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GUIDE TO THE ATHABASCA OIL SANDS AREA

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INTRODUCTION

Topography and Drainage

The oil sands area is located in northeastern Alberta adjacent to the Canadian Shield (Fig. 1). The main drainage of the area is provided by the Athabasca-Clearwater system, the valleys of which are incised into a broad, muskeg-covered interior plain to depths of 200 to 300 feet. The tributary streams originate in three highland areas (Fig. 2): the Birch Mountains to the west of the Athabasca River which rise to about 2,700 feet, Stony Mountain south of Fort McMurray which reaches an elevation of 2,500 feet, and Muskeg Mountain to the east of the Athabasca River which rises gradually to 1,900 feet. To the southwest of the area, between Birch Mountain and Stony Mountain and north of the eastward flowing Athabasca River, is a subdued highland area with gentle slopes called the Thickwood Hills. These hills give rise to northward flowing tributaries of the MacKay River, and a few short streams flowing southward to the Athabasca.

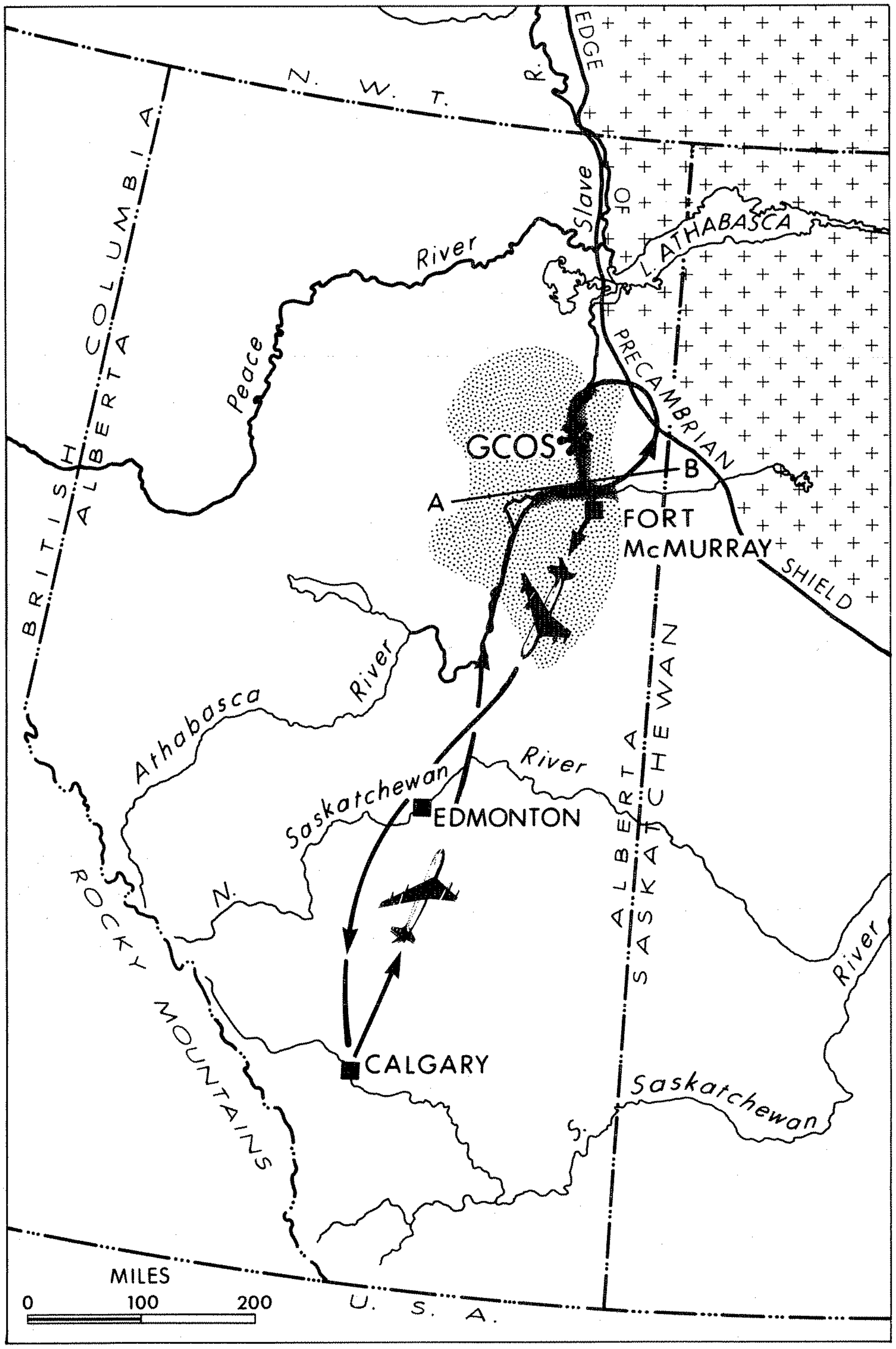
A number of shallow lakes are located in the area, the largest and most numerous of which are located on the top of the Birch Mountains and form an interconnected chain of lakes which flow into the Ells River. These are called Eaglenest, Gardiner, and Namur Lakes. The only lakes of any size south of Fort McMurray are Algar and Gregoire Lakes. McClelland Lake, which is located in the lowlands northeast of Bitumount, is an area of internal drainage.

Climate

The climate of the oil sands area is subarctic and similar in many respects to that experienced in Edmonton. Fort McMurray, at an elevation of 800 feet, has a mean annual temperature of 29.8 degrees Fahrenheit and remains frost free for approximately 67 days each year. Mean annual precipitation is approximately 18 inches over the region, although there is good reason to believe that there is an orographic effect on precipitation distribution. The standard 30-year normals (1931-1960) of temperature and precipitation for the Fort McMurray airport are shown in table 1.

Soils

All mineral soils developed in the oil sands area fall into the Grey Wooded soil group; however, at least 60 percent of the area is covered by organic soil, often referred to as muskeg or sphagnum moss bog. Organic soils are defined as those which have over 12 inches of peat at the surface. These soils are acid to moderately acid in reaction and have a high water-holding capacity; ice is commonly encountered at depths below 16 to 30 inches. Grey Wooded-Podzol soils develop where there is better drainage and a continuous tree



SUBSURFACE EXTENT OF OIL SANDS

OUTCROP OF OIL SANDS

FIGURE 1. Location of the Athabasca Oil Sands showing flight plan for the CSPG field trip, 1973.

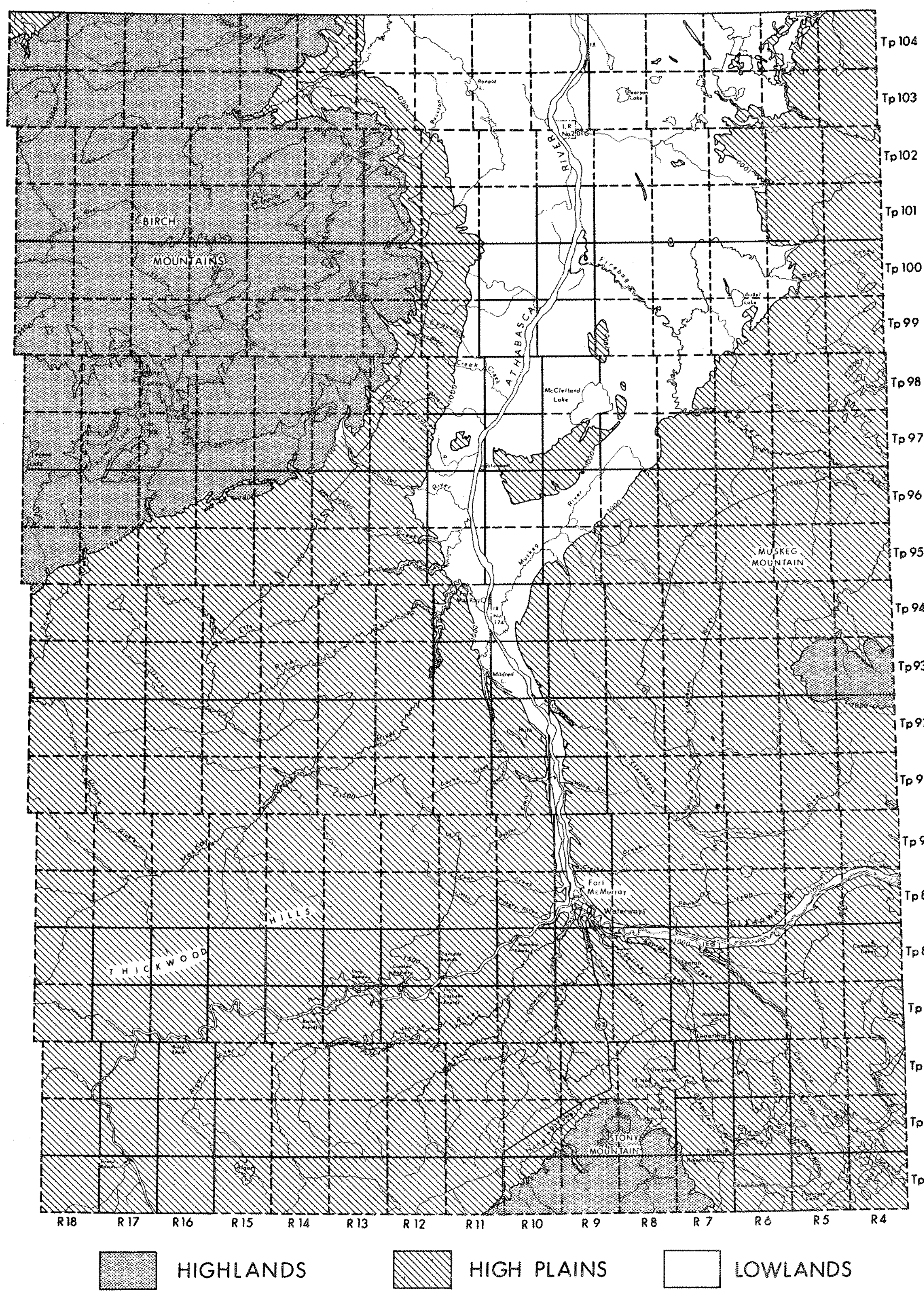


FIGURE 2. Topography and drainage of the Lower Athabasca River drainage area.

Table 1. Temperature and Precipitation Data* for Fort McMurray Airport and Edmonton Industrial Airport (Data from Alberta Bureau of Statistics, 1973)

Temperature (°F)

			January Mean Daily		July Mean Daily	
Station	Maximum	Minimum	Max	Min	Max	Min
Fort McMurray	96	-59	4	-16	76	48
Edmonton	99	-57	15	-2	74	52

Precipitation (inches)

	Mean Annual		Mean Monthly			
Station	Total Precipitation	Snowfall	April	May	June	July
Fort McMurray	16.85	50.0	0.75	1.31	2.36	2.93
Edmonton	18.64	53.8	1.10	1.83	3.15	3.34

*Standard 30-year (1931-1960) normals

cover. The soil profile typically has a few inches of leaf litter beneath which there is a grey zone where the soil is leached of any plant nutrients.

Most of the oil sands area has been classed as pasture and woodland. A combination of poor soil and lack of drainage makes it of little value for agricultural development (Lindsay *et al.*, 1957, 1961, 1962).

Vegetation

The oil sands area lies entirely within the boreal forest region. The vegetation is a mixture of deciduous and evergreen trees. The greater part of the area is treed by aspen poplar but large areas are open sphagnum moss bogs with clumps of stunted black spruce. Small islands of jack pine and white spruce are scattered throughout the area.

There is very close relationship between topography, soils, and vegetation in the area. The inorganic grey wooded soils have a mixed cover of trembling aspen, white spruce, and jack pine where the drainage is moderately good. The poorly drained areas have white spruce as the major cover with occasional aspen. Drainage improvement and irregular topography give rise to relatively pure aspen stands on hill crests.

The organic soils are generally treeless but where the layer of organic matter is thin and drainage improves, black spruce and labrador tea appears. Tamarack is also present, but is not common.

Fauna

Among the most characteristic large mammals of this area are the black bear, wolf, Canada lynx, white-tailed deer, mule deer, moose, and caribou.

The area is located on the Mississippi and Central flyway of waterfowl but it is not believed to be an important resting or nesting ground.

Common fish found in lakes and rivers of the lower Athabasca River drainage system are the walleye, northern pike, goldeye, lake trout, and Arctic grayling.

Settlement

There are two settlements within the oil sands area: Fort McMurray and Fort MacKay. The largest of these, Fort McMurray, is located in the Clearwater River valley at its confluence with the Athabasca. This site has had a trading post for the past 182 years, being first occupied by the North-west Company and later by the Hudson's Bay Company. The population of Fort McMurray has shown a dramatic growth over the past 10 years from about 2,000 people in 1963 to more than 7,000 people in 1973.

The only other population center of any note in the area is the 400 or so people who have settled around the Hudson's Bay Company trading post at Fort MacKay, situated on the west bank of the Athabasca River about 35 miles north of Fort McMurray. A good road which follows the west bank of the Athabasca River now connects these two settlements.

Fort McMurray is connected to the outside world by an all-weather highway, a scheduled air service, and a single-track railway from Edmonton. However, the importance of Fort McMurray as a major trans-shipping point for heavy freight bound for the Arctic coast has been declining in recent years due to the construction of new road and rail facilities to more northerly points such as Hay River on Great Slave Lake. The major factor contributing to population growth in the future will be the development of oil sands and related industry.

GENERAL GEOLOGY

Bedrock Geology

The stratigraphy of the sedimentary column underlying the oil sands area is summarized in table 2. Detailed descriptions of the lithology, thickness, distribution, and structure of the Paleozoic and Mesozoic rock units mentioned here are given in later sections of the book. A generalized cross section of the strata is shown in figure 3. A geological subcrop map of the bedrock geology under the area adjacent to the Athabasca and Clearwater Rivers between Fort McMurray and Fort MacKay is shown in figure 4.

Surficial Geology

Surficial deposits are the debris left behind by the melting of an ice sheet which covered the whole of northern Canada to a depth of several thousand feet during the Pleistocene epoch. Some surficial deposits are directly related to the melting of this ice (moraine); other features are the result of erosion (meltwater channels) and deposition from discharging meltwaters (gravel and sand); still other sediments (silt) were deposited in ice-dammed lakes which formed as the ice melted and receded. Remnants of beach ridges formed at various lake levels are common around the Thickwood Hills west of Fort McMurray (Fig. 5).

After the ice melted the original deposits were subjected to wind erosion. The finer-grained particles (dust) blew away and were deposited elsewhere as loess, the sand-sized particles were blown into large migrating dune fields, and the coarser-grained particles were left behind as lag deposits. As the climate ameliorated the dunes were stabilized by vegetation and the depressions on the poorly-drained surface were filled by the growth of mosses and sedges to form peat bogs or muskeg.

The thickness and stratigraphy of the surficial deposits of the area are not well known. In some small areas, such as in lease 86 where open pit mining is in progress, the surficial deposits have been studied in detail (see paper by Allen and Sanford, this volume). At this locality at least six stratigraphic units have been recognized in the glacial drift.

The most conspicuous erosional feature in the oil sands area is the U-shaped Athabasca-Clearwater valley which was probably formed in part by the movement of glacial ice, and may have acted subsequently as a spillway for the drainage of the large glacial lakes which covered the area at the end of the Pleistocene epoch. In addition to this major feature many small meltwater channels can still be recognized on the surface of the upland plains (Fig. 5). Most of the tributary streams to the Athabasca and Clearwater Rivers have cut through the unconsolidated glacial drift down into the soft Mesozoic bedrock and some of the

Table 2. General Stratigraphy of Post-Precambrian Strata in the Athabasca Oil Sands Area

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

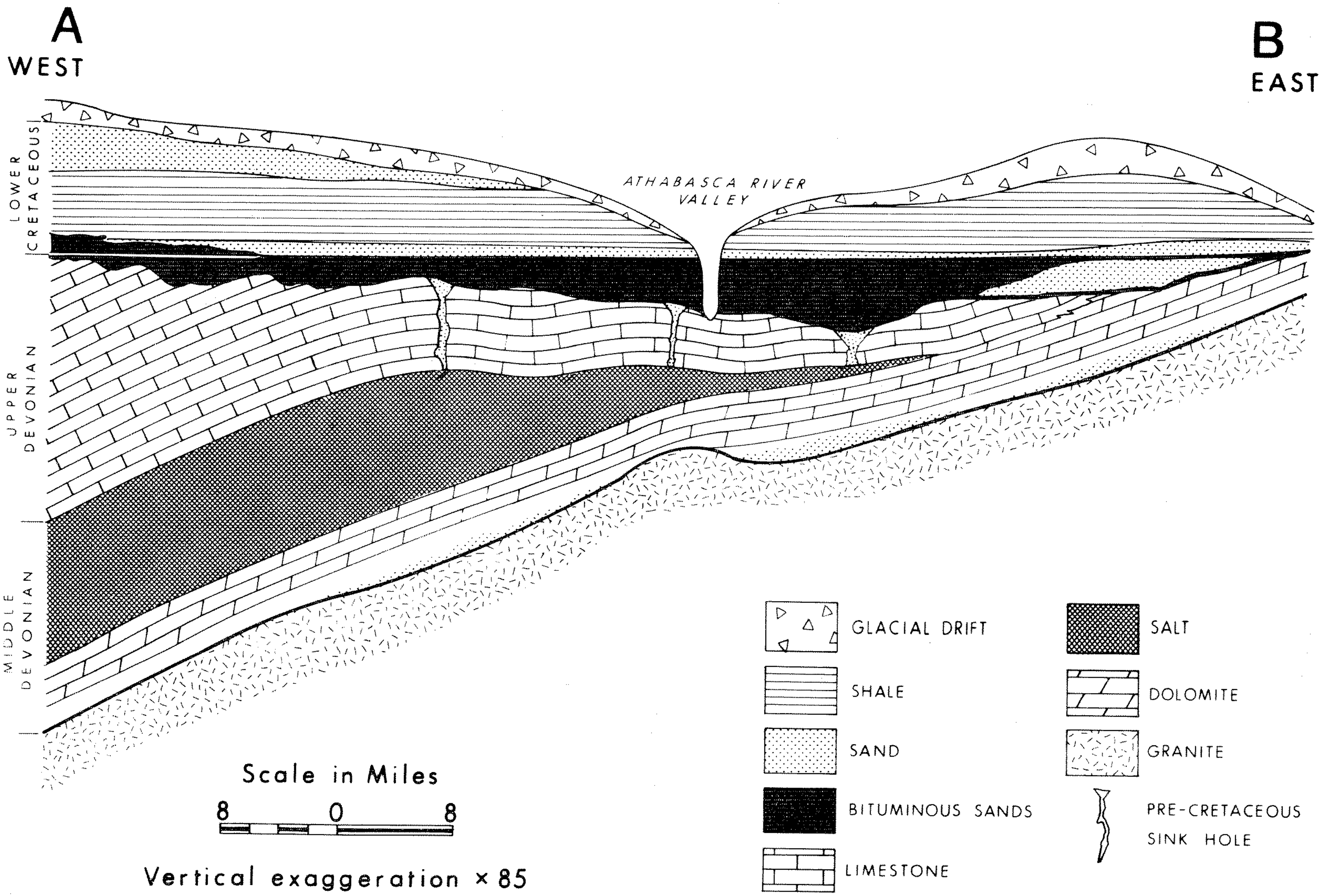


FIGURE 3. Simplified geological cross section (A-B on figure 1).

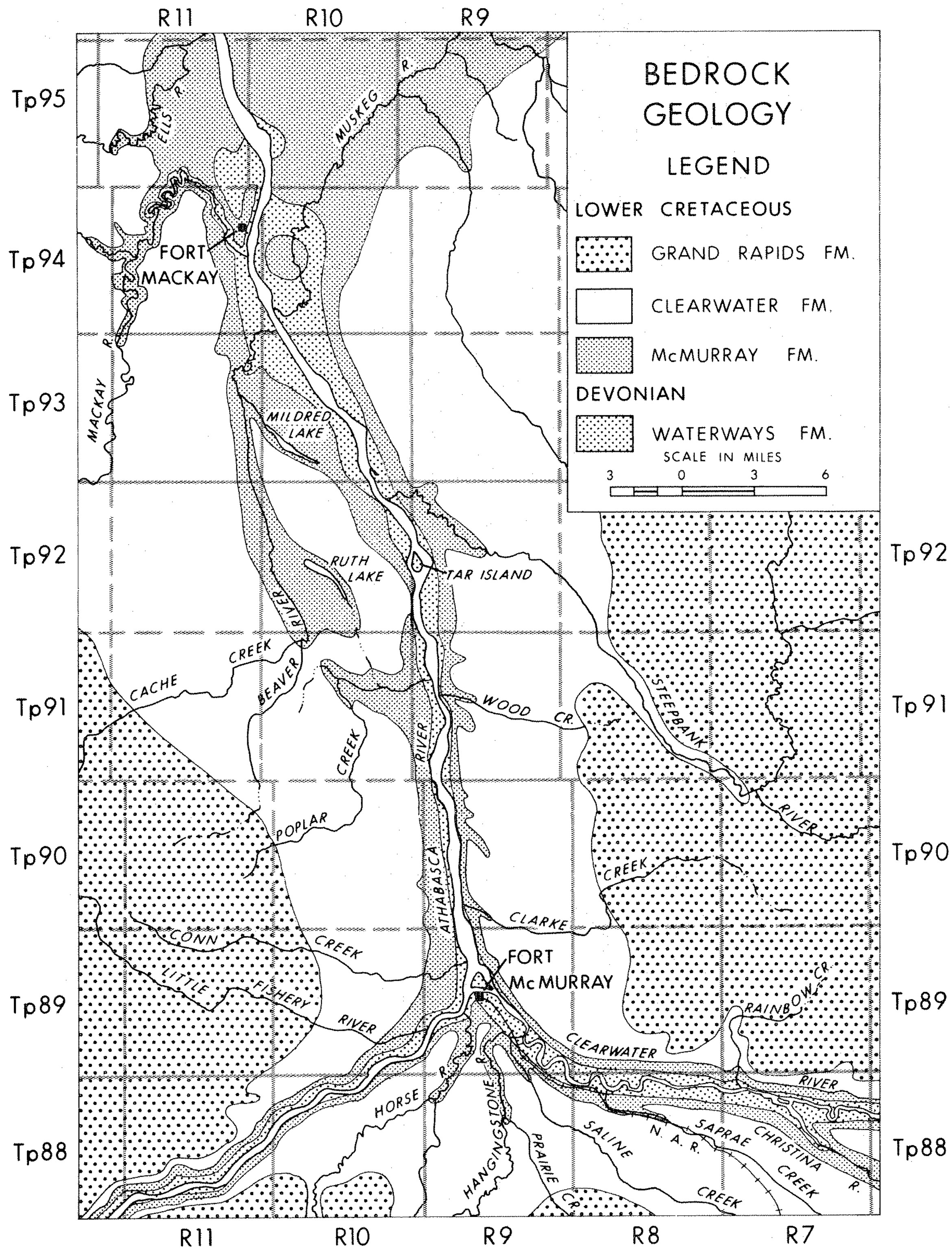


FIGURE 4. Bedrock geology of the area between Fort McMurray and Fort MacKay.

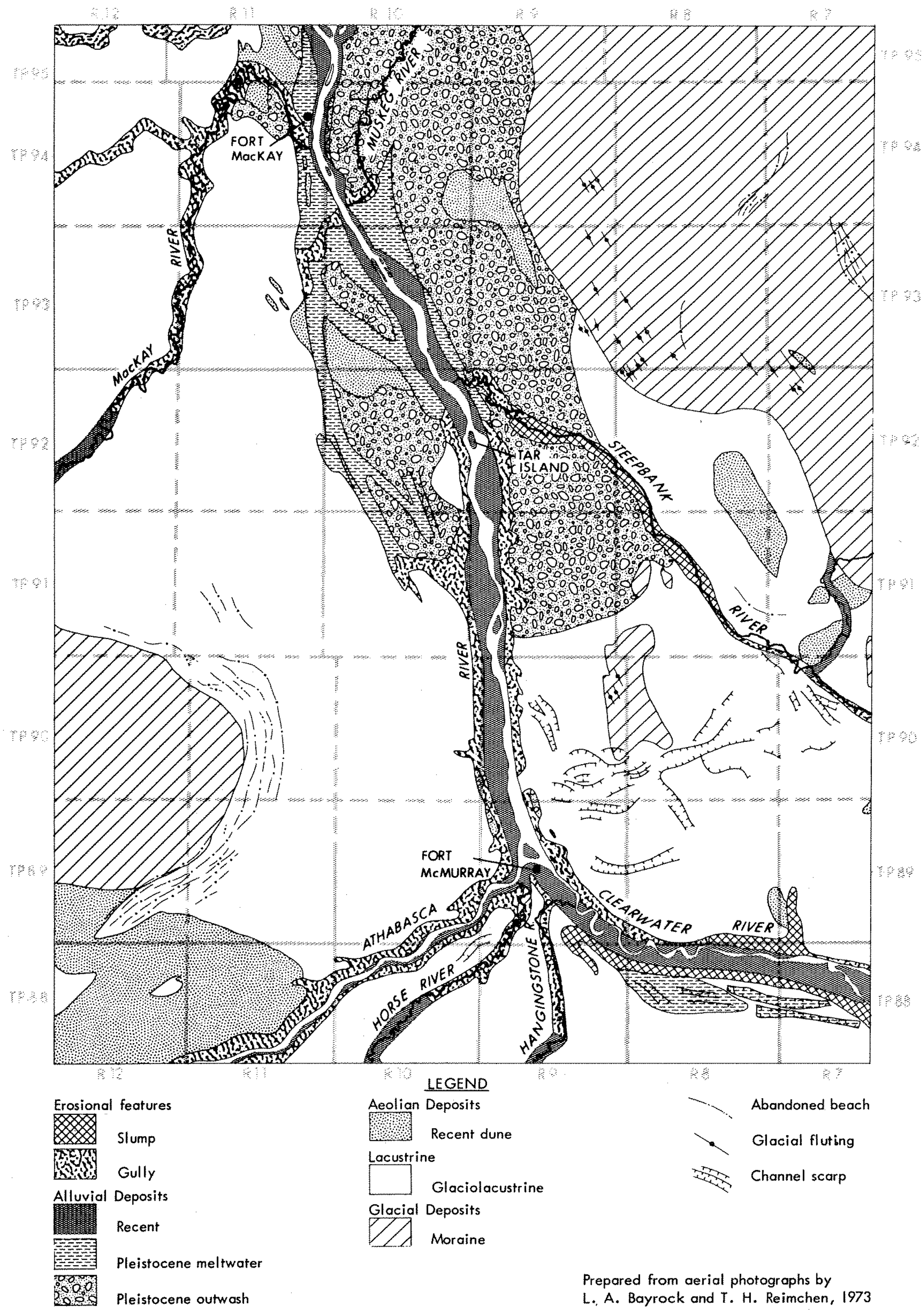


FIGURE 5. Surficial geology of the area between Fort McMurray and Fort MacKay.

larger streams have cut into the hard Paleozoic limestone. Associated with these actively eroding streams are many active slump features. Slumping of the Mesozoic bedrock is especially prevalent in the stream valleys which are cut into the Clearwater shale.

The surficial geology of the oil sands area is currently being mapped on a scale of 1:250,000 by L. A. Bayrock. The Bitumount sheet has been published (Bayrock, 1972) and the Waterways sheet is now being mapped. A generalized map of the major surficial features of the Athabasca River valley and surrounding area is given in figure 5.

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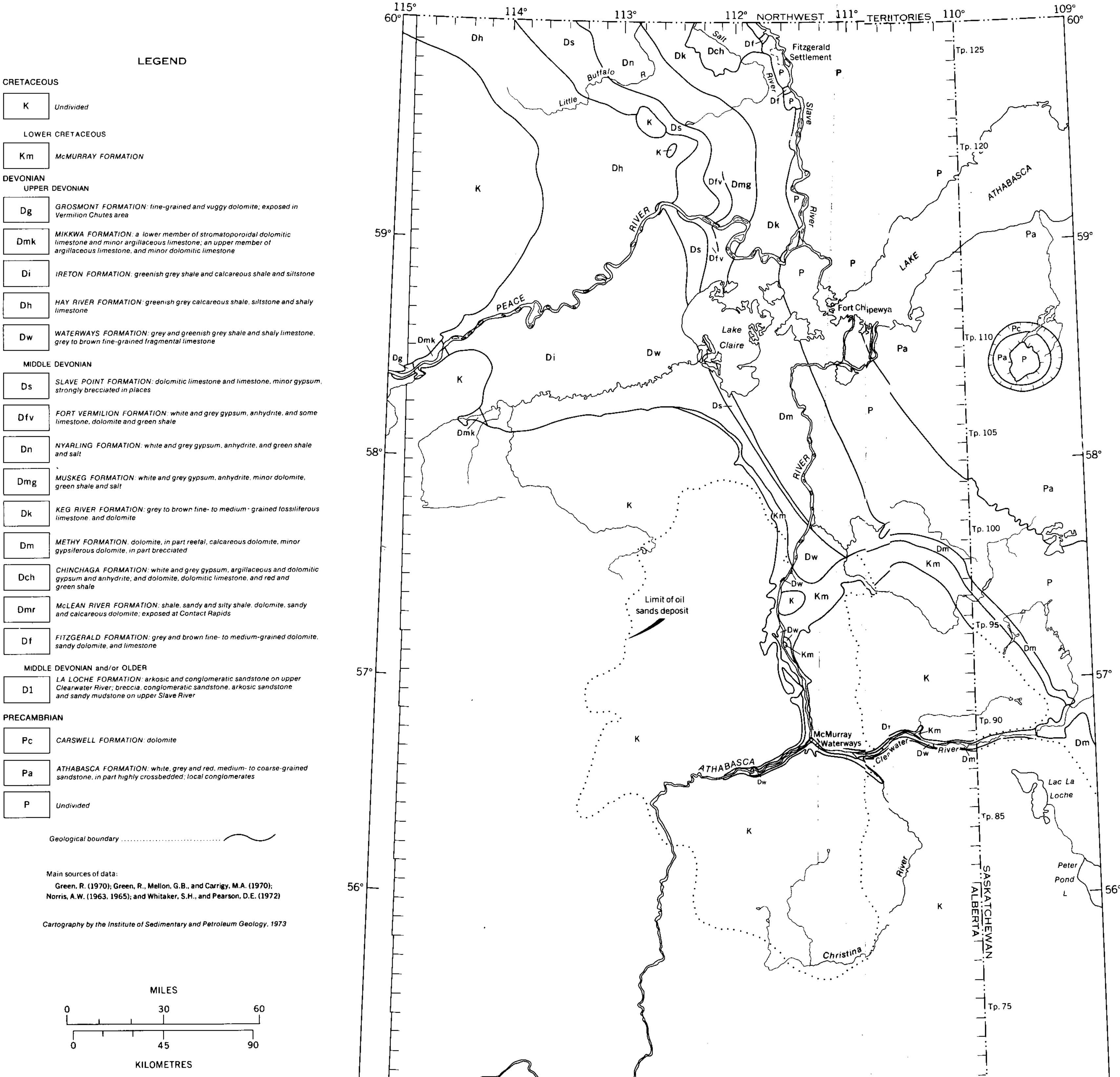

FIGURE 2. General geology of northeastern Alberta and northwestern Saskatchewan showing the distribution of Paleozoic (Devonian) rocks.

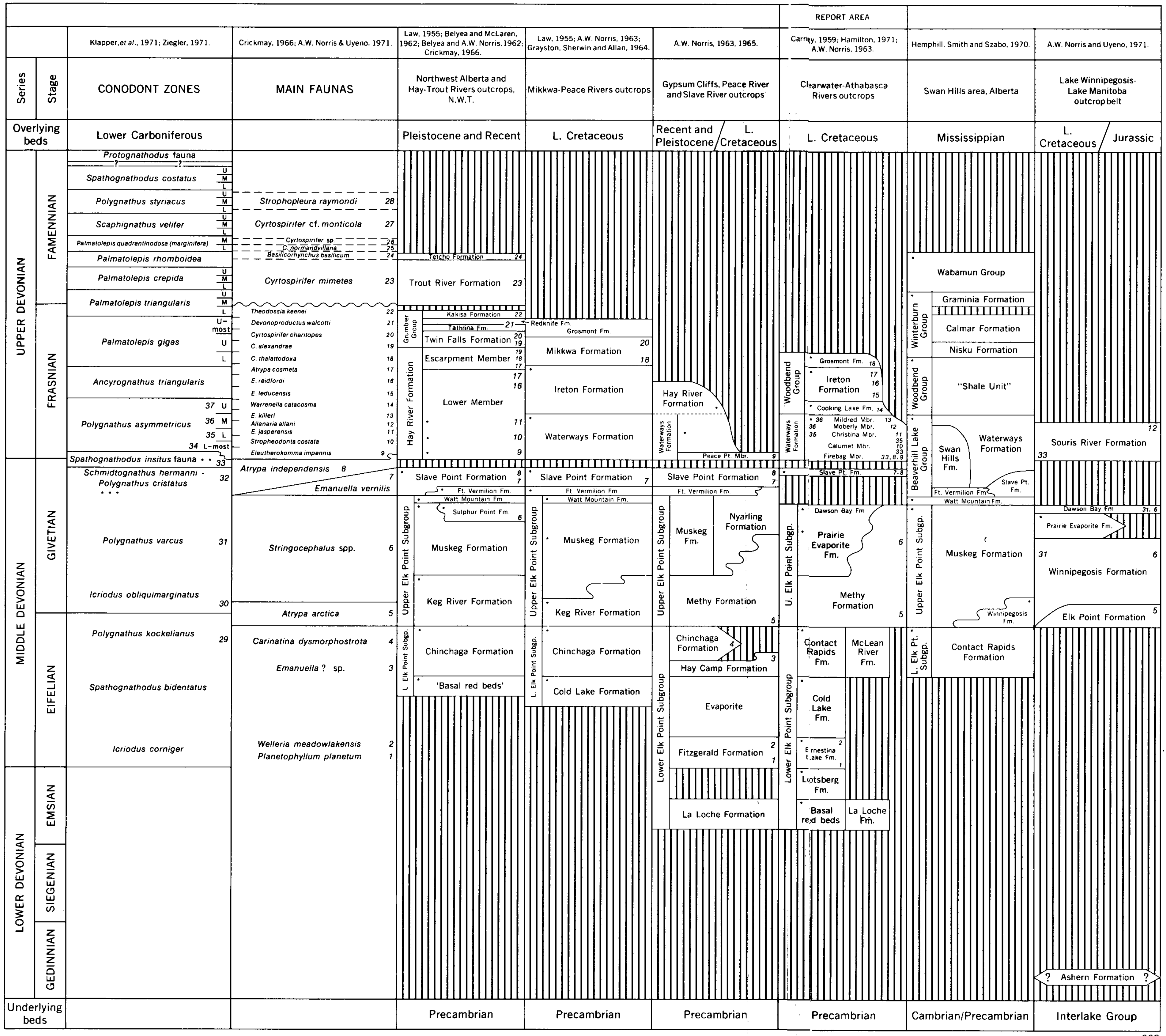

FIGURE 3. Stratigraphic nomenclature, main faunas, and correlation with other areas.

