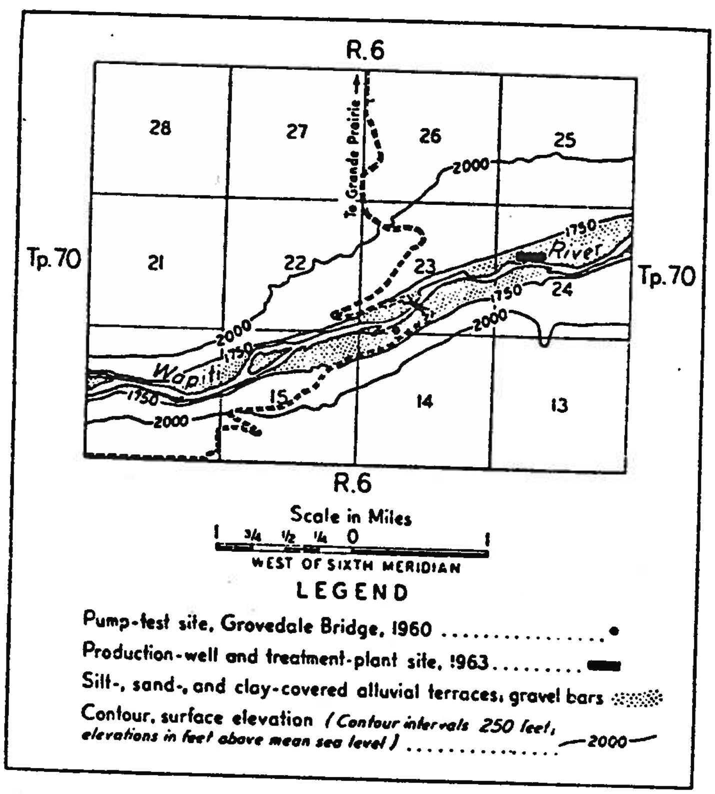

FIGURE 26. Grande Prairie aquifer site.

Estimates at this time predicted that three wells spaced at 500-foot intervals along the south terrace could each be pumped at 200 igpm. It was recognized, however, that the aquifer test had been too short to establish the rate of recharge from the river and that additional data were required concerning the variation of river stage throughout the year. A thorough test-drilling and pump-testing program and the daily measurement of river levels were recommended as essential to an accurate evaluation of the groundwater potential of the terrace. The test results and these conclusions were transmitted to the city of Grande Prairie and to their firm of consulting engineers, Stanley, Grimble, Roblin Ltd., who were investigating additional sources of water for the city.

In the fall and winter of 1961-62, a testing program was carried out by the city of Grande Prairie in conjunction with the Research Council of Alberta on another alluvial terrace on the north side of the river (Fig. 26) to determine the feasibility of obtaining a water supply from the terrace. A 3-day pump test concluded the program. The test data were examined by the Research Council; the pump test was again considered too short to be conclusive as water levels did not stabilize, nevertheless there were indications that the gravels of the north terrace were somewhat less permeable than those of the south terrace. The fact that the drawdown was more than anticipated was attributed to inadequate development of the well being tested giving rise to excessive well loss. Iron content of the terrace water was found to be high and remained high throughout the test.

Recommendations made to the city of Grande Prairie on the basis of the 1961 test results included: (1) further development of the test well, (2) testing for an extended period at a rate of between 100 and 200 igpm, and (3) regular sampling of the water produced during the test period to discover whether there was any tendency for iron content to reduce with time. In the fall and winter of 1962-63, however, a 9-mile pipeline was constructed to the second test site where a water-treatment plant (Fig. 26) was built to treat water obtained from several large wells constructed in the terrace. The new water plant went into production in June 1963. It continued in operation for about two years. Fairly early in this period it became apparent that production rates could not be sustained at the anticipated high levels and that continued pumping failed to reduce the high iron content. The number of wells constructed in the terrace was then gradually increased from three to ten but the total production was still not adequate and iron content remained unchanged. It could only be inferred that induced infiltration was not taking place.

During the production period a series of tests was run to test this hypothesis and to investigate means of augmenting and improving the supply. The tests included: (1) a 3-day pump test in April 1964, (2) a

23-day pump test beginning in January 1965, and (3) a 3-month recharge-pit and pump test beginning in March 1965. The evaluation of these tests, together with a re-evaluation of the two previous tests, is given in an unpublished Research Council report by D. H. Lennox (1965).

The 1964 test was short and the results considered inconclusive. Both 1965 tests, however, provided useful data. The 23-day pump-test results demonstrated that infiltration of river water into the terrace was indeed negligible. Hence the quantities produced from the well system could be expected to remain small and the quality poor. The estimated long-term production rate for the well tested (Terrace Well No. 5) was about 55 igpm. Rates for other wells could be expected to vary somewhat from this figure, depending on local variations in permeability and aquifer thickness. Yields for all wells could be expected to vary with river stage since any change in river stage leads to a change in loading on part of the aquifer. Nevertheless, the analysis of these test data provided convincing evidence that the terrace was unsuitable under natural conditions as a source of water supply for the city of Grande Prairie.

By early 1965 the only possibility for making the well system pay off seemed to be artificial recharge of the terrace gravels. A recharge pit was constructed in the terrace and water was pumped into the pit from the river beginning on March 21, 1965. Recharge was continued at varying rates, with one 3-week interruption, until the end of June. At the same time Terrace Well No. 5 was also pumped at varying rates. It was concluded from the analysis of the test data (D. H. Lennox, unpublished Research Council report, 1965) that artificial recharge of the gravels would allow the test well to be pumped at about 100 igpm on a long-term basis. Some decrease was noted in iron content during the test but it could not be established whether the iron concentration would be reduced to a sufficiently low level as a result of prolonged use of a recharge-pit and pumping-well system. The advantages to be gained with respect to quantity and quality with the adoption of such a system would be offset to some degree by the added complexity of the system and added costs for periodic maintenance and cleaning of the pits.

Quantity and quality, however, were not the only considerations in electing whether to continue with the terrace water supply. In the summers of 1964 and 1965 parts of the terrace were swept away during flood stages of the Wapiti River. Flood waters rose particularly high in 1965, making the terrace inaccessible for about 3 days and damaging some of the wells and the access road leading to them. Consideration of all factors has led to a decision against the terrace groundwater supply. At the time of writing a direct intake in the river is believed to be the most favorable long-term solution to the city's water-supply problem.

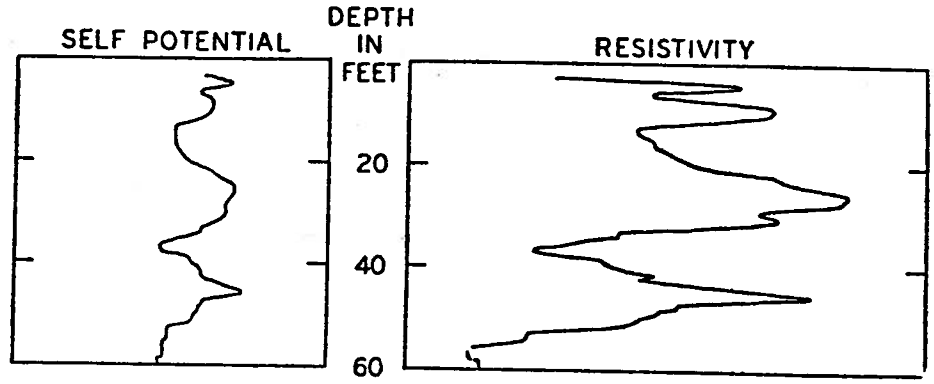

FIGURE 27. Electric log, Northern Alberta test hole No. 23, Grande Prairie.

Geology and Hydrology. The aquifer used by the city of Grande Prairie from 1963 to 1965 consists of an alluvial terrace of sand and gravel adjacent to the Wapiti River. It is located in Secs. 23 and 24, Tp. 70, R. 6, W. 6th Mer. (Fig. 26). The terrace is approximately 1 mile long and varies between 500 to 1,000 feet wide. The saturated thickness of the terrace ranges from 15 to 20 feet. The drill-hole logs in appendix A give the depths and thickness of sand and gravel at the well site. Figure 27 shows an electric log for the deepest test hole (Nothern Alberta test hole No. 23). Several other similar terraces are located upstream and downstream from this site, from which it was hoped additional water might be obtained by induced infiltration in the future.

The initial analysis of the pump-test data for the 1960 and 1961 tests indicated the hydraulic conductivity of the gravels to be high: over 3.0×10^3 igpd/ft^2 for the south terrace and about 2.4×10^3 igpd/ft^2 for the north terrace. Such values are characteristic of coarse clean sands or mixtures of coarse clean sands and gravels (Fig. 19). They were used in estimating the anticipated well yields of 150 to 200 igpm. In making the estimates, possible recharge from the river was neglected and it was felt that this would lead, therefore, to reasonably safe yield figures.

As remarked above, however, observations made during the production period and the results of the 23-day test early in 1965 definitely established that infiltration from the river was negligible. Not only was an anticipated safety factor thereby eliminated, but also a totally unexpected impermeable boundary was now found at the river's edge. The impermeable boundary at the north side of the terrace along the valley wall also exerted an effect and both boundaries combined to cause greater drawdowns that had been originally expected. Futhermore, the 1965 test results indicated that hydraulic conductivities were appreciably less than those calculated from the results of the 1960 and 1961 tests. No exact method of analysis was available, but various estimates based on approximate methodes suggested that the true hydraulic conductivity for the north terrace lay in the range 2.0 to 4.0 x 10^2 igpd/ft^2 (D. H. Lennox, pers. comm.). This value is more consistent with the actual physical appearance of the aquifer materials and would also help to contribute to the disappointing yields for the terrace wells.

As has been intimated, the existence of an impermeable rather than a permeable boundary at the river's edge was completely unexpected. Analysis of the 1965 test data, however, allowed no other conclusion, and re-examination of the exposed sands and gravels along the river bank during a period of low water supported this conclusion. The river has apparently deposited fine silts along its beds and banks and these have infiltrated the coarser gravels and sands, reducing their permeability. The barrier inflow of river water thus created is probably not completely impermeable but it provides a likely explanation for the lack of observable recharge from the river. The existence of such barrier to induced infiltration does not seem to have been reported in the literatur, although Hantush has rcently written a paper describing a method of analyzing test data for such a case (Hantush ,1965).

Distribution. In September 1963 there were 2,300 water-service connections which could be classified as follows: 9.6 per cent commercial; 0.5 per cent industrial, institutional; 83.5 per cent residential; 6.4 per cent other (municipal, schools, churches, etc.). Consumers are charged 11 cents per 100 gallons for the first 40,000 gallons. For consumption over this amount the rates become progessively lower at 10,000-gallon intervals. For the next four intervals up to 80,000 gallons, charges are 10, 9, 7 and 6 cents per 100 gallons. The minimum monthly charge per service is $3.30.

Table 18 lists the high and low monthly water consumption in Grande Prairie for the years 1960 to 1963 inclusive.

Recommendations and Conclusions. The existing data indicate that wells in the north terrace cannot supply present demands because water

Table 18. High and Low Monthly Water Consumption, Grande Prairie

Year	Monthly consumption (millions of gallons)	
	High	Low
1960	11.1	8.3
1961	13.9	8.7
1962	15.0	9.0
1963	18.2	10.2

cannot be induced to infiltrate into the terrace from the river. Other nearby alluvial terraces, however, might be suitable for induced-infiltration supplies and could warrant investigation at some future date. Susceptibility to flooding must, however, be considered. All of the nearby terraces are probably unsuitable from this point of view at the present time.

If the flow of the Wapiti River should be controlled upstream in the future, terrace sites may become more attractive. The history of the Grande Prairie terrace supply indicates, however, that extreme care should be used in the evaluation of terrace sites before any commitment to a groundwater-supply system.

The only other possible groundwater source for Grande Prairie is in the sandstones of the Wapiti Formation. Information about this formation is sparse and a deep test hole probing its potential could prove rewarding.

Grimshaw

The town of Grimshaw is located in Sec. 17, Tp. 83, R. 23, W. 5th Mer. The population, according to the Alberta Bureau of Statistics, was 169 in 1941, 287 in 1946, 546 in 1951, 904 in 1956, and 1,095 in 1961. It is estimated to be 1,200 in 1963.

Grimshaw is fortunate in having a natural spring, located in Sec. 29, Tp. 83, R. 23, W. 5th Mer., which up until the summer of 1963 flowed at approximately 55 igpm. This supply flows 2 miles into the town by gravity through a pipeline. The flow of the spring was increased to approximately 120 igpm in the summer of 1963 by installing perforated pipe into the gravel bed from which the natural spring flows.

The spring flows from an outcrop of buried sands and gravels that underlie a considerable area north of the spring site. No records have been kept on changes in spring flow, but in the summer of 1963 the Research Council of Alberta installed an automatic water-level recorder at the spring site. It appears that large quantities of groundwater could be developed in this area to provide water for future expansion of the town.

The water quality at Grimshaw is quite good, and no treatment is needed (Tables 13 and 14). The water is quite hard and makes excellent drinking water. Water storage is provided by a 72,000-gallon underground reservoir at the spring site, and by a 120,000-gallon elevated storage tank installed in the town in 1962.

During the summer of 1963 the approximate daily consumption average between 80,000 and 100,000 gallons. The town has approximately 300 services which are not metered. The charge to water users is a minimum of $3.50 per month.

It appears that the town of Grimshaw has a more adequate water supply of good quality to meet the requirements of the town's growth for the next few years. If additional water is required in the future, it can be fairly easily obtained through testing and development of the buried sands and gravels north of the spring site.

High Prairie

Location, Population, and Water Supply. The town of High Prairie is located in the central eastern portion of the map-area in Sec. 23, Tp. 74, R. 17, W. 5th Mer. According to the Alberta Bureau of Statistics the population was 643 in 1946, 1,143 in 1951, 1,743 in 1956, and 1,756 in 1961. Estimates of the 1963 population are slightly in excess of 2,000.

Until 1962 High Prairie obtained its water supply from two deep wells. The first well was drilled by Western Water Wells of Calgary in 1951. The second well was drilled by Lund Drilling of Peace River in 1955.

The reported depth of the 1951 well is 570 feet. This well is equipped with a pump capable of delivering 70 gpm from a depth of 60 to 65 feet. From the available records there appears to have been no screen set opposite the water-bearing formation.

The second well has a reported drilled depth of 588 feet. The bottom of the well was cemented back to 574 feet. A water-bearing sand zone 16 feet thick was reported to occur in the interval between 548 and 574 feet below ground level. This aquifer was screened with 0.020-inch slot-opening Cook water-well screen. The pump was installed with a setting of 65 feet and was capable of delivering 40 igpm.

Both wells have 5-inch outside-diameter water-well casing.

The initial nonpumping or static water level in the 1951 well was reported to be about 10 feet below ground level and in 1961 the nonpumping level of both wells was approximately 14 feet. This drop may indicate a 4-foot regional lowering of the piezometric surface of the aquifer in the period from 1951 to 1961.

