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SURFICIAL GEOLOGY OF POTENTIAL MINING AREAS IN THE ATHABASCA OIL SANDS REGION

prepared by

R.A. McPherson

and

C.P. Kathol

of

QUATERNARY GEOSCIENCES LTD.

for

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CONTENTS

ILLUSTRATIONS

TABLES

ABSTRACT

A surficial geology study of potential mining areas in the Athabasca oil sands region was undertaken by the Alberta Research Council in response to increasing demand for geologic information on deposits overlying the Athabasca Oil Sands.

The near surface bedrock in the study area includes the Devonian Waterways Formation (primarily carbonates), the Cretaceous McMurray Formation (oil impregnated sandstone), the Cretaceous Clearwater Formation (shale), the Grand Rapids Formation (sandstone) and younger undifferentiated Cretaceous units (shales).

The Waterways, McMurray, and Clearwater Formations form the surface bedrock in the Athabasca Lowlands and the Clearwater, Grand Rapids, and undifferentiated shales are found on major bedrock uplands.

The basic configuration of the bedrock surface was established during preglacial times when rivers flowing northeastward from the Alberta Plains produced a series of drainage basins separated by major bedrock uplands, namely Birch Mountains, Thickwood Hills and Muskeg Mountain. These large scale features of the bedrock surface are still reflected by the configuration of the present land surface.

The top of the Waterways Formation is highly dissected by erosion and exhibits evidence of well developed karst topography. The surface of the overlying bedrock units is considerably more uniform except in areas of extensive postglacial erosion.

Surficial deposits composed of preglacial, glacial and postglacial sediments completely cover the study area. They range in thickness from a few feet to over 450 feet on the slopes of Muskeg Mountain.

Surface deposits and landforms resulting from glacial and postglacial deposition and erosion include till, glacio-fluvial, glacio-lacustrine, lacustrine, aeolian, alluvial and organic deposits and recent erosional features.

The surficial sediments have been subdivided into several stratigraphic units. These are in ascending order, preglacial gravels and sands, Saskatchewan gravels and sands, undifferentiated till and stratified sediments, unnamed till, Firebag till, lower stratified sediments, Fort Hills till, upper stratified sediments, meltwater channel sediments, and recent sediments.

The unnamed till has been identified on Thickwood Hills and on the Steepbank River. The Firebag till is known to underlie most of the study area and represents the last major glaciation in the region. The Fort Hills till occurs in the northern portion of the study area and is attributed to a local readvance of ice in the Athabasca valley.

The till units are not correlated with tills found elsewhere in Western Canada because their age is uncertain. It is postulated that the Firebag and Fort Hills tills are Late Wisconsin in age.

Sand and gravel deposits suitable for aggregate manufacture are present in the region but they are not overly abundant. Reserves sufficient for development of several additional oil sands plants can likely be found in meltwater channels along the Athabasca valley and in outwash deposits elsewhere.

The geotechnical characteristics and engineering behavior of surficial and bedrock deposits will exert considerable influence on the development of both surface mining and in situ recovery operations. Detailed examination of these materials will be essential in areas where surface mining operations proceed.

INTRODUCTION

PURPOSE OF STUDY

The Athabasca Oil Sands, which contain in excess of 700 billion barrels of heavy oil, constitute one of the worlds largest known reserves of petroleum. To date, one oil sands plant is on production (Great Canadian Oil Sands) and a second under construction (Syncrude). Continued demand for conventional energy resources is expected to result in construction of additional oil sands plants in the future. Development of these reserves will likely include both surface mining operations and in situ recovery techniques; the method of recovery being, to some extent, a function of the depth of occurrence of the oil sands below surface. Both methods of recovery will require a working knowledge of the geologic materials overlying the oil sands; however the demand for geologic information is expected to be greatest in areas where surface mining occurs because the deposits overlying the oil sands have to be completely removed prior to mining and the excavated areas reclaimed upon completion of mining operations.

In response to the increasing demand for geologic information, Alberta Energy and Natural Resources and Alberta Research Council in co-operation, initiated a project to outline the nature and distribution of the surficial geologic deposits overlying the oil sands in areas which have potential for development of surface mining operations. The following report summarizes the results of this study. It is important to note that geologic mapping, although conducted on a scale of 1:50,000, should be considered of a reconnaissance nature, suitable for outlining the basic geologic framework of the study area. Considerably more detailed mapping will be required in areas where actual mining operations occur because of the variability of the geologic deposits over short distances.

LOCATION AND ACCESS

The study area, situated in the Athabasca Oil Sands region of northeast Alberta, occurs between latitudes 56°58'37" and 57°30' north and longitudes 111° and 112° west (Figure 1). It covers approximately 1720 square miles and includes all or portions of townships 91 to 98 between ranges 7 to 13 west of the fourth meridian. Fort McMurray, located 9 miles south of the study area, is the main population centre in the region. The two existing oil sands extraction plants, Great Canadian Oil Sands at Tar Island (in production) and the Syncrude Project at Mildred Lake (under construction) are located in the south central portion of the study area (Figure 1).

Access to Fort McMurray is good consisting of provincial highway No. 63, a rail line operated by Northern Alberta Railways, and regular scheduled air service. Provincial trunk road 963 trends north from Fort McMurray along

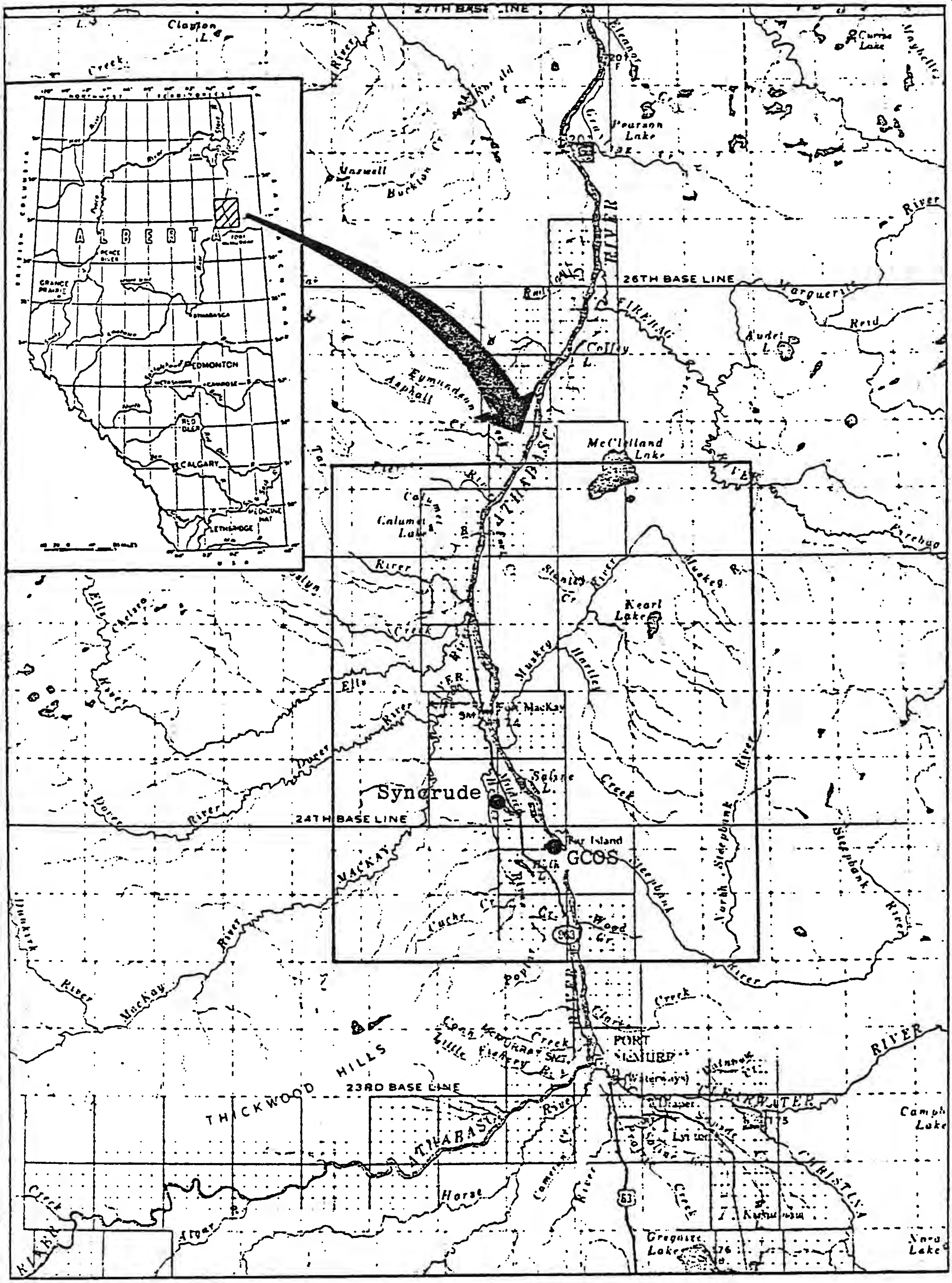


FIGURE 1: Location map of study area.

the Athabasca River providing all weather access to the region as far north as Fort McKay. Access to the remainder of the study area is limited consisting primarily of roads and trails constructed for exploration programs; these roads and trails are often only suitable for travel in winter when muskegs and streams are frozen.

PREVIOUS WORK

The oil sands deposits have been the subject of considerable geologic interest since they were discovered, primarily because of their immense size and potential economic significance.

The earliest geologic reports on the area were published by Bell (1884) and McConnell (1893a). Since that date, numerous published and unpublished reports have been compiled by various workers, government agencies and oil companies. A historical review of studies conducted to date on the oil sands deposits is provided by Carrigy (1973).

The most comprehensive published information on the bedrock geology of the region is found on geologic maps by Green, Mellon and Carrigy (1970) and in reports by Carrigy (1959, 1973) and Norris (1973). In addition, Hamilton and Mellon (1973) published a report outlining the industrial mineral resources of the region. There is little published information on the surficial geology of the area; the most recent consisting of 1:250,000 scale surficial geology maps of NTS sheet 74D (Waterways) by Bayrock and Reimchen (1973) and NTS sheet 74E (Bitumount) by Bayrock (1970). Considerable unpublished data on the surficial deposits has been compiled from numerous exploration programs; most of this data is on file with various government departments and has been incorporated in this report.

METHOD OF STUDY

In the initial stages of the study, a preliminary air photo interpretation of the surficial geology was prepared on a scale of 1:50,000. Field mapping was conducted in the summer of 1974 utilizing 4 wheel drive vehicle, boat, and helicopter support. Field stops were made along systematic traverses throughout the study area to describe the surface materials and available geologic sections and to collect samples for laboratory analyses.

Upon completion of the field mapping, surficial geology maps were completed on a scale of 1:50,000.

In 1975, a portion of the existing test hole data was examined and a drilling program designed to provide additional information in areas of sparse test hole data.

The drilling program, which was conducted in the winter of 1975-76, consisted of fifty-three (7 inch diameter) dry auger holes (maximum depth 145') and two hundred twenty-two (6 inch diameter) dry auger holes (maximum depth 87') or a total of 275 holes. Ninety-three of the holes were drilled in the northeast portion of the study area as part of a program to determine the suitability of the area for townsite development. The remainder of the holes were drilled along existing trails in the balance of the area.

Field tests and procedures for the drilling program included:

(1) collection of samples at 5' intervals,

(2) standard penetration tests,

(3) continuous cone penetrometer tests,

(4) selected shelby tube samples

and (5) installation of standpipes for monitoring groundwater table fluctuations in the potential townsite areas.

Upon completion of the drilling program, samples were analyzed for mineralogical composition (very coarse sand fraction), geotechnical properties and indicies and the surficial maps revised to include the new test hole information.

Data from the drilling program was combined with existing test hole data to prepare a series of subsurface geologic maps and cross sections of both surficial and bedrock deposits.

In the final stages of the study, the results were synthesized and the following report prepared which outlines the nature and extent of the surficial geologic deposits on a scale of 1:125,000. To a lesser extent, the bedrock units are also described; however no attempt has been made to outline the quality of the oil sands.

ACKNOWLEDGEMENTS

The surficial geology mapping portion of the project was initiated in 1974 with funding provided by

Alberta Energy and Natural Resources, and supervision by Alberta Research Council. The project was expanded in 1975 to include subsurface studies of the surficial deposits.

Certain of the data used in the northeast portion of the study area was obtained from a drilling program conducted for a survey of potential new townsites. This program was financed by the Office of the Northeast Alberta Regional Commissioner, Alberta Energy and Natural Resources, and the Alberta Research Council. Personnel from the Alberta Research Council who conducted portions of the field mapping included L.D. Andriashek, M.M. Fenton, and R. May. Supervision of parts of the drilling program was provided by L.D. Andriashek, M.M. Fenton, G. Lobb, J.J. Olic, and R. Young. Helicopter services were provided by Associated Helicopters Ltd., and drilling and support services by Canadian Geological Drilling Ltd. The writers wish to give particular thanks to Mr. & Mrs. C. Pearson of Canadian Geological Drilling for their efforts in aiding the completion of the drilling program. Shell Canada Ltd., provided the use of their base camp for a portion of the drilling program as well as of their ice bridge on the Athabasca River. Information on road and trail conditions was provided by R. McCombe of Syncrude Canada Ltd., and personnel from the Fort MacKay Ranger Station.

Unpublished drill hole data was supplied by D.A. Hackbarth of the Alberta Research Council, Petrofina Canada Ltd., B.P. Canada Ltd., and the Alberta Energy Resources

Conservation Board. J. Chipperfield of Alberta Energy and Natural Resources provided access to a log library of test holes drilled in the oil sands region.

Laboratory analyses were supervised by B. Brugger and S. Bellwood, and drafting services provided by S. Bellwood and L. Jankowski. Many personnel at the Alberta Research Council contributed to the project; the authors would like to give particular thanks to R. Green for his editorial comments, ideas and constructive criticism. Invaluable insights into various aspects of the project were obtained from discussions with M.M. Fenton, L.D. Andriashek, J.W. Kramers and E.A. Babcock. Dr. Fenton provided mineralogical data on several till samples collected from surface exposures in the study area. Many other individuals offered advice and assistance on various aspects of the study and so aided completion of this report.

PHYSICAL GEOGRAPHY

PHYSIOGRAPHIC UNITS

The study area and adjacent regions can be divided into three physiographic units, related to the bedrock geology and major topographic features of northeastern Alberta - these are:

(1) the Canadian Shield to the northeast,

(2) the lowlands adjacent to the Athabasca River,

and (3) dissected highlands (plateau) extending along the western, southwestern and eastern portions of the study area.

Precambrian rocks of the Canadian Shield occur northeast of the study area (Figure 2); however bedrock exposures are scarce owing to the widespread cover of glacial and postglacial deposits.

Lowlands adjacent to the Athabasca River form a large part of the central and north central portions of the study area, generally occurring below an elevation of 1200 feet above sea level. In the northeast part of the area, the lowlands are underlain by carbonate and evaporite rocks of Devonian age. The Devonian strata dip gently to the south and west beneath the cover of lower Cretaceous oil sands (McMurray Formation) and marine shales, into which the Athabasca River is entrenched. The lowest elevations in the study area occur along the Athabasca River ranging from approximately 880 feet (above

FIGURE 2: Physiography and general geology of the Oil Sands Region (after Hamilton and Mellon, 1973).

LEGEND

HIGHLANDS

CRETACEOUS
Clearwater, Grand Rapids and Younger Fms: shales, sandstones

LOWLANDS

CRETACEOUS
McMurray and Clearwater Fms: oil sands, sandstones, shales

DEVONIAN
Carbonates, evaporites

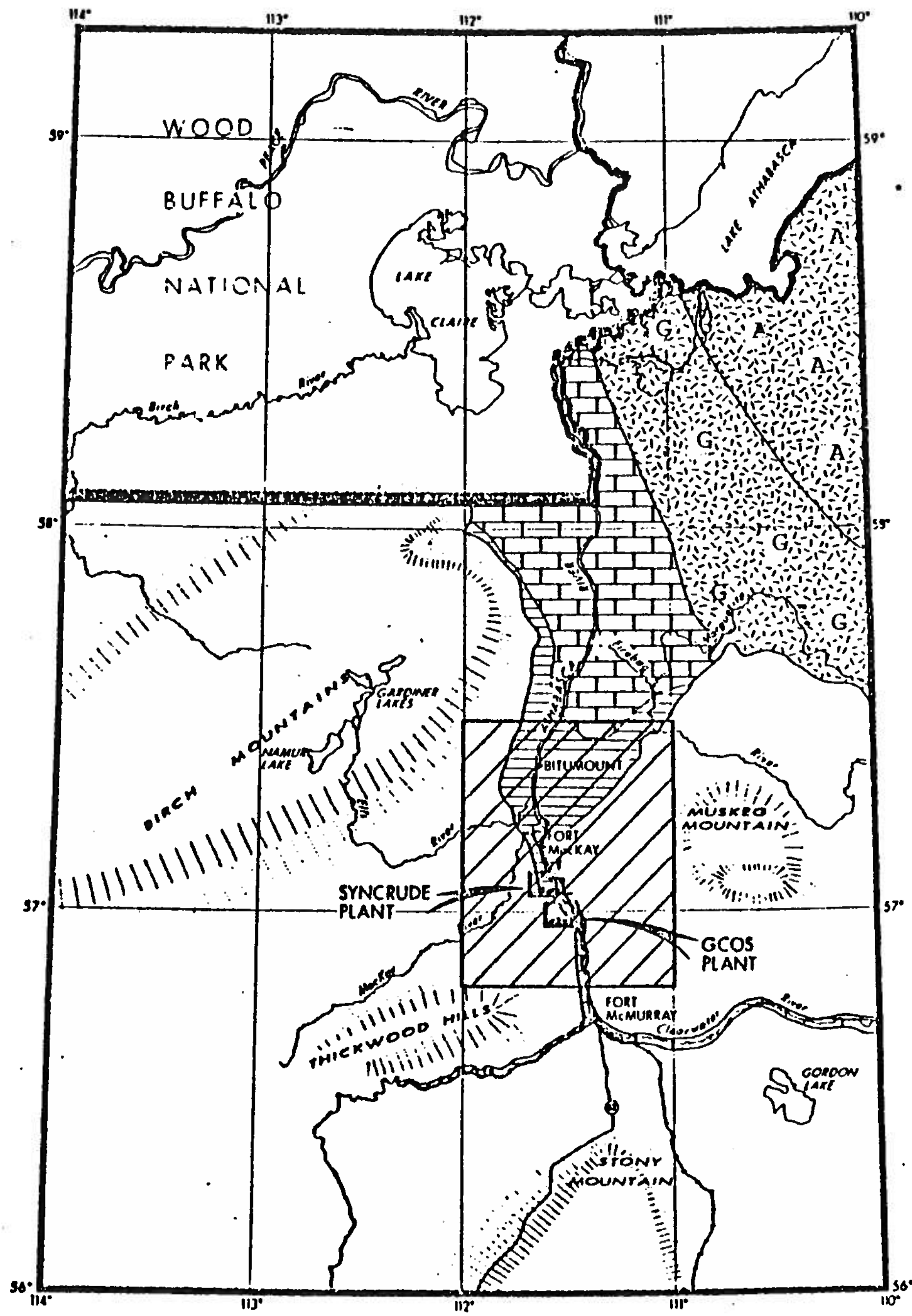
CANADIAN SHIELD

A PRECAMBRIAN
Athabasca Fm: quartzite, sandstone

G PRECAMBRIAN
Crystalline "Basement" Complex: granitic plutonic rocks

Study area boundary

National Park boundary



sea level) at the south boundary of the area to 730 feet at the north end.

The lowland has a veneer of glacial drift, mantled in many places by muskeg, so that bedrock exposures are confined mainly to the Athabasca valley and the lower reaches of its tributary streams.

The drift is generally low relief, the exception being three kame deposits which form highlands up to 200 feet above the surrounding plain. Prominent segments of the kames include highlands near Calumet Lake, the Fort Hills and highlands along the Firebag River to the east of the Fort Hills.

The lowlands adjacent to the Athabasca River merge to the west with the Birch Mountains, to the southwest with Thickwood Hills and to the east Muskeg Mountain (Figure 2). These areas form a series of dissected highlands or tablelands underlain by nearly flat lying shales and sandstones of Cretaceous age (Hamilton and Mellon, 1973). The upper surfaces of the highlands are flat to gently undulating, having been modified somewhat by glaciation. The slopes are gradual to relatively steep depending to some extent on the degree of postglacial erosion that has occurred.

The highest part of the study area is the eastern flank of the Birch Mountains which has an elevation of approximately 2400 feet. Elevations of Thickwood Hills are approximately 1600 feet and on Muskeg Mountain about 1800 feet. The maximum range in elevation in the study area occurs between the Birch Mountains (>2400 feet) and the Athabasca River at the north boundary of the area (approximately 730 feet); a difference of more than 1670 feet.

DRAINAGE

The largest stream in the region, the Athabasca River, is joined by the Clearwater River - a major tributary - near the town of Fort McMurray. The Athabasca River flows northward from Fort McMurray through the central portions of the study area to empty into Lake Athabasca (Figures 1, 2). Numerous tributary rivers and creeks which flow into the Athabasca River have their headwaters on major highlands.

The Steepbank and Muskeg Rivers, both westward flowing tributaries, have their headwaters on Muskeg Mountain. The westward flowing Firebag River has its headwaters in Saskatchewan; the Firebag has a deep trench-like valley incised into both upland and lowland areas. Eastward flowing rivers and creeks are common in the study area having their headwaters in the Birch Mountains or the Thickwood Hills. The MacKay River and Beaver River originate in the Thickwood Hills and flow primarily east and northeast into the Athabasca River. Rivers that have their headwaters in the Birch Mountains and empty into the Athabasca, include the Ells, Tar, Calumet and Pierre Rivers.

CLIMATE

General

In brief, the Fort McMurray region has a climate described as continental, varying between dry and moist subhumid; warm summers and cold winters are typical with moderate precipitation during all seasons. This description, while succinct and simple, is not sufficiently detailed for land use planning. A comprehensive knowledge of climate will be an important and necessary component in planning for future industrial and urban development in the oil sands region. The following description of climate provides a brief insight into climatic conditions and complexities that can be expected in the study area.

The only long term meteorological data that is available for establishing climatic trends is information recorded at the Fort McMurray weather station.

Temperature and precipitation data are also recorded at several Alberta Forestry Stations in and adjacent to the study area - namely Birch Mountain, Ells, Thickwood Hills, Tar Island, Bitumount and Muskeg Stations. Data from all the stations are available for the months of May, June, July and August. Some records are available for the month of September but consistency is poor. Tar Island and Mildred Lake Station (not a forestry station), both of which are located within the Athabasca River valley at the site of oil sands plants, are year round climatic stations but have been in operation only since 1970 and 1973 respectively.

The following brief description of climate is based on data from the Fort McMurray Station for the period 1941-1970. This period (1941-1970) is the current standard 30 year period as recommended by the World Meteorological Organization and reflects the best possible estimate of current climate conditions. Data from the McMurray station provides a general indication of climate; however the microclimate at specific localities in the study area could vary considerably due to such factors as topographic position, vegetative cover, presence of water bodies and industrial development.

Temperature

The temperature at Fort McMurray A Station is quite variable from day to day, season to season and year to year. Daily mean temperature over the 30 year period (1941-1970) was 31.1°F varying between a daily maximum mean temperature of 42.4°F and a mean daily minimum temperature of 19.8°F (Table 1). Winter, if defined as the period of snow cover, lasts 4 to 5 months beginning in November and ending in April. Because little heat is received from the sun at this time, the daily temperature range is relatively small. January, the coldest month of winter has a mean daily temperature of -6.7°F varying between a maximum daily mean of 3.2°F and a minimum daily mean of -8.8°F (Table 1).

Spring is very short, generally occurring over a span of a few weeks during the period March to May. Temperatures rise rapidly as indicated by an increase of the mean daily temperature from 15.1°F in March to 48.2°F in May (Table 1). Although temperatures are rising in March, cold periods with subzero temperatures are not uncommon. The warm summer period extends from mid June to mid August, July being the warmest month of the year with a mean daily temperature of 61.3°F and

TABLE 1. Temperature and precipitation data for Fort McMurray A weather station. *

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
MEAN DAILY TEMPERATURE	- 6.7	2.1	15.1	34.2	48.2	56.3	61.3	58.4	48.2	37.5	16.8	1.5	31.1
MEAN DAILY MAXIMUM TEMPERATURE	3.2	13.6	27.8	46.0	61.3	69.4	74.2	71.0	59.3	47.3	25.1	10.1	42.4
MEAN DAILY MINIMUM TEMPERATURE	-16.5	-9.4	2.4	22.3	35.1	43.1	48.4	45.7	37.1	27.6	8.4	-7.1	19.8
NO. OF DAYS WITH FROST	31	28	31	25	12	3	*	2	9	22	29	31	223
MEAN RAINFALL	0.02	0.01	0.04	0.28	1.22	2.42	2.90	2.52	1.95	0.51	0.10	0.02	11.99
MEAN SNOWFALL	8.7	7.5	7.6	5.0	0.8	T	0.0	0.0	1.1	4.4	9.7	10.2	55.0
MEAN TOTAL PRECIPITATION	0.83	0.68	0.72	0.80	1.30	2.42	2.90	2.52	2.09	0.95	0.98	0.95	17.14

* Station location: 56° 39' N, 111° 13' W
Station elevation: 1213 ft., A.S.L.
Temperature: °F
Precipitation: inches

maximum and minimum daily means of 74.2°F and 48.4°F respectively. As in all continental areas, the transition from summer to winter is rapid, generally occurring within the interval September to November. The rapid transition is reflected by a drop in temperature from a mean daily value of 48.2°F in September to 16.8°F in November. Because of the low angle of the sun in autumn, the mean daily range of temperature is lower than in summer. However, temperatures may occasionally exceed 80° in September or fall below zero in October.

Precipitation

Precipitation at the Fort McMurray A weather station was moderate during all seasons for the 30-year period 1941-1970, the total mean precipitation being 17.14 inches (Table 1). Of this total 69.95% was rain (11.99 inches) and 30.05% was snow (55 inches)[1]. Precipitation in the winter months which is relatively low consists mainly of snow (Table 1). The maximum snowfall occurs in December which has a mean of 10.2 inches. Minimum monthly precipitation occurs in February with a mean of 0.68 inches, most of which is snow.

In the spring months, there is a rapid increase in precipitation from the winter mimumum. This is reflected by an increase in total precipitation from 0.72 inches in March (primarily snow) to 1.30 inches in May (primarily rain).

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1 In computing precipitation, 1 inch of snow is generally assumed to have 0.1 inches of moisture.

Precipitation during the summer months is normally greater than any other season; the period June to August providing 45.4% of the total yearly precipitation. July is the wettest month of the year receiving a mean precipitation of 2.90 inches of rainfall. Precipitation decreases rapidly in autumn as reflected by a drop in total mean precipitation from 2.09 inches in September to 0.95 inches in October. Snowfall increases substantially during this time span from a mean of 4.4 inches in September to 9.7 inches in November.

Frost

Fort McMurray A weather station received a mean total of 223 days of frost per year over the 30 year period 1941 to 1970; 88.3% of which occurred during the interval October to April (Table 1). For the study area, the average date of the last frost in spring occurs in the first two weeks of June (Longley, 1972); the average date of the first fall frost is in the last week of August to the first week of September (op. cit.). The mean length of the frost free season is approximately 80 days; however, the variability of frost from year to year is considerable and the values presented should serve as a guideline to expected conditions.

Wind

Wind speed, as well as prevailing wind direction fluctuate according to the season. For most of the year calm periods or extended periods of light winds are common. Wind speeds range from 4 to 7 mph for much of the year and seldom exceed 12 mph.

In winter, prevailing winds are from the east although winds from the east-south-east in November and December and from the northwest in January and February are also common (Climatology Division, Meteorological Branch, Department of Transport, 1968).

In summer, prevailing winds are from the east-south-east and southwest (op. cit.).

VEGETATION AND SOILS

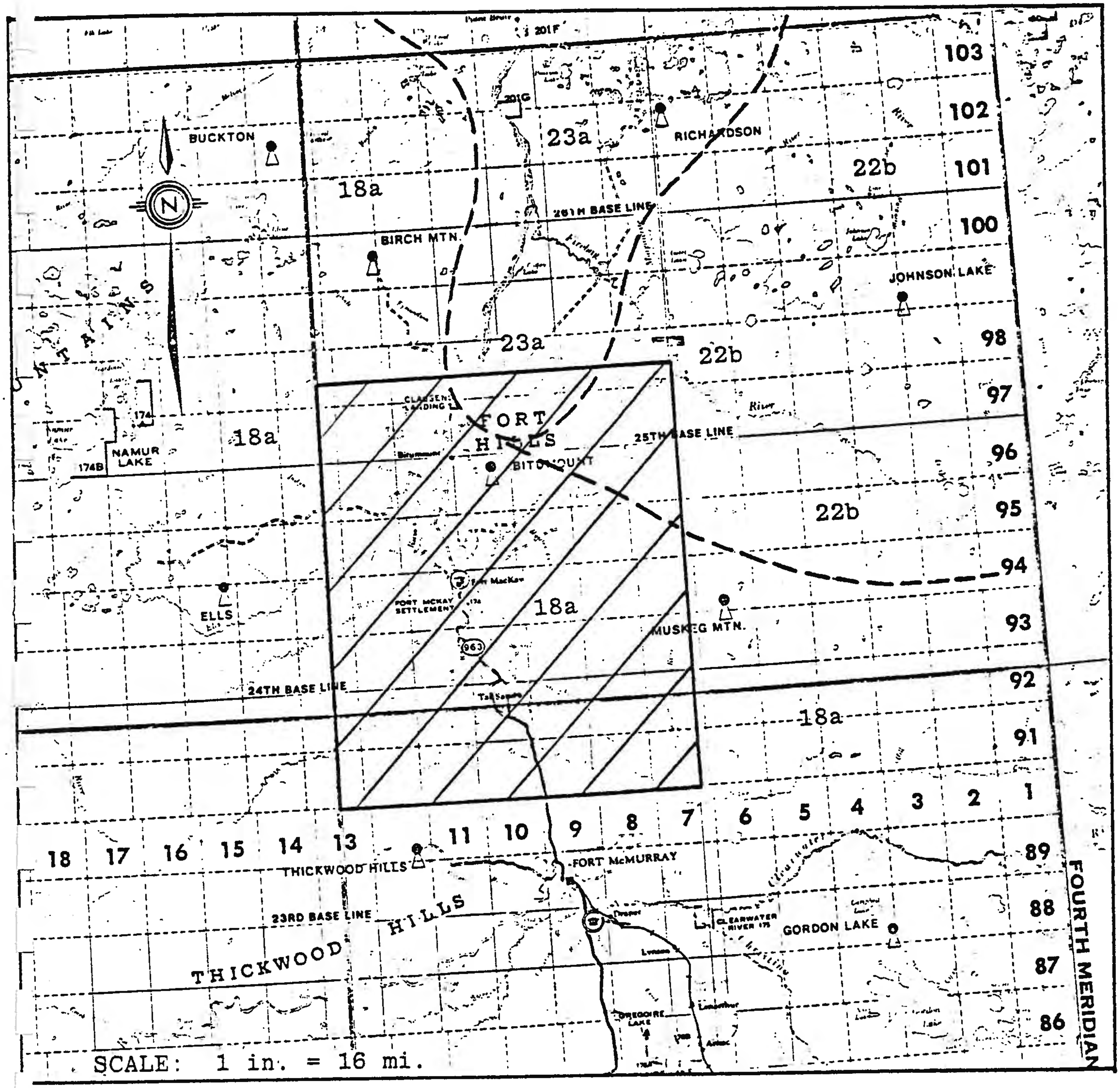
Northeast Alberta is entirely within the Boreal Forest Region as described by Rowe (1972). This is the largest forest region in Canada forming a continuous band from Newfoundland and the Labrador coast to Alaska. The Boreal Forest Region has been subdivided on the basis of distinctive patterns of vegetation and physiography into Forest Sections (Rowe, 1972). Three of these sections are present in and adjacent to the study area, namely:

(1) Mixedwood Section,

(2) Athabasca South Section,

and (3) Upper Mackenzie Section.

In the Mixedwood Section, which covers most of the study area, the characteristic forest association of well drained uplands is a mixture of trembling aspen and balsam poplar, white and Alaska birches, white spruce and balsam fir (Figure 3). The trembling aspen cover type accounts for the greatest area as a result of its rapid regeneration following disturbance. Jackpine is present on sandier areas



LEGEND

Study area

Forest section number

18a	Mixedwood Section
22b	Athabasca South Section
23a	Upper Mackenzie Section

FIGURE 3: Regional forest distribution in the study area (after Rowe, 1972).

and mixes with black spruce on hills. Wetter areas commonly have a cover of black spruce and tamarack.

Forest cover in the Athabasca South Section which occurs in the northeast portion of the study area, consists primarily of jackpine which is adapted to the sandy soils, rigorous climate and frequent fires. Moister sandy and finer-textured soils support black spruce and tamarack. Trembling aspen, balsam poplar and white spruce are common along river valleys. Balsam fir is sometimes associated with the white spruce as well.

A small segment in the northeast portion of the study area is within the Upper Mackenzie Section as defined by Rowe(1972). On alluvial terraces along streams, common tree types are white spruce, balsam poplar, balsam fir and Alaska and white birch. On higher areas, jackpine and trembling aspen are common whereas moist to wet areas commonly have a growth of black spruce and tamarack.

More detailed data on the nature and extent of the vegetation in the study area are available on Forest Cover Maps (Scale 1:63,360) published by Alberta Energy and Natural Resources.

Mineral soils in the oil sands area belong to the Grey Wooded Soil Group; however at least 60% of the area is covered by organic soil which is often referred to as muskeg. Because of the affect of muskeg on development, its nature and extent is discussed more fully in subsequent sections of the report. Most of the study area has been classified as pasture and woodland (Lindsay et al., 1957, 1961, 1962). Poor soil and lack of drainage generally makes the region unsuitable for agricultural development.