Key:

* Present in subsurface.

** In North America the higher beds containing the *Spathognathodus insitus* fauna may be dated as Upper Devonian on megafaunal evidence. In places lower beds containing this fauna are not independently dated and may be Middle or Upper Devonian in age (Klapper, *et al.*, 1971, p. 300). In northeastern Alberta the *S. insitus* fauna is equivalent, at least in part, to the Lowermost *P. asymmetricus* Zone of Europe (Uyeno, in press).

*** Megafaunal evidence in North America supports a Middle Devonian age for the *Schmidtognathus hermanni-Polygnathus cristatus* Zone (Klapper, *et al.*, 1971, p. 299).

The numbers refer to occurrences of characteristic fossils or faunal zones.

Except in places indicated, precise correlations between conodont and megafaunal zones have not been established.

PALEOZOIC (DEVONIAN) GEOLOGY OF NORTHEASTERN ALBERTA AND NORTHWESTERN SASKATCHEWAN

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INTRODUCTION

The present paper is a summary and synthesis of the Paleozoic geology of the Athabasca-Clearwater Rivers outcrop belt, based primarily on detailed reports by Crickmay (1957), Carrigy (1959), Norris (1963) and others, and incorporating more recent published data from many sources. Aside from the presence of saturated oil sands of Early Cretaceous age, this area is of special importance because it is one of the few places along the eastern margin of the Western Canada Sedimentary Basin (Fig. 1) where Devonian rocks can be examined at the surface (Fig. 2; Fig. 4, in pocket).

The erosion of the Clearwater and Athabasca Rivers has partly exposed a wedge of westward-dipping Devonian rocks which nonconformably overlaps the Canadian Shield at Contact Rapids on the Clearwater River, and thickens westward to about 1,160 feet at Fort McMurray. The top of the Devonian succession is an erosion surface overlain by Lower Cretaceous strata that overlap progressively younger Devonian rocks westward. The Devonian succession consists of the La Loche Formation (Eifelian or older); the McLean River, Methy, and Prairie Evaporite Formations (Eifelian and Givetian); the Slave Point Formation (late Givetian); the Waterways Formation subdivided into five members comprising the Firebag, Calumet, Christina, Moberly, and Mildred (early Frasnian); and the Woodbend Group comprising the Cooking Lake, Ireton, and Grosmont Formations (early to late Frasnian). Parts of the Devonian succession that are not represented in outcrops and are present only in the subsurface comprise the Middle Devonian Prairie Evaporite and Slave Point Formations, and the Upper Devonian Mildred Member of the Waterways Formation and formations of the Woodbend Group.

The east-west and south-north columnar and structure cross sections presented in this paper are based mainly on wells drilled along and near the Clearwater and Athabasca Rivers by Bear Oil Company in 1948-49 of which there are published logs. Since 1949 many new wells have been drilled in the area but most of these more recent subsurface data remain unpublished. The Devonian stratigraphic nomenclature of the report area, main faunas, and correlation with other areas are shown in a general way by figure 3.

ACKNOWLEDGEMENTS

The writer wishes to thank Helen R. Belyea and T. T. Uyeno of the Geological Survey of Canada for information on Devonian stratigraphy and conodonts, respectively, incorporated in this paper. M. A. Carrigy and W. N. Hamilton of the Research Council of Alberta critically read the manuscript and made valuable suggestions for its improvement.

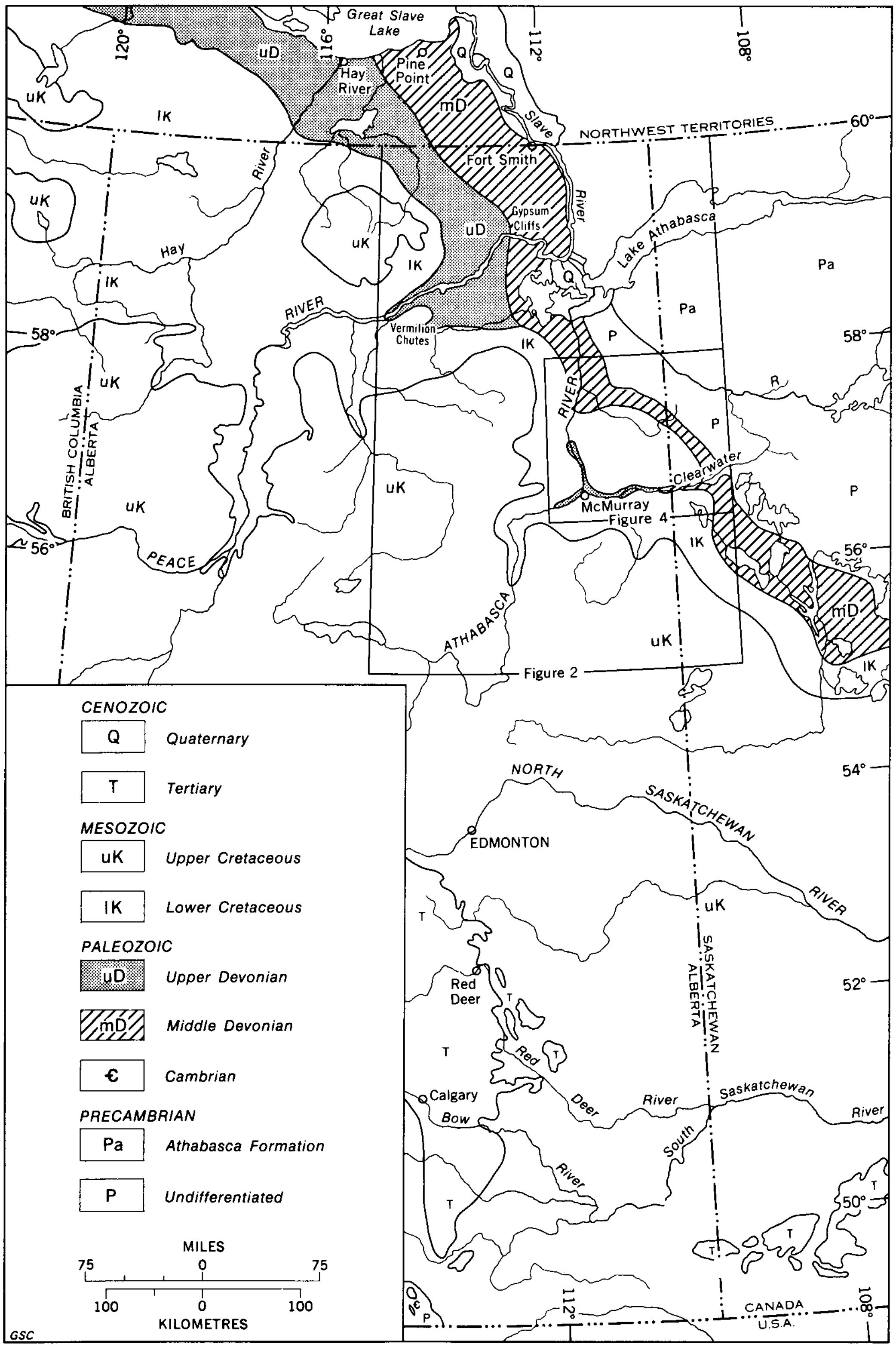

FIGURE 1. The Paleozoic (Devonian) outcrop belt in the Athabasca-Clearwater Rivers area.

DEVONIAN STRATIGRAPHY

Middle Devonian and/or Older

Lower Elk Point Subgroup

The name Elk Point Formation was introduced by McGehee (1949) for a series of evaporites, dolomites, and shales lying between the Waterways Formation and the Cambrian in the Elk Point area of east-central Alberta. His type section was a composite of three wells drilled by Anglo Canadian in townships 56 and 57, and ranges 5 and 6, west of the fourth meridian. Belyea (1952) raised the Elk Point to group status in north-central Alberta. Baillie (1953) used the name Elk Point Group to apply to strata in Saskatchewan and Manitoba lying between the base of the Second Red Bed and the Lower Paleozoic surface. Crickmay (1954) selected the Anglo Canadian Elk Point No. 11 well (2-21-57-5-W4) as a more suitable type section of the Elk Point Formation and subdivided it into nine members numbered in descending sequence which were correlated over a wide area. Law (1955a,b) introduced a new terminology for subdivisions of the Elk Point Group in the subsurface of northwestern Alberta. Van Hees (1956) selected the base of the Ashern Formation as the boundary to subdivide the Elk Point Group into upper and lower subdivisions in Manitoba and Saskatchewan. Sherwin (1962) subdivided the Lower Elk Point Subgroup of east-central Alberta into five mappable units, and introduced four new names to apply to the upper four units. He selected the base of the Winnipegosis carbonate as the upper boundary of the Lower Elk Point Subgroup. His five mappable units of the subgroup comprise, in ascending sequence: the Basal Red Beds, and Lotsburg, Ernestina Lake, Cold Lake, and Contact Rapids Formations. Equivalents of two of Sherwin's (1962) mappable units are recognizable in the Athabasca-Clearwater Rivers region comprising the La Loche and McLean River Formations.

La Loche Formation

The name La Loche Formation was introduced in 1958 by Norris (1963) for the basal Paleozoic beds consisting mainly of arkosic sandstones that nonconformably overlie the Precambrian and are overlain by beds of the McLean River Formation. The type section is along the Clearwater River in the vicinity of Contact and Simonson Rapids (Norris, 1963, pp. 8-9, 86). Sandy beds at the base of the Paleozoic succession overlying the Precambrian have been penetrated by numerous wells west of the outcrop edge of the Canadian Shield, where they have been variously referred to as the "basal red beds" or "granite wash" (Carrigy, 1959; Hamilton, 1971; and others). In outcrops the sandstone appears to be preserved only in depressions in the Precambrian surface. In the subsurface there is a pronounced thinning of the unit over the tops of local Precambrian highs as is evident in the Alberta Government Salt Well No. 2 (Fig. 5, in pocket; and Fig. 6).

The lithology of the La Loche Formation at the type locality consists of pale brown, fine- to medium-grained, irregularly lenticular, thin-bedded

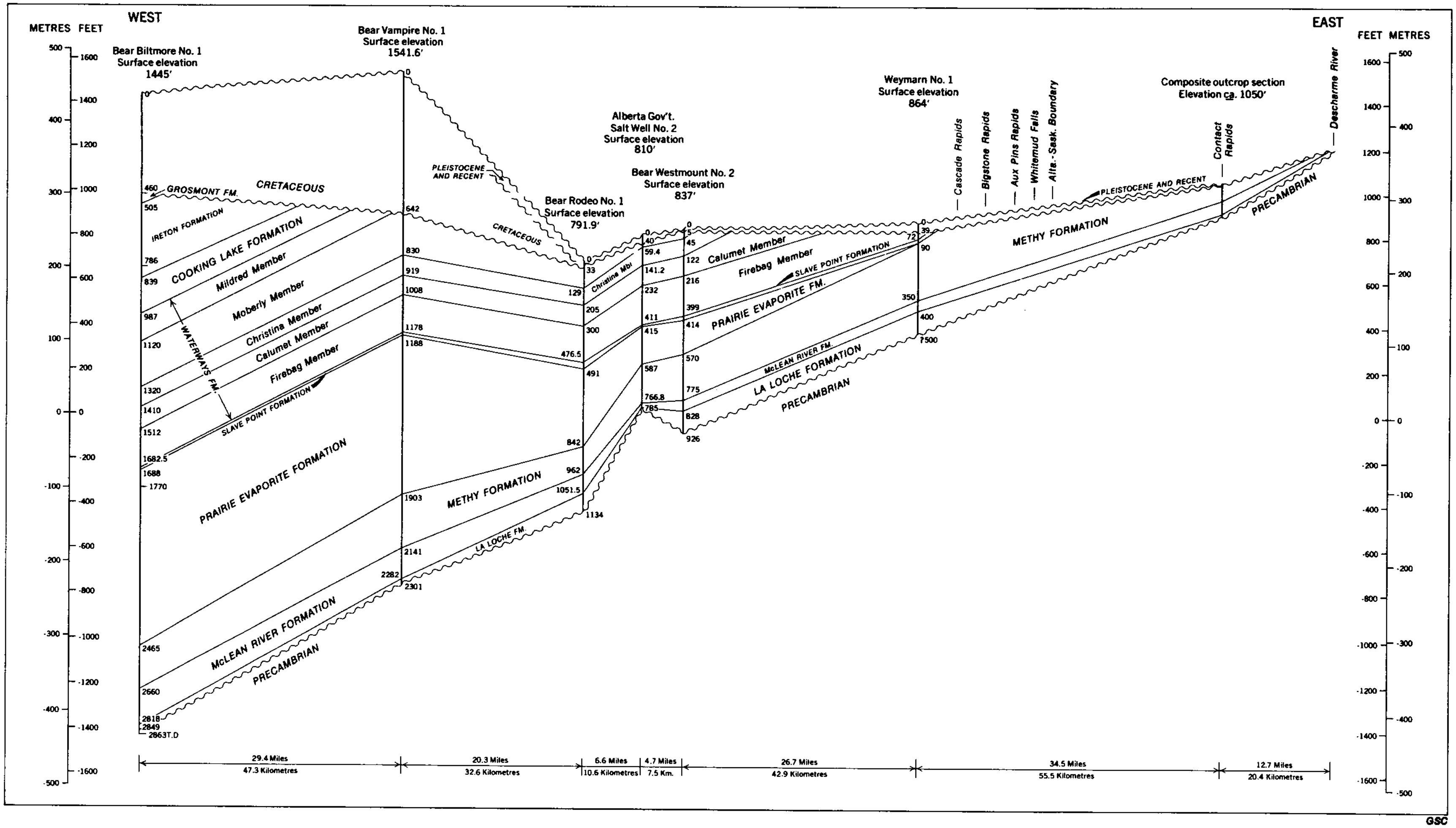

FIGURE 6. Structure section from Bear Biltmore No. 1 well in the west to the edge of the Canadian Shield near the mouth of Descharme River in the east.

arkosic sandstone. Scattered coarse angular and partly rounded fragments of feldspar and quartz are conspicuous in some of the beds, and some iron oxide is evident in the cement.

In the subsurface the La Loche Formation consists mainly of feldspathic and gritty sandstone, some sandy dolomite, mudstone and shale, and thin minor beds of anhydrite and gypsum. The beds immediately overlying the Precambrian consist in places of weathered igneous rock (e.g., Bear Vampire No. 2), but more commonly consist of granite wash (e.g., Bear Biltmore No. 1, Bear Rodeo No. 1 and Bear Westmount No. 2). Some of the higher sandstone beds contain rounded and frosted grains of quartz, which along with a red colour, point to intermittent periods of subaerial exposure.

The maximum thickness of the La Loche Formation in the type area is about 5 feet. In the east-to-west structure section of bore holes shown in figure 6 a maximum thickness of 98 feet is present in the Bear Westmount No. 2 well and a minimum thickness of 19 feet is present in the Bear Vampire No. 1 well. In the south-to-north structure section shown in figure 8 a maximum thickness of 130 feet is present in the Athabasca Oils Limited No. 1 well and a minimum thickness of 23 feet is present in the Bear Vampire No. 2 well.

At the type section neither the lower nor upper contact of the La Loche Formation is exposed. The contacts can be observed, however, in the numerous bore holes that penetrate this unit to the west. The lower contact is nonconformable with Precambrian metamorphic and igneous rocks. The upper contact with the McLean River Formation is drawn where the lithology changes from predominantly sandstone to siltstone, silty and argillaceous dolomite, and evaporites. In most places the basal beds of the McLean River Formation are sandy, suggesting that the contact is transitional.

No fossils have been found in the La Loche Formation and its precise age is unknown. Because it is limited below by the Precambrian and above by the McLean River Formation which is considered to be of early Middle Devonian age, the La Loche Formation is tentatively dated as Early Devonian or older Paleozoic age.

In the more central and deeper parts of the Elk Point Basin to the west, analogous basal red beds overlie the Precambrian and underlie the Lotsburg Formation of the Lower Elk Point Subgroup (Hamilton, 1971). The "basal red beds" rise in the section and appear to be younger in age towards the eastern margin of the Elk Point Basin bordering the Canadian Shield and over Precambrian highs within the basin.

Middle Devonian

McLean River Formation

The name McLean River Formation was introduced in 1958 by Norris (1963, pp. 11-13, 86) for the olive green shale, brown siltstone, and sandy dolomite overlying the La Loche Formation and underlying the Methy Formation. The type

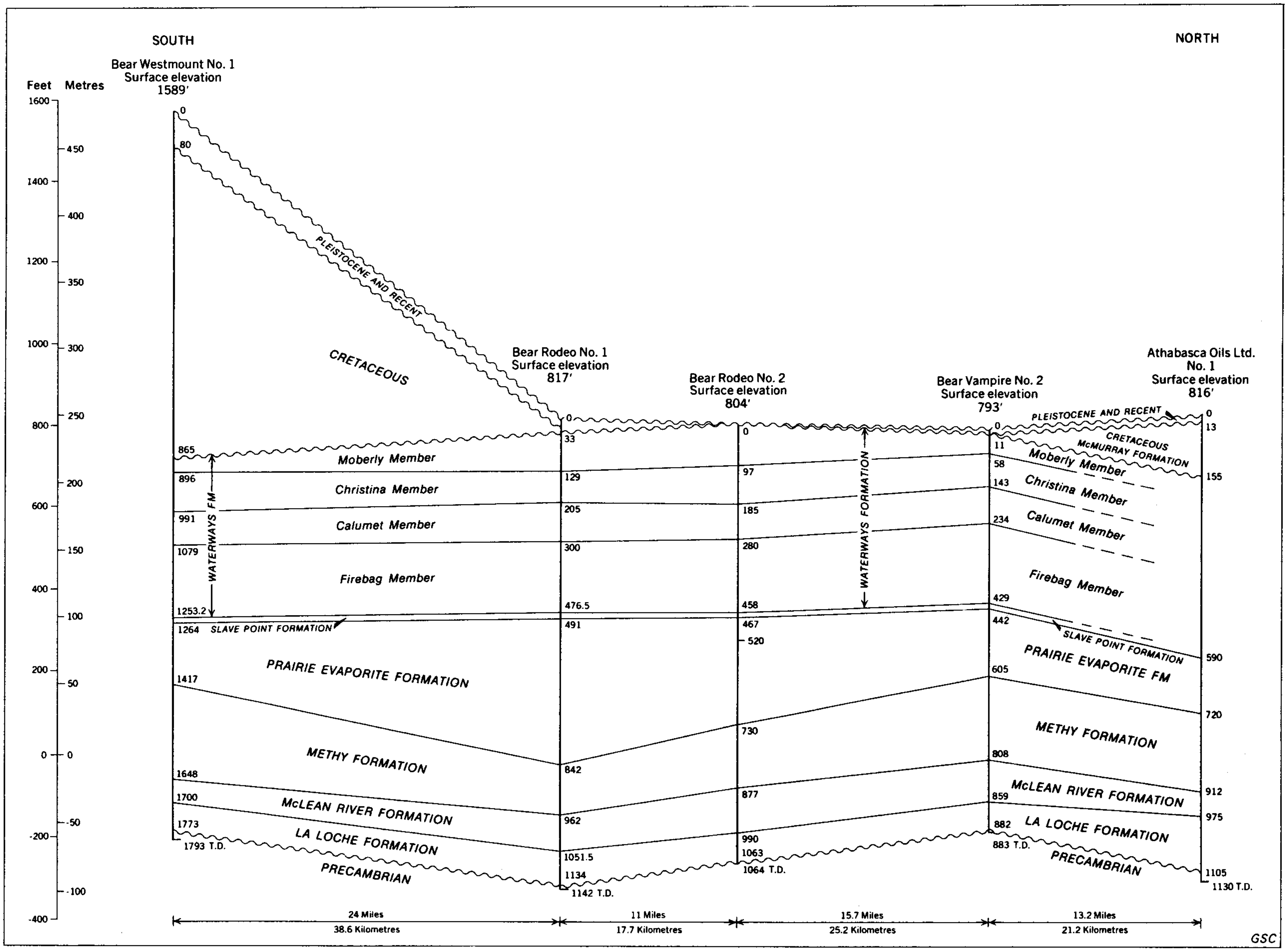

FIGURE 8. Structure section from Bear Westmount No. 1 well in the south to Athabasca Oil Limited No. 1 well in the north.

section is composite from a number of outcrops along the south bank of the Clearwater River opposite the lower end of Contact Rapids. The McLean River Formation appears to be continuous, at least in part, with the Contact Rapids Formation defined by Sherwin (1962, pp. 190-191) which he considered as the uppermost rock unit of the Lower Elk Point Subgroup. His type section is in east-central Alberta in the Canadian Seaboard Ernestina Lake No. 10-13 well between depths of 3,076 and 3,222 feet.

In the subsurface the McLean River-Contact Rapids beds appear to be confined to the Central Alberta Basin as delineated by Grayston, Sherwin and Allan (1964, pp. 50, 58, figs. 5-11A, B).

The lithology of exposed beds of the McLean River Formation in ascending sequence in the type area (Norris, 1963, pp. 85-86) consists of: highly sandy and calcareous, light brownish grey, fine-grained medium- to thick-bedded dolomite, containing thin interbeds of olive green sandy shale (12 feet thick); medium greenish grey calcareous, silty, and sandy shale and mudstone (*ca.* 5 feet thick); olive green, calcareous and sandy, recessive weathering shale (16 feet thick); light grey, cryptograined, medium even-bedded dolomite with olive green shale partings (8 feet thick); and olive green, calcareous and sandy shale (7 feet thick).

In the subsurface west of Contact Rapids the McLean River Formation consists largely of dolomitic siltstone, some silty and sandy shale, and mudstone, with scattered thin beds of anhydrite and gypsum. In the western parts of the report area beds of dolomite, in part oolitic and brecciated, and thicker sequences of anhydrite are also present (e.g., Bear Biltmore No. 1 and Bear Vampire No. 1; fig. 5). Some glauconite is present also in this formation in the Bear Rodeo No. 1 and Bear Biltmore No. 1 wells.

At the type section a covered interval of about 5 feet separates the McLean River Formation from the underlying sandstone beds of the La Loche Formation. In the same area a covered interval of about 8 feet separates the McLean River Formation from the overlying calcareous dolomite beds of the Methy Formation. In some wells the lower contact is transitional and arbitrary, whereas in other wells the change in lithology from fine to coarse clastics is more abrupt. The upper contact in the subsurface is generally fairly sharp and is marked by a change from fine clastic rocks to various types of dolomite.

Thickness of the McLean River Formation at Contact Rapids is about 61 feet. In the east-to-west cross section of wells shown in figure 5 the thickness varies from 60 feet in the Weymarn No. 1 well to 158 feet in the Bear Biltmore No. 1 well. In the same cross section an abrupt thinning of the formation is seen in Alberta Government Salt Well No. 2 which is located over a local Precambrian high. In the south-to-north cross section of wells shown in figure 7 (in pocket) the thickness varies from 51 feet in the Bear Vampire No. 2 well to 113 feet in the Bear Rodeo No. 2 well.

The only recorded fossils from the McLean River Formation are small *Tasmanites*-like sporomorphs, *Tentaculites* sp., and an indeterminate brachiopod cast suggestive of *Emanuella* sp., which were collected by Norris (1963, pp. 13, 85-86) at the type section. On the basis of these fossils and stratigraphic position immediately below the Methy Formation, an early Middle Devonian (Eifelian) age is suggested.

To the northwest the McLean River-Contact Rapids Formation appears to correlate approximately with the evaporitic Chinchaga Formation described by Law (1955) with its type section in the California Standard Steen River No. 2-22 well (2-22-117-5-W6) where the Chinchaga anhydrite rests directly on "Basal Red Beds." To the north, along Slave River, the McLean River-Contact Rapids interval appears to correlate approximately with carbonate and brecciated carbonate beds of the Hay Camp Formation and evaporites of the Chinchaga Formation described by Norris (1963, 1965). Sparse fossils in both the Hay Camp and in carbonate beds within the Chinchaga Formation also suggest an early Middle Devonian (Eifelian) age. The latter beds contain a few forms that occur typically in the Hume Formation of the Norman Wells area.

Upper Elk Point Subgroup

Methy Formation

The name Methy, after Methy Portage, was used in an oil company report by P. E. Cote in 1949, and applied to the dolomite discontinuously exposed along the Clearwater River between Cascade Rapids and Whitemud Falls. The name "Methy dolomite" first appeared in a paper by Nauss (1950), but designation of a type section (Bear Westmount No. 2 well; 9-36-88-8-W4) and detailed lithological descriptions did not appear until Greiner's (1956) paper based on a M.Sc. thesis done in 1950-51 at the University of Alberta. A Ph.D. thesis by Bassett (1952MS) also contains information on the Methy Formation. More recent detailed descriptions of the Methy Formation are given by Carrigy (1959) and Norris (1963).

The Methy Formation in the subsurface of the Athabasca-Clearwater Rivers area, is composed mainly of dolomite, underlain by fine clastic beds of the McLean River Formation and overlain by evaporites of the Prairie Evaporite Formation. Eastward, towards the edge of the Canadian Shield, the Prairie Evaporite Formation thins to zero immediately west of the Weymarn No. 1 well. Accordingly, the Methy Formation may be overlapped successively by the Slave Point Formation, Waterways Formation, and by strata of Lower Cretaceous and Tertiary ages.

The Methy Formation outcrops discontinuously along the Clearwater River from about 3 miles above the mouth of Descharme River to 1.7 miles below Cascade Rapids, a total distance of about 49 miles (Fig. 4). The main outcrops occur at and near the mouth of the Descharme River, Gould Rapids, Simonson Rapids, Contact Rapids, Whitemud Falls, Pine Rapids (Plate 1), Bigstone Rapids, Long Rapids, and Cascade Rapids. To the north, along the edge of the Canadian Shield, loose dolomite fragments suggestive of the Methy Formation have been mapped by Tremblay (1961b) on Johnson Lake, Reid Creek, Dick Lake, and Clay Lake. Other outcrops and loose fragments of the Methy Formation have been mapped by geologists of the Research Council of Alberta (Green, Mellon and Carrigy, 1970) along the lower parts of the Firebag River and Reid Creek.

At Contact Rapids, where the lower part of the Paleozoic outcrop sequence is most complete, the Methy Formation may be subdivided into two distinct members, informally referred to as the "Lower thin-bedded member" and the "Upper massive member" (Norris, 1963, pp. 13, 85). The lower member consists of light brown, fine-grained, granular, in part vuggy, highly calcareous dolomite, occurring as recessively weathering, even beds varying between 1 and 8 inches in thickness. Crenulated silty laminae are present in some beds and sparse nodules of medium grey chert are also present. Fossils are moderately abundant and generally better preserved than in the overlying member. The upper member consists of light brown, in places mottled light and medium brown, vuggy in part, resistant cliff-forming, irregular thick-bedded to massive reefoid dolomite. Light greenish grey chert is present in the basal part of the member in the Contact Rapids area.

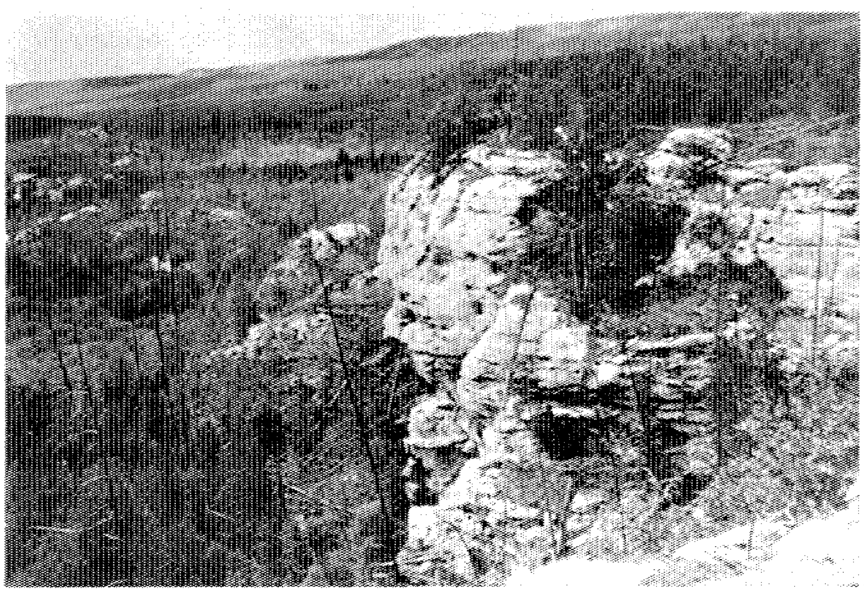

PLATE 1. Dolomite beds of the Methy Formation, north of the Clearwater River near Pine Rapids.

In the subsurface the lithology of the Methy Formation, as seen in the cores of the Bear wells, is highly variable. Greiner (1956) recognized three arbitrary subdivisions within the formation: a basal, relatively thin-bedded unit; a relatively thick middle unit containing reefal and interreefal beds; and a relatively thin upper, distinctly-bedded unit in which fossils are apparently absent. The lower unit (2 to 35 feet thick) consists of light yellowish grey dolomite and evaporite, and silty dolomite with thin interbeds of anhydrite and minor shale. Minor quartzose sand is evident in some of the basal beds. The middle unit (130 to 200 feet thick) consists mainly of pale brown to brownish grey dolomite which is in places massive, poorly to well bedded, "flow-layered" and brecciated. The approximate lower half of this unit in the Bear Westmount No. 1 well consists of a dolomitic limestone. Fragmentary fossils including stromatoporoids, corals, crinoid fragments, brachiopods, bryozoans, sponge spicules, and calcareous algae are abundant at scattered intervals in the unit. The upper unit (3 to 55 feet thick) consists of unfossiliferous well-bedded dolomites, evaporitic dolomite, some oolitic and argillaceous dolomite, and thin interbeds of anhydrite.

Where the Methy Formation has overstepped the underlying formations to rest directly on the Canadian Shield as it appears to have done east of Contact Rapids, the basal part of the Methy contains sand, pebbles, and cobbles of granite and gneiss (Tremblay, 1961a).

In the east-to-west cross section of wells shown in figure 5 a maximum thickness of 270 feet is present in the Weymarn No. 1 well and a minimum thickness of 120 feet is present in the Bear Rodeo No. 1 well. A structure section (Fig. 6) shows that the maximum carbonate reef build-up occurred towards the edge of the Canadian Shield. An abrupt westward thinning of the Methy Formation apparently occurs between the Research Council of Alberta Test Holes A and B (Hamilton, 1969) located on the Clearwater River (Fig. 4) and suggests the presence of a westward-facing reef front between these two wells. In the north-to-south cross section of wells shown in figure 7 a maximum thickness of 231 feet is recorded in the Bear Westmount No. 1 well.

Numerous fossils from the Methy Formation have been listed or mentioned by Bassett (1952MS), Greiner (1956), Crickmay (1957), Carrigy (1959), Warren and Stelck (1962), Norris (1963) and others. The more important forms include: *Sphaerospongia tessellata* (Phillips), *Dendrostella disjuncta* (Whiteaves), *Schizophoria* sp. cf. *S. manitobensis* Whiteaves, *Atrypa arctica* Warren, *Atrypa perfimbriata* Crickmay, *Spinatrypa* cf. *S. andersonensis* (Warren), *Emanuella sublineata* (Meek), *Warrenella* sp., *Stringocephalus* spp., and *Mastigospira alata* (Whiteaves).

The presence of the exceedingly finely costate brachiopod *Atrypa arctica* in the lower part of the Methy Formation suggests a correlation with the Elm Point Formation of Manitoba, the lower part of the Pine Point Formation of the Great Slave Lake area, the Murray Island Formation of the Hudson Bay Lowlands, and a thin interval in the lower part of the Rogers City Formation of Michigan. Uyeno has shown (*in* Norris and Uyeno, 1971, p. 212) on the basis of conodonts that the basal part of the Elm Point Formation is of late Eifelian (early Middle Devonian) age. The reefal part of the Methy Formation is lithologically and faunally similar to the Winnipegosis Formation of Manitoba. Fossils in common to both formations include *Sphaerospongia tessellata* (Phillips), *Atrypa* sp. cf. *A. arctica* Warren, a thin flat form of *Stringocephalus* sp., *Schizophoria manitobensis* Whiteaves, *Mastigospira alata* (Whiteaves), and others. The Methy Formation has also some faunal similarities in common with the upper part of the Rogers City Formation of Michigan and the Miami Bend Formation of Indiana (Norris and Uyeno, 1971). Uyeno (*in* Norris and Uyeno, 1971) has shown that the conodont fauna of the Winnipegosis and overlying Dawson Bay Formations are within the *Polygnathus varcus* Zone. Accordingly, by comparison with the Winnipegosis Formation of Manitoba, the Methy Formation appears to range in age from late Eifelian in its lower part to middle or late Givetian in its upper part.

West and northwest of the Athabasca-Clearwater Rivers area the Methy Formation in the subsurface is continuous with the Keg River Formation of Law (1955a,b).

Prairie Evaporite Formation

The name Prairie Evaporite Formation was introduced by Baillie (1953a; 1953b, p. 24) for the salt and anhydrite beds forming the upper unit of the Elk Point Group throughout most of the Elk Point Basin. The name was extended into the Athabasca-Clearwater Rivers area of northeastern Alberta by Carrigy (1959) and replaces the older informal term "First Salt" used by Belyea (1952), Norris (1963) and others. The Prairie Evaporite Formation is approximately equivalent to Crickmay's (1954) Members 1 and 2 of the Elk Point Group.

