Earth Sciences Report 78-6

Hydrogeology of the Bitumount-Namur Lake Area, Alberta

G. Ozoray
D. Hackbarth
A.T. Lytviak

Alberta Research Council
1980

TABLE OF CONTENTS

ILLUSTRATIONS

LIST OF TABLES

HYDROGEOLOGY OF THE BITUMOUNT-NAMUR LAKE AREA, ALBERTA

ABSTRACT

The hydrogeology of the uppermost 1000 ft (305 m) of strata in the Bitumount and Namur Lake areas is characterized by 20-year safe yields generally over 5 igpm (about 0.4 L/sec). Along the Athabasca River higher yields are available, mainly from Quaternary sands and gravels. Over 500 igpm (38 L/sec) may be obtained near the Muskeg River from basal McMurray sands.

A practical limiting factor on groundwater use is quality, as salinity of bedrock groundwater usually exceeds 2,000 mg/L and may reach 300,000 mg/L. Water from the bedrock is usually of sodium chloride type. In some places chloridic or sulfatic groundwater discharges to the surface. Quality of groundwater from the Quaternary sands and gravels is usually better.

Muskeg is widespread in the area and degeneration of the groundwater flow systems is noted.

A unique slope denudation process was observed: rock falls from bitumen-cemented sandstone when the viscosity of the bitumen is temporarily reduced by the summer noon-time heat.

INTRODUCTION

The Bitumount (NTS 74E) and Namur Lake (NTS 84H) map areas are located in northern Alberta, between latitudes 57° and 58° north and longitudes 110° and 114° west, in Tp 92 to 104, R 1 to 25, W 4th Mer. The area covers about 10,266 sq mi (26,588 km^2).

Fort MacKay is the only village in the map area. Other centers of population are small hamlets, temporary drilling or lumbering camps, lookout towers, and forestry cabins. The entire permanent population of the area does not exceed several hundred people. There are four Indian reserves within the map area: Chipewyan, Fort MacKay, Namur Lake, and Namur River.

Access is provided by paved highway from the south to the Suncor Ltd. plant (Tp 92, R 10); from there a gravel road extends to Fort MacKay. Occasional cutlines, dirt tracks, and locally improved roads to drilling or lumbering sites are the only other passable roads in the area. The greater part of the area can only be reached by helicopter or boat in the summer. During winter, roads may be constructed over the muskeg.

The area is mostly covered with forest, bush, and muskeg. The main types of vegetation are forests of aspen poplar, jackpine, white spruce, white birch, and black spruce on sandy soil; and muskeg containing sphagnum, moss, and black spruce (Government and University of Alberta, 1969). Agriculture is practically nonexistent in the area.

The purpose of this mapping project was to produce a hydrogeological map for an area experiencing rapid development due to exploitation of the Athabasca oil sands.

Field survey was carried out in 1973 by helicopter and boat. Seventeen water samples were collected. In 1974 pump tests were performed for Home Oil Company and Petrofina Canada Ltd. (Hackbarth, 1974). During the winters of 1974-75 and 1975-76, 75 observation wells were installed at 14 different locations in the study area. The wells were completed at various depths in order to observe heads and water quality changes with depth. Factual details of this system are available (Alberta Research Council, 1976-1977).

The Alberta Oil Sands Environmental Research Program (AOSERP) is conducting comprehensive environmental

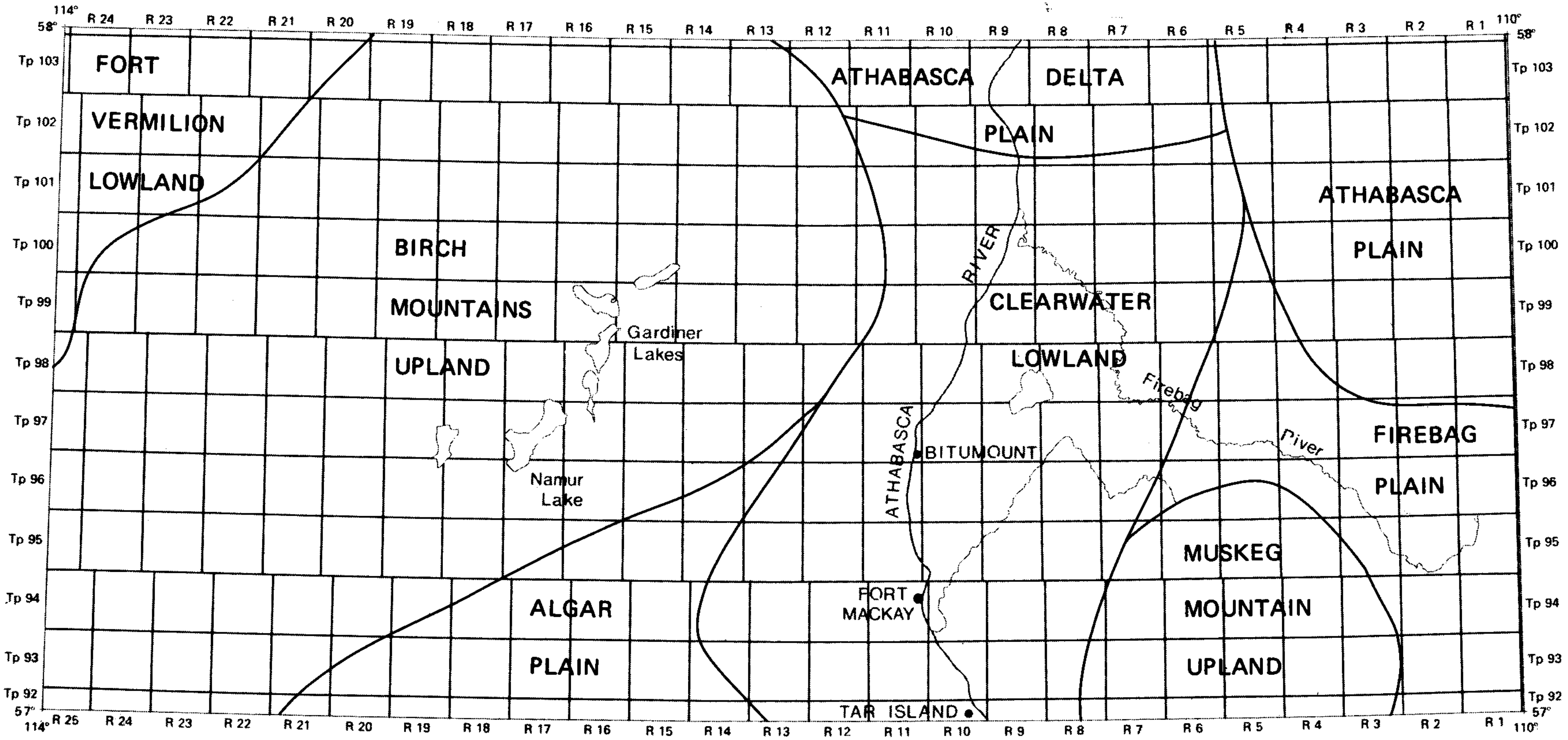


FIGURE 1. Physiographic regions, Namur Lake-Bitumount area, Alberta

research in the area. Various publications relating to environmental concerns are available through that group.

Publications of general background interest include a detailed bibliography of the oil sands by Carrigy (1965) and an environmental study by Intercontinental Engineering of Alberta Ltd. (1973).