Since the town required more water, the Research Council was approached in 1961 for advice on how to determine the actual capacities of the existing town wells and the nature of the aquifer. As the information on the existing wells was very meagre, and as no records of any previous pumping tests were available, it was recommend that a properly conducted pumping test be carried out. The test was carried out by Mr. A. Henderson, works foreman of the town of High Prairie, from November 21 to November 23, 1961. These records were then forwarded to Stanley, Grimble, Roblin Ltd., Edmonton, Counsulting engineers, who passed them on to the Research Council of Alberta for analysis. Analysis indicated that a large supply of water could be obtained from a properly constructed well. Subsequently, in the winter of 1962, a new well and water-treatment plant were installed. A lithologic log for this well is given in Appendix A and an electric log on figure 28.

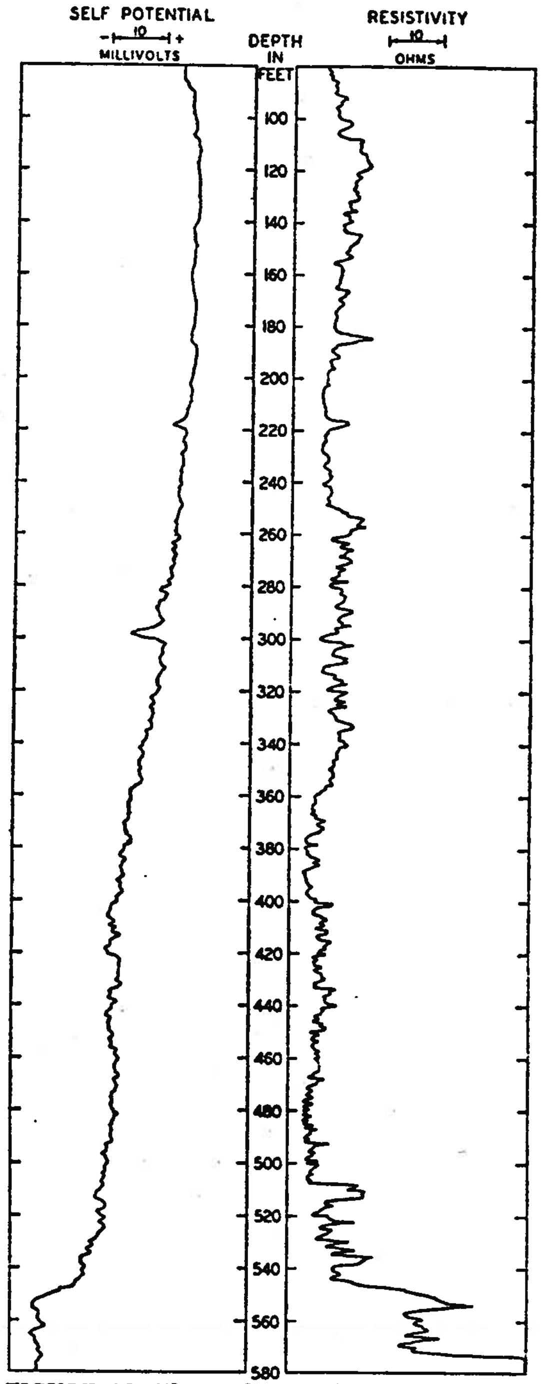

FIGURE 28. Electric log, High Prairie test hole.

The new well is 8 inches in diameter and contains 30 feet of 0.020-inch slot-opening well screen in the depth interval from 545 to 575 feet. The screen was selected on the basis of mechanical analyses of aquifer samples from the depth interval 540 to 580 feet obtained during the drilling of the new well.

The present pump capacity is 300 igpm but, with a larger pump installed, it would be possible to pump a maximum of 485 igpm through the present screen. If larger quantities were required it would be necessary to install a well screen of a larger diameter and length.

The pump capacity of 300 igpm is considerably more than the capacity of the new water works. Consequently it now pumps at about 200 igpm. The 1951 and 1955 wells remain on standby.

Geology and Hydrology. Very little information is available in the immediate vicinity of High Prairie on the subsurface geology of the aquifer from which the town derives its water. Examination of samples obtained from the 1962 well and from a deep test hole (Northern Alberta test hole No. 1) put down in the summer of 1963 by the Research Council of Alberta indicates that the aquifer probably consists of glacial-outwash sands in a deeply buried channel. The lithologic and electric logs of this hole are given in appendix B.

A gravity survey was carried out in 1962 and 1963 by the Research Council of Alberta to aid in the delineation of the High Prairie buried-channel aquifer. There is some indication that a trend of gravity low may be correlated with the trend of the buried channel but further test-drilling is required to substantiate this hypothesis (Lennox, 1963).

The nonpumping water levels in the wells were determined for a period of 12 hours prior to the start of the 1961 test. The nonpumping water levels were 15.0 feet for the pumping well and 14.8 feet for the observation well located 85 feet to the northeast. The test was run for a period of 48 hours commencing on Nov. 21 at 9.00 a.m. with the pump discharging at a constant rate of 65 igpm. An airline gauge was used to measure the water level in the pumping well at specified intervals throughout the test, and a chalked steel tape was used to measure the water level in the observation well. When the pumping test ceased recovery measurements were made on both wells for a period of 12 hours.

The nonequilibrium formula (Theis, 1935) and the modified nonequilibrium formula (Jacob, 1946) were used in determining the aquifer coefficients. The coefficient of transmissibility was found to be 9.8×10^3 igpd/ft and the coefficient of storage 6.6×10^{-4}. From the pumping-test data it appears that the aquifer is fairly large in area extent because no boundary effects were observed. Further test drilling will be necessary to determine its limits.

After the new well was constructed in 1962 an extended constant-rate pumping test was run from November 12 to November 13, 1962 for a period of 24 hours. In addition a step-drawdown pumping test was run on November 6, 1962 to determine the efficiency of the new well. This aquifer test was carried out by Stanley, Grimble, Roblin Ltd., Edmonton, consulting engineers. The calculated aquifer coefficients were substantially the same as those determined from the first test, the transmissibility and storage coefficient being 9.5×10^3 igpd/ft and 1.35×10^{-3} respectively. The results of the step-drawdown test indicated that flow in the vicinity of the production well was laminar at least up to flow rates of 241 igpm.

Estimated Safe Production. In estimating the safe yield for a 20-year period from a single well completed in the High Prairie aquifer the formation and well losses at the production well were calculated using equations (3) and (4) (p. ....), and the method suggested by Lennox (1966), it being assumed that the effective well radius is 1 foot and that

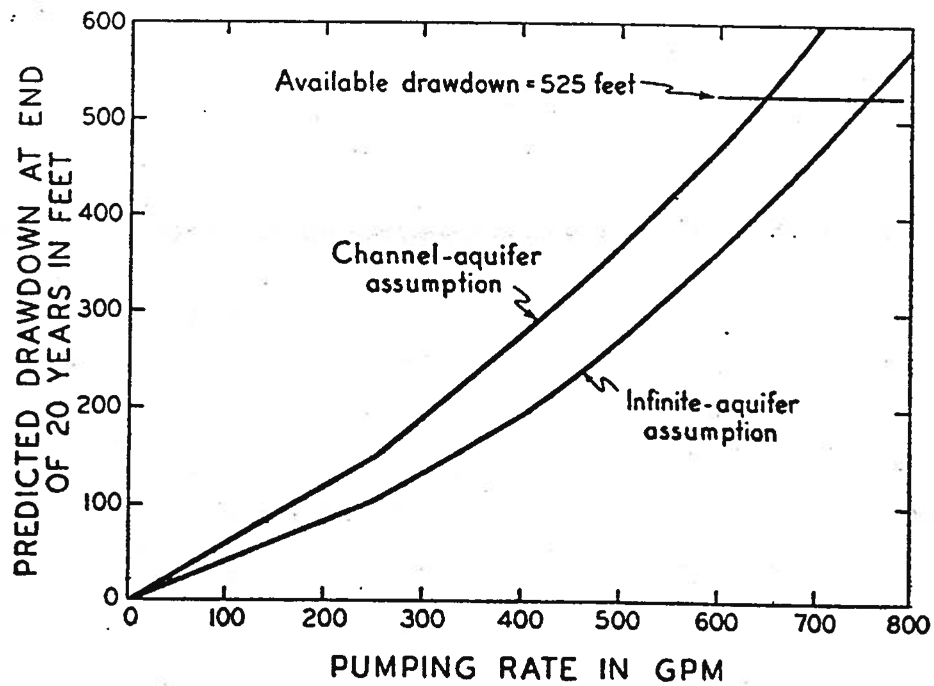

FIGURE 29. Twenty-year drawdowns, High Prairie aquifer.

the onset of turbulent flow is at 241 igpm. Because no boundary effects were observed during the two aquifer tests, although the aquifer is believed to be of the buried-channel type, two distinct safe-yield calculations were made: in the first it was assumed that the aquifer was of infinite extent; in the second that it was an infinite strip 8 miles in width with the producing well at the center of the channel. The infinite-strip solution was obtained by making use of a digital-computer program similar to that reported by Walton and Neill (1960). In both safe-yield calculations T was assumed to be 9.65×10^3 igpd/ft and S to be 1.00×10^{-3}. The results of the calculations are shown in figure 29.

On the assumption that there is 525 feet of available drawdown, the maximum safe 20-year pumping rate for the infinite-aquifer case is about 750 igpm and for the infinite-strip or buried-channel case it is about 640 igpm. Both rates are well in excess of High Prairie's requirements. Still higher long-term production rates could be achieved by going to multiple-well systems in which well losses could be reduced by increasing screen dimensions. The actual pumping capacity of the new High Prairie well is 300 igpm and there should be no serious depletion of the aquifer at this rate.

Treatment, Storage, and Distribution. The chemical analysis of the water is presented in tables 13 and 14. In general the quality of the water is much better than that normally expected for waters from this depth in most parts of the province; however the water does have to be treated. It is very high in iron, possesses high alkalinity, is somewhat discolored, and contains some dissolved gases.

In the new water-treatment plant the water is aerated and filtered through diatomaceous-earth filters to remove the dissolved gases and high iron content.

The water storage is provided by a 100,000-gallon underground reservoir.

High Prairie in 1963 had approximately 400 water services. The monthly charges to water consumers effective January 1, 1963 are: $4.00 for the first 2,000 gallons; $1.50 per thousand for the next 3,000 gallons; and $1.25 per thousand for consumption over 5,000 gallons. Most of the services are metered. For unmetered services the rate is a flat $4.00 per month.

According to information collected by Stanley, Grimble, Roblin Ltd. the average daily water consumption in 1960 amounted to 52,500 gallons with an estimated per capita consumption of 35 igpd. Table 19, prepared by Stanley, Grimble, Roblin Ltd., shows present and predicted future water consumption.

Table 19. Present and Predicted Water Consumption, High Prairie

Year	Population		Daily per capita consumption, connected population		Total peak daily consumption (gallons)	Required plant capacity, assuming 20-hour operation (igpm)
	Total	Connected to water distribution system	Average (gallons)	Peak; 1.5 x average (gallons)		
1960	2,185	1,500	35	52.5	79,000	66
1970	3,000	2,900	55	82.5	240,000	200
1980	4,000	3,900	60	90	351,000	292

Recommendations and Conclusions. High Prairie in fortunate in having a buried-channel aquifer from which a more than adequate water supply can be obtained. It is suggested that a further testing should be carried out to delineate the extent of the aquifer and its over-all yield. The results of these tests may encourage further industrial and agricultural development in the vicinity of High Prairie.

It is also recommended that the 1955 well with the 15 feet of well screen should be cleaned (possibly acidized), surged, and have a step-drawdown test run to determine whether it can be rehabilitated for use as a standby well. From existing data it appears that approximately 150 igpm could be pumped from it safely on a long-term basis if it were rehabilitated and a larger pump installed.

The 1951 well should be cleaned out and used as a permanent observation well with an automatic water-level recorder installed in it to measure continuously the water-level fluctuations in the aquifer. If rehabilitation attempts in the 1955 well fail, consideration should be given to the drilling of another standy well similar in construction and capacity to the new 1962 well for use in case of mechanical failure of the new well and to be put into production in the future as the water requirements of the community grow.

Hines Creek

The village of Hines Creek is located in Sec. 32, Tp. 83, R. 4, W. 6th Mer. and takes its name from the creek lying about 3 miles to the southeast. The population, according to the Alberta Bureau of Statistics, was 360 in 1956, and 398 in 1961.

The village of Hines Creek obtains its water supply from Jack Creek by direct pumping. The only treatment of the water is chlorination. The water distribution system was completed in 1958 and now has approximately 90 services.

During the summer of 1957 prior to the installation of the present surface-water supply, a detailed groundwater survey was carried out in the vicinity of Hines Creek. The survey included geological interpretation of aerial photographs, electrical resistivity and seismic surveys, and a water-well survey of the area. A test-drilling program was carried out in the fall of 1957 to verify the results of the above-mentioned investigations.

The investigation revealed that there were no suitable potential groundwater supplies in the surficial deposits in the immediate vicinity of Hines Creek. In the bedrock the water in the Dunvegan Formation sandstones is unsuitable for human consumption, being very high in sulfates and iron. Although two favorable areas for further groundwater exploration were found nearby, the village did not investigate them in 1957 as the cost of a drilling program, and particularly the cost of laying a pipeline if the drilling program were to prove successful, were prohibitive. Either or both of the areas might be investigated in detail if the water needs of the village should increase.

In Secs. 32 and 33, Tp. 83, R. 3, W. 6th Mer. there is a large Pleistocene sand and gravel terrace which appears to be part of a glacial meltwater channel. This location is approximately 7 miles east of the village. High-capacity wells might be drilled here. A shallow well exists in the sands and gravels of this terrace and is often used to supply water for local farmers. Before the present water system was installed in Hines Creek, water was hauled from here.

Approximately 3½ miles south of the village, in Secs. 7, 8, 16, 17, and 18, Tp. 83, R. 4 and Secs. 13, 14, and 15, Tp. 83, R. 5, W. 6th Mer. there is an area known locally as "Little Prairie" which is traversed by Hines Creek. Here a glacial-outwash plain composed of sands and gravels varying in thickness on the average between 20 and 50 feet is a potential aquifer. Farther to the south this outwash plain may have an even greater water-supply potential as sand and gravel thicknesses of up to 120 feet have been reported. Several springs are located along Hines Creek in this area with flows of from 2 to 3 igpm.

Hythe

The Village of Hythe is located in Sec. 13, Tp. 73, R. 11, W. 6th Mer. The population, according to the Alberta Bureau of Statistics, was 247 in 1941, 288 in 1946, 342 in 1951, 481 in 1956 and 449 in 1961.

Hythe has been aptly called the "village with the flowing wells", for the water supply is obtained from private wells, which commonly flow at rates between 1 and 5 igpm. The wells are completed in sandstones of the Wapiti Formation at depths of between 200 and 250 feet. There are approximately 80 wells in the village.