BEDROCK GEOLOGY

INTRODUCTION

The prime purpose of this report is to provide information on the nature and extent of surficial geologic deposits overlying the Athabasca Oil Sands. However, when analyzing existing test hole data, it was often necessary to identify the contacts of the bedrock units from geophysical logs to be certain whether the materials were bedrock or surficial deposits. This problem arose because of the poor quality of lithologic descriptions of surficial deposits in existing test holes as well as the similarity in log response between certain bedrock and surficial materials. Because a large volume of bedrock data was generated from the examination of existing test holes, as well as from the 1976 drilling program, a series of structure contour and isopach maps of the bedrock units were prepared. These maps will be relevant to oil sands mining operations because all bedrock above mineable oil sands has to be removed prior to development.

In the following section of the report, the geology of the bedrock deposits in the study area is discussed. Geologic descriptions are based primarily on the work of Norris (1973), Carrigy (1959, 1973) and Green, Mellon and Carrigy (1970); however descriptions of the maps constructed as part of this project are also provided.

GENERAL GEOLOGY

The general stratigraphy of post Precambrain strata in the oil sands region is outlined on Table 2. Geologic deposits consist of rocks of Precambrian, Devonian and Cretaceous age unconformably overlain by surficial deposits of Pleistocene and Recent Age.

PRECAMBRIAN

Precambrian rocks do not outcrop in the study area but form the surface bedrock in a wide northwest-southeast trending belt located approximately 10-15 miles northeast of the study area (Figure 2). Rock types consist of granitic plutonic rocks with some granite gneiss and metasedimentary rocks (Green, Mellon and Carrigy, 1970). Farther east, the Precambrian Athabasca Formation forms the surface bedrock, consisting of variously coloured, medium to coarse grained sandstone.

In and adjacent to the study area, several wells have penetrated into the Precambrian basement; data on these wells is outlined on Table 3.

A structure contour map of the Precambrian surface in the oil sands region prepared by Carrigy (1959) indicates that considerable local relief is superimposed on a south-westerly regional slope of about 30 feet to the mile. It is expected that further drilling will demonstrate that the configuration of the Precambrian surface is quite complex.

Table 2. General Stratigraphy of Post-Precambrian Strata in the Athabasca Oil Sands Area (after Carrigy, 1973)

System or Series	Formation	Member	Lithology
Pleistocene and Recent			Surface deposits of till, sand, silt, and gravel
	Erosional unconformity		
Cretaceous	Colorado Group		
	LaBiche		Shale
	Pelican		Sandstone
	Joli Fou		Shale
	Mannville Group		
	Grand Rapids		Lithic sand and sandstones
	Clearwater		Shale
		Wabiskaw	Glauconitic sandstone
	McMurray		Quartzose sand impregnated with heavy oil
	Erosional unconformity		
Upper Devonian	Woodbend Group		
	Grosmont		Limestone reef
	Ireton		Shale and shaly limestone
	Cooking Lake		Limestone
	Beaverhill Lake Group		
	Waterways	Mildred	Argillaceous limestone
		Moberly	Limestone
		Christina	Calcareous shale
		Calumet	Clastic limestone
		Firebag	Argillaceous limestone
	Paraconformity		
	Slave Point		Limestone and dolomite
	Paraconformity		
Middle Devonian	Elk Point Group		
	Prairie Evaporite		Anhydrite and salt
	Methy		Reefal dolomite
	McLean River		Dolomite claystone and evaporite
	LaLoche		Claystone and Arkosic sandstone
	Erosional unconformity		
Precambrian			Metasedimentary rocks and granite

Table 3

Data on wells drilled to Precambrian basement in study area

Well Name	Location Lsd	Sec	Twp	Rge	Elevation (K.B.) (feet)	Total Depth (feet)	Elevation of Precambrian Surface (ft)
Baysel Steepbank 13-16	13	16	91	8	1439	1568	-129
Baysel Steepbank 15-29	15	29	91	8	1319	1438	-119
Bear Rodeo No. 2	5	17	91	9	804	1064	-259
Bear Vampire No. 2	4	32	93	10	793	883	-82
Athabasca Oils Ltd. No. 1	8	2	96	11	816	1130	-289

PALEOZOIC

Paleozoic rocks in the oil sands region include middle and upper Devonian successions as outlined on Table 2.

Middle Devonian

Middle Devonian rocks in the study area comprise the Elk Point Group which includes the LaLoche, McLean River, Methy, and Prairie Evaporite Formations (Table 2).

The LaLoche Formation consists of the basal Paleozoic beds, mainly arkosic sandstones, unconformably overlying the Precambrian basement.

The McLean River Formation was named for the shale, siltstone and dolomite beds conformably overlying the LaLoche Formation and underlying the Methy Formation.

The Methy Formation in the study area consists mainly of dolomite with minor dolomitic limestone. None of these three Formations outcrop in the study area.

Prairie Evaporite and Muskeg Formations

The evaporite beds of the upper Elk Point Group change facies from predominantly salt in Saskatchewan and central Alberta to predominantly anhydrite in northern Alberta. The name Prairie Evaporite was introduced by Baillie (1953a, b) for the salt beds and the name Muskeg Formation by Law (1955) for the equivalent strata in northern Alberta.

In the study area, these strata overlie the Methy Formation and are overlain in turn by the thin limestone and limestone breccia of the Slave Point Formation.

In the Bear Biltmore well (7-11-87-17W4) this interval consists of a lower unit (697 feet thick) of mainly smoky grey rock salt with anhydrite and an upper unit (82 feet thick) composed of silty shale, dolomitic shale, and silty anhydrite in the lower half, and mainly dolomite with some limestone and anhydrite in the upper half. Eastward from this well, towards the edge of the Canadian Shield, some of the salt grades laterally to anhydrite, gypsum and dolomite, and a large part of the salt has been removed by solution. Norris (1973) indicated that the upper unit is not readily distinguishable towards the east. Further data on the lithology and thickness of the evaporite formations in wells in the study area may be found in Norris (1973) and Carrigy (1959).

The presence of the evaporites under the oil sands is of considerable importance to oil sands mining operations for several reasons.

Firstly, groundwater flow often causes solution of the evaporites, resulting in saline groundwater which has to be dealt with in oil sands operations.

Secondly, as Martin and Jamin (1963) pointed out, there has been considerable thinning of the evaporite section of the Elk Point Group, caused by the gradual removal of salt beds by solution in a belt about 40 miles west of where the evaporite beds intersect the surface. Much of the resulting subsidence is expected to have taken place in pre-Cretaceous times, but the fact that the process has been active more recently is indicated by salt springs and the presence of numerous sinkholes and collapse structures reflecting through the overlying bedrock and/or glacial drift. This solution and resultant collapse of the overlying Waterways Formation has exerted considerable influence on the deposition of the oil sands.

Thirdly, the presence of active and/or inactive sinkholes in mining areas could be of significant geotechnical importance. For these reasons, the nature and extent of the sinkholes and collapse structures, as well as their importance to mining operations is discussed more fully in subsequent sections of the report.

Slave Point Formation

The Slave Point Formation (Cameron, 1918) in the oil sands region is a relatively thin rock unit composed of limestone, silty limestone, siltstone and minor dolomitic limestone, overlying beds of the Elk Point Group and overlain by the Firebag member of the Waterways Formation. The Slave Point Formation does not outcrop in the study area; well data on the lithology and thickness of the Slave Point may be found in Norris (1973) and Carrigy (1959).

Some difference of opinion exists as to the age of the Slave Point Formation. Carrigy (1973) assigns the Slave Point to the Upper Devonian, whereas Norris (1973) feels the Middle - Upper Devonian boundary should be placed at the contact between the Slave Point Formation and the overlying Waterways Formation.

Upper Devonian

The Waterways Formation constitutes the only Upper Devonian rock unit which occurs within the boundaries of the study area.

Waterways Formation

The name Waterways Formation was applied by Warren (1933) to the Devonian strata overlying an evaporitic sequence in the lower Athabasca River area and underlying the Cretaceous McMurray Formation. Subsequent wells drilled west of Fort McMurray indicated younger Devonian rocks unconformably underlying the McMurray Formation (Norris, 1973). About 300 feet of these younger Devonian strata are closely related faunally and lithologically to the Waterways Formation and are included in it (Crickmay, 1957; Norris, 1963). Crickmay (1957) subdivided the Waterways Formation into five members which are in ascending order: Firebag, Calumet, Christina, Moberly and Mildred.

Outcrops of the Waterways Formation are confined primarily to the lowland along the Athabasca River valley, being most extensive between Fort MacKay and the south boundary of the study area. Outcrops also occur along the lower reaches of the MacKay and Muskeg Rivers, along the Firebag River to the northeast of the study area and in isolated localities elsewhere.

The Waterways Formation, which underlies the entire study area forms the surface bedrock along the Athabasca lowland between Fort MacKay and the south boundary of the study area, in a large area between McClelland Lake and the Firebag River, and in scattered localities elsewhere (Figure 4).

Firebag Member

The Firebag Member is approximately 170 feet of shales and argillaceous limestones which paraconformably overlie the Slave Point Formation and conformably underlie the Calumet Member. The Firebag Member consists mainly of calcareous shale with thin, more resistant sequences of limestone, argillaceous limestone and non calcareous shale. Exposures of the Firebag Member in the study area are confined to two closely spaced outcrops below the mouth of Eymundson Creek, and one exposure on the Firebag River northeast of the study area.

Based on outcrop data, as well as data along the Clearwater River to the south, the Firebag Member likely comprises the subcrop unit of the Waterways Formation in much of the

FIGURE 4.

Bedrock geology of the study area.

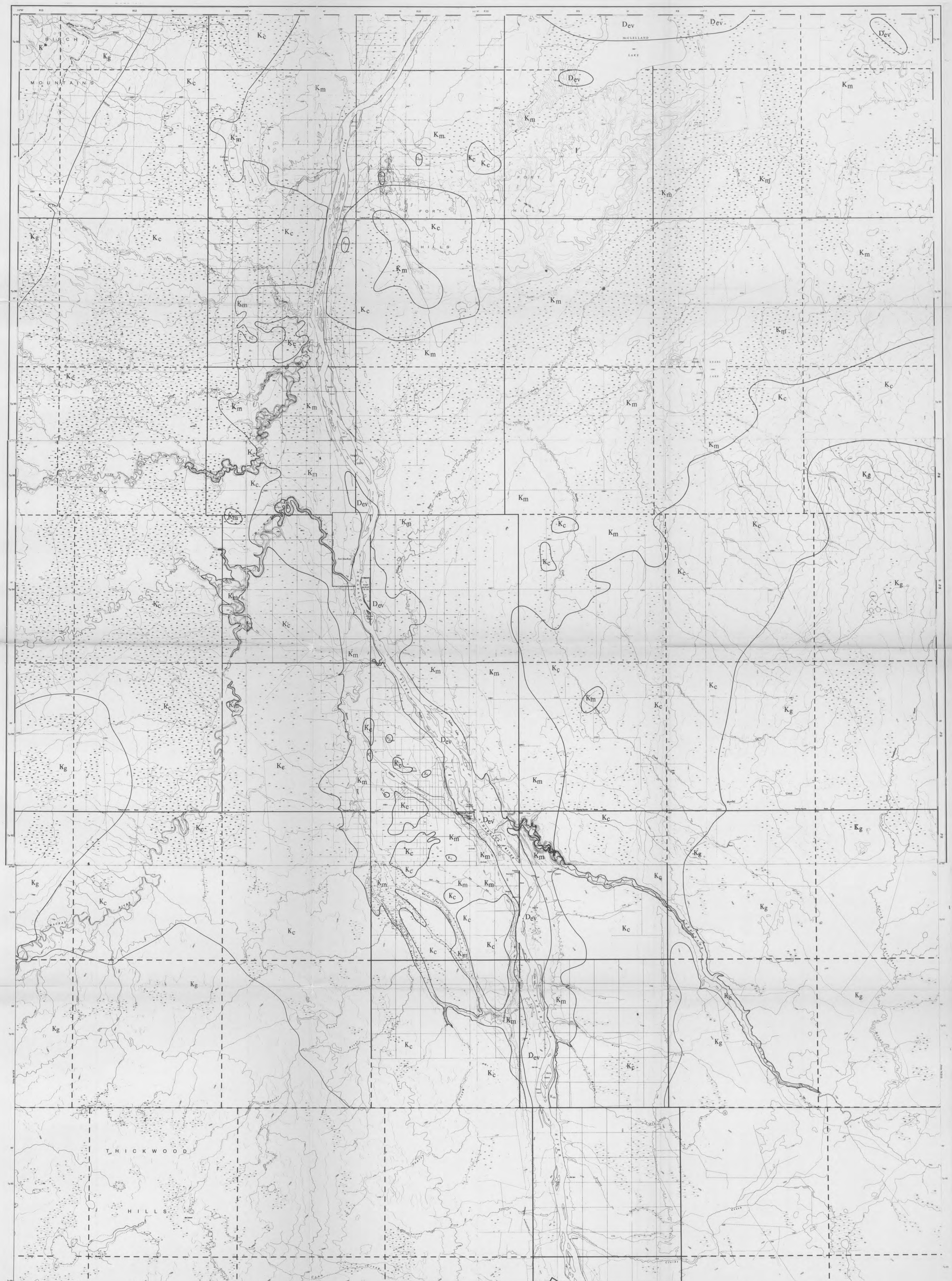


FIGURE 4

Bedrock Geology of the Study Area.

LEGEND

River or Stream
Intermittent River or Stream
Lake
Organic Terrain
Road
Trail
Building
Township Boundary
Section Line
Topographic Contour (975)

Undifferentiated Cretaceous Sandstone and Shale . . . . K*
Cretaceous GRAND RAPIDS Formation . . . . Kg
Cretaceous CLEARWATER Formation . . . . Kc
Cretaceous McMURRAY Formation . . . . Km
Devonian WATERWAYS Formation . . . . Dev
Geologic Boundary

SCALE: 1:125,000

northeast portion of the area. Further data on the lithology and thickness of the Firebag Member in wells in the study area can be found in Norris (1973) and Carrigy (1959).

Calumet Member

The Calumet Member is about 100 feet of resistant, fine grained and clastic limestone, sharply bounded above and below by shales. Only one outcrop of the Calumet Member is known in the study area, which occurs near the mouth of the Pierre River. However, outcrops of this member are common along the Clearwater River east of Fort McMurray (Norris, 1973). Further data on the Calumet Member from wells in the study area is provided by Norris (1973) and Carrigy (1959).

Christina Member

Crickmay (1957) defined the Christina Member as 90 feet more or less of argillaceous limestone and shale, lying above the Calumet Member.

In the study area, only one outcrop on the east bank of the Athabasca River opposite the north end of the Fort MacKay Settlement is questionably assigned to the Christina Member (Norris, 1973). At this locality, the member is unconformably overlain by the Lower Cretaceous McMurray Formation. However, there are several outcrops of the Christina Member east of Fort McMurray near the mouth of the Christina River. The Christina Member consists mainly of greenish grey shale, grey argillaceous limestone, and pale brown limestone. Sandstone and sandy limestone beds are present in some exposures along the Christina River. Data on the lithology and thickness of the Christina Member in wells in the study area is provided by Norris (1973) and Carrigy (1959).

Moberly Member

The Moberly Member was defined by Crickmay (1957) as dominantly clastic limestone, about 200 feet thick lying above the Christina Member. Exposures of this member are numerous in the study area, along the Athabasca River from the south boundary to as far north as Fort MacKay. Outcrops are also present along the lower stretches of some tributary streams, in particular the MacKay and Muskeg Rivers. The Moberly Member consists of alternating olive green, rubbly, argillaceous limestones and shales, with some hard beds of pale brown, aphanitic, fragmental limestone. The member becomes more shaly towards the top, and shale content appears to increase from south to north (Norris, 1973). The top of the Moberly Member is an erosion surface throughout most of the Clearwater - Athabasca Rivers area, and it is unconformably overlain by the McMurray Formation, with progressively younger beds overlapped from east to west.

Mildred Member

The Mildred Member does not appear to outcrop in the study area. In the type well, the member is 140 feet thick and consists of greenish grey calcareous shale and argillaceous limestone, and some pale brown clastic limestone. It conformably overlies the Moberly Member and conformably underlies the Cooking Lake Formation. Data on the lithology and thickness of the Mildred Member in wells in the study area can be found in Norris (1973) and Carrigy (1959).

Structural Geology of the Waterways Formation

Carrigy (1959) indicated that the Precambrian basement in the oil sands region has a southwesterly slope in the order of 30 feet per mile. The regional structure of the overlying Paleozoic rocks is a southwest dipping monocline with a north-northwest trending strike (Norris, 1973). In detail, this monocline has been modified by anticlines, synclines, terracing, and possibly some faulting (Norris, op. cit.). During the long time interval between deposition of the Devonian rocks and the overlying Cretaceous strata, the Devonian rocks were probably subjected to several periods of subaerial erosion which resulted in a complex configuration of the surface of the Devonian.

On a regional scale, it appears that westward tilting of the Devonian rocks of about 15 feet per mile took place prior to deposition of Cretaceous beds, as indicated by the overlap of younger Devonian beds westward

(Norris, 1973).

Martin and Jamin (1963) indicated that post-Cretaceous tilting was in the order of an additional 5 to 7 feet per mile to the west. Norris (1973) observed that there has been considerable thinning of the evaporite section of the Elk Point group caused by the gradual removal of salt beds in a belt about 40 miles wide, immediately west of where the evaporite beds intersect the surface. This belt of subsidence encompasses the entire study area. Much of the resulting subsidence likely took place in pre-Cretaceous times but evidence to suggest that subsidence has occurred in more recent times includes the presence of salt springs in the area, as well as sinkholes which reflect through overlying bedrock and glacial deposits to the present land surface. The subsidence has resulted in collapse and deformation of the overlying Waterways Formation, as evidenced by structural features along the banks of the Athabasca and Clearwater Rivers: flexures in beds of the Waterways Formation have resulted in numerous small basins and domes (Plate I, Figure 1). The amplitudes of these structures are in the order of 50 to 100 feet with wave lengths ranging from several hundred feet up to about a mile (Norris, 1973). Hume (1947) suggested that these local domes and basins were due to volume changes accompanying the hydration of anhydrite in the Prairie Evaporite Formation. Although this process possibly occurred, it also appears likely that some or all of the structures are due to differential solution of water soluble evaporites and the associated subsidence.

Further evidence to suggest collapse and structural deformation of the Waterways was presented by Hume (1947) who, on the basis of closely spaced drilling in the Mildred-Ruth Lake area, suggested possible post-Cretaceous folding; Carrigy (1959) presented evidence to indicate the possibility of post-Devonian movement along a fault in the Precambrian basement rocks. The concept of collapse and deformation structures overlying evaporites is not new. Reasoner and Hunt (1954) have attributed structures observed in Cretaceous strata in the Coleville-Buffalo Coulee area in Saskatchewan to collapse of the surface due to leaching of salt and anhydrite from the underlying Potlach evaporite beds. Walker (1957) has suggested at least three periods of major solution in central and southern Saskatchewan, and considered that collapse structures may be common in strata overlying beds of the Elk Point Group.

Additional evidence to support solution of evaporites and collapse of overlying strata is presented in the following section of the report in which the configuration of the surface of the Waterways Formation is described.

Configuration of the Waterways Formation Erosional Surface

Martin and Jamin (1963) prepared a regional structure contour map of the Devonian rocks in the oil sands region which includes the study area (Figure 5). As part of this project, a structure contour map of the Waterways Formation

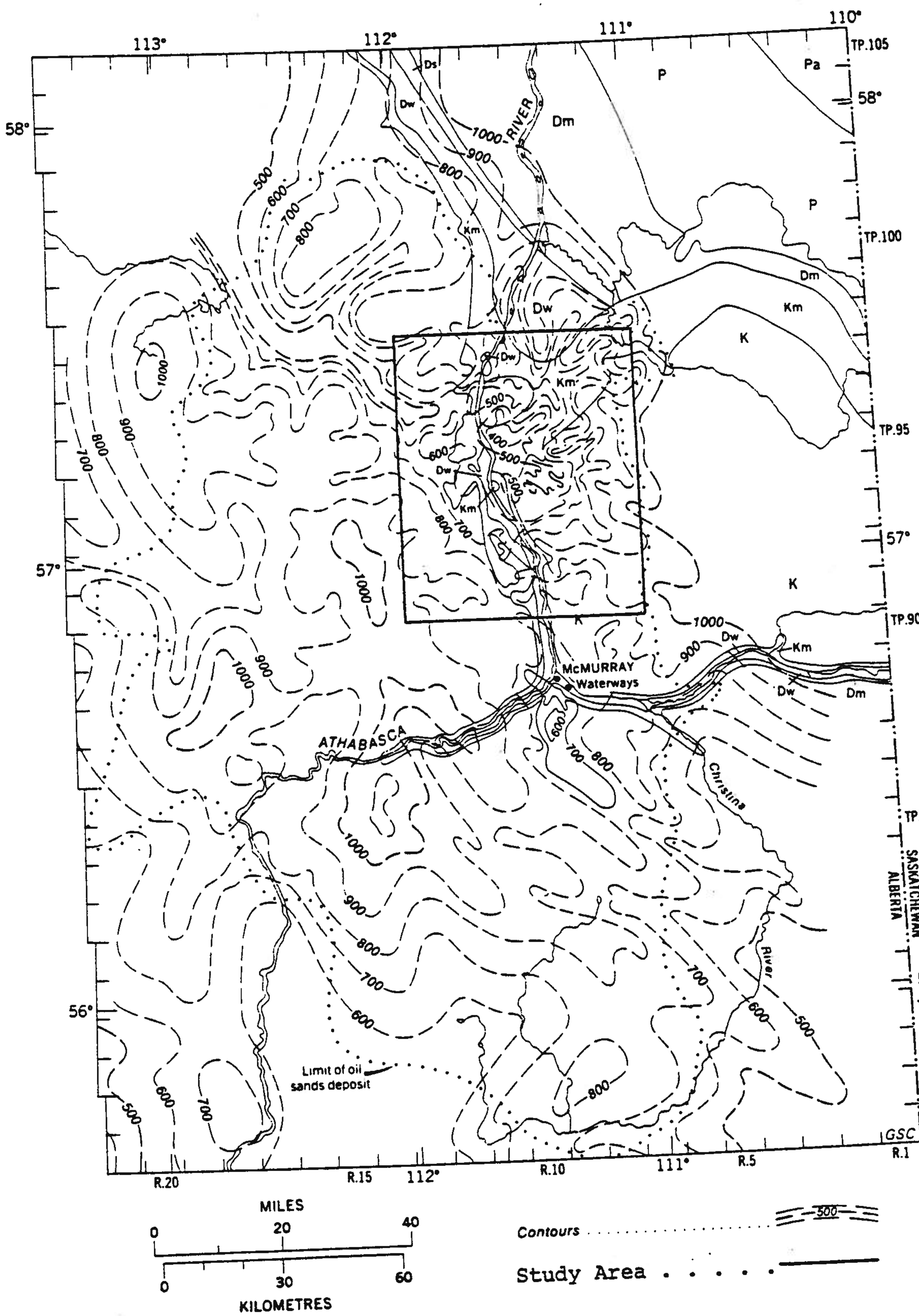


FIGURE 5: Structure contour map of the erosion surface of Devonian rocks in northeastern Alberta (from Martin and Jamin, 1963).

was prepared for the study area utilizing available outcrop and test hole data. The map included with the report is on a scale of 1:125,000 (Figure 6); however, 1:50,000 scale maps were also prepared and are on file at the Alberta Research Council. The distribution of data control points used to prepare the maps is shown on Figure 26 (Appendix 1). A series of geologic cross-sections were also prepared which provide further data on the configuration of the Waterways surface (Figures 7, 8 and 9).

The following discussion of the Waterways surface is based primarily on the maps prepared for this project but relates as well to Martin and Jamin's regional map.

Martin and Jamin (1963) pointed out that the Devonian surface has considerable relief with some slopes as steep as 360 feet per mile. Many of the ridges trend north-northwest and correspond to the strike of the erosion resistant carbonates. One of the best examples is the irregular dissected ridge with elevations of 900 to over 1000 feet which occurs near the southwest corner of the study area as well as farther west; this ridge approximately parallels the subcrop of the Cooking Lake Formation. North of the study area, the 900-foot and 1000-foot contours strike north-northwest along the contact between the Devonian Waterways and Methy Formations. Martin and Jamin's map also outlines the Bitumount basin (named by Carrigy, 1959) in the central portion of the study area. From the

FIGURE 6.

Structure contour map of the top of the Devonian Waterways Formation.

FIGURE 6

Structure Contour Map of the Top of the Devonian Waterways Formation.

LEGEND

River or Steam . . . . Trail . . . .

Intermittent River or Stream . Building . . . .

Lake . . . . Township Boundary . . . . . .

Organic Terrain . . . . Section Line . . . .

Road . . . . Topographic Contour . . . . . —975—

DEVONIAN STRUCTURE CONTOUR (generally 25 ft. interval).

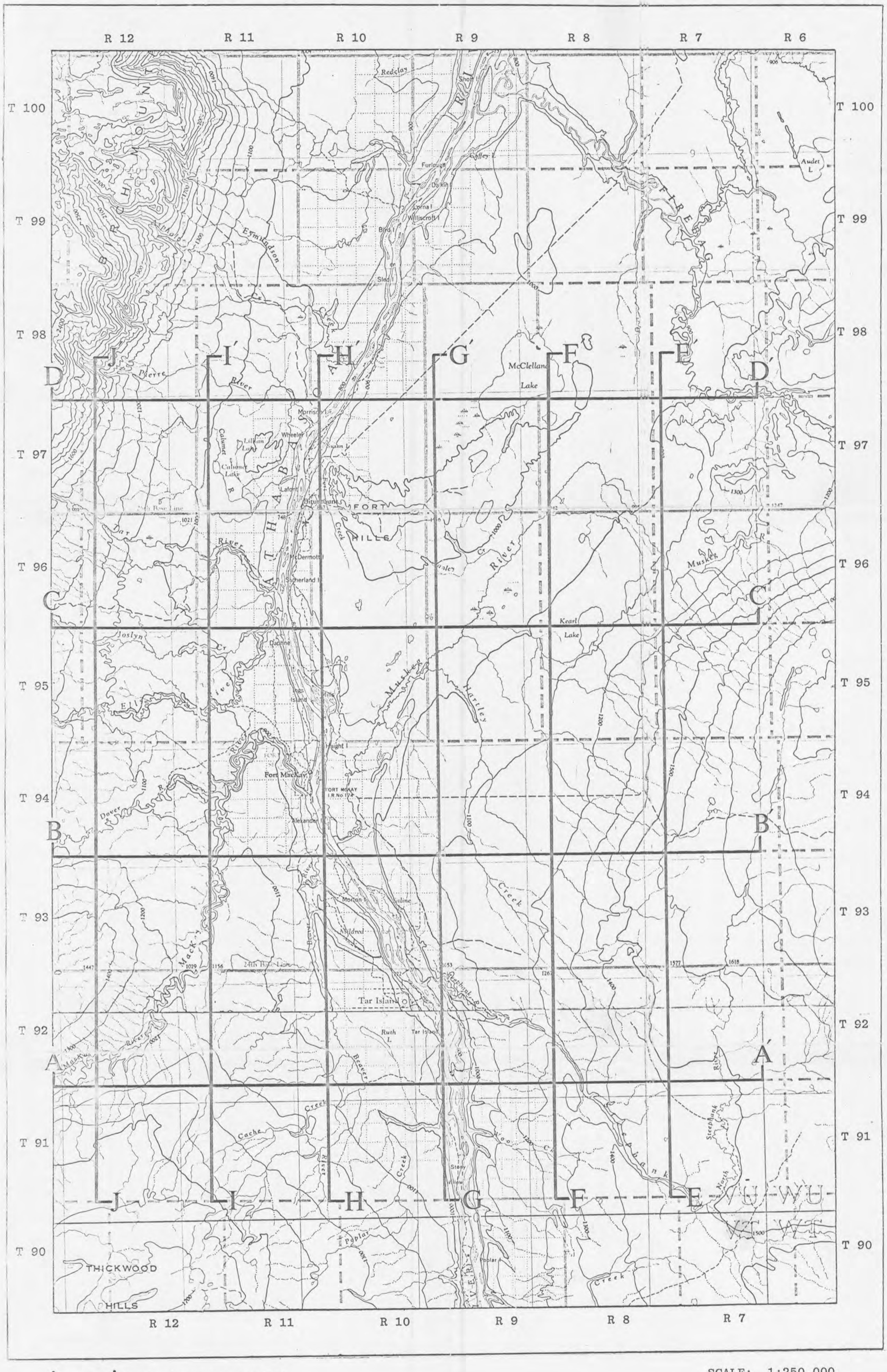
Defined, approximate . . . . —850— — — — —

Elevations shown are in feet A.S.L.

SCALE: 1:125,000

FIGURE 7.

Location map for geologic cross sections.



Geologic cross section

SCALE: 1:250,000

FIGURE 7: Location map for geologic cross sections shown on figures 8 and 9.

FIGURE 8.

East-West geologic cross sections in the study area.

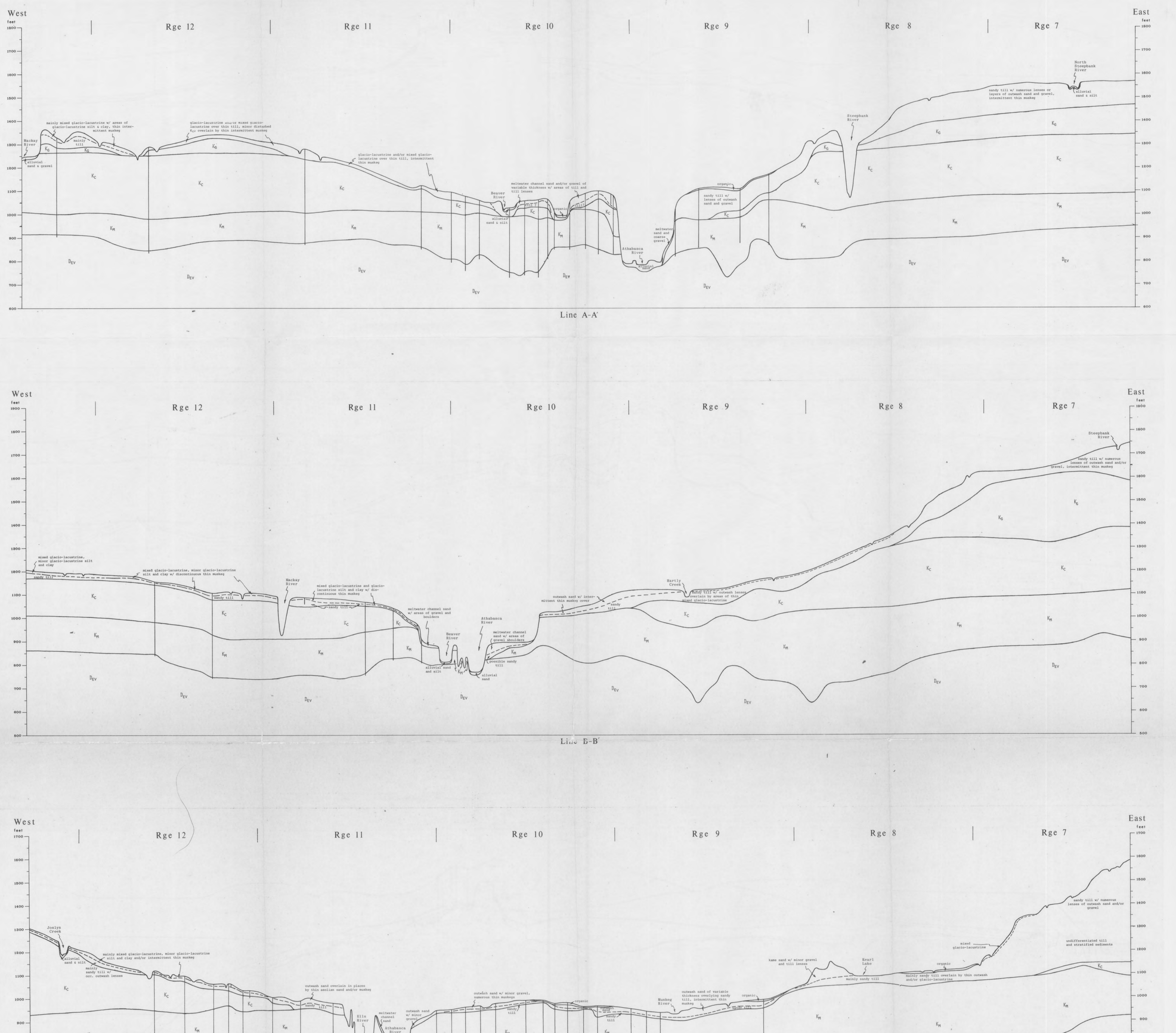


FIGURE 8: EAST-WEST GEOLOGIC CROSS SECTION IN STUDY AREA.

LEGEND

Geologic contacts

Defined, approximate . . . . ——— - - - -

Bedrock Symbols

Cretaceous Grand Rapids Formation . . . . K_G

Cretaceous Clearwater Formation . . . . K_C

Cretaceous McMurray Formation . . . . K_M

Devonian Waterways Formation . . . . D_{EV}

All drill holes are indicated by a solid vertical line

Location of geologic cross sections are shown on FIGURE 7.

All elevations are in feet A.S.L.

SCALE: 1:125,000

FIGURE 9.

North-South geologic cross sections in the study area.

FIGURE 9: NORTH-SOUTH GEOLOGIC CROSS SECTION IN STUDY AREA.

LEGEND

Geologic Contact,

Defined, approximate . . . . ——— - - - -

Bedrock Symbol

Cretaceous Grand Rapids Formation . . . . K_G

Cretaceous Clearwater Formation . . . . K_C

Cretaceous McMurray Formation . . . . K_M

Devonian Waterways Formation . . . . D_{EV}

All drill holes are indicated by a solid vertical line

Location of geologic cross sections are shown on FIGURE 7.

All elevations are in feet A.S.L.

SCALE: 1:125,000

configuration of the contours, there appears to be internal drainage into this basin.

Most of the features of the Waterways surface shown on Martin and Jamin's map are also apparent on the map prepared for this project, however, the configuration of specific features has been modified considerably and a number of additional features delineated as well.