This rock unit does not outcrop in the Athabasca-Clearwater Rivers area. However, a number of salt springs, probably first mentioned by Bell (1884, p. 27), are present on the banks of the Clearwater River immediately west of the most westerly outcrops of the Methy Formation, where one would expect to find the "feather edge" of the evaporites intersecting the surface. The evaporites are missing from the Weymarn No. 1 well (Fig. 5) which is probably located just beyond the eastern margin of the evaporite basin. The Prairie Evaporite Formation is present, however, in all of the wells drilled to the west of the Weymarn No. 1 well.

In the report area the name Prairie Evaporite Formation is applied to a unit consisting mainly of evaporites overlying the dolomites of the Methy Formation and underlying the thin limestone and limestone breccia of the Slave Point Formation. It is equivalent to the succession between depths 1,688 to 2,465 feet in the Bear Biltmore No. 1 well, which Belyea (1952, fig. 2) subdivided into three unnamed units. The same interval in this well has been subdivided by Carrigy (1959, fig. 6) into two units; the lower unit

(2,467 to 1,770 feet depths) is referred to as the "Prairie Evaporite," and the upper (1,770 to 1,688 feet depths) as the "Dawson Bay Formation Equivalent(?)." The lower unit (697 feet thick) consists mainly of smoky grey rock salt, with brownish grey anhydrite at the bottom, top, and at scattered intervals within the salt. Minor thin beds of siltstone are present also within the mainly salt interval. The upper unit (82 feet thick) consists of silty shale, dolomitic shale, silty anhydrite with green and red mottling in the lower half, and mainly dolomite with some limestone and anhydrite in the upper half.

More recently, Hamilton (1969, fig. 3) has suggested that the lower shaly part of the upper unit may be equivalent to the Watt Mountain Formation. Another interpretation is that the sparse evaporites present in the upper part of the upper interval may be in part equivalent to the Fort Vermilion Formation that is typically developed in northwestern Alberta.

Eastward, 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. Salt, other than as impurities, is missing in all of the bore holes east of Alberta Government Salt Well No. 2 (Fig. 5). The upper unit, questionably designated as equivalent to the Dawson Bay Formation, is not readily distinguishable towards the east. Some workers, notably Hamilton (1969), suggest that the Watt Mountain Formation equivalent is present in some of the wells along the Clearwater River including the Weymarn No. 1 well.

The thickness of the Prairie Evaporite Formation in the Athabasca-Clearwater Rivers area varies from zero in the east to a maximum of 777 feet in the west in the Bear Biltmore No. 1 well (Figs. 5 and 7).

Except for calcareous algal forms of the Charophyta, the Prairie Evaporite Formation is barren of fossils. Charophyta are abundant in a dolomitic shale (1,729 to 1,739 feet depths) in the Bear Biltmore No. 1 well reported by Belyea (1952, p. 11 and fig. 2) from beds considered equivalent to the Dawson Bay by Carrigy (1959). Charophyta are reported by Law (1955b, p. 1,952) to be common in the shaly seams of the Watt Mountain Formation in northern Alberta, and are present also in the Fort Vermilion Formation of the Swan Hills area (Jansa and Fishbuch, in press). The charophytes are of interest because they suggest a brackish or fresh water environment of deposition (Rice, 1970).

The lower major part of the Prairie Evaporite Formation, consisting largely of salt, is the approximate equivalent of the evaporite sequence consisting largely of anhydrite named by Law (1955b) the Muskeg Formation. The type section of the Muskeg Formation is in California Standard's Steen River No. 2-22 well in northwestern Alberta, north of the Peace River Arch. There it overlies a unit, consisting mainly of dolomite or limestone with little or no anhydrite, named by Law the Keg River Formation, and underlies a unit of terrigenous clastics and limestone breccia named by Law the Watt Mountain Formation (Fig. 3).

The age of the Prairie Evaporite Formation is late Middle Devonian (Givetian) based on its stratigraphic position between the fossiliferous Methy Formation and the sparsely fossiliferous Slave Point Formation. Other indirect evidence supporting the Givetian age is the presence of *Stringocephalus* sp. reported by Workman *et al.* (1960, p. 95) from the Dawson Bay Formation in the subsurface of Saskatchewan where it overlies the Prairie Evaporite Formation of that area.

Slave Point Formation

The name Slave Point Formation was proposed by Cameron (1918) to apply to the upper part of the Middle Devonian succession in the Great Slave Lake area. Subsequently the name has been extended southward into the subsurface by Law (1955a,b), Belyea and Norris (1962) and others.

The Slave Point Formation in the Athabasca-Clearwater Rivers area is a relatively thin rock unit composed of limestone, some silty limestone, siltstone, and minor dolomitic limestone, in places brecciated; overlying dolomite, anhydritic dolomite, or anhydrite of the Prairie Evaporite Formation; and overlain by shale or argillaceous limestone of the Firebag Member of the Waterways Formation. It has long been recognized as a separate unit; Belyea (1952) indicated it as the basal member of the Beaverhill [Lake] Formation; Bassett (1952MS) referred to it as the "Slave Point Formation"; and Crickmay (1957) referred to this unit as the "Slave Point Equivalent." Norris (1963, pp. 22-25), because of the difficulty of correlating with the type and other areas, introduced the name Livock River Formation to apply to this unit, but the name has not gained wide acceptance.

Beds of the Slave Point Formation do not appear to outcrop in the area. The nearest outcrops are found north of the area, along and near the mouth of the McIvor River and on a point on the southwest shore of Lake Claire in an area recently mapped by geologists of the Research Council of Alberta (Green, Mellon and Carrigy, 1970), and in the Gypsum Cliffs area on the Peace River described by Norris (1963).

The beds assigned by Crickmay (1957, pp. 10, 11) to the Slave Point Formation in the Bear Biltmore No. 1 well are between depths 1,682.5 and 1,688 feet.

The lower contact of the Slave Point Formation in the Athabasca-Clearwater Rivers area appears to be disconformable. Eastwards, towards the edge of the Canadian Shield, the Slave Point appears to overstep the erosional and depositional edge of the Prairie Evaporite Formation, to rest directly on dolomites of the Methy Formation (e.g., Weymarn No. 1 well; fig. 5). It should be pointed out, however, that an alternative interpretation, based on two new boreholes along the Clearwater River, has been presented recently by Hamilton (1969, figs. 3 and 4). He indicated that the Slave Point Formation is missing by erosion from the Weymarn No. 1 well. The upper contact is paraconformable with the basal beds of the Firebag Member of the Waterways Formation and is marked by a change in lithology and faunas which in places also appears to represent an erosional surface.

The thickness of the Slave Point Formation in the report area varies from 5.5 feet in the Bear Biltmore No. 1 well to 15 feet in the Bear Westmount No. 2 well. West and northwest of the report area the formation thickens considerably.

Macrofossils are exceedingly scarce in beds of the Slave Point Formation throughout its wide area of distribution. From these beds in the Bear Biltmore No. 1 well Crickmay (1957, pp. 10, 11) recorded the following fossils which he referred to as Zone U: *Atrypa* sp. aff. *A. independensis* Webster and *Ambothyris* sp. (= *Emanuella* sp.). By comparison with other sections, notably Gypsum Cliffs on the Peace River and Burnt Point on the northwest side of Great Slave Lake, Crickmay (1966, pp. 20-21) referred to this fauna as the *Emanuella* sp. S Zone, later renamed *Emanuella vernilis* (Crickmay, 1967, pp. 8-9). The latter is presumably equivalent to a form designated as *Emanuella* sp. C by Norris (1965, p. 78) that is present in Slave Point beds at Gypsum Cliffs on the Peace River and between Windy and Burnt Points on Great Slave Lake.

The ostracode faunas from the Slave Point Formation of the Lesser Slave Lake area have been described by McGill (1966), and commented on by Braun (1968). Conodonts from the Slave Point Formation of northeastern and central Alberta where sampled by Uyeno (in press) were meagre and undiagnostic.

Beds of the Slave Point Formation in the subsurface southwest of Great Slave Lake have been placed by Pedder (1972, pp. 696, 708) within the *Grypophyllum mackenziensis* coral zone which in turn occurs in the upper part of the *hermanni-cristatus* conodont zone. The latter zone in North America is taken as the highest Middle Devonian conodont zone, but in Germany some authors, notably Kullman and Ziegler (1970), claim that the upper part of the zone is better referred to the Upper Devonian on the basis of associated ammonites.

The age of the Slave Point Formation in the report area is considered to be late Givetian (late Middle Devonian). There is now wide agreement in placing the Middle-Upper Devonian boundary at the contact between the Slave Point Formation and overlying Waterways Formation (Norris, 1963; McGill, 1966; Uyeno, in press, and others).

It should be pointed out, however, that the boundary separating the Givetian from Frasnian in the type area of Belgium is still an unsettled problem. Bultynck (1972, p. 71) has indicated that the term Givetian has been used in Belgium in a more restricted sense than it was originally defined, so at least the Lower Frasnian ("Assise de Fromelennes") belongs to the Givetian in its original sense. Bultynck (1972, p. 71) reported also that the stratal subdivisions Gid and Fla are in the *Polygnathus varcus* Zone, and that *Spathognathodus insitus* Stauffer had been found recently in the higher part of Fla in the Lower *asymmetricus* Zone.

Upper Devonian

Waterways Formation

Warren (1933, p. 149) first applied the name Waterways Formation to the Devonian strata overlying an evaporitic sequence in the lower Athabasca River area. He gave a thickness of 405 feet for the formation, based on the log of a well (Alberta Government Salt Well No. 1) drilled at Fort McMurray, and pointed out that the upper boundary was an erosional surface. Subsequent wells drilled west of Fort McMurray indicated younger Devonian rocks unconformably underlying the Lower Cretaceous McMurray Formation. 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, p. 25). Crickmay (1957) subdivided the Waterways Formation into five members using the Bear Biltmore No. 1 well (7-11-87-17-W4; located about 48 miles west-southwest of Fort McMurray) as his standard for comparison with the incomplete outcrop succession on the Athabasca and Clearwater Rivers. In this well the Waterways Formation is defined as the sequence of shale and argillaceous limestone alternating with mainly limestone units lying between the top of the Slave Point Formation and the base of the Devonian Cooking Lake Formation of the Woodbend Group. In this type well, the Waterways Formation is 701.5 feet thick lying between depths of 981 to 1,682.5 feet. The lower contact is paraconformable with the Slave Point Formation and the upper contact with the Cooking Lake Formation appears to be transitional.

The name Beaverhill Lake Formation was proposed by the geological staff of Imperial Oil Limited (1950) for the sequence of shale and limestone between the Elk Point and Cooking Lake Formations in the subsurface of the Edmonton area of central Alberta. Subsequent drilling between the Edmonton area and the Devonian outcrop belt along the Canadian Shield in the vicinity of Waterways and Fort McMurray showed the Beaverhill Lake to be approximately equivalent to the Waterways Formation, a relationship clearly shown by Belyea (1952). The Committee on Slave Point and Beaverhill Lake Formations (1964) have extended the five subdivisions of the Waterways Formation as members of the Beaverhill Lake Formation into the subsurface of Alberta. Massive carbonate development within the Beaverhill Lake Formation of the Swan Hills area was named the Swan Hills Member by Fong (1960) and informally subdivided into lower dark brown and upper light brown units. Various workers, including Murray (1965, 1966), have shown that the lower dark brown unit is the approximate equivalent of the Slave Point Formation. In the Swan Hills area Leavitt and Fischbuch (1968) have raised the Beaverhill Lake to group status and included in it the Waterways, Swan Hills, and Fort Vermilion Formations.

North and west of the Athabasca-Clearwater Rivers area the Waterways Formation gradually becomes more shaly and is approximately equivalent to the lower half of the Hay River Formation as defined by Belyea and McLaren (1962) in the Great Slave Lake area (Braun, 1968, fig. 8).

The five members of the Waterways Formation erected by Crickmay (1957), and more completely described by Carrigy (1959) and Norris (1963), are as follows in ascending sequence: Firebag, Calmut (changed to Calumet by Carrigy, 1959; Norris, 1963), Christina, Moberly, and Mildred.

Firebag Member. The Firebag Member was defined by Crickmay (1957, p. 9) "...as the 170 feet more or less of shales and argillaceous limestones with *Lingula* cf. *spatulata* Vanuxem, *Atrypa* cf. *independensis* Webster, *Eleutherokomma impennis* Crickmay, *Cyrtina billingsi* Meek, etc." This member paraconformably overlies the Slave Point Formation and conformably underlies the Calumet Member.

The Firebag Member consists mainly of olive green calcareous shale with thin, more resistant sequences of olive green limestone, argillaceous limestone, and non-calcareous shale. A thin fragmental limestone is commonly present at the base.

Exposures of the Firebag Member are present in a belt about 11 miles wide along the Clearwater River between a point about one mile below Cascade Rapids to about five miles above the mouth of Cottonwood Creek (Fig. 4). Within this belt exposures are known also up and near the mouths of Edwin Creek and High Hill River. Only two closely spaced exposures of the Firebag Member are known on the Athabasca River. These occur on the east bank of the river about 64 miles downstream from the Waterway's wharf, and about 1.5 miles below the mouth of Eymundson Creek. Only one exposure of the member is known on Firebag River (Fig. 4), after which the member was named.

The thickness of the Firebag Member in the type well is 170.5 feet. Wells in the report area show a very slight decrease in thickness for the member from east to west and from north to south.

Macrofossils consisting mainly of brachiopods from outcrops of the Firebag Member are abundant, but species are relatively few (Norris, 1963, pp. 27-28). The more diagnostic elements consist of *Ladogioides pax* McLaren, *Platyerorhynchus russelli* (McLaren), *Tecnocyrtina billingsi* (Meek), a coarsely costate form of *Spinatrypa*, and *Eleutherokomma impennis* Crickmay. A closely similar brachiopod fauna is found also in the Peace Point Member of the Waterways Formation outcropping at Gypsum Cliffs on the Peace River. Crickmay (1966, pp. 20-21, 37-38) recognized two fossil zones within the Firebag Member in the report area, a lower *Atrypa independensis* Zone, and an upper *Eleutherokomma impennis* Zone.

Elements of this fauna have been found at scattered localities over a wide area of western and northwestern Canada (Johnson and Norris, 1972) including the basal beds of the Hay River Formation in the Great Slave Lake area, southern District of Mackenzie (Norris, 1965, pp. 83-85, 158-159); at the base of the Fairholme section in the Ancient Wall, Alberta (McLaren, 1954, p. 168); in the Flume Formation of Kakwa Lake, British Columbia (McLaren, 1962, p. 5); and elsewhere. An atrypid closely related to *Atrypa snyderensis* Greger of the Snyder Creek Shale of Missouri is abundant in some beds of the Firebag Member on the Clearwater River.

Calumet (Calmut) Member. In the type Bear Biltmore No. 1 well Crickmay (1957, p. 9) defined this member "...as the 102 feet more or less of resistant, fine-grained and clastic limestone with abundant *Stropheodonta costata* and a small *Eleutherokomma* close to *impennis,* sharply bounded above and below by shales."

About eight scattered outcrops of the Calumet Member are present along the Clearwater River extending from about 4.5 miles above Cottonwood Creek to about 2 miles above the mouth of the Christina River (Fig. 4). The outcrop belt along the Clearwater River measured perpendicular to strike is about 13 miles wide. Only one outcrop of the Calumet Member is known on the Athabasca River and it is located on the west bank of the river immediately below the mouth of Pierre River (Fig. 4), and 58 miles downstream from the Waterway's wharf.

The lithology of the Calumet Member consists mainly of grey to buff clastic limestone, variably argillaceous limestone, some olive green nodular calcareous shale, and minor non-calcareous shale. Both the lower and upper contacts of the Calumet Member are marked by a change from limestone to shale in most of the wells in the report area. The thickness of the Calumet Member is remarkably uniform throughout the area varying from a minimum of 88 feet in the Bear Westmount No. 1 well to a maximum of 102 feet in the Bear Biltmore No. 1 well.

Some of the exposed beds of the Calumet Member contain an abundant and varied brachiopod fauna. Whiteaves (1891a, p. 248), Warren and Stelck (1956), Crickmay (1957, 1966), Carrigy (1959), Norris (1963) and others have listed or illustrated fossils from Calumet beds. Brachiopods common in the Calumet Member include *Schizophoria* sp. cf. *S. lata* Stainbrook, *Stropheodonta* sp. cf. *S. costata* Owen, *Atrypa gigantea* Webster, and others. Other forms that are less abundant but were collected only from this member include *Tabulophyllum athabascensis* (Whiteaves), *Pachyphyllum* sp., *Spinocyrtia* sp. cf. *S. euryteines* (Owen), and *Ambocoelia* sp. The fauna of this member has been called the *Stropheodonta costata* Zone by Crickmay (1957, p. 11; 1966, p. 20).

Christina Member. Crickmay (1957, p. 9) defined the Christina Member "...as the 90 feet more or less of argillaceous limestone and shale, with small sized-forms of *Eleutherokomma,* lying between the limestone with *Allanaria allani* above, and the limestone with very numerous *Stropheodonta costata* below."

Outcrops showing thin sequences of this member are present between 1.5 and 3 miles up the Christina River (Fig. 4), where the member is unconformably overlain by the Lower Cretaceous McMurray Formation. In this area the Christina beds are locally folded with dips up to 16 degrees. The pre-Cretaceous erosion surface is nearly horizontal and truncates the Christina beds at several places along the river. Only one outcrop located on the east bank of Athabasca River opposite the north end of the Fort MacKay Settlement is questionably assigned to the Christina Member. There, the member is unconformably overlain also by the Lower Cretaceous McMurray Formation.

The lithology of the Christina Member consists mainly of greenish grey shale, grey argillaceous limestone, pale brown aphanitic limestone, and minor pale brown fragmental limestone. Sandstone and sandy limestone beds are present in the member in some of the exposures up the Christina River. This suggests a local uplift of Precambrian rocks in a nearby area shedding coarse clastics in Christina time.

Where complete, the thickness of the Christina Member varies from 76 feet in the Bear Rodeo No. 1 well to about 122 feet in the Bear Rodeo No. 2 well.

A revised list of fossils from the Christina Member in the type well given by Crickmay (1966, pp. 19-20) include the following: bryozoa, *Athabaschia* sp., *Lorangerella* sp., *Leiorhynchus* sp., *Atrypa* sp. cf. *A. clarkei* Warren, *Eleutherokomma jasperensis* (Warren), *E.* sp. cf. *E. aechmophora* Crickmay, *Nervostrophia* sp., *Productella* sp., *Schizophoria lata* Stainbrook, and *Cyrtina* sp. Crickmay (1966, p. 20) placed this fauna in the lower part of the *Eleutherokomma jasperensis* Zone. The earliest appearance in the Waterways Formation of the genus *Allanaria* is in the Christina Member.

Moberly Member. The Moberly Member was defined by Crickmay (1957, p. 8) "...as the dominantly clastic limestone, 200 feet more or less, lying between the *killeri* shale zone [above] and the argillaceous limestone and shales with the first small forms of *Eleutherokomma* [below]; ...." This member was named after Moberly Rapids on the Athabasca River, 1.5 miles upstream from the junction with the Clearwater River.

Beds of the Moberly Member outcrop along the Clearwater River at seven main localities between 6 to 13 miles (straight line distance) upstream from the mouth of the river. On the Athabasca River exposures of this member extend from Crooked Rapids, 24 miles (river distance) above the junction with the Clearwater, to 33.6 miles below the junction, or opposite the north edge of the Fort MacKay Settlement (Fig. 4). Outcrops of this member are present also along the lower stretches of some of the tributary streams of the Athabasca River, particularly on the MacKay and Muskeg Rivers.

The discontinuous outcrops of the Moberly Member along the Clearwater River (Plate 2) are thought to span roughly the lower half of the member, representing about 100 feet of section including covered intervals. About 120 feet of composite

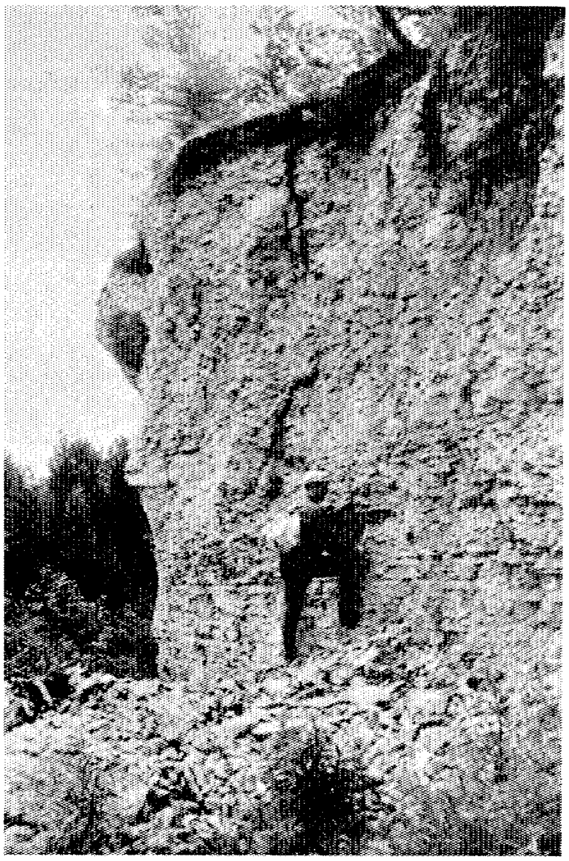

PLATE 2.

Close-up view of limestone beds of the Moberly Member of the Waterways Formation, south bank of the Clearwater River 2.5 miles below the junction with the Christina River.

section of the Moberly Member can be pieced together from the exposures along the Athabasca River. This latter sequence, although in part younger, appears to overlap approximately the upper 45 feet of the Clearwater River composite section.

The lithology of the Moberly Member in outcrops consists of an alternating succession of light olive green, rubbly, thinly-interbedded, variably argillaceous limestone and shales, and even, hard beds of pale brown, aphanitic, fragmental limestone. The member becomes more shaly towards the top, and shale content appears to increase also from south to north.

The top of the Moberly Member is an erosion surface throughout most of the Clearwater-Athabasca Rivers area, and therefore only a part of the member is represented. In this area it is unconformably overlain by the Lower Cretaceous McMurray Formation, with progressively younger beds overlapped from east to west. In the Bear Biltmore No. 1 well where the member is complete it is 200 feet thick.

Fossils are exceedingly abundant in most beds of the Moberly Member, and long lists of fossils collected from outcrops along the Clearwater and Athabasca Rivers are presented by Norris (1963, pp. 33-36).

Crickmay (1966, p. 19) listed the following fossils obtained from the lower 60 feet of the type section of the Moberly Member in the Bear Biltmore No. 1 well which he assigned to the upper part of the *Eleutherokomma jasperensis* Zone: *Allanaria minutilla* Crickmay, *Eleutherokomma* aff. *jasperensis* Warren, *Chonetes* sp. n., *Productella* sp., and others.

Fossils from the upper 140 feet of the member in the same well were assigned to the *Allanaria allani* Zone and include the following (Crickmay, 1966, p. 19): *Stromatopora* sp., *Idiostroma* sp., *Lorangerella* sp., *Atrypa clarkei* Warren, *Allanaria allani* (Warren), *Eleutherokomma hamiltoni* Crickmay, *Athyris occidentalis* Whiteaves, *Maclarenella maculosa* Stehli, and *Leptodesma* sp. cf. *L. jason* Hall.

It is mainly elements of the Moberly Member fauna, particularly those of the *Allanaria allani* Zone, that bear the closest resemblance to the sparse fauna of the Point Wilkins Member of the Souris River Formation outcropping in southeastern Manitoba (Norris and Uyeno, 1971).

Mildred Member. The Mildred Member was defined by Crickmay (1957, p. 8): "...as the 140 feet more or less of argillaceous limestones and shales with *Eleutherokomma killeri* that lie between the hard, fragmental limestones with *Cylindrophyllum*, *Atrypa* cf. *brandonensis* and *E. leducensis* and the uppermost fragmental limestones of the Moberly Member with *E. hamiltoni*." This uppermost member of the Waterways Formation occurs between the depths of 980 and 1,120 feet in the type Bear Biltmore No. 1 well. It was named after Mildred Lake, located about 28 miles north of the Waterway's wharf and a few miles west of the Moberly outcrops along Athabasca River.

The Mildred Member does not appear to outcrop in the Athabasca-Clearwater Rivers area. In the Bear Vampire No. 1 well located near Rock Rapids on Athabasca River about 20 miles west-southwest of Fort McMurray, the highest Paleozoic beds penetrated are part of the Moberly Member.

In the type well the member is 140 feet thick and consists of greenish grey calcareous shale, greenish grey argillaceous limestone, and some pale brown aphanitic, clastic limestone. It conformably overlies the Moberly Member and conformably underlies the Cooking Lake Formation.

Fossils listed by Crickmay (1966, p. 19) from the type section of this member include: *Orbiculoidea* sp., *Calvinaria* sp. cf. *C. variabilis athabascensis* (Kindle), *Eleutherokomma killeri* Crickmay, *Productella* sp., and *Schizophoria* sp. indet. These were assigned to the *Eleutherokomma killeri* Zone (Crickmay, 1966, p. 19).

Discussion of Fossils of Waterways Formation

The macrofossils in the Waterways Formation are exceedingly abundant comprising some stromatoporoids, a few corals, numerous pelecypods, some gastropods, a few cephalopods, abundant brachiopods, some bryozoans, a few crinoids, a few ostracodes, and traces of fish remains. The stromatoporoids which occur mainly in the Moberly Member have been described by Stearn (1961b, 1962). The few known corals in the Waterways Formation are from the Calumet Member (Whiteaves, 1891, pp. 202, 248, pl. 32, figs. 1, 1a, 1b; Belyea and McLaren, 1957). Some of the pelecypods, gastropods and cephalopods have been illustrated by Warren and Stelck (1956). Many of the numerous Waterways brachiopods have been illustrated or described by Meek (1867), Whiteaves (1891), Warren (1944), Stehli (1955), Warren and Stelck (1956), Crickmay (1950, 1953, 1963, 1967), McLaren (1962), Johnson and Norris (1972), and others. Astrova (1972) recently described a new bryozoan species collected from the Moberly Member of the Waterways Formation outcropping along the Athabasca River below Fort McMurray.

Some of the brachiopods of the Waterways Formation are closely comparable to forms in the Snyder Creek Shale of Missouri, a resemblance that was first pointed out by Warren (1933, p. 149), and confirmed by Norris (1963) and others. On the basis of this fauna the Waterways was dated as early Frasnian (early Upper Devonian).

Some of the microfaunas of the Waterways Formation were studied by Loranger (1963, 1965a) including Ostracoda, Annelida, Charophyta, Foraminifera, Branchiopoda, and Conodontophorida. McGill (1963) dated an ostracode fauna from the Waterways Formation in the Bear Biltmore No. 1 well. Uyeno (1967, in press) has recently completed a detailed study of the conodonts of the Waterways Formation of northeastern and central Alberta.

In terms of conodont zonation in North America Uyeno (in press) indicated that the *Spathognathodus insitus* fauna occurs in the Firebag and basal part of the Calumet Members, the Lower *Polygnathus asymmetricus* Zone is present in the Calumet and basal Christina Members, and the Middle *P. asymmetricus* Zone occurs in the upper part of the Christina through Moberly Members. Pollock (1968) indicated that the Mildred Member may be assigned also to the Middle *P. asymmetricus* Zone.

Comparison with the conodont-ammonoid zonation in the Rhenish Schiefergebirge of West Germany (Ziegler, 1962b, 1971) suggests that the Waterways Formation correlates with the Lowermost(?), Lower, and Middle *P. asymmetricus* Zones. These conodont zones occur in the lowest part of the *Manticoceras* Stufe (*do*Iα) (Uyeno, in press).

Woodbend Group

In the Bear Biltmore No. 1 well drilled in Tp. 87, R. 17, near the Athabasca River and about 50 miles west southwest of Fort McMurray, a sequence of 527 feet of strata conformably overlying the Mildred Member of the Waterways Formation and unconformably underlying Lower Cretaceous strata have been referred to the Woodbend Group (Belyea, 1952; Carrigy, 1959). In this well this interval has been subdivided into three formations; the Cooking Lake, Ireton, and Grosmont (Belyea, 1952, 1955). Crickmay (1966, p. 18) recognized a fourth formation, the Duvernay equivalent, lying between the Cooking Lake and Ireton Formations. Because none of these formations outcrop in the Athabasca-Clearwater Rivers area, being confined to the subsurface of the western edge of the area (Fig. 11), only a brief description of each is given below.

Cooking Lake Formation

The Cooking Lake Formation consists of 148 feet of pale brown, fine-grained calcarenitic limestone, in part dolomitic and argillaceous, lying between depths of 839 and 987 feet in the Bear Biltmore No. 1 well. Fossils identified by Crickmay (1966, p. 18) from an interval between 880 and 980 feet depths comprise: stromatoporoids, *Spongophyllum* sp. aff. *S. imperfectum* Smith, *Alveolites* sp. cf. *A. rockfordensis* H. and W., bryozoa, *Leiorhynchus* sp., *Atrypa* sp. cf. *A. brandonensis* Stainbrook, *Eleutherokomma* sp. cf. *E. killeri* Crickmay, *Douvillina* sp., *Schizophoria* sp. cf. *S. lata* Stainbrook, ostracodes, and *Trochiliscus* sp. This interval was assigned by Crickmay (1966, p. 19) to the *Warrenella catacosma* Zone.

Ireton Formation

Belyea (1952) assigned the interval between depths of 505 and 850 feet in the Bear Biltmore No. 1 well to the Ireton Formation. It consists of argillaceous and pelletoidal limestone, medium- to coarse-grained limestone, and greenish grey calcareous shale.

Crickmay (1966, p. 18) from approximately the same interval (510 to 880 feet depths) identified numerous brachiopods and other fossils which he subdivided into three zones in ascending sequence as follows: the *Eleutherokomma leducensis* Zone (780 to 880 feet), the *Eleutherokomma reidfordi* Zone (638 to 780 feet), and the *Atrypa cosmeta* Zone (510 to 638 feet). Ostracodes from the upper 150 feet of the Ireton Formation in this well were described by Loranger (1954a).

Grosmont Formation

An erosional remnant of a reef consisting of dolomitic limestone with scattered fossil fragments between depths of 460 and 505 feet in the Bear

Biltmore No. 1 well was assigned to the Grosmont Formation by Belyea (1952). It is unconformably overlain by the Lower Cretaceous McMurray Formation. The nearest outcrops of the Grosmont Formation are those immediately above Vermilion Chutes on the Peace River (Norris, 1963, pp. 73-74), about 170 miles northwest of Fort McMurray.

Fossils identified by Crickmay (1966, pp. 17-18) from Grosmont beds in the Bear Biltmore No. 1 well were assigned to the *Cyrtospirifer thalattodoxa* Zone of late Frasnian age and comprise: *Trupestostroma* sp., *Metriophyllum* sp., *Thamnopora* sp., *Atrypa* sp. cf. *A. devoniana* Webster, *Cyrtospirifer* sp. cf. *C. thalattodoxa* Crickmay, *Nervostrophia* sp., and *Schizophoria* sp.

STRUCTURAL GEOLOGY

The present westerly slope of the Precambrian basement between the outcrop edge of the Canadian Shield at Contact Rapids on the Clearwater River and the Bear Rodeo No. 1 well at the junction of the Clearwater and Athabasca Rivers is about 20 feet per mile (Fig. 9). The regional structure of the overlying Paleozoic rocks of the Athabasca-Clearwater Rivers area is a southwest-dipping monocline with the strike trending north-northwest (Fig. 10). In detail this monocline has been modified by anticlines, synclines, terraces, and possibly some faulting.

The outcrops of the Methy Formation along the Clearwater River, particularly those between Whitemud Falls and Cascade Rapids, show many minor flexures with dips up to 15 degrees, but more commonly the dips are about 5 degrees. These are presumably initial dips in the flanking beds on the margins of irregular scattered reefal buildups.

Immediately west of the most westerly Methy outcrops, Sproule (1932a, pp. 14-15) has suggested a fault. The break is not exposed but it apparently crosses the Clearwater River somewhere between Edwin Creek and High Hill River, possibly just below the Weymarn No. 1 well (Fig. 4). Kidd (1951, p. 37) presented evidence to suggest that the downthrown side is to the west and that the movement took place in post Lower Cretaceous Clearwater Formation time. The trend of the fault trace judging from aeromagnetic data is about N 35° W (Norris, 1963, p. 40; Carrigy, 1959, p. 31, fig. 5).

Along the banks of the Clearwater and Athabasca Rivers there are numerous flexures in beds of the Waterways Formation showing small basins and domes. The amplitude of these small structures are of the order of 50 to 100 feet and wave lengths of several hundred feet up to about one mile. Hume (1947, p. 310) suggested that these local domes and basins were due to volume changes accompanying the hydration of some of the anhydrite in the Prairie Evaporite Formation. No doubt some of the structures are due also to differential solution of water-soluble evaporites and subsequent differential subsidence.