The water is soft and high in soda (Tables 13 and 14).

The sandstones of the Wapiti Formation are excellent aquifers in the vicinity of Hythe. No difficulty should be experienced in obtaining a suitable well to supply the community through a central distribution system if and when one is considered. Under the present system there is some possibility that local overdevelopment may reduce the pressure in the aquifer to the extent that some of the private wells may cease to flow. Such a reduction will necessitate the installation of pumping equipment in the existing wells.

La Glace

The unincorporated village of La Glace is located in Sec. 10, Tp. 74, R. 8, W. 6th Mer. The population, according to the Alberta Bureau of Statistics, was 120 in 1951, 119 in 1956, and 119 in 1961.

The hamlet has no central distribution system and water is obtained from individual household wells drilled into sandstones of the Wapiti Formation at depths ranging from 140 to 175 feet. These wells appear to be adequate and additional wells can be easily completed as required in the same sandstones. A chemical analysis of the water is shown in tables 13 and 14.

Manning

The town of Manning is located in Sec. 28, Tp. 91, R. 23, W. 5th Mer. The population, according to the Alberta Bureau of Statistics, was 726 in 1956, and 896 in 1961.

The town of Manning utilizes water from the Notikewin River to supply approximately 140 services. Chlorination is the only treatment applied at present. Groundwater possibilities are poor in the Shaftesbury Shales which form the underlying bedrock but nearby surficial deposits might bear investigation.

McLennan

The town of McLennan is located in Sec. 31, Tp. 77, R. 19, W. 5th Mer. The population, according to the Alberta Bureau of Statistics, was 1,074 in 1951, 1,092 in 1956, and 1,078 in 1961.

Groundwater possibilities in and near the town of McLennan are quite unfavorable as the town is underlain by Smoky River Shales. Two wells drilled prior to 1930 obtained water from the upper part of the underlying Dunvegan Formation at depths of over 650 feet (Rutherford, 1930). The log of one of these wells is given in appendix A. The water was soft and had a high total solids content, making it unsuitable for drinking.

The present supply is from Kimiwian Lake via a supply canal. Coagulation, filtration, and chlorination are the only treatments applied. The town has approximately 140 services.

Peace River

The town of Peace River is located below the confluence of the Smoky and Peace Rivers in Tp. 83, R. 21, W. 5th Mer. The population, according to the Alberta Bureau of Statistics, was 873 in 1941, 997 in 1946, 1,672 in 1951, 2,034 in 1956 and 2,543 in 1961.

The town of Peace River treats surface water obtained from the Peace River.

In the vicinity of the town are alluvial terraces consisting of sand and gravel which might provide large sources of water by induced infiltration from the Peace River. On the west side of the town, and at the Shaftesbury Settlement in particular, water is obtained by the residents from sand and gravel wells which have depths of up to 45 feet (pers. comm., Sven Lund, Sven Lund Drilling Co., Peace River). These large alluvial terraces extend up the Peace River in the area of the Shaftesbury Settlement for several miles. In addition, large alluvial terraces and islands are present below the town of Peace River (Map 28). Investigation of these alluvial terraces and islands is recommended to determine the possibilities of obtaining large supplies of water from wells by induced infiltration. If large supplies of uniform-quality water needing little treatment can be found, industry could possibly be encouraged to locate in the town of Peace River. The capital cost of large-capacity wells is considerably below that of equivalent-capacity surface-water treatment plants.

The bedrock strata of Peace River are unsuitable for obtaining large supplies of good-quality water.

Sexsmith

The village of Sexsmith is located in Sec. 25, Tp. 73, R. 6, W. 6th Mer. According to the Alberta Bureau of Statistics the population was 325 in 1941, 302 in 1946, 331 in 1951, 345 in 1956, 531 in 1961 and 542 in 1963.

Two wells furnish water to the village. One well was drilled in 1952 and the other in 1955. One well is drilled to a depth of 238 feet and the other to a depth of 137 feet. Both wells have turbine pumps installed in them which are capable of producing approximately 20 igpm each. Initially these wells experienced some trouble with sand, but they appear to be yielding water satisfactorily at the present time. They obtain water from sandstones in the Wapiti Formation. The water from the wells in Sexsmith is quite soft and is high in soda. (Tables 13 and 14).

Sexsmith has approximately 128 water services and has a 40,000-gallon water-storage tank. No information is available at present on daily water consumption. The rates charged to water consumers are $4.50 per month for the first 3,000 gallons and 10 cents per 100 gallons for amounts in excess of 3,000 gallons.

The present water supply from wells appears to be adequate for Sexsmith. If additional water is required, the present wells should first be evaluated to determine their hydrologic characteristics and to ascertain whether it would be possible to obtain the necessary quantities of water by installing pumps with larger capacities. If the only solution to the problem should be the construction of additional wells, adequate testing and evaluation of the aquifers should be carried out for the determination of safe pumping rates and prediction of long-term yields. All new test holes or wells should be carefully sampled and electrologged.

Spirit River

The town of Spirit River is located in Sec. 27, Tp. 78, R. 6, W. 6th Mer. The population, as given by the Alberta Bureau of Statistics, was 553 in 1951, 743 in 1956, and 890 in 1961.

Groundwater possibilities in and near the town of Spirit River are quite unfavorable. Smoky River Shales are the underlying bedrock and drift cover is thin. Water from the Dunvegan Formation has been obtained at depths of 950 to 1,000 feet but is high in total solids and in soda and unsuitable for domestic supplies.

Water from the Spirit River is utilized at present to supply approximately 180 services.

Valleyview

The town of Valleyview is located in Sec. 15, Tp. 70, R. 22, W. 5th Mer. The population, according to the Alberta Bureau of Statistics, was 973 in 1956 and 1,077 in 1961.

The town of Valleyview obtains its water supply from Sturgeon Creek located north of the town. Some difficulty has been experienced because the creek is susceptible to freezing under low-flow conditions. Prior to the installation of the surface-water plant, residents obtained water from wells finished in sandstones or coal beds of the Wapiti Formation. Yields of the wells were 3 to 10 igpm and were adequate for private supplies. It was judged, however, that these aquifers would not provide a sufficient supply for the town.

Some bedrock sandstones in the Wapiti Formation are thought to have a fairly good groundwater potential; a well drilled for the Canadian Utilities Ltd. power plant 9 miles south of Valleyview near the Little Smoky River flowed at 150 igpm when first developed. It is evident that the sandstones of the Wapiti Formation in this area should be thoroughly tested, at least to a depth of 600 feet. Some of the Wapiti sandstones in the area are 20 to 40 feet thick, as indicated from electric logs run on oil-company boreholes. The cause of low yields of the bedrock wells in the area in the past has been poor methods of completion and development.

The alluvial terraces adjacent to the Little Smoky River 2 miles southeast of the town are also promising sites for groundwater exploration. Large wells might be developed in the alluvial sands and gravels to obtain water by induced infiltration from the Little Smoky River. A thorough exploration and development program would be necessary to ascertain the potential of these deposits.

Wembley

The village of Wembley is located in Sec. 21, Tp. 71, R. 8, W. 6th Mer. The population, according to the Alberta Bureau of Statistics, was 188 in 1941, 237 in 1946, 251 in 1951, 272 in 1956 and 303 in 1961.

The village of Wembley obtained a water-distribution and sewer system in 1957. Water is obtained from a well drilled in 1957 by Michele Drilling and Exploration Co. Ltd., Edmonton. The well log is given in appendix A.

This well is completed in a thick sandstone bed of the Wapiti Formation in the 105- to 136-foot interval. The well when drilled was pumped at 10 igpm and little apparent drawdown was noted. The well is now pumped at between 8 and 10 igpm and no trouble has been experienced with the supply.

The water is fairly soft and high in soda (Tables 13 and 14) and is not treated. Storage is provided by an elevated 40,000-gallon storage tank.

In 1958 Wembley had an average daily water consumption of about 5,000 gallons, with approximately 50 services. In 1962 the number of services had increased to 70. Estimated 1962 water consumption is approximately 7,000 to 8,000 igpd.

It appears that Wembley has an adequate supply of suitable water at the present, as the Wapiti Formation in this area is known to be capable of producing large amounts of groundwater (up to 60 igpm). As future need arises the well in Wembley should be evaluated as to its actual long-term safe yield by means of a constant-rate and a step-drawdown pumping test.

Whitelaw

The unincorporated village of Whitelaw is located in Sec. 15, Tp. 82, R. 1, W. 6th Mer. The population, according to the Alberta Bureau of Statistics, was 153 in 1951, 212 in 1956, and 264 in 1961.

There are several private wells in the village which obtain water from buried sands and gravels at depths of between 50 and 70 feet. A log for one of these wells is given in appendix A. There is no central water-distribution system at the present time. Some water is hauled from a spring located 2 miles south and 1 mile east of the community.

The well water is fairly hard and contains some iron. An analysis of the spring water is given in Tables 13 and 14.

If the village of Whitelaw should consider installing a municipal water system in the future, there should be no difficulty in obtaining a water supply from buried sands and gravels either in the village or nearby. Consideration should be given to the proper testing and development of the buried aquifer as it is possible that a water well with a fairly high yield could be obtained. The sands and gravels at Whitelaw are probably similar to those from which Fairview, Berwyn, and Grimshaw obtain water supplies.

Woking

The unincorporated village of Woking is located in Sec. 19, Tp. 76, R. 5, W. 6th Mer. The population, according to the Alberta Bureau of Statistics, was 87 in 1951, 113 in 1956, and 157 in 1961.

The village of Woking has two private wells which obtain water from sandstones in the Wapiti Formation. Detailed logs are not available for these wells. A 4-inch diameter well was drilled to a depth of 180 feet at the hotel. The nonpumping water level was approximately 40 feet below ground level. The well is pumped at a rate of approximately 6 igpm, and the supply appears to be adequate.

Another well was drilled at the general store but no information is available on it.

As the Wapiti Formation dips southward from Woking, suitable water-bearing zones are liable to be encountered in this direction. Any further drilling should be carried out to the southward as the Wapiti Formation thickens in this direction.

RECOMMENDATIONS AND CONCLUSIONS

Considerable scope exists for further exploration and development of groundwater in the Peace River district. In this report emphasis has been directed toward outlining the broad geological and groundwater aspects of the various aquifers. In addition, it is hoped that some guidance has been given to the many municipalities in the district concerning the finding of groundwater. Further studies will, of necessity, have to be of a more local and detailed nature.

As has been pointed out in the text, considerable potential exists for obtaining groundwater supplies from buried-channel aquifers. It is, therefore, recommended that further detailed work outlining the nature and extent—both geologic and hydrologic—of these channels be undertaken, particularly in the vicinity of High Prairie and the Fairview-Grimshaw area.

Test drilling into bedrock aquifers, such as the Dunvegan and Peace River Formations north of the Peace River, should be continued—particularly in the new areas where land is being opened for agricultural settlement. Detailed studies on deeper aquifers such as the Cardium and Peace River Formations would also be of value, especially to the petroleum industry, if large amounts of water should be required for pressure maintenance in oil reservoirs. In addition, as research into the demineralization of brackish and saline waters progresses and economic treatment processes are found, some of these formation waters could possibly be used for future municipal and industrial supplies.

The investigation of suitable exploration, testing, and development procedures for water supplies obtained by induced infiltration from nearby surface-water bodies should be pursued further. There is a marked lack of satisfactory methods and considerable scope exists, particularly along the Peace River, for studies in this field.

Water-budget studies should be carried out to find out the amount of precipitation that is available for groundwater recharge in the district. Quantitative studies such as these are invaluable in calculating the safe yields of aquifers and well systems. The basic-data observation-well network, a very important adjunct to water-budget studies, should be expanded.

With respect to geological aspects, attention should be focussed on the many, still unresolved stratigraphic problems in bedrock and surficial deposits in the Peace River district. Further work along these lines should prove fruitful and enlightening, particularly with respect to the Dunvegan-Kaskapau complex, the distribution and significance of the Bad Heart Formation, and elucidation of the late Tertiary and Pleistocene history of the region.

Educational and information programs, although not previously mentioned in this study, should be carried out to outline the basic requirements of good practice in development and construction of individual, municipal, and industrial groundwater supplies. This will help avoid many of the well problems that exist now and that have existed in the past, in no small measure due to lack of technology.

In conclusion, it should be recalled that groundwater is just one part of the hydrologic cycle. A better understanding of groundwater in the Peace River district will be furthered by any increase in knowledge of the other segments of the cycle. Knowledge of the surface-water phase, in particular, could lead to the integrated, and thus more efficient, utilization of both groundwater and surface-water supplies. Any groundwater study, whether applied or a basic research program, should be directed toward the production and utilization of water for the greatest common good.

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APPENDIX A. WELL AND TEST-HOLE AND WELL-CONSTRUCTION DETAILS

Beaverlodge

Oszust well (No. 1 town well)
Driller: Western Water Wells Ltd., Calgary
Nonpumping water level: 72 feet
Location: Sec. 2, Tp. 72, R. 10, W. 6th Mer.
Date: October 26, 1954

Depth (feet)	Description
0- 74	Glacial clay with boulders
74- 98	Sand and sandy clay with a little water
98-125	Soft sandy clay
125-135	Sand, some water
135-140	Coarse gravel, some sand, water-bearing
140-142	Glacial clay
142-145	Hard bed of clay
145-150	Glacial clay

Depth (feet)	Completion details
0-116	10-inch I.D. casing
0-138	8-inch I.D. casing
129-150	7-inch I.D. casing
135-140	Screened with eighty 12x¼" slots in 7-inch O.D. screen. Reda submersible pump.

Howey well (No. 2 town well)
Driller: Western Water Wells Ltd., Calgary
Nonpumping water level: 79 feet
Location: Sec. 2, Tp. 72, R. 10, W. 6th Mer.
Date: June, 1951

Depth (feet)	Description
0- 43	Boulder clay
43- 80	Wet yellow sand
80- 90	Yellow sand, clay
90-127	Boulder clay
127-139	Dirty fine sand, some water
139-145	Glacial clay
145-156	Sand and gravel
156-232	Glacial clay, with water-bearing sandy lenses

Depth (feet)	Completion details
0 -103.4	10-inch I.D. casing
100.6-161	8-inch I.D. casing
128 -232	6¼-inch I.D. casing perforated.