In the study area, the surface of the Waterways exceeds 960 feet in elevation in the southwest corner near Thickwood Hills (Figure 6). This high occurs on the northeast flank of the elongate ridge west of the study area which parallels the subcrop of the Cooking Lake Formation. The Waterways surface is also high along the east side of the study area where elevations generally exceed 900 to 950 feet (Figure 6). The highest elevation of the Waterways surface, which is 975 feet, occurs in the northeast corner of the study area. This high along the east side of the study area follows the high indicated by Martin and Jamin (1963) which farther north trends north-northwest along the contact between the Waterways and Methy Formations.

From the highs on either side of the area, the surface of the Waterways drops off in an irregular trough shape into the Athabasca River valley. Elevation of the Waterways surface along the Athabasca River at the south end of the study area is approximately 775 feet, and at the north end about 600 to 625 feet.

Perhaps the outstanding feature of the Waterways surface is its irregularity. The surface is characterized by numerous elongate ridges and channels which trend in various directions and often end abruptly, and irregular to circular highs and lows of various sizes. Relief of these features ranges from low to over 200 feet with slopes varying from gentle to over 400 feet per mile. Most of the slopes produced by post glacial erosion along the Athabasca, MacKay, Muskeg and Steepbank Rivers, are steep and some are near vertical (Plate I, Figure 2).

It is apparent that certain of the highs are erosional noses and ridges characteristic of erosion of carbonate rocks elsewhere in the subsurface of the Alberta basin, and certain of the lows are channels along old drainage systems. However many of the highs and lows, in particular the more circular ones, could be either erosional highs and lows or flexures in the Waterways surface or a combination of both types of feature. Their origin could only be ascertained by detailed drilling and correlation of units within the Waterways Formation.

One of the most conspicuous features on the Waterways surface is the large irregularly shaped low along both sides of the Athabasca River near Bitumount. It covers an area of approximately 15 square miles and has a few localities with an elevation of less than 400 feet; this is more than 200 feet below the level of the Waterways in the surrounding area. Carrigy (1959) termed this feature the Bitumount basin. Another broad low encompassing 18 to 20 square miles occurs below the southwest portion of the Fort Hills. It has elevations of less than 600 feet over much of the area, and in a few localities elevations below 500 feet.

Numerous channels appear to trend into both of these major lows suggesting that an internal drainage system existed at one time. One of the best developed channels trends northeast along the Muskeg River and then swings north to enter the broad low under the Fort Hills (Figure 6). Another major channel appears to enter this low from the north. In addition to these two major lows, there are many smaller, irregularly shaped basins that appear to have developed internal drainage systems.

Carrigy (1959) felt that pre-Cretaceous drainage was originally across the Bitumount basin and that some of the water found its way downward through a collapse, solution pipe or fault plane and dissolved the underlying evaporites causing the development of a collapse topography on the surface of the limestone. The writers concur that collapse has occurred and feel that based on structures observed in the overlying Cretaceous Formations (to be discussed in a subsequent section of the report) this subsidence has continued in post-Cretaceous times and may still be in progress.

Based on the overall configuration of the Waterways surface, it appears that many or most of the features of classical karst topography are present. Blind valleys, which end abruptly, internal drainage sinks, pinnacles and sharp ridges are characteristic of karst topography. Rounded hills called "haystack hills" or pepinos are also common in karst areas.

This concept of well developed karst topography on the Waterways surface (which may still be active) is supported by the presence of saline springs in the area, numerous sink-holes which reflect through overlying bedrock and glacial deposits (Plate I, Figure 3) and the presence of flexures and folds in the Waterways rocks in outcrop. It should be noted that well developed karst topography occurs in the Hay River Formation (equivalent in age to the Waterways Formation) and in the Keg River Formation northwest of the study area in Wood Buffalo Park (Green, Mellon and Carrigy, 1970).

One other feature of the structure contour map of the Waterways surface should be mentioned. The areas that exhibit the most complex erosion surface are areas with the most drill hole data. It is expected that further drilling in areas of sparse data will reveal that the surface of the Waterways is complex in those areas also; however there appears to be a tendency for the surface to be somewhat less irregular on the erosion resistant highlands.

It should be stressed that the complex configuration of the Waterways surface will have a significant bearing on oil sands developments. The Cretaceous McMurray Formation oil sands were deposited on the irregular surface of the Waterways with the result that the lower contact of the McMurray Formation is highly irregular. This means that detailed, closely spaced drilling will be required to delineate the oil sands and calculate reserves. The irregular lows and highs in the Waterways are also expected to significantly affect the logistics of actual mining operations. Furthermore, the presence of sinkholes and karst topography which may still be active could have significant geotechnical implications for mining operations.

MESOZOIC

A marked change in lithology and a long interval of time separate the Paleozoic and Mesozoic rocks in the oil sands region. During this interval of time, the pre-Cretaceous strata were probably subjected to several periods of subaerial erosion. Structure contours on the upper surface of the Paleozoic limestones indicate that the erosion surface is highly irregular with much evidence of karst phenomena. Sedimentation of the lowermost Mesozoic beds (McMurray Formation) was profoundly influenced by the pre-Cretaceous topography, but the influence of the topography lessened as the landscape was buried and is not readily noticeable in strata above the Middle Clearwater Formation (Carrigy, 1973).

In the following section of the report, the lithology and extent of the Mesozoic strata in the study area is described.

McMurray Formation

McLearn (1917) proposed the name McMurray for the oil impregnated sands overlying the limestones on the lower Athabasca River. Since that time numerous workers have studied the oil sands; however the most detailed published data is by Carrigy (1959, 1973). The subsequent discussion of the McMurray Formation is based largely on that work but also includes new information generated by this project. It should be noted that only the gross lithology and extent of the McMurray Formation is discussed. No attempt is made to describe the oil sands reservoir in detail because it is beyond the scope of the project.

The Cretaceous McMurray Formation outcrops along the Athabasca River in the study area as well as along many of the tributary streams. It forms the surface bedrock along much of the broad Athabasca lowland and the northeast part of the study area (Figure 4). It underlies all of the study region with the exception of a few small areas along the Athabasca River Valley, an area near McClelland Lake and in isolated localities elsewhere, where the Waterways Formation forms the surface bedrock. The McMurray Formation overlies the Devonian Waterways Formation and is overlain by younger Cretaceous rocks or by glacial and recent sediments.

Carrigy (1959), on the basic of lithological evidence, subdivided the McMurray Formation into four informal stratigraphic units, namely pre-McMurray beds, lower, middle and upper units.

Pre-McMurray Beds

Carrigy (1966) presented evidence for remnants of a coarse-grained, quartzose sandstone, cemented by silica and goethite which appears to unconformably underlie the McMurray Formation. It is believed that these beds are remnants of a once more extensive sandstone unit that was subsequently largely removed by erosion.

Lower Unit

The lower unit of the McMurray Formation is comprised of lenticular beds of congomerate, sand, shale, and silt which occupy the deeper depressions on the pre-Cretaceous erosion surface (Carrigy, 1973). Basal strata consist of residual clays derived from weathering of the Waterways limestones. Considering the long time interval and extensive erosion that occurred between deposition of Devonian rocks and the McMurray Formation, it appears uncertain whether all these clays should be considered part of the McMurray Formation, but rather should be considered as possible pre-McMurray beds.

The clays are overlain by conglomerates, sand with some silt and shale, the lithology of the sediments in any specific locality having been controlled by the topography of the surface on which they were deposited (Carrigy, 1973).

The coarse grained sands often contain large wood fragments, well rounded quartz grains, numerous feldspar cleavage fragments and minor mica. In some places, the sand contains only fresh water and in others it is impregnated with heavy oil. Siderite nodules are also common in this unit.

Middle Unit

The middle unit, which generally lies between elevations of 750 and 940 feet, consists mainly of an oil cemented quartz sand of fairly uniform mineralogy (Carrigy, 1973). Interbedded with these sands are lenticular beds of silts, shales and clay. Plant remains, worm casts, logs of wood, and thin coal beds are also present. Carrigy (1973) indicated that beds of this unit are characterized by many primary sedimentary structures, particularily current bedding.

Upper Unit

The upper unit is not easily differentiated from the middle unit because it has a similar lithology. However it is generally horizontally bedded and can be identified by the presence of beds containing a limited brackish-water fauna (Mellon and Wall, 1956). Large shallow channels or scours filled with silts and siderite cemented siltstones are also present (Carrigy, 1973). Carrigy (1973) indicated that the McMurray Formation is largely deltaic in origin, with beds of the middle unit being primarily foreset beds and beds of the upper unit largely topset beds.

Configuration of the Surface of the McMurray Formation

A structure contour map of the top of the McMurray Formation was prepared for the study area, utilizing available outcrop and test hole data. The map included with the report is on a scale of 1:125,000 (Figure 10) (1:50,000 scale maps were also prepared and are on file at the Alberta Research Council). The distribution of data control points used to prepare the maps is shown on Figure 27 (Appendix 1). Further data on the configuration of the surface of the McMurray Formation is provided by a series of geologic cross sections (Figures 8 and 9).

The complex configuration of the Waterways surface profoundly affected sedimentation of the lower McMurray units, but this affect is not as noticeable in the upper units as indicated by the more uniform topography of the McMurray Formation surface.

The McMurray surface is quite high in the southwest portion of the study area where it is generally over 1000 feet and as high as 1050 feet. It is also high along most of the east side of the area, often exceeding 1100 feet. The highest elevation on the McMurray surface occurs in the northeast where it attains an elevation of 1162 feet.

From these broad highlands, the McMurray surface drops off irregularly to form a trough-shaped low along the Athabasca valley and a general low in certain of the northeast portions of the study area (Figure 10). Most elevations of the McMurray surface in the lowlands range between 800 and 1000 feet. Elevation of the surface along the

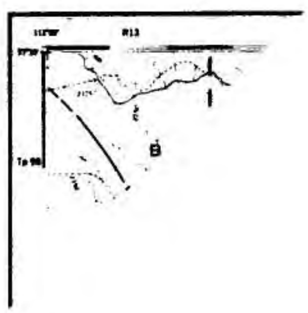


FIGURE 10.

Structure contour map of the top of the Cretaceous McMurray Formation.

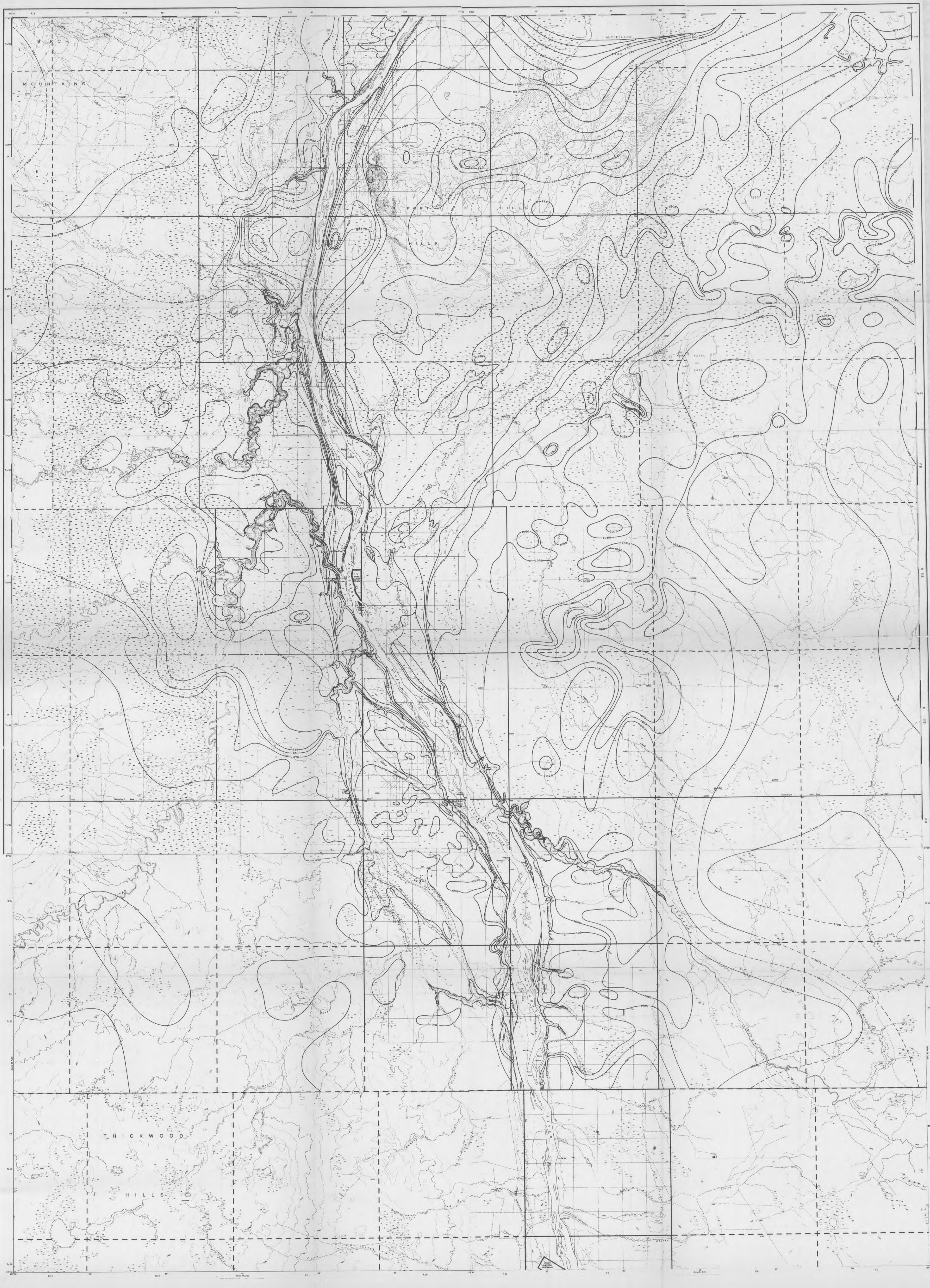


FIGURE 10

Structure Contour Map of the Top of the Cretaceous McMurray Formation.

LEGEND

River or Stream
Intermittent River or Steam
Lake
Organic Terrain
Road
Trail
Building
Township Boundary
Section Line
Topographic Contour — 975

McMURRAY STRUCTURE CONTOUR (generally 25 ft. interval).

Defined, approximate — 1025 — — —

Elevations shown are in feet A.S.L.

SCALE: 1:125,000

Athabasca River at the south boundary of the study area is 775 to 800 feet and at the north end of the area between 750 and 775 feet.

The large highs in the McMurray surface in the southwest corner and along the east side of the map sheet are coincident with highs in the underlying Waterways surface. In addition, a number of smaller highs in the McMurray surface are coincident with highs in the underlying Waterways Formation (Figures 10 and 6 respectively).

The broad trough-shaped low in the McMurray surface along the Athabasca River corresponds to a broad trough shaped low in the underlying Waterways surface. Another low in the McMurray surface, with elevations between 780 and 900 feet occurs near the southwest portion of the Fort Hills; this low corresponds to a collapse feature in the underlying Waterways Formation. A similar low in the McMurray surface is present overlying the other large collapse feature termed the Bitumount basin.

A broad elongate low in the McMurray surface, with elevations in the order of 925 feet, trends approximately along the course of the Muskeg River; this low parallels a drainage channel developed in the Waterways surface. In addition, a number of smaller lows in the McMurray surface correspond to lows in the underlying Waterways Formation (Figures 10 and 6).

The range of slopes on the McMurray surface is quite variable throughout the study area. Slopes are commonly steep to near vertical where erosion by modern day streams has occurred. Streams on which erosion has been most extensive include the Athabasca, MacKay, Beaver, Ells, Steepbank, Pierre, Calumet and Tar Rivers. The slope of the McMurray surface is also relatively steep (up to 80 feet per mile) along its subcrop edge near McClelland Lake. Elsewhere in the study area, slopes are generally quite low, being considerably less steep than most slopes on the underlying Waterways surface.

It is expected that future drilling (especially in areas of sparse data) will reveal that the McMurray surface is more complex than has been shown on the structure contour map; however it will undoubtedley be less complex than the surface of the underlying Waterways Formation.

Thickness of Overburden Above the McMurray Formation

In the preceding section of the report, the configuration of the surface of the McMurray Formation was described (Figure 10). An isopach map of the thickness of overburden above the McMurray Formation has also been prepared (Figure 11). The term overburden is used in the sense that it refers to all sediments overlying the upper surface (top) of the McMurray Formation. Therefore, overburden includes younger Cretaceous bedrock as well as surficial deposits.

It is important to stress that additional materials

FIGURE 11.

Thickness of overburden above the Cretaceous McMurray Formation.

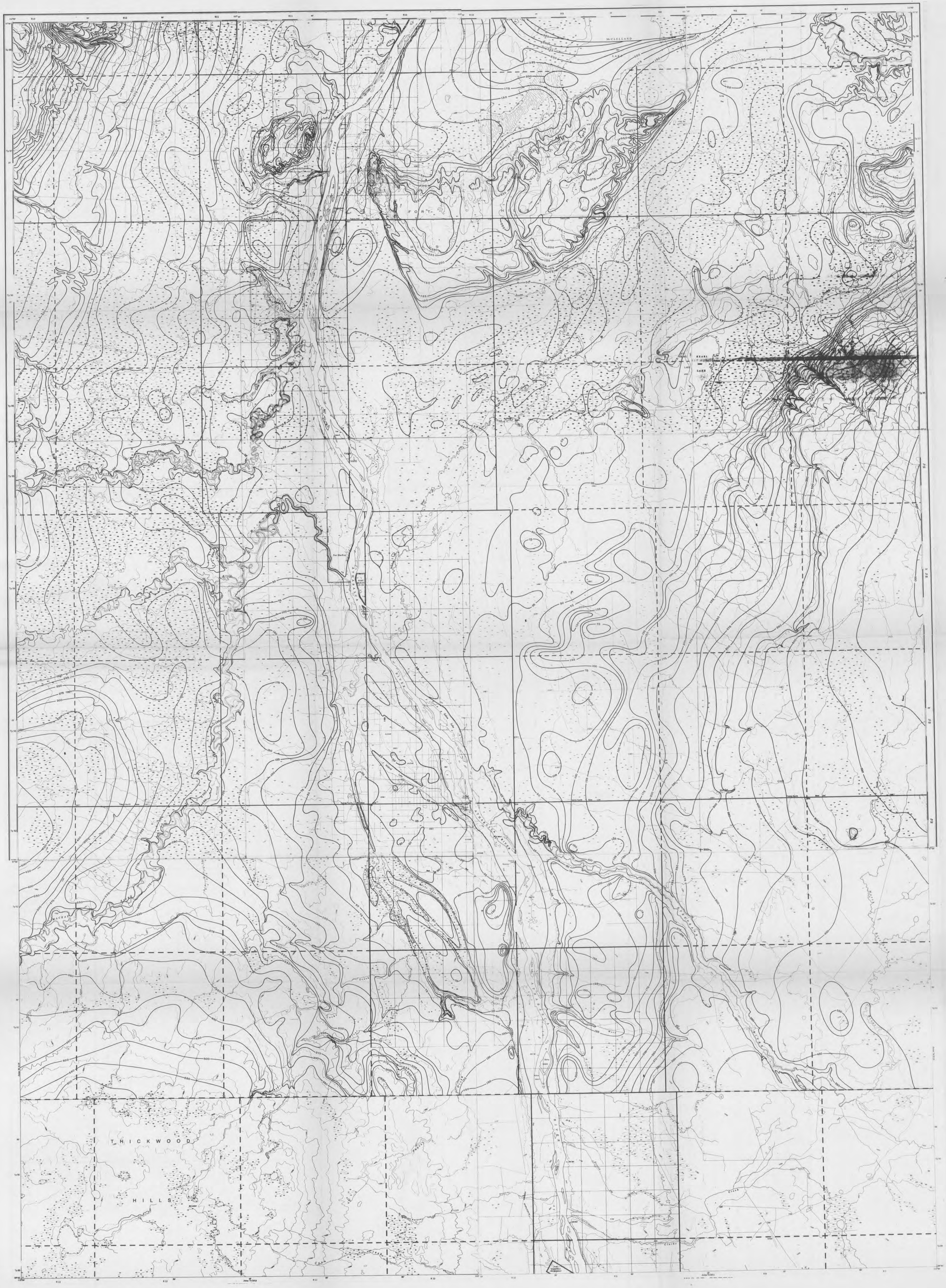


FIGURE 11

Thickness of Overburden Above the Cretaceous McMurray Formation.

LEGEND

River or Stream

Intermittent River or Stream

Lake

Organic Terrain

Road

Trail

Building

Township Boundary

Section Line

Topographic Contour — 975 —

OVERBURDEN THICKNESS ISOPACH (generally 25 ft. interval).

Defined, approximate — 75 —

SCALE: 1:125,000

may have to be removed during actual mining operations, in areas where upper portions of the McMurray Formation are too low in oil saturation to be considered economic to process. A map outlining the thickness of overburden over economically recoverable oil sands has not been prepared because the economic cutoff for different mining operations will undoubtedley vary.

In general, overburden is thick where the McMurray Formation is overlain by both younger Cretaceous sediments and surficial deposits. It is thickest on the flanks and tops of the major bedrock uplands. In the northwest corner of the study area, the overburden obtains a maximum thickness of 1400 feet on the Birch Mountains (Figure 11). On the Thickwood Hills upland, it is up to 500 feet thick north of the MacKay River and up to 600 feet thick south of the MacKay River. Similarily, it attains a thickness of up to 650 feet on Muskeg Mountain.

The overburden is thinnest (generally 25 to 50 feet thick) along both sides of the Athabasca valley and in most of the northeast part of the study region, primarily where the McMurray Formation forms the surface bedrock. Local areas of thick overburden (up to 400 feet thick) are present where large kame moraines occur (Figures 11 and 15).

Elsewhere in the study area, the overburden is relatively thick where the McMurray Formation is overlain by the Clearwater Formation as well as surficial deposits. West of the Athabasca River, the overburden begins to thicken along the subcrop of the Clearwater Formation and becomes progressively thicker to the west attaining a thickness of up to 250 feet along the west margin of the map area. East of the Athabasca River, the overburden also begins to thicken along the subcrop of the Clearwater Formation and becomes progressively thicker to the south and east (Figure 11).

The nature of the overburden in various areas is outlined on the geologic cross sections (Figures 8 and 9) and in subsequent sections of the report.

Clearwater Formation

McConnell (1893) proposed the name "Clearwater shale" for an outcrop on the Athabasca River at Point LaBiche. The base of the Clearwater Formation was defined by McLearn (1917) as the bottom of the well defined glauconitic sand bed underlying the shale and overlying the oil impregnated sands of the McMurray Formation. Subsequently, Badgley (1952), described a glauconitic sandstone bed found in the Barnsdall West Wabiskaw No. 1 well as the Wabiskaw member. Carrigy (1973) indicated that the age of the formation has been established as Lower Cretaceous (Albian) by several workers. Throughout the study area, the Clearwater Formation overlies the McMurray Formation and is directly overlain by the Grand Rapids Formation where present and by glacial and post-glacial deposits elsewhere.

The Clearwater is present in much of the western and southeast portions of the sheet as well as a few other scattered localities (Figure 4). More detailed description of the distribution of the Clearwater is provided in subsequent discussions of the structure contour map of the Clearwater surface.

The dominant lithology of the Clearwater Formation is a grey to grey black shale, commonly containing varying amounts of sand, silt, indurated siltstone, ironstone layers and gypsum crystals. The Wabiskaw member, found at the base of the Clearwater Formation, consists of a thin bed of glauconitic sandstone; the sand is generally fine to medium grained and contains varying proportions of silt and clay. In some instances, the Wabiskaw member has been impregnated with heavy oil, similar to that found in the underlying McMurray Formation.

Configuration of the Surface of the Clearwater Formation

A structure contour map of the top of the Clearwater Formation was prepared for the study area utilizing available outcrop and test hole data. The map included with the report is on a scale of 1:125,000 (Figure 12); however 1:50,000 scale maps were also prepared and are on file at the Alberta Research Council. The distribution of data control points used to prepare the maps is shown on Figure 28 (Appendix 1). Further data on the configuration of the surface of the Clearwater Formation is provided by a series of geologic cross sections (Figures 8 and 9).

When analyzing existing test hole data it was found that geophysical log response could be used quite readily

FIGURE 12.

Structure contour map of the top of the Cretaceous Clearwater Formation.

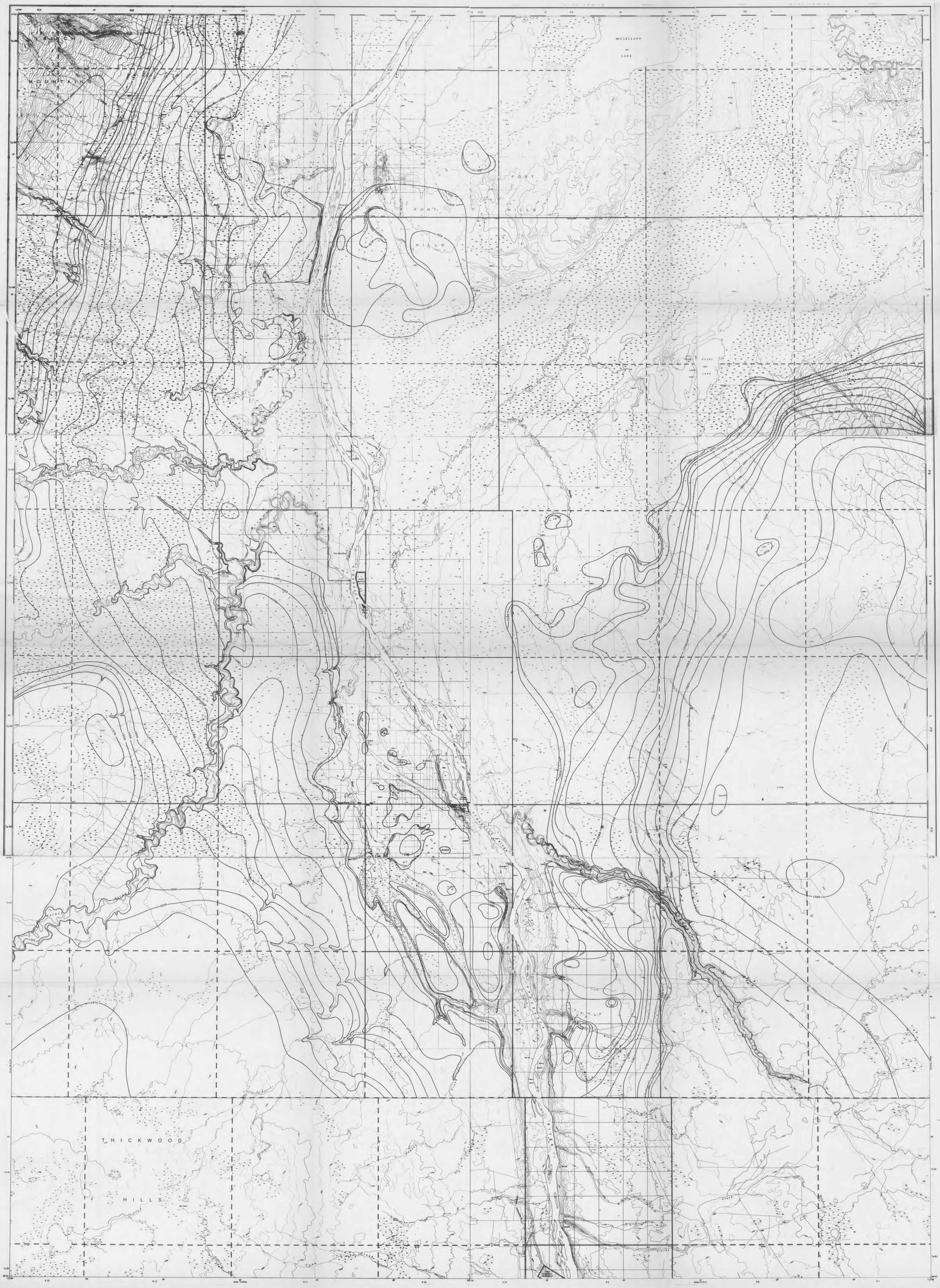


FIGURE 12

Structure Contour Map of the Top of the Cretaceous Clearwater Formation.

LEGEND

River or Stream	Trail
Intermittent River or Stream	Building
Lake	Township Boundary
Organic Terrain	Section Line
Road	Topographic Contour — 975 —

CLEARWATER STRUCTURE CONTOUR (generally 25 ft. interval).

Defined, approximate . . . . —1125— - - - -

Elevations shown are in feet A.S.L.

SCALE: 1:125,000

to pick the top of the Clearwater Formation because of the contrast between the Clearwater shale and other units as well the remarkably consistent units within the Clearwater Formation which can be correlated over wide areas. This is in contrast to the McMurray Formation which is usually hard to correlate between holes and difficult to distinguish from certain glacial deposits because of the similarity in log response.

On the east side of the Athabasca River, most of the southeast portion of the study area is underlain by the Clearwater Formation. The subcrop boundary trends north from near the mouth of the Steepbank River to the middle of Township 94 and then trends northeast to the eastern edge of the study area. The subcrop boundary generally occurs at an elevation of 1025 to 1050 feet. South of the mouth of the Steepbank River, the subcrop edge trends parallel to the Athabasca River and has an elevation of 1000 to 1050 feet.

The most distinct feature of the Clearwater surface is that it slopes upward to the east onto the flanks of Muskeg Mountain, attaining a maximum elevation of 1390 feet. A break in slope occurs between the 1200 and 1300 foot contours which parallels the subcrop edge of the Grand Rapids Formation. The areas where the Clearwater surface is flattest are overlain by the Grand Rapids Formation; these areas also coincide with the highest elevations of the Clearwater sediments.

The Clearwater Formation in the southeast portion of the study has been dissected by erosion along the Steepbank River to within three miles of the North Steepbank River (Figure 12). Further, less extensive erosion has taken place along other streams in this area. Two small erosional remnants of the Clearwater Formation occur in Township 94 Range 9 and one small area where the Clearwater is absent (within the main area of its occurrence) has been found about 6 miles further south. It is expected that other small erosional remnants will be found by further more detailed drilling.

The only other area where the Clearwater Formation is present on the east side of the Athabasca River is in the vicinity of the Bitumount basin (Figure 12). It encompasses a roughly circular area of approximately 30 square miles which corresponds to the underlying collapse structure in the Waterways Surface. Elevation of the Clearwater surface in this area ranges from approximately 850 to 950 feet. The Clearwater Formation is absent near the centre of this circular area where the McMurray or Waterways Formations form the surface bedrock.

On the west side of the Athabasca River, the Clearwater Formation is considerably more extensive than on the east side. The subcrop edge occurs close to the Athabasca River at the south end of the study area. Further north the edge trends roughly parallel to the Athabasca River, but in many instances is several miles west of the actual river. The elevation of the Clearwater surface along this subcrop edge ranges from 925 to 1000 feet.

From the 0 edge, the Clearwater surface slopes upward towards the west attaining an elevation of 1250 to 1300 feet on the flanks of the Thickwood Hills and 1275 to 1300 feet on the flanks of the Birch Mountains. The slope of the surface becomes less steep where it is overlain by the Grand Rapids Formation on the flanks of the Thickwood Hills; however this is not the case on the flanks of the Birch Mountains.

Numerous small outliers of Clearwater sediments are present between the subcrop edge and the Athabasca River, especially in the vicinity of Mildred Lake. This is an area of detailed drilling for the Syncrude Oil sands plant and it is expected that further drilling will reveal additional outliers.

The only other large area where the Clearwater Formation occurs on the west side of the Athabasca River is in the vicinity of the Bitumount basin. Adjacent to the west bank of the Athabasca River, the Clearwater surface has an elevation of approximately 800 feet; the surface slopes upwards to the west over an irregular 15 square mile area to join the main body of the Clearwater at an elevation of approximately 950 feet. This low in the Clearwater surface, as well as the corresponding low on the east side of the Athabasca River overlies a collapse feature in the underlying Waterways surface.

Erosion of the Clearwater sediments has been fairly extensive along the Athabasca and Clearwater Rivers. Other streams, on the west side of the study area, where erosion has modified the Clearwater surface include the Beaver, Dover, Ells and Tar Rivers and Joslyn and Poplar Creeks.

When mapping the surficial deposits in the region, two small pre-glacial channels were observed in the surface of the Clearwater Formation west of the study area. It is expected that similar channels are present within the study area because they are present on the bedrock surface throughout much of Alberta; however these channels could only be located by detailed closely spaced drilling.

In concluding the discussion of the Clearwater Formation it should be stressed that the nature and distribution of the Clearwater Formation in the oil sands region is relevant to oil sands development for several reasons.

In potential mining areas, it will have to be removed to expose the underlying oil sands. Because it is prone to large scale slumping on natural and man made cuts, it could present considerable engineering problems during excavation.

This is in contrast to areas where it overlies deeply buried oil sands. In these regions it could serve as an impermeable cap rock for in situ recovery techniques. Further discussion of the geotechnical properties and expected engineering behavior of the Clearwater Formation is provided in a subsequent section of the report because of the importance of these deposits to oil sands operations.

Grand Rapids Formation

The Grand Rapids Formation was defined by McConnell (1893) from its outcrops on the Athabasca River. It overlies the Clearwater Formation and is overlain by younger Cretaceous strata and/or glacial and post-glacial sediments. The thickness of the Grand Rapids Formation although variable can exceed 300 feet.

In the study area, the Grand Rapids is present only on the flanks of major bedrock uplands, namely Muskeg Mountain, Thickwood Hills and the Birch Mountains (Figure 4).

The dominant lithology is a sandstone which is commonly referred to as a "salt and pepper sand"; however siltstone and shale layers are also common. Based on test hole data in the study area, there is often a major sandstone unit at the base of the Grand Rapids Formation which is up to 125 feet thick. Overlying this sandstone unit is a middle shale unit of variable thickness and an upper sandstone unit up to 100 feet thick. Interbedded within these major units are thinner layers of sandstone, siltstone and shale. It should be stressed that the three main units are not always present because of facies changes but they are found in sufficient localities to be recognizable as major depositional units.