ACKNOWLEDGMENTS

Structure testhole data and formation water analyses were received from the Energy Resources Conservation Board. Unpublished materials were kindly made available by Suncor Ltd. (formerly Great Canadian Oil Sands Ltd.), Cities Service Inc., Home Oil Co. Ltd., Shell Canada Resources Ltd., and Amerada Minerals Corporation of Canada Ltd. Aquifer performance tests were conducted in cooperation with Home Oil Company Ltd. and Petrofina Canada Ltd. A grateful acknowledgment is due to the Fort McMurray Forest Office for their permission to use the cabin at Clausen's Landing.

Chemical analyses were performed by J.R. Nelson and by M. Hnit, both of Alberta Research Council.

The manuscript was critically read by R. Stein and J. Tóth.

TOPOGRAPHY AND DRAINAGE

Most of the map area (Fig. 1) lies within the Interior Plains and includes parts of the Fort Vermilion Lowland, Birch Mountains Upland, Algar Plain, Athabasca Delta Plain, Clearwater Lowland, Muskeg Mountain Upland, and Firebag Plain physiographic regions (Government and University of Alberta, 1969). The northwest corner of the map area lies within the Canadian Shield, in the Athabasca Delta Plain region. The elevation of the Birch Mountains exceeds 2800 ft (853 m) above mean sea level. Muskeg Mountain (Tp 94, R 6) exceeds 2200 ft (671 m). The lowest elevation is in the north, where the Athabasca River leaves the map area at an elevation of about 740 ft (226 m).

Topography and morphology are varied and not yet studied in detail. The entire area was covered by the Wisconsin ice sheet which left a variety of glacial, glaciofluvial, and lacustrine features.

These features were studied and documented by Gravenor and Kupsch (1959) and Stalker (1960). Air photographs and ERTS-1 satellite images show widespread glacial flutings (Ozoray, 1975) and slumping. A 1:250,000 scale surficial geology map is available for the eastern half of the area (Bayrock, 1971).

A unique process of slope denudation was observed in 1973 by G. Ozoray along the high banks of the Athabasca River: rockfall occurs in the bitumen-cemented sandstone of the McMurray Formation when the viscosity of the bitumen is temporarily reduced by the summer noon-time heat. The lessened stability of south-facing slopes of oil sand was noted by Mollard and Dishaw (1961) and explained as a consequence of drying out by Dusseault (1977).

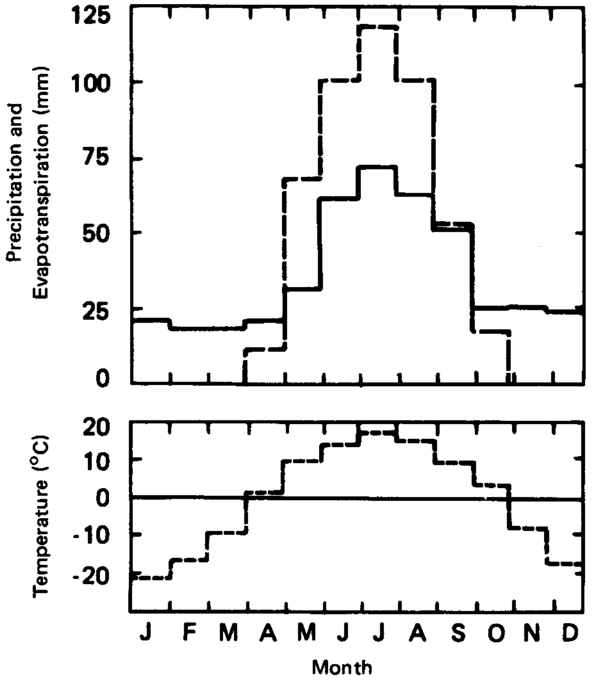
Less than one mile (1.6 km) from the strong juvenile erosion and developing canyons along the Athabasca River, erosionally stagnant muskeg-covered plateaus with uncertain, undeveloped drainage are found. There are many lakes and ponds on these plateaus, mostly glacial in origin, some of them occupying meltwater channels. The lakes show every stage of sedimentation and many are completely silted up (Taylor, 1960). Many creeks are transformed to chains of ponds by beaver dams.

The entire mapping area lies within the Mackenzie River-Arctic Ocean drainage system and is divided between the Athabasca River, Peace River, and Lake Claire basins. The watersheds of important tributaries are also indicated on the attached hydrogeological map. Studies of surface waters have been carried out by Hitchon *et al.* (1969) and Reeder *et al.* (1972).

CLIMATE

The entire area has been classified (Longley, 1972) as a "cold, snowy forest zone" with "short, cool summers". Isohyets, modified from Longley (1972), are shown on the meteorological map. Longley's precipitation map was modified by incorporating May-to-September data published by Stashko (1971) for 10 forestry lookout towers in the area. These data were extrapolated to yearly values by using proportions determined at Fort McMurray (Fig. 2) (Tp 89, R 9) located 20 miles south of the map area. Extrapolated values given in Table 1 show that the annual precipitation exceeds 20 in (508 mm) in the Birch Mountains and in the Muskeg Mountain Upland, while in the south-central part of the area it likely exceeds 22 in (559 mm). The Athabasca River valley likely receives less than 16 in (406 mm) precipitation annually.

At Fort McMurray the mean January temperature is -21.3°C, the mean July temperature is 16.5°C, and the annual mean is -0.6°C (Canada Department of Transport, 1967) (Fig. 2). The annual potential evaporation, estimated from the maps of Bruce and Weisman (1967) is about 19 in (483 mm). Potential evaporation exceeds precipitation annually and also for the months May to August inclusive and in October. Potential evapotranspiration (Thornthwaite and Mather,



	Fort McMurray (1944-1972)
Annual precipitation (mm)	437*
Annual evapotranspiration (mm)	483*
Mean annual temperature (°C)	–0.6*

* long-term average

FIGURE 2. Mean monthly precipitation, potential evapotranspiration, and temperature at Fort McMurray Airport, 1944 - 1972

1957) is about 19 in (483 mm) per year and exceeds precipitation from May through September.

The southern limit of discontinuous permafrost crosses the area from the northwest to the southeast (Brown, 1967) and is shown on the meteorology side map. Most of the area is within the climafrost zone (Lindsay and Odynsky, 1965) where frozen conditions in organic soils are temporary but frequently last for more than one year. Permafrost was noted in organic soils in the Birch Mountains. String bogs or ribbed fens are widespread in the area.

GEOLOGY

The first data on the geology and hydrography of the area were gathered by explorer-geologists in the last century (Franklin, 1828; Richardson, 1851). The area is rich in oil sand (Carrigy, 1959) and there are unused supplies of salt, gypsum, limestone, gravel, and sand.

Information used for the construction of the geological side maps and hydrogeological profiles included: the 1:500,000 scale bedrock geology map of northern Alberta (Green, Carrigy and Mellon, 1970), the 1:1,267,000 scale Geological Map of Alberta (Green, 1972), geological maps of Carrigy and Collins (1959), Norris (1963), Tremblay (1961), Godfrey (1970), and electric and lithological logs from boreholes.