Fairview

Town test hole No. 17
Driller: Hi-Rate Drilling, Stettler
Location: Lsd. 3, Sec. 27, Tp. 82, R. 2, W. 6th Mer.
Date: 1961

Depth (feet)	Description
0- 30	Clay and boulders
30- 48	Sand and gravel
48- 50	Clay
50- 60	Shale

Town test hole No. 18
Driller: Hi-Rate Drilling, Stettler

Location: Lsd. 1, Sec. 28, Tp. 82, R. 2, W. 6th Mer.
Date: 1961

Depth (feet)	Description
0- 45	Clay and boulders
45- 90	Shale

Town test hole No. 19
(observation well)
Driller: Hi-Rate Drilling, Stettler

Location: Lsd. 1, Sec. 27, Tp. 82, R. 2, W. 6th Mer.
Date: 1961

Depth (feet)	Description
0- 28	Clay and boulders
28- 62	Sand and gravel
62- 70	Shale

Town test hole No. 20
(pumping well)
Driller: Hi-Rate Drilling, Stettler
Nonpumping water level: 6.6 ft. below casing top

Location: Lsd. 1, Sec. 27, Tp. 82, R. 2, W. 6th Mer.
Date: December 12, 1961

Depth (feet)	Description
0- 28	Brown clay and rocks
28- 58	Sand and gravel
58- 62	Gravel
62	Shale

Depth (feet)	Completion details
0- 52	8⅝-inch O.D. casing
52- 62	Screened with stainless steel sand screen 10 feet long, 8 inches in diameter with No. 100 slot openings. Developed to sand-free condition by use of surge blocks, jetting tools, and air compressors.

Town test hole No. 21
(observation well)
Driller: Hi-Rate Drilling, Stettler

Location: Lsd. 1, Sec. 27, Tp. 82, R. 2, W. 6th Mer.
Date: 1961

Depth (feet)	Description
0- 28	Clay and boulders
28- 58	Sand and gravel
58	Shale

Town test hole No. 22
(observation well)
Driller: Hi-Rate Drilling, Stettler

Location: Lsd. 1, Sec. 27, Tp. 82, R. 2, W. 6th Mer.
Date: 1961

Depth (feet)	Description
0- 27	Clay and boulders
27- 56	Sand and gravel
56- 60	Clay
60	Shale

Grande Prairie

Research Council of Alberta test hole No. 1, Grovedale Bridge
Driller: Independent Drilling & Exploration Co. Ltd., Edmonton
Nonpumping water level: 14 feet

Location: Sec. 23, Tp. 70, R. 6, W. 6th Mer.
Date: August, 1960

Depth (feet)	Description
0 - 8.5	Silt, sand, minor clay
8.5-26	Coarse gravel, minor sand
26 -29	Coarse to medium gravel
29 -36	Grey shale (Wapiti Formation)

Test pumping well (capped)
Driller: Becker Drilling, Calgary
Nonpumping water level: 16.17 feet

Location: Sec. 23, Tp. 70, R. 6, W. 6th Mer.
Date: September, 1961

Depth (feet)	Description
0 -17	Sand, silt, and clay
17 -33.5	Sand and gravel
33.5-39	Sandy shale (Wapiti Formation)

Depth (feet)	Completion details
0- 29	8-inch O.D. casing
29- 39	Screened with No. 100 slot stainless steel screen.

Observation well 50 feet south of test pumping well
Driller: Becker Drilling, Calgary
Nonpumping water level: 15.52 feet

Location: Sec. 23, Tp. 70, R. 6, W. 6th Mer.
Date: September, 1961

Depth (feet)	Description
0 -17	Sand, silt, and clay
17 -33.5	Sand and gravel
33.5-43	Silty sand
43	Shale (Wapiti Formation)

Depth (feet)	Completion details
0- 43	2⅜-inch O.D. pipe
23- 43	Perforated. Developed with air.

Observation well 100 feet north of test pumping well
Driller: Becker Drilling, Calgary
Nonpumping water level: 15.63 feet

Location: Sec. 23, Tp. 70, R. 6, W. 6th Mer.
Date: September, 1961

Depth (feet)	Description
0- 17	Sand, silt, and clay
17-34	Sand and gravel
34	Shale (Wapiti Formation)

Depth (feet)	Completion details
0- 34	2⅞-inch O.D. pipe
14- 34	Perforated.
	Developed with air.

Observation well 100 feet west of test pumping well
Driller: Becker Drilling, Calgary
Nonpumping water level: 16.67 feet

Location: Sec. 23, Tp. 70, R. 6, W. 6th Mer.
Date: September, 1961

Depth (feet)	Description
0- 17	Sand, silt and clay
17- 33	Sand and gravel
33- 35	Shale (Wapiti Formation)

Depth (feet)	Completion details
0- 35	2⅞-inch O.D. pipe
15- 35	Perforated.
	Developed with air.

Observation well 100 feet east of test pumping well
Driller: Becker Drilling, Calgary
Nonpumping water level: 15.74 feet

Location: Sec. 23, Tp. 70, R. 6, W. 6th Mer.
Date: September, 1961

Depth (feet)	Description
0- 15	Sand, silt, and clay
15- 33	Sand and gravel
33- 35	Sand
35	Shale (Wapiti Formation)

Depth (feet)	Completion details
0- 35	2⅞-inch O.D. pipe
15- 35	Perforated.
	Developed with air.

Observation well 500 feet east of test pumping well
Driller: Becker Drilling, Calgary
Nonpumping water level: 13.16 feet

Location: Sec. 23, Tp. 70, R. 6, W. 6th Mer.
Date: September 1961

Depth (feet)	Description
0- 15	Sand, silt, and clay
15- 33	Sand and gravel
33- 34	Silty clay

Depth (feet)	Completion details
0- 34	2⅞-inch O.D. pipe
14- 34	Perforated.
	Developed with air.

Northern Alberta test hole No. 23, 400 feet east of test pumping well, equipped with permanent recorder
Driller: Hi-Rate Drilling, Stettler
Nonpumping water level: 16 feet

Location: Sec. 23, Tp. 70, R. 6, W. 6th Mer.
Date: September, 1963

Depth (feet)	Description
0- 8	Sand
8- 27	Gravel
27- 35	Sand and very fine gravel
35	Clay
35- 37	Sand and very fine gravel
37- 42	Sand
42- 47	Gravel and sand
47- 55	Light grey sandy shale
55- 60	Medium grey shale

High Prairie

Town well
Driller: Coralta Drilling, Edmonton
Nonpumping water level: 20 feet

Location: Lsd. 16, Sec. 23, Tp. 74, R. 17, W. 5th Mer.
Date: February, 1962

Depth (feet)	Description
0-508	Hard clay
508-514	Silty clay
514-545	Soft clay
545-572	Loose sand
572-580	Consolidated sand
580-582	Loose sand
582-584	Gravel

Depth (feet)	Completion details
0- 50	12-inch O.D. casing
0-545	10-inch O.D. casing
545-575	Screened with Johnson Everdur telescoping screen with No. 20 slot.

McLennan

Northern Alberta Railway well
Driller: Unknown
(Well log is very poor due to contamination of samples)

Location: N.W. Lsd. 13, Sec. 28, Tp. 77, R. 19, W. 5th Mer.
Date: March, 1944

Depth (feet)	Completion details
0-207	10-inch O.D. casing
0-604	8-inch O.D. casing

Depth (feet)	Description
0-140	No samples
140-160	Glacial material: quartz, feldspar, granite, silty limestone, pyrite
160-170	Silt and sand with pyrite, silty limestone, columnar calcite (possibly gypsum)
170-180	Ditto, with coal, grey shaly fragments, glacial material
190-200	Quartz sand, silt, columnar calcite
210-220	Silt, silty limestone, shale?
220-230	Quartz sand with dark grey silty limestone, coal, columnar calcite, pyrite, burnt shale, pyritized stems?
230-270	As above, but siltier, and with occasional granite pebbles, cinders 260-270
270-280	Fine salt-and-pepper sand
280-290	Fine sand, pyrite, limestone chips
290-300	Sand, shale, quartzite, coal, burnt shale
300-310	Fine silty sand

320-330	Silty sand, pyrite, shale chips, quartzitic sand
340-350	Micaceous sand, cinders, burnt shale
350-360	Silty sand
360-370	Silty sand, burnt shale
370-390	Ditto, with coal and cinder
400-410	Silty sand, cinder, coal, burnt shale, etc.
430-440	Silt
440-460	Top of bedrock in this interval; recent deposits above
460-480	Shale flakes, dark grey, with silt
480-490	Shale, coal, silt, burnt shale
490-520	Silt and shale
520-530	Shale, silt, burnt shale, columnar calcite
530-540	Shale and silt, fish-scale fragment in shale?
560-570	Shale, sand, silt, burnt shale
580-590	Shale, columnar calcite
600-615	Quartz sand, pyrite, coal, columnar calcite, mica cavings; some cinders, shale and silt at 609, less sand at 615, and much shale at 615
615-620	Shale and silt
620-650	Burnt shale, siltstone, pyrite, iron wire, etc., cavings

Wembley

Village well
Driller: Michele Drilling, Edmonton

Location: Sec. 21, Tp. 71, R. 8, W. 6th Mer.
Date: 1957

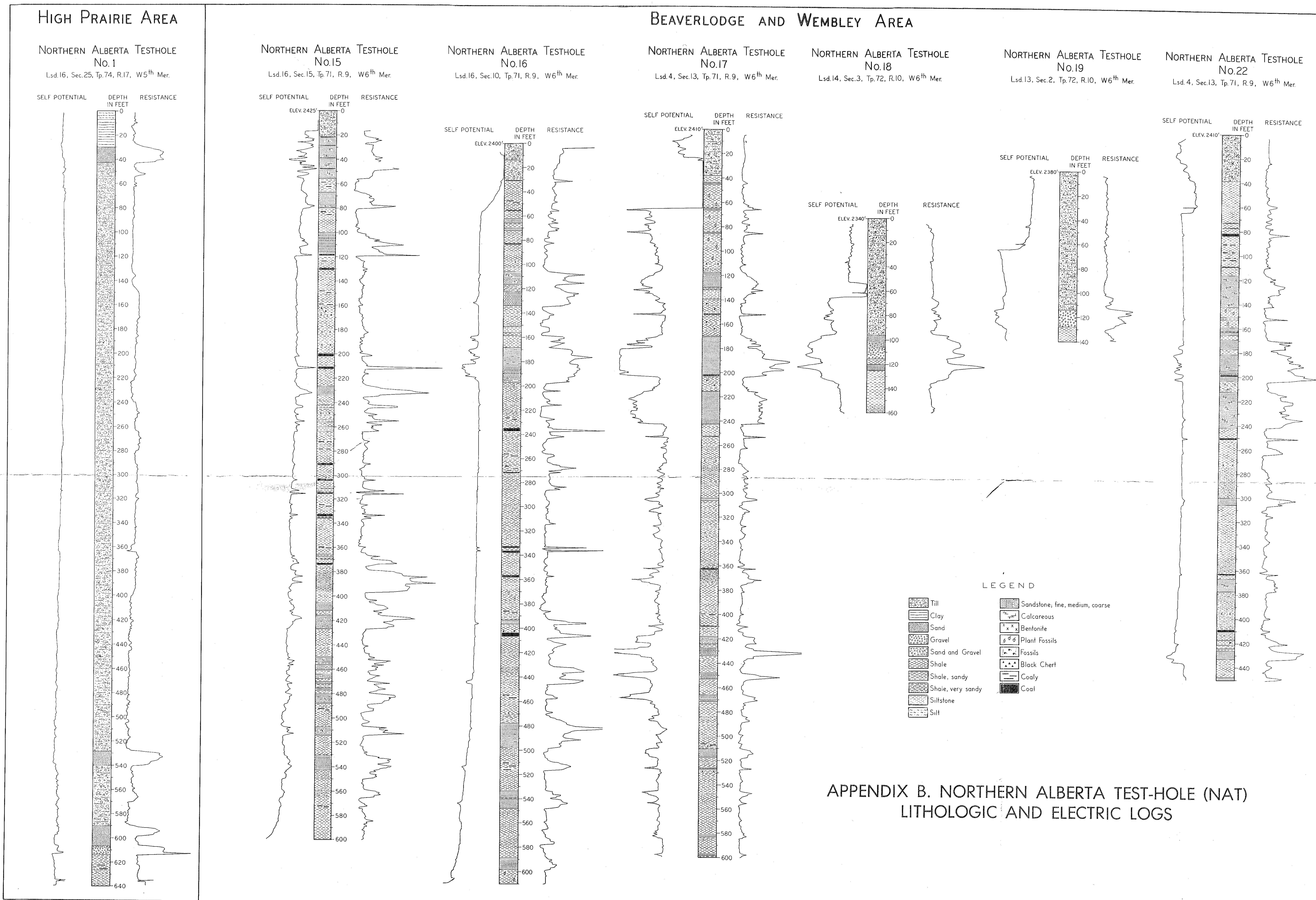
Depth (feet)	Description
0- 47	Clay
47- 55	Sand and coarse gravel
55- 65	Sandy blue clay
65- 77	Blue grey shale
77- 78	Sandstone
78- 85	Blue grey shale
85- 88	Coal
88- 90	Blue shale
90-105	White shale
105-136	Sandstone (water-bearing)
136-145	Blue grey shale

Whitelaw

Village well

Location: Sec. 15, Tp. 82, R. 1, W. 6th Mer.

Depth (feet)	Description
0 -18	Clay
18 -38	Gravel
38 -40	Grey shale (clay)
40 -46	Clean sand
46 -46.5	Grey shale (clay)
46.5-69	Sand



APPENDIX B. NORTHERN ALBERTA TEST-HOLE (NAT) LITHOLOGIC AND ELECTRIC LOGS

To accompany Research Council of Alberta Bulletin 16,
by J. F. Jones

APPENDIX C. SUGGESTED MINIMUM SPECIFICATIONS FOR WATER WELLS FOR DOMESTIC AND STOCK USE*

Scope of Work

All the work to be done hereunder includes the furnishing of all labor, material, transportation, tool supplies, plant equipment, etc., necessary for the complete and satisfactory construction, sampling and testing of the proposed water wells as further described and at the locations shown on the tender form.

Qualifications

(a) The Contractor must be licensed to drill water wells in Alberta and be active and experienced in water-well drilling.

(b) He shall comply with all federal, provincial or local laws, ordinances or rules and regulations relating to the performance of his work.

Local Conditions

At each water-well site the Contractor must be prepared to drill through formations of clay, silt, sand, gravel, shale, sandstone, limestone, and boulders in accordance with the conditions encountered at each particular site.

The Contractor must carry the necessary materials and equipment including drilling-fluid additive to cope with caving-hole and lost-circulation conditions.

The Contractor must be prepared to seal off or control holes that encounter artesian flow.

The Contractor should try to obtain the necessary information regarding the nature of the strata at each well site at which he is going to construct a well before submitting a bid. Some general information may be obtained from the Groundwater Division, Research Council of Alberta, Edmonton.

Protection of the Site

Excepting as otherwise provided herein, the Contractor shall protect all structures, trees, shrubbery, lawns, fences, etc., during the progress of his work; shall remove from the sites all cuttings, drillings, debris, and unused material; and shall upon completion of the work fill in all pits and restore as nearly as possible the original conditions of the site.

*These specifications are based, in part, on the American Water Works Association Standard for Deep Wells (AWWA A100-58).

Water pumped from any well during the construction and development of the well shall be conducted to a place where it will be possible to dispose of the water without damage to property or creation of a nuisance.