The sandstone has a heterogeneous mineral composition which includes grains of quartz, feldspar, glauconite, chert, muscovite and biotite. Most of the sandstone is uncemented and commonly contains spherical calcareous nodules up to 10 feet in diameter (Carrigy, 1973). Numerous small springs have been reported along the contact between the Grand Rapids and the underlying Clearwater shale.

Configuration of the Surface of the Grand Rapids Formation

A structure contour map of the top of the Grand Rapids Formation was prepared for the study area utilizing available outcrop and test hole data. The map included with this report is on a scale of 1:125,000 (Figure 13); however 1:50,000 scale maps were also prepared and are on file at the Alberta Research Council. The distribution of data control points used to prepare the maps is shown on Figure 29 (Appendix 1). Further data on the configuration of the Grand Rapids Formation is provided by a series of geologic cross sections (Figures 8 and 9).

The Grand Rapids Formation is present in three parts of the study area; namely:

(1) the flanks of Muskeg Mountain in the southeast portion of the study area,

(2) the flanks of Thickwood Hills in the southwest portion of the study area,

and (3) the flanks of Birch Mountains in the northwest corner of the study area.

In the southeast portion of the study area, the subcrop edge of the Grand Rapids usually occurs at an elevation of 1275 to 1325 feet (Figure 13). From the 0

FIGURE 13.

Structure contour map of the top of the Cretaceous Grand Rapids Formation.

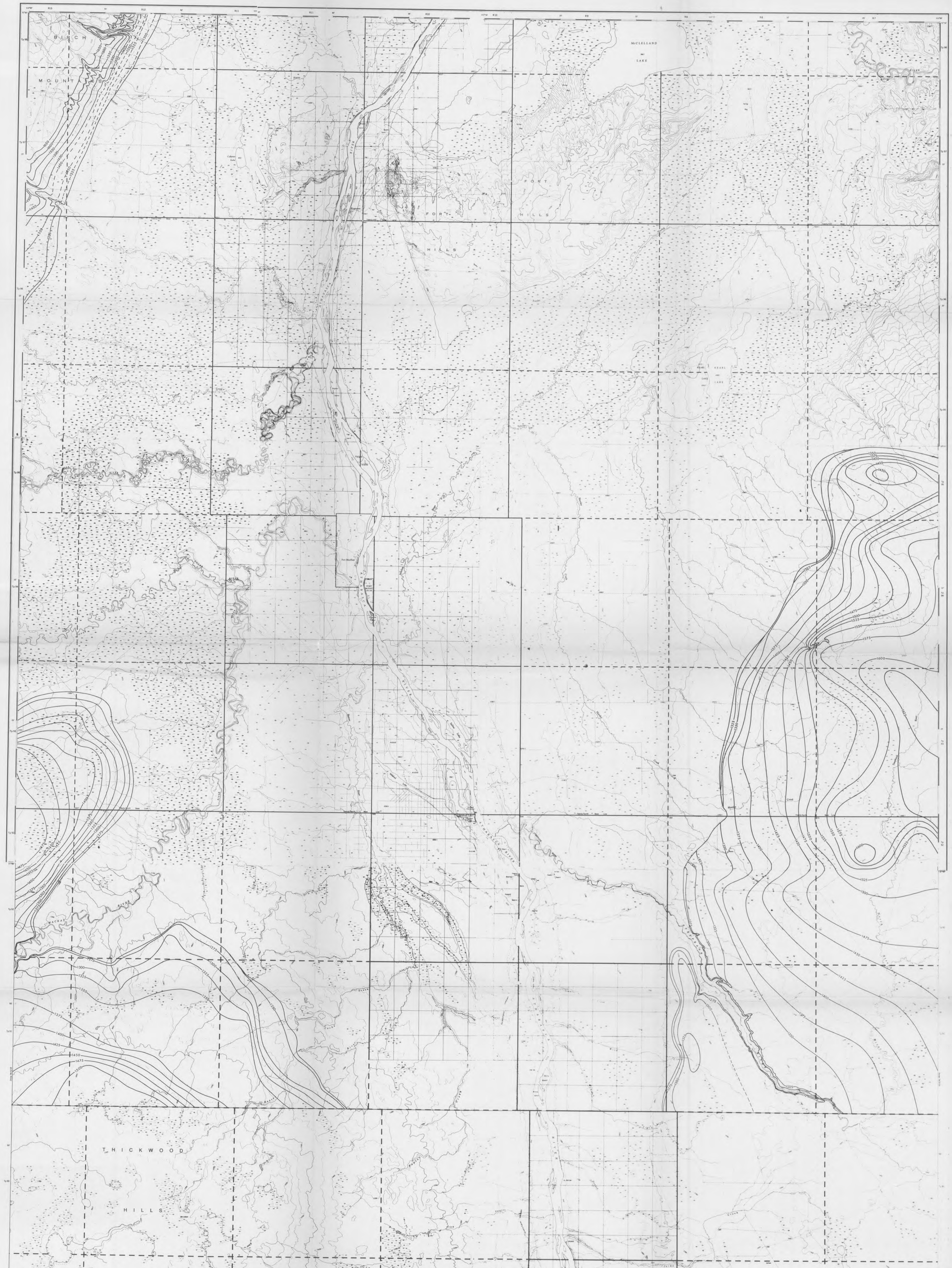


FIGURE 13

Structure Contour Map of the Top of the Cretaceous Grand Rapids Formation.

LEGEND

River or Stream
Intermittent River or Stream
Lake
Organic Terrain
Road
Trail
Building
Township Boundary
Section Line
Topographic Contour 975

GRAND RAPIDS STRUCTURE CONTOUR (generally 25 ft. interval).

Defined, approximate 1375

Elevations shown are in feet A.S.L.

SCALE: 1:125,000

edge the surface of the Grand Rapids slopes upwards to the west or southwest reaching an elevation of over 1475 feet north of the MacKay River and an elevation of over 1500 feet south of the MacKay River. As is the case in the southeast portion of the study area, a break in slope in the Clearwater surface occurs along the O edge of the Grand Rapids Formation.

The subcrop edge of the Grand Rapids Formation in the northwest portion of the study area is generally at an elevation of 1325 to 1350 feet. From the O edge the surface slopes upwards to a maximum height of over 1650 feet. Based on limited well data and surface elevations it is expected that erosion of the Grand Rapids has occurred along a number of small streams in this area; however no outcrops have been observed.

Cretaceous Strata Overlying the Grand Rapids Formation

The only area where younger Cretaceous strata overlie the Grand Rapids Formation is in the northwest corner of the study area on the flank of the Birch Mountains (Figure 4). On a bedrock geology map by Green, Mellon and Carrigy (1970), the Shaftesbury, Dunvegan and LaBiche Formations are shown to be present; however both well data and outcrops are limited. In this report, no additional data has been obtained for these strata.

According to Green, Mellon and Carrigy (1970) the Shaftesbury Formation consists primarily of shale, minor sandstone and silstone, and thin bentonite beds. The Dunvegan Formation is comprised of light grey, fine grained feldspathic sandstone with scattered hard calcareous beds, laminated carbonaceous siltstone, and dark grey silty shale. The LaBiche Formation consists of dark grey shale and silty shale with ironstone partings and concretions.

BEDROCK TOPOGRAPHY

A map of the bedrock surface topography was prepared utilizing available outcrop and test hole data (Figure 14). The map included with this report is on a scale of 1:125,000; however 1:50,000 scale maps were also prepared and are on file at the Alberta Research Council. Many of the features of the bedrock topography have been discussed previously; however the following description is considered relevant because it synthesizes the overall configuration of the bedrock surface.

The most conspicuous features of the bedrock surface are the major dissected highlands or tablelands separated by intervening lowlands. The major highlands, namely Birch Mountains, Muskeg Mountain, and Thickwood Hills are remnants of a large dissected plateau termed the Alberta Plateau.

In the southeast portion of the study area, the bedrock surface slopes upwards onto the flanks of Muskeg Mountain. The most consistent increase in elevation begins along the contact between the McMurray and Clearwater Formations at an elevation of 1050 to 1075 feet. From this contact, the top of the bedrock increases in height, approximately 35 feet per mile, up the slopes of Muskeg Mountain to an elevation of 1575 to 1600 feet. The surface becomes relatively flat further east where the Grand Rapids Formation is present. Considerable post glacial erosion of the upland has occurred along the Steepbank River as far

FIGURE 14.

Bedrock topography in the study area.

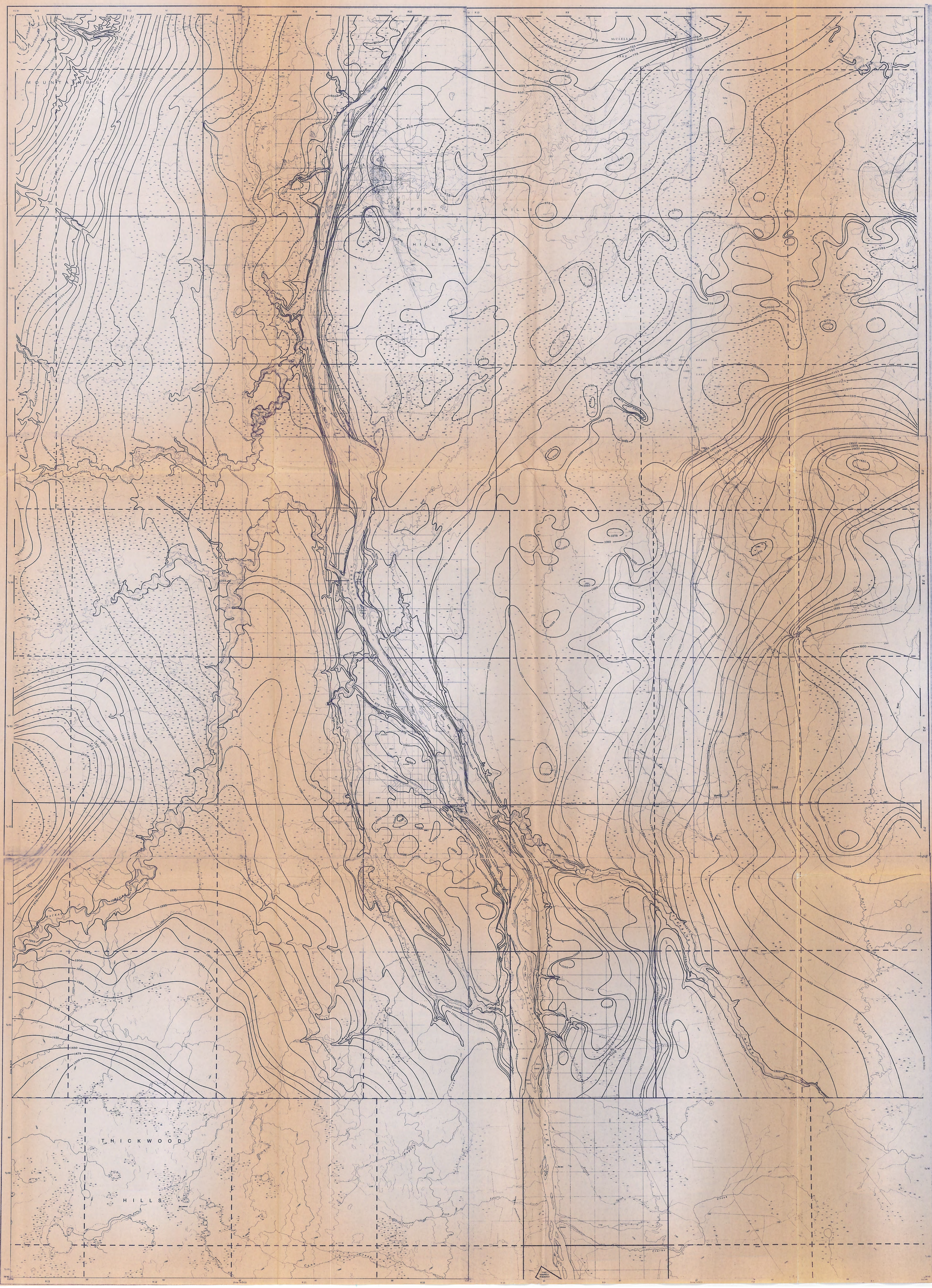


FIGURE 14

Bedrock Topography in the Study Area.

LEGEND

River or Stream	————	Trail	– – – – – –
Intermittent River or Stream	– ·· ———	Building	■
Lake	(outline)	Township Boundary	━━━━
Organic Terrain	⺌ ⺌ ⺌	Section Line	————
Road	═════	Topographic Contour	—975—

BEDROCK SURFACE CONTOUR (generally 25 ft. interval).

Defined, approximate . . . . . —1125——— — — —

Elevations shown are in feet A.S.L.

SCALE: 1:125,000

Fig 14
OFR 1977-4
10/15

upstream as the North Steepbank River.

On the west side of the Athabasca River, the bedrock surface becomes higher, in a fairly regular fashion, towards the west. From the contact between the Clearwater and McMurray Formations, at an elevation between 925 and 1000 feet, the top of the bedrock slopes upwards in a generally westward direction. On the flanks of the Birch Mountains, the bedrock surface slopes to the northwest attaining a maximum elevation of over 2200 feet. Post glacial stream erosion has altered the bedrock surface on this upland in a number of localities (Figure 14).

In the southwest portion of the region, the major bedrock upland has been divided into two lobes by the MacKay River. North of the MacKay River, the slope of the bedrock surface steepens considerably at an elevation of approximately 1275 feet along the contact between the Grand Rapids and Clearwater Formations. The slope remains relatively steep (up to 130 feet per mile) to an elevation of approximately 1400 feet, and then flattens considerably. Maximum bedrock elevation on the upland is approximately 1475 feet. On the flanks of Thickwood Hills to the south of the MacKay River, the slope of the bedrock surface is somewhat more variable and does not appear to change significantly along bedrock contacts. Maximum elevation of the bedrock surface on this upland exceeds 1500 feet.

West of the Athabasca River, the bedrock surface has been significantly altered by post glacial erosion, in particular along the MacKay, Dover and Ells Rivers (Figure 14).

Another major feature of the bedrock surface is the broad trough-shaped low which follows the trend of the Athabasca River in the southern portion of the area, but broadens northwards to include most of the northeast portion of the map area. These lowlands occur, for the most part, where the McMurray or Waterways Formations form the surface bedrock. Elevations of the bedrock surface along the Athabasca River is approximately 775 at both ends of the area. Slope of the surface is variable and often steep along the Athabasca River and its tributaries due to extensive erosion (Plate 1, Figure 2). Slopes are also relatively steep near McClelland Lake along the contact between the Waterways and McMurray Formations. In the remainder of the lowlands, usually in areas where the McMurray Formation is present, the bedrock surface is relatively flat. Smaller scale features of the bedrock surface topography include:

(1) the unique configuration of the bedrock surface in the Bitumount area where subsurface collapse structures are present in the underlying Waterways Formation,

(2) the low in the bedrock surface along the trend of the Muskeg River (elevation of 900 to 925 feet) which parallels a bedrock channel in the Waterways Formation,

and (3) a number of smaller highs and lows in the bedrock surface which correspond to highs and lows in the underlying Waterways Formation.

By comparing the bedrock topography with the present surface topography, it is readily apparent that there are many similarities. In spite of modification of the land surface by glacial and post glacial deposition and erosion, most of the large bedrock features are still reflected by the configuration of the present land surface.

The configuration of the bedrock surface also had a profound affect on the type of surficial sediments that were deposited. The relationship between the sediment type and the bedrock surface topography will be discussed in subsequent sections of the report.

SURFICIAL GEOLOGY

Published information on the surficial geology of the study area is limited. Lindsay 'et al.' (1957) presented exploratory soil surveys of NTS maps sheets 74D and 74E; these reports contain reconnaissance data on the distribution of near surface materials in the region. The most up to date and comprehensive published data on the surficial deposits consits of 1:250,000 scale surficial geology maps of NTS sheets 74D and 74E, by Bayrock (1971) and Bayrock and Reimchen (1973) respectively. Several unpublished reports on the surficial deposits have also been prepared by exploration firms with oil sands leases in the area.

The following description of the surficial geology of the study area is based on data from all previous studies as well as from air photo interpretations, field mapping, a controlled drilling program, examination of existing test hole data, and laboratory analyses.

SURFICIAL DEPOSITS AND LANDFORMS

The areal distribution of the surficial deposits is shown on the surficial geology map (Figure 15). The map is on a scale of 1:125,000 (1:50,000 scale maps were also prepared and are on file at the Alberta Research Council). The main purpose of the map is to show the sediment to be expected in the upper 10 feet.

27 x 27

FIGURE 15.

Surficial geology of the study area.

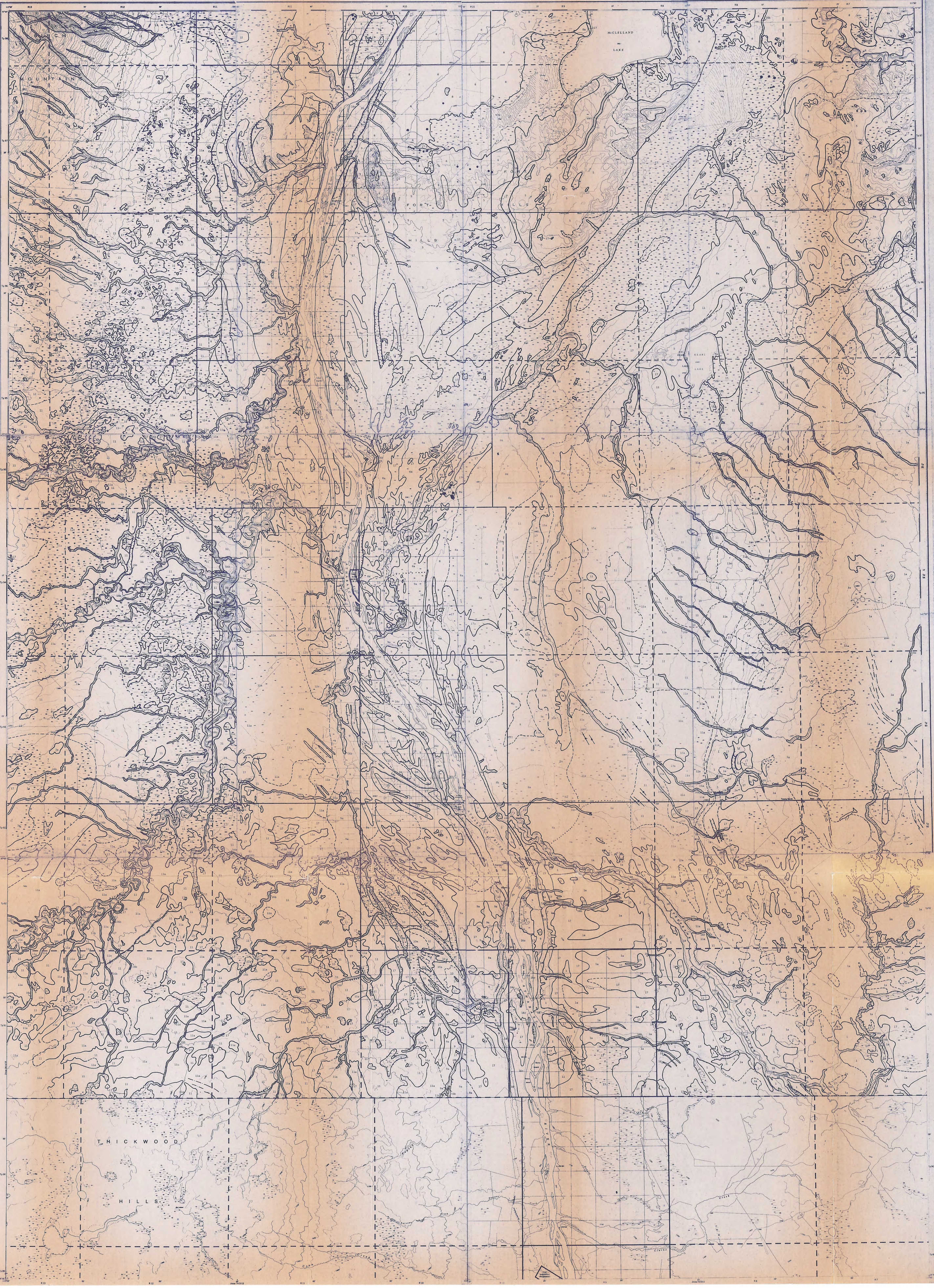


FIGURE 15

SURFICIAL GEOLOGY MAP

LEGEND

Recent

EROSIONAL FEATURES

19	Slump: mixed glacial and bedrock materials; unstable slope.
18	Eroded slope, gully, stream valley: discontinuous colluvial cover on slopes; discontinuous alluvial gravel, sand, silt and clay along streams.

ORGANIC DEPOSITS

17	Muskeg: generally less than 10 feet thick but occasionally up to 30 feet thick; moss bogs generally thin and sedge and string bogs thicker; in places the muskeg is discontinuous.

ALLUVIAL DEPOSITS

16c	Alluvial sand: minor silt and clay; confined mainly to the flood plain of the Athabasca River.
16b	Alluvial silt and clay: minor sand and gravel; common along most streams; generally discontinuous and less than 10 feet thick.
16a	Alluvial silt and clay, underlain by alluvial sand and gravel: generally discontinuous and less than 25 feet thick; confined to the terraces of the Mackay River.
15	Alluvial fan: bedded sand, silt and clay; variable thickness; generally overlying glacial deposits.

LACUSTRINE DEPOSITS

14	Silt and clay, minor sand: common around modern lakes, generally less than 5 feet thick.

AEOLIAN DEPOSITS

13	Aeolian sand: fine to medium grained sand in sheet and dune form; thicker in dunes, discontinuous and thin in sheet sand.

Pleistocene

GLACIO-LACUSTRINE DEPOSITS

12 . 12a	Silt and clay: stratified silt and clay with minor sand; occassional pebbles and till lenses. 12a: overlain by discontinuous muskeg.
11 . 11a	Mixed: stratified clay, silt and sand with pebbles and till-like layers; portions of these deposits may be waterlaid till. 11a: overlain by discontinuous muskeg.

GLACIO-FLUVIAL DEPOSITS

10	Meltwater channel sediment: fine to coarse grained sand and gravel; contains variable amounts of pebbles and boulders; commonly occurs as bars; possibly early Athabasca River alluvium.
9 . 9a	Meltwater channel sediment: fine to coarse grained sand, minor silt and clay: overlying thin sand and gravel and lag gravel containing numerous boulders; possibly early Athabasca River alluvium; 9a: overlain by discontinuous muskeg.
8 . 8a	Outwash sand: commonly very fine to fine grained; also contains minor medium to coarse grained sand, gravel layers, till fragments, pebbles, boulders and silt and clay; surface level to gently undulating. 8a. overlain by discontinuous muskeg.
7 . 7a	Outwash sand and gravel: fine to coarse grained sand and gravel; contains variable amounts of pebbles and boulders; commonly occurs in bars, discontinuous terraces and distributary channels. 7a: overlain by discontinuous muskeg.
6	Eroded kames and kame moraine: highly dissected by post-depositional erosion; composed primarily of stratified sand and silt with minor gravel, clay and till lenses.
5 . 5a	Kames and kame moraine: composed primarily of stratified sand and silt with minor gravel, clay and till lenses; rolling topography; larger kames mark ice-marginal position of glacial advances. 5a: overlain by discontinuous muskeg.

GLACIAL DEPOSITS

4	Colluviated high relief till (>20'): high relief till that has been highly dissected by erosion.
3 . 3a	High relief till (>20'): till composed of sand, silt and clay with gravel and boulders; generally thick; topography undulating to gently rolling; topography due to stagnant ice deposition; overlain by thin lacustrine and organic deposits in depressions 3a: overlain by discontinuous muskeg.
2	Colluviated low relief till (<20'): low relief till that has been highly dissected by erosion.
1 . 1a	Low relief till(<20'): till composed of sand, silt and clay with gravel and boulders; variable in thickness; topography level to undulating; overlain by thin lacustrine and organic deposits in depressions. 1a: overlain by discontinuous muskeg.

Geologic boundary: defined, approximate, assumed

Abandoned beach

Channel scarp (ticks indicate downslope side)

Glacial fluting

Karst area

Sink hole

Notes:

1. The map was prepared from air photograph interpretations and helicopter supported field traverses. Geologic boundaries have been selected primarily from air photograph interpretations.
2. The map is intended to show sediment types found in the upper 10 feet (below surface); exceptions are the recent sediments which are often less than 10 feet thick.

To accompany a report entitled Surficial Geology of Potential Mining Areas in the Athabasca Oil Sands Region by R.A. McPherson and C.P. Kathol, July, 1977.

SCALE: 1:125,000

Fig-15

OFR 1977-4

11/15

Exceptions to this guideline are the recent sediments; these deposits are often less than 10 feet thick but are readily identifiable as distinct units. If more than one sediment type is present in the upper 10 feet, the most extensive type is chosen as the map unit and comments are provided in the map legend to indicate the presence of the less extensive material.

The primary map units are genetic namely: glacial, glaciofluvial, glaciolacustrine, aeolian, lacustrine, alluvial and organic units. Where possible, these units are subdivided on the basis of lithology and landform into subunits.

When using these maps, it is important to realize that surficial sediments are characterized by abrupt changes in lithology and grain size over short distances, often on a scale too small to be shown on 1:125,000 or 1:50,000 scale maps. The maps should therefore be considered adequate to delineate only the more extensive surficial deposits.

Considerably larger scale maps (in the order of 1" = 200') will be required to define properly surficial materials in areas where oil sands mining operations take place. A description of the units on the surficial map follows and additional information on certain of the units can be found in the section on stratigraphy.

Glacial Deposits

Glacial till, commonly defined as nonstratified sediment carried or deposited by a glacier, is present at or near surface in several areas. It is found on the flanks of the major bedrock uplands, namely Muskeg Mountain, Thickwood Hills, and Birch Mountains and in scattered localities elsewhere (Figure 15). Based on subsurface data, it is known to underlie most of the study area.

The surface till can be divided into four mappable units based primarily on geomorphic expression:

(1) low relief till (<20'),

(2) colluviated low relief till (<20'),

(3) high relief till (>20')

and (4) colluviated high relief till (>20').

Low Relief Till (<20')

In this report, low relief till is considered to be those till deposits with a local surface relief of less than 20 feet. It forms a level to gently undulating till plain on the flanks of Muskeg Mountain and in scattered localities elsewhere (Figure 15). The surface of the till is characterized by small knobs up to 350 feet in diameter and 20 feet in height (generally <10 feet), and kettles up to 150 feet in diameter and 20 feet deep.

Transverse elements such as small till ridges, aligned knobs and flutings are also present. The geomorphic features of the till surface are commonly not recognizable on air photographs because of extensive tree or muskeg cover; only in cleared areas such as wellsites and seismic trails do these features become apparent. Most of the low relief till unit could likely be termed ground moraine but the presence of transverse linear elements suggests that certain of these sediments are a product of deposition by stagnant ice. The surface of the till has been modified by a glacial lake (or lakes) as indicated by numerous wave washed boulder concentrations, beaches, and thin discontinuous lacustrine sediments. The till is comprised of a heterogeneous mixture of materials ranging in size from boulders to clay; however the till matrix (<2mm) is generally a loam to sandy loam [1]. Lenses of glacio-fluvial sands and gravel are common within the till. Further data on the nature and extent of this surface till can be found in subsequent sections of the report.

<u>Colluviated Low Relief Till (<20')</u>

Colluviated low relief till (<20') has been mapped

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[1] United States Department of Agriculture. soil classification, 1951.

on the flanks of Birch Mountains. It exhibits the same geomorphic features as the low relief till, with the exception that the original surface has been highly dissected by erosion and gullying. Most of the erosion likely occurred prior to establishment of a well developed vegetative cover because present day erosion appears minimal.

High Relief Till (>20')

High relief till, as defined in this report, comprises till with a local surface relief generally exceeding 20 feet. It is present on a bedrock upland north of the MacKay River in the southwest portion of the area and on the Birch Mountains (Figure 15). Knobs and kettles are the most prevalent geomorphic features of this unit. Knobs, comprised mainly of till, range up to several hundred feet in diameter and average 20 to 30 feet in height, although they may attain heights of up to 50 feet; kettles are of similar size with depths of up to 50 feet. In cleared areas, many of the features of stagnant ice deposition have been observed, namely: knobs, kettles, disintegration ridges and trenches, and moraine plateaus. It is expected that most or all of this unit could be termed "hummocky dead ice moraine" as defined by Gravenor and Kupsch (1959). The relief of the depositional surface of the till has been modified by infilling of depressions with muskeg and/or alluvial sediments. The till is comprised of a heterogeneous mixture of materials ranging in size from boulders to clay; however the till matrix (<2mm) is generally a loam to sandy loam. Lenses of glacio-fluvial sand and gravel and glacio-lacustrine silt and clay are also common within the till. Further data on the nature and extent of the high relief till can be found in subsequent sections of the report.

It is generally accepted that this type of till was deposited where blocks of ice stagnated during deglaciation but the way in which the hummocky topography originated is still a subject of controversy. The ablation theory, generally favored by most geologists working in western Canada - including the writers - envisages englacial debris gradually accumulating on the surface of the ice, and due to differential melting of the ice at the surface, let down irregularly on the ground. An alternate theory is that the geomorphic features are due to ice pressing underneath the ice sheet; this concept was discussed by Henderson (1959) and Stalker (1960) for similar deposits elsewhere in Alberta.

<u>Colluviated High Relief Till (>20')</u>

Colluviated high relief till (>20') has been mapped on the slopes of the Birch Mountains. It exhibits the same geomorphic features as the high relief till unit except that the original depositional surface has been highly dissected by erosion and gullying. Erosion of these sediments is presently minimal due to a well developed vegetative cover.

Glaciofluvial Deposits

Glaciofluvial deposits is a genetic term used to describe sediments deposited by glacial meltwater streams. These sediments are widespread in the area except on bedrock uplands. They are most extensive east of the Athabasca River but are also common along the west bank of the Athabasca River valley (Figure 15). Glaciofluvial deposits, on the basis of geomorphic expression and lithology have been divided into 6 map units:

(1) kames and kame moraine,

(2) eroded kames and kame moraine,

(3) outwash sand and gravel,

(4) outwash sand,

(5) meltwater channel sediment (sand),

and (6) meltwater channel sediment (sand and gravel).

Kames and Kame Moraines

Kames are moundlike hills of ice-contact stratified drift which originate in two principal ways. Some are bodies of sediment deposited in crevasses or other openings in or on the surface of stagnant or near stagnant ice which later melted away, leaving the accumulated sediment in the form of isolated or semi-isolated mounds. Another type of kame consists of deltas and fans built outwards from ice or inwards against ice which later melted collapsing and isolating the mass of sediment to form an irregular mound. Kame moraine is a general term used for a series of kames which were deposited along the margins of a glacier.

There are three large kames or kame delta complexes in the study area, namely the Fort Hills, a prominent kame to the west of the Fort Hills (tp. 97, Rge. 11), and a major kame complex in the northeast portion of the area (Figure 15). Other smaller kames exist in scattered localities throughout the region.

The kame complex which comprises the Fort Hills covers an area of approximately 65 square miles adjacent to McClelland Lake. Elevations of the hills range from 975 to 1175 or up to 200 feet above the surrounding countryside. Local relief is up to 50 feet where erosional channels separate irregularly shaped highlands. The depositional surface of the hills is further modified by the presence of muskeg, sinkholes, and discontinuous aeolian deposits. The slopes of the Fort Hills are generally quite rugged because they have been highly dissected by erosion (Plate 1, Figure 4). The sediments comprising the hills, although quite variable in grain size over short distances (both laterally and vertically) consist primarily of stratified silts and fine grained silty sand. The sands often contain a relatively high percentage of reworked bitumen, which gives them an appearance similar to the McMurray Formation oil sands. Lenses and layers of clay, till, and coarse sand and gravel are also present in minor amounts. Based on limited test hole data the kame complex is underlain by till. The thickness of the stratified sediments comprising the hills is variable but is at least 275 feet in certain localities. Further data on the lithology and extent of the Fort Hills is presented on the geologic cross sections (Figures 8 and 9) and in subsequent sections of the report.

Although the Fort Hills are expected to have a fairly complex depositional history (typical of ice contact deposits), most of the sediments are believed to have been deposited as a kame delta or fan complex. It is postulated that the glacier margin was to the north and that deposition occurred in a fan like pattern in a general southerly direction. Another feature to note is that the slope of the bedrock surface is quite steep beneath the Fort Hills along the subcrop edge of the McMurray Formation (Figure 10). The steep slope may have been a factor in localizing the kame delta complex in its current position. A second large kame occurs on the west side of the Athabasca River, northwest of the Fort Hills (Tp. 97, Rge. 11). It has an irregular, somewhat circular configuration and covers an area of approximately 5 square miles. Elevations on the kame range up to 1125 feet or over 200 feet above the surrounding countryside. Local relief is highly variable, especially around the margins of the kame, where it has been highly dissected by erosion. The presence of a discontinuous muskeg and aeolian sand cover further modifies the surface topography. Based on limited test hole data, the kame is comprised primarily of sand and silt with lenses and layers of clay, till, and gravel. The kame may, in part, be similar to the Fort Hills but appears to contain coarser grained sand and a higher percentage of till. Reworked bitumen is present in the sand as it is in the Fort Hills. The thickness of the kame is variable but it is at least 200 feet thick in certain localities and could exceed 250 feet.

This kame is believed to mark the same ice frontal position as the Fort Hills. It is uncertain whether it was originally connected to the Fort Hills and has since been cut into two separate segments by the Athabasca River.

The third major kame complex occurs in the northeast portion of the study area (Figure 15). It encompasses about 50 square miles along the east boundary of the region. Elevations on this highland range from 1125 to 1450 feet or up to 325 feet above the surrounding countryside. Local relief is highly variable because erosional channels separate irregularly shaped highlands; slopes are particularly rugged due to extensive erosion. The presence of discontinuous muskeg and aeolian sand further modified the topography.