The northeastern corner of the map area is underlain by crystalline Precambrian Shield rocks which crop out or subcrop under thin drift. These Precambrian rocks are

TABLE 1
Short-Term May to September Average and Extrapolated Annual Precipitation at Alberta Forestry Lookouts up to 1970

Name of Lookout	May to September average precipitation*		Extrapolated annual precipitation*		Number of years*
	inches	mm	inches	mm	
Birch Mountain	13.5	343	20.9	531	8
Bitumount	11.7	297	18.1	460	8
Buckton	12.9	328	20.0	508	6
Edra	13.3	338	20.6	523	5
Ells	10.9	277	16.9	429	8
Jean Lake	13.5	343	20.9	531	8
Johnson Lake	13.1	333	20.3	516	6
Legend	11.3	287	17.5	445	8
Muskeg	13.1	333	20.3	516	8
Richardson	10.7	272	16.6	422	8

* after Stashko (1971)

** the total of January to April and October to December precipitation was taken as 54.7% of the May to September precipitation as is the case at the nearest meteorological station (McMurray)

Archean granitic plutonic rocks and Proterozoic Athabasca Formation sandstone, with local conglomerate and shale beds. The Precambrian surface dips towards the west and south at about 23 ft/mi (4.4 m/km) and forms part of the western Canadian basin (Green, 1958; Carrigy, 1959; Pugh, 1973).

Devonian strata (Table 2) underlie the entire area outside the Shield (Belyea, 1952; Norris, 1963) and subcrops in a wide belt skirting it. Outcrops are limited to deep river valleys. For the purposes of this report the Middle Devonian is subdivided only into two generalized units (see hydrogeological profiles): (1) the sequence including the Prairie Evaporite, Muskeg, Watt Mountain, and Fort Vermilion Formations (Table 2) and (2) the La Loche, McLean River, and Methy Formations. The Upper Devonian is undivided for purposes of this report and includes the Slave Point, Beaverhill Lake, Cooking Lake, Ireton, and Grosmont Formations.

The Devonian strata dip southwestward at approximately the same angle as the Precambrian surface. Solution of the evaporites has taken place east of a line running approximately from Tp 92, R 14 to Tp 103, R 21 (Hackbarth and Nastasa, 1979). East of this line the evaporite sequence thins to disappearance. The overlying Beaverhill Lake Formation has collapsed several hundred feet because of the salt solution and is expected to have developed some secondary permeability as a result.

The pre-Cretaceous erosion surface on the Devonian rocks is karstic. The abundance of collapse features on the surface has been suggested by Carrigy (1959) to be caused by the solution of the underlying evaporites. Hackbarth and Nastasa, (1979) have suggested faulting as a contributing factor to karstification. Collapse features in the drift-covered Devonian subcrop area are identified by Bayrock (1971) and Ozoray (1976, 1977). Contours on the Devonian surface are presented on Geology side map III. The contours in several locations agree with those shown by Carrigy and Zamora (1960) and Martin and Jamin (1963).

The McMurray Formation is 150 to 300 ft (46 to 91 m) thick, consists of mostly deltaic, crossbedded quartzose sandstone with occasional siltstone and shale (Carrigy, 1959), and lies unconformably on the Devonian limestones. The McMurray Formation subcrops in a belt around the Devonian subcrop area and crops out along the Athabasca River and its tributaries to the east. In most of the area the McMurray Formation is saturated with oil and is known as the Athabasca Oil Sands. It has been extensively studied

TABLE 2
Stratigraphic Succession

System or Series	Rock Unit	Lithology
Pleistocene and Recent	Alluvium Glacial drift	Till, sand, silt and gravel
	Erosional unconformity	
Cretaceous	Smoky Group (U)	Shale
	Labiche Formation (U&L)	Shale
	Dunvegan Formation (U)	Sandstone
	Shaftesbury Formation (U&L)	Shale
	Grand Rapids Formation (L)	Lithic sand and sandstone
	Clearwater Formation (L)	Shale and siltstone
	Wabiskaw Member (L)	Glauconitic sandstone
	McMurray Formation (L)	Quartzose sand impregnated with heavy oil
	Erosional unconformity	
Upper Devonian	Woodbend Group	
	Grosmont Formation	Limestone reef
	Ireton Formation	Shale and shaly limstone
	Cooking Lake Formation	Limestone
	Beaverhill Lake Formation	Limestone and shale
	Slave Point Formation	Limestone and dolmite
Middle Devonian	Fort Vermilion Formation	Anhydrite and dolomite
	Elk Point Group	
	Watt Mountain Formation	Shale and anhydrite
	Muskeg Formation	Anhydrite and dolomite
	Prairie Evaporite Formation	Anhydrite and salt
	Methy Formation	Reefal dolomite
	McLean River Formation	Dolomite, claystone and evaporite
	La Loche Formation	Claystone and arkosic sandstone
	Erosional unconformity	
Precambrian		Metasedimentary rocks and granite

U = Upper Cretaceous

U&L = Upper and Lower Cretaceous

L = Lower Cretaceous

The formations joined by bracket } to a group form part of that group; the other formations do not; also, the Wabiskaw Member is a part of the Clearwater Formation.

(Mellon and Wall, 1956; Carrigy, 1959, 1965). Contours based on litholog and electric log data for the top of the McMurray Formation are given on a Geology side map.

The upper part of the McMurray Formation includes locally thin tongues of marine shale which are conformable with the overlying Clearwater Formation. The latter consists of 250 to 300 ft (76 to 91 m) of marine shales, siltstones, and cherty sandstones. The basal unit of the Clearwater Formation – the Wabiskaw Member – may be oil saturated and is considered as a part of the Athabasca Oil Sands (Carrigy, 1963). On the maps and profiles no distinction is made between the Clearwater Formation and the equivalent Loon River Formation of the northwestern part of the area. The subcrop of Clearwater Formation lies in a belt around Muskeg Mountain and around the Birch Mountains.

The Grand Rapids Formation, which overlies conformably the Clearwater Formation, is 200 to 330 ft (61 to 100 m) thick and consists of poorly consolidated fine-grained quartzose, feldspathic or glauconitic, cherty sandstone, siltstone, and shale of deltaic to marine origin. It subcrops under Muskeg Mountain and crops out on the east slopes of the Birch Mountains.

The Grand Rapids Formation is successively overlain in the northern part of the Birch Mountains by the marine Shaftesbury Formation, the deltaic Dunvegan Formation, and the marine Smoky Group. The Dunvegan Formation pinches out towards the south and the La Biche Formation, consisting mostly of marine shales, substitutes for both the Shaftesbury Formation and Smoky Group. On some of the profiles, these units are combined.

The glacial drift consists of a great variety of materials including: till, huge glacial blocks, pebble and gravel, sand, silt, and clay. Lithological observations are not commonly made when drilling through drift in oil exploration holes; hence, data are limited. Some electric logs show gravel beds which are probably preglacial in origin. Drift thickness varies, but over large areas of the uplands and in the bedrock channels it may be more than 500 ft (150 m) (Geology side map II).

HYDROGEOLOGY

DATA DENSITY

Pump, bail, or drill stem tests from which groundwater yields could be calculated are available for only a small portion of the area (Kahil, 1968a, 1968b; Hackbarth, 1971, 1974; Alberta Research Council 1976-1977). The reader should carefully note the data distribution in general (Data Density side map) and for the hydrochemical side maps. It is important to remember that the extrapolation of groundwater yields to areas having no data is done on the basis of geology alone; thus it is usual that yield boundaries follow geological boundaries.

Overburden dewatering has been studied at the Suncor Ltd. plant (Tp 92, R 10, W 4th Mer) (Linckens, 1965; Kahil, 1968a and 1968b; Hackbarth, 1971). Water supply for Fort MacKay was investigated by Kerr and Shillabeer (1969). Hydrodynamic and hydrochemical studies which included the mapping area or were applicable to it were conducted by Hitchon (1963), van Everdingen (1968), Hackbarth (1977), and Hackbarth and Nastasa (1979).