General Description of the Water Wells

Drilling

The Contractor must be prepared to drill a hole of sufficient size to accommodate a 4⅛-inch internal-diameter casing and to be able to cement grout the casing in place. The Contractor at all times will complete the well in the first suitable water-bearing material.

All wells shall be constructed plumb such that all formation intervals and sample depths, where applicable, shall represent true vertical distances.

The client reserves the right to require the Contractor to discontinue drilling if, in the opinion of the client, water cannot be obtained at a reasonable depth.

In the case of a dry hole, the client will only pay for the depth drilled and the cost of mobilization to and from the site in accordance with the bid price.

Casing

The casing installed in the well shall be new black insert-joint water-well casing 4⅛-inch internal diameter and 4½-inch external diameter.

The casing shall be installed to the top of the water-bearing formation and shall be cement grouted back to the ground surface.

The casing shall project a minimum of one foot above ground level to allow for a concrete pad to be installed around the well.

Well Development

The Contractor shall furnish all necessary pumps, surge plunger, bailers, jetting tools, or other needed equipment and shall develop each water-bearing formation by such approved methods as shall be necessary to give the maximum yield of water per foot of drawdown and extract from the formation the maximum practical quantity of sand and other material so that when the well is pumped at its maximum rate the water obtained from the well will be sand-free and clear. This development procedure also applies when well screens are installed.

Well Screens and Water-Bearing Formation Samples

In the case where the Contractor finds it necessary to use a well screen to develop water from a water formation, the Contractor shall obtain a suitably sized representative sample of the material and submit it to a recognized and competent authority to have the particle sizes of the material determined in order to determine properly the correct slot opening of the well screen. The driller must submit a copy of the analysis of the water-bearing formation material where a screen is installed to the client in order to receive payment for the well screen.

The driller shall in all cases install the well screen by standard approved methods, in casing that has been grouted to the top of the water-bearing formation and the full length of the screen shall be exposed to the water-bearing formation.

In all cases, where screens are required, they will be of suitable length to obtain the required amount of water and 3¾ inches in external diameter. The driller will quote on the tender form provided for the type of well screen, the necessary fittings, etc., to install it.

Materials for Pump Installations, etc.

The Contractor is to supply all materials required for the construction of the completed well, such as casing, pumps and fittings, cement, etc. All materials used in the construction of the well must be new.

Pumps

The Contractor shall be prepared to furnish and install a suitable pump to produce the required amount of water under the existing conditions. The pump may be either a deep or shallow well jet, or a submersible, turbine, or reciprocating (jack or piston type) pump, whichever best suits the situation.

Pumping Test

After the pump is installed, a 24-hour pumping test shall be run on the completed water well at the maximum possible pumping rate.

Drawdown measurements shall be made and recorded in the following manner:

(1) Determine the static or nonpumping water levels immediately before the test starts.

(2) Start the pump, recording the exact time of starting. This time is the zero time, $t=0$, and all later times are referred to it. Measure the depth to the water, recording the exact time that each measurement is taken.

Measurements should be spaced in the following manner:

(a) about every minute from 1 to 10 minutes; an initial 30-second reading is desirable, if it can be obtained

(b) every 5 minutes from 10 to 30 minutes

(c) every 10 minutes from 30 minutes to 1 hour

(d) every 15 minutes from 1 hour to 2 hours

(e) every 30 minutes from 2 to 6 hours

(f) every hour until the end of the test.

Maintaining a Constant Discharge Rate during Pumping Tests

During the pumping test the pumping rate should be maintained as constant as possible and variations should not be allowed to exceed 5 per cent of the average rate.

Recovery Test

After the pump is shut off after the pumping test has been conducted, water-level recovery measurements are taken immediately to determine the rate of recovery, following the same procedure as outlined above in obtaining the drawdown measurements. These water-level measurements are continued until the original nonpumping or static water level is approached. This is particularly important if the pumping rate has varied excessively during the course of the test, as the average pumping rate can then be used with these recovery data.

The measurements shall be recorded on the back of all copies of the water-well log form supplied to all licensed drillers by the Water Resources Branch, Department of Agriculture.

Disinfection

The Contractor shall disinfect the well and install pumping equipment according to good practice upon completion of the project.

Well Logs

A copy of the water well log shall be submitted to the client upon completion of the well construction.

Equipment

The Contractor shall supply a list of the equipment to be used showing make, model, and year when submitting a tender for water-well drilling.

Guarantee

The Contractor shall make good any defects which become apparent within one year from the date of completion of the work, provided that such defects are due to either (1) poor or improper workmanship, or (2) improper or defective materials.

APPENDIX D. INVITATION TO TENDER FOR WATER WELLS

TENDERS, duly signed and sealed, will be received at the office of ______________________________ Alberta, not later than 11:00 A.M.__________ the __________ day of __________ 19______, for the due performance and final completion of the following work:

The drilling, developing, testing and completion of water wells in the following locations in accordance with the attached Specifications:

TENDERS shall be completed on the enclosed form and are to be signed, sealed, and submitted in the enclosed envelope marked with the project and time of opening as well as the name of the individual or firm submitting the tender.

The envelope must be sealed and placed in the larger envelope addressed to the ______________________________, Alberta. The successful bidder must be prepared to commence work on or before the __________ day of __________ 19______, and complete the work on or before the __________ day of __________ 19______.

The successful bidder may be required to furnish a surety bond in the amount of 100 per cent of the total sum tendered for the work as a guarantee of the performance of the work and for the payment of all material and labour. In the event that no performance bond is required, the ______________________ may retain 10 per cent of the amount of the tender until completion of the work and final acceptance of the same.

The Contractor shall not sublet, assign, or sell any portion of the Contract, or the work provided therein, without the written consent of ______________________________. Requests for permission to sublet, assign, or otherwise dispose of any portion of this Contract shall be in writing accompanied by a surety bond for 100 per cent of the amount of work to be assigned, sublet, or otherwise disposed of. No such subletting, selling, or assignment, even though duly consented to, shall exonerate the Contractor from liability under this Contract. The Contractor shall be responsible for all acts, defaults, neglects, and delays of any subcontractor and subcontractors, assignee and assignees, their and every one of their servants, agents, and employees to the same extent as if no assignment or subcontract had been made or entered into.

Prior to final payment being made, the successful bidder shall furnish a form provided by the ______________________________, a statutory declaration declaring that all outstanding claims have been discharged, including a release from The Workmen's Compensation Board.

The lowest or any tender will not necessarily be accepted.

APPENDIX E. TENDER FOR WATER WELLS

To the

____

The undersigned hereby tenders and agrees to execute and construct all the work of every description required in the construction and final completion of the following work:

> The drilling, developing, test, and completion of water well(s) in the following locations in accordance with the Specifications attached to the Invitation to Tender:

Bid Prices for Each Well

Item	Description		Bid Price
1	Moving to and from water-well locations	(lump sum)	________
2	Drilling—diameter suitable for 4⅛" internal-diameter casing	(per vertical foot)	________
3	Supplying, installing, and cement grouting 4⅛" internal-diameter black insert-joint new water-well casing	(per lineal foot)	________
4	Bailing and well development	(per hour)	________
5	Supplying and installing a suitable drop pipe and couplings	(per lineal foot)	________
6	Supplying and installing a suitable pump	(lump sum)	________
7	Pumping test	(lump sum)	________
8	Screens if required—Supplying and installing well screen and fittings 4 feet in length and 3¾-inches external diameter suitable for 4⅛-inch internal-diameter water-well casing. Slot openings to be continuous and slot-opening size to be determined from analysis of water-bearing material	(lump sum)	________
	4-inch Everdur metal screen and fittings	(lump sum)	________
	or		
	4-inch stainless steel screen and fittings	(lump sum)	________

Should this tender be accepted, the undersigned agrees to commence work on or before __________ the __________ day of __________ 19____, and complete the work on or before ______________ the ____________ day of ____________ 19____.

Upon acceptance of this tender, and if the ________________ requires, the undersigned agrees to furnish a surety bond in the amount of 100 per cent of the total sum tendered for the work as a guarantee for the performance of the work, and for the payment of all material and labour. The undersigned further agrees that if no performance bond is required, the ______________________ may retain 10 per cent of the amount of the tender until completion of the work and final acceptance of the same. The undersigned further agrees to indemnify and save harmless the ______________________ and the employees of the ________________ from and against all claims and demands, loss, costs, damages, actions, suits, or other proceedings by whomsoever made, brought, or prosecuted in any manner based upon, occasioned by, attributed to any such damages, injury, or infringement. The successful bidder shall furnish and maintain a policy of insurance in a form approved by the ____________________ in a minimum amount of $200,000.00, insuring the successful bidder against all claims, demands, loss, costs, damages, or actions arising out of the performance of this tender.

Upon acceptance of this tender, and notification of such acceptance to the undersigned, this tender document together with the invitation to tender shall constitute a written agreement between the undersigned and the ____________________ and shall be irrevocable by either party.

The lowest or any tender will not necessarily be accepted .

______________________	______________________
Witness	Contractor
	______________________
	Address
	______________________
	Date