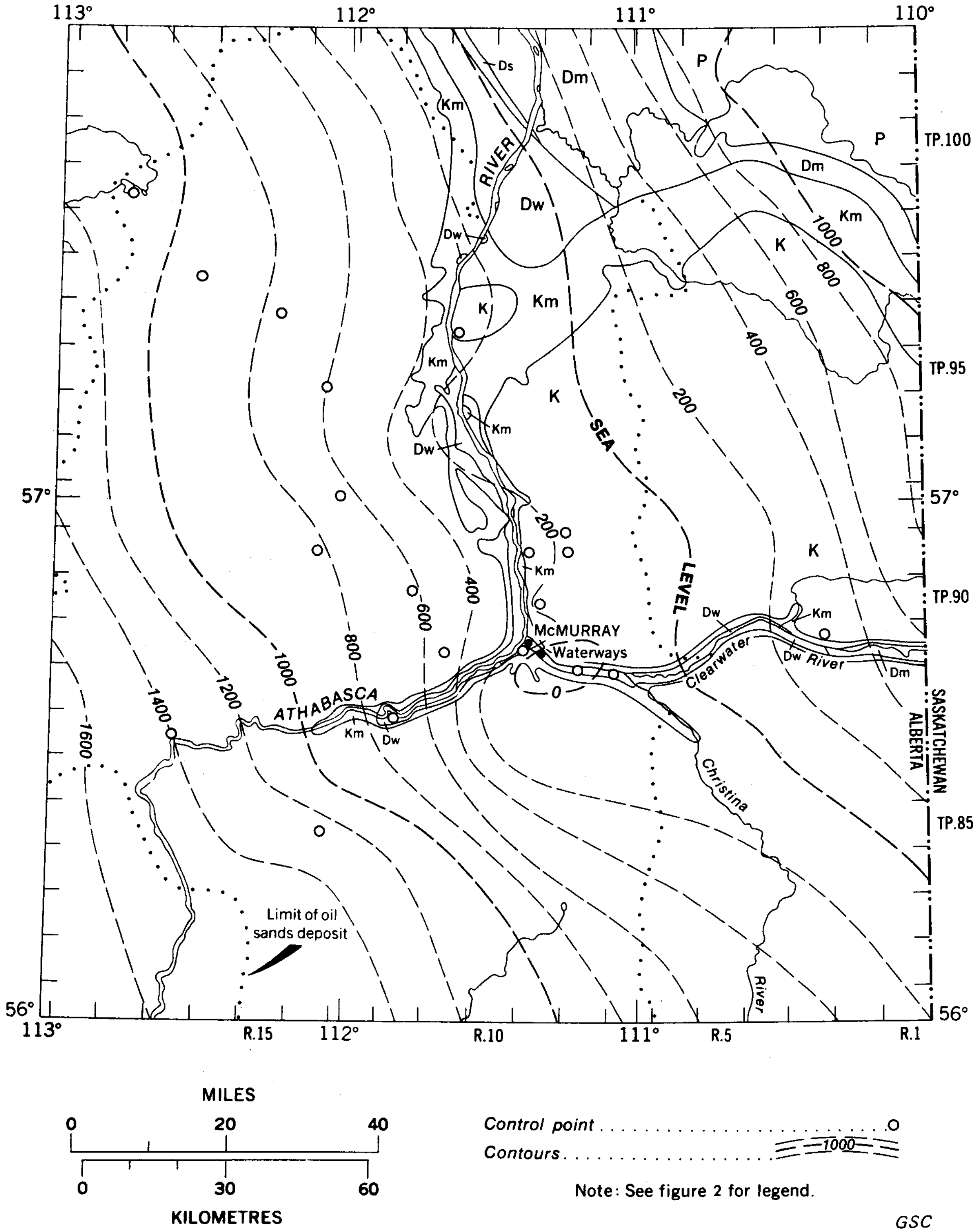

FIGURE 9. Structure contours on Precambrian surface (from Carrigy, 1959, fig. 4).

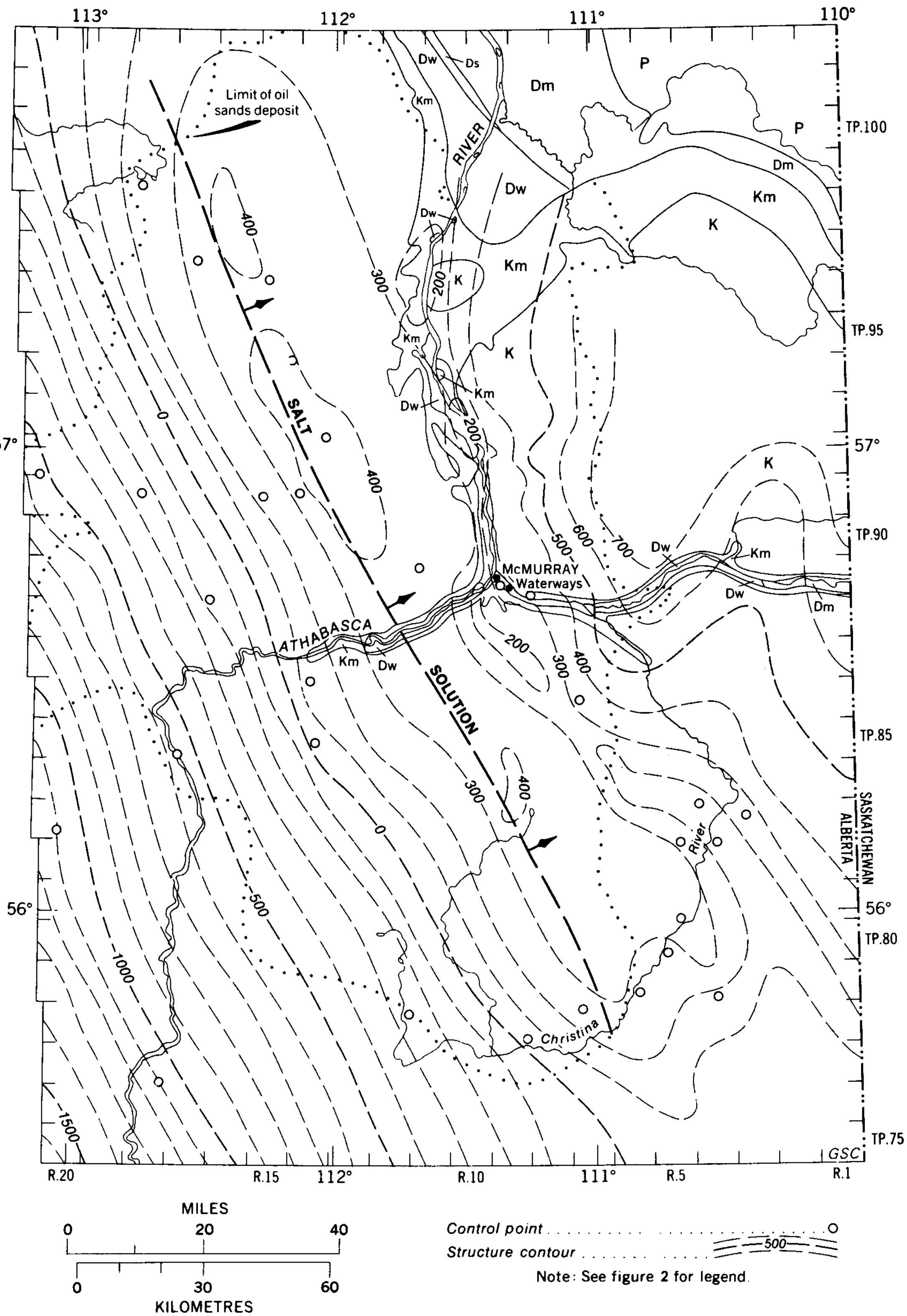

FIGURE 10. Structure contours on the upper surface of the Elk Point Evaporites (from Carrigy, 1959, fig. 5).

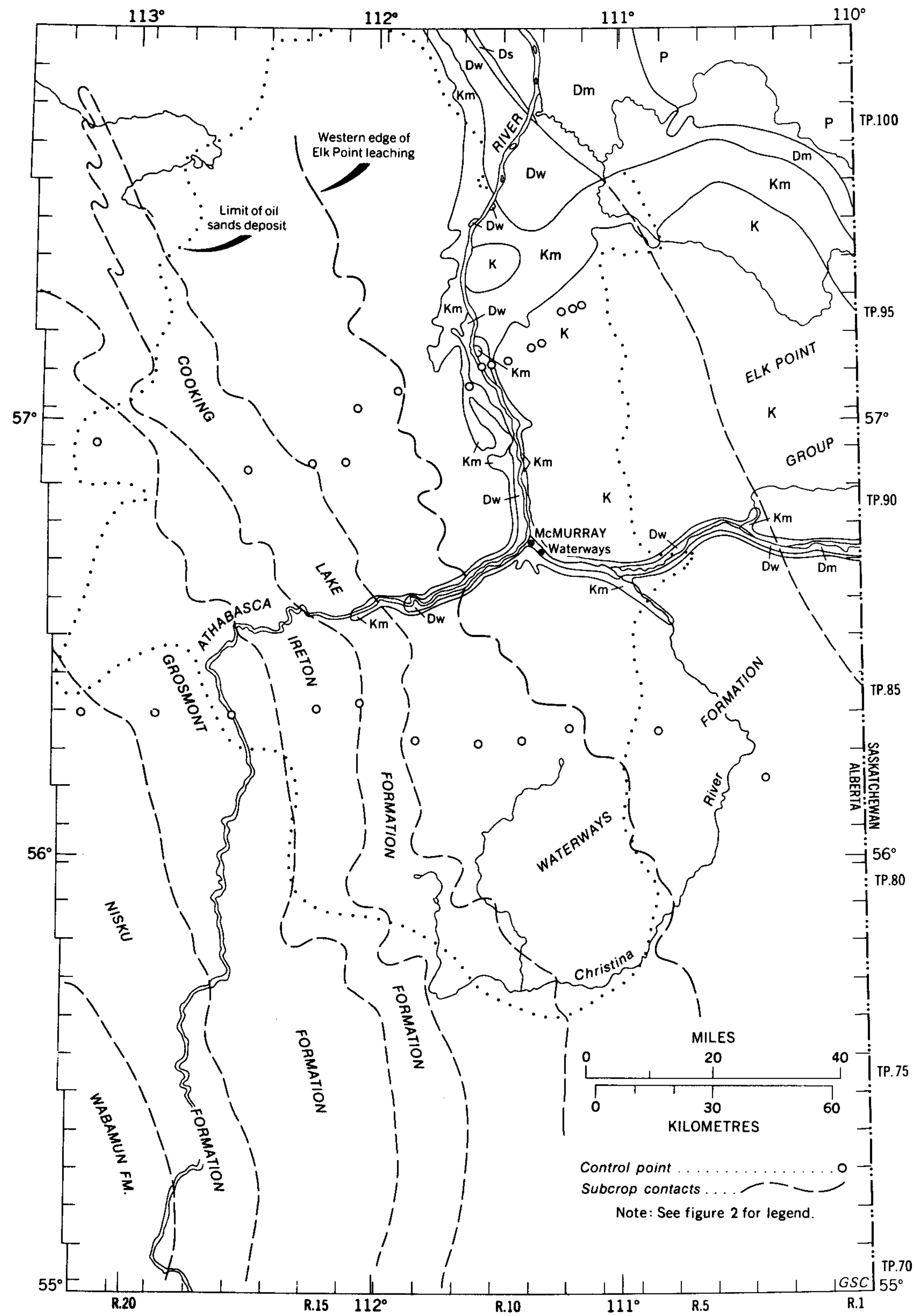

FIGURE 11. Distribution of Paleozoic formations at the pre-Cretaceous unconformity (from Stewart, 1963, fig. 4).

The unconformity separating the Devonian from the overlying Lower Cretaceous McMurray Formation can be seen at numerous localities along the Clearwater and Athabasca Rivers and in the numerous bore holes in the area. During the long time interval separating Devonian from Lower Cretaceous strata the area was probably subjected to several periods of subaerial erosion. On a regional scale it is readily apparent that westward tilting of about 15 feet per mile took place prior to deposition of Cretaceous beds, as indicated by the overlap of younger Devonian beds westward. Post-Cretaceous tilting was about 5 to 7 feet per mile throughout most of the report area according to Martin and Jamin (1963, p. 35). Hume (1949, p. 10), on the basis of closely spaced drilling in the Mildred-Ruth Lakes area, has suggested possible post-Cretaceous folding in that area.

From cross sections (Fig. 6 and Martin and Jamin, 1963, p. 39, fig. 3) it is evident that 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 wide, immediately west of where the evaporite beds intersect the surface. Most of the resulting subsidence presumably took place in pre-Cretaceous times, but the process is continuing to the present day as indicated by salt springs in the area. Carrigy (1959, p. 33) has mentioned solution and collapse structures in the Devonian within the subsided belt.

A contour map of the present buried Devonian surface of the oil sands area (Fig. 12) compiled by Martin and Jamin (1963, p. 37, fig. 2) shows a very uneven surface of considerable relief and with some slopes as steep as 360 feet per mile. A comparison of figure 12 with figure 11 shows that many of the ridges trend north-northwest and correspond to the strike of the erosion-resistant carbonates of the Grosmont, Cooking Lake, and Waterways Formations. Solution of salt from the Prairie Evaporite Formation and the resulting collapse of the overlying Waterways Formation has produced a highly irregular topography which includes two major closed depressions, one in the vicinity of Bitumount and the other immediately south of Fort McMurray. Two main systems of valleys (Fig. 12) draining the area northward and southward are shown also by Martin and Jamin (1963) in the northwestern part of the area.

EVIDENCE OF OIL IN PALEOZOIC ROCKS OF THE AREA

North of the report area a tarry residue has been reported by Craig *et al.* (1967, p. 133) in brecciated limestone beds referred to the Hay Camp Formation by Norris (1963, 1965) that outcrop on the west bank of Slave River opposite La Butte about 24 miles south of Fitzgerald. These rocks are of early Middle Devonian (Eifelian) age (Fig. 3) and contain the earliest traces of oil near the report area.

Some oil staining has been noted in dolomite rocks of the Methy Formation of late Middle Devonian age both in outcrops and in the subsurface. In outcrops

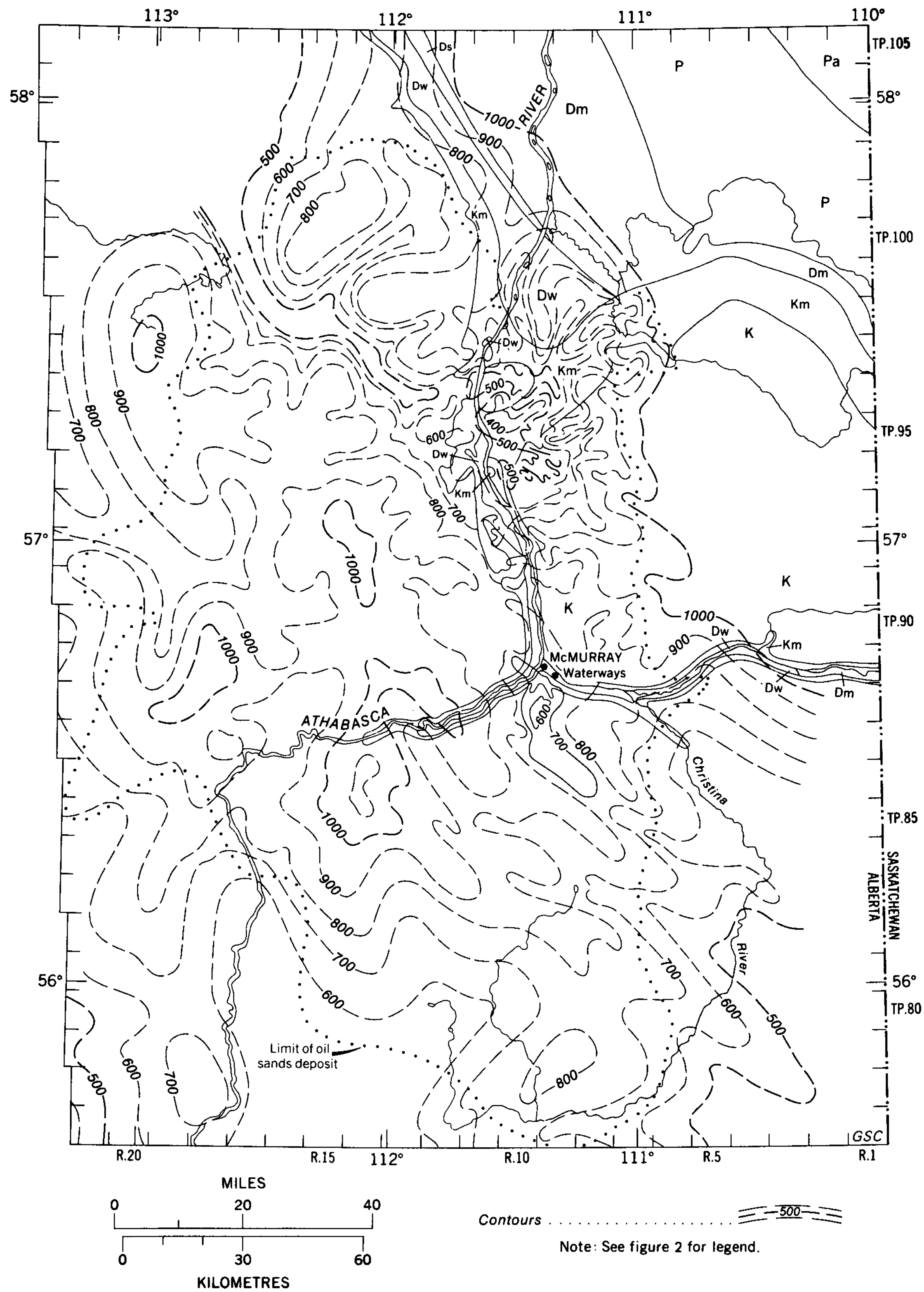

FIGURE 12. Structure contours on the erosional surface of Devonian rocks in northeastern Alberta (from Martin and Jamin, 1963, p. 37, fig. 2).

it has been observed in the vicinity of Cascade Rapids on the Clearwater River. In the subsurface it has been recorded in the western part of the report area in the Bear Biltmore No. 1, Bear Vampire No. 1, Bear Rodeo No. 1 (Fig. 5) and in the Bear Westmount No. 1 wells (Fig. 7). The Methy Formation is approximately the same age as the oil-productive Keg River Formation in the Rainbow Lake area of northwestern Alberta.

Light oil staining is relatively common in some limestone beds of the Moberly Member of the Waterways Formation of early Upper Devonian age outcropping along the Athabasca River. Where seen in outcrops one is never sure that the oil staining is not the result of contamination from the overlying oil-saturated sands of the McMurray Formation of Lower Cretaceous age. In the subsurface, oil staining has been recorded in this member in the Bear Biltmore No. 1 and Bear Vampire No. 1 wells (Fig. 5), where there is less chance of the beds being contaminated from above and the evidence is more convincing that the oil staining is in place.

Dark tar-like oil has been recorded in dolomitic limestone beds of the Grosmont Formation of late early Upper Devonian age in the Bear Biltmore No. 1 well (Fig. 5). The same type of heavy oil has been noted by the writer and others in the coarsely vuggy dolomite beds of the Grosmont Formation outcropping immediately above Vermilion Rapids and Chutes on the Peace River in northern Alberta.

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APPENDIX

MEASURED SECTIONS FROM SELECTED OUTCROPS

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Moberly Rapids section

An outcrop of beds of the Waterways Formation exposed along the water's edge and in a steep cliff on the north bank of the Athabasca River at the upper end of Moberly Rapids. It can be reached by following a narrow winding trail along the lower part of the bank of the river which intersects the road to Fort MacKay at the west end of the bridge crossing the Athabasca River at Fort McMurray.

Unit	Description	Thickness (feet) Unit	From Base
	LOWER CRETACEOUS		
	McMurray Formation		
1	Oil sands exposed at the top of the bank unconformably overlying beds of the Waterways Formation.	ca.3 exposed	3
	UPPER DEVONIAN		
	Waterways Formation		
	Moberly Member		
7	Limestone, slightly argillaceous, pale cream and brown, very fine grained to aphanitic, thin rubbly bedded, less resistant than unit below, appears to be unfossiliferous.	1.5 exposed	19.4
	Unit 7 is exposed near top of a nearly vertical cliff where it is almost inaccessible.		
	Bedding 095T/4N on east side of cliff.		
6	Limestone, light brown with pale yellowish brown mottling, fine grained, massive, highly resistant, cliff-forming, markings suggestive of burrowings, almost inaccessible near top of cliff.	3.2	17.9
5	Shale, light greenish grey, with small nodular argillaceous limestone fragments about 1 inch in diameter, pale cream brown, moderately resistant, appears to be unfossiliferous.	5.6	14.7
4	Limestone, pale brownish grey, very fine grained, granular, a single massive bed, resistant, weathers		

	cream brown and pale orange, some sparry calcite, contains poorly preserved macerated brachiopod remains, some oil staining evident. Fossils: *Atrypa clarkei* Warren, *Athyris occidentalis* Whiteaves, and other brachiopods.	1	9.1
3	Shale, calcareous, greenish grey, recessive, orange ochre on some fractured surfaces, weathers pale orange, appears to be unfossiliferous.	1.3	8.1
2	Limestone, argillaceous, light greenish grey, brecciated, rubbly bedded, less resistant than unit below, weathers light greenish grey with a pale orange cast, no megafossils seen.	0.8	6.8
1	Limestone, cream coloured, fine grained, granular, massive, resistant, beds up to 4 feet thick, weathers light cream brown, oil staining in the upper 1 foot, contains widely scattered bulbous stromatoporoids, and numerous other macerated organic fragments. Fossils: stromatoporoids, gastropods, *Atrypa clarkei* Warren, *Allanaria* sp., *Athyris occidentalis* Whiteaves, and *Maclarenella maculosa* Stehli.	6.0	6.0

Measured from river level up starting about 100 feet east of cliff at upper end of Moberly Rapids and working westward to cliff.

Conn Creek section

An outcrop of the Waterways Formation on the east side of road connecting Fort McMurray with Fort MacKay. The beds are exposed on the banks of Conn Creek emptying into the Athabasca River 1.2 miles north of the west end of the bridge at Fort McMurray. The beds were measured from creek level up, immediately east of a large culvert.

Unit	Description	Thickness (feet) Unit	From Base
	UPPER DEVONIAN Waterways Formation Moberly Member		
5	Limestone, light grey, aphanitic, massive, highly resistant, weathers pale orange and light cream grey, contains a few brachiopods including *Atrypa* sp., *Athyris* sp., and *Eleutherokomma* sp.	1.3	14.1
	Unit 5 is overlain by about 6 feet of glacial debris and soil at the top of the bank.		
4	Shale, calcareous, greenish grey, with small nodular fragments of light grey aphanitic limestone within it, recessive, weathers light greenish grey, sparse *Atrypa clarkei* Warren noted.	0.5	12.8
3	Limestone, slightly argillaceous, light cream grey and greenish grey, very fine grained, forming a lower resistant bed 5 inches thick; a middle recessive bed, 2 inches thick, consisting of argillaceous fragmental limestone; and an upper resistant bed, 3 inches thick, consisting of fragmental argillaceous limestone containing some bituminous material. Sparse fossils from upper bed.	ca.0.8	12.3
2	Shale, light greenish grey, with nodular fragments between 0.5 inch and 1.5 inches in diameter of light cream grey argillaceous limestone stained pale orange, some limestone fragments contain bituminous material, thin rubbly bedded, fairly resistant but less so than unit below, appears to be unfossiliferous.	8.5	11.5
1	Limestone, coarsely fragmental, light grey, very fine grained, irregular fragments are surrounded by argillaceous limestone, massive, highly resistant, contains a few fossils including pelecypods, echinoderm ossicles, *Devonoproductus?* sp., *Athyris* sp. and *Eleutherokomma* sp.	3	3

Outcrop at road log mile 20.6

Bedding surface outcrop of the Waterways Formation exposed in a pit excavated for gravel on the east side of the road connecting Fort McMurray and Fort MacKay, 9.9 miles north of the west end of the bridge crossing the Athabasca River at Fort McMurray.

Unit	Description	Thickness (feet) Unit	From Base
	UPPER DEVONIAN Waterways Formation Moberly Member		
1	Limestone, and argillaceous limestone, 'fragmental,' light cream grey with pale orange mottling, very fine grained, thin rubbly bedded, contains numerous fossils including gastropods, cephalopods, *Schizophoria* sp., *Atrypa* sp., *Eleutherokomma* sp., *Lorangerella phaulomorpha* Crickmay, and others. Bedding 015T/3E taken in the northeast part of pit cleared of loose rock debris.		

Road cut at road log mile 22.0

An outcrop of beds of the Waterways Formation exposed in a road cut on the west side of the road connecting Fort McMurray with Fort MacKay. Road cut is 11.3 miles north of the west end of the bridge crossing the Athabasca River at Fort McMurray.

Unit	Description	Thickness (feet) Unit	Thickness (feet) From Base
	UPPER DEVONIAN		
	Waterways Formation		
	Moberly Member		
5	Limestone, light grey, calcirudite, thin irregularly bedded, beds between 1 inch and 3 inches thick, stained a rusty orange, unit poorly exposed, only an occasional bed showing through slumped soil from above. Fossils present include *Atrypa clarkei* Warren, and a small *Allanaria* sp.	1.6	14.3
4	Limestone, calcilutite, light grey, aphanitic, thin irregularly bedded, weathers light grey, with considerable pale orange staining; only the lower 0.7 feet is well exposed and resistant; contains *Atrypa clarkei* Warren.	3	12.7
3	Shale, greenish grey, with a few scattered argillaceous limestone nodular beds, weathers pale orange, poorly exposed and recessive. Fossils: *Atrypa clarkei* Warren and *Emanuella?* sp. collected loose and presumably derived from a limestone unit above.	1.6	9.7
2	Limestone, argillaceous, and interbedded calcareous shale, fine grained, thin rubbly bedded, beds between 0.5 inch and 3 inches thick, much more resistant than unit below; in detail unit is composed of three hard argillaceous limestone beds, 4, 2 and 3 inches thick respectively, separated by thin calcareous shale beds; some oil staining in the basal limestone bed. Fossils: *Atrypa gregeri* Rowley collected loose in upper part of unit, and from base of unit.	1.9	8.1
1	Shale, calcareous, greenish grey, with irregular greenish grey nodules of argillaceous limestone, thin rubbly bedded, recessive and poorly exposed, contains echinoderm ossicles, *Devonoproductus* sp., *Emanuella* sp., *Allanaria* sp. and *Lorangerella sulciplicata* Crickmay.	6.2	6.2
	Measured from bottom of ditch.		

Syncrude pilot plant, outcrop no. 1

About 22 feet of beds of the Moberly Member of the Waterways Formation are exposed in a small knoll immediately south of road and office and workshop buildings of the Syncrude pilot plant. An elongate pond of water separates the knoll from the west bank of the Athabasca River where oil sands of the McMurray Formation are well exposed. Access road leading into the Syncrude pilot plant is 24.2 miles by road north of the west end of the bridge crossing the Athabasca River at Fort McMurray.

Unit	Description	Thickness (feet) Unit	Thickness (feet) From Base
	UPPER DEVONIAN		
	Waterways Formation		
	Moberly Member		
7	Limestone, light to medium brown, fine grained, massive, highly resistant, cliff-forming, weathers a pale cream orange, contains sparse echinoderm ossicles and scattered brachiopods; markings suggestive of burrowings evident on north face of cliff particularly in the upper 3 to 4 feet of the unit; on weathered surface brecciated fragments appear to be present in unit. Fossils: indeterminable brachiopods.	6.5	22
	Bedding 040T/6SE taken at west end of outcrop.		
	Unit 7 forms the capping rock of the knoll.		
6	Shale, calcareous, nodular, light greenish grey, recessive, weathers a medium orange, a layer of brownish grey clay with brown bituminous material 0.25 to 0.5 inch thick about 4 inches from top of unit.	1.7	15.5
5	Limestone, argillaceous, light greenish grey, rubbly bedded, fairly resistant, weathers pale orange, contains a minor amount of bituminous material.	0.5	13.8
	Sparse fossils present include: *Atrypa* sp. -- medium costate, *Maclarenella maculosa* Stehli, and *Athyris* sp.		
4	Shale, with small calcareous shale nodules, dark orange, recessive, weathers medium orange, only upper 2 feet well exposed, contains sparse *Maclarenella maculosa* Stehli.	3.5	13.3

3	Limestone, with minor dark bituminous material, light grey, massive, highly resistant, weathers a mottled pale orange and cream colour, appears brecciated, highly fractured, contains markings suggestive of burrowings. Fossils: very poorly preserved macerated brachiopod fragments including *Atrypa* sp. and *Athyris occidentalis* Whiteaves, also a few echinoderm ossicles.	3.6	9.8
2	Shale, calcareous, light greenish grey, with thin nodules of argillaceous limestone, pale orange, recessive, weathers pale orange; a conspicuous resistant limestone bed 4 inches thick is present 8 inches from top of unit; most of unit is very poorly exposed.	3.4	6.2
	Sparse fossils include pelecypods, *Atrypa* spp. -- fine and medium costate forms, and *Maclarenella maculosa* Stehli.		
1	Covered from water level of small pond to base of unit 2.	2.8	2.8

Syncrude pilot plant, outcrop no. 2

Beds of the Waterways Formation outcropping in a small knoll on east side of road and opposite three fuel storage tanks in Syncrude pilot plant area, about 200 yards north-northeast of Syncrude pilot plant, outcrop no. 1.

Unit	Description	Thickness (feet) Unit	From Base
	UPPER DEVONIAN		
	Waterways Formation		
	Moberly Member		
3	Limestone, light grey, with dusky red mottling, massive, highly resistant, irregular parting planes spaced 6 to 8 inches apart, weathers pale yellowish orange; contains highly macerated organic fragments including *Schizophoria* sp.	4.2	12.7
	Bedding 045/11SE taken on top of a small knoll near a radio aerial mast.		
2	Shale, with argillaceous limestone nodules, light greenish grey, recessive, weathers pale orange; unit is very poorly exposed except for upper 2 feet where there is considerable rusty brown staining.	4.5	8.5
1	Limestone, pale brown, fine grained, granular, massive, highly resistant, weathers light orange brown with some darker orange staining and mottling; contains highly macerated organic remains including *Athyris occidentalis* Whiteaves.	4.0	4.0

Syncrude pilot plant, outcrop no. 3

A small outcrop of beds of the Waterways Formation on the north side of a small knoll at Syncrude pilot plant garbage incinerator on south side of road leading eastward to a water pump house on the west bank of Athabasca River.

Unit	Description	Thickness (feet) Unit	From Base
	UPPER DEVONIAN		
	Waterways Formation		
	Moberly Member		
3	Covered to top of knoll which appears to be underlain and capped by resistant limestone beds similar to those seen at Syncrude pilot plant, outcrop no. 2.	6	12.9
2	Loose rubble of limestone, light grey, fine grained, weathers light cream grey, some fragments with pale orange mottling, fossils collected from rubble include pelecypods, *Schizophoria* sp., *Athyris occidentalis* Whiteaves, *Atrypa gregeri* Rowley, and *Cyrtina* sp.	ca.2	6.9
1	Shale, with thin argillaceous limestone nodules and lenses, light greenish grey, recessive, weathers pale orange; contains numerous *Lorangerella* sp. cf. *L. sulciplicata* Crickmay and sparse *Productella* sp. in upper 2 feet of unit. Bedding 145T/6SW.	4.9	4.9

Fort MacKay section

About 41 feet of beds of the Moberly Member of the Waterways Formation of early Upper Devonian age are exposed above river level in a broad gentle anticlinal fold extending from the north edge of Fort MacKay Settlement northward for about 0.6 mile along the west bank of Athabasca River. On the south flank of the anticline the basal beds of the Lower Cretaceous McMurray Formation can be seen unconformably overlying the Waterways Formation. A brine spring emanating from an old drill hole is present on the river bank at the downstream end of the outcrop on the north flank of the anticline. The north edge of Fort MacKay Settlement is 39.4 miles north by road of the west end of the bridge crossing the Athabasca River at Fort McMurray.

Unit	Description	Thickness (feet) Unit	Thickness (feet) From Base
	LOWER CRETACEOUS		
	McMurray Formation		
	'Basal beds'		
2	Sandstone, conglomeratic, quartzose, well indurated, dark dusky red, highly ferruginous cement, massive, irregular bed, fairly resistant, contains conspicuous angular quartz fragments up to about 0.25 inch in diameter, weathers dark dusky red.	1.3	3.4
	Overlying beds of the McMurray Formation not measured.		
1	Covered; talus consists of clay, sandy and silty, mixed with soil from above, interval weathers a dark dusky red.	2.1	2.1
	Material of unit 1 probably derived in large part from the weathering and reworking of beds of the early Upper Devonian Waterways Formation.		
	UPPER DEVONIAN		
	Waterways Formation		
	Moberly Member		
16	Limestone, argillaceous, aphanitic, light greenish grey, thin rubbly bedded, weathers light greenish grey with some pale orange and red staining. Fossils present include *Schizophoria* sp., *Devonoproductus* sp., *Atrypa clarkei* Warren, and *Eleutherokomma hamiltoni* Crickmay.	3.2	40.8

Enlarged joint fissures within unit 16 have been infilled with sand to produce brown ferruginous sandstone dykes. The fissures were presumably enlarged and filled during the long interval separating the Upper Devonian Waterways Formation and Lower Cretaceous McMurray Formation. Orientation of two prominent dykes: 335T/80NE and 090T/81S.

15	Limestone, fine grained, light brown, thin rubbly bedded, fairly resistant, weathers light greenish grey, with dark and pale orange staining, most of the beds contain numerous brachiopods including *Devonoproductus* sp., *Atrypa gregeri* Rowley, and *Eleutherokomma hamiltoni* Crickmay.	2.6	37.6
14	Limestone, pale greenish grey, medium evenly bedded, fairly resistant, weathers light greenish grey, contains macerated brachiopod fragments including *Atrypa gregeri* Rowley and *Eleutherokomma hamiltoni* Crickmay.	0.6	35.1
13	Limestone, argillaceous, light greenish grey, thin rubbly and nodular bedded, beds separated by light greenish grey shale partings, recessive, fossils present include *Schizophoria* sp., *Atrypa* sp. -- medium costate, and *Eleutherokomma hamiltoni* Crickmay.	1.2	34.5
12	Limestone, light greenish grey, fine grained, an even resistant bed, coated with a medium to dark orange stain, numerous macerated brachiopod remains. Fossils: *Atrypa* sp. -- coarsely costate form in upper part of unit, and *Eleutherokomma* sp. and some pelecypods.	0.7	33.3
11	Limestone, medium grey, fine grained, irregularly thin bedded, beds 1 inch to 2 inches thick, separated by shale partings, weathers a light greenish grey; some beds contain fairly numerous brachiopods including: *Eleutherokomma* sp., *Lorangerella* sp., and some bryozoa.	3.5	32.6
10	Limestone, light brownish grey, fine grained, irregularly thin bedded, beds 1.5 to 4 inches thick, argillaceous partings between beds, some pale orange mottling, a fairly resistant unit. Fossils present include: echinoderm ossicles, gastropods, and *Atrypa devoniana* Webster.	7.5	29.1

9	Limestone, light grey, aphanitic, irregularly thin to medium bedded, beds 1 inch to 4 inches thick, weathers light greenish grey, fossils numerous along some bedding surfaces, consisting mainly of *Atrypa* sp., a small form of *Allanaria* sp., and some gastropods.	0.9	21.6
8	Mainly covered; about 6 inches of shale, nodular, pale green, exposed at top of interval.	1.2	20.7
7	Limestone, argillaceous, greenish grey, nodular thin beds, 1 inch to 2 inches thick, separated by shale partings, weathers greenish grey, contains echinoderm ossicles, pelecypods, *Atrypa* sp., *Eleutherokomma* sp., and *Lorangerella phaulomorpha* Crickmay.	4.8	19.5
6	Limestone, light grey, aphanitic, nodular, weathers light grey, a highly resistant unit, sharp contact with overlying unit; fossils present in upper part of unit include *Atrypa* sp., and *Lorangerella* sp. cf. *L. phaulomorpha* Crickmay.	1.9	14.7
5	Limestone, argillaceous and silty, light greenish grey, very fine grained, a hard resistant bed, weathers light greenish grey, contains sparry calcite, and markings suggestive of worm burrows.	1.1	12.8
4	Covered.	2	11.7
3	Limestone, medium brown, calcirudite, parting planes spaced 0.4 feet apart, weathers medium brown, a highly resistant unit, contains *Atrypa* sp. -- medium costate.	1.6	8.4
2	Limestone, light grey, fine grained, fissile platy beds up to 0.25 inch thick, separated by greenish grey shale partings, recessive, no megafossils seen.	1.6	8.4
	This is the lowest rock unit that can be traced northward along the bank at about 0.2 mile north of the south end of the outcrop.		
1	Covered interval to river level.	6.8	6.8
	Measured at or very near the axis of a broad gentle anticlinal fold.		