The material comprising these deposits is not well known because of limited reliable lithologic logs; however they appear to consist primarily of sand, silt, and till. Lenses and layers of clay and gravel can also be expected. Commonly a layer of sand and silt as much as 240 feet thick (generally <100 feet thick) is found to overlie till layers of variable thickness and extent; the till is often separated by layers of sand. It is uncertain whether the kame sediments extend only to the uppermost till layer or whether much of the till occurs as lenses and pockets within the kames. This could be ascertained only by further drilling. Additional data on the lithology and extent of these deposits is available in subsequent sections of the report. The till associated with these kames is commonly sandy as opposed to a more silty till in the case of the other kames suggesting that they do not represent the same ice marginal positions. Data on the different tills is provided in a subsequent section of the report. Kame moraine occurs as an elongate northeast-southwest trending ridge near Kearl Lake (Figure 15). It covers an area of approximately 2½ square miles and has an elevation of up to 1150 feet or 50 feet above adjacent areas. The moraine once marked the shoreline of a glacial lake because beaches are developed along the northwest side of the ridge (Figure 15).

Based on limited drilling, the kame moraine is composed of variable amounts of sand and till. It has been termed a kame moraine because the surface materials are generally sands; however if further drilling revealed it consisted mostly of till it would more appropriately be called an end moraine. Other small kames are present in scattered localities throughout the region; the larger ones having been shown on Figure 15.

Eroded Kame Moraine

As mentioned previously, portions of the kames have been highly dissected by erosion, especially the steepest slopes. In areas where erosion has been so extensive as to completely alter the original depositional surface, a separate map unit has been used (Eroded kame moraine).

Most of the erosion is presently stabilized by a well developed vegetative cover; however it is expected that erosion would be extensive if the vegetation were removed.

Outwash Sand and Gravel

The term outwash is commonly used for stratified drift built by streams (washed out) beyond a glacier. Such sediment can also be termed glacio-fluvial - a term which also applies to ice contact stratified sediments. For the purposes of this report, outwash is used as a general term to refer to sediments of glacio-fluvial origin which exhibit no evidence of ice contact deposition.

Both outwash sand and outwash sand and gravel are found on surface in the study area. The distribution of the sand and gravel deposits is difficult to delineate because of major changes in lithology and grain size over short distances. Detailed drilling would be required to properly define these deposits. The areas mapped as sand and gravel on the surficial geology map are areas where these sediments are known to occur, however the boundaries have been approximated by air photograph interpretation.

Sand and gravel outwash deposits occur northeast of the Firebag River, within a large outwash deposit south and west of the Fort Hills, and in scattered localities elsewhere.

Northeast of the Firebag River, an approximately 3 square mile area has been mapped as outwash sand and gravel. This area forms part of a major deposit farther east that was mapped by Bayrock (1970) as outwash sand and gravel. The sediments consist primarily of sand but also contain gravel and boulders in variable quantities. The thickness of these deposits is unknown.

A number of sand and gravel bars have been mapped south and west of the Fort Hills (Figure 15). These deposits are generally less than 30 feet thick and contain layers of sand and gravel. Size of the materials ranges from cobbles to fine sand and is so variable that specific description of individual deposits is unwarranted; limited data on certain deposits is found in subsequent sections of the report or is on file at the Alberta Research Council. Other small deposits of outwash sand and gravel occur in scattered localities throughout the study area as shown on Figure 15.

Outwash Sand

Outwash sand is one of the most common surface sediments in the study area. It occurs in a discontinuous belt along the broad Athabasca valley, in much of the north-east portion of the study area and in scattered localities elsewhere (Figure 15).

The original depositional surface of the outwash sand is relatively flat with a local relief of generally less than 15 feet. The relief results from the presence of bars, discontinuous terraces, complex "braided stream" patterns, possibly buried ice blocks which subsequently melted, and occasional sinkholes (Plate 1, Figure 3). The depositional surface has been further modified by the presence of discontinuous aeolian and muskeg deposits and by post-glacial erosion. In certain areas, muskeg infillings of lows in the outwash surface are too complex to map individually; these areas have been mapped as outwash overlain by discontinuous muskeg.

The bulk of the outwash sand is very fine to fine grained; however, coarser sand, gravel, till fragments, silt and clay are all present in minor amounts. Based on test drilling, the outwash is generally coarser grained near the base of the deposits. The sand commonly contains reworked bitumen which gives the outwash an appearance similar to McMurray Formation oil sand. The thickness of the outwash sand where it forms the surface sediment is quite variable. On the west side of the Athabasca River, the outwash is generally 20 to 30 feet thick but exceeds 50 feet in some localities. On the east side of the Athabasca River the outwash is also commonly 20 to 30 feet thick. The only major area of thick outwash occurs in the vicinity of McClelland Lake where it is up to 150 feet thick. Studies conducted to the north of McClelland Lake confirmed that the thick outwash sand continues at least as far north as the Firebag River (Plate 1, Figure 5). Further data on the thickness and extent of the outwash sand is provided on the geologic cross sections (Figures 8 and 9) and in subsequent sections of the report.

One of the distinctive features of the major outwash sand deposits is that they commonly occur below an elevation of approximately 1000 feet; this elevation thus represents the maximum level of aggradation by the glacial streams and isolated deposits at higher elevations are considered unrelated to the main outwash sand deposit.

Most streams that build outwash originate within or upon the glacier itself. The drainage system takes the form of many small streams upon, beneath, or along the margins of the glacier. Ordinarily, the gradient of the streams decreases beyond the glacier and aggradation occurs. When both meltwater and drift are abundant, the outwash may build up so that it extends gradually headward over the terminus of the glacier. This tends to produce a great mass of outwash that may bury not only any end moraine that may be present but possibly the terminal zone of the glacier itself. This process could account for the partial burial of the Fort Hills kame delta complex by outwash sand and the presence of the thick outwash near McClelland Lake.

Meltwater Channel Sediment (sand)

Meltwater channel sediment refers to stratified materials deposited along channels that conducted meltwater from glaciers. These sediments commonly occur along the lower portions of the Athabasca River valley or below a maximum elevation of 1025 feet (in most instances <1000 feet). These sediments were deposited in irregular, discontinuous, but often well defined channels that have been eroded into the underlying surficial materials.

Meltwater channel sediments composed primarily of sand (in the upper 10 feet) have been shown as a separate map unit on the surficial geology map (Figure 15). Meltwater channel sands are fairly extensive on both sides of the Athabasca River valley in the south half of the study area, and from Bitumount to the north end of the map area.

South of Fort MacKay, the sand occurs in a belt up to 6 miles wide along the west side of the Athabasca valley. The west bank of the channel trends approximately parallel to the Beaver River and has been cut into glacio-lacustrine sediments and outwash.

The general slope of the surface of the meltwater channel (with numerous local exceptions) is to the east towards the Athabasca River and to the north along the Athabasca valley. Both Mildred Lake and Ruth Lake are elongate lakes occupying depressions in the surface of this meltwater channel (Plate 1, Figure 6). Local relief in the channel is commonly less than 15 feet; the original depositional surface is masked by the presence of discontinuous muskeg and aeolian sand deposits and by post glacial erosion. Remnants of a pre-existing outwash body are also present, in particular, north and south of Mildred Lake.

The corresponding channel on the east side of the Athabasca River has a maximum width of 2½ miles. The main deposit is present from the mouth of the Muskeg River to approximately 2 miles south of the Steepbank River. The top of the channel bank is at an elevation of approximately 1000 feet (or less) and the height of the bank is up to 100 feet.

North of Bitumount, meltwater channels have been eroded into outwash and kame delta deposits on both sides of the Athabasca valley. The elevation of the top of the banks seldom exceeds 900 feet. The surface of the channels is marked by several terraces down to present river level of approximately 775 feet. General slope on the channel surface is towards the river and to the north along the river valley. The surface of the channel has generally low relief as is the case with the meltwater channel sediments to the south.

The meltwater channel sediment is quite heterogeneous but the dominant lithology is a fine to coarse grained sand. Lenses and layers of gravel, silt and clay, and minor boulders are also present. The gravel and boulders are most prevalent near the base of the deposits. The thickness of these deposits is quite variable but generally less than 20 feet. Further information on the thickness of these deposits is presented on the geologic cross sections (Figures 8, 9). Limited data on cross stratification indicates that flow was to the north along the Athabasca valley.

Prior to deposition of the meltwater channel sediments, it is believed that a pre-existing bedrock low along the Athabasca valley had been partially filled with till, lacustrine and outwash sediments to an elevation of approximately 1000 feet.

As the glaciers receded, following deposition of the outwash, drainage to the north became feasible. Runoff from normal precipitation and the melting of glacier ice eroded the meltwater channel in the existing surficial deposits and the meltwater channel sediments were deposited. It should be noted that the amount of flow that can be attributed to glacier meltwater is uncertain and that the channel sediments may be more appropriately termed early Athabasca River alluvium.

Meltwater Channel Sediment (sand and gravel)

Areas within the meltwater channels that are known to be composed of sand and gravel have been outlined on the surficial geology map (Figure 15). These areas usually outline stream bars readily identifiable on air photographs. It should be stressed that detailed drilling would be required to delineate all the sand and gravel deposits within the channels because of the variability in grain size of these deposits over short distances. These sediments are believed to have considerable potential for aggregate supply and will be discussed more fully in subsequent sections of the report.

Glacio-lacustrine Deposits

Glacio-lacustrine deposits are those sediments deposited in glacial lakes. They are fairly extensive in the study area, forming the surface sediments in much of the region west of the Athabasca River, around the lower margins of Muskeg Mountain, and in scattered localities elsewhere. Glacio-lacustrine deposits have been divided into two map units namely:

(1) mixed deposits,

and (2) silt and clay.

Mixed Deposits

The mixed deposits are widespread west of the Athabasca River between the main outwash sand body and the western boundary of the study area. They occur on the flanks of Birch Mountains and Thickwood Hills up to elevations between 1400 and 1450 feet (Figure 15). They also occur on the east side of the study area between the outwash sand along the Athabasca valley and the till on Muskeg Mountain (Figure 15). Based on test drilling they are known to underlie much of the study area.

Local relief is flat to gently undulating (generally <10 feet); however the original depositional surface is somewhat masked due to a discontinuous cover of muskeg, recent lacustrine and aeolian deposits. Concentrations of wave washed pebbles and boulders on highs attest to modification by lake action.

The lithology of the mixed deposits is quite variable but they generally consist of stratified sand, silt, clay, and till or till like material. Lenses and layers of gravel, till balls and rock fragments are also common. The matrix of these sediments (<2mm) ranges from a heavy clay to a loamy sand but usually does not contain more than 50% silt.

In certain localities, stratification is poorly developed and the sediments are similar in appearance to till. In other localities, sand, silt and/or clay layers are interbedded with till like layers. In outcrop, individual layers pinch out both horizontally and vertically over relatively short distances. Slump and flow structures are also common in this unit. A unique feature of these sediments is their pink to pink grey colour. The more massive deposits are pinkish grey; the stratified ones are comprised of alternating layers of pink and grey. There is a tendency for the finer grained layers to be darker (grey) but numerous exceptions have been noted.

The boundary between the mixed sediments and normal glacio-lacustrine silts and clays is often difficult to delineate. The thickness of these deposits is quite variable but usually averages between 10 and 20 feet. Further data on the thickness of these sediments is presented on the geologic cross sections (Figure 8, 9).

These deposits are difficult to classify genetically because they have features similar to till as well as glacio-lacustrine sediments. Deposits of a similar nature have been described by Berg (1966), Kathol and McPherson (1975) and Bayrock (1970), all of whom interpreted them to be of lacustrine origin. Dreimanis (1969) utilized the name waterlaid tills for those tills deposited in a marine or lacustrine environment. Harland 'et al.' (1966) proposed the term para-tills for this type of sediment. Dreimanis (1969) indicated that waterlaid till is characterized by its stratification, flow structures, and impact marks formed by the dropping of clasts. He further pointed out that deformations caused by the glacial or ice-berg pressure are randomly oriented, due to sporadic or irregular contacts of the base of floating ice masses with the underlying waterlaid sediments.

The writers feel that the mixed sediments in the study area were deposited at or near the margins of glacial ice but in a lacustrine environment. They have been termed glacio-lacustrine sediments; however in at least some localities, they could conceivably be waterlaid till deposits.

Silt and Clay

These deposits form the surface sediments in much of the southwest portion of the study area and in scattered localities elsewhere (Figure 15). They are usually found between elevations of 1000 and 1600 feet or over a range of elevation of approximately 600 feet. The local relief is flat to gently undulating and normally less than 10 feet.

The silt and clay is overlain by muskeg and aeolian deposits in scattered localities and has been subjected to post glacial erosion.

The dominant grain size of the matrix (<2mm) is a silty clay to silty clay loam (U.S.D.A. classification, 1951). The sediments are well layered and frequently rhythmically laminated. Individual layers are comprised of varying proportions of silt and clay with minor sand. Lenses and layers of sand, and sand and gravel are occasionally present as are pebbles, quartz grains, and till-like layers. Certain of the rhythmically layered sediments may be varved, however an annual origin has not been proven. The fine grained nature of these sediments suggests that the ice margin was more remote during deposition than it was for the mixed deposits.

The thickness of these deposits is generally less than 20 feet; additional information on their distribution may be found on the geologic cross sections (Figures 8 and 9).

Shoreline Features

Beaches of former glacial lakes in the region have been delineated from air photographs; symbols are used to define them on the surficial map because they are too narrow to map as separate units (Figure 15).

Beaches are present on the flanks of Muskeg Mountain, Thickwood Hills and a kame moraine northwest of Kearl Lake. Beaches have also been mapped on the north slopes of Stony Mountain by Bayrock and Reimchen (1973). They occur over a wide range of elevations from approximately 1025 feet to 1675 feet. Attempts to correlate individual beaches have not been made because of a lack of reliable elevation data.

The beaches range from a few hundred feet long to over 10 miles in length. They are commonly less than 100 feet wide and composed primarily of sand.

The presence of beaches at elevations of up to 1675 feet indicates that either a very deep glacial lake was present in the area (>600 feet deep) or that the high level beaches mark the shorelines of nunatak lakes which formed along the slopes of the bedrock uplands during deglaciation.

Recent Deposits and Features

Recent deposits and features, formed subsequent to deglaciation of the region are common in the study area. They will be briefly discussed under 5 headings (comprising 9 map units) namely:

(1) aeolian deposits,

(2) lacustrine deposits,

(3) alluvial deposits,

(4) organic deposits,

and (5) erosional features.

Aeolian Deposits

Aeolian sand is common in the study area, primarily where glacio-fluvial sand constitutes the near surface material.

In most localities, the aeolian deposits form a thin discontinuous cover in dune and/or sheet form. Areas where aeolian sand is most extensive have been delineated on the surficial geology map (Figure 15). It is important to realize that it is also present in other areas but is not extensive enough to show on the 1:125,000 scale map.

Both parabolic and longitudinal dunes are found, but parabolic dunes predominate. The largest dunes occur between McClelland Lake and the Firebag River where they are up to 2 miles long and 30 feet high.

The sand is well sorted, fine to medium grained and comprised primarily of quartz grains.

Most of the aeolian deposits are presently stabilized by a well developed vegetative cover. Minor recent erosion, mainly blowouts, have been observed where vegetation is sparse.

Lacustrine Deposits

Recent lacustrine deposits are fairly common in the study area. They are most extensive around Kearl Lake, McClelland Lake, and along the meltwater channels which flank both sides of the Athabasca valley (Figure 15). They also occur in many of the smaller depressions in the land surface but are usually not extensive enough to show as separate map units.

The sediments are comprised of layers of sand, silt and clay, with silt and clay predominating. They often have a high organic content and may contain muck and marl. Based on limited data, they are generally less than 5 feet thick.

Alluvial Deposits

Alluvial deposits in the study area consist of either alluvial fans or sediments deposited along modern streams.

Alluvial fans occur on the lower slopes of Birch Mountains, on the slopes of kame moraines and meltwater channels, and in scattered localities elsewhere (Figure 15). They have been delineated from air photographs and were not examined in detail in the field. The fans are believed to be comprised of varying proportions of sand, silt and clay. Almost all the fans are presently stabilized by a well developed tree cover.

Alluvial sediments are common along most of the streams. They occur discontinuously along the lower portions of the stream valleys and are comprised of clay, silt, sand and gravel. These deposits have been subdivided into three types as shown on Figure 15.

Alluvial silt and clay underlain by alluvial sand and gravel is present along the MacKay River downstream from the Dover River. A low level terrace, near river level, consists primarily of silt and clay; however a higher terrace, about 20 feet above the river, is comprised of 10 to 15 feet of silt and clay underlain by 5 to 15 feet of sand and gravel (Figure 15). The sand and gravel is poorly sorted and contains appreciable quantities of local bedrock fragments, clay lumps and organic matter. These deposits have some potential as a source of low quality aggregate.

Alluvial silt and clay is present along the majority of the streams in the area (Figure 15). It is usually less than 10 feet thick, although locally it may be much thicker.

Minor lenses of sand and gravel are common within or below the silt and clay.

Alluvial sand, present in limited quantities along many streams, is sufficiently extensive to show as a separate map unit along the flood plain of the Athabasca River (Figure 15). The areas delineated on the map consist primarily of fine sands up to 25 feet thick; however smaller amounts of silt and clay can also be expected.

Organic Deposits

Organic deposits or muskegs are widespread, comprising the surface materials in at least half the study area. Areas where muskeg forms a fairly continuous cover have been delineated on the surficial geology map (Figure 15); areas with a discontinuous but relatively extensive muskeg cover have also been outlined. Organic deposits can be expected in other areas, however they are generally too small to show on the 1:125,000 scale map. Individual muskegs are unclassified as to depth and plant colonies because these sediments were not examined in detail. Two main types of organic soils were observed, namely mosses and sedges.

The moss type, derived primarily from sphagnum moss, is relatively coarse textured. Black spruce, tamarack, labrador tea, reindeer moss, and sphagnum moss are characteristic tree and ground cover plants in these bogs (Plate 2, Figure 1).

The sedge type is formed from sedges and grasses and is a relatively fine textured fibrous peat; tree cover on these bogs is relatively sparse (Plate 2, Figure 2). Well developed string bogs are present in some areas, particularily near McClelland Lake and south-east of the Fort Hills (Plate 2, Figure 3). Based on limited field data, the muskegs are generally less than 10 feet thick; the maximum observed thickness is 30 feet. Data on muskeg depths in specific localities is on file at the Alberta Research Council.

During field mapping, the muskeg was found to be frozen at depth in a number of localities in late summer. Similar occurrences have been reported by several other workers (Lindsay, Pawluk, and Odynsky, 1962). This indicates that permafrost may be present discontinuously in the organic soils of the region.

The organic soils will exert considerable influence on oil sands mining operations because they have to be removed prior to mining. They may also serve as a source of material for reclamation purposes. Detailed mapping of these deposits will be required in areas where actual mining operations occur.

Erosional Features

Erosional features have been subdivided into two units on the surficial geology map, namely:

(1) eroded slopes, gullies and stream valleys

and (2) slump areas.

<u>Eroded slopes</u>, which generally occur along stream valleys and meltwater channels, are characteristically steep and commonly gullied. Materials comprising the slopes include surficial or bedrock deposits overlain by a discontinuous veneer of colluvium. The materials are so variable in different areas that description of specific slopes is not provided. Many, but not all of the slopes are presently stable due to a well developed vegetative cover which retards erosion.

Areas where readily apparent slumping has occurred, have been delineated on the surficial geology map; boundaries of the slumps have been estimated from air photographs. The slumping is most prevalent where Cretaceous shales comprise the slopes, in particular the Clearwater Formation shales. Slumping of glacio-lacustrine silts and clays is also common, however many of the slumps are too small to show on the surficial map.

THICKNESS OF SURFICIAL DEPOSITS

The areal distribution of the surficial deposits as shown on the surficial geology map (Figure 15) has been previously discussed. A map outlining the thickness of the surficial deposits was also prepared utilizing available outcrop and test hole data (Figure 16). The map included with this report is on a scale of 1:125,000 (1:50,000 scale maps were also prepared and are on file at the Alberta Research Council). The distribution of data control points for the surficial geologic deposits is shown on Figure 30 (Appendix 1). The term surficial deposits (or drift), as used in this report refers to all sediments above bedrock, and may include preglacial, glacial, and postglacial materials. In general, surficial sediments are relatively thick on the slopes and tops of the major bedrock uplands. The drift is 50 to 75 feet thick on the slopes of Birch Mountains except in areas along streams where extensive erosion has occurred (Figure 16). Thick drift is also known to be present on the top of Birch Mountains west of the map area.

On the slopes and top of the bedrock upland north of the MacKay River, the drift is commonly 25 to 50 feet thick but is greater than 50 feet thick in a few localities.

FIGURE 16.

Thickness of surficial deposits in the study area.

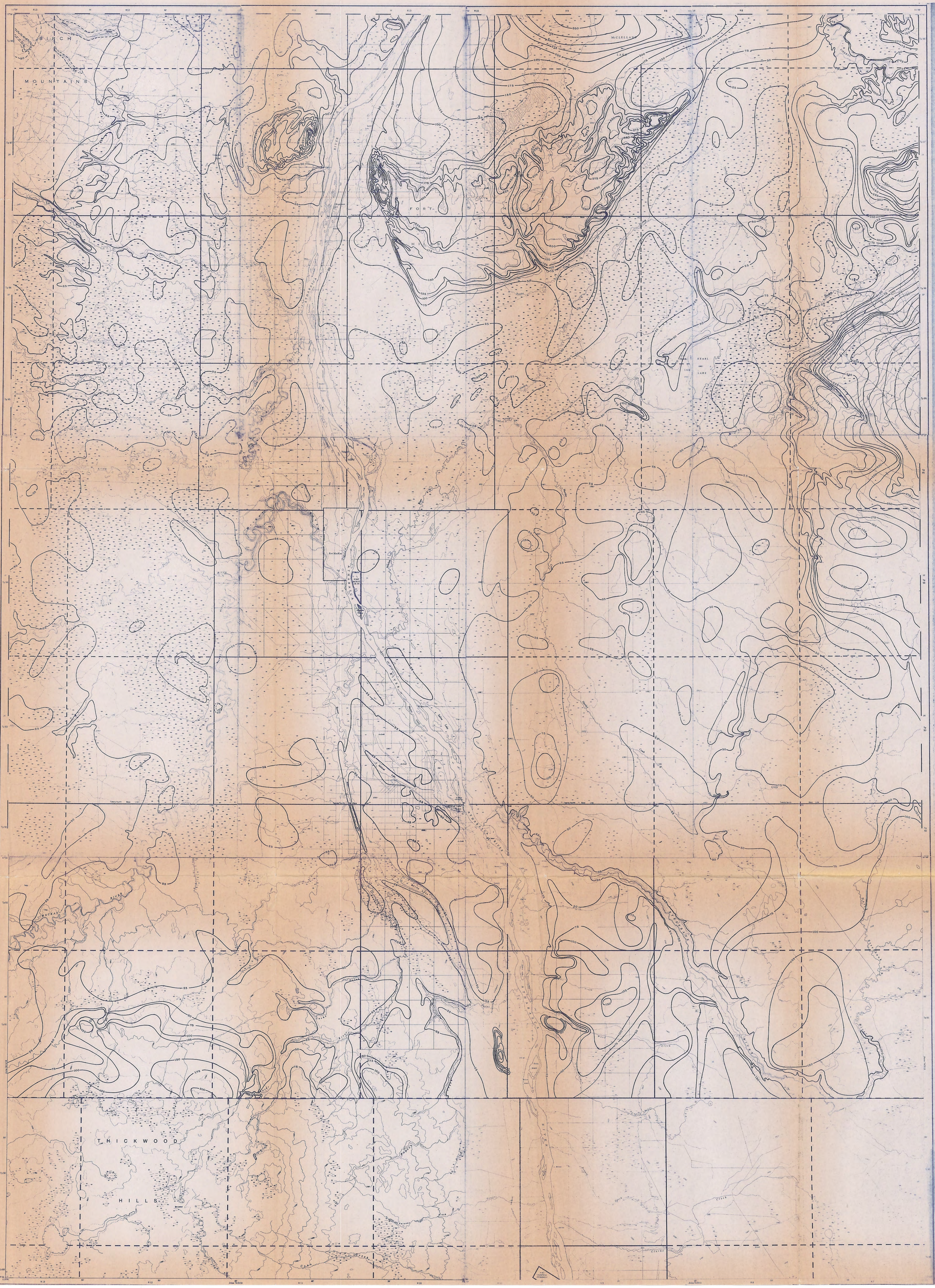


FIGURE 16

Thickness of Surficial Deposits in the Study Area.

Fig 16

LEGEND

River or Stream . . . . Trail . . . .

Intermittent River or Stream . . Building . . . .

Lake . . . . Township Line . . . .

Organic Terrain . . . . Section Line . . . .

Road . . . . Topographic Contour 975

THICKNESS OF SURFICIAL DEPOSITS ISOPACH (generally 25 ft. interval)..

Defined, approximate 75

SCALE: 1:125,000

OFR 1977-4
12/15

South of the MacKay River, on the Thickwood Hills, the drift is usually 50 to 100 feet thick; it exceeds 200 feet in thickness along the south boundary of the area where extensive till is present (Figure 16). The slopes and top of Muskeg Mountain are mantled by drift, usually 50 to 150 feet thick, comprised primarily of till and glacio-fluvial sand and gravel. Maximum drift thickness of over 450 feet occurs on the north slope of Muskeg Mountain along the east boundary of the study area (Figure 16).

Thick drift, mainly glacio-fluvial sand and silt, is present in kames and kame moraines, namely the Fort Hills (up to 300 feet thick), a large kame west of the Fort Hills (up to 225 feet thick), and the kame moraines east of the Fort Hills (up to 400 feet thick).

In the vicinity of McClelland Lake, and north of the study area between McClelland Lake and the Firebag River, the surficial materials attain a thickness of up to 350 feet. Sediment types in these areas are mainly outwash sand, glacio-lacustrine silts and clays, and till.

Another area of relatively thick drift (75 to 150 feet) is present south of the Steepbank River.

Elsewhere in the study area, the drift is somewhat thinner. Along the modern Athabasca River valley, surficial materials are usually less than 25 feet thick because extensive postglacial erosion has occurred. It should be noted that drilling data is sparse in the river valley in the study area. However, salt well logs presented by Carrigy (1959) indicate up to 125 feet of drift in the river valley at Fort McMurray and bedrock elevations of less than 700 feet. Unless this indicates recent salt solution and local collapse, a buried channel is likely present below the actual river. Most of the area west of the Athabasca River, excluding the uplands, has drift less than 50 feet thick and commonly less than 25 feet thick (Figure 16). Exceptions occur along the Pierre River where the drift exceeds 75 feet in thickness, and along portions of the Beaver River channel where surficial materials are known to be thick. In the eastern part of the study region, a large area bounded by the Athabasca River, the Fort Hills and Muskeg Mountain has drift either less than 25 feet thick or 25 to 50 feet thick. Smaller areas of thick drift are also present (Figure 16). One of particular interest occurs southeast of the Fort Hills where a short steep-sided bedrock channel is reported to contain thick sand and gravel. It is not known whether the sand and gravel is glacial or preglacial in age because reliable lithologic descriptions are not available.

Further information on the thickness of surficial deposits can be found on the geologic cross sections (Figures 8, 9).

STRATIGRAPHY OF SURFICIAL DEPOSITS

The Quaternary deposits in the study area can be divided into a number of stratigraphic units (Table 4). These units consist of preglacial gravels and sands, till, stratified deposits and recent sediments. Parameters which have been used to characterize these deposits include:

(1) textural analyses,
(2) lithology of the very coarse sand fraction (2-1mm),
(3) Atterberg limits,
(4) moisture content,
(5) dry density,
and (6) stratigraphic position.

A summary of the properties of the various units has been prepared (Table 5). A comparison of certain properties of the till units is also provided to show the manner in which they have been identified (Figures 17, 18, 19 and 20). Each of the stratigraphic units is discussed separately in the following section of the report.

Table 4
Succession of Surficial Geologic Deposits
in Study Area

ERA	PERIOD	DESCRIPTION OF UNITS	
CENOZOIC	Quaternary	Recent sediments:	includes lacustrine, alluvial and aeolian deposits and muskeg
		Meltwater channel sediments	possibly early Athabasca River alluvium
		Upper stratified sediments	outwash deposits glacio-lacustrine deposits mixed glacio-lacustrine deposits Fort Hills kame moraine deposits
		Fort Hills till [1]	
		Lower stratified sediments (?)	glacio-lacustrine deposits glacio-fluvial deposits
		Firebag till [2]	
		Unnamed till	
		Undifferentiated till and stratified sediments	
	?		
	Tertiary	Saskatchewan gravels and sands Preglacial gravels and sands	primarily quartzite with minor chert, ironstone, coal fragments and clay lumps
MESOZOIC	Cretaceous	Sandstone, siltstone and shales	

Notes 1: Referred to as till A by Fenton and Dreimanis (1976).

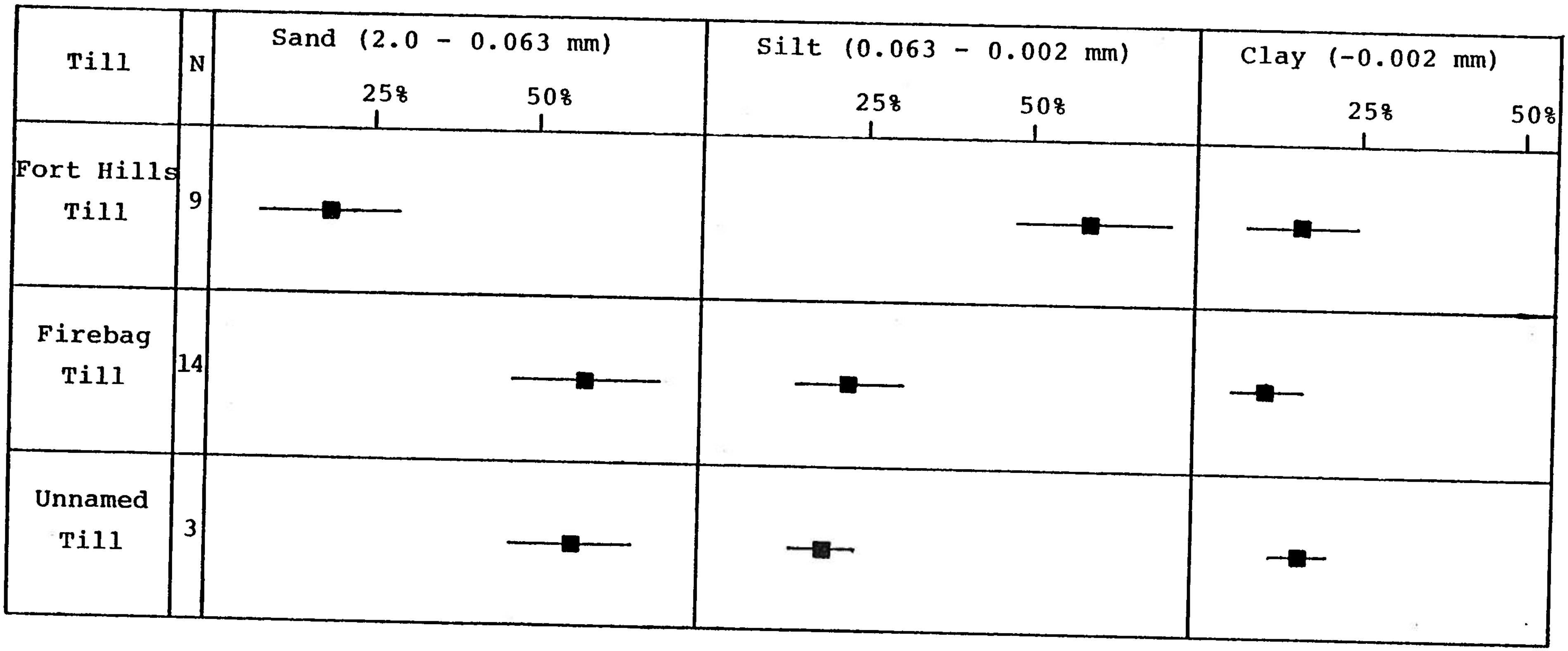
Table [illegible]

Summary of properties and indicies of the major Quaternary units

UNIT	LITHOLOGY	TEXTURE[1] % Sand	% Silt	% Clay	V.C. SAND MINERALOGY (2-1mm) % Cr	% Qtz	% Ls	% Ds	% Cb	ATTERBERG LIMITS L.L.	P.L.	P.I.	MOISTURE Content %	DRY DENSITY[2] #/ft³
Recent Sediments	aeolian sand	M 97.5 SD (3.2) N= 13	2.5 (3.2)		---					---			---	M 103.9 (A) SD (2.2) N= 2
Meltwater channel sediments	sand and gravel	variable			---					---			---	---
Glacio-lacustrine sediments	silt and clay	15.0 (14.1) N= 28	45.1 (14.5)	39.9 (15.6)	---					M 47.0 SD(13.2) N=21	24 (6.4)	23.0 (10.7)	M 28.4 SD (10.6)	M 114.4 (A) SD= (9.7) N= 7
Mixed glacio-lacustrine sediments	sand silt and clay	M 32.3 SD(18.1) N= 52	33.9 (10.3)	33.4 (18.0)	---					M 35.5 SD (8.8) N=46	18.8 (4.5)	16.9 (7.7)	M 21.4 SD (6.3) N= 117	M 125.3 (A) SD (8.9) N= 20
Glacio-fluvial sediments	Outwash sand	Graphic Mean=0.32MM SD (0.13) N= 16			---					---			M 7.5 SD (3.9) N= 9	M 114.9 (P) SD (7.2) N= 9
	Fort Hills Kame Complex	Graphic Mean=0.23MM SD (0.10) N= 16			---					---			M 8.9 SD (5.0) N= 17	M 114.6 (P) SD (4.8) N= 12
Fort Hills Till	Silty till	M 18.4 SD(10.5) N= 19	69.0 (12.1)	12.6 (7.8)	M 14.2 SD(5.2) N=15	26.0 (6.8)	5.3 (2.9)	32.4 (8.6)	41.3 (9.4)	M 36.0 SD (4.9) N= 8	22.3 (2.8)	13.8 (6.7)	M 23.8 SD (4.5) N= 8	M 129.2 (A) N= 1
Firebag Till	Sandy till	M 57.4 SD(12.3) N= 14	32.2 (8.0)	10.4 (6.6)	M 12.3 SD(6.0) N=36	50.0 (7.8)	5.6 (5.2)	19.7 (8.4)	27.4 (8.7)	M 25.6 SD (7.8) N=9	17.4 (4.8)	8.3 (5.1)	M 10 SD (2.6) N= 7	M 131.1 (A) SD (9.6) N= 8
Unnamed Till	Sandy till	N 55.6 SD(8.5) N=3	28.7 (4.0)	15.7 (4.5)	M 41.9 SD(16.9) N= 8	46.6 (22.3)	0.4 (0.4)	1.7 (2.1)	2.4 (2.1)	M 25 SD (0.7) N=2	18.7 (0.4)	6.4 (0.4)	M 11.3 SD (2.1) N= 3	M 133.9 (A) SD (2.1) N= 2
Lower Units	---	No analyses			---					---			---	---

Notes: 1:Texture, Sand = 2.-0.063mm, Silt= 0.063-0.002mm, Clay= -0.002mm
Glacio-fluvial deposits not analysed for clay content, graphic mean calculated (after Folk, 1965)
Textural analyses of the tills represent analyses of the till matrix only (<2mm)
2:Dry densities calculated from disturbed auger samples (A) and penetration tube samples (P)

Symbols used: Cr=crystalline, Qtz=quartz, Ls=Limestone, Ds=dolostone, Cb=carbonate
LL=Liquid limit, P.L.=plastic limit, P.I.=plasticity index
M=mean, SD=standard deviation, N=number of samples



N = number of samples

-■- = mean and standard deviation

FIGURE 17: Summary of matrix texture of the tills in study area.