GROUNDWATER DISCHARGE FEATURES

La Saline Spring (Lsd 16, Sec 15, Tp 93, R 10) discharges onto a terrace 60 ft (18 m) above La Saline Lake – an abandoned oxbow of the Athabasca River. The main spring has formed a conical mound of calcareous tuff. A spring pool about 10 ft (3 m) in diameter and 2 ft (0.6 m) deep occupies the top of the mound. On August 21, 1973, at 25°C (77°F) air temperature, the water in the pool was 8°C (46°F), and the discharge was about 10 igpm (0.75 L/sec) of water with a distinct hydrogen sulfide odor. A spring at the base of the mound, also smelling of hydrogen sulfide, yielded about 2 igpm (0.15 L/sec) and had a temperature of 12°C (53.6°F) on the same date.

The water of the main spring was of sodium-chloride character and contained 71,140 mg/L dissolved salts. Previous analyses published by Ells (1926) and by Hitchon *et al.* (1969) show that the dissolved salt concentration fluctuates considerably in time. The springs deposit mineral precipitates in the form of encrustation, rimstones, oolitic or coralline structures, and free-grown crystals. Calcite, dolomite, quartz, gypsum, anhydrite, baryte, and sulfur were determined by X-ray analysis.

Further north, in another abandoned oxbow of the Athabasca River, several low yielding (less than 1 igpm or 0.7 L/sec) springs were noted in Sec 11, Tp 100, R 9, W 4th Mer. The springs form shallow pools covering areas 45 to 60 ft (14 to 18 m) in diameter over mud and decomposing plant material. The water is covered by a yellowish-silvery film and has a hydrogen sulfide odor. The water of a spring in Lsd 5 of this section is of sodium calcium-sulfate type, with a total dissolved solids concentration of 4904 mg/L.

The high chloride and sulfate ion concentrations in the described springs can be interpreted as evidence of ascending flow through the Middle Devonian evaporites. Both La Saline Spring and the sulfatic springs originate where the steep slope of the older Holocene valley of the Athabasca River changes direction and also where small creeks cut into that slope. These observations suggest structural control, although convincing direct evidence cannot be obtained since the bedrock is drift covered. The salt springs in the Clearwater River valley (Ozoray, 1974) show similar features. The collapse ponds at McClelland Lake (Tp 98, R 9, W 4th Mer) appear to have formed along two orthogonal lines, which suggests tectonic control.

The valleys of the Athabasca River and the lower reaches of its tributaries are bordered for long stretches by rockslides and slumps. The water seeping through a slump on the MacKay River (Lsd 11, Sec 23, Tp 94, R 11, W 4th Mer) is of sodium-chloride bicarbonate type with dissolved solids concentration of 1292 mg/L . The water of a pond in back of a slump on the Ells River (Lsd 13, Sec 30, Tp 94, R 13, W 4th Mer) is of sodium-sulfate type with 5072 mg/L total dissolved solids. Mineral precipitates on slumping surfaces were observed at several places along the Athabasca River. The presence of chloridic and sulfatic water at the slump sites suggests that the slumping process is related to the discharge of groundwater. Therefore, the slumps can be classified as discharge features.

A considerable part of the map area is overlain by muskeg, treed muskeg, or wet soil. On the surface elongated crescents of ribbed fens and other solifluctional phenomena are noticeable. In such places the groundwater table is at the surface or very near to it. However, the water table may occasionally be perched. The abundance of muskegs is an indication of the degeneration of flow systems in those areas, because of the extended periods of soil frost. In this case the greater part of groundwater movement occurs in the upper few feet (1 to 3 m) of the soil (mostly organic deposits) and is parallel to the surface, in contrast to the more deeply penetrating normal groundwater flow in areas experiencing shorter frost periods.

GROUNDWATER PROBABILITY

The largest safe yield from the upper 1000 ft (305 m) is shown on the main map by color-coded areas. Darker color shades indicate that yield estimates are based upon aquifer tests; lighter shades indicate that yields are based on lithology and topography.

The lithology of each rock unit has been generalized on the hydrogeological profiles. The best aquifer within the uppermost 1000 ft (305 m) is shown on the main map. Thick drift is indicated as the major aquifer in preference to bedrock in the case of equal yield since it is on the surface and easily available.

The Jacob modified nonequilibrium formula was used for the calculation of transmissivity from pumping test data:

$$T = 264Q/\Delta s$$

where T = transmissivity in imperial gallons/day/foot (igpd/ft); Q = pumping rate in imperial gallons/minute (igpm); s = drawdown in feet/log cycle of time.

The safe yield for 20 years of a well is calculated by rearranging the modified nonequilibrium formula as follows:

$$Q_{20} = TH/2110$$

where Q_{20} = safe yield in igpm which is defined as the constant rate at which the well can be continuously pumped so that at the end of 20 years the water level will be drawn down just to the top of the producing aquifer; H = total available drawdown in feet, which is the depth from the static water level to the top of the producing aquifer.

Safe yields of over 500 igpm (38 L/sec) may be expected in the east-central portion of the map area. Generally these yields will be obtained from the basal portion of the McMurray Formation. Yields of 100 to 500 igpm (8 to 38 L/sec) are predicted to the north and south of the above area where the basal McMurray thins somewhat. West of the Athabasca River, in the south-central portion of the map area, yields of 25 to 100 igpm (2 to 8 L/sec) are anticipated from the base of the McMurray Formation.

The Grand Rapids Formation constitutes the major aquifer under the eastern portion of the Birch Mountains. Low hydraulic heads and great pumping lifts will complicate development even though the overall permeability of the formation is quite good.

The Beaverhill Lake Formation is not expected to yield significant quantities of water except where it has been disturbed by solution of the underlying evaporites. The yield of the Beaverhill Lake Formation may reach as high as 5 igpm (0.4 L/sec) in those areas where a significant increase in secondary permeability has been caused by collapse.

The Middle Devonian evaporites are considered to have no yield except perhaps in the eastern portion of the map area where solution has been significant. In those areas where solution has not been significant it is apparent that groundwater is not present. Over the western half of the area the evaporites act as an impermeable base to groundwater flow.

Only very low hydraulic conductivities have been observed in the Methy, McLean River, and La Loche Formations. As a result these units have a very low yield. Farther to the west, where the hydraulic head in these units is much higher, yields may reach up to 5 igpm (0.4 L/sec); however, the units lie at great depths.

Glacial deposits are anticipated to be the major source of groundwater in the eastern and western thirds of the area. In the east these deposits overlie units of low hydraulic conductivity such as the Precambrian crystalline rocks, the Methy Formation, and the Clearwater Formation. Up to 600 ft (183 m) of glacial drift is found in this area as well. In the western one-third of the area several hundred feet (30 to 60 m) of glacial drift is anticipated; this, coupled with a strong downward gradient of hydraulic heads, means that the shallow drift will have higher static water levels and therefore will be more desirable as a source of groundwater.

HYDROCHEMISTRY

The waters of the Devonian strata and of the McMurray Formation are usually sodium-chloride or sulfate type with total dissolved solids concentrations ranging from 3000 to more than 300,000 mg/L. Groundwater of the nonsaline portions of the bedrock is of sodium-bicarbonate or, in places, of calcium-bicarbonate type, with 500 to 3000 mg/L total dissolved solids.