MESOZOIC GEOLOGY OF THE FORT McMURRAY AREA

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INTRODUCTION

A very marked change in lithology and a very long interval of time separate the apparently conformable Paleozoic and Mesozoic rocks in the Oil Sands Area. 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 there was a well-developed drainage system and much evidence of karst phenomena on this surface as the result of solution of the underlying salt and subsequent collapse of the overlying beds. 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 noticeable in strata above the Middle Clearwater Formation.

The lithology and stratigraphy of the Mesozoic strata are described in the following section. The most conspicuous feature of these strata is the massive in-flow of liquid petroleum which saturated the western half of the McMurray Formation under an area of approximately 20,000 square miles. This huge petroleum reservoir, known as the Athabasca Oil Sands, is described in some detail at the end of this section.

DESCRIPTION OF FORMATIONS

McMurray Formation (McLearn, 1917)

General Discussion

The oil sands were believed by Richardson (*in* Franklin, 1828) and Isbister (1855) to overlie the Devonian limestones conformably and were thus correlated with the Marcellus shale of the Devonian sequence in New York State. Meek (1868) was doubtful of the correlation made by Richardson and Isbister, but believed most of the oil sands to be Devonian in age and to represent the Chemung Group of the New York Geological Survey. Bell (1884) recognized that the sands were not Paleozoic but Mesozoic in age and that the contact with the limestone was unconformable. McConnell (1891, 1893) correlated the oil sands with the "Dakota" sandstones of Cretaceous age in Manitoba and Minnesota.

McLearn (1917) proposed the name McMurray for the oil-impregnated sands overlying the limestones on the lower Athabasca River. The lower sands of the outcrops were found to contain much wood in a good state of preservation and specimens were identified by I. M. Bailey as *Xenoxylon* sp., *Sciadopitys*, and *Keteloeria*. He believed them to be representatives of a Jurassic flora (Ells, 1931). On the basis of a brackish-water molluscan fauna, Russell (1932) correlated the upper beds of the formation with the Lower Cretaceous portion of the Blairmore Group, and McLearn (1932, 1945), using the *Astarte natosini* fauna, correlated the uppermost McMurray strata with the lower Luscar Formation of west-central Alberta. Mellon and Wall (1956) described a brackish-water foraminiferal suite from the upper part of the McMurray Formation. This suite was calibrated with key ammonites of early Middle Albian age. As no satisfactory faunas have yet been found in the lower continental beds, their precise age is still uncertain.

Definition

> The McMurray Formation was defined by McLearn (1917, p. 147) as follows: "The top is placed at the base of a bed of green sandstone, in places somewhat argillaceous, immediately below which the sands of the McMurray appear carrying a small invertebrate fauna of freshwater origin. The formation is prevailingly arenaceous and of rather coarse grain, the uppermost part lies horizontal and varies from massive to thick-bedded, but is never thin-bedded. The remainder and greater part of the formation is, in many places, cross-bedded on a very large scale with the beds dipping from 5 to 40 degrees. This part may be bedded above by intercalation of argillaceous sandstone or finer sandstone beds with the coarser sandstone, but is always massive below. Sometimes conglomerate and more rarely clay or shale are found at the very base."

Distribution

The McMurray Formation outcrops on the Athabasca River from Tp. 87, R. 14, to Tp. 98, R. 10 W.4 Mer., and on the Clearwater River from the Saskatchewan-Alberta border to its junction with the Athabasca River at Fort McMurray. It thins to the west against a hill on the pre-Cretaceous erosion surface. This buried hill on the Paleozoic surface reaches an elevation of 1,000 feet in the vicinity of Brule Rapids (Tp. 87, R. 17 W.4 Mer.). On the Clearwater River near the Saskatchewan border at Whitemud Falls roughly 60 feet of clean white McMurray sandstone is exposed in the valley wall at an elevation of over 1,000 feet. The formation was traced 6 miles east of the Saskatchewan-Alberta border on the Clearwater River but the eastern limit was not reached. The northern boundary of the McMurray Formation is obscured by a cover of glacial drift. The southern boundary has not yet been determined. Strata of equivalent age are widespread in the subsurface of Western Canada.

Lithology

The sedimentary deposits between the Clearwater Formation and the Devonian limestone formations can be subdivided on lithological evidence into four informal stratigraphic units.

1. Pre-McMurray(?) beds. Remnants of a coarse-grained, quartzose sandstone, cemented by silica and goethite, which appear to unconformably underly the McMurray Formation, have been described by Carrigy (1966, p. 6-9). The most

extensive outcrops of these beds are found between the Athabasca and Muskeg Rivers, to the east of Fort MacKay. Other smaller outcrops are found along the Athabasca River. The lack of stratigraphic control on the isolated outcrops makes correlation difficult, but similarity in mineral composition and stages of lithification as observed in thin section is seen in all of these outcrops, and leads one to suspect that these beds are remnants of a once-continuous body of sandstone.

2. The lower unit of the McMurray Formation consists of lenticular beds of conglomerate, sand, shale, and silt which occupy the deeper depressions on the pre-Cretaceous erosion surface. The basal strata are residual clays derived from weathering of the Waterways limestones. These are overlain by sediment whose general characteristics have been controlled by the topography of the surface on which they were deposited. These coarse-grained sands contain large fragments of wood, well-rounded quartz grains, numerous feldspar cleavage fragments, and small amounts of mica. In some test holes this sand is barren and contains only fresh water; in others it is impregnated with heavy oil. Interbedded with these sands are grey micaceous siltstones which in many cases have a brown color as the result of oil staining.

Outcrops of these beds are present on the Steepbank and MacKay Rivers and on the west bank of the Athabasca River between township 92 and the landing at Fort MacKay. The bed contains boulders of Athabasca sandstone, angular vein-quartz, and some white quartzite grains. The quartz grains vary in shape from angular to rounded, and in thin section individual grains show fractures, crystal intergrowth, a granoblastic texture, and strain extinction when viewed in polarized light. The bed also contains many siderite nodules.

3. The middle unit lies between elevations of 750 feet and 940 feet. This is the so-called typical McMurray Formation and consists mainly of an oil-cemented quartz sand of very uniform mineralogy, the major accessory mineral being muscovite. Interbedded with these sands are lenticular beds of micaceous silts, shales, and in places clay. Beds of this member are characterized by many primary sedimentary structures, particularly current bedding. They also contain plant remains, worm casts, logs of wood, and thin coal beds.

4. The upper unit is not everywhere clearly differentiated from the middle member. It has a similar lithology but is mostly horizontally bedded and is identified by the presence of beds containing a limited brackish-water fauna (Mellon and Wall, 1956). Large shallow channels or scours filled with silt beds and siderite-cemented siltstones are present.

The Hangingstone River shell beds, which occur in the upper member, have lithological and faunal affinities with the *Metacypris angularis* beds of Badgley (1952) and the *Metacypris persulcata* beds of Loranger (1954) in central Alberta. Mellon and Wall (1956) postulated, on the basis of micro-faunal evidence, that these beds were a transitional sequence of brackish-water sediments related to a transgressing sea. A sharp change in the sedimentary sequence is visible at the contact of these sands with the overlying sands of the lower Clearwater Formation where the presence of glauconite pellets indicates marine sediments and a slowing down of the rate of sedimentation. In formations of Cretaceous age higher in the stratigraphic section glauconite is a common accessory mineral.

The contact with the Clearwater Formation on the lower Athabasca River valley is in general at the 1,000-foot contour except in the area of the Bitumount basin where, as a result of collapse, the contact may be as low as the 800-foot contour. The upper unit as defined here corresponds to the "upper leaner banded beds" of Ells (1926) which generally overlie the richer sands.

Type Sections

No type section for the McMurray Formation was designated by McLearn (1917), so an outcrop type section was measured for the McMurray Formation on the east bank of the Athabasca River, a few miles north of Fort McMurray (Plate 1; Table 1), and was designated by Carrigy (1959).

Clearwater Formation (McConnell, 1893)

Definition

"Clearwater shale" was the name given by McConnell (1893, p. 30D) to the outcrop 8 miles below Grand Rapids on the Athabasca River at Pointe La Biche (Tp. 86, R. 18, W.4th Mer.). He noted that this shale contained lenticular beds of fossiliferous glauconitic sandstone at Burnt Rapids (Tp. 87, R. 16, W.4 Mer.) and published a list of fossils, identified by Whiteaves. He estimated the thickness of the shales to be 275 feet. McLearn (1917) defined the base of the Clearwater Formation as the bottom of the well-defined glauconite sand bed underlying the shale and overlying the oil-impregnated sands of the McMurray Formation. The age of the formation has been established by paleontological evidence as Lower Cretaceous (Albian) (Whiteaves, 1893; Whiteaves *in* McConnell, 1893; McLearn, 1917, 1919, 1932, 1933 and 1945; Wickenden, 1949; Mellon and Wall, 1956; Stelck *et al.*, 1956).

The Wabiskaw Member, a glauconitic sandstone bed found in Barnsdall West Wabiskaw No. 1 well has been described by Badgley (1952).

Distribution

The Clearwater Formation outcrops almost continuously on the Athabasca River from 8 miles above Grand Rapids (Tp. 84, R. 17, W.4 Mer.) as far north as the Bitumount basin and probably extends under the higher ground to the

Plate 1. Type section of the McMurray Formation on the east bank of the Athabasca River.

northwest. It has been penetrated by wells drilled in the Birch Mountains. In the Fort McMurray area, the base of the formation varies in elevation between 1,000 and 1,100 feet and the top lies between 1,250 and 1,300 feet, except in the Bitumount basin (Tp. 96, Rs. 9 and 10, W.4th Mer.) where it has been affected by movement of the Devonian rocks below. The elevation of the base in the Bitumount basin is below 800 feet and the upper contact is not preserved. In the Clearwater River valley outcrops are rare because of slumping and a thick vegetation cover. One outcrop, however, was found at Whitemud Falls (Tp. 89, R. 1, W.4th Mer.). Other exposures are found in the tributary streams of the Clearwater -- Christina River, Cottonwood Creek (Sec. 6, Tp. 89, R. 5, W.4th Mer.) and High Hills River (Tp. 89, R. 3, W.4th Mer.).

Lithology

The lithology of this formation has been described by Badgley (1952). Because exposures showing both upper and lower contacts are not readily found in the Fort McMurray area, descriptions of the lithology in this report are confined to the basal marine sandstone unit and the lower section of the marine shale unit.

Table 1. Type Section of McMurray Formation Measured on Outcrop on East Side of Athabasca River Three Miles North of McMurray in Sec.5, Tp.90, R.9*

Formation	Description of Lithology	Thickness of bed in feet
Clearwater 26 feet	Grey shale	10
	Ironstone bed	1
	Fine-grained glauconite sandstone, no cement, gypsum crystals on surface	6
	Ironstone bed	1
	Fine-grained glauconite sandstone, no cement, gypsum crystals on surface	7
	Ironstone bed	1
McMurray 237 feet	Grey shale with salt and crystals of gypsum on surface	12
	Fine-grained horizontally-bedded sandstone, some iron-oxide cement	13
	Ironstone bed	1
	Oil-impregnated and iron-oxide cemented sands, interbedded	6
	Horizontally-bedded oil-cemented sands ...	9
	Ironstone bed	0.5
	Richly-impregnated oil sand	3
	Ironstone bed	2
	Rich oil sands, bedding has slight dip ...	150
	Oil sand with small-scale cross bedding, few irregular saline seepages. Lower section obscured by talus	42 plus or minus 5
Unconformity	Ironstone conglomerate bed	1
Beaverhill Lake	Fossiliferous limestone containing brachiopods and algae	18

* Approximate elevation of river level 780 feet.

A thin bed of glauconitic sandstone, rarely exceeding 20 feet in thickness, has been found at the base of the formation throughout the area, overlying the upper McMurray Formation strata. This sand is commonly very dirty and can be described as a shaly or clayey sand. It is composed of a fine-grained well-sorted sand with varying proportions of silt- and clay-size material filling the voids. This bed has so far failed to yield any fossils in this area.

A grey shale carrying a marine fauna is the characteristic lithology of the Clearwater Formation in the Fort McMurray area. Large crystals of gypsum are found on many outcrop faces of this unit. The upper boundary with the Grand Rapids Formation is transitional where observed on the Clearwater River near Whitemud Falls and the Athabasca River west of Fort McMurray.

Grand Rapids Formation (McConnell, 1893)

Definition

The Grand Rapids sandstone was defined by McConnell (1893) as a formation from its outcrops on the Athabasca River. It is what is commonly called a "salt and pepper" sand and has a heterogeneous mineral composition which includes grains of quartz, feldspar, glauconite, chert, muscovite, and biotite. The greater part of the sand is uncemented, but spherical calcareous nodules up to 10 feet in diameter are present in outcrop sections throughout the greater Fort McMurray area. At the Grand Rapids on the Athabasca River there is a concentration of these large nodular boulders in the river bed. The sandstone is over 300 feet thick and is overlain by the Pelican shale (McLearn, 1917) or, as it is now known, the Joli Fou Formation (Wickenden, 1949).

In the Fort McMurray area, Grand Rapids sandstone outcrops are generally found between the 1,200- and 1,500-foot contours. The bed is porous and permeable and many small springs emerge at its contact with the underlying Clearwater shale. These springs have eroded small blind valleys by cutting away the unconsolidated sand to form vertical cliff faces up to 300 feet high. The combined action of many such springs has produced a terrace of varying width at the top of the Clearwater shale which can be easily recognized on vertical aerial photographs. Outcrops have been found in the Athabasca River valley west of Fort McMurray, on the Clearwater River valley, and in the upper Ells River valley on the eastern side of the Birch Mountains.

Joli Fou Formation (Wickenden, 1949)

The name "Joli Fou" was applied by Wickenden (1949) to the dark grey marine shale about 110 feet thick, which outcrops near Joli Fou Rapids on the Athabasca River (Tp. 81, R. 17, W.4th Mer.). It was previously known as the Pelican shale (McConnell, 1893). The contact between the Joli Fou shale and the underlying Grand Rapids sandstone is considered by Badgley (1952) to be useful for stratigraphic correlation and structural interpretation beneath the Plains of Alberta. In the Fort McMurray area, outcrops showing this contact are not sufficiently numerous to be of much use for structural interpretation.

An assemblage of arenaceous foraminifera, sufficient to establish its age as Lower Cretaceous, has been described from this formation by Wickenden (1949). Stelck *et al.*, (1956) have made a more complete study of the foraminifera and have equated them with the *Haplophragmoides gigas* zone of Middle Albian age.

Pelican Formation

This formation is a series of lenses of sands and siltstones of marine origin which outcrop on the Athabasca River southwest of Fort McMurray. The subsurface extent of this deposit in the oil sands area has not been determined.

La Biche Formation

Classification of the strata reported as overlying the Pelican Formation in the Birch Mountains has not been attempted, but the grey shales containing limestone concretions which outcrop 2 miles below Moose Lake were assigned to this unit by McConnell (1893).

THE ATHABASCA OIL SANDS RESERVOIR

Definition and Location of the Athabasca Oil Sands

The Athabasca Oil Sands as defined by Carrigy and Zamora (1960, p. 44) include the oil-impregnated portions of the Lower Cretaceous strata found in northeastern Alberta in the lower Athabasca River area. They take their name from the steep, oil-soaked cliffs of the McMurray Formation found in the valleys of the Athabasca River and its tributaries in the vicinity of the town of Fort McMurray. In the subsurface these oil sands underlie an area of about 20,000 square miles, extending from latitudes 55 to 58 degrees north between the fourth and fifth meridians.

Boundaries

The boundaries of the petroleum impregnation in the Athabasca deposit have not been determined with any degree of accuracy. To the west the clean sandy sediments of the McMurray Formation reservoir pinch out against a ridge of Devonian limestone. To the north, in the Athabasca River valley, the boundary of the deposit is erosional and is hidden from view beneath a thin layer of glacial drift. To the northwest beneath the Birch Mountains the absence of drilling in Wood Buffalo National Park has prevented the northern boundary from being established. The eastern and southern boundaries are believed to be determined by the limits of impregnation. A conventional oil-water contact is suggested for these limits by the outcrop evidence on Cottonwood Creek (Carrigy, 1959). However, much more data is needed to establish the boundaries of this huge reservoir with any degree of certainty. The area of the deposit shown on the 1963 maps of the Energy Resources Conservation Board cover only the area for which there is a reasonable amount of drilling data and does not cover the full extent of the Athabasca deposit.

Depth of Burial

The depth from the surface to the top of the oil-impregnated strata varies according to the surface topography and the structure on the top of the reservoir. The upper surface of the oil sands on a regional scale is generally flat in areas north of Fort McMurray with a slight regional dip to the southwest. The major anomalies in depth of burial are due to post-depositional salt collapse. Most of these are found to the east of a line which runs in a north-south direction through Fort McMurray. The largest of these collapse structures mapped to date is present to the east of the Athabasca River near Bitumount. In this locality collapse over a circular area with a diameter of 6-10 miles has lowered the oil sands almost 200 feet below its expected level. Other smaller areas of collapse are present and many more will be found as the density of drilling increases.

Overburden, which is defined as the thickness of sediment above a desired grade of oil sand, will depend on the cut-off value chosen and will include a varying thickness of the poorly-saturated silty oil sands at the top of the McMurray Formation. Figure 1 shows the thickness of overburden above the first oil sand containing more than 10 percent of bitumen by weight. Overburden, depending on its location, can include the Upper McMurray Formation, the Clearwater Formation, the Grand Rapids Formation, the La Biche shales, and the Pleistocene drift to give a total thickness of 1,700 feet.

Thickness

An isopach of the total thickness of oil-impregnated strata is shown in figure 2, and the subsurface aspects of the beds are illustrated on the electric-log correlation shown in figure 3. The upper boundary of the Wabiskaw Member, a thin but persistent, poorly sorted clayey sandstone averaging 20 feet in thickness, has been used as a datum for the west-east correlations. The correlations can be carried only to the central part of the basin as the eastern half is believed to be barren (no wells have been drilled there). The cross section shows that the formation consists of a series of collateral sandstone

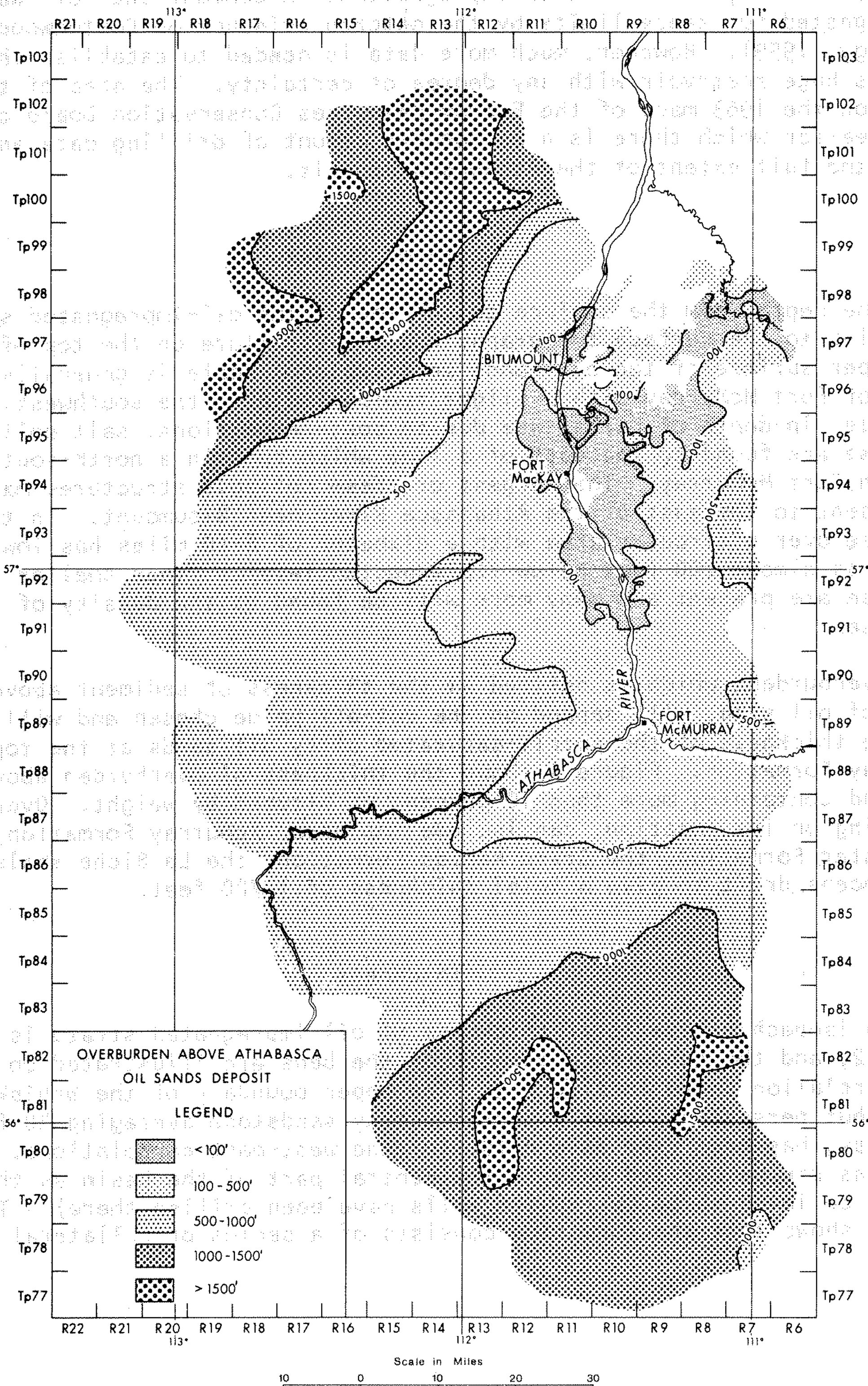

FIGURE 1. Thickness of overburden above the Athabasca Oil Sands deposit (after Alberta Oil and Gas Conservation Board, 1963).

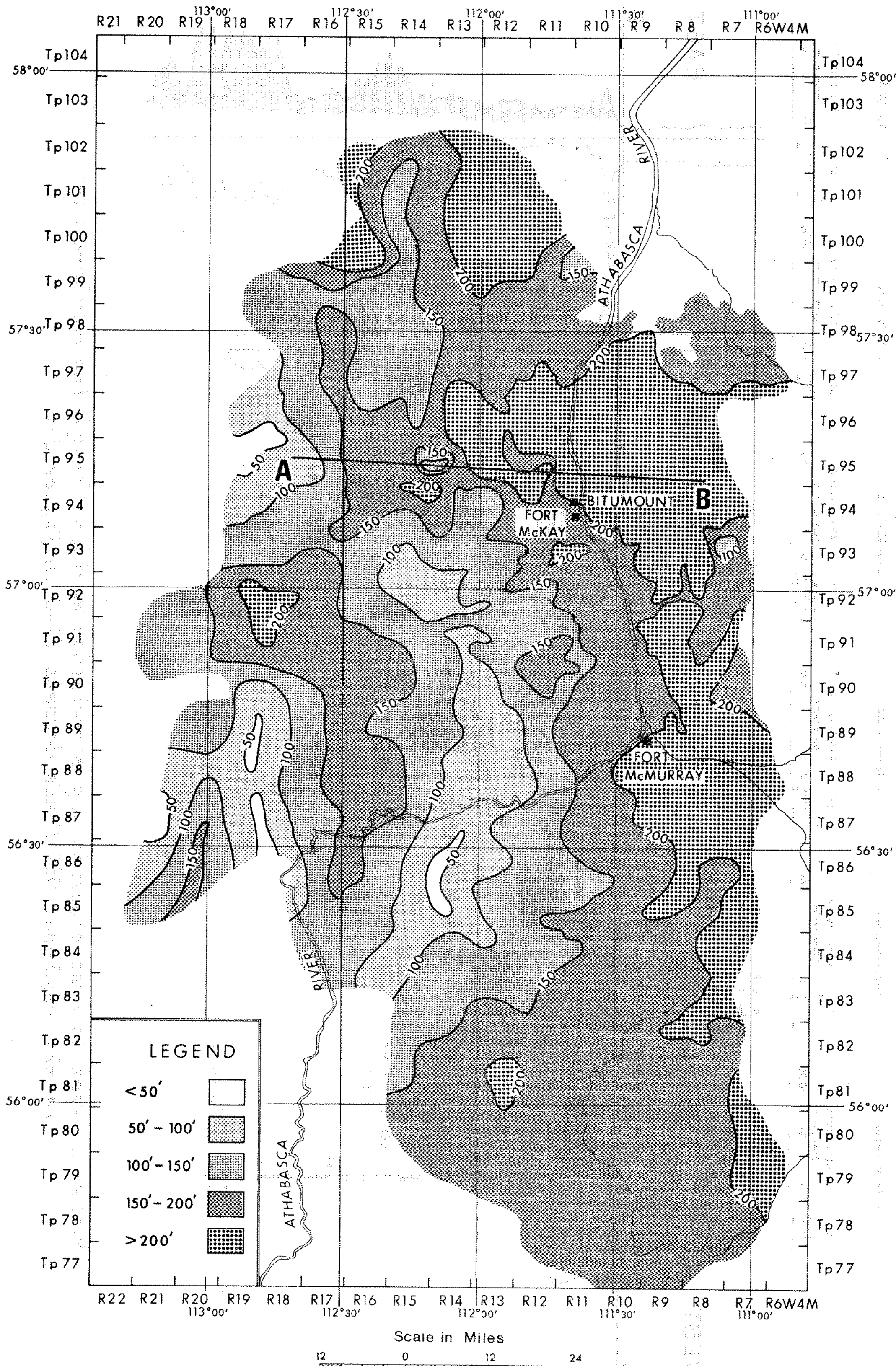

FIGURE 2. Thickness of oil-impregnated strata of the Athabasca Oil Sands deposit (after Alberta Oil and Gas Conservation Board, 1963).

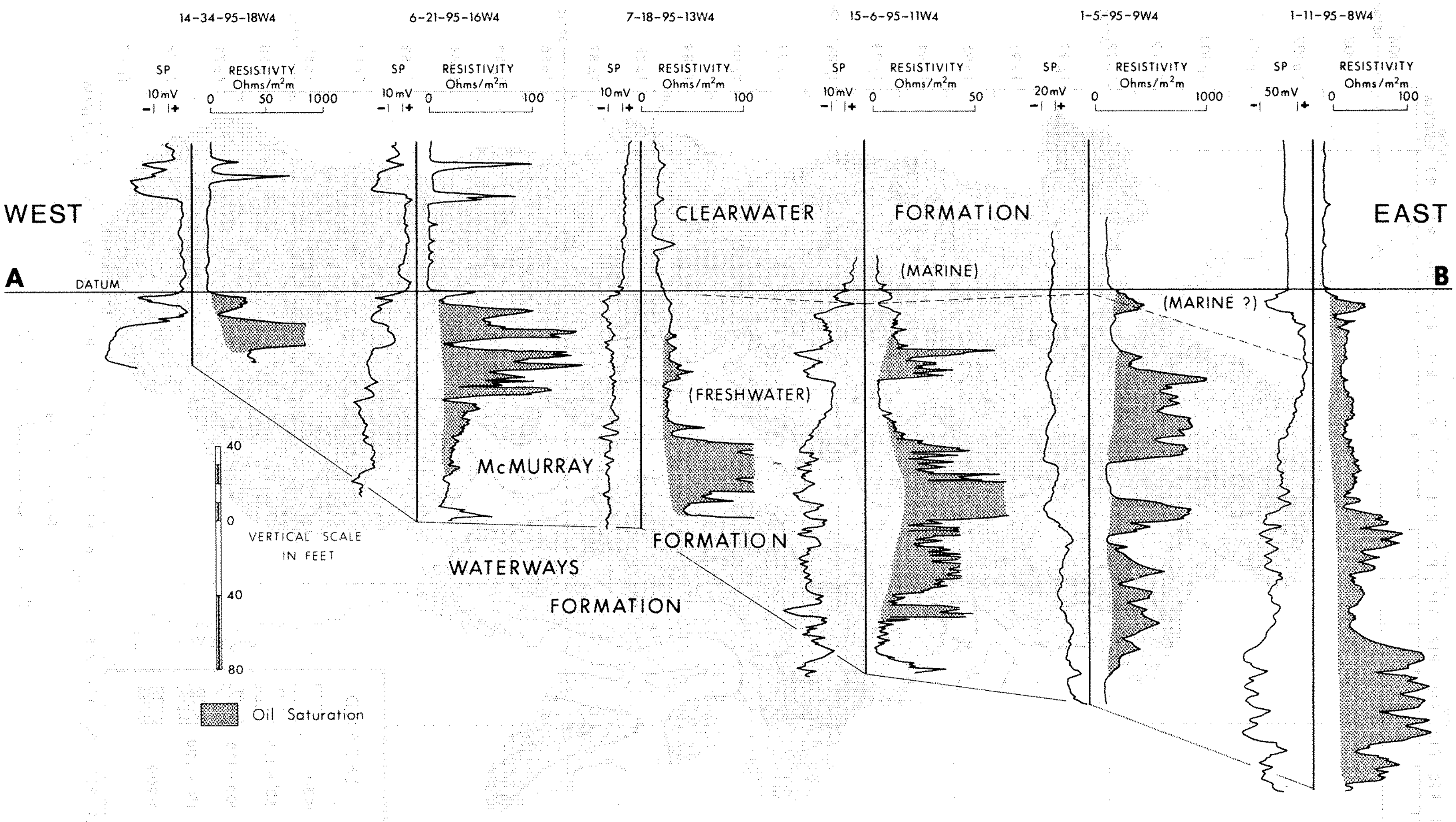

FIGURE 3. West to east electric log correlation section through the northern part of the Athabasca Oil Sands deposit (A-B in figure 2).

bodies, generally basal in position and interbedded with thick siltstones. One of the outstanding features of the McMurray Formation is the absence of correlatable units within the formation. The nature of the reservoir boundary is difficult to determine because of the lensing nature of the sandstone bodies.

Structure

The Cretaceous strata dip uniformly southwest toward the Rocky Mountains at a rate of 5 feet per mile, with local exceptions. One of these is in a relatively small area of about 50 square miles near Bitumount (Carrigy, 1959). The relation of salt tectonics to the accumulation of heavy oil in the Lower Cretaceous strata of Western Canada is discussed by Vigrass (1966).

Petrography

Grain Size

The grain size of the sediments in the Athabasca deposit vary from clay-size material to small cobbles. Rich oil sands are generally the medium- to fine-grained well-sorted sands which are found in the lower and middle parts of the McMurray Formation. The typical fining upwards trend in the average grain size in a vertical section of the McMurray Formation is shown in figure 4.

Texture

The textures of the reservoir sands in the Athabasca deposit are shown graphically in figure 5. Most oil sands are relatively clean, well-sorted sands, silty sands, or silts. Pure clay and clayey silt samples are not common. The relationship between texture and oil content in the Athabasca deposit was studied in detail by Carrigy (1962), who found that the oil content was related inversely to the clay content of the sediment. The oil sands were found to be a typical petroleum reservoir rock with good primary porosity and permeability. The relationship between oil content and sediment texture is illustrated in figures 4 and 5.

Packing

The typical structural framework of oil sand sediment is illustrated in figure 5. The pore space between the grains is occupied by heavy oil, but the oil is not in direct contact with the mineral grains because of a thin water film which surrounds the hydrophilic quartz grains. It is the water-wet nature of the sands which makes the hot water extraction process so effective in this deposit. Measurements of porosity and oil content show that it is common for the heavy oil to occupy up to 90 percent of the pore space in these sediments.