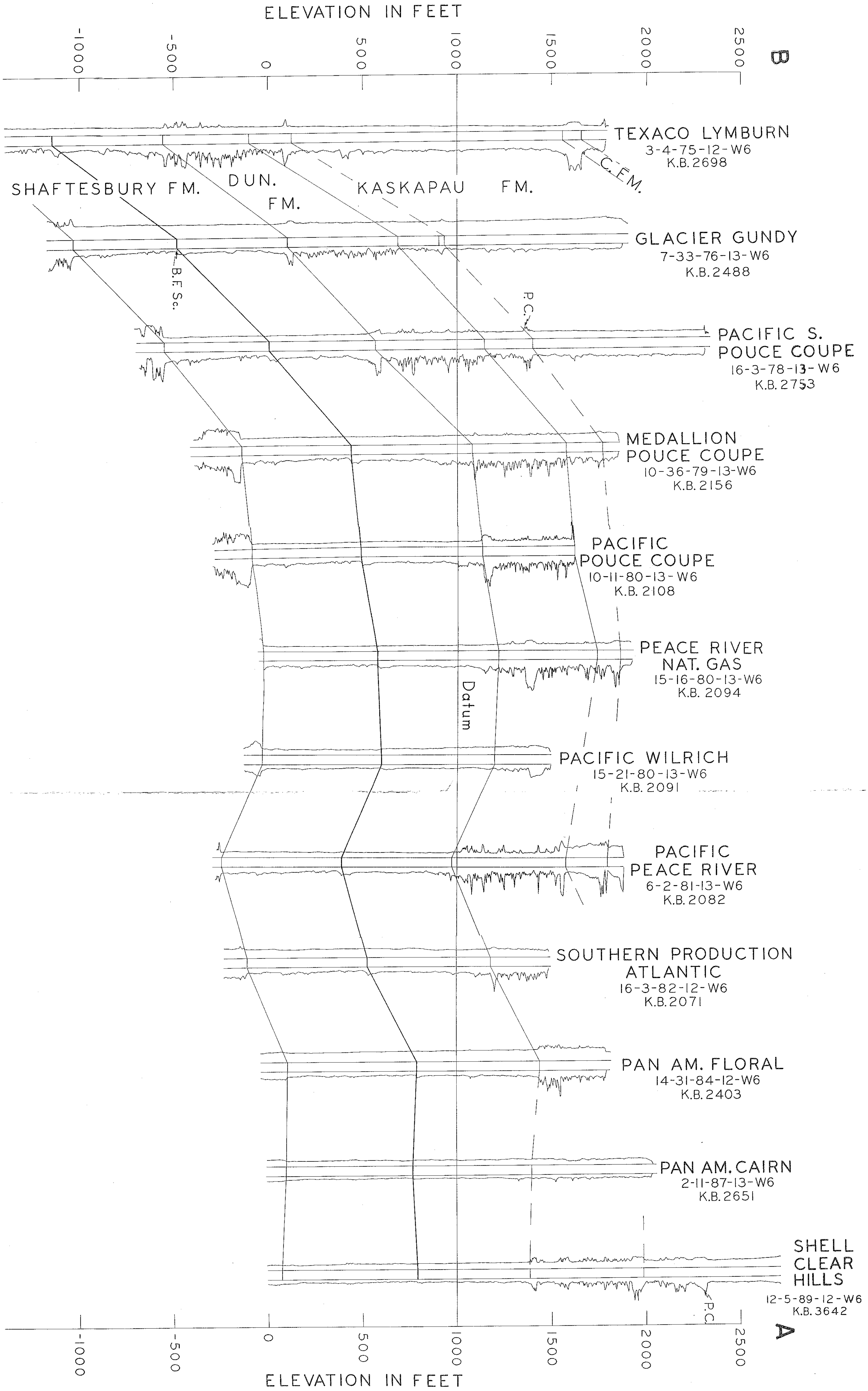


FIGURE 3. Electric-log cross section along line A-B of figure 10

To accompany Research Council of Alberta Bulletin 16,
by J. F. Jones

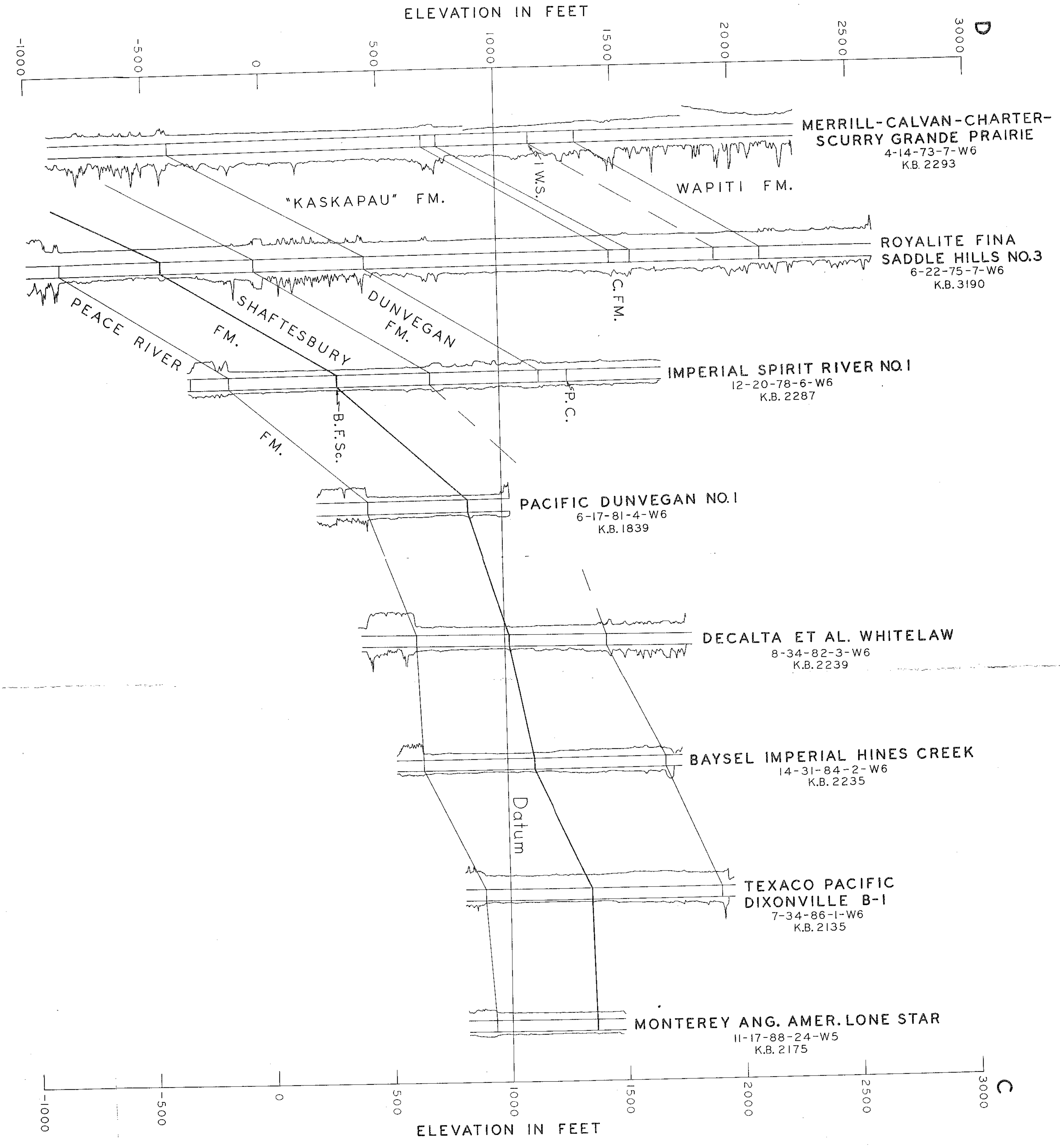


FIGURE 4. Electric-log cross section along line C-D of figure 10

To accompany Research Council of Alberta Bulletin 16,
by J. F. Jones

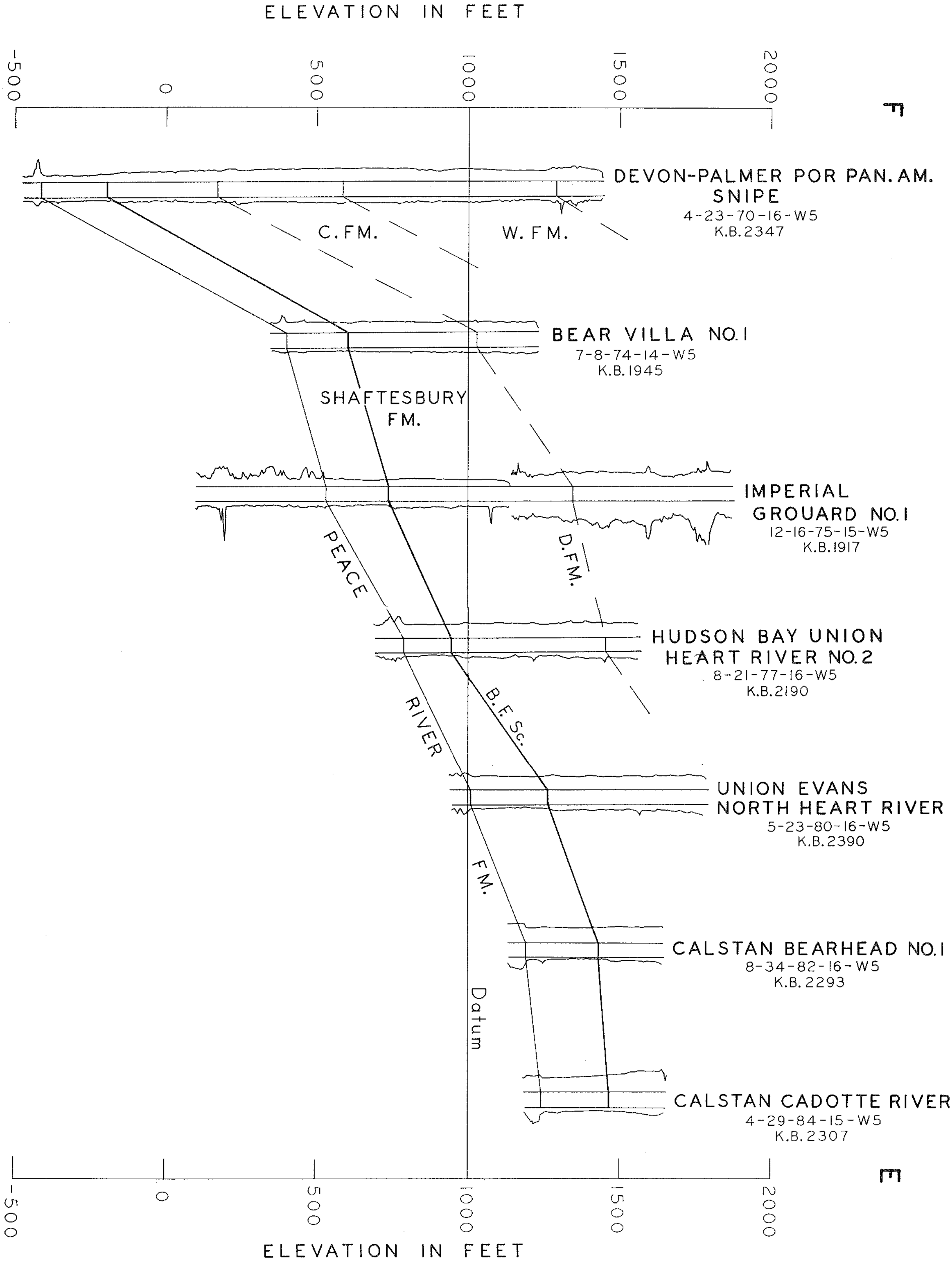


FIGURE 5. Electric-log cross section along line E-F of figure 10

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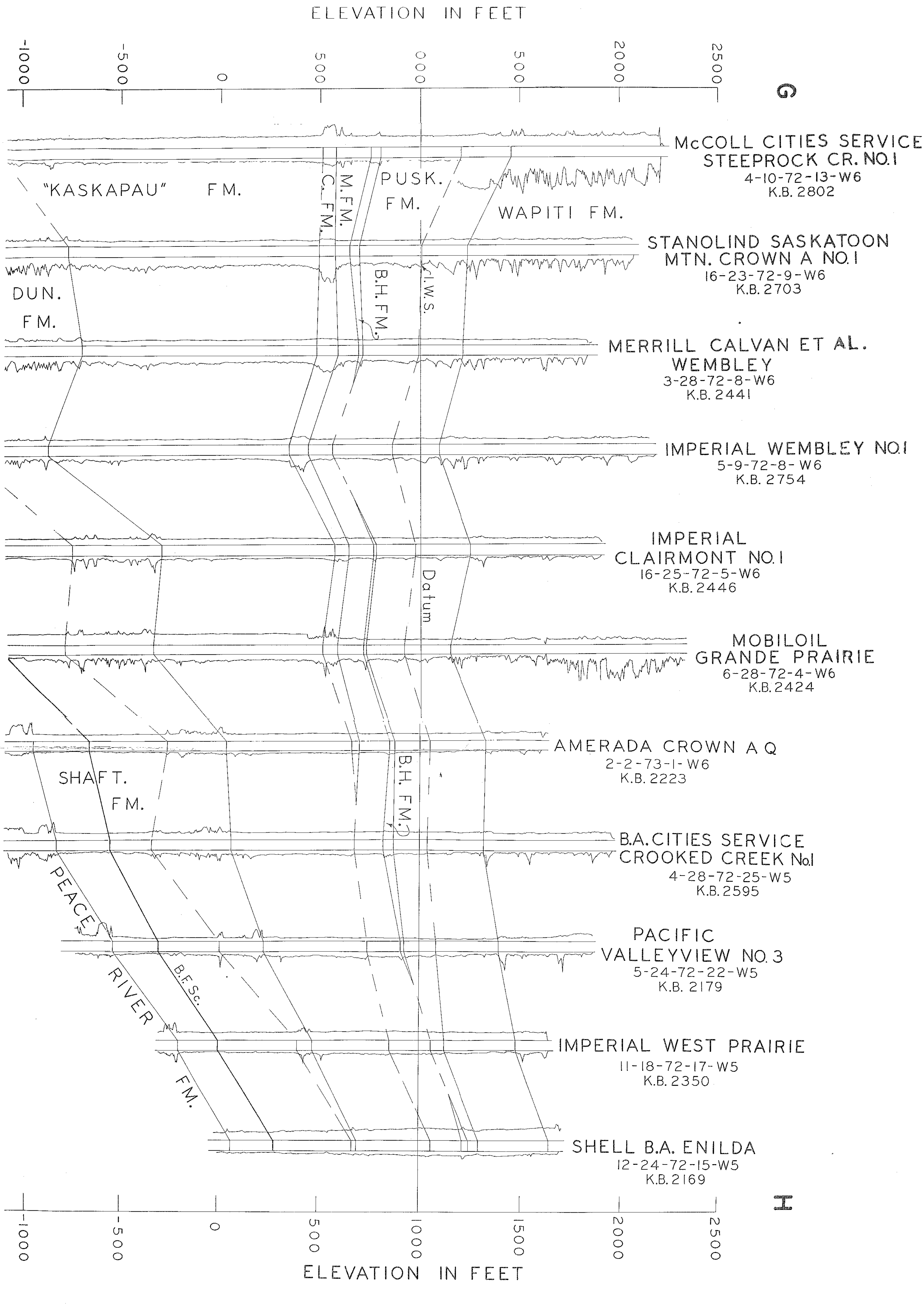

FIGURE 6. Electric-log cross section along line G-H of figure 10

To accompany Research Council of Alberta Bulletin 16,
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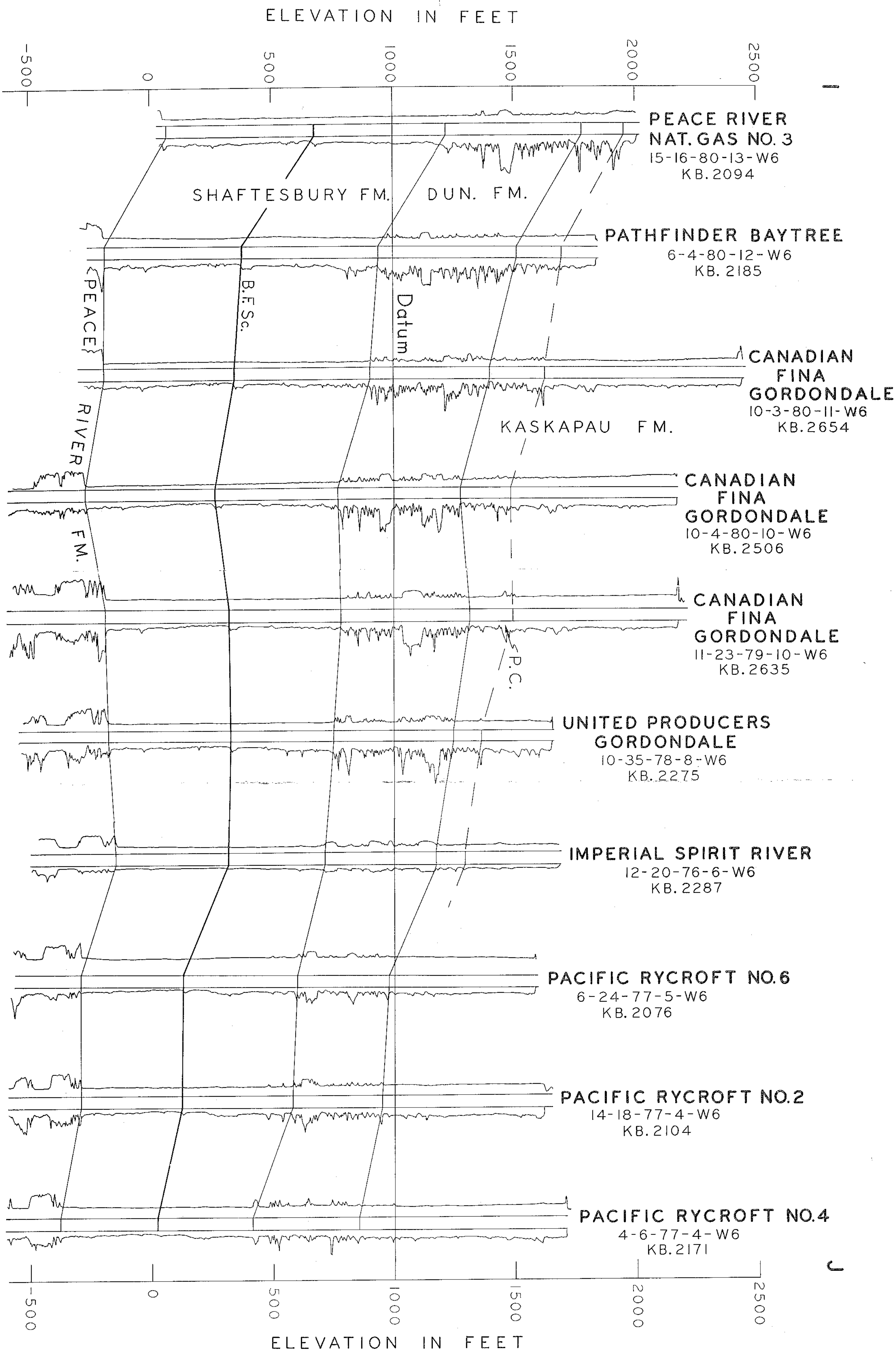