The Quaternary deposits contain either calcium magnesium-bicarbonate or sodium-bicarbonate type of groundwater. Waters from muskegs in upland areas contain as little as 50 mg/L total dissolved solids. In the muskegs and quasi-springs areas (Ozoray, 1974), where groundwater is assumed to discharge, the waters contain up to 300 ppm total dissolved solids and their chemical character is varied.

CONCLUSIONS

Safe yields of over 500 igpm (38 L/sec) were found in an area near the Muskeg River. Yields of about 5 to 25 igpm (0.4 to 2 L/sec) can be found everywhere in the area except in the vicinity of the Athabasca River and in the crystalline rock outcrop area.

Water quality is far from desirable. Deeper groundwater has total dissolved solids concentrations ranging from 3000 to 300,000 ppm and saline springs discharge at many places. The best aquifers, in terms of both quality and quantity, are Quaternary sands and gravels.

The springs along the Athabasca River are interpreted as discharge points of flow systems of undetermined size. The characteristic landslides along the steep slopes – particularly along the Athabasca River – are interpreted as caused by discharge of local to regional flow systems.

Muskegs are widespread over both inferred recharge and discharge areas. The extended period of soil frost disrupts the normal groundwater circulation for most of the year. Flow systems degenerate, with most groundwater moving in a thin active layer parallel to the surface. Solifluction phenomena such as ribbed fens are noticeable.

The Devonian carbonates and evaporites cause a widespread buried karst. Features on the surface of the Devonian have been accentuated by erosion, solution collapse, and repeated tectonism. The Athabasca Oil Sands were deposited over and into the depressions on the surface of the Devonian. Holocene collapse structures have developed and may still be active.

A unique mechanism of slope denudation was observed: rockfall due to decreased viscosity of the bitumen when the summer sun shines on oil-bearing sands.

REFERENCES

Alberta Research Council (1976, 1977): Groundwater Observation Well Network: Athabasca Oil Sands Area; (D. Hackbarth, editor), 17 volumes.

Bayrock, L.A. (1971): Surficial geology, Bitumount, NTS 74E; Research Council of Alberta map, scale 1:250,000.

Belyea, H.R. (1952): Notes on the Devonian system of the north-central plains of Alberta; Geological Survey of Canada Paper 52-57, 66 pages.

Brown, R.J.E. (1967): Permafrost in Canada, Geological Survey of Canada Map 1246A (map with explanatory notes).

Bruce, J.P. and B. Weisman (1967): Provisional evaporation maps of Canada; Canada Department of Transport, Meteorological Branch, 21 pages.

Canada Department of Transport, Meteorological Branch (1967): Temperature and precipitation tables for Prairie Provinces, Vol. III, 56 pages.

Carrigy, M.A. (1959): Geology of the McMurray Formation: Part III. General geology of the McMurray area; Research Council of Alberta Memoir I, 130 pages.

——— (1963): Criteria for differentiating the McMurray and Clearwater Formations in the Athabasca Oil Sands; Research Council of Alberta Bulletin 14, 32 pages.

——— (1965): Athabasca Oil Sands bibliography (1789-1964); Research Council of Alberta Report 65-3, 91 pages.

Carrigy, M.A. and G.A. Collins (1959): Geology of McMurray area Alberta; map, scale 1:253,440, attached to Research Council of Alberta Memoir I.

Carrigy, M.A. and M.J. Zamora (1960): The Athabasca Oil Sands; *in* Oil Fields of Alberta; Alberta Society of Petroleum Geologists, pages 38-49.

Dusseault, M.B. (1977): The geotechnical characteristics of the Athabasca oil sands; unpublished Ph.D. thesis, University of Alberta, Edmonton, 472 pages.

Ells, S.C. (1926): Bituminous sands of northern Alberta; Canada Mines Branch Report 632, 239 pages.

Franklin, J. (1828): Narrative of a second expedition to the shores of the polar sea in the years 1825, 1826, and 1827, including an account of the progress of a detachment to the eastward by John Richardson; John Murray, London.

Godfrey, J.D. (1970): Geology of the Marguerite River district, Alberta, Research Council of Alberta map, scale 1:63,360.

Government and University of Alberta (1969): Atlas of Alberta; University of Alberta Press in association with University of Toronto Press.

Gravenor, C.P. and W.O. Kupsch (1959): Ice-disintegration features in Western Canada; Journal of Geology, Vol. 67, pages 48-64.

Green, R. (1958): Precambrian basement features in northern Alberta; Research Council of Alberta Bulletin 3, 12 pages.

——— (1972): Geological Map of Alberta; Research Council of Alberta map, scale 1:1,267,000.

Green, R., M.A. Carrigy and G.B. Mellon (1970): Bedrock geology of northern Alberta (map with descriptive notes); Research Council of Alberta map, scale 1:500,000.

Hackbarth, D.A. (1971): Dewatering scheme for overburden of Great Canadian Oil Sands, Fort McMurray; Research Council of Alberta, Groundwater Division Internal Report, 72 pages.

——— (1974): Preliminary hydrogeological assessment of Daphne Island Lease for Petrofina Canada Ltd.; Alberta Research Council Groundwater Division Internal Report, 42 pages.

——— (1977): Regional hydrogeology of the Athabasca Oil Sands Area, Alberta, Canada; Canadian Institute of Mining and Metallurgy, Special Volume 17, pp. 87-102.

Hackbarth, D.A. and N. Nastasa (1979): Hydrogeology of the Athabasca Oil Sands Area, Alberta, Alberta Research Council Bulletin 38, 39 pages.

Hitchon, B. (1963): Composition and movement of formation fluids in strata above and below the pre-Cretaceous unconformity in relation to the Athabasca Oil Sands; *in* the K.A. Clark Volume, Research Council of Alberta Information Series 45, pages 63-74.

Hitchon, B., A.A. Levinson and S.W. Reeder (1969): Regional variations of river water composition resulting from halite solution, Mackenzie River Drainage Basin, Canada; Water Resources Research, Volume 5, pages 1395-1403.

Intercontinental Engineering of Alberta Ltd. (1973): An environmental study of the Athabasca tar sands; Alberta Environment, 111 pages.

Kahil, A. (1968a): Interim report of feasibility study for dewatering the overburden in GCOS Lease 86; Research Council of Alberta Groundwater Division Internal Report, 39 pages.

——— (1968b): Second interim report on feasibility study for dewatering the overburden in GCOS Lease 86; Research Council of Alberta Groundwater Division Internal Report, 12 pages.

Kerr, H.A. and D.A. Shillabeer (1969): Fort MacKay Settlement water supply report; Alberta Department of Agriculture Internal Report, 17 pages.

Linckens, W.M.J. (1965): Final report on the overburden - Lease 4 - Athabasca River area, Alberta, Canada; Great Canadian Oil Sands Ltd., unpublished manuscript, 20 pages.

Lindsay, J.D. and W. Odynsky (1965): Permafrost in organic soils of northern Alberta; Canadian Journal of Soil Science, Vol. 45, pages 265-269.

Longley, R.W. (1972): The climatic maps of the Prairie Provinces; Environment Canada, Atmospheric Environment, Climatological Studies B, Toronto, 79 pages.

Martin, R. and F.G.S. Jamin (1963): Paleogeomorphology of the buried Devonian landscape in northeastern Alberta; *in* the K.A. Clark Volume, Research Council of Alberta Information Series 45, pages 31-42.

Mellon, G.B. and J.H. Wall (1956): Geology of the McMurray Formation Parts I and II; Research Council of Alberta Report 72, 43 pages.