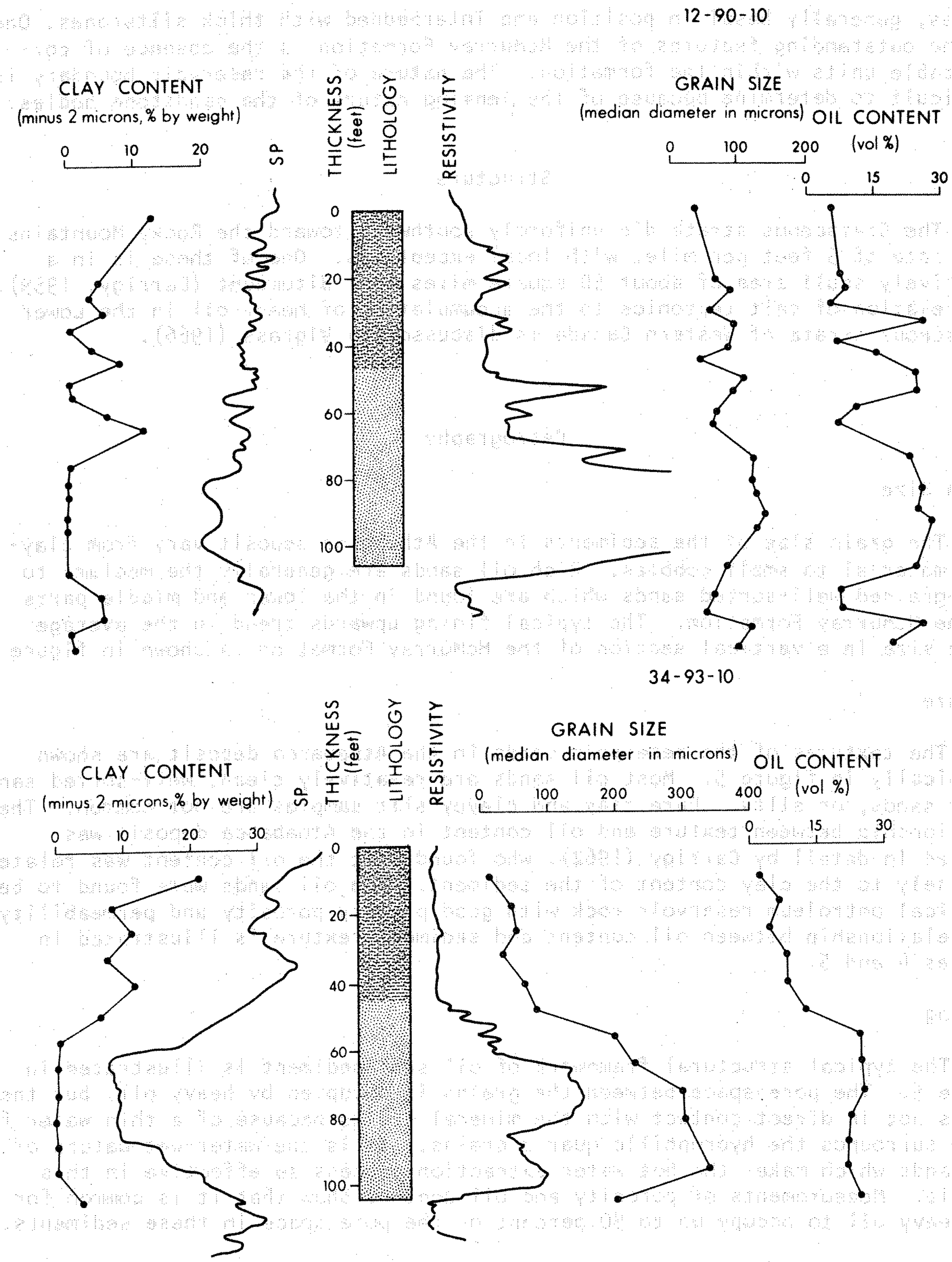

FIGURE 4. Typical lithological properties and geophysical responses of two oil sands cores.

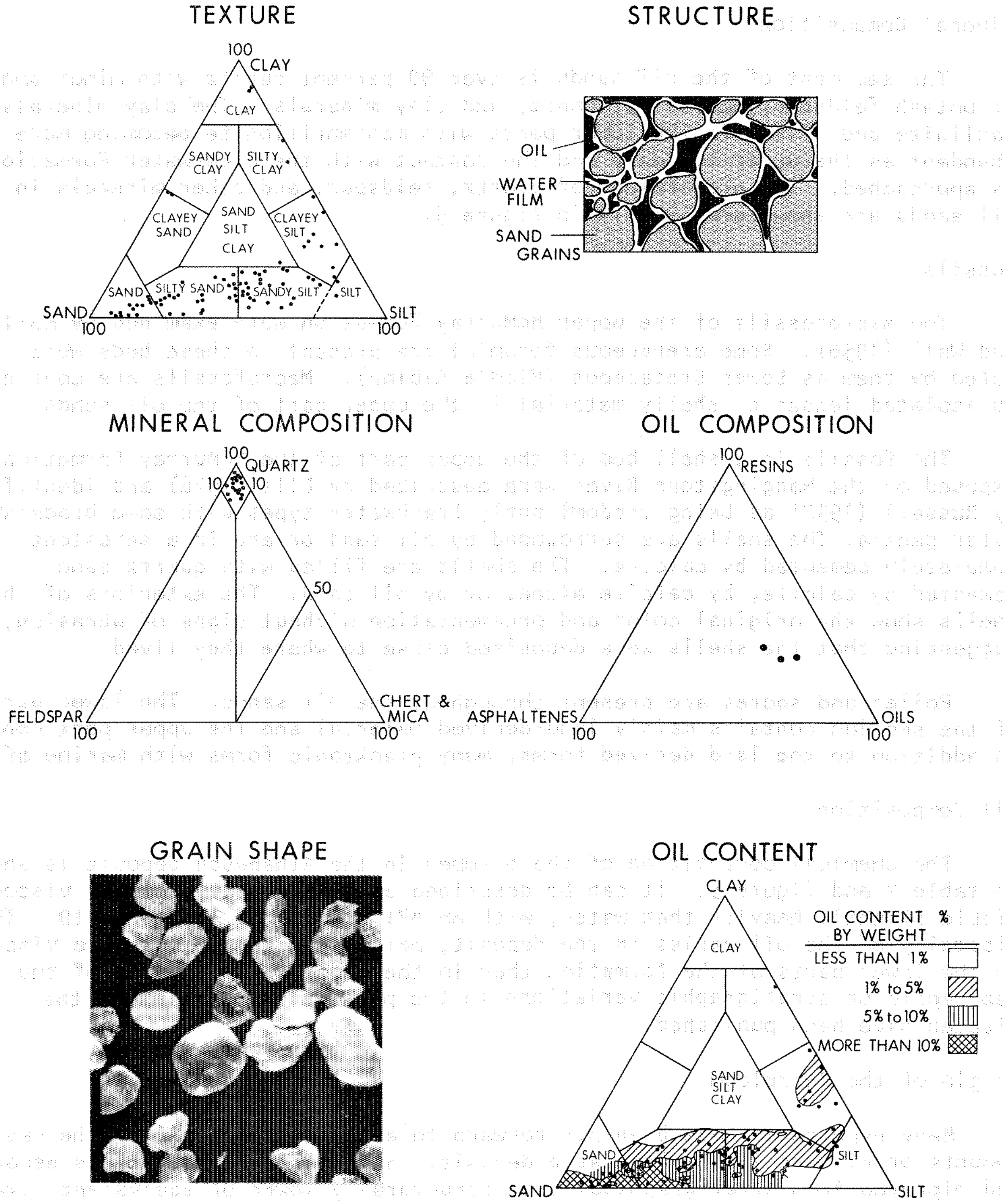

FIGURE 5. Petrographic features of the Athabasca Oil Sands Reservoir rocks.

Grain Shape

There is a wide range of shapes to the grains in the Athabasca oil sands. Some of the large grains are well rounded but in general most of the grains are angular (Fig. 5).

Mineral Composition

The sediment of the oil sands is over 90 percent quartz with minor amounts of potash feldspar, muscovite, chert, and clay minerals. The clay minerals are kaolinite and illite in the lower parts with montmorillonite becoming more abundant as the upper boundary and the contact with the Clearwater Formation is approached. The proportions of quartz, feldspar, and other minerals in the oil sands are shown graphically in figure 5.

Fossils

The microfossils of the upper McMurray Formation were examined by Mellon and Wall (1956). Some arenaceous foraminifera present in these beds were dated by them as Lower Cretaceous (Middle Albian). Macrofossils are confined to isolated lenses of shelly material in the upper part of the oil sands.

The fossils in a shell bed of the upper part of the McMurray Formation exposed on the Hangingstone River were described by Ells (1926) and identified by Russell (1932) as being predominantly freshwater types with some brackish-water genera. The shells are surrounded by oil sand or are in a sandstone completely cemented by calcite. The shells are filled with quartz sand cemented by calcite, by calcite alone, or by oil sand. The exteriors of the shells show the original color and ornamentation without signs of abrasion, suggesting that the shells were deposited close to where they lived.

Pollen and spores are present throughout the oil sands. The lower part of the section contains mainly land-derived material and the upper part contains, in addition to the land derived forms, many planktonic forms with marine affinities.

Oil Composition

The chemical composition of the bitumen in the Athabasca deposit is shown in table 2 and figure 5. It can be described as a very heavy, black, viscous liquid slightly heavier than water, with an API gravity of less than 10. The viscosity of the oil varies in the deposit, being in general much more viscous in the lower parts of the formation than in the upper. Few studies of the geographic or stratigraphic variations in the physical properties of the bitumen have been published.

Origin of the Petroleum

Many hypotheses have been put forward to explain the origin of the vast amounts of bitumen in the Athabasca deposit. Some believe that it has escaped and migrated from stratigraphically or structurally lower or equivalent strata

Table 2. Properties of Athabasca Bitumen

Gravity at 60°F	6.0 °API
UOP characterization factor	11.18
Pour point	+50°F
Specific heat	0.35 cal/gm/°C
Calorific value	17,900 BTU/lb
Viscosity at 60°F	3,000-300,000 poise
C/H ratio	8.1
Components:	
Asphaltenes	20.0%
Resins	25.0%
Oils	55.0%
Ultimate Analysis:	
Carbon	83.6%
Hydrogen	10.3%
Sulphur	5.5%
Nitrogen	0.4%
Oxygen	0.2%
Heavy Metals:	
Nickel	100 ppm
Vanadium	250 ppm
Copper	5 ppm

as a light oil and then been bituminized in the present reservoir; others believe that this is a virgin oil or proto-petroleum from which lighter oils will be produced when it is buried and subjected to higher temperatures and greater pressures.

History of Sedimentation

The outline of the pre-McMurray drainage system shown in figure 6(1) was reconstructed by matching isopachs of the McMurray-Wabiskaw interval with structure contours on the Cretaceous-Devonian unconformity. Some adjustments are necessary in the isopachs because of the time-transgressive nature of the upper boundary. Where strata overlying the McMurray Formation have been removed by erosion, the location of channels is based entirely on the structure contours on the upper surface of the Devonian limestone. It is recognized that these may have been lowered somewhat by continued leaching of

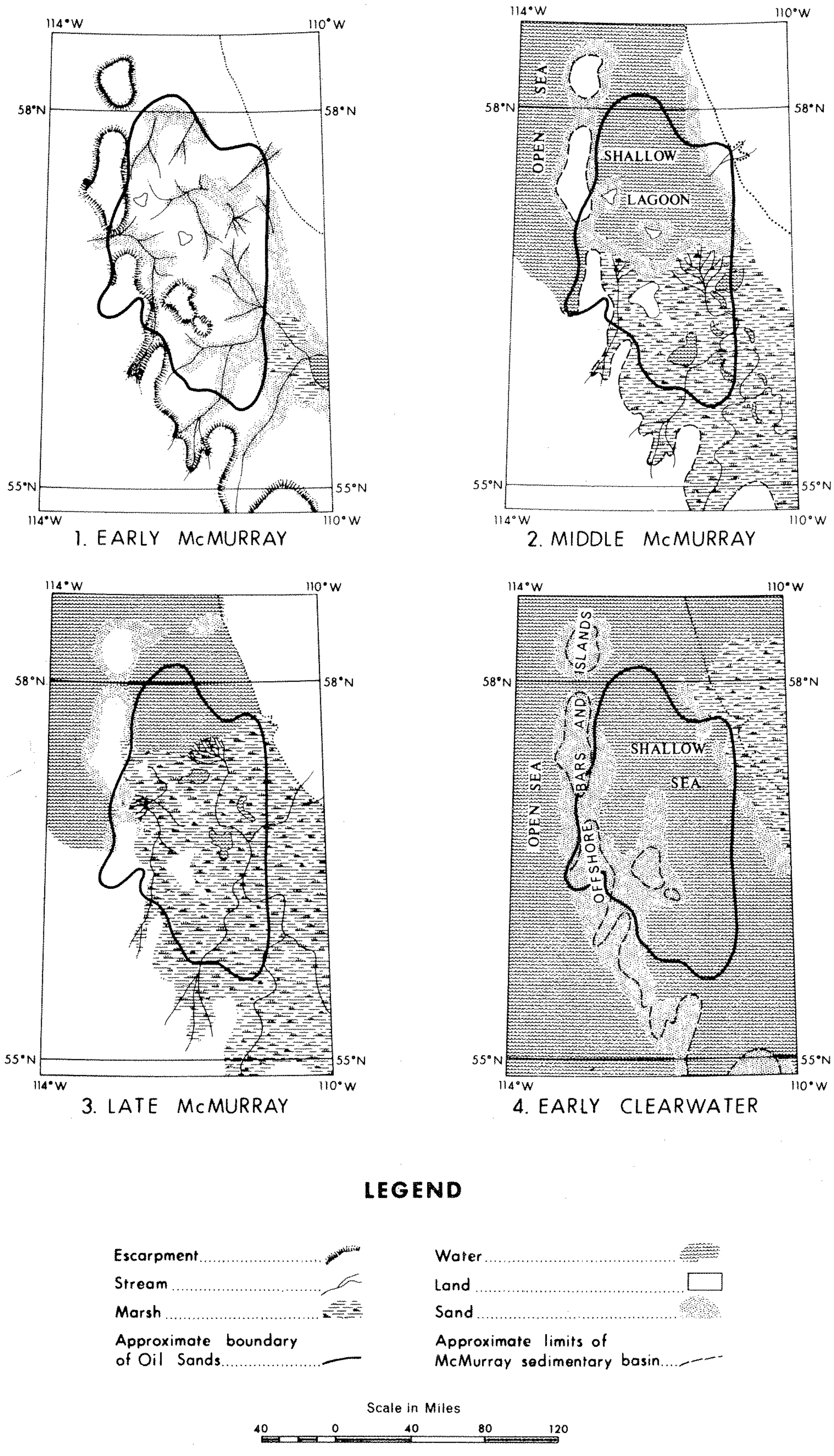

FIGURE 6. History of sedimentation of the McMurray Formation.

salt from the underlying strata since Cretaceous time; nevertheless, the outlines shown are believed to give a close approximation of the drainage basin in which the McMurray Formation was deposited.

The pattern of internal drainage shown was probably produced by the gradual disruption of a single drainage basin into two areas of subsurface drainage, leaving a minor watershed in the vicinity of the town of Fort McMurray. The smaller, northerly basin drained underground into the Bitumount collapse area, and the larger southern basin had its outlet in a sink on the Alberta-Saskatchewan border at about 56°N. The drainage channels shown on this map commonly contain coarse-grained sands and conglomerate, the precise age of which has not yet been determined (Carrigy, 1963a).

Figure 6(2) shows the landscape midway through the filling of the McMurray basin. A major stream from the south and east is shown building a delta, which is advancing across a shallow lagoon or lake. The concept of a northward-flowing river system is supported by the analysis of the cross stratification in the lower and middle parts of the McMurray Formation (Carrigy, 1963b).

Pollen analysis suggests that the lagoon filled a depression formerly occupied by a lake (Carrigy, 1967). It is surmised that as sea level rose, the lake in turn became a brackish water lagoon, then a restricted bay, and finally open sea. This reconstruction of deltaic deposition is based on the fact that foreset and topset structures are well preserved in the middle part of the McMurray Formation (Fig. 7; Plate 1) in outcrops along the lower Athabasca River; a circumstance that could be due to the maintenance of a static water level during their formation. The general absence of micro-plankton and marine fossils in foreset beds near Fort McMurray suggests that the water filling the basin was fresh or brackish and that it was cut off from the sea until the very latest stages of its existence.

Figure 6(3) shows the final stage in the burial of the pre-McMurray depression. The Devonian strata are covered except for the highest hills and ridges extending along the western margin of the basin, and the delta is shown as having reached the margin of the open boreal sea to the north.

Figure 6(4) shows the early stages of the Clearwater marine transgression. The Devonian limestone ridges and hills are now shoals, the high-energy environments over them producing the clean, sorted, glauconite sands which are now reservoirs for some of the heavy oil.

Sedimentary Structures

Many of the sedimentary structures present in the Athabasca reservoir are illustrated in Carrigy (1967). The major structures are inclined bedding in the central part of the section and horizontal bedding and large channel "scours"

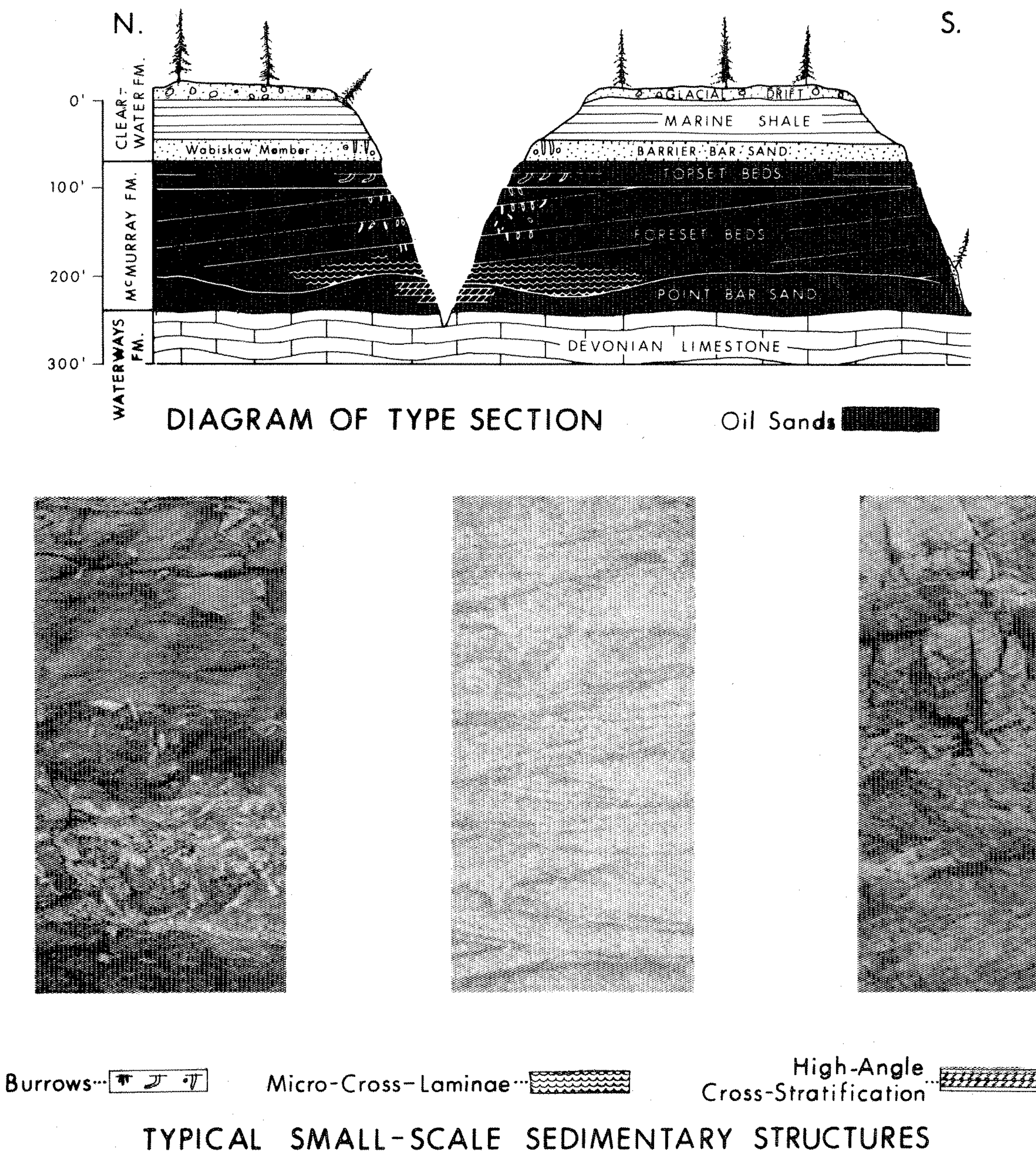

FIGURE 7. Stratigraphy and sedimentary structures of the McMurray Formation.

Table 3. Summary of Stratigraphic and Lithologic Data for the Athabasca Oil Sands Reservoir

ROCK UNIT	AGE	GRAIN SIZE	MINERAL CEMENT	NODULES	ORGANIC MATTER	OIL CONTENT	MINERAL COMPOSITION: Major Constituents	MINERAL COMPOSITION: Significant Nonopaque Heavy Minerals	MINERAL COMPOSITION: Clay Minerals	SEDIMENTARY STRUCTURES: Major	SEDIMENTARY STRUCTURES: Minor	FOSSIL CONTENT	ENVIRONMENT OF DEPOSITION
Clearwater Formation (Wabiskaw Member) *(6 to 30 ft)*	Middle Albian	Clay				Nil	Clay		Montmorillonite Illite Kaolinite	Horizontal beds		Ammonites Pelecypods Calcareous foraminifera	Marine, open shelf
		Sand Silt Clay	Siderite			No oil in sand beds due to clay matrix	Quartz Chert Glauconite	Tourmaline Chloritoid Euhedral biotite	Montmorillonite Illite Kaolinite Chlorite	Horizontal beds	Large burrows filled with clean sand Small-scale bedding destroyed by animal activity	Foraminifera* Radiolaria* Sponge spicules* Diatoms* Dinoflagellates Hystrichospherids	Marine, nearshore
		Sand				Rich in oil, locally	Quartz Chert Glauconite	Tourmaline Chloritoid	Illite Kaolinite Chlorite	Lenticular beds			
McMurray Formation (Upper) *(15 to 30 ft)*	Middle Albian	Silt Very fine sand	Siderite Calcite		Abundant macerated vegetable matter in clay matrix	Thin oil sand layers interbedded with barren silts or mottled oil impregnation or staining (5-10% by volume)	Quartz K-feldspar Muscovite	Chloritoid Tourmaline Zircon	Kaolinite Illite	Horizontal laminations Large shallow channels or "scours"	Small burrows filled with oil-impregnated silt and sand Small-scale penecontemporaneous slumps	Molluscs Agglutinated foraminifera Fish teeth Spores Pollen grains	Delta platform, mud flats, bays, lagoons, etc. Shallow depth of brackish water Tidal channels?
										minor disconformity			
(Middle) *(60 to 90 ft)*		Fine sand	Rare		Comminuted carbon	Rich uniform impregnation (20-30% by volume)	Quartz K-feldspar Muscovite	Tourmaline Zircon Chloritoid	Kaolinite Illite	Large scale, low-angle foreset beds 4-6 inches thick, separated by thin silt laminae a few mm thick	Small-scale cross-stratification Abundant burrows 2 to 3 inches long	Spores Pollen grains	Delta foresets, fresh to brackish water over 100 feet deep
										minor disconformity			
		Medium sand	Rare	Pyrite up to 6 ins. diam.	Mummified logs Lignite Comminuted carbon	Rich uniform impregnation (20-30% by volume)	Quartz K-feldspar Muscovite	Tourmaline Zircon Chloritoid	Kaolinite Illite	Lenticular beds made of sets of high-angle cross-beds 8-12 inches thick			Fluviatile, sand bars
										minor disconformity			
(Lower) *(0 to 50 ft)*		Coarse sand Gravel Silt Clay	Siderite	Siderite spherulites	Autochthonous coal seams Lignite Carbon	Rich but variable (up to 35% by volume)	Quartzite Quartz K-feldspar	Garnet Kyanite Staurolite	Kaolinite Illite	Lenticular beds of gravel and gritty beds			Fluviatile, river channel and associated flood plain silts and swamp deposits
										unconformity			
Pre-McMurray? *(0 to 20 ft)*	Barremian	Coarse sand Silt Clay	Quartz Goethite	Clay ironstone nodules at unconformity	Coal Carbon	Variable, barren to rich (0-30% by volume)	Quartzite Quartz K-feldspar	Zircon Tourmaline Staurolite Kyanite	Kaolinite in sandstones Mixed layers in shales	Contorted bedding, cross-bedding Minor folding good jointing		Spores Pollen grains	Fluviatile, river channel Paludal, isolated swamps in depressions on limestone surface
										unconformity			

*Pyritized

in the upper part of the section. On a smaller scale, high-angle cross bedding, micro-cross-laminae, burrows, and castings are visible in many of the oil sands outcrops (Fig. 7).

A typical feature of inclined bedding in the central part of the deposit is the presence of thin grey micaceous silt laminae (1 cm thick) at regular intervals of about 10-25 cms in the fine-grained oil sands.

The economic significance of the broad shallow channels scoured into the essentially horizontal beds of the upper member of the McMurray Formation is discussed by Allen and Sanford (this volume). They are filled with low-grade oil sands, silty beds, and hard siderite-cemented sandstones which can cause severe difficulties in mining.

A summary of stratigraphic and lithologic data for the Athabasca reservoir is given in table 3.

Bitumen Reserves

The latest estimate of the bitumen in the Athabasca deposit is 626 billion (1 billion = 1,000 million) barrels. Of these, 45.1 billion barrels are buried at a depth of 0 to 100 feet, 373.9 billion barrels at 100 to 1,000 feet, and 207.0 billion barrels at a depth greater than 1,000 feet.

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THE GREAT CANADIAN OIL SANDS OPERATION

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Fort McMurray, Alberta

INTRODUCTION

The completion and official opening, in 1967, of Great Canadian Oil Sands Limited's Athabasca plant represented a unique achievement for Alberta and all of Canada, for this $235 million industrial complex is the first of its kind anywhere in the world. The operation is located on lease 86 which covers an area of about 4,000 acres and is situated on the west bank of the Athabasca River about 21 miles north of Fort McMurray.

Active work on technical and economic feasibility studies started shortly after Great Canadian Oil Sands Ltd. received the original permit in late 1962. This work, which led to an amended permit in early 1964, established the basic concepts of the design. Detailed final design work was begun in April 1964 and was essentially completed in the fall of 1966. During that period, approximately 850,000 technical man hours were expended by the engineer-constructor, Canadian Bechtel Limited, in various offices in Canada and the United States.

In 1972 the plant produced an average of 51,000 barrels of synthetic crude oil daily. The oil is pumped through Great Canadian's 266-mile pipeline to Edmonton where it is delivered to Interprovincial Pipe Line for shipment to eastern refineries.

Mining and processing facilities at Tar Island are operated by a work force of some 450 employees. Additional crews provide maintenance services on a contract basis.

In 1964, the Energy Resources Conservation Board[1] estimated that lease 86 contained 1,031,000,000 barrels of raw bitumen in good grade oil sand beds and that the recoverable reserves of synthetic crude oil were in the order of 630,000,000 barrels.

GEOLOGY

The major part of lease 86 is about 250 feet above the river level. A sharp escarpment, which roughly forms the eastern boundary of the oil sands deposit, falls to a gently sloping area bordering the river where the processing plants are located. The surface in the mining area is relatively flat and is covered with muskeg, small trees, and brush. The undulating limestone surface, underlying the oil sands, stands about 20 feet above the Athabasca River, and the thickness of both the oil sand and overburden, the ratio of overburden to oil sand, the bitumen saturation, the mineral content and character, and other properties vary considerably.

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[1] Energy Resources Conservation Board Report 64-3

In exploring the property approximately 320 core holes, averaging one hole per 15 acres, were drilled through the oil sands to the limestone. These holes were spaced from 200 to 800 feet apart and ranged in depth from 200 to 300 feet. The bitumen and water content, together with the silt and clay content of the mineral residue, were measured on the core samples recovered.

The data produced on the overburden and oil sand were recorded in a computer-retrievable form. Fully automatic cross-section and mapping programs were developed and used to provide input data for an X-Y plotter which produced maps and sections of the significant properties for the entire lease on demand.

Within the present pit limits, which enclose approximately 90 percent of the lease, the overburden averages 53 feet in thickness, varying from 0 to 150 feet. The economical oil sands averages 130 feet in thickness, varying from 0 to 235 feet. The bitumen content of the economical oil sand varies from 8 to 18 percent and averages 12 percent (weight percent on dry basis). The "fines" content of the oil sand varies from about 5 to 45 percent and averages about 16 percent (weight percent of fines in the mineral fraction). A columnar section of the strata present on lease 86 is given in figure 1.

Overburden

The material making up the overburden on lease 86 can be divided into four major units as follows:

1) Organic soils of recent age
   - (a) Muskeg

2) Glacial drift of Pleistocene age
   - (a) Boulder sands consisting of loose, granular, unsorted material containing varying amounts of boulders, cobbles, pebbles, and sand.
   - (b) Sands consisting of fine- to medium-grained sizes, with some pebbles and cobbles, traces of small boulders, and rare medium and small boulders.
   - (c) Boulder clay consisting of grey to brown, unsorted, dense, clay beds, commonly very sandy with small amounts of pebbles, cobbles, and very few boulders. The boulder clay is often calcareous and/or petroliferous.

3) Clearwater Formation
   - (a) Grey to green glauconitic sands and shales.

4) Uneconomic oil sands
   - (a) Quartzose sands with less than 8 percent bitumen.

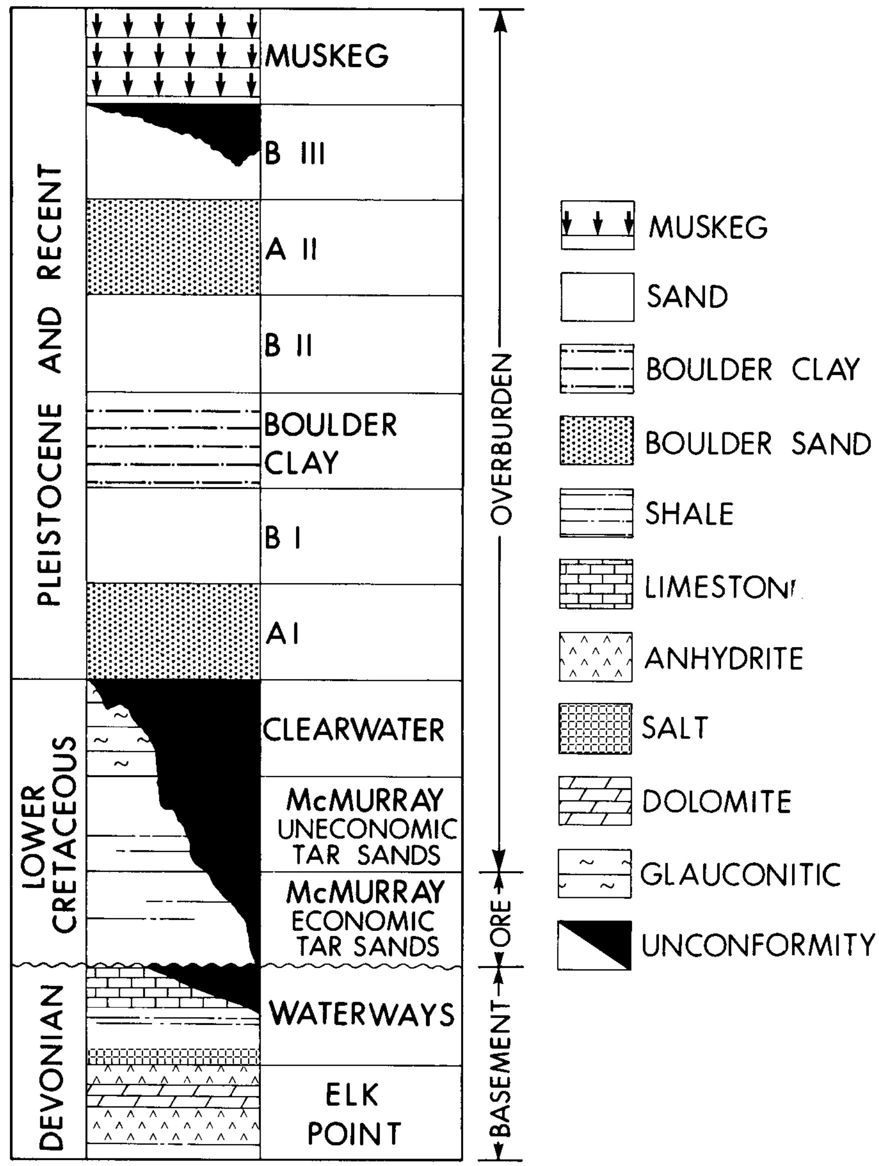

FIGURE 1. Columnar section of strata present in the mining area of lease 86.

The overburden is the source of most of the material used in the construction of large earthworks within the pit. A detailed knowledge of its physical properties and the quantities of the different materials available is necessary so that stripping and dyke construction can proceed simultaneously. The amount of overburden that has to be removed each year for the next 10 years to maintain a production rate of 55,000 barrels of synthetic crude oil per day is shown in figure 2. The maximum rate of 23 million cubic yards per year will be reached in 1983, and the minimum rate of 7 million cubic yards will occur in 1976.

The Ore Body

The ore body consists of a basal fluvial sand overlain by lagoonal deposits which have been channelled into and refilled with silty beds, some of which are now cemented by siderite.

The oil impregnation within the ore body is not homogeneous, but varies in richness from 0 to 18 percent (by weight). The deposit also contains numerous thin beds of clay which contain no bitumen. Pockets of low pressure combustible gas have been encountered on the property within the ore body.

There is a noticeable increase in coarseness of the sediments and in bitumen saturation toward the base of the formation. In the basal unit the grain size varies from pea-sized pebbles to coarse silts and the bitumen content is high. Thin and discontinuous clay beds with dips of 5 to 8 degrees to the north are

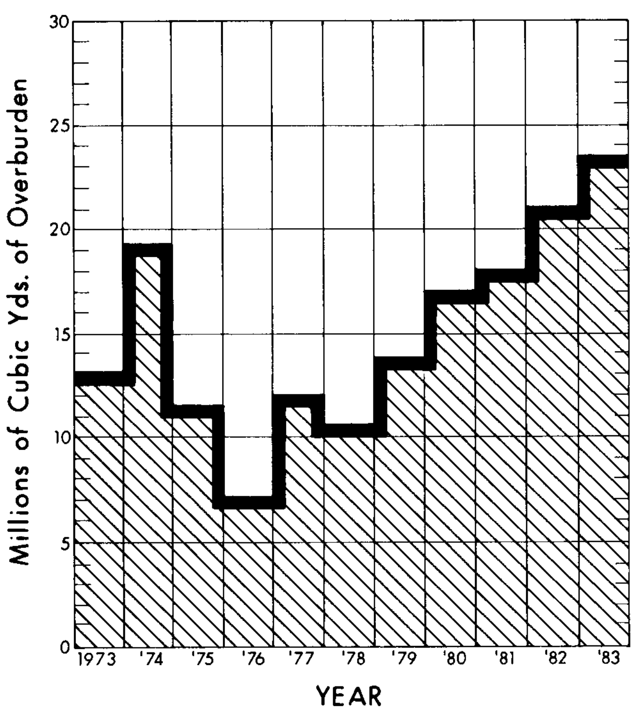

FIGURE 2. Amount of overburden to be moved each year from lease 86 to maintain a production rate of 55,000 barrels of synthetic oil per calendar day.

common. Fragments of wood up to a few cubic inches in size and occasional logs and stumps occur within these beds. Silt lenses up to 6 inches thick are also present.