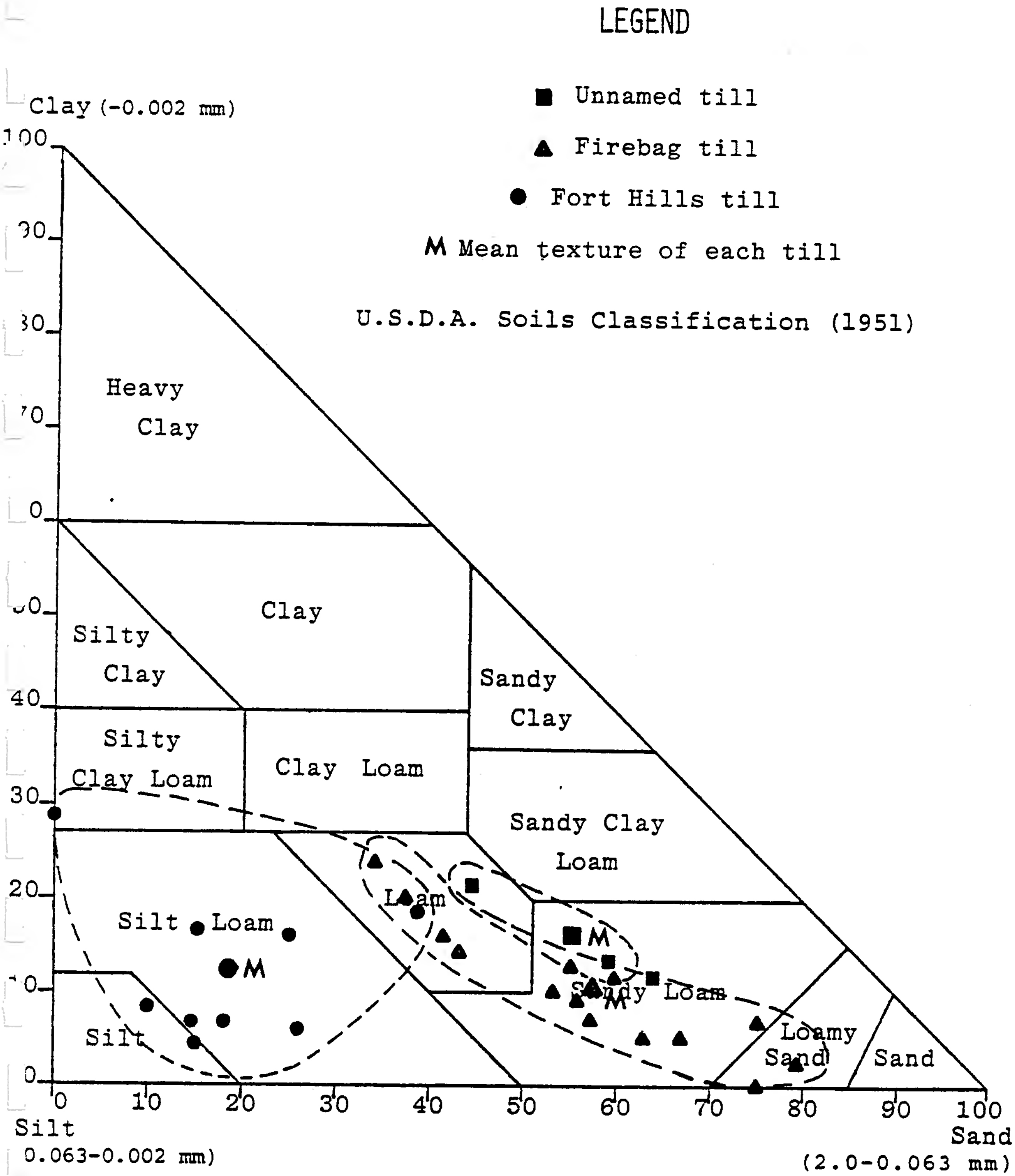
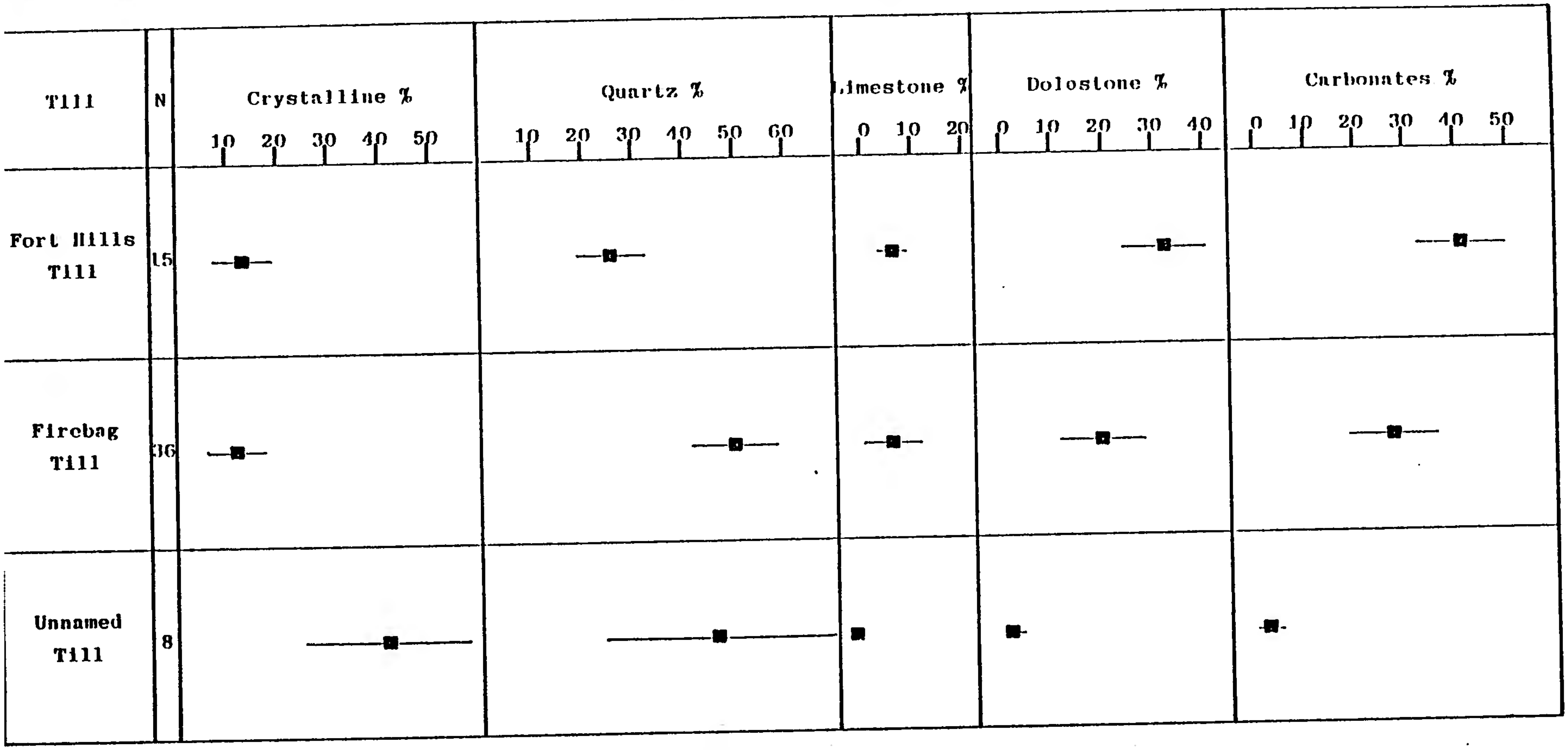
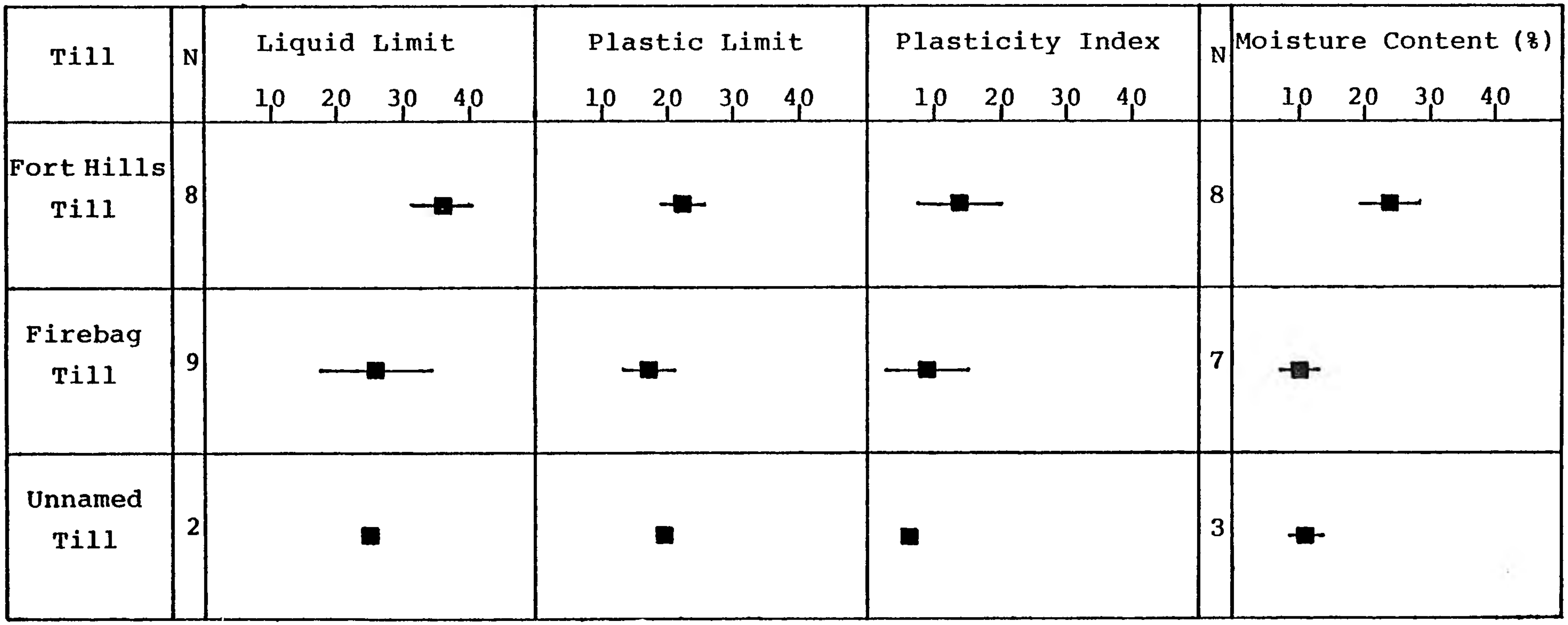


FIGURE 18: Textural comparison of the matrix (-2 mm fraction) of the unnamed, Firebag and Fort Hills tills.



N = number of samples
-■- = mean and standard deviation

FIGURE 19: Percentage of the major lithologic components of the very coarse sand fraction of each till unit in the study area.



N = number of samples
-■- = mean and standard deviation

FIGURE 20: Comparison of Atterberg limits and moisture content of the tills in the study area.

Preglacial Sediments

Oligocene and younger gravels and sands found throughout Alberta were deposited by streams flowing northeastward or eastward from the Rocky Mountains. Deposition of this "preglacial" alluvium continued intermittently from the last half of the Tertiary Period well into the Quaternary period. During this time, gradual uplift of the Plains caused the streams to incise deep valleys. These streams also migrated laterally during their history. The downcutting and lateral migration often resulted in remnant uplands being left between the streams.

The preglacial sediments deposited by these streams can be divided into three types:

(1) high level sediments, which commonly form protective caps which retard erosion on bedrock uplands; these preglacial gravels and sands are the oldest and represent early stages of lowering of the land surface,

(2) intermediate-level sediments which typically form benches and terraces in proximity to

major preglacial stream valleys.

(3) low level sediments deposited by streams prior to glaciation and which are found as channel fill at the base of the preglacial valleys.

The name used for alluvium belonging to this third group is Saskatchewan gravels and sands (Stalker, 1968). Saskatchewan gravels are generally quite similar in lithology throughout the plains being composed mainly of quartzite rock fragments. Minor amounts of chert, arkose, petrified wood, coal and clay ironstone and bedrock fragments are often found at the contact with bedrock.

The Saskatchewan sands are similar in lithology to the gravels, but generally contain a higher percentage of local bedrock material.

The sands are usually fine to medium grained and poorly sorted. Both the sands and gravels are rounded and contain minor silt and clay beds.

In the study area, bedrock uplands separated by intervening lowlands have a configuration similar to those found in other parts of Alberta where preglacial sands and gravels are present. However, little evidence of preglacial sediments is available for the study area. The presence of sand and gravel cappings on the bedrock uplands, namely Thickwood Hills, Birch Mountains, and Muskeg Mountain is uncertain due to the lack of reliable drilling data. Bayrock and Reimchen (1973) indicated that the till on

Stony Mountain upland south of Fort McMurray consists of a significant proportion of rounded quartzites derived from Tertiary gravel signifying that these sediments are likely present on this upland.

When mapping the surficial deposits, two small preglacial channels containing sand and gravel were observed in the surface of the Clearwater Formation west of the map region. Similar channels are likely present in the study area. A number of occurrences of sand and gravel in lows in the bedrock surface were found; however the lack of reliable lithologic data prevented them from being positively identified as Saskatchewan gravels and sands. It is possible that the Athabasca River follows the course of a preglacial channel; however no drill hole data is available to support this hypothesis.

Undifferentiated Till and Stratified Sediments

No reliable data is available to confirm the existence of these sediments; however they are inferred to be present for the following reasons:

(1) The drift is thick in portions of the study area, in particular on the slopes and tops of bedrock uplands. It is known to be over 200 feet thick in several localities and over 450 feet thick on the slopes of Muskeg Mountain along the eastern boundary of the

map area. Because the maximum depth of sampling for this project was 150 feet (depth capacity of the auger drills), it is possible that older Quaternary units are present in the subsurface.

(2) Gamma Ray and Spontaneous Potential logs of existing test holes in the thick drift areas reveal complex drift sequences (below 150 feet) interpreted to be sand and/or gravel interbedded with clay rich sediments (either till and/or lacustrine sediments).

However, no reliable samples of these materials are available.

It is therefore postulated that undifferentiated till and stratified sediments are present in areas of thick drift. Certain of the sediments may form part of the overlying drift units, but it is likely that at least some of the deeply buried sediments represent distinct units. These deposits are expected to be the oldest Quaternary sediments in the area and may in fact contain a valuable record of early Quaternary events in Northeast Alberta.

Unamed Till

A distinct till referred to as the unnamed till has been identified in two localities in the study area

(Figure 21); reference sections for this till are T4-S5 and drill hole 76-403 (Figure 21 and Appendix 2). No formal name has been given to this till because of the lack of extensive information on its nature and distribution.

The till is a silty to sandy loam[1] with a mean matrix texture (<2mm fraction) of 55.6 percent sand, 28.7 percent silt and 15.7 percent clay; a ternary plot of the matrix texture is presented on Figure 18. The mean composition of the very coarse sand fraction indicates the till is relatively high in crystalline and quartz grains and low in carbonates (Table 5, Figure 19). Other properties of the till are outlined on Figures 17 and 20. The till is dark grey when wet and unoxidized and contains a moderate percentage of clasts.

The unnamed till is overlain by glacio-lacustrine sediments in drill hole 76-403 and by the Firebag Till in the section of the Steepbank River; the lower contact has not been reached.

The unnamed till is distinguished from the overlying Firebag till by the mineralogy of the coarse sand fraction being higher in crystalline grains and lower in carbonate grains, primarily dolostone (Figure 19). The

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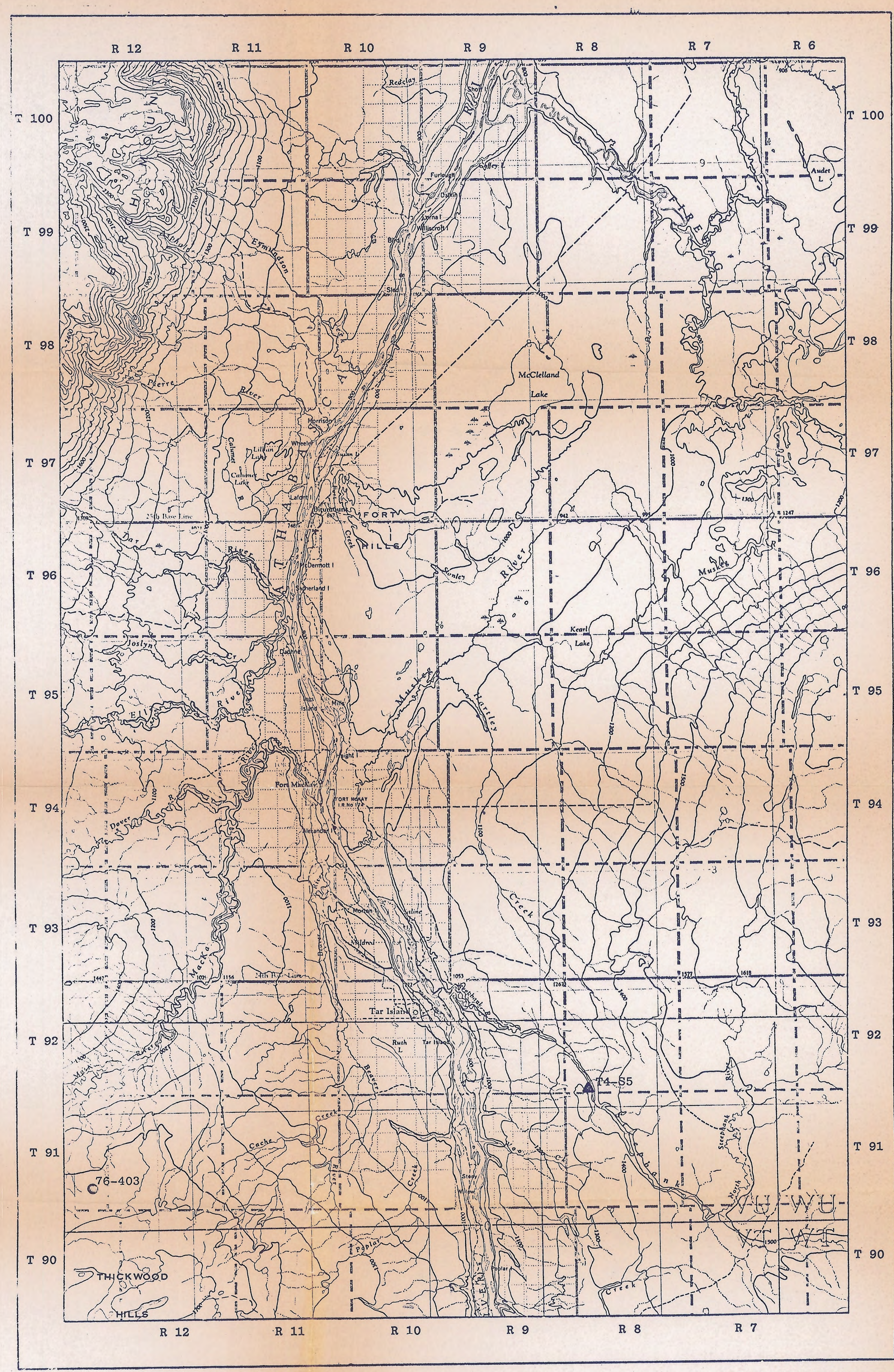
[1]The textural designation and similar ones in the following text are based on the United States Department of Agriculture soil classification (1951).

FIGURE 21.
Map showing known occurences of the unnamed till in the study area.



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O Drill hole

Δ Field stop

FIGURE 21: Map showing known occurences of the unnamed till in the study area. Future studies may reveal that it occurs elsewhere in the study area.

OFR 1977-4

13/15

Fig 21

unnamed till is different from the younger Fort Hills till in most properties analyzed (Table 5). It is higher in crystalline and quartz grains than the Fort Hills till and is lower in carbonates (very coarse sand fraction). It is significantly sandier and less silty than the Fort Hills till (Figures 17, 18). Other properties which can be used to differentiate the unnamed till from the Fort Hills till include Atterberg Limits and moisture content (Figure 20).

Information concerning the source of this till is limited to textural and compositional data. The high quartz-crystalline and low carbonate content (very coarse sand fraction) suggests it was derived by an ice advance from the east or east northeast where extensive Precambrian outcrops and a relatively thin outcrop belt of Methy Formation dolomite are present.

Because of the lack of data on this unit, it is not known whether stratified drift occurs between the unnamed till and the overlying Firebag till. Further studies may result in additional information which is deemed necessary to apply a formal name to this till.

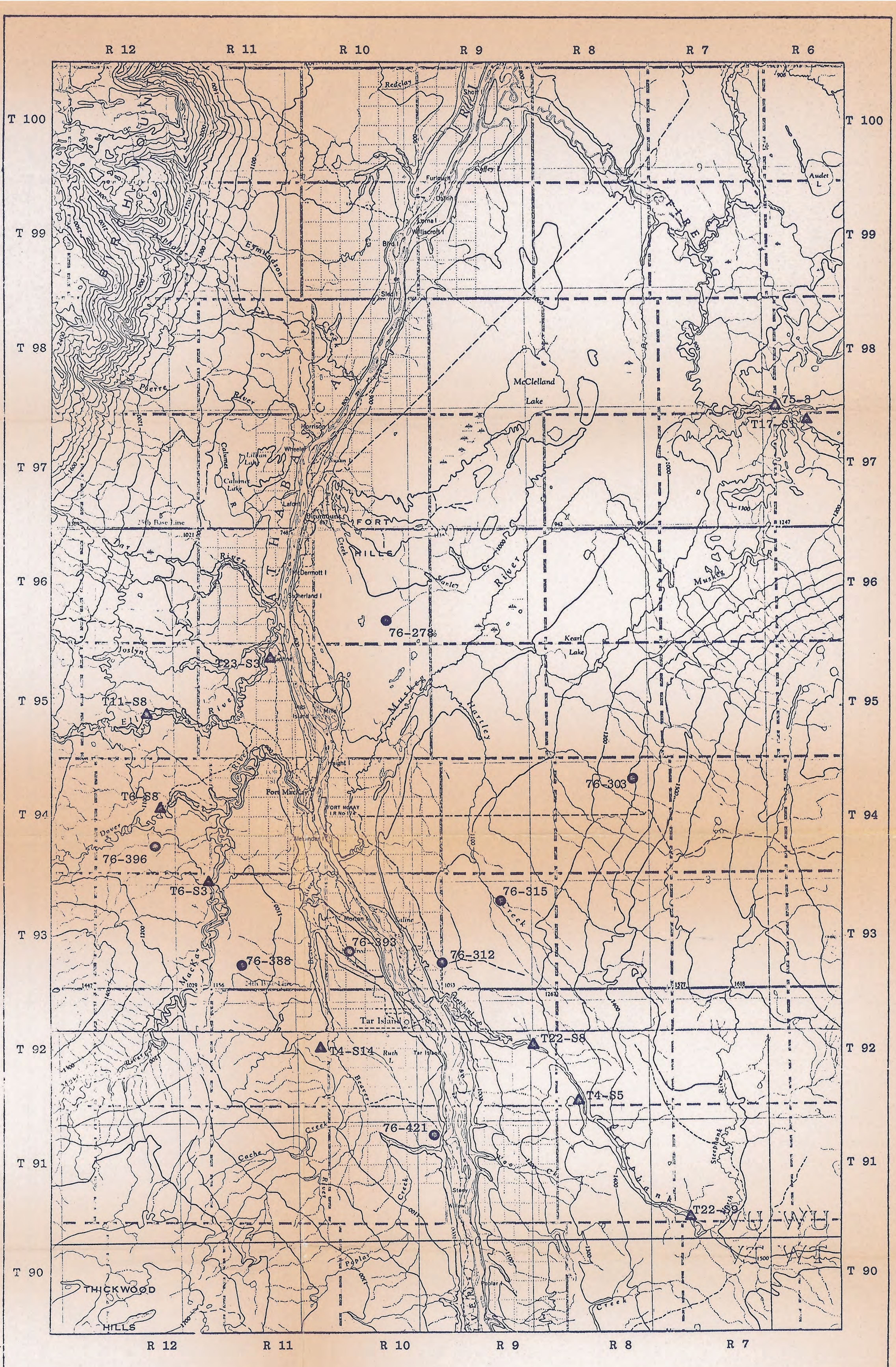
Firebag Till

The Firebag till derives its name from extensive outcrops along the Firebag River northeast of the study area. The type section is T17-S1 on the

Firebag River and a reference section is drill hole 76-312 (Figure 22 and Appendix 2). The known distribution of this unit is shown on Figure 22; photographs of sections of this till are included in Appendix 4 (Plate 2, Figures 4, 5). It forms the surface till in most of the area mapped as till on the surficial geology map (Figure 15) with the possible exception of the till found on the top of Thickwood Hills and Birch Mountains which may be older. It is underlain by bedrock in many instances and by the unnamed till and undifferentiated older Quaternary units in areas of thick drift. None of the sections or drill holes examined were found to have the Firebag till overlain by the Fort Hills till. This sequence is postulated to exist in the thick drift area north of the Fort Hills but could not be confirmed because of the depth limitation of the auger drills used for this project. South of the Fort Hills, the Firebag Till is overlain by stratified sediments interpreted to be younger than the Fort Hills till. The presence of stratified sediments between the Fort Hills and Firebag till is discussed in a subsequent section of the report. The till is a loam to sandy loam with a mean matrix texture of 57.4 percent sand, 32.2 percent silt and 10.4 percent clay; a ternary plot of the matrix texture is presented on Figure 18. The mean composition of the very coarse sand fraction indicates

FIGURE 22.

Map showing known occurences of the Firebag Till in the study area.



○ Drill hole

△ Field stop

SCALE: 1:250,000

FIGURE 22: Map showing known occurences of the Firebag Till in the study area. This till is interpreted to underlie the entire study area with the possible exception of the highest portions of the Birch Mountains and Thickwood Hills.

OFR 1977-4

14/15

Fig 22

the till is relatively low in crystalline grains, high in quartz and contains appreciable carbonate grains, primarily dolostone (Table 5, Figure 19). Other properties of this till are summarized on Table 5 and Figures 17 and 20. The till is dark grey to dark grey-brown when wet and unoxidized and contains a relatively high percentage of clasts.

The Firebag till is differentiated from the lower unnamed till by the very coarse sand mineralogy being lower in crystalline grains and higher in carbonates, primarily dolostone (Table 5, Figure 19). It can also be differentiated from the younger Fort Hills till by the very coarse sand mineralogy because it has a higher quartz and lower carbonate (primarily dolostone) content. It is further distinguished from the Fort Hills till by matrix texture, Atterberg Limits and moisture content (Table 5, Figure 20). The properties of the Firebag till exhibit a tendency to be related to the type of underlying bedrock deposits. The till is commonly sandier when it directly overlies the McMurray Formation and becomes quite bituminous near the contact with oil sands. Blocks of ice transported shale are often found near the base of the till when it is underlain by Clearwater Formation shales and the matrix tends to have a somewhat higher clay content. At least a portion of the deviation of the matrix texture from the mean shown on Figure 17 can be attributed to incorporation of the underlying bedrock into the till.

The Firebag till is interpreted to have been deposited by an ice advance from the north east where the ice would have passed over fairly extensive outcrop belts of Precambrian rocks and Methy Formation dolomite. This would account for the higher percentage of carbonate grains in the coarse sand fraction as compared to the unnamed till.

Lower Stratified Sediments

The pressure of extensive stratified sediments between the Firebag and Fort Hills tills has not been clearly demonstrated because no geologic sections or drill holes were found in which the Firebag till is overlain by the Fort Hills till. The presence of these sediments in the thick drift area north of the Fort Hills remains a possibility. In two sections along the Firebag River, pink and grey lacustrine silts and clays were found to underlie the Fort Hills till, however they are highly folded and faulted. These sediments may have been deposited in the bedrock low between McClelland Lake and the Firebag River following retreat of the Firebag ice sheet from the area. The deformation would have resulted from the Fort Hills ice over-riding these sediments; they may therefore be more appropriately termed deformation till associated with the Fort Hills ice advance.

Glacio-fluvial deposits comprising the large kames east of the Fort Hills are interpreted to have been deposited along the terminus of the Firebag glacier because:

(1) they contain no till lenses of the Fort Hills till (as are found in the Fort Hills kame moraine),

and (2) the Fort Hills till has not been found along the Firebag River north and east of the kames.

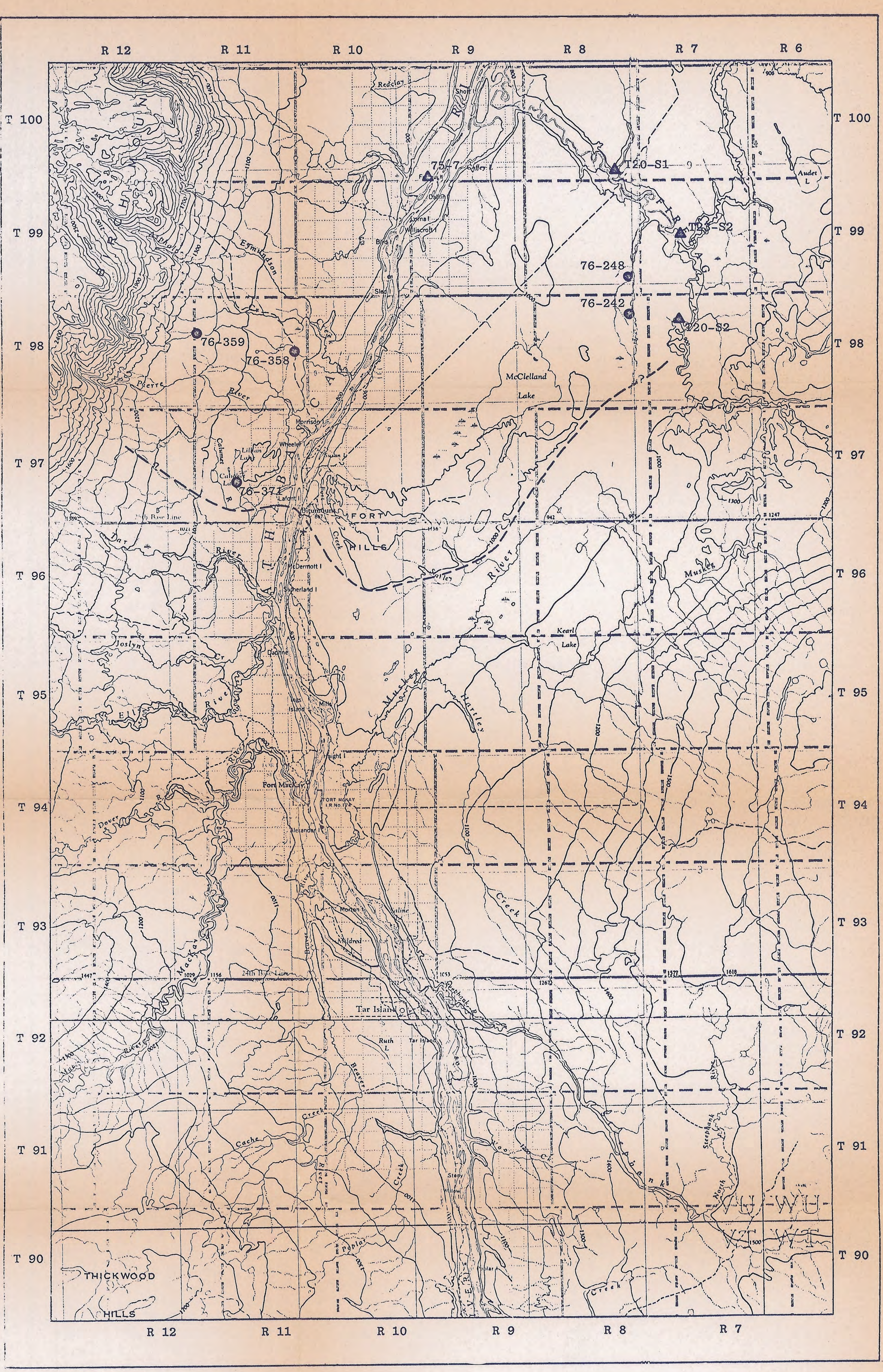
It is hoped that future studies will provide more definitive information on the presence of stratified sediments between the Firebag and Fort Hills tills.

Fort Hills Till

The Fort Hills till is named after the Fort Hills kame moraine complex which is interpreted to mark an ice frontal position of the glacier that deposited the Fort Hills till. The type section is T20-S1 on the Firebag River and a reference section is T23-S2 (Figure 23 and Appendix 2). The known distribution of this unit is shown on Figure 23. It is directly underlain by bedrock in some instances and by glacio-lacustrine sediments in others. It is overlain by a varied sequence of stratified sediments which may include glacio-fluvial,

FIGURE 23.