Mollard, J.D. and H.E. Dishaw (1961): Regional slope-stability study Fort McMurray-Bitumount region, Alberta; 19 pages.

Norris, A.W. (1963): Devonian stratigraphy of northeastern Alberta and northwestern Saskatchewan; Geological Survey of Canada Memoir 313, 168 pages.

Ozoray, G. (1974): Hydrogeology of the Waterways — Winefred Lake Area, Alberta; Alberta Research Council Report 74-2, 18 pages.

——— (1975): Lineament analysis using ERTS-1 images of Alberta; Proceedings, International Water Resources Association, Seminar and Exposition Water Resources Instrumentation, Chicago, 1974, Vol. 2, pages 456-466.

——— (1976): The scientific and economic value of karst studies in Alberta; The Albertan Geographer, No. 12, pages 43-60.

——— (1977): The Athabasca carbonate and evaporite buried karst; International Association of Hydrogeologists, Memoir 12, pages 85-98.

Pugh, D.C. (1973): Subsurface lower Paleozoic stratigraphy in northern and central Alberta; Geological Survey of Canada Paper 72-12, 54 pages and 13 figures.

Reeder, S.W., B. Hitchon and A.A. Levinson (1972): Hydrogeochemistry of the surface waters of the Mackenzie River drainage basin, Canada - 1. Factors controlling inorganic composition; Geochemica et Cosmochemica Acta, Vol. 36, pages 825-865.

Richardson, J. (1851): Arctic searching expedition: A journal of a boat voyage through Rupert's land and the Arctic sea, in search of the discovery ships under command of Sir John Franklin, with an appendix on the physical geography of North America, Vol. 1; Longman Brown, Green, and Langman, London, 413 pages.

Stalker, A. Mac S. (1960): Ice-pressed drift forms and associated deposits in Alberta; Geological Survey of Canada Bulletin 57, 38 pages.

Stashko, E.V. (1971): Precipitation means, Alberta forestry stations May to September 1963-70, 32 pages.

Taylor, R.S. (1960): Some Pleistocene lakes of northern Alberta and adjacent areas; Alberta Society of Petroleum Geologists, Vol. 8, No. 6, pages 167-178 and 185.

Thornthwaite, C.W. and J.R. Mather (1957): Instructions and tables for computing potential evapotranspiration and the water balance; Drexel Institute of Technology, Laboratory of Climatology, Publications in Climatology, Vol. 10, No. 3, pages 181-289.

Tremblay, L.P. (1961): Geology, Firebag River Area, Alberta and Saskatchewan; Geological Survey of Canada Map 16-1961, 1:253,440.

van Everdingen, R.O. (1968): Studies of formation waters in Western Canada — geochemistry and hydrodynamics; Canadian Journal of Earth Science, Vol. 5, pages 523-543.

Alberta
RESEARCH COUNCIL

MAIN MAP LEGEND

Topography

Surface contours and elevation in feet (interval 500 feet) .... —3000—

Geology

Geological boundary ....

QUATERNARY

Qd	Unconsolidated deposits

CRETACEOUS

Klb	Labiche Formation	Kg	Grand Rapids Formation
Kd	Dunvegan Formation	Kc	Clearwater Formation
Ksh	Shaftesbury Formation	Km	McMurray Formation

DEVONIAN

Dum	Undivided Middle to Upper Devonian: Grosmont, Ireton, Cooking Lake, Beaverhill Lake, and Slave Point Formations
Dmm	Undivided Middle Devonian: Fort Vermilion, Watt Mountain, Muskeg, and Prairie Evaporite Formations
Dml	Undivided Lower to Middle Devonian: Methy McLean River and LaLoche Formations

ARCHEAN

A	Undivided Granitic Plutonic Rocks

Note: In the main map legend the designation Dml should read, Undivided Middle Devonian.

Lithology

- Clay
- Sand and gravel
- Sand
- Sandstone
- Sandstone, oil-impregnated
- Silt
- Siltstone
- Shale
- Limestone
- Dolomite
- Salt, anydrite and gypsum
- Granitic plutonic rocks

Hydrography

- Lake or slough, perennial
- Lake or slough, seasonal
- Stream, perennial
- Collapse sink, usually containing a natural pond
- Surface water divide

Hydrogeology

- Spring, flow rate unknown
- Spring, flow rate in igpm (L/sec) 12 (1)
- Nonpumping water level contour in the bedrock (elevation in feet followed by metres in brackets) and vertical component of groundwater movement .... Upward flow 2500(760) Downward flow
- Direction of groundwater flow

Groundwater Probability†

Range of average expected yield of wells in imperial gallons per minute (l /sec)

Probable: estimated from quantitative information (pump tests, bail tests, etc.)
Possible: estimated from qualitative information (flow regime, lithology, etc.)

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

Yield area boundary ....

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

Wells and Other Artificial Works

Depth Scale

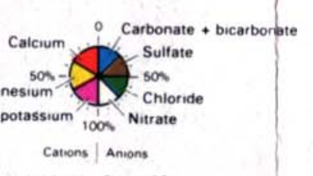
FEET
0
100
200
300
400

Depth to water
Depth of well or seismic shot hole

- Water well, flowing
- Water well, 20-year safe yield calculated from a good bail test or a short pump test
- Water well, 20-year safe yield calculated from a pump test of sufficient length to reflect regional hydraulic conditions
- Observation well:
  - With automatic recorder
  - Without automatic recorder
- Location of Alberta Research Council test hole* .... ARC
- Shothole, flowing
- Structure testhole
- Other testholes (oil well, gas well etc.)
- Depth of exploratory well
- Line of hydrogeological profile .... A A'

*Observation well sites may contain wells of various depths

Hydrochemistry



Note: When the yellow Mg pie sector is absent, Ca + Mg are represented as a unit by the red pie sector.

Total dissolved solids in parts per million:
defined 500
approximate 500

Isogram along which calcium + magnesium constitute 60 percent of total cations*; teeth indicate direction of lesser calcium + magnesium content:
defined
approximate

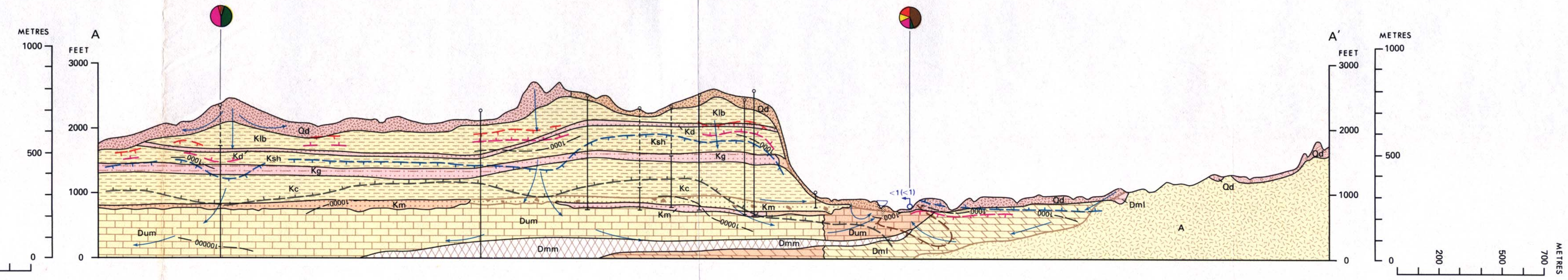
Isogram along which sodium + potassium constitute 60 percent of total cations*; teeth indicate direction of lesser sodium + potassium content:
approximate