Transition of the "basal sand" to the overlying fine-grained "lagoonal" deposits is gradational. Clay bands varying from 1 inch to an occasional 6 feet in thickness, traceable for 100 to 200 feet, are characteristic of this unit, and the dip of the beds varies from horizontal up to 5 degrees to the north.

A conspicuous old channel cuts through the "lagoonal" deposits. The base of the channel dips to the north but massive (up to 60 inches thick) clay beds within the channel dip to the north at steeper angles than the surrounding "lagoonal" beds.

Within the channel there are two types of hard rock lenses:

1) A light brown-grey rock, rarely more than 12 inches thick, sometimes totally surrounded by oil sands. Microscopic examination shows that these rocks are composed chiefly of quartz grains ranging in size from silt to fine sand cemented by calcite and siderite.

2) Cemented oil-saturated sandstone: A black, massive, very hard, sandstone lens composed of quartz grains cemented by siderite and calcite. This lens ranges in thickness from 3 to 42 inches and is impregnated with bitumen.

Observations at the mining faces have established that the rock lenses are invariably associated with minor channels within the major scour.

MINING

The economics of the mining operation are dependent on a great number of factors, particularly the stripping ratios and grade of the ore. The cut-off grade used as the basis for computer definition of vertical and horizontal pit limits is 8 percent bitumen, but the stripping ratio also affects this decision.

Oil sand mining and bitumen extraction is complex and includes the following steps: land clearing, muskeg stripping, overburden removal and dyke building, oil sand mining, and extraction of bitumen.

Land Clearing

The vegetation on the mineable part of the lease is largely a black spruce and tamarack swamp with very low grade trees growing in wet muskeg from 5 to 20 feet thick. The timber cannot be included in the earthworks, and must be completely cleared. Because muskeg does not freeze to great depths, wide-tracked crawler tractors with brush rakes must be used to stay afloat during clearing operations. Despite the precautions taken, tractors frequently break through the frozen crust.

Muskeg Stripping

Muskeg must be thoroughly drained before removal is possible. This is achieved by digging an extensive network of ditches, and allowing the muskeg to drain naturally for two years. Despite the extended drainage period, muskeg will remain spongy and wet and must be removed after freezeup. The system used to remove muskeg by Great Canadian Oil Sands employs 15-cubic yard front-end loaders and 150-ton trucks. The muskeg piles cannot be left unrestrained, since on melting the material spreads over the countryside producing a very messy condition over a large area. In order to produce a reasonably orderly array of muskeg waste piles, a retaining structure of soil is built around them and the height of the muskeg dumps is limited to 100 feet.

Main Overburden Removal and Dyke Building

Eighty percent of the overburden is needed to build high dams inside the pit to contain the future tailings. These structures can be 300 feet high and are built with surface slopes of 1 to 2.5 percent with impervious clay cores. The compaction of material controls the rate at which the structure can be built, and the main dyke construction can only be done when the materials are not frozen.

The original mode of operation, using a 15-cubic yard shovel and 75-ton dump trucks for dam building, was abandoned in 1971. Studies were made to find the least costly overburden-removal scheme which would meet all of the physical requirements of the operation. The method now in use employs five Caterpillar D9G bulldozers for ripping and dozing, seven Marathon LeTourneau L700 15-cubic yard front-end loaders, and a fleet of 21 WABCO 150-ton capacity trucks.

Maintenance of haul roads and housekeeping in borrow and fill areas is accomplished by the use of caterpillar M16 graders and, for extra heavy work, a Raygo giant. Three Allis-Chalmers HD41 tractors are used for spreading on the dump, and compaction is accomplished by four Caterpillar 835 packers augmented by one 50-ton rubber-tired compactor.

Mining operations

The average thickness of the ore body is 150 feet, and most of the oil sand is mined by two bucket wheels, each operating on a separate bench, one above the other. Transfer of the materials from the face to the extraction plant is accomplished by an articulated conveyor system. Some isolated pockets of oil sand occur which are not readily accessible to mining by the large bucket wheels; these areas are mined by the use of a small bucket wheel discharging into trucks which unload onto the trunk conveyor. One of the complications in the mining and extraction activity is the logistics problem of providing surge capacity between mining and extraction. With a plant processing an average of 140,000 tons per day of oil sand (Fig. 3) it is not logical to provide a quarter of a million ton surge pile between the mine and the mill. The surge of hydrocarbons in the system is located after extraction and before the refining process. The material from the mine is dropped into one 5,000-ton feed bin which is the sole surge capacity ahead of extraction. This bin will only keep the extraction plant going for thirty minutes at full rates.

The two principle mining machines are bucket wheel excavators, manufactured by a German company (Orenstein & Koppel LMG). Each bucket wheel excavator weighs about 1,800 tons and is supported on six large tracks. The units are electrically powered and have a 33-foot diameter digging wheel on the end of a long boom. Each digging wheel is equipped with 10 buckets and 10 pre-cutters. Approximately 1,400 H.P. is required to drive the wheel. The normal action of the wheel is to take a slewing cut, terrace form, approximately 120 feet wide and 70 feet thick. Each bucket wheel has produced peak quantities in the order of 10,000 tons per hour for short periods, but the average output of a wheel is closer to 5,000 tons per hour. A large amount of productive capacity is tied up in each machine; therefore, when a machine is stopped for maintenance, a large amount of productive capacity is lost. The normal availability of bucket wheel excavators is expected to be in the order of 55 to 60 percent. At the Great Canadian Oil Sands mine, early records gave availability in the order of 47 percent but recent experience has given availability in the order of 63 percent. The combined output of the two bucket wheels at peak rates cannot be handled by the conveyors, neither can advantage be taken of this peak output for any sustained period of time due to the low capacity of the surge bin between extraction and the mine. For this reason average rates, high sustained availabilities, and shared production tend to be the rule.

All conveyors in the mining system operate at 1,080 feet per minute. The face conveyors which are shiftable, and the collector conveyors which are permanent but extendable, are 60 inches wide. The main trunk conveyors are both 72 inches wide. All transfer points between the conveyors are equipped with impact plates providing for a vertical drop of material onto the belt beneath with striker bars to prevent major impact damage from large lumps. Each of the principle mining systems employs eight men per shift.

The basic principle of a bucket-wheel system is continuous operation with a minimum of maneuvering and wasted time; therefore, selective mining for rejection of undesirable oil sand within the pit limits is not possible.

The physical properties of the oil sand vary greatly with the weather. In summertime, the floor of the bench upon which the large bucket wheels must travel is soft, and these large machines with ground pressures of 18 psi have been known

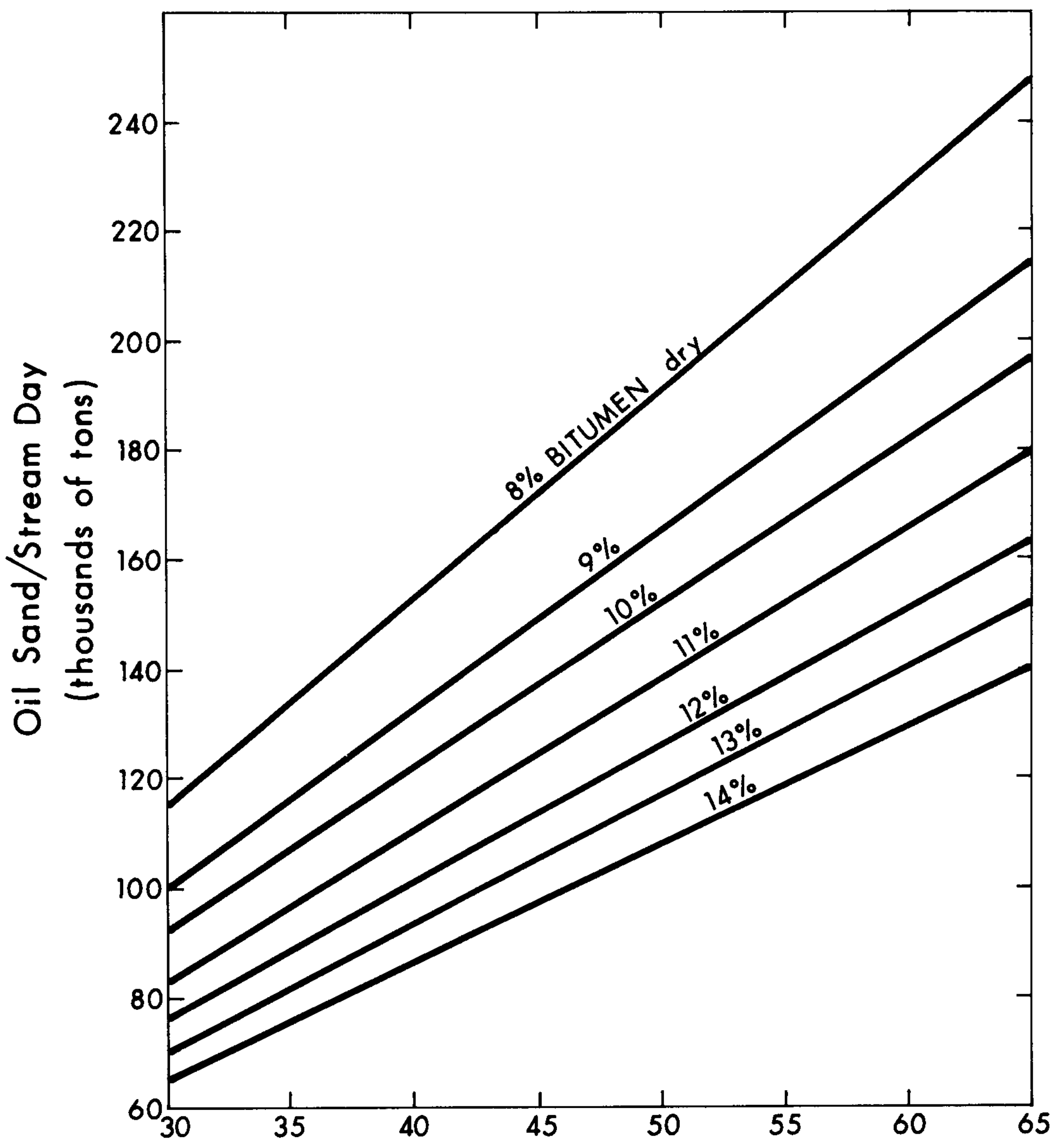

FIGURE 3. Mining capacity required per stream day for several grades of oil sand.

to sink up to their hubs. The degree of ground softness, however, depends not only on the summer temperatures, but also on the bitumen content, the particle size of the sand, the amount of moisture, and the gas concentration in the oil sand. In wintertime, due to the relatively low specific heat and the fairly high thermal conductivity of the oil sand, there is usually enough frost penetration on the benches to support very heavy units of equipment. Under normal summer conditions the viscous fluid film between the sand grains binds the mass together like a fine-grained asphalt road mix, and the oil sand on the mining faces is mineable by the bucket wheels without prior preparation. There are 120 teeth on each bucket wheel and during the first few months of operation the teeth were being consumed so rapidly that it was necessary to bring teeth to the mining area by plane from as many sources as could be found, as quickly as they could be made. In the early days, each tooth weighed over 100 pounds and a set of teeth could be completely worn out in four hours of digging.

In the wintertime, a mining face which has not been disturbed is similar to concrete but tougher; it will not shatter in the cold. The bitumen matrix between the sand grains is merely more viscous. Under these conditions, excavating the face is virtually impossible. Teeth glow red and can be torn out of the sockets, and the thick steel plates from which the buckets are made can be torn. Very heavy shock loads are transmitted through the booms of the digging wheels. Once the frozen face is penetrated, the sand behind the face is at about -40°F. In excavating the 40-degree material, the water envelope around the sand particles is ruptured, a considerable amount of vapour is released into the atmosphere, and visibility drops. The water tends to freeze and frozen masses of oil sand will completely close off the bucket opening, stick to the sides of the bucket wheel, freeze to conveyors, build up in transfer points and cause general distress. Occasionally, large blocks of frozen sand may peel out along the planes of weakness and endanger the machinery working beneath.

Some mobile equipment is required in support of the main mining apparatus. Rubber-tired bulldozers are needed to clean up the backspill from the bucket wheel so that the wheels may approach close enough to the toe of the mining bench to reach the face and take a proper cut. Also, large tractors are required to shift the conveyors and move large blocks of oil sand which may roll to the pit floor. Front-end loaders and 75-ton trucks are used to clear the lumps off the mine benches. Front-end loaders and trucks or self-loading scrapers are used to clean the pit floor. This mobile equipment operating in the oil sands area has a wider variety of problems than those associated with the bucket wheels and conveyors. Warm oil sand, wet oil sand, or freshly excavated oil sand in cold weather is sticky. The accumulation of this gritty, adhesive mass onto any exposed surface creates serious problems in both small and large vehicle operation. Control cables and hoses underneath a machine will gather an inch of oil sand coating in just two passes along the bench during the mud season. A splash of oil sand will plug up a vehicle radiator during one shift. The lubrication and fueling necessary in the field has to be done with meticulous care to avoid the inclusion of sticky oil sand particles. The same problems of abrasion occur on the cutting surfaces of scrapers, dozers, and loaders as on bucket wheel teeth. Tractor undercarriage repairs cost twice as much per machine as one would normally experience in other applications. Transmission fluid cooling systems are generally quite inadequate for the filthy condition which prevails underneath equipment operating in oil sands. One final operating problem is that the organic compounds in the bitumen attack the rubber of tires, resulting in heavier than usual tire costs, and if rubber is made to resist the attack of these hydrocarbons then the tire walls will generally fail in the cold weather and have very low tear resistance. In the last few years, Great Canadian Oil Sands Ltd. has overcome many of the major problems associated with the mining activity, and over the next few years hopes to have all of them solved.

Extraction of bitumen from oil sands

The extraction plant has four parallel independent processing lines. A generalized flow sheet of the entire operation is shown in figure 4. Each line will operate normally at 1,100-1,200 tons per hour of oil sand feed and has a peak capability of 1,500 tons per hour to allow for periods of below average grade in the feed.

The fundamental steps in extraction are feed conditioning, separation of the bitumen, waste disposal, and cleaning the bitumen concentrate as shown in figure 5.

Conditioning is achieved by mixing feed with water and caustic soda at 180°F to bring the pH value within the 8.0 to 8.5 range (without the addition of an alkaline agent[2] the pH is 5.5 to 7.5). Each conditioning drum is a rotating horizontal vessel, 17 feet in diameter and 51 feet long. Oil sand, hot water, and dilute caustic soda for pH adjustment are introduced into the feed end of the drum, and steam is sparged into the drum under the surface of the pulp to maintain the outlet temperature at 180-190°F. The conditioned pulp at this point contains approximately 70 percent solids and is discharged from the drum through a screen to a feed sump. Any necessary make-up process water is added on the screen. Middlings recycle is added to the feed sump to maintain the proper density for pumping the slurry to the separation cells.

The separation cells are vertical cone-bottom vessels, 44 feet in diameter and 24 feet high, with a center feed well into which the diluted pulp is pumped. The froth which floats is skimmed by rakes to a peripheral launder where it is collected and pumped to the final extraction plant. The coarse mineral matter, which settles to the bottom cone, is raked to the center discharge and, thence, to a pump sump, where it is repulped with scavenger tailings and dilution water and pumped to the tailings pump house. These combined tailings are then pumped to the tailings pond.

The middlings stream is withdrawn from the side of the separation cell and pumped to the feed sump for recycle and also to the scavenger circuit. The scavenger circuit consists of two banks of cells, each bank serving two processing

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2 Several alkaline agents were tested for pH control. Caustic soda proved to be the most effective and economical choice.

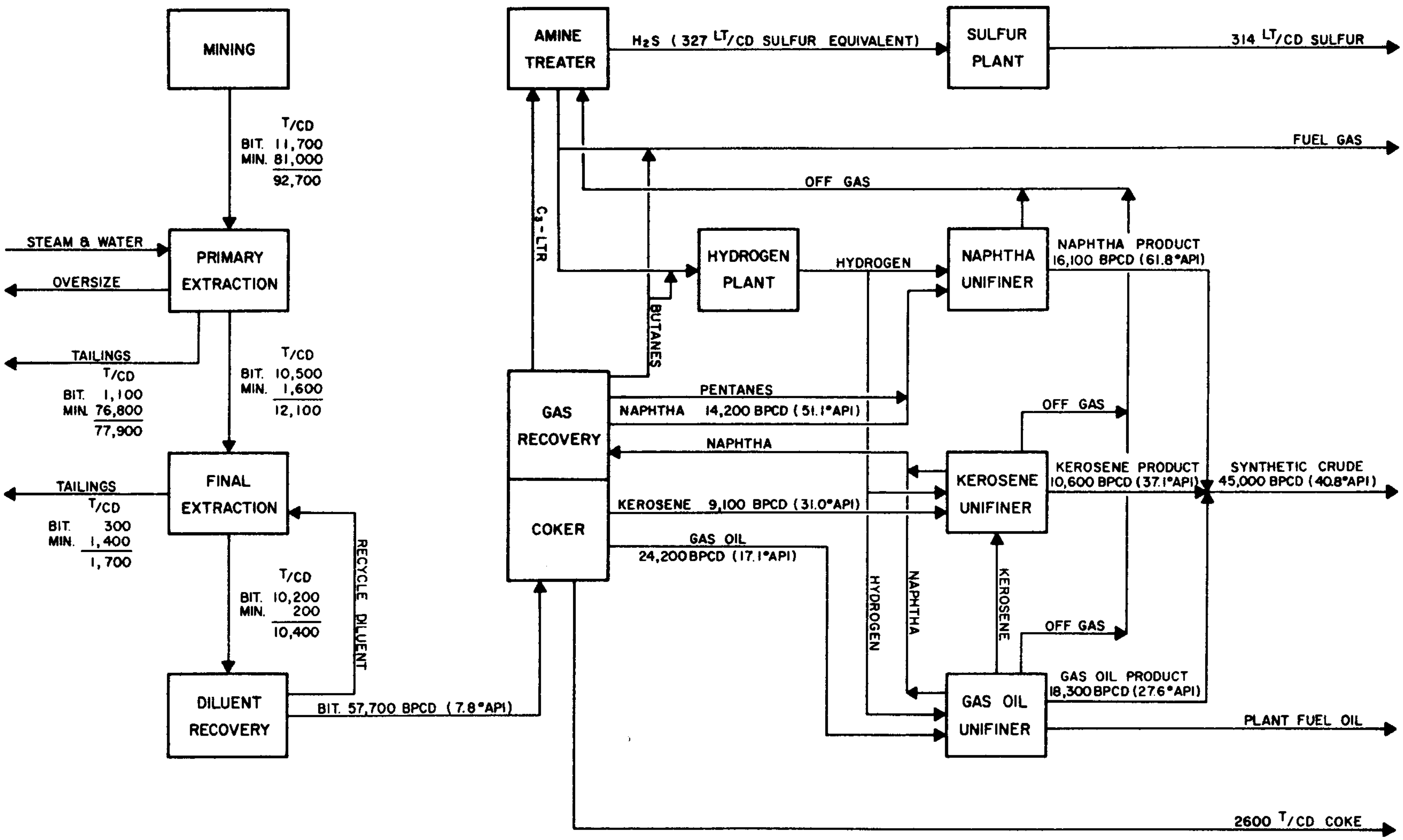

FIGURE 4. Generalized flow sheet showing major process steps and material flows in the GCOS plant (after Innes and Fear, 1967).

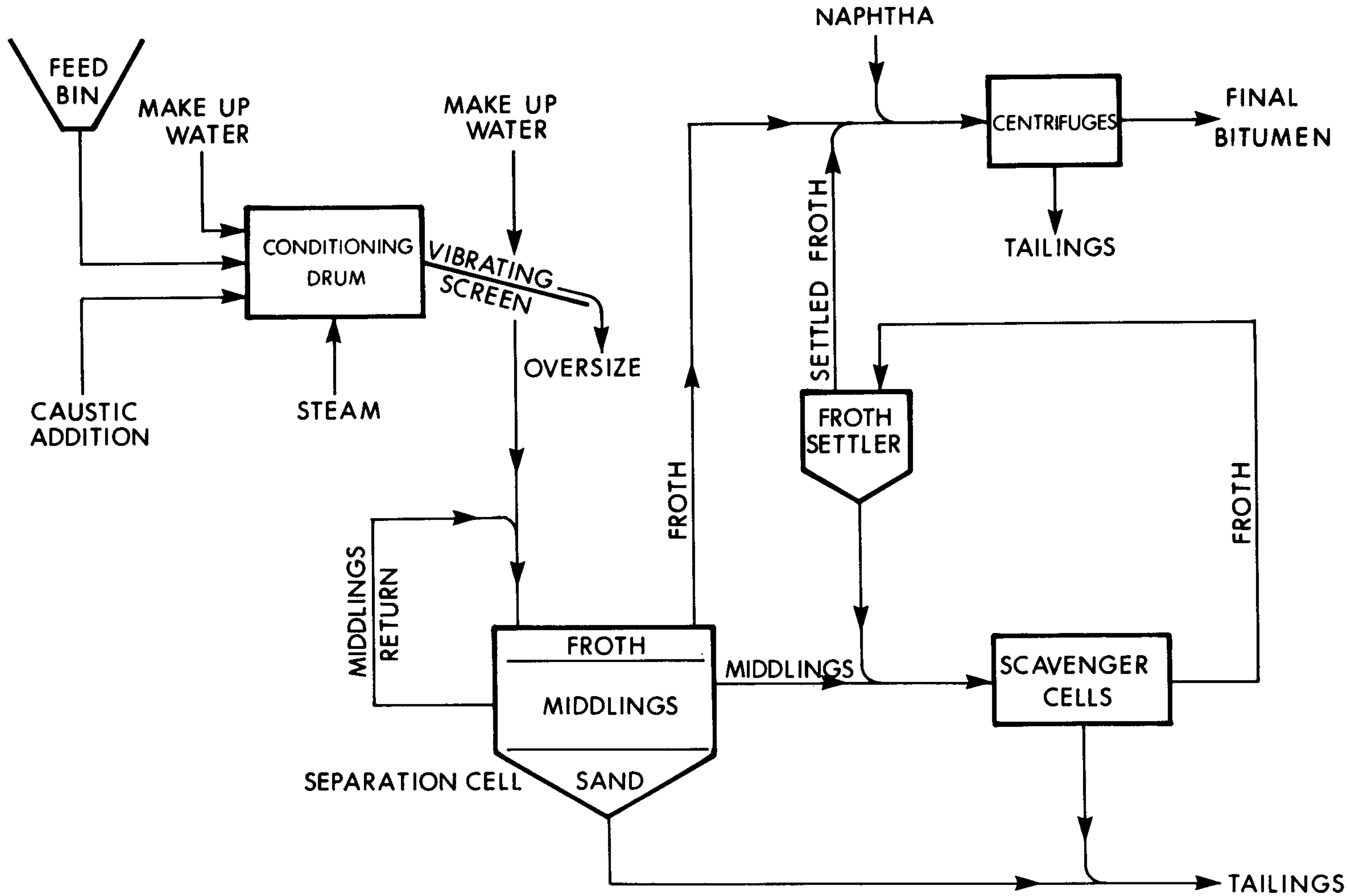

FIGURE 5. Flow diagram of the primary extraction process.

lines. The cells are the largest conventional air-flotation units commercially available. The combined bitumen froth from all the scavenger cells, rich in water and mineral, is allowed to settle in the froth settlers; again, there is one settler for each two processing lines. The settler bottoms are recycled to the scavenger cell feed while the froth is combined with that from the separation cells as feed to the final extraction plant. The mineral product from the scavenger flotation cells is combined with the separation cell minerals as mentioned above.

The plant is designed for a recovery of 90 percent of the bitumen in the oil sand feed.

Final Extraction

A schematic diagram of the final extraction process is given in figure 6. The combined froths arriving from the primary extraction at a temperature of about 160°F are heated with steam and diluted with sufficient coker naphtha to reduce the viscosity of the bitumen for centrifugation. The centrifuge process is conventional, using standard commercially available machines in parallel. The diluted bitumen product contains approximately 5 percent (by weight) water and 1 percent (by weight) mineral. The plant is designed for a recovery of 97 percent of the bitumen in the feed. The solid material removed by the centrifuges is repulped with water and pumped to the tailings pond. The diluent and water are removed from the bitumen by distillation and the diluent is recycled.

UPGRADING

The bitumen produced in the extraction plant is not suitable for market and must be upgraded before it can be shipped to customers (Table 1). The processing units used in the GCOS upgrading operations are standard, but because the bitumen feed is so different from conventional crude oil, a whole series of operating problems had to be solved and a new set of operating standards have been established.

The diluent used for viscosity reduction is recovered by heating the mixture to about 600°F and distilling it overhead in the diluent-recovery unit. It is then returned to the extraction plant for reuse. After the diluent is removed, bitumen only remains which is heated to about 900°F and introduced into a coking drum. This is a standard delayed-coking operation in which the bitumen is physically broken into lighter materials and the heavy coke deposited in the drum. A proportion of the sulfur and virtually all of the metals are deposited with the coke. The hydrocarbons pass overhead into a fractionating tower where they are separated into four main components:

1) light gases, which are desulfurized and used as heating fuels or charge gas for the manufacture of hydrogen which itself is used in desulfurizing the final liquid products;

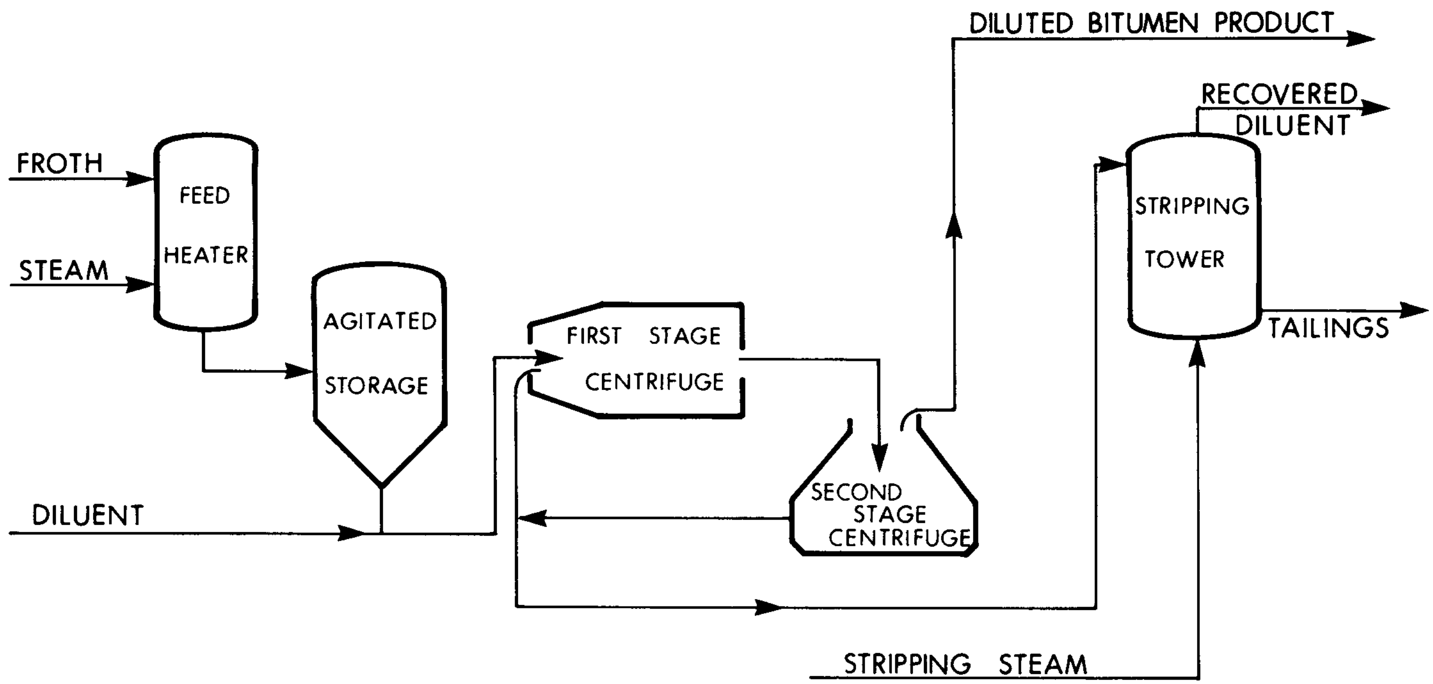

FIGURE 6. Schematic flow diagram of the final extraction process.

2) naphtha or the portion which can be upgraded to gasoline;

3) kerosene or the component from which jet fuels can be manufactured;

4) gas oil -- the heaviest component -- which is used as a heating fuel or mixed with kerosene for use as fuel in diesel engines.

Each of the three liquid components is then charged to a separate hydro-desulfurizer where most of the remaining sulfur, nitrogen, and trace metals (if any) are removed and some of the aromatic compounds hydrogenated. The stock to be upgraded is heated to temperatures of 600° to 750°F (depending on which component is being treated) and introduced into a reactor tower in the presence of hydrogen and a catalyst. The naphtha system operates at about 600 psi and the other two (gas oil and kerosene) at about 1,400 psi. Trying to pioneer units such as air-cooled condensers or coolers at 40 to 50 degrees below zero (°F) can also be a problem.

The hydrogen plant is a standard type unit where methane gas is reformed in the presence of steam to produce hydrogen for hydrotreating the component streams. The hydrogen plant is designed to produce 63.5 million standard cubic feet a day of 95 percent hydrogen for use in the unifiners. Hydrogen is produced by steam-reforming of amine-treated gas from the coker and unifiners. The unit will operate at 300 psig and 1,500°F reactor outlet. The CO_2 is removed from the product gas after two shift stages by treating with an activated carbonate solution.

Table 1. Comparison of Bitumen and Synthetic Crude (after Humphreys, 1973)

	Raw Bitumen	Synthetic Crude Product
API Gravity	9-10	35
Boiling range	400-1100°F	80-900°F
Sulfur	4.5-5.0%	0.2%
Nitrogen	0.5-1.0%	0.1%
Vanadium	150 ppm	Nil
Colour	Black	Straw
Ash	1.0%	Nil

SHIPPING

After upgrading, the three components are blended together and the blend shipped *via* GCOS pipeline to the Interprovincial system in Edmonton, from whence it is shipped to customers as far east as Ontario and Ohio.

TAILINGS DISPOSAL

The tailings stream, about 24,000 gallons per minute, is delivered to the pond by pumps. In the tailings area the coarse fraction of the tailings, sand, is used to build the retaining dyke, while the slimes portion flows into the center of the pond. Some of the excess water in the tailings pond can be recycled as a substitute for fresh water. Some of the fines in the original oil sands are 2 microns and smaller in size and take a long time to settle; thus, recycle water contains a fair amount of "clay-size" material. When the tailings pond water is recycled, this material builds up and contributes to middlings viscosity. While the subject is too complicated to discuss in this brief article, it can be said that, for oil sands having the particle size distributions we have observed, recycle water having 10 percent or more of less than 2 micron size material is not suitable for recycling; but water having 5 percent of less than 2 micron size material can be substituted on the basis of 2 gallons of recycle water for 1 gallon of fresh water.

LAND RECLAMATION

Research studies are in progress to define the chemical, physical, mineralogical, and microbiological properties of tailings deposits. Concurrently, field studies to determine how tailings can be treated to improve their quality by the addition of topsoil, leaching experiments, use of synthetic fibres, muskeg, and manure are also in progress, as are field revegetation experiments and "high-speed" laboratory growth experiments.

The fact that most of the lease is mineable, that the overburden swell factor is 7 percent, and the effective swell factor of tailings is 35 percent means that when the lease has been worked out the "land surface" to be reclaimed will be over 100 feet higher than the original surface. This factor will have to be taken into account in final reclamation plans.

SULFUR RECOVERY

The various gas streams are treated in either a high or low pressure amine absorption unit which produces sweet fuel gas and hydrogen plant feed. The H_2S removed from the gas streams is processed in a conventional two-stage sulfur recovery plant. The sulfur recovery facilities are designed for a capacity of 340 long tons per stream day, which represents approximately 95 percent of the sulfur charge in the sour gases..

POWER AND STEAM GENERATION

The entire facility, because of its remote location, is completely self-sufficient in utilities. The power plant consists of three independent steam boilers coupled to two turbo-generators. The boilers burn pulverized coke as the primary fuel with some heavy oil support if required. The steam capacity of the plant is 2.25 million pounds per hour at 820 psig and 750°F. The electric generating capacity of the plant is 76,500 KVA at 13.8 KV.

Approximately one-half of the exhaust steam produced is consumed in the hot water extraction process. Roughly one-half of this consumption is used as direct steam to the conditioning drums while the balance is used to heat the extraction process water indirectly.

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INDUSTRIAL MINERAL RESOURCES OF THE FORT McMURRAY AREA

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INTRODUCTION

Present indications are that the Fort McMurray area in northeastern Alberta is on the verge of major industrial expansion associated with development of the Athabasca Oil Sands. It is too early to predict the scale and particularly the rate at which oil sands development will take place, but the growing worldwide demand for conventional energy resources suggests that the Athabasca deposits, which contain in the order of 700 billion barrels of heavy oil, will provide a major share of Western Canada's petroleum production by the mid 1980's.

Much of the industrial activity in the Fort McMurray area will be focused upon extracting and processing the heavy oil deposits themselves, and in this connection the requirements for equipment, manpower, and a wide variety of supporting services and facilities (roads, housing, consumer goods) will be immense. Furthermore, should part of the oil sands production be processed or refined in the Fort McMurray area for petrochemical purposes -- rather than be shipped elsewhere for upgrading -- the demand for industrial materials and services will be further enhanced, depending on the nature and scale of the refining facilities. In any case, the pressure to utilize the *total* resources of the Fort McMurray-lower Athabasca River region is bound to gain momentum as development of the oil sands proceeds. It is worth considering at this time those mineral resources -- other than heavy oil deposits themselves -- which have some potential for economic development.