Map showing known occurrences of the Fort Hills Till in the study area.



○ Drill hole
△ Field stop

SCALE: 1:250,000

FIGURE 23: Map showing known occurences of the Fort Hills Till in the study area. The dashed line defines the known southern limit of the Fort Hills Till ie. the Fort Hills kame moraine complex.

OFR 1977-4
15/15

Fig 23

glacio-lacustrine and recent deposits.

The till is commonly a silt loam with a mean matrix texture of 18.4 percent sand, 69 percent silt and 12.6 percent clay; a ternary plot of the matrix texture is presented on Figure 18. The mean composition of the very coarse sand fraction indicates that it is relatively low in crystalline and quartz grains and contains a relatively high percentage of carbonates, particularly dolostone (Table 5, Figure 19). Other properties of this till are summarized on Table 5 and Figures 17 and 20.

The Fort Hills till is dark grey (with pink lenses and layers) or pinkish grey when wet and unoxidized; it commonly contains a relatively low percentage of clasts. Thin lenses or layers of lacustrine silts and clay and/or glacio-fluvial sand are commonly found in this unit.

The Fort Hills till is differentiated from the lower Firebag and unnamed tills by its very coarse sand mineralogy being lower in quartz grains and higher in carbonate grains (primarily dolostone) than the older tills (Table 5, Figure 19). It also has significantly less crystalline grains than the unnamed till. Other properties which can be used to identify the Fort Hills till include matrix texture, Atterberg Limits and moisture content (Figures 17, 18 and 20).

The Fort Hills till is interpreted to have been deposited by an ice advance from the north along the Athabasca valley. The extensive outcrop belt of carbonate rocks (Methy and Waterways Formations) to the north would account for the high carbonate content in the very coarse sand fraction. The absence of the Fort Hills till and associated mixed glacio-lacustrine sediments from higher portions of the bedrock uplands indicates that the Fort Hills ice was less extensive than the Firebag glacier and probably constituted a somewhat local re-advance. A thin ice sheet of limited extent would naturally follow the pre-existing topography giving further support to the concept of an ice advance from the north along the Athabasca lowland. Discussion of the possibility of the Fort Hills ice advance continuing farther south than the Fort Hills is provided in the subsequent section of the report describing the mixed glacio-lacustrine sediments.

Upper Stratified Sediments

Upper stratified sediments include those deposits interpreted to be associated with melting of the Fort Hills ice sheet and include:

(1) Fort Hills kame moraine complex,

(2) mixed glacio-lacustrine sediments,

(3) glacio-lacustrine sediments

and (4) outwash sand.

Each of these sediments will be discussed in the following portion of the report.

Fort Hills Kame Moraine Complex

The Fort Hills kame moraine complex and the major kame west of the Athabasca River (Township 97, Range 11) are interpreted to mark an ice frontal position of the Fort Hills ice advance. The sediments comprising the Fort Hills consist primarily of stratified silts and fine grained silty sand (Graphic mean of 16 samples is 0.23mm, Table 5; other properties of these materials are also outlined on Table 5). Rock fragments coarser than sand are present but uncommon. Lenses and layers of pink-grey glacio-lacustrine sediments are present below, within and above the kame. The kame to the west of the Fort Hills is somewhat similar but the sand is usually slightly coarser and contains lenses and layers of till. Evidence to support the concept that these kames are associated with melting of the Fort Hills glacier includes:

(1) the Fort Hills till forms the uppermost till north of the kames,

(2) both the kame sediments and the Fort Hills till have a high silt and low clast content suggesting they are related,

and (3) the pink-grey glacio-lacustrine sediments in the kames are similar to those found below, within and above the pink-grey Fort Hills till.

As mentioned previously, the steep slope of the bedrock surface beneath the Fort Hills, along the subcrop edge of the McMurray Formation (Figure 10) may have been a factor in localizing the kame delta complex in its present position.

Mixed Glacio-lacustrine Deposits

The mixed glacio-lacustrine deposits have been discussed in some detail in a previous section of the report. They are further discussed here to show their relationship with the Fort Hills ice advance.

These sediments are widespread in the study area except on the higher portions of the bedrock uplands and are generally found below 1450 feet; they always occur below the level of the highest beaches (1675 feet). They are directly underlain by either bedrock, glacio-lacustrine sediments, the Fort Hills till or the Firebag till. They are directly overlain by any one of glacio-lacustrine silts and clays, outwash sand, meltwater channel sediments or recent deposits. They are characteristically pink to pink-grey in colour and consist of stratified silt, sand, and clay and till like material.

The matrix of these sediments (<2mm) ranges from a heavy clay to a loam sand with a mean texture of 32.3% sand, 33.9% silt and 33.4% clay; a ternary plot of the matrix texture is presented on Figure 24. Other properties of these sediments are summarized on Table 5.

The mixed deposits are believed to be closely associated with the Fort Hills ice advance because:

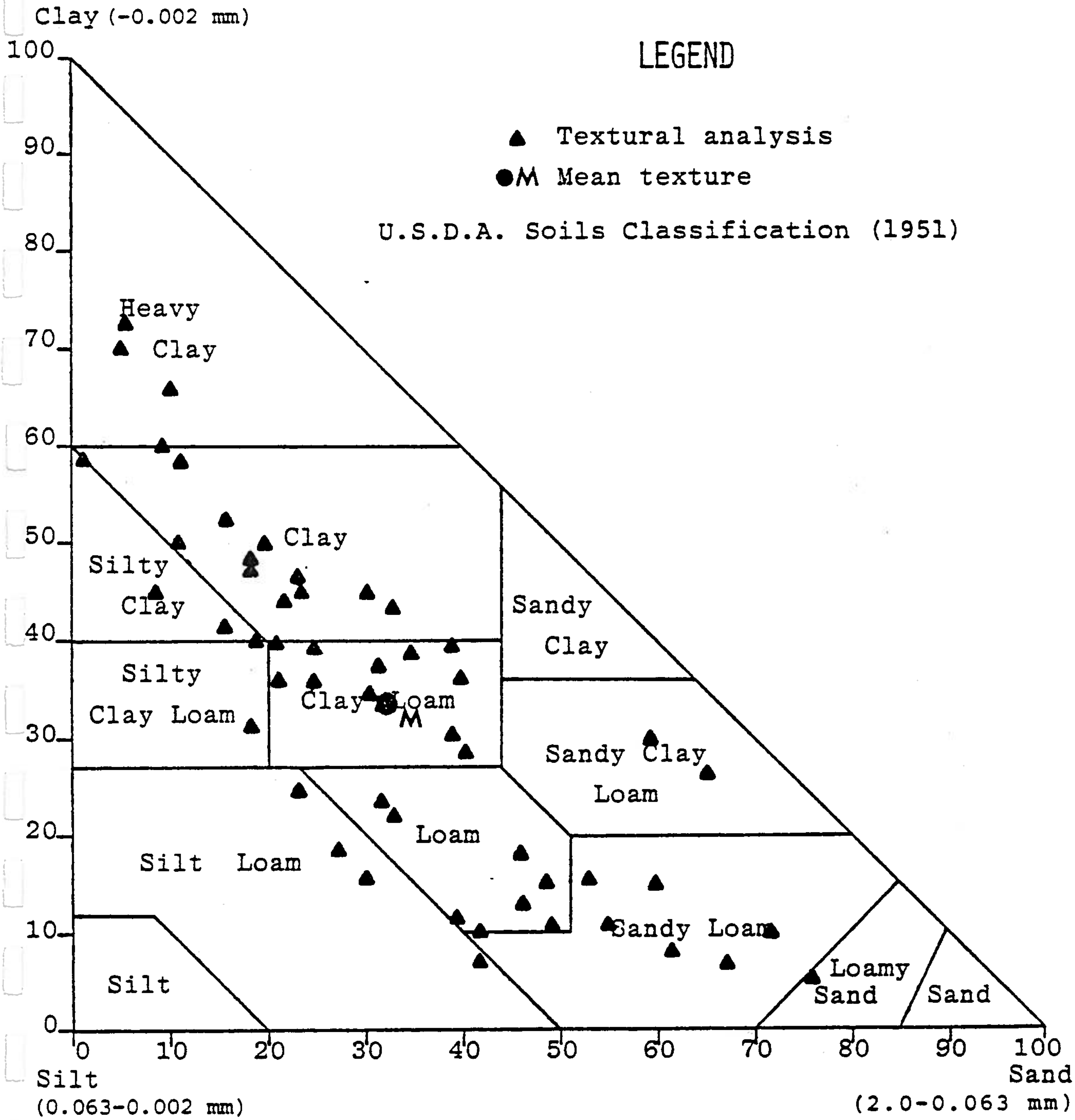


FIGURE 24: Textural analyses of the matrix (-2 mm fraction) of the mixed glacio-lacustrine deposits in the study area.

(1) their pink-grey colour is similar to the colour of the Fort Hills till,

(2) they directly overlie the Fort Hills till where present

and (3) the till like layers in the mixed deposits have a marked resemblance to the Fort Hills till.

The high percentage of till like material and the frequently well developed stratification is interpreted to be due to deposition near the glacier margin but in a lacustrine environment. It is now known how far in front of an ice sheet such deposits could be formed by processes such as mud flows, slumps and turbidity currents. It is therefore suggested that the Fort Hills ice may have advanced much farther south of the Fort Hills to account for the presence of these sediments in the southern portion of the study area. However, the ice would have to have advanced into a glacial lake which formed between the Fort Hills ice and the bedrock uplands. The Clearwater River system would have to have been blocked by ice at this time to prevent drainage of this lake to the south and east. The ice margin could have been floating in the lake, at least along part of its terminus. This hypothesis would account for the absence of the Fort Hills till south of the Fort Hills as well as explain the relatively high content of till like material in the mixed sediments. If deposition occurred in this manner, the mixed sediments may be more appropriately termed waterlaid tills after Dreimanis (1969).

Glacio-lacustrine Deposits (silt and clay)

Glacio-lacustrine silts and clays are common in the study area, occurring between a range of elevations of 1000 and 1600 feet (Figure 15). In some instances, the contact between the mixed sediments and silts and clays is sharp and in others it is gradational. The silts and clays are overlain by outwash sand, meltwater channel sediments and/or recent deposits.

The matrix (<2mm) is commonly a silty clay to silty clay loam with a mean texture of 15% sand, 45.1% silt and 39.8% clay; a ternary plot of the matrix texture is presented on Figure 25. Other properties of these sediments are summarized on Table 5.

The silts and clays are believed to have been deposited in a lake which formed in front of the Fort Hills ice sheet. Drainage to the north was blocked by the ice; drainage to the south and east may also have been blocked during the early stages of this lake. If the Fort Hills ice advanced south of the Fort Hills, the lake would have initially been relatively small, occurring as a series of nunatak lakes bounded by the ice sheet and the bedrock uplands, namely Birch Mountains, Thickwood Hills and Muskeg Mountain. Maximum level of the lake or lakes was 1675 feet (the elevation of the highest beaches). Retreat of the Fort Hills ice combined with melting of ice in the Clearwater River system would have resulted in expansion of the lake northward and lowering of the water

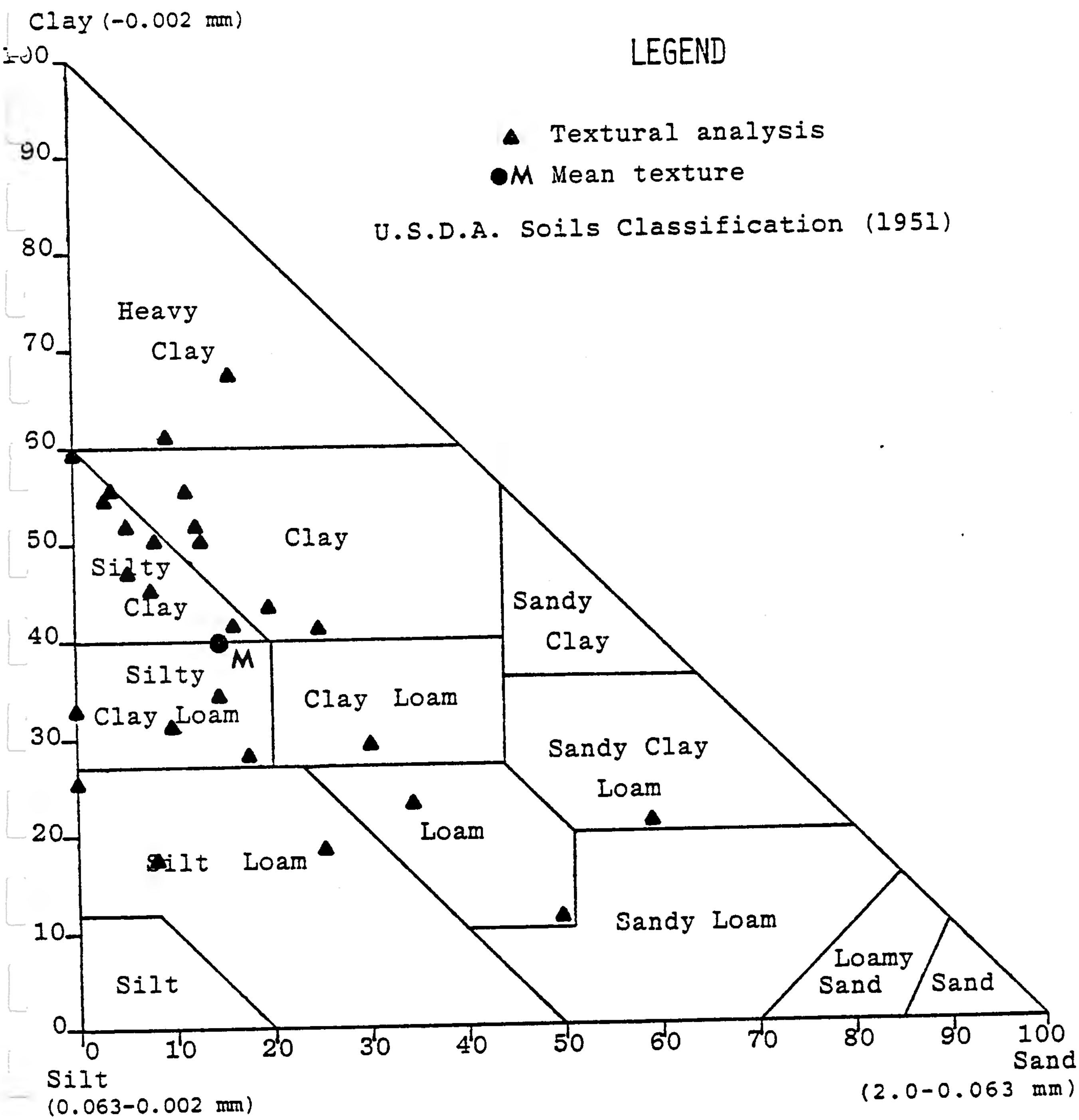


FIGURE 25: Textural analyses of the matrix (-2 mm fraction) of the glacio-lacustrine silt and clay deposits

level by drainage into the Clearwater River system.

An alternate interpretation is that the Fort Hills ice advanced only as far south as the Fort Hills and a large lake formed in front of the ice sheet, in its early stages being over 600 feet deep. The mixed sediments and the glacio-lacustrine silts and clays were deposited in this lake; the silts and clays usually being deposited farther from the ice margin than the mixed sediments. Melting of ice in the Clearwater drainage system permitted drainage of the lake to the south and east. Various stages during draining of the lake are marked by the series of beaches which occur over an elevation range of 1025 to 1675 feet.

Outwash Deposits

Outwash deposits, comprised primarily of sand, overlie the glacio-lacustrine sediments in much of the study area. They have been described previously and their distribution shown on the surficial geology map (Figure 15) and the geologic cross sections (Figures 8, 9). They are most prevalent in a broad belt along the Athabasca valley and in the northeast portion of the study area. This large outwash body commonly occurs below an elevation of approximately 1000 feet.

The dominant lithology of the outwash is a fine to medium grained sand (Graphic mean of 16 samples is 0.32mm, Table 5). Other properties of the outwash are also summarized on Table 5. Sand and gravel occurs within the outwash body as discontinuous bars and channel fill, being most prevalent south of the Fort Hills. Lenses of pink-grey glacio-lacustrine sediments and till fragments are also found in the outwash.

The outwash is interpreted to have been deposited by streams flowing from the Fort Hills ice sheet. Aggradation occurred to an elevation of approximately 1000 feet and was likely controlled by a drainage outlet to the south and east into the Clearwater River system. Aggradation was most extensive in the area between the Fort Hills and the Firebag River where the outwash exceeds 150 feet in thickness and has partially buried the Fort Hills kame moraine.

Meltwater Channel Sediments

Meltwater channel sediments have been described in a previous section of the report; they are further discussed here to establish their stratigraphic relationship to the other surficial deposits. They generally occur along the sides of the Athabasca River valley below an elevation of 1025 feet (Figure 15). These, sediments comprised primarily of sand and gravel were deposited in irregular, discontinuous but often well defined channels that have been eroded into the underlying surficial materials.

Surface slopes and limited cross stratification data indicate that these sediments were deposited by streams flowing northward along the Athabasca valley. They are interpreted to have been deposited when ice in the Athabasca valley melted permitting drainage to the north. The streams carried glacial meltwater as well as runoff from precipitation. It should be noted that the amount of flow that can be attributed to glacier meltwater is uncertain and that the channel sediments may be more appropriately termed early Athabasca River alluvium.

Recent Sediments

These sediments are the youngest in the study area, having been deposited since deglaciation of the region. They have been adequately described in previous sections of the report and will not be discussed in further detail.

QUATERNARY HISTORY OF THE AREA

The Quaternary history of the study area is described under two headings namely:

(1) the sequence of geologic events

and (2) the age and regional correlations of the observed events.

SEQUENCE OF GEOLOGIC EVENTS

Based on the Quaternary stratigraphy present in the study area, the following sequence of events is postulated to have taken place.

(1) Prior to deposition of the unnamed till, glaciers advanced and retreated through the area an unknown number of times to deposit the undifferentiated till and stratified sediments found below the unnamed till.

(2) A glacier advanced, probably from the east or east north east and deposited the unnamed till.

(3) Following retreat of this glacier, a significant glacial advance from the northeast deposited the Firebag till throughout most of the study area.

(4) As the Firebag ice retreated, the lower stratified sediments were deposited. The large kames in the northeast part of the study area formed along the margins of the Firebag ice sheet and lacustrine sediments accumulated in the bedrock low north of McClelland Lake.

(5) A glacier advanced from the north along the Athabasca valley and deposited the Fort Hills till. The southerly extent of this advance is uncertain which results in two possible interpretations of events during this time.

One interpretation is that the ice stabilized in the vicinity of the Fort Hills and deposited the Fort Hills kame moraine. The ice blocked drainage to the north and a large glacial lake formed between the ice sheet and the bedrock uplands. The mixed glacio-lacustrine sediments and glacio-lacustrine silts and clays were deposited in this lake.

A second interpretation is that the Fort Hills glacier advanced south of the Fort Hills an undetermined distance. As glacial retreat commenced, a lake or possibly a series of nunatak lakes formed between the ice sheet and the bedrock uplands. The mixed glacio-lacustrine sediments were deposited in the lake or lakes along the margins of the ice sheet; certain of these sediments may actually be waterlaid tills. Glacio-lacustrine silts and clays were also deposited at this time but further from the ice margin than the mixed sediments. The ice retreated to the vicinity of the Fort Hills and the large kame moraine complex was deposited. Further retreat resulted in deposition of glacio-lacustrine sediments north of the Fort Hills.

Both of these interpretations require drainage to the south and east to be blocked by ice at this time.

(6) As the ice in the Clearwater River system melted, the glacial lake or lakes receded due to drainage to the south and east. When the lake level had dropped sufficiently, streams flowing southward from the Fort Hills ice sheet deposited extensive outwash deposits over the glacio-lacustrine sediments. Aggradation of outwash occurred to an elevation of approximately 1000 feet.

(7) Melting of the Fort Hills ice sheet in the Athabasca valley north of the study area resulted in drainage to the north commencing. A series of meltwater channels formed along the Athabasca valley in which extensive sands and gravels were deposited. These sediments have been termed meltwater channel sediments but may be more appropriately termed early Athabasca River alluvium.

(8) Following deglaciation, recent deposition and erosion resulted in the present configuration of the land surface.

AGE AND REGIONAL CORRELATIONS

Within the study area, the ages of the Quaternary stratigraphic units are unknown because no material suitable for radiocarbon dating was found. It is postulated that the Firebag till is Lake Wisconsin in age because it records the last major glaciation in the area. The Fort Hills till is younger and is believed to represent a somewhat local readvance up the Athabasca valley; it would also be Late Wisconsin in age.

The age of the unnamed till and older undifferentiated till and stratified sediments could be Mid Wisconsin or older. Correlation of the Quaternary units with those found in other areas is premature because of the lack of age dates and the lack of Quaternary studies in adjacent areas. Studies in the Sand River Map Area (N.T.S. 73L) to the south have confirmed a multiple till stratigraphy (Fenton, personal communication [1]).

It is hoped that future studies will establish the relationship between the tills found in the oil sands region and the tills found in the Sand River area as well as the tills identified by Christiansen (1971) in Saskatchewan.

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[1] Dr. M. Fenton, Alberta Research Council.

NATURAL RESOURCES

Natural resources are abundant in the study area being comprised of surface and groundwater, a wide variety of industrial minerals, and the vast Athabasca oil sands deposits. It is not the intent of this report to examine these resources in detail.

The Alberta Research Council and others are conducting surveys on water supply potential. Hamilton and Mellon (1973) described in some detail, the types of industrial minerals found in the region and many workers, notably Carrigy (1959, 1973) have published considerable information on the Athabasca oil sands. This project provides additional data on many of the resources in the sense that the extent and distribution of the geologic deposits has been delineated. In particular, numerous occurrences of sand and gravel have been found and the geologic setting in which they occur established. Sufficient data has been generated to assess, with some degree of certainty, the <u>potential</u> aggregate resources of the region. Therefore, in the following section of the report, the geologic deposits with potential for aggregate supply are discussed. This assessment is intended to serve as an exploration guideline for future more detailed studies which will be required to establish the quality and quantity of aggregate reserves in specific localities.

POTENTIAL AGGREGATE DEPOSITS

Waterways Formation

The Waterways Formation either outcrops or occurs near surface along much of the Athabasca River and in scattered localities elsewhere (Figure 4). Along the Athabasca River, the Moberly Member is usually present: an alternating succession of argillaceous limestone, shale and hard beds of pale brown aphanitic limestone. It is expected that certain of the less shaly or more competent beds of the Moberly Member would be suitable for manufacture of crushed aggregates if they are close enough to surface to be economically recovered. Detailed drilling and sampling would be required to delineate specific deposits, but the potential of the Waterways Formation for aggregate supply should not be overlooked.

Saskatchewan Gravels and Sands

The distribution of Saskatchewan gravels and sands found in channels in the bedrock surface is poorly known. They represent a potential source of aggregate but would commonly be too deeply buried to economically excavate solely for aggregate supply. If they are found in areas being mined for oil sands, it may be possible to separate them from other types of overburden and utilize them as an aggregate source.

Outwash Sand and Gravel

Outwash sand and gravel form the surface sediment as well as occurs as lenses and layers in the subsurface in numerous localities. The distribution of these deposits is difficult to determine because they commonly vary considerably in grain size and lithology over short distances.

The areas mapped as sand and gravel on the surficial geology map (Figure 15) indicate localities where sand and gravel is known to occur on surface; however, the boundaries of the deposits have been approximated from air photographs. Drilling data on all known occurrences of outwash sand and gravel have been plotted on 1:50,000 scale maps which are on file at the Alberta Research Council.

Based on existing information, the best potential for aggregate deposits occurs in the area south and west of the Fort Hills where several outwash sand and gravel bars have been mapped (Figure 15). A major bar occurs near the Bitumount air strip. It is up to ½ mile wide and at least 3 miles long. Sand and gravel occurs on surface and varies from 5 to 21 feet in thickness (in 5 test holes). The material is well graded ranging in size from cobbles to clay but consists primarily of medium to coarse sand and gravel. Grain size analyses of this deposit are provided on Table 8 (Appendix 3). Rock contents (+4 mesh) are often relatively high and amounts of deleterious materials low. Based on the limited drilling data, it is expected that several million yards of sand and gravel are present in this deposit. Other outwash bars in this area are generally less than 30 feet thick and are comprised of interbedded sand and gravel having a wide range of clay and rock (+4 mesh) content. Detailed drilling would be required to determine the suitability of these deposits for aggregate supply.

Meltwater Channel Sediments

Meltwater channel sediments are present along both sides of the Athabasca River valley in much of the study area.

Fine to coarse grained sand is the most common sediment in the channels, however sand and gravel is known to occur in many instances. Areas where sand and gravel bars and terraces are present on surface are indicated on Figure 15; and available data on subsurface occurrences are on file at the Alberta Research Council.

These deposits are considered to have the best potential for aggregate supply in the region. The materials range in size from boulders to clay but fine to coarse sand and gravel usually predominates. Rock contents (+4 mesh) are also quite variable but are commonly high. The deposits generally do not exceed 30 feet in thickness.

Meltwater channel sediments have been utilized for aggregates at both the G.C.O.S. and Syncrude oil sands plants as well as for road construction.

A large sand and gravel deposit occurs in the meltwater channel on the east side of the Athabasca River near Susan Lake (Figure 15). It forms a terrace approximately ½ mile wide and 3 miles long being comprised of 10 to 20 feet of sand and gravel with numerous boulders. This deposit is not ideally suited for aggregate manufacture because the high boulder content would necessitate extensive crushing and screening. Nonetheless it represents a major source of raw materials which could be processed should the need arise.

Other significant deposits of sand and gravel likely exist in the areas mapped as meltwater channel sediments, both on surface and in the subsurface. However, they could only be delineated by detailed drilling.

Recent Alluvium

Recent alluvium is present along streams, being comprised of varying proportions of sand, silt, clay and gravel. Localized deposits of sand and gravel are common, however they are generally too small to have significant potential for aggregate supply.

The only alluvial sediments considered to have good potential for aggregate supply are found along the MacKay River, downstream from the mouth of the Dover

River. A well developed terrace, approximately 20 feet above the MacKay River, consists of 10 to 15 feet of silt and clay overlying 5 to 15 feet of sand and gravel (Figure 15).

The sand and gravel is poorly sorted and contains appreciable quantities of local bedrock fragments as well as clay lumps and organic matter. These sediments are too high in deleterious substances to be used for concrete aggregate but may be suitable for fill, road base and asphalt aggregate. Drilling of specific deposits would be required, however potential exists for fairly extensive reserves of low quality aggregate.

In summary, materials suitable for aggregate manufacture are present in the study area, however they are not overly abundant. Reserves sufficient for development of several additional oil sands plants can likely be found, in the meltwater channel sediments, outwash deposits, and the terraces along the MacKay River.

GEOTECHNICAL FACTORS AFFECTING DEVELOPMENT

The extent and distribution of surficial and bedrock deposits as well as their geotechnical characteristics will exert considerable influence on development of the study area. Materials above the oil sands will have to be completely removed prior to mining and the areas reclaimed upon completion of mining operations.

Near surface materials will also affect most other developments such as construction of new townsites, roads, power lines and associated facilities.

Because the geologic deposits are so variable in nature and extent, the information generated by this project is considered insufficient to permit construction of meaningful land use maps in which specific areas are rated in terms of their suitability for development. However, the various types of deposits present are known and considerable information on their engineering properties has been outlined in a previous section of the report or is on file at the Alberta Research Council.

In order to provide some insight into the affect the various deposits may have on development, two charts have been prepared which summarize geotechnical characteristics of both surficial and near surface bedrock deposits (Tables 6, 7). More specifically the

Table [illegible]. Geotechnical characteristics of near surface bedrock deposits[1]

Material	Lithology	Susceptibility to Erosion	Performance in Slopes	Bearing Capacity for Structures	Suitability for Construction Material [2]
Undifferentiated Cretaceous units	primarily shale minor sandstone and siltstone	-moderate to high erosion on exposed slopes	-natural slopes are unstable -man made slopes require detailed design	-poor to fair -sandier units have better bearing capacity	-poor aggregate -poor to fair fill -easily excavated
Grand Rapids Formation	sandstone, with interbedded siltstone and shale	-moderate erosion when cemented -high erosion if loose	-natural slopes relatively stable if drained -man made slopes should be stable at or less than angle of repose	-fair to good when adequately drained	-poor aggregate -fair to good fill -moderately easy to excavate
Clearwater Formation	shale with indurated siltstone and ironstone layers	-high to moderate erosion on exposed slopes	-prone to large scale landslides in natural slopes -man made slopes require detailed design	-poor to fair	-poor aggregate -poor to fair fill -easily excavated except where ironstone and indurated siltstone layers are present
Clearwater Formation Wabiskaw Member	fine to medium grained glauconitic sandstone	-high erosion on exposed slopes	-natural slopes relatively stable if drained -man made slopes should be stable at or less than the angle of repose	-fair, commonly too thin to be considered suitable for structures	-poor aggregate -fair to good fill -easily excavated
McMurray Formation	sandstone, both oil impregnated and barren, minor siltstone and shale	-low erosion where oil bearing, moderate to high erosion where barren	-if oil bearing stable at steep angles -if barren, natural slopes are relatively stable if drained -man made cuts should be stable at or less than the angle of repose	-fair to good bearing capacity for structures if adequately drained	-poor aggregate -barren sands are fair to good fill -moderately easy to excavate (often difficult when frozen)
Waterways Formation	limestone, argillaceous limestone and minor shale	-low to moderate erosion, generally erodes along joints or shaley layers	-natural slopes are stable (often near vertical) -man made cuts should be stable	-good except in areas where sink holes occur. Many of the sink holes may still be active	-fair to good potential for crushed aggregate -good fill -difficult to excavate

Notes: 1. The chart is intended as a general <u>guideline</u> to expected conditions. Under no circumstances should it replace detailed site investigations prior to development.
2. Also indicates the ease or difficulty of excavating the materials (rating system: easy, moderately easy, and difficult).

Table 7: Geotechnical characteristics of the surficial deposits [1]

Material [2]	Lithology	Susceptibility to Erosion	Performance in Slopes	Bearing Capacity for Structures	Suitability for Construction Material [3]
Organic Deposits, Muskeg	Organic material moss and sedge bogs	-prone to wind erosion when dry	-no natural slopes -man made cuts unstable	-poor	-possible source of peat and reclamation material -generally requires draining for removal
Alluvial sand	sand, minor silt and clay, confined to flood plain of Athabasca River	-moderate to high erosion on exposed slopes	-man made slopes require adequate design	-fair -possible high groundwater table -possible flooding	-poor aggregate -fair to good fill -easily excavated
Alluvial silt and clay	silt and clay, minor sand and gravel, found as discontinuous deposits along streams	-moderate to high erosion on exposed slopes -silts more prone to erosion	-man made slopes require adequate design	-poor to fair -possible high ground-water table -possible flooding	-poor aggregate -poor to fair fill -easily excavated
Alluvial silt and clay under-lain by sand and gravel	silt and clay underlain by sand and gravel, forms terraces on the MacKay River	-moderate to high erosion in silts and clays, low where sand and gravels are present	-man made slopes require adequate design	-fair to good -possible high ground-water table	-potential source of low quality aggregate -poor to good fill -easily excavated
Aeolian sand	medium grained sand in sheet and dune form	-moderate to high erosion on exposed slopes -prone to wind erosion	-natural slopes stable -man made slopes stable at or less than the angle of repose	-fair	-poor aggregate -fair fill -easily excavated
Glacio-lacustrine silt and clay	silt and clay with minor sand	-moderate to high erosion on exposed slopes	-some natural slopes unstable -man made slopes require adequate design	-poor to fair	-possible source of clay for dykes and dams -easily excavated
Mixed glacio-lacustrine sediments	sand, silt and clay with till like layers	-low to moderate erosion on exposed slopes	-natural slopes generally stable -man made slopes should be stable	-poor to good depending on proport-ion of sand, silt and clay	-fair fill -moderately easily excavated
Meltwater channel sediments: sand and gravel	medium to coarse grained sand and gravel	-low erosion on exposed slopes	-natural slopes stable -man made cuts should be stable at or less than angle of repose	-good -possible high ground-water table	-potential aggregate source -fair to good fill -moderately easily excavated
Meltwater channel sediments: sand	medium to coarse grained sand, minor gravel, silt and clay	-moderate to high erosion on exposed slopes	-natural slopes generally stable -man made slopes should be stable at or less than the angle of repose	-fair to good -possible high ground-water table	-poor aggregate -fair to good fill -easily excavated
Outwash sand	fine to coarse grained sand, minor gravel	-moderate to high erosion on exposed slopes	-natural slopes generally stable -man made slopes should be stable at or less than the angle of repose	-fair to good -possible high ground-water table	-poor aggregate -fair to good fill -easily excavated
Outwash sand and gravel	fine to coarse grained sand and gravel	-low erosion on exposed slopes	-natural slopes stable -man made cuts should be stable at or less than the angle of repose	-good -possible high ground-water table	-potential aggregate source -fair to good fill -moderately easily excavated
Kames and Kame moraines	sand and silt, minor gravel and clay	-high erosion on exposed slopes	-natural slopes unstable unless well vegetated -man made slopes require extensive design	-poor to fair -possible high ground-water table	-poor aggregate -poor to fair fill -easily excavated
Fort Hills till	sand, silt, clay and gravel with boulders, silt predominates	-moderate to high erosion on exposed slopes	-natural slopes stable -man made slopes may require design	-poor to good, rating depends on silt content	-fair fill -moderately easily excavated
Firebag Till	sand, silt, clay and gravel with boulders	-low to moderate erosion on exposed slopes	-natural slopes stable -man made slopes should be stable	-fair to good	-fair to good fill -moderately easily excavated
Unnamed Till	sand, silt, clay and gravel with boulders	-low to moderate erosion on exposed slopes	-no natural slopes -man made slopes should be stable	-fair to good	-fair to good fill -moderately easily excavated

Notes: 1. This chart is intended as a general guideline to expected conditions. Under no circumstances should it replace detailed site investigations prior to development.
2. Includes sediments that form surface deposits (Figure 15) and materials found below surface but above the bedrock contact. Only those materials for which sufficient information is available are shown on the Table.
3. Also indicates the ease or difficulty of excavating the materials (rating system: easy, moderately easy, and difficult).

materials are rated in terms of the following:

(1) susceptibility to erosion,

(2) performance in slopes,

(3) bearing capacity for structures

and (4) suitability for construction materials.