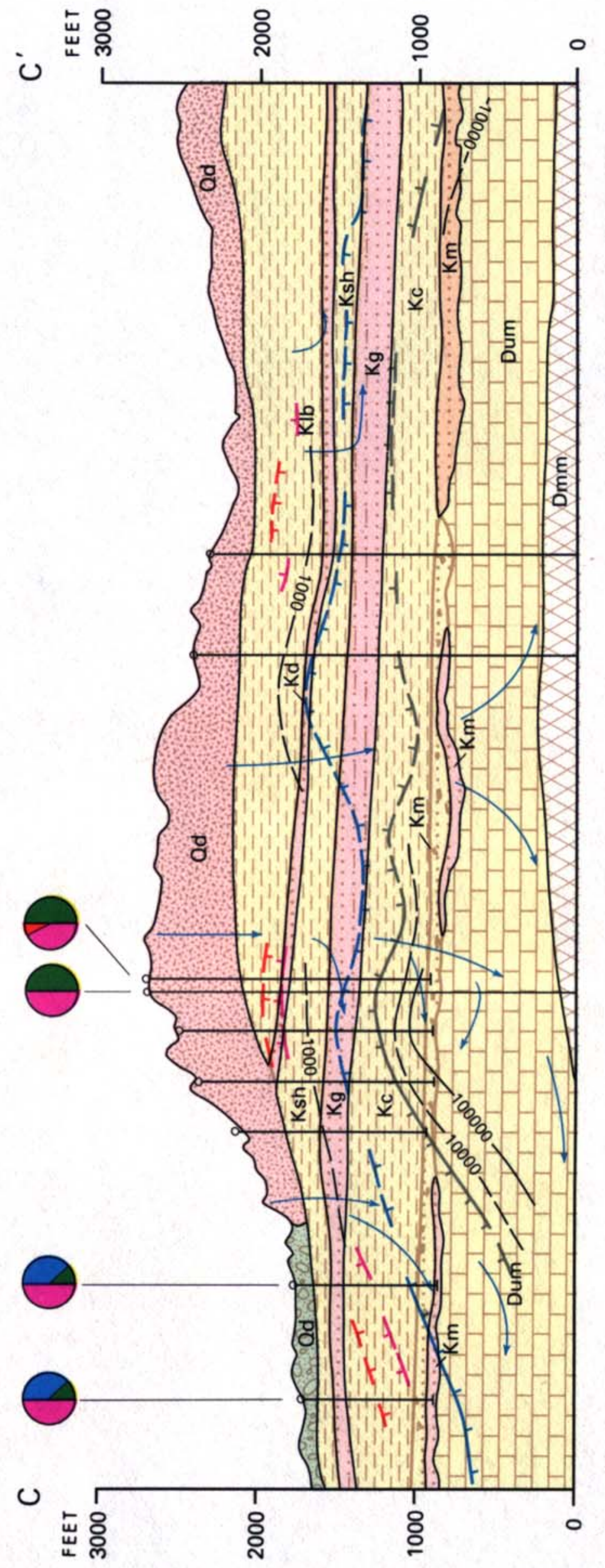
Isogram along which carbonate + bicarbonate constitute 60 percent of total anions*; teeth indicate direction of lesser carbonate + bicarbonate content:
defined
approximate

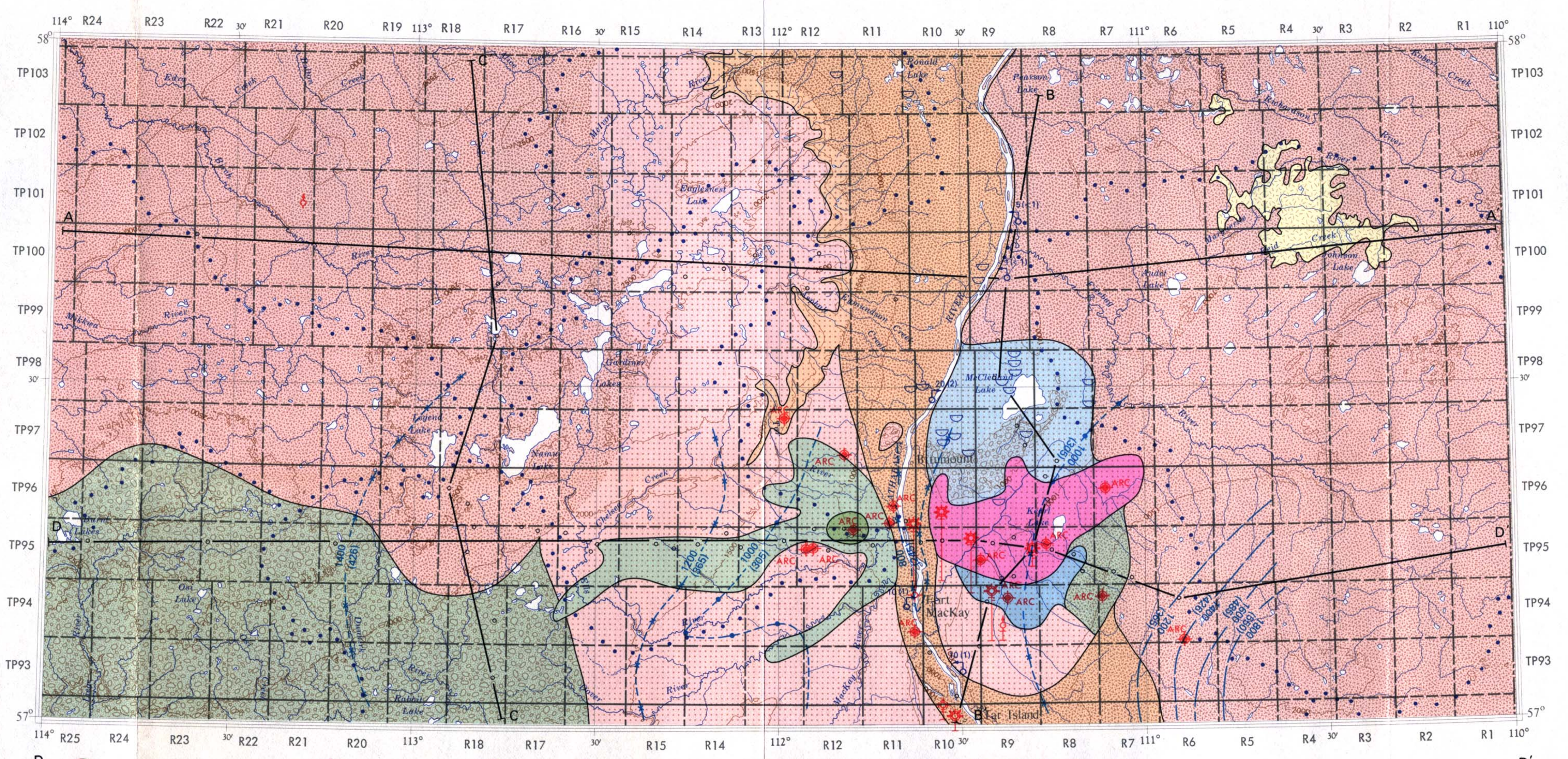
Isogram along which sulfate constitutes 60 percent of total anions*; teeth indicate direction of lesser sulfate content:
defined
approximate