This paper describes the existing and potential mineral resources of that part of northeastern Alberta for which Fort McMurray is the main distribution center. The area involved extends from the Saskatchewan border on the east, west to the fifth meridian (longitude 114°) and from latitude 56° on the south, north to Lake Athabasca and the boundary of Wood Buffalo National Park (Fig. 1). Fort McMurray, situated at the junction of the Athabasca and Clearwater Rivers, is the only significant population center in the region. The town is serviced by a main line of the Northern Alberta Railway which extends northeast from Edmonton *via* Lac La Biche, and by Alberta Highway No. 63, an all-weather road which connects with highways leading to Edmonton about 220 air miles south of Fort McMurray.

The mineral resources of the Fort McMurray area include a wide array of industrial raw materials, ranging from metallic byproducts of oil sands to sand and gravel deposits found in glacial drift. A few of these resources can be developed independently of oil sands, but the economic potential of most is closely related to industrial growth associated with oil sands extraction and processing. An attempt is made below to assess these resources in relation to the probable sequence of industrial activities which the writers foresee taking place in northeastern Alberta during the next 10 to 25 years.

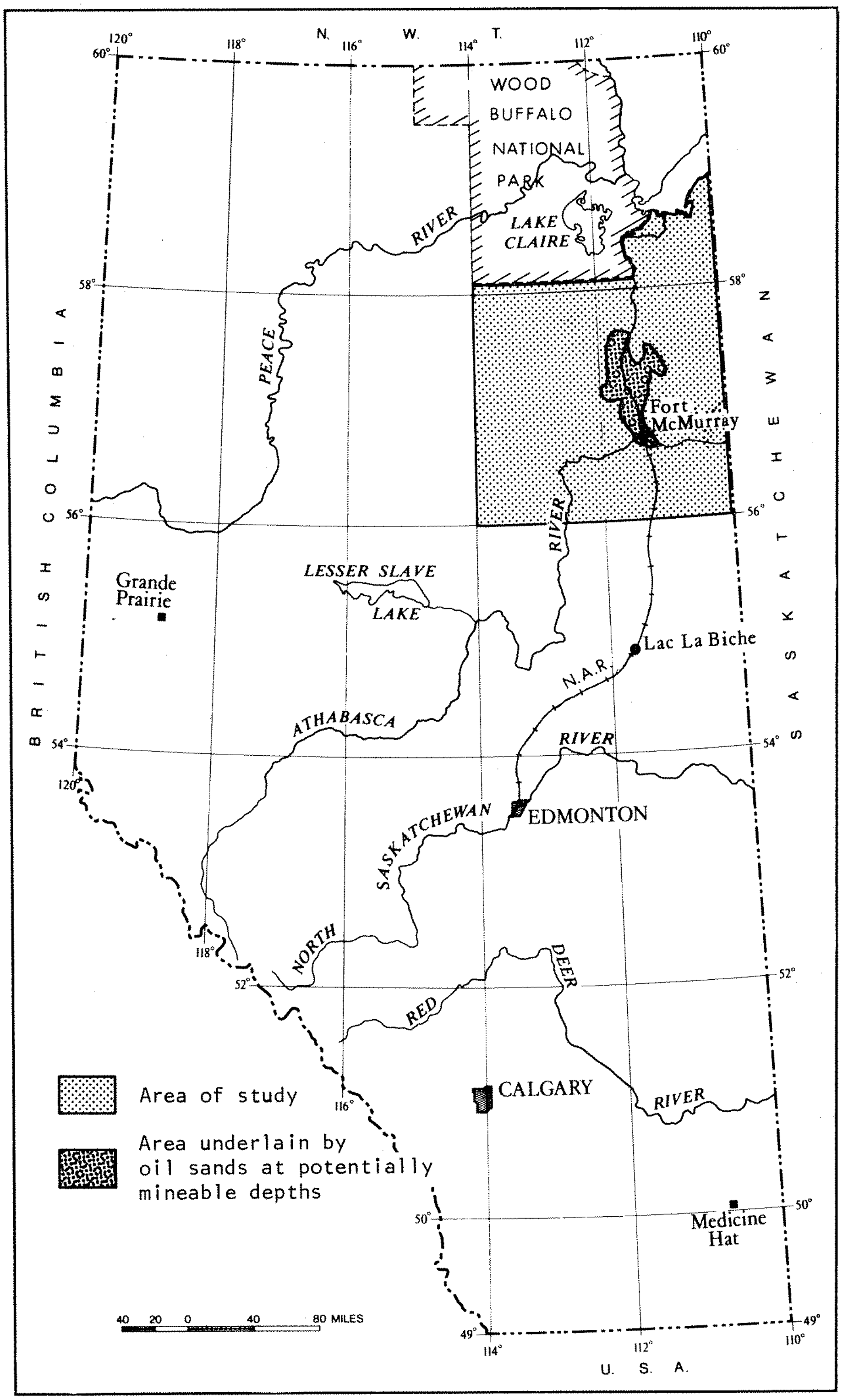


FIGURE 1. Location of study area.

PHYSIOGRAPHY AND GENERAL GEOLOGY

Physiographic Units

The area 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 in the northeast;

(2) the lowlands adjacent to the Athabasca River;

(3) dissected highlands (plateau) extending about the western, southern, and southeastern perimeter of the area.

Precambrian rocks of the Canadian Shield underlie approximately 3,000 square miles in the northeast part of the area, between Lake Athabasca and the Marguerite River (Fig. 2). However, bedrock exposures are scarce, owing to the widespread cover of glacial and recent delta deposits. The only extensive outcrops of Precambrian rocks are in the vicinity of the Marguerite River, near the southern limit of the Shield. The Marguerite River outcrops consist of crystalline "basement" rocks, mainly various types of granite and quartz monzonite and derived cataclastic rocks (Godfrey, 1970). To the northeast, "basement" rocks are overlain unconformably by nearly flatlying quartzites (Athabasca Formation) of Late Precambrian age. However, exposures of the Athabasca Formation are rare and the areal extent of these strata beneath the glacial drift is uncertain.

Lowlands adjacent to the Athabasca River are most extensive in the northern part of the area and are underlain by carbonate and evaporite rocks of Devonian age. 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 valleys of the Athabasca and Clearwater Rivers are entrenched 200 to 500 feet below the surrounding "plains" level. The region has a veneer of glacial drift, mantled in most places by muskeg, so that bedrock exposures are confined mainly to the major river valleys and the lower reaches of their tributary streams (Norris, 1963; Green *et al.*, 1970). The regional structure is a homocline with dips in the order of a few feet per mile to the southwest. Local folds seen in exposures of the Upper Devonian Waterways Formation along the Athabasca and Clearwater Rivers are the result of solution of the underlying salt beds.

The lowlands merge to the south and west with a series of dissected highlands or tablelands (Fig. 2) -- Birch Mountains, Muskeg Mountain, Stony Mountain, Thickwood Hills -- underlain by nearly flatlying shales and sandstones of Cretaceous age. These areas are remnants of a large dissected plateau (Alberta Plateau) and attain elevations up to 1,500 feet above the surrounding "plains" level. The upper surfaces of the highlands are flat to gently undulating, having been modified locally by glaciation. The slopes are gradual to

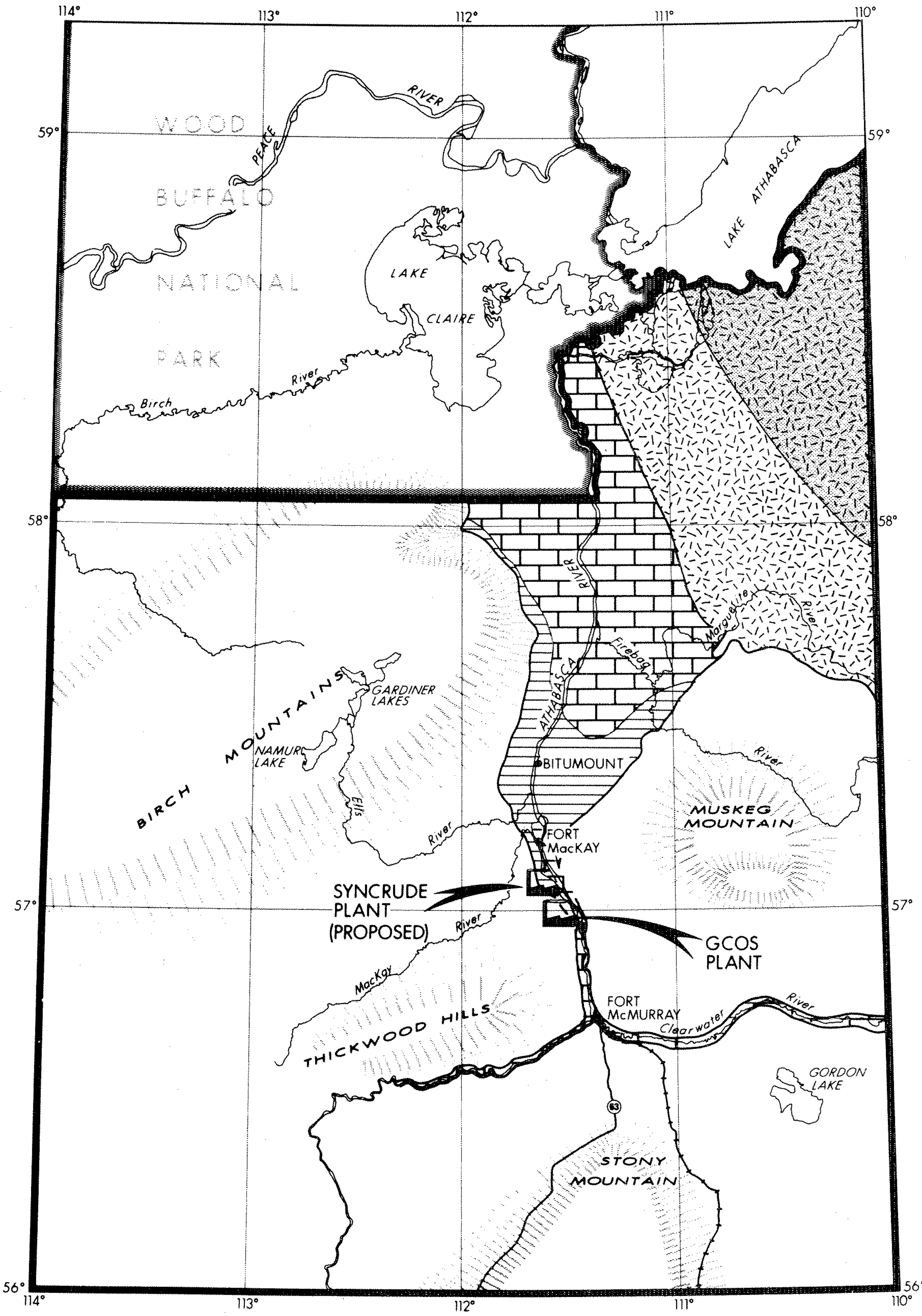


FIGURE 2. Physiography and general geology of the Fort McMurray area.

LEGEND FOR FIGURE 2

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

PRECAMBRIAN
Athabasca Fm: quartzite, sandstone

PRECAMBRIAN
Crystalline "Basement" Complex: granitic plutonic rocks

Study area boundary

National Park boundary

relatively steep, as, for example, along the northeast margin of the Birch Mountains where several small, fast-flowing streams have cut through the mantle of glacial drift and colluvium into Cretaceous bedrock.

Glacial Deposits

Although the major physiographic features of the Fort McMurray area are the result of erosion of different bedrock lithologies during Tertiary and Early Pleistocene time, the land surface has been modified by continental glaciation during Late Pleistocene (Wisconsin) time. Virtually the entire area is covered by a veneer of unconsolidated glacial and derived postglacial deposits (Fig. 3), which range in thickness from a few to several hundred feet, and exploration for mineral deposits by conventional means -- other than drilling -- is severely restricted over most of the region.

Glacial deposits are thickest in the eastern and southern parts of the area, and along the southwest flank of the Birch Mountains where accumulations of till, sand, and gravel cover bedrock to depths of more than 600 feet (Green *et al.*, 1970; Bayrock, 1971). Along the Athabasca River lowlands and the Shield area to the northeast, glacial deposits are mainly sand and gravel derived from nearby quartzites of the Athabasca Formation (Fig. 3). In the southern and western parts of the area, underlain by Cretaceous sandstones and bentonitic shales, glacial deposits have a much higher proportion of clay and silt, reflecting the composition of the underlying bedrock. Extensive deposits of aeolian sand in sheet and dune form are found along the Athabasca River lowlands, being developed from underlying or adjacent deposits of outwash sand and gravel. Similar dune fields also are widespread in the southeast part of the area, being derived from associated glaciolacustrine sands and silts.

Organic deposits -- muskeg or peat bog -- cover surficial deposits to depths of one to tens of feet over 60 to 75 percent of the region. They are most prevalent in the highland areas.

POTENTIAL MINERAL RESOURCES

The mineral resources of the Fort McMurray region include naturally occurring rocks and minerals as well as certain byproduct materials derived from oil sands mining and processing. Excepting salt (from earlier times) and sand and gravel, essentially no development of these resources has taken place nor is any likely to for some time, for their potential relies to a great extent on large-scale development of the indigenous oil sands resources. The rich variety of industrial minerals found in the region provides almost limitless scope for industrialization concomitant with oil sands extraction and processing.

The industrial minerals of the region are presented in their geological context in figure 4 (in pocket) and are listed in table 1 under broad categories of potential industrial use. Those derived as byproducts are indicated on a flow chart of the oil extraction process in figure 5. The minerals are discussed below within the scheme of grouping in table 1, each mineral according to its *principal* potential use.

Agriculture and Related Uses

This category includes minerals having potential use as soil conditioners or fertilizers, and in certain aspects of pollution control and surface reclamation. The minerals of principal use as such are peat moss and glauconite sand. Others of subordinate use (sulfur, fly ash, limestone) are dealt with subsequently.

The potential for agriculture in the Fort McMurray area appears limited owing to unfavorable climatic and soil conditions (Lindsay, *et al.*, 1958). However, the projected population increase with oil sands development will create a substantial market for fruit and vegetable produce in the region, providing for possible development of an indoor horticultural industry. Indoor horticulture is practised on a commercial scale in other areas and appears ideally suited to a region of such short "outdoor" growing season as Fort McMurray (average frost-free period 67 days).

Peat Moss

Peat moss bogs are extensive in the region; more than half the surface is estimated to have 70 to 100 percent organic soil cover -- generally water saturated and called muskeg. The muskeg varies in depth up to several feet, and in many places is permanently frozen below depths varying from 9 to 30 inches beneath the surface. Individual bogs are unclassified as to extent, depth, or plant colonies (only the sphagnum mosses are marketable); thus, the commercial potential of peat moss in northeastern Alberta is undetermined. Widespread conditions of poor drainage may preclude commercial harvesting of many of the sphagnum bogs. The peat moss scraped off in preparation for oil sands mining may have value in subsequent surface reclamation.

The main commercial use of peat moss is as a soil conditioner. Another possible application in the Fort McMurray region is in pressed peat containers for use in reforestation programs, horticulture, etc. Peat moss also has been demonstrated to be an effective absorbent for cleaning up oil spills (D'Hennezal and Coupal, 1972).

Glauconite Sand

A thin but persistent bed of glauconite-bearing sand (Wabiskaw Member) directly overlies the McMurray Formation oil sands and forms the base of the

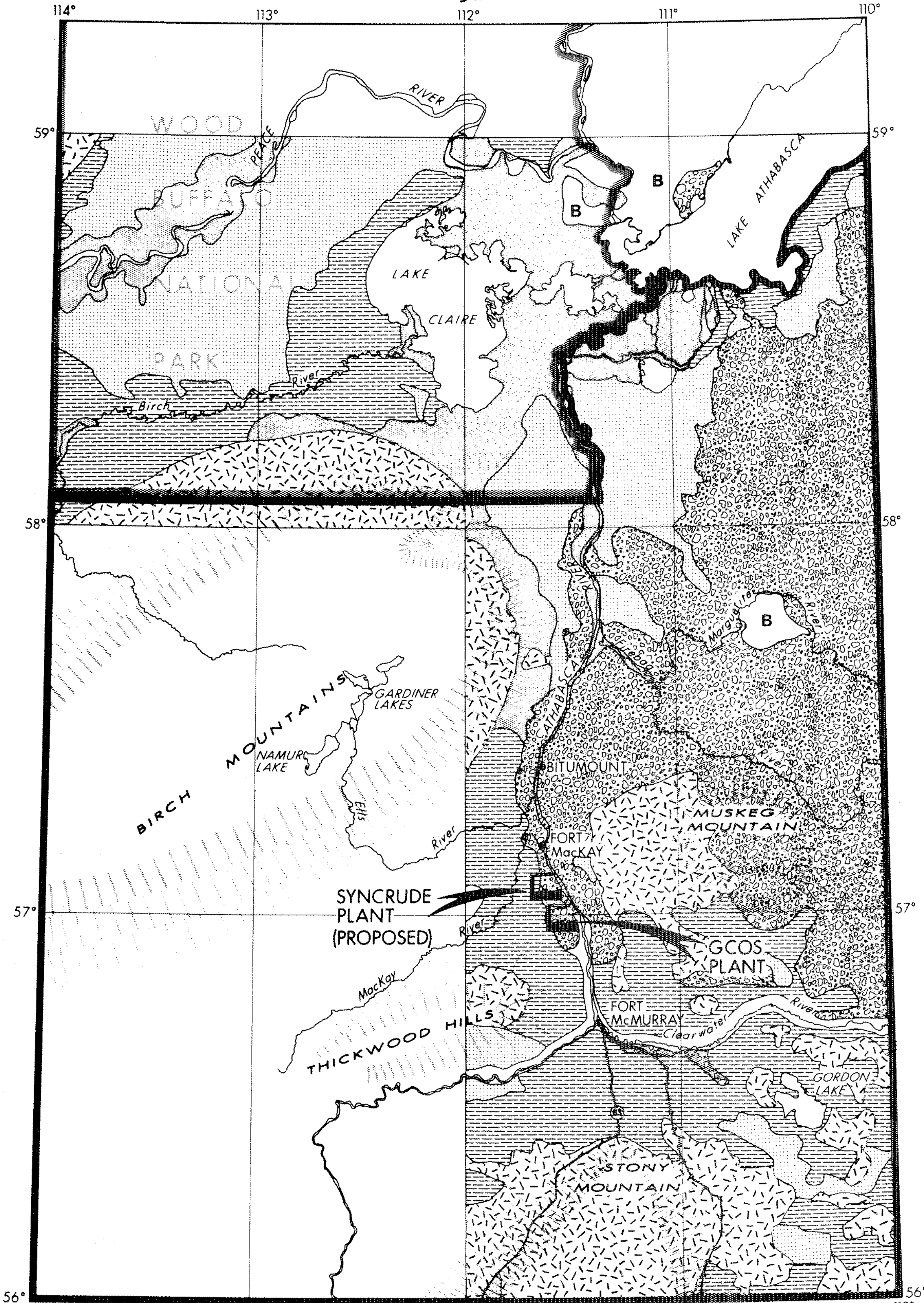


FIGURE 3. Surficial geology of the Fort McMurray area.

LEGEND FOR FIGURE 3

RECENT

Alluvial deposits: sand, silt, clay

Aeolian deposits: sand, in sheet and dune form

PLEISTOCENE

Lacustrine deposits: bedded silt, clay, sand

Outwash, ice-contact deposits: sand, gravel

Ground and hummocky moraine: till

PRE-PLEISTOCENE

B Bedrock

Study area boundary

National Park boundary

Compiled from surficial geology maps published by Alberta Research:

Surficial geology of the Bitumount map area, NTS 74E, Alberta, by L. A. Bayrock. Scale 1:250,000. 1971.

Surficial geology of the Fort Chipewyan map area, NTS 74L, Alberta, by L. A. Bayrock. Scale 1:250,000. 1972.

Surficial geology of the Lake Claire map area, NTS 84I, Alberta, by L. A. Bayrock. Scale 1:250,000. 1972.

Surficial geology of the Waterways map area, by L. A. Bayrock (in preparation).

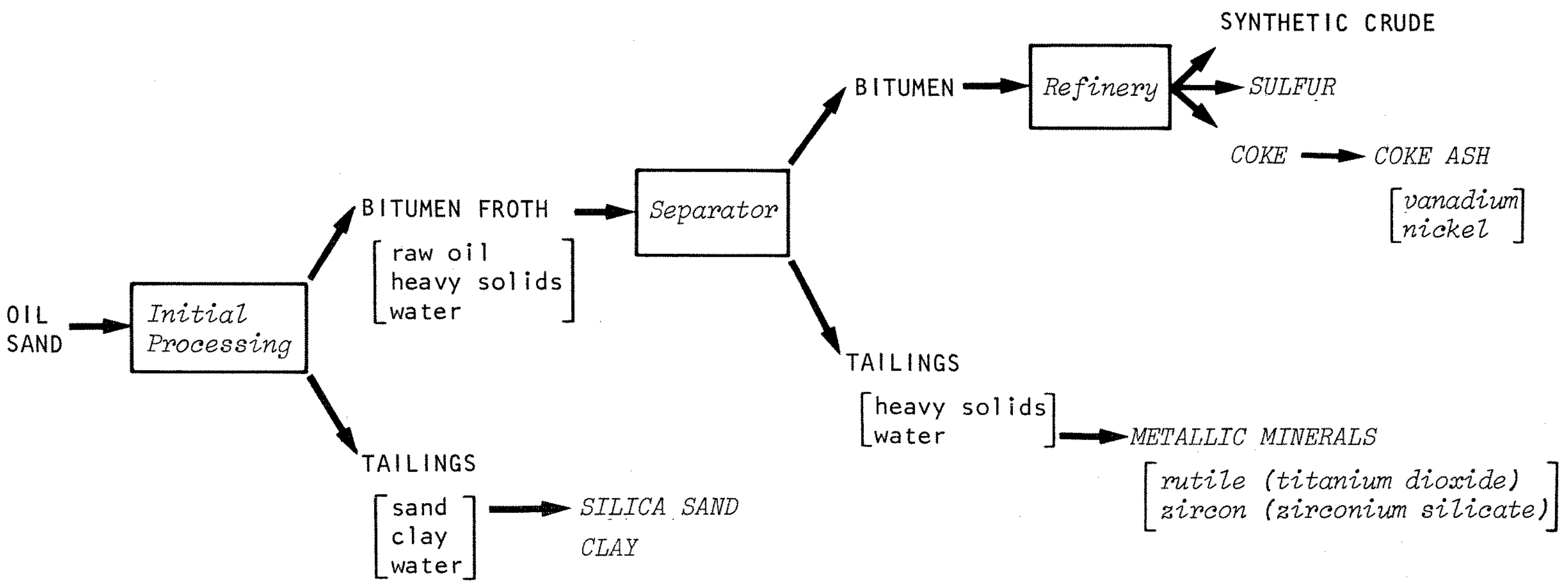


FIGURE 5. Flow chart for conventional oil extraction process, showing byproduct minerals evolved.

Table 1. Industrial Mineral Resources of the Fort McMurray Region, Grouped by Potential Industrial Use

Agriculture and Related Uses	Construction Materials	Ceramics	Chemical and Metallurgical Uses
Principal	*Principal*	*Principal*	*Principal*
Peat moss	Sand and gravel	Clay	Salt
Glauconite sand	Limestone	Quartz (silica) sand[bp]	Sulfur[bp]
	Shale		Limestone
Subordinate	Gypsum	*Subordinate*	Dolomite
Sulfur[bp]	Granite	Accessory "heavy" minerals	Coke[bp]
Limestone		Limestone	Fly ash (Ni-V)[bp]
Fly ash[bp]	*Subordinate*	Dolomite	Accessory "heavy" minerals (Ti-Zr)[bp]
	Quartz (silica) sand[bp]		
	Sulfur[bp]		*Subordinate*
	Fly ash[bp]		Quartz (silica) sand[bp]
			Clay

[bp] indicates mineral derived as byproduct from oil sands processing (Fig. 5).

predominantly shaly Clearwater Formation (Carrigy, 1966, p. 17). This bed, from 10 to 20 feet thick, contains up to 27 percent glauconite in the form of small green pellets (Carrigy, 1963, p. 20). The mineral glauconite contains up to 7 percent potash (K_2O), and is prized by some horticulturalists as "greensand," a natural source of slow-release potash. Glauconite also has been used in water softening compounds for base exchange reactions. It can be separated readily from other components of the sand by conventional magnetic separation techniques.

Construction Materials

Minerals listed under this category in table 1 are mainly large volume, low value materials of the construction industry, depending for their markets (and hence their development) on local construction requirements. Possible exceptions are gypsum and granite, both of which have the potential to serve markets outside the region in view of their relative scarcity and specialized use.

Future construction activity in northeastern Alberta will relate not only to the massive-scale industrial projects of oil sands development, but also to the housing and recreational requirements of a growing population. This activity will result in a heavy demand for construction materials, notably aggregates, Portland cement, plasterboard, and insulation products. The remoteness of the region may alone provide sufficient economic stimulus for utilizing local materials (e.g., a Portland cement manufacturing industry based on locally available raw materials).

Sand and Gravel

Sand and gravel are in plentiful supply in the Fort McMurray region, found largely in deposits of glaciofluvial origin, either as outwash or as meltwater channel deposits. Outwash gravels are found throughout the region as scattered local deposits, or (particularly in the hinterland northeast of Fort McMurray) as extensive outwash plains (Fig. 3). Meltwater channel deposits are located mainly in and on the flanks of the Athabasca and Clearwater River valleys as low benches or terraces; these are the most accessible deposits for exploitation and economically the most important.

One very large deposit of this latter type is located just south of Fort McMurray townsite and has served until now as the sole source of gravel for aggregates and sub-base road construction in Fort McMurray and vicinity. The deposit forms a terrace high on the southwest side of the Clearwater River valley. Its thickness averages about 15 feet, and it contains an estimated 22,000,000 cubic yards (enough to satisfy the needs of Fort McMurray for many years to come).

Gravel for construction of the GCOS plant was obtained largely from deposits on the plant site; other large deposits undoubtedly will be found north of Fort McMurray along the Athabasca River valley as future needs arise.

Limestone

Limestone is present in the Fort McMurray region in strata of the Upper Devonian Waterways Formation, a succession of limestones, shales, and shaly limestone, 600 to 700 feet thick, eroded on its upper surface and truncated toward the east (Norris, this volume). These limestone beds underlie the Cretaceous oil sands of the region and are exposed along the Clearwater and Athabasca River valleys as indicated in figure 6. The beds are nearly flat-lying, with a regional southwestward dip of a few feet per mile (except along the Clearwater River, and along the Athabasca River in the vicinity of Bitumount, where solution of the underlying salt beds has produced local warping and reversals in the regional dip).

Outcrops of limestone are common along the valley floors of the Athabasca and Clearwater Rivers as discontinuous benches, rarely exposing more than 10 to 15 feet of section above water level. The industrial potential of these beds has been investigated recently by Holter (1973). In general, the conditions for quarrying are ideal, although in some cases the small thickness of strata limits the size of reserves. Some characteristics of the limestones are given in table 2.

The Waterways Formation limestones tend to be consistently argillaceous. The better grades (those of the Moberly Member) fall well short of high purity, high calcium limestones (95 percent $CaCO_3$ or better) that industrial users prefer. Nevertheless, the overall compositional aspects of the Moberly limestones indicate their suitability for cement-making. They show a fair degree of consistency, the magnesia levels are tolerable, and the argillaceous "contaminant" is an essential requirement in cement raw materials. Some analyses published earlier (Carrigy, 1959, p. 29) indicate that higher purity material (93 to 95 percent $CaCO_3$) can be obtained from selected beds.

None of the Waterways limestones have been developed for industrial use to date, but rubble from outcrops along the Athabasca River valley has been used to some extent as road metal for the GCOS access road. Many possible future uses for this limestone can be foreseen. For example, Portland cement manufacture appears to be an obvious use considering the coexistence of limestone with other essential raw materials for cement-making (shale and gypsum). Other uses are: crushed stone for road metal, concrete aggregate, and railroad ballast (where glacial gravel deposits are deficient); raw material for manufacturing mineral rockwool; and as a soil conditioner in agricultural or revegetation projects (for neutralizing acid soils). The roles played by limestone in the chemical and metallurgical industries and in lime-making are discussed subsequently.

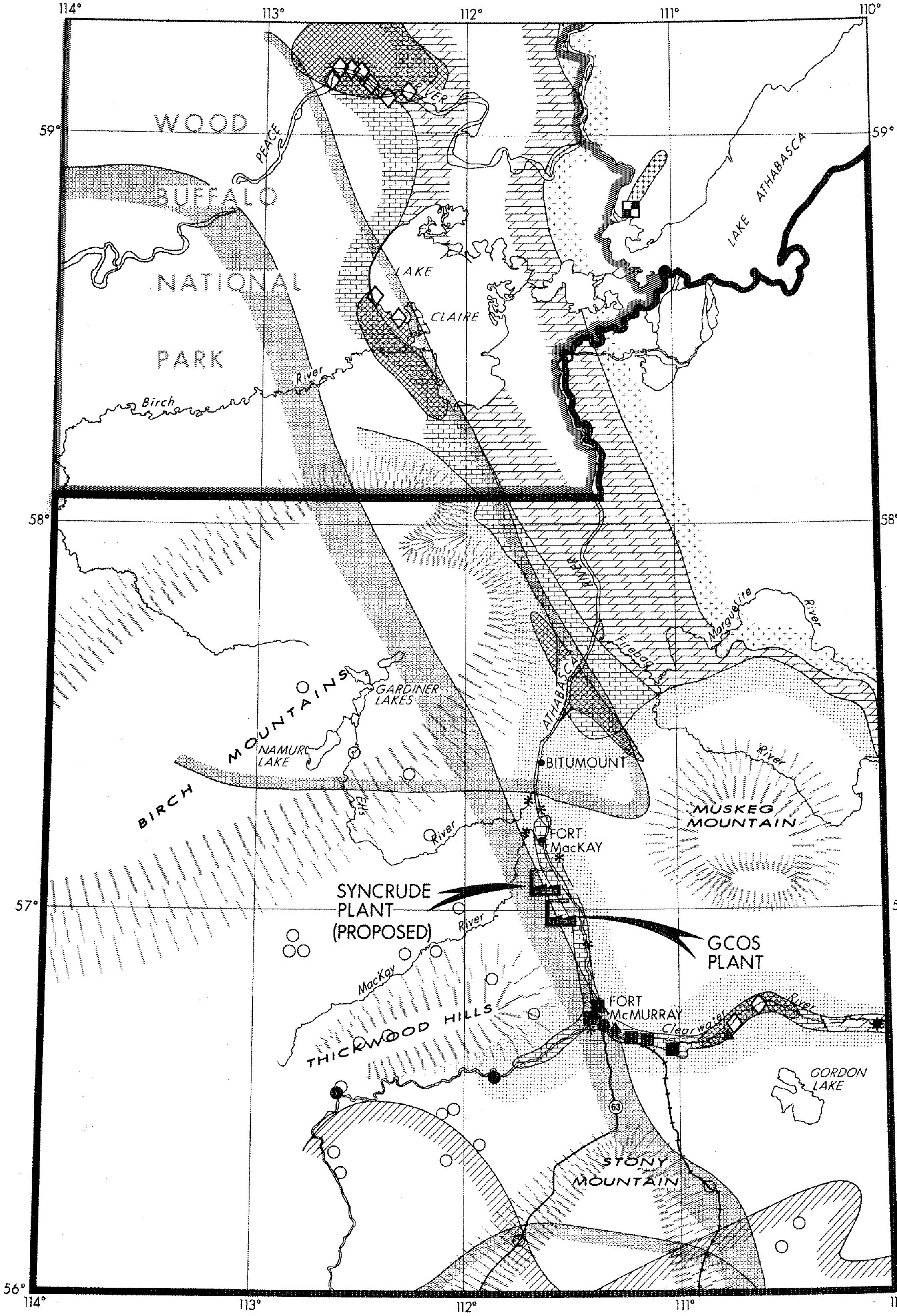


FIGURE 6. Industrial minerals of the Fort McMurray region.

LEGEND FOR FIGURE 6

- Basal Cretaceous boundary (McMurray Fm)
- Upper Devonian limestone boundary (Waterways Fm)
- Gypsum deposit
- Salt deposit boundary (Prairie Evaporite)
- Middle Devonian carbonate and evaporite boundary
- Salt deposit boundary (Cold Lake)
- Salt deposit boundary (Lotsberg)
- Precambrian Shield - western limit
- Precambrian granite pluton

MINERAL DEPOSITS - EVALUATED LOCALITIES

- ▲ Silica sand (preglacial channel sand)
- * Clay
- ■ Limestone
- ◇ Gypsum
- ○ Salt - borehole (drilled)
- ● Salt - borehole (cored)
- ✱ Dolomite
- Dimension stone (granite)
- Study area boundary
- National Park boundary

Table 2. Characteristics of Limestones in Waterways Formation Outcrops, Fort McMurray Region (after Holter, in press)

Locality	Stratigraphic Unit	Exposed Thickness of Beds	$CaCO_3$ (%)	$MgCO_3$ (%)	Remarks
Athabasca River (east bank), at junction of Clearwater River	Moberly Member (middle)	14 ft	86-88	4.3-2.6	Argillaceous; beds flat-lying, good quarriability on McMurray Island but limited reserves.
Clearwater River, 4 to 10 miles east of Fort McMurray	Moberly Member (lower)	90 ft (composite)	87-91	3.2-2.4	Argillaceous, shaly interbeds; section is composite of outcrops along 7-mile stretch of river — mostly less than 5 feet of exposure; beds flat-lying, good quarriability.
Christina River (east bank), just above junction with Clearwater River	Christina Member	10 ft	66	2.7	Argillaceous, anomalous Fe_2O_3 content (15.3%); thick overburden
Clearwater River (south bank), 4 miles above junction of Christina River	Calumet Member	2 ft	79	5.1	Silty, argillaceous.

Shale

Shale is probably the most common bedrock material found in northeastern Alberta outside of the Precambrian Shield area. Shales