FIGURE 7. Electric-log cross section along line I-J of figure 10

To accompany Research Council of Alberta Bulletin 16,
by J. F. Jones

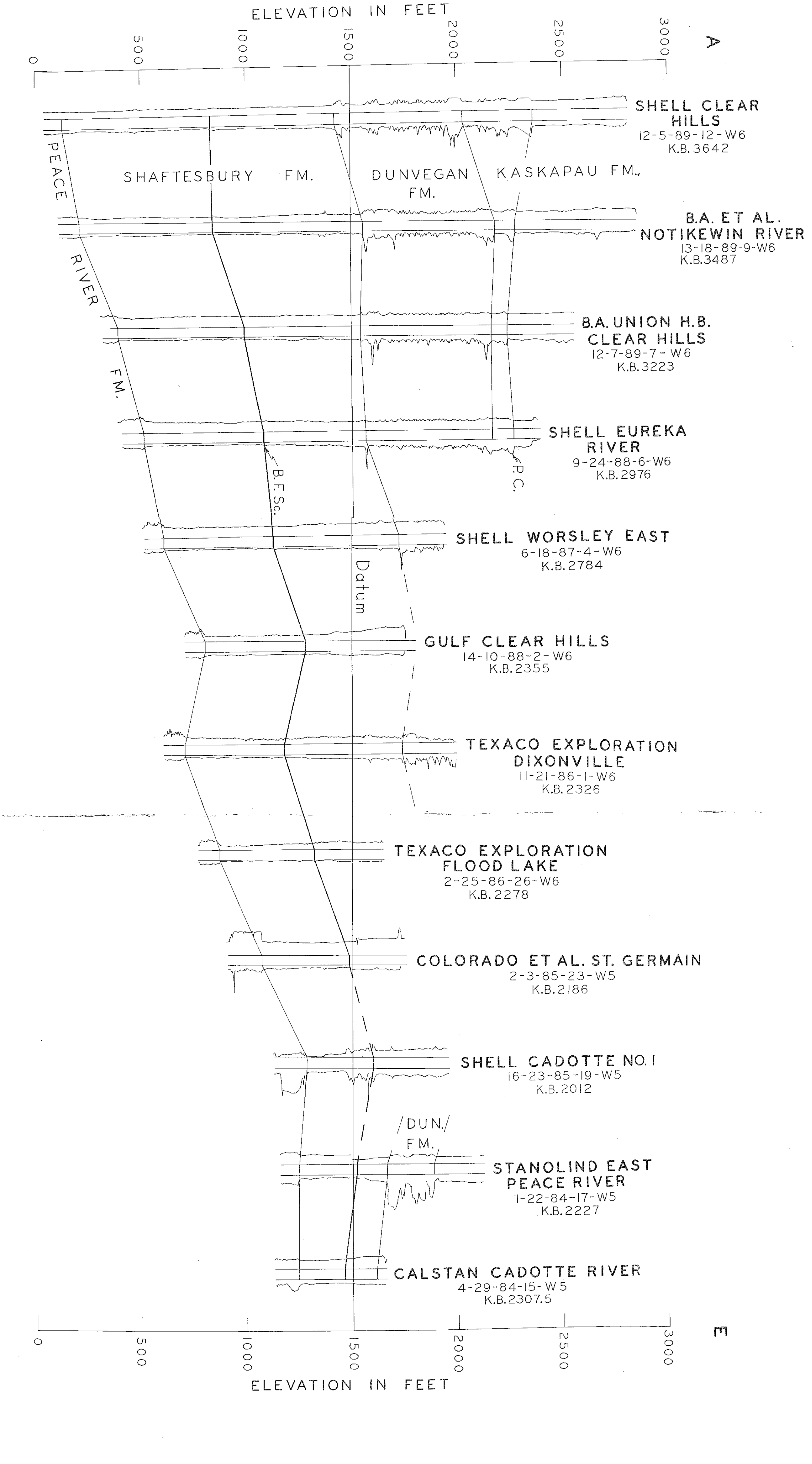
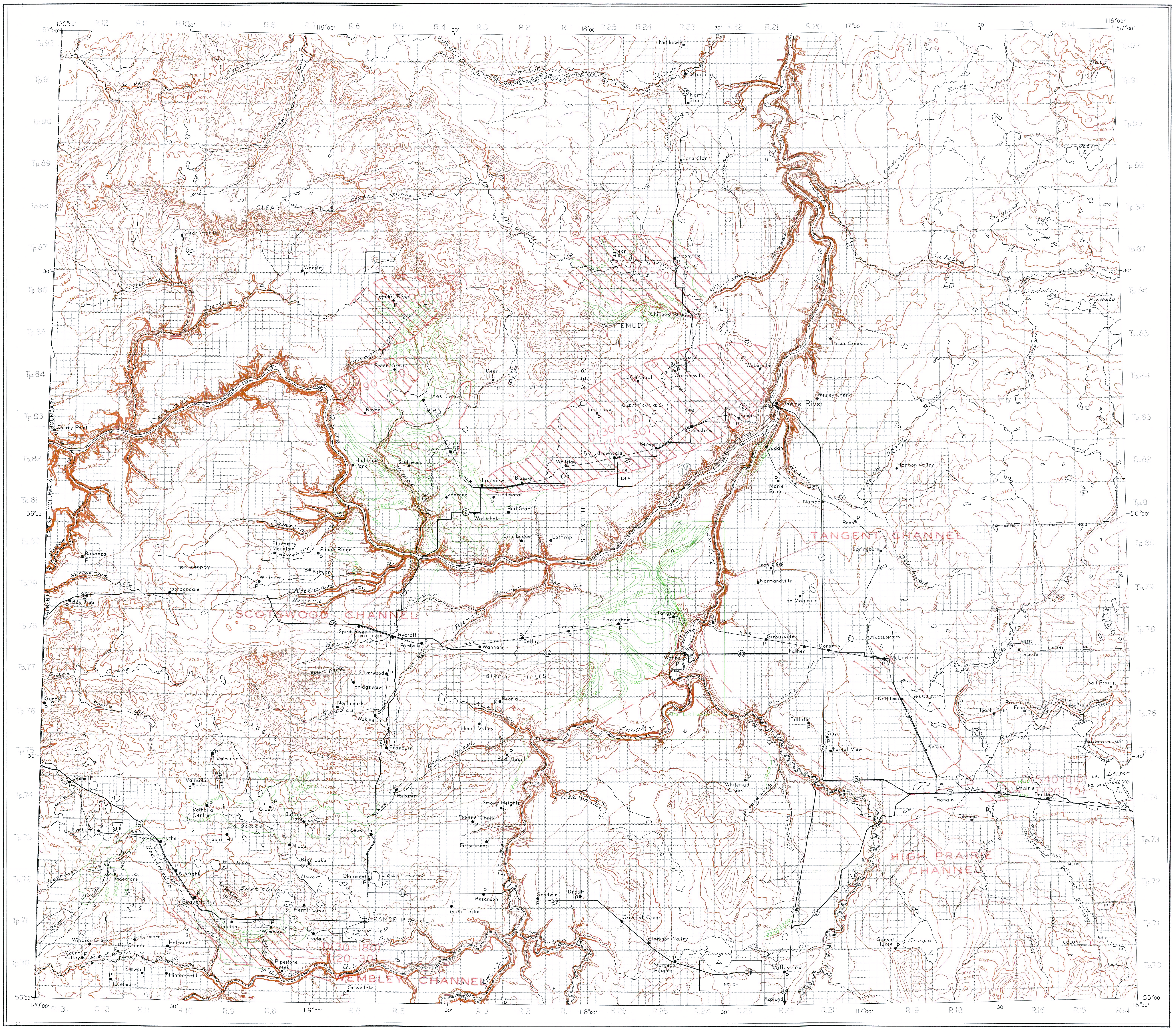


FIGURE 8. Electric-log cross section along line A-E of figure 10

To accompany Research Council of Alberta Bulletin 16,
by J. F. Jones



To accompany Research Council of Alberta Bulletin 16,
by J. F. Jones

Published in 1966

FIGURE 16
BEDROCK TOPOGRAPHY AND SAND AND GRAVEL DEPOSITS, PEACE RIVER DISTRICT, ALBERTA

SCALE IN MILES

4 2 0 4 8 12 16 20

WEST OF FIFTH AND SIXTH MERIDIANS

CONTOUR INTERVAL 100 FEET

EXPLANATION

Contour, bedrock elevation, definite 2700

indefinite 1500

Buried-channel boundary, definite ....

indefinite ....

Sands and/or gravels, buried ....

surface ....

range in depth .... D

range in thickness .... T

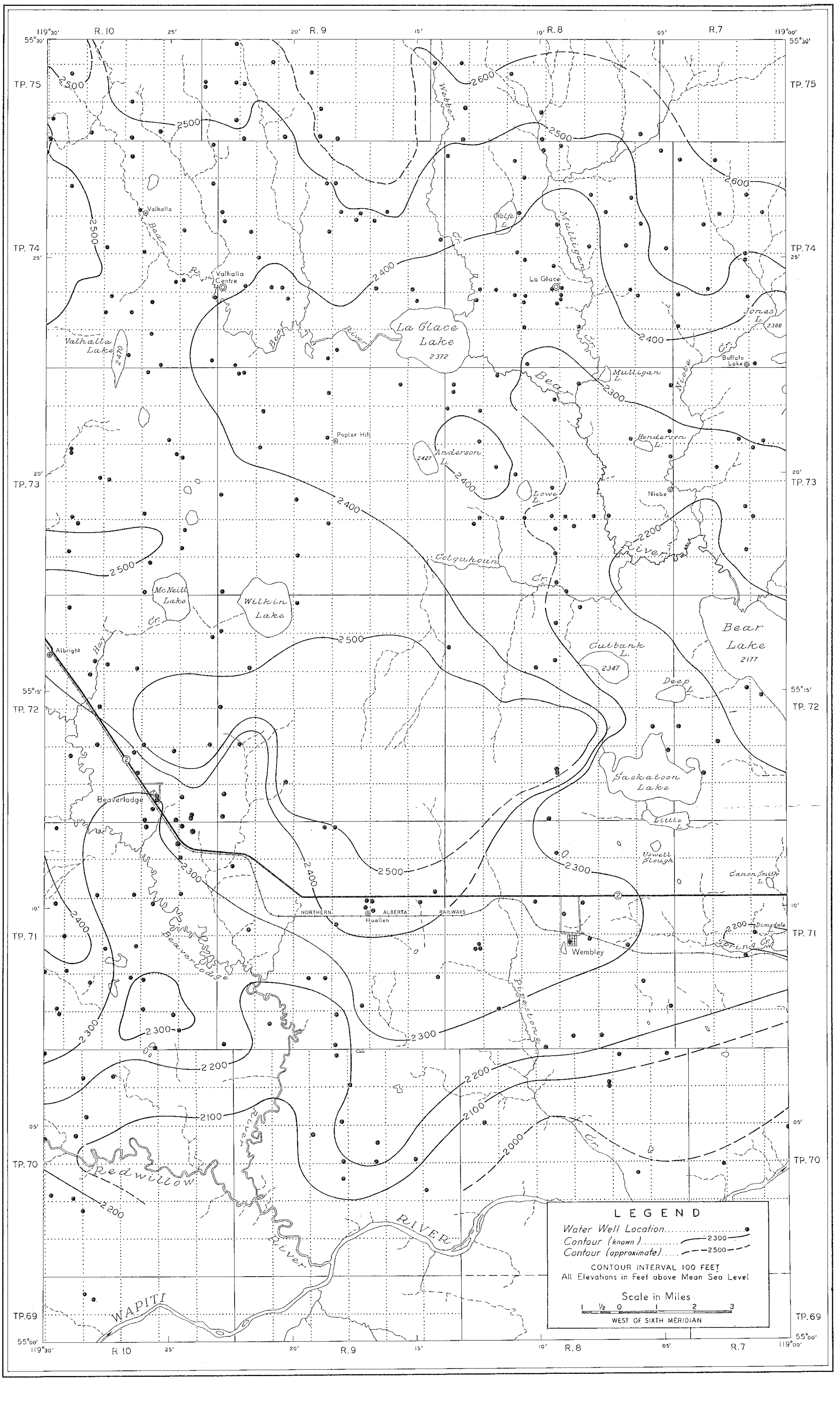
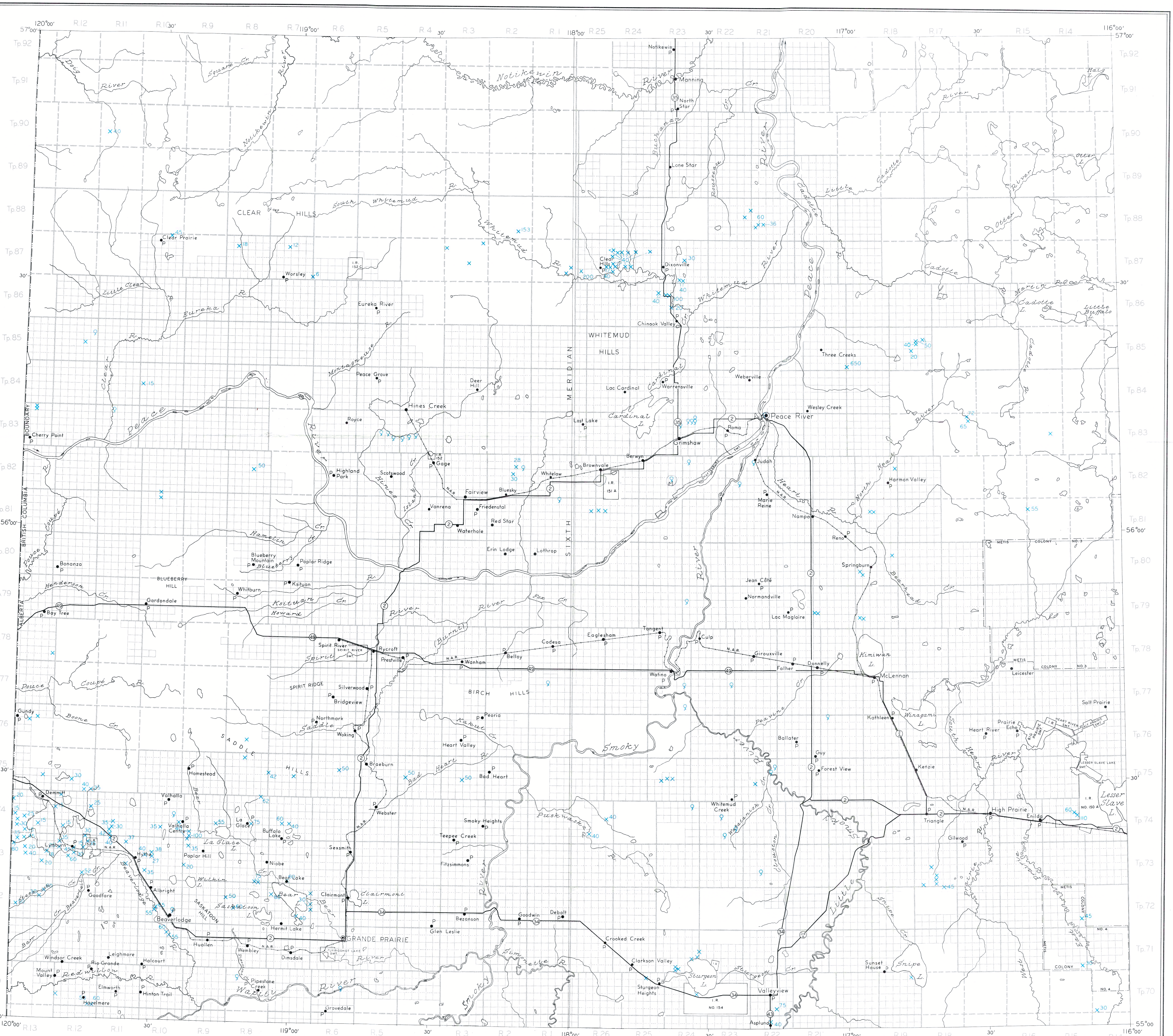


FIGURE 21. Nonpumping water levels, summer of 1958, Beaverlodge district

To accompany Research Council of Alberta Bulletin 16, by J. F. Jones



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SCALE IN MILES

4 2 0 4 8 12 16 20

WEST OF FIFTH AND SIXTH MERIDIANS

FIGURE 22
SPRINGS AND FLOWING SHOT HOLES,
PEACE RIVER DISTRICT,
ALBERTA

EXPLANATION

Spring .... ♀

Flowing shot hole, depth in feet .... ×75

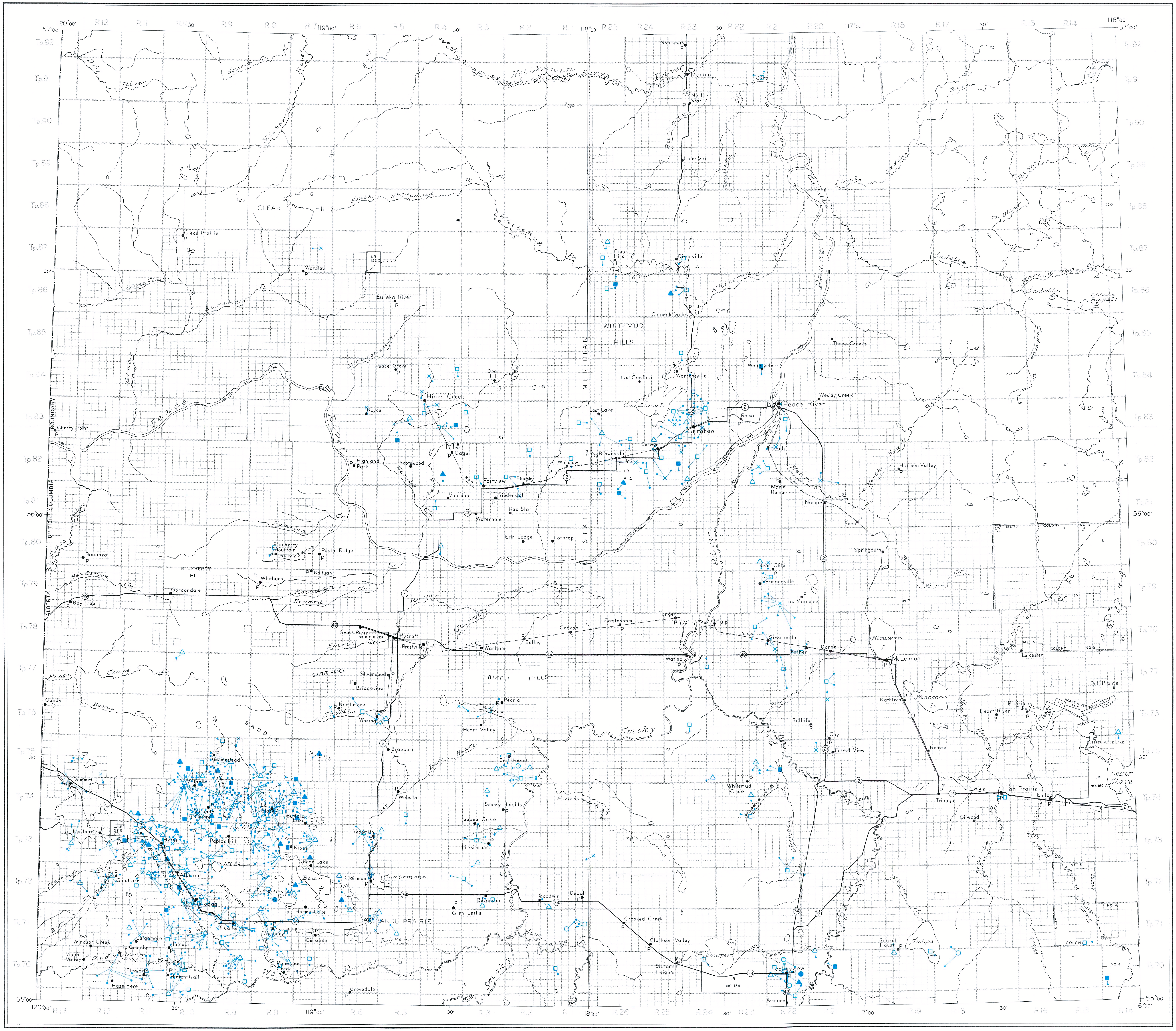

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FIGURE 23
WATER-WELL LOCATIONS AND CLASSIFICATIONS, PEACE RIVER DISTRICT, ALBERTA

SCALE IN MILES

4 2 0 4 8 12 16 20

WEST OF FIFTH AND SIXTH MERIDIANS

EXPLANATION

Well location .... •

Flowing well completed in:
- sandstone .... ▲
- coal .... ●
- sand and/or gravel .... ■

Nonflowing well completed in:
- sandstone .... △
- coal .... ○
- sand and/or gravel .... □
- unknown x

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LEGEND

- Alluvial: *sand and gravel, some silt; mainly recent terraces along river and stream courses.*
- Slump and colluvium: *mixed glacial and bedrock materials, mainly along steep flanks of valleys.*
- Aeolian, outwash and alluvial: *silt, sands, and gravel; mainly developed as thin mantles over heavier-textured materials.*
- Lacustrine: *clay, silt, sand; ranging from poorly to well sorted deposits; commonly varved at depth.*
- Lacustrine: *gravel and sand; beach deposits.*
- Till: *mainly clayey tills, of sand, silt, and clay with some gravel and sand patches.*
- Till: *mainly stoney, of sand, silt and clay, with common lenses of sand and gravel; generally overlying sand and gravel.*
- Residual: *weathered bedrock deposits; generally sandy, locally gravelly.*

Compiled 1963, by J. F. Jones, from field data, and from published reports and unpublished data of the Soils Division, Research Council of Alberta.

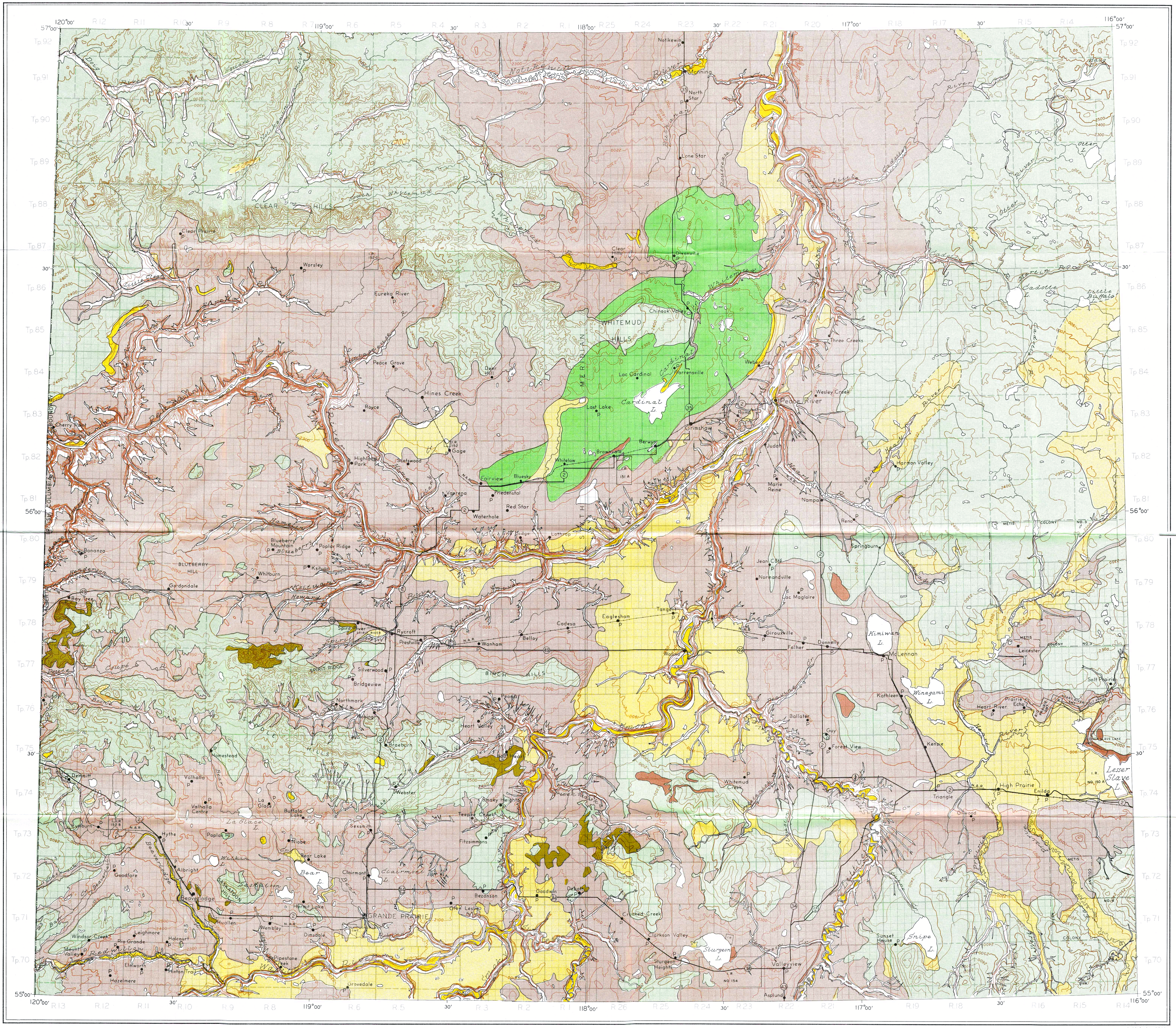
City or town, village or hamlet
Highway
Railroad
Post office
Stream
Lake
Township line, surveyed
unsurveyed
Section line, surveyed
unsurveyed
Contour, interval 100 feet

MAP 28

SURFICIAL DEPOSITS

OF THE PEACE RIVER DISTRICT,

ALBERTA



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4 2 0 4 8 12 16 20

WEST OF FIFTH AND SIXTH MERIDIANS

CONTOUR INTERVAL 100 FEET

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LEGEND

- Wapiti Formation: *non-marine sandstone, shale, coal seams.*
- W — Wapiabi Formation: *dark grey shale; marine.*
- P — Puskwaskau Formation: *dark grey shale; marine.*
- Bad Heart Formation: *sandstone and oolitic, iron-rich sandstone; marine?*
- M — Muskiki Formation: *dark grey shale; marine.*
- Cardium Formation, Baytree Member: *conglomerate and sandstone.*
- K — Kaskapau Formation: *dark grey shale, silty shale, and sandstone; marine.*

(W through K bracketed as:) Smoky River Group, undivided.

- Dunvegan Formation: *sandstone, siltstone, shale, minor coal; non-marine and marine.*
- Shaftesbury Formation: *dark grey shale and silty shale; marine.*
- Peace River Formation: *sandstone, minor shale.*

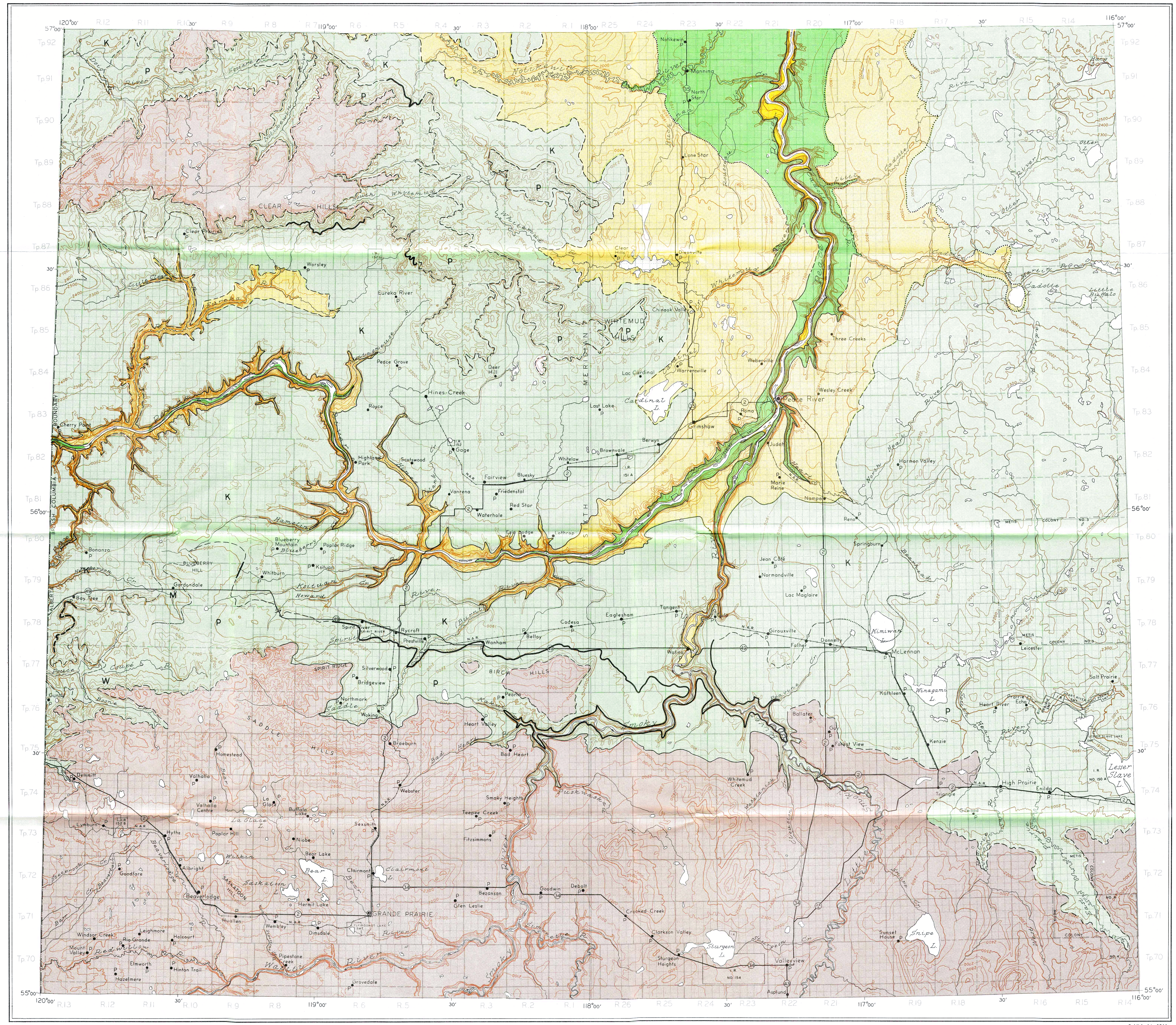
Rock unit boundary, definite
approximate
assumed

Geology by J. F. Jones and R. Green, 1957-1963

City or town, village or hamlet
Highway
Railroad
Post office
Stream
Lake
Township line, surveyed
unsurveyed
Section line, surveyed
unsurveyed
Contour, interval 100 feet

MAP 27

BEDROCK GEOLOGY OF THE PEACE RIVER DISTRICT, ALBERTA



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