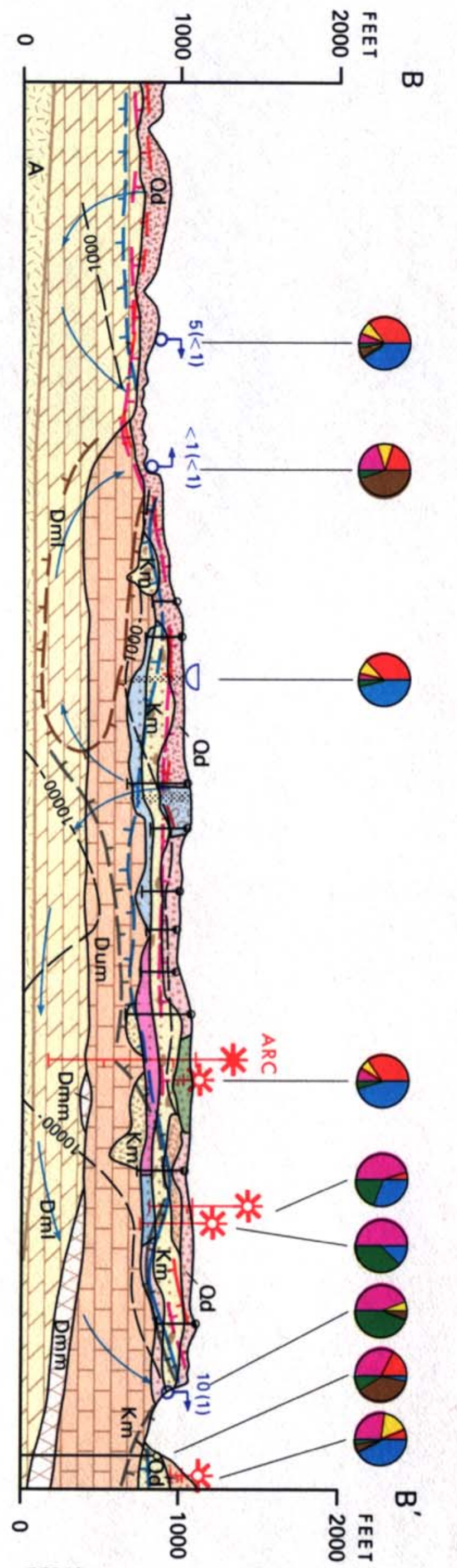
Isogram along which chloride constitutes 60 percent of total anions*; teeth indicate direction of lesser chloride content:
defined
approximate

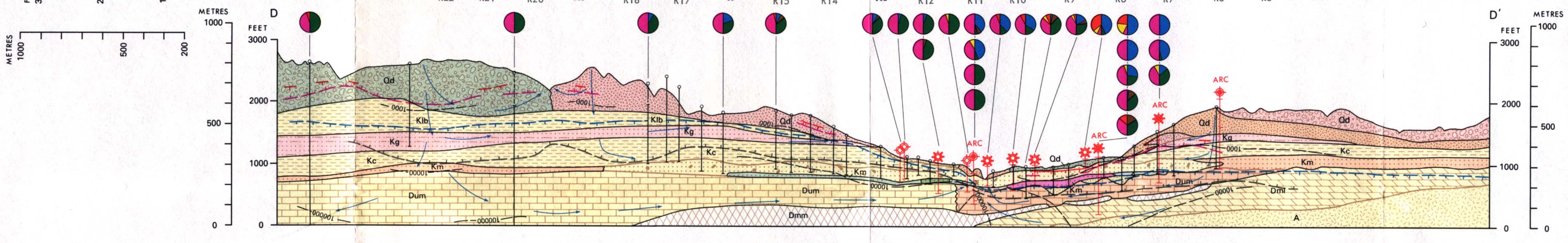
*Determined on equivalents per million basis

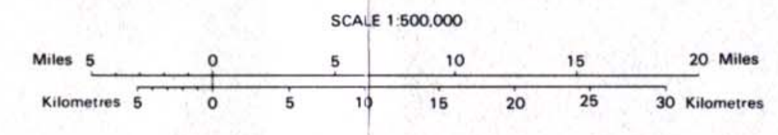












HYDROGEOLOGICAL MAP
BITUMOUNT-NAMUR LAKE
ALBERTA

NTS 74E-84H

All elevations in feet above mean sea level.

Vertical exaggeration of the hydrogeological profiles is approximately 40X.

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

Map to accompany Earth Sciences Report 78-6.

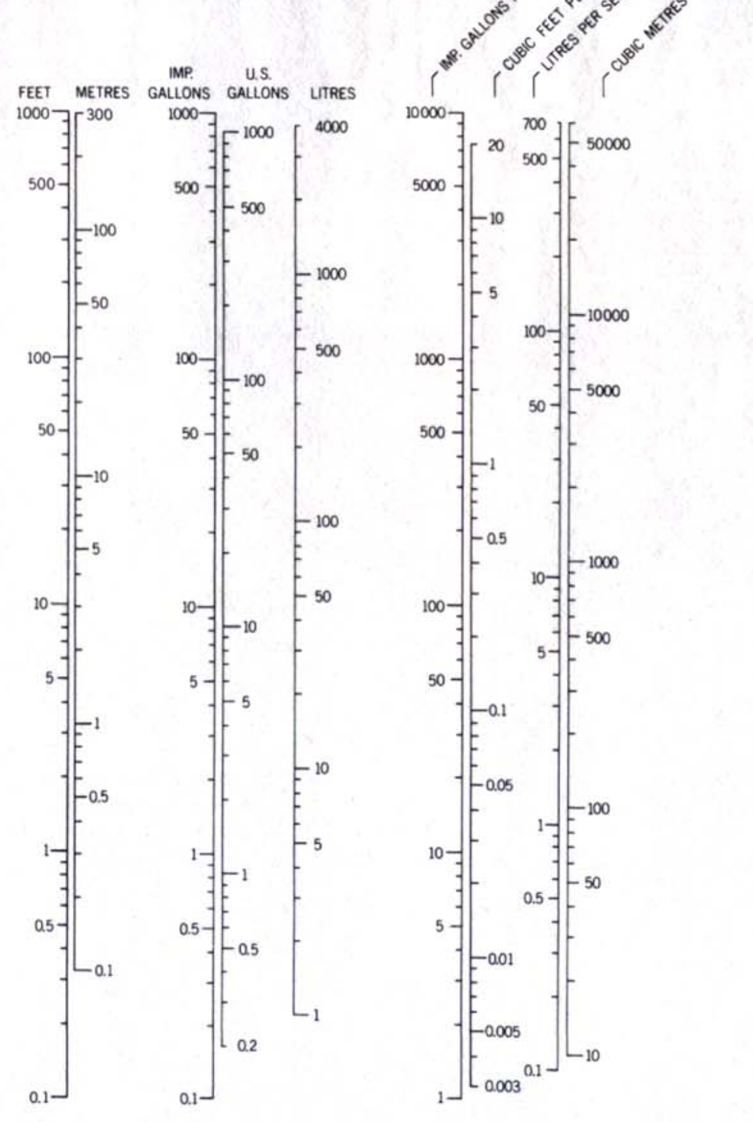
Hydrogeology by G.F. Ozoray, D.A. Hackbarth and A.T. Lytviak.

Drafted by R.W. Swenson.

Cartographic editing by A.R. Campbell.

CONVERSION TABLE

LOGARITHMIC SCALE



Sheet 1 of 2

Base map provided by Surveys and Mapping Branch.