These charts are intended as a general guideline to expected characteristics. Under no circumstances should they be substituted for detailed site investigations in areas where development occurs.

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

(1) The surface of the Waterways Formation is extremely complex because it exhibits a well developed karst topography and has been subjected to several periods of subareal erosion.

(2) The surface of the McMurray Formation is less complex being highest in the southwest and eastern portions of the area and lowest in the Athabasca lowlands. Many of the larger highs and lows in the McMurray Formation correspond to highs and lows in the underlying Waterways Formation.

(3) Overburden on the McMurray Formation consists of younger Cretaceous rocks and surficial deposits. It ranges from less than 25 feet thick to a maximum of 1400 feet thick (on Birch Mountains). The overburden is generally thickest where both bedrock and surficial materials overlie the McMurray sands; it is generally thinnest where the McMurray Formation forms the surface bedrock.

(4) The top of the Clearwater Formation is highest on the bedrock uplands namely Birch Mountains, Thickwood Hills and Muskeg Mountain. It is usually lowest along the subcrop edge in the Athabasca lowlands.

(5) The Grand Rapids Formation is present only on the major bedrock uplands. Younger Cretaceous rocks are confined

to the higher portions of the Birch Mountains.

(6) The topography of the bedrock surface is complex due to extensive post depositional erosion. It is characterized by major bedrock uplands separated by intervening lowlands. The present day surface topography reflects, in a general fashion, most of the large scale features of the bedrock surface.

(7) Surficial deposits comprised of preglacial, glacial, and post glacial sediments completely cover the study area. They range in thickness from less than 10 feet thick to a maximum of over 450 feet thick. Glacial till and kame sediments usually form the surface sediments in topographically higher areas and glacio-fluvial and glacio-lacustrine sediments are most prevalent in lower areas. Extensive muskeg cover is present over much of the study area.

(8) The surficial sediments have been subdivided into several stratigraphic units. These are in ascending order, preglacial gravels and sands, Saskatchewan gravels and sands, undifferentiated till and stratified sediments, unnamed till, Firebag till, lower stratified sediments, Fort Hills till, upper stratified sediments, meltwater channel sediments and recent sediments.

(9) The most useful criteria for differentiating the tills in the study area are, textural analyses, lithology of the very coarse sand fraction (2-1mm),

Atterberg Limits, and stratigraphic position.

(10) The unnamed till has been found in only two localities namely on Thickwood Hills and along the Steepbank River.

(11) The Firebag till is known to underlie most of the study area and represents the last major glaciation in the region.

(12) The Fort Hills till has been identified north of the Fort Hills kame moraine. The presence of this till farther south has not been clearly demonstrated. The Fort Hills till represents a local readvance of ice along the Athabasca lowlands.

(13) The till units are not correlated with tills found elsewhere in Western Canada because their age is unknown and the nature of tills in adjacent areas is poorly understood. It is postulated that the Firebag and Fort Hills tills are Late Wisconsin in age.

(14) Information on stratified sediments between the Firebag and Fort Hills tills is sparse but stratified sediments deposited since retreat of the Fort Hills ice are well documented because they form surface deposits in much of the study area.

(15) Sand and gravel deposits suitable for aggregate manufacture are present in the study area but they are not overly abundant. Reserves sufficient for development of several additional oil sands plants

can likely be found in the meltwater channel sediments along the Athabasca valley and in outwash deposits elsewhere.

(16) The geotechnical characteristics and engineering behavior of both the surficial and bedrock deposits will exert a major influence on the development of both surface mining and in situ recovery operations. Detailed examination of these materials will be essential in areas where surface mining operations occur.

RECOMMENDATIONS FOR FUTURE STUDIES

Future studies could be conducted on a number of aspects of the Quaternary geology of the oil sands region; these include:

(1) Detailed mineralogical examination of the very coarse sand fraction of additional till samples from the auger drilling program is highly recommended to more clearly define the distribution of the tills.

(2) Examination of additional sections on the Firebag and MacKay Rivers should be conducted to provide further data on the Quaternary stratigraphy.

(3) The drilling of a number of deep test holes would be useful to obtain information on the Quaternary stratigraphy below the depth sampled for this study (150 feet).

(4) Detailed drilling of the numerous sand and gravel

prospects could be conducted to establish sufficient aggregate supplies for development of additional oil sands plants.

(5) The present study examined the surficial and near surface bedrock deposits in the portion of the oil sands region considered to have potential for surface mining operations. Similar studies in the remainder of the area underlain by oil sands would be useful not only in providing a better understanding of the Quaternary history of northeast Alberta but also in establishing the geologic framework of the materials overlying the oil sands; the nature of these materials will have a significant bearing on all types of oil sand recovery operations.

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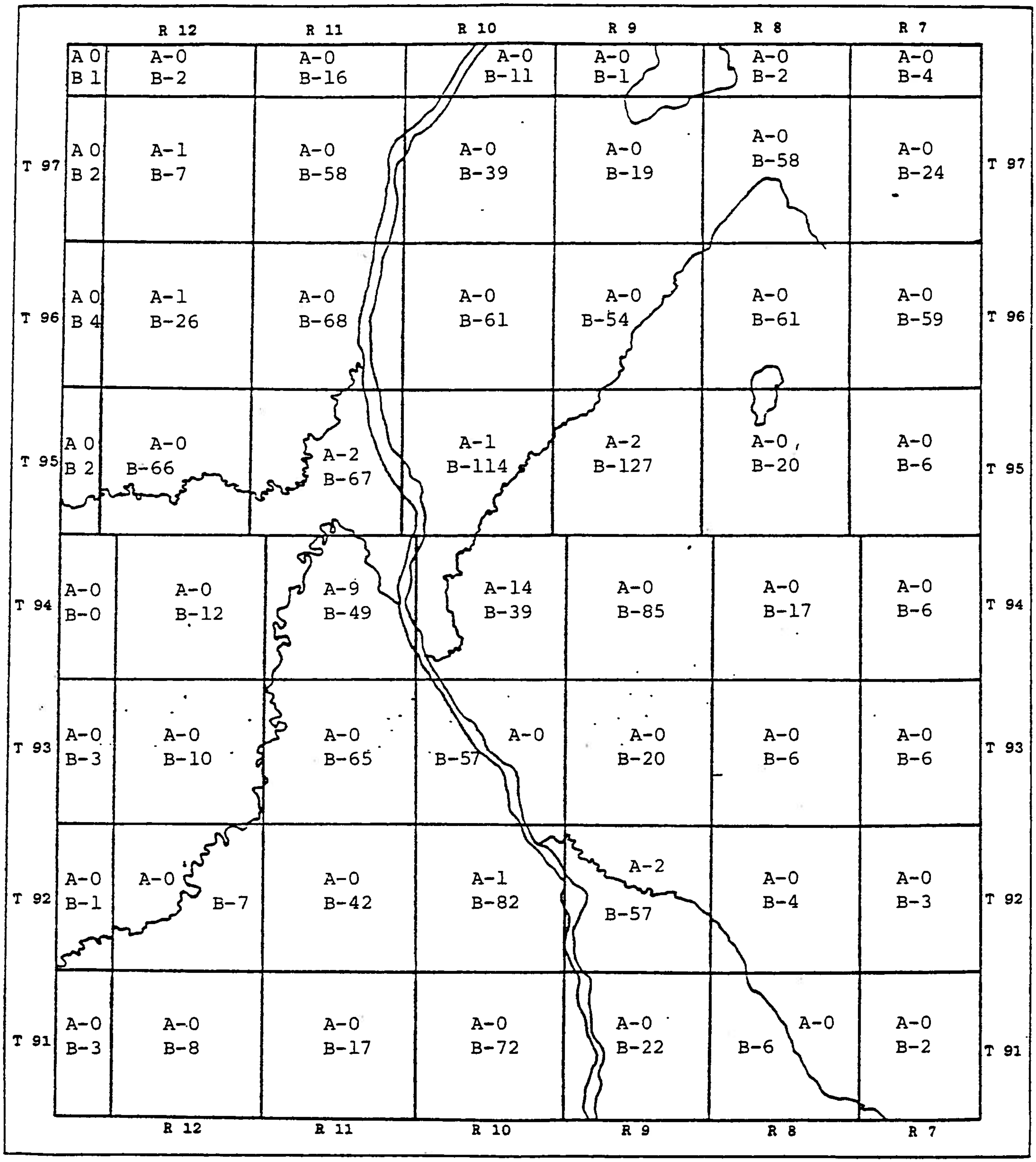
APPENDICES



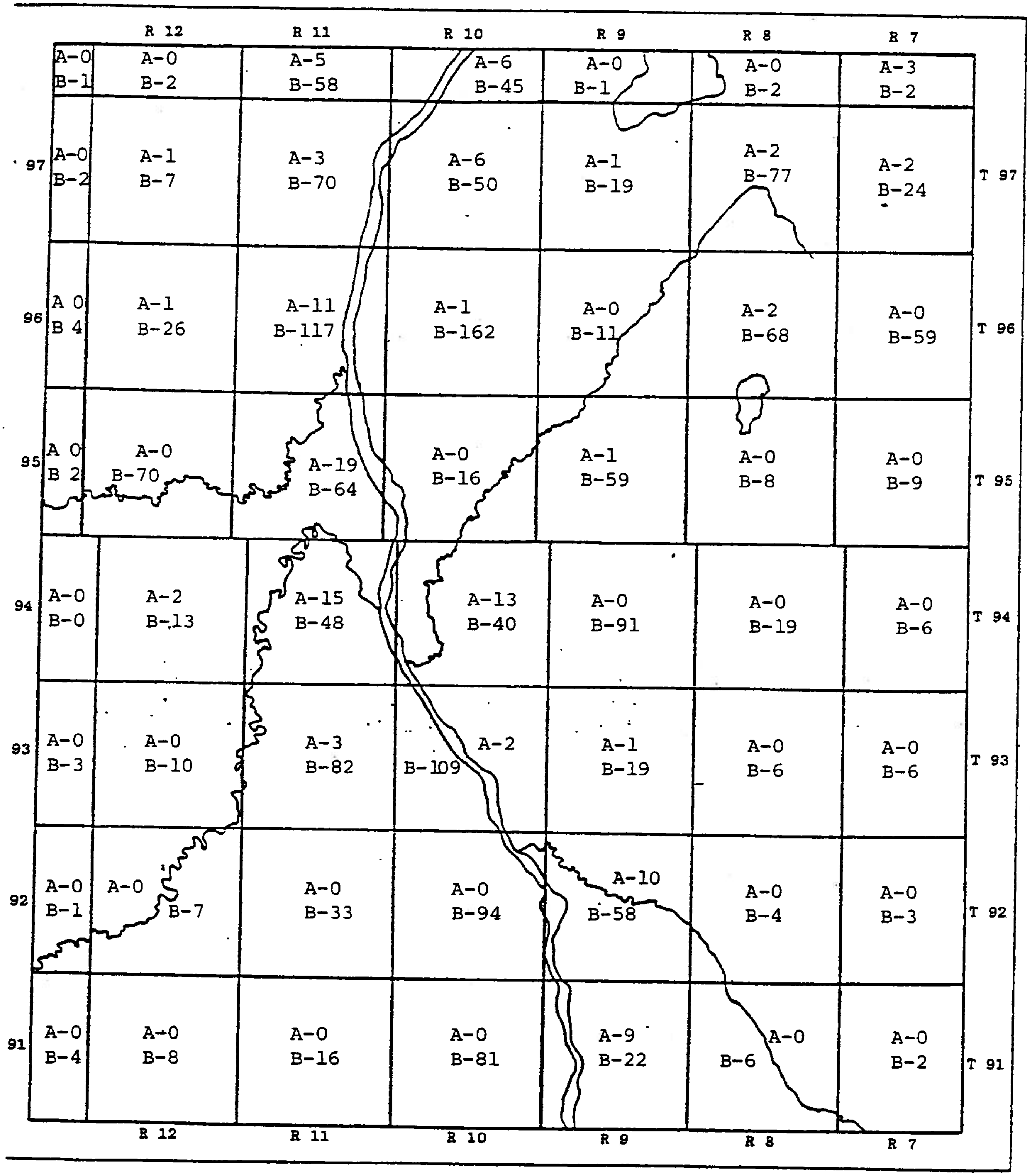
LEGEND

Alberta Research Council control point . . . . . . A - 3*

Control points from other sources . . . . . . B - 6

*The letter identifies the data source and the number indicates the number of control points per township.

FIGURE 26: Data density map for Devonian Waterways Formation.



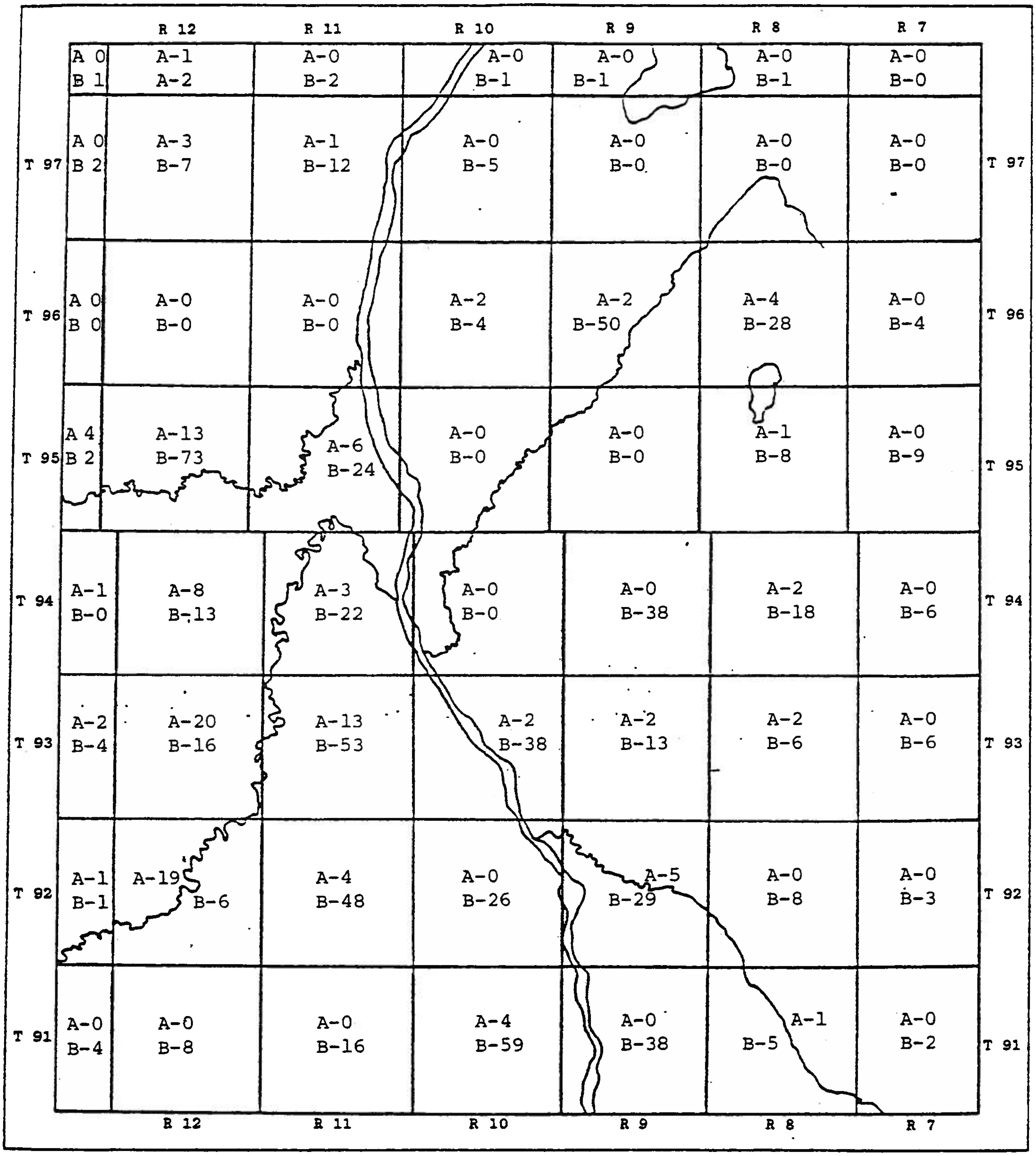
LEGEND

Alberta Research Council control point . . . . . . A - 3*

Control points from other sources . . . . B - 6

*The letter identifies the data source and the number indicates the number of control points per township.

FIGURE 27: Data density map for Cretaceous McMurray Formation.



LEGEND

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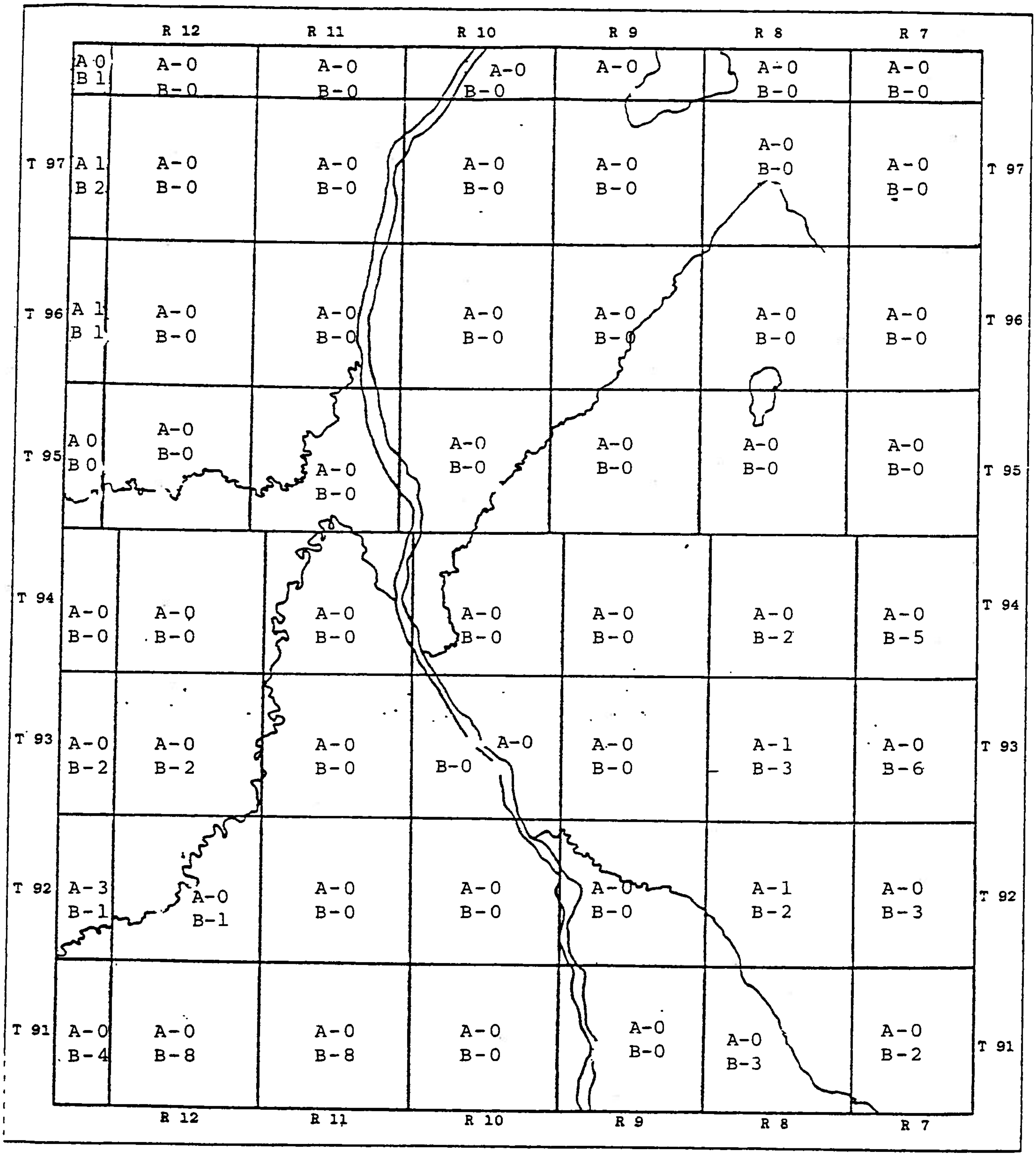
*The letter identifies the data source and the number indicates the number of control points per township.



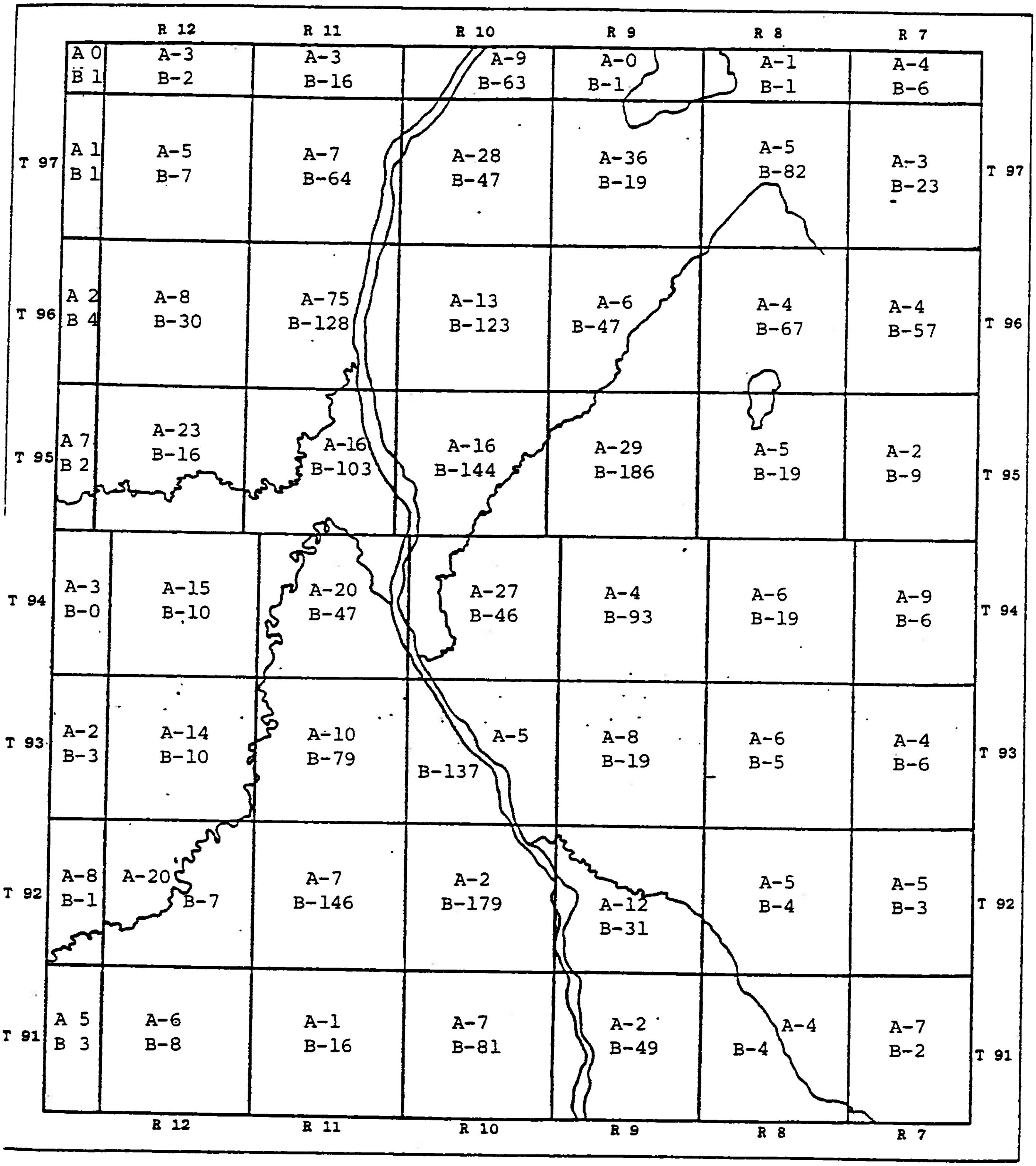
LEGEND

Alberta Research Council control point . . . . . . A - 3*

Control points from other sources . . . . B - 6

*The letter identifies the data source and the number indicates the number of control points per township.

FIGURE 29: Data density map for Cretaceous Grand Rapids Formation.



LEGEND

Alberta Research Council control point . . . . . . A - 3*

Control points from other sources . . . . B - 6

*The letter identifies the data source and the number indicates the number of control points per township.

FIGURE 30: Data density map for surficial geologic deposits.

APPENDIX 2

Type sections and reference sections for till units

Reference Section - Unnamed Till

Geologic Section: T4-S5

Location: Lsd. - Sec. 5, Tp. 92, Rge. 8 W4M

Elevation: Approximately 1200 ft.

Depth (ft.)	Description
0-10	till (Firebag): sand, silty, clayey, stony, numerous sand lenses, jointed, grey -brown, dry, low plastic, stiff.
10-20	outwash: sand; clayey, fine to medium grained, minor gravel, buff, dry.
20-25	till (unnamed?): clay; minor stones, grey, moist, medium plastic, stiff.
25-35	till (unnamed): sand; clayey, silty, some stones, grey, moist, low plastic, stiff.

Reference Section - Unnamed Till

Drill Hole: 76-403

Location: Lsd. 15, Sec. 1, Tp. 91, Rge. 13 W4M

Elevation: 1580 ft.

Depth (ft.)	Description
0-8.5	mixed glacio-lacustrine (lacustro-till): clay; silty, minor stones, pink-brown, moist, medium stiff.
8.5-11	outwash: sand; fine to medium grained, grey, wet.
11-80	till (unnamed): clay; sandy, silty, some stones, grey, moist, low plastic, stiff to hard.
80	T.D.

Type Section - Firebag Till

Geologic Section: T17-S1

Location: Lsd. - Sec. 32, Tp. 97, Rge. 6 W4M

Elevation: Approximately 1100 ft.

Depth (ft.)	Description
0-5	outwash; sand, fine to medium grained, buff dry.

Depth (ft.)	Description
5-40	till (Firebag): sandy; silty clay, stony, grey-buff, dry to moist, low plastic; numerous sand and sand and gravel layers and lenses.
40-80	till (Firebag): sandy; silty clay, stony, grey, dry to moist, low plastic; minor sand lenses, jointed, slightly bituminous.
80-90	till (Firebag): sandy; silty clay, stony, grey, dry to moist, low plastic; minor sand lenses, highly bituminous.
90	Firebag River level.

Reference Section - Firebag Till

Drill Hole: 76-312

Location: Lsd. 8, Sec. 12, Tp. 93, Rge. 10 W4M

Elevation: 1090 ft.

Depth (ft.)	Description
0-2	peat: woody, brown, wet.
2-35	till (Firebag): sandy; silty clay, moderately stony, dark grey, moist, bituminous, medium plastic, medium soft.
35-40	bedrock (McMurray Formation): sandstone; medium grained, bituminous, grey black, wet.
40	T.D.

Type Section - Fort Hills Till

Geologic Section: T20-S1

Location: Lsd. - Sec. 2, Tp. 100, Rge. 8 W4M

Elevation: Approximately 900 ft.

Depth (ft.)	Description
0-5	aeolian sand: fine to medium grained; well sorted, buff, dry, occurs discontinuously.
5-50	outwash: sand; very fine to fine grained, dry to moist, buff to grey, horizontally bedded.

Depth (ft.)	Description
50-100	outwash: sand; very fine to medium grained, moist, buff to grey, cross-bedded, contains layers of reworked bitumen.
100-105	glaciolacustrine: clay, silty, pink to pink grey, moist, medium stiff, plastic.
105-115	till (Fort Hills): silty; sandy, very few stones, grey brown with pink flecs, moist, medium plastic, soft.
115-140	till (Fort Hills): silty; sandy, very few stones, grey brown, moist, medium stiff, plastic.
140	Firebag River level.

Reference Section - Fort Hills Till

Geologic Section: T23-S2 Location: Lsd. 4, Sec. 21, Tp. 99, Rge. 7 W4M

Elevation: approximately 900 ft.

Depth (ft.)	Description
0-20	outwash: sand; very fine to fine grained, minor stones, dry, buff to grey, horizontally bedded.
20-50	outwash: sand; very fine to medium grained, moist, buff to grey, cross-bedded, contains layers of reworked bitumen, numerous small springs at base of outwash.
50-55	glaciolacustrine: clay, silty, some stones, pink-grey, moist, medium stiff, plastic.
55-75	till (Fort Hills): silty; sandy, very few stones, grey with pink flecs, moist, medium plastic, soft.
75-85	glaciolacustrine?: silt, clayey, grey with pink flecs, no stones, moist, medium stiff, medium plastic.
85-90	till (Fort Hills): silty; sandy, very few stones, pink to pink grey, moist, medium plastic, medium stiff.
90	Firebag River level.

APPENDIX 3

Grain size analyses of sand and gravel deposits

TABLE 8

Grain size analyses of sand and gravel deposits in the study area.

Sample Number	Location	Description [1]	Weigh Percent Retained by Mesh Size												
			1¼	1	3/4	1/2	3/8	4	8	16	30	50	100	200	<200
76-253, 5-10'	10-25-96-11 W4M	sand and gravel bar		33.6	9.2	8.0	3.7	8.0	8.9	12.6	0.1	4.8	1.8	0.1	-
76-256, 5-10'	4-36-96-11 W4M	sand and gravel bar		9.8	4.3	11.4	6.6	15.8	9.8	10.4	11.6	13.2	5.8	0.2	-
76-257, 5-10'	4- 6-97-10 W4M	sand and gravel bar		12.9	9.5	1.2	0.9	4.8	16.4	27.6	13.8	7.3	3.2	1.9	-
76-258, 5-10'	5- 6-97-10 W4M	sand and gravel bar		5.0	1.6	2.2	1.2	8.3	12.4	19.1	26.4	11.3	7.0	4.1	-
76-344, 10'	4-22-96-11 W4M	sand and gravel bar		13.4	10.6	6.9	2.1	2.9	1.5	5.0	10.9	16.6	19.6	6.8	3.7

[1] The distribution of the sand and gravel deposits is shown on the surficial geology map (Figure 15)

APPENDIX 4

Photographs of geologic deposits and features

Plates 1 and 2

PLATE 1

Figure 1:

Flexure in Waterways Formation along the east side of the Athabasca River near Fort MacKay.

Figure 2:

Steep erosional slopes of the Waterways Formation o the Athabasca River near the mouth of the Muskeg River.

Figure 3:

Sink hole lake in thick outwash sand deposits near McClelland Lake.

Figure 4:

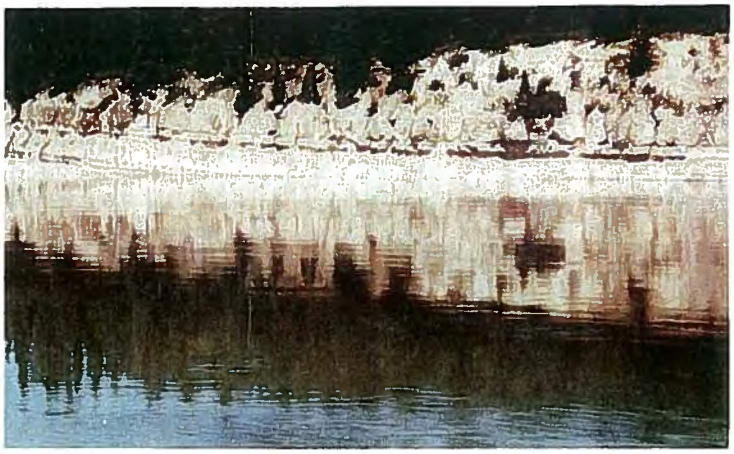
Steep erosional gullies o the west side of the Fort Hills.

Figure 5:

Geologic section exposing thick outwash sand on the Firebag River near the mouth of the Marguerite River.

Figure 6:

Aerial view of Mildred Lake meltwater channel; Syncru e construction site in back ground.



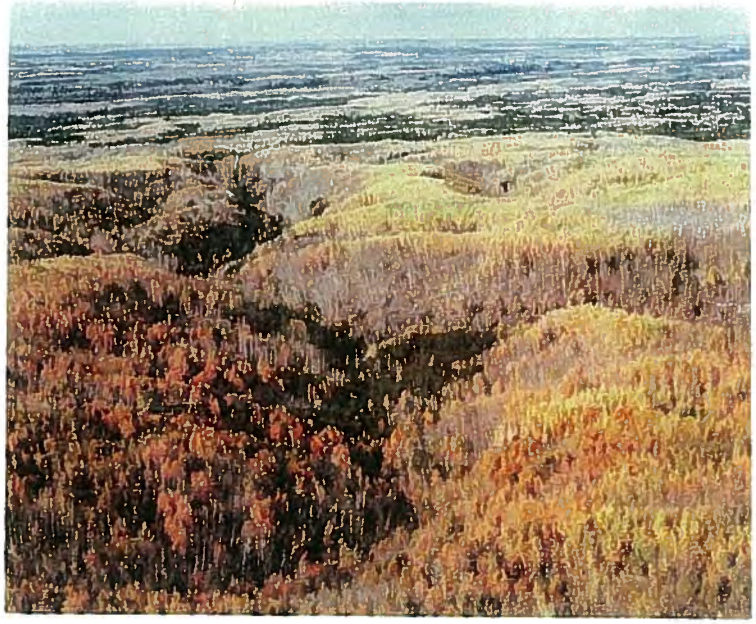



PLATE 2

Figure 1:

Typical moss bog (woody muskeg) in study area.

Figure 2:

Sedge bog in study area.

Figure 3:

String bog south-east of McClelland Lake.

Figure 4:

Outwash sand overlying the Firebag till on the Firebag River.

Figure 5:

Section of Firebag till exposed on the Firebag River.

Figure 6:

Erosional gullies in glacio-lacustrine silts and clays; on Thickwood Hills forestry road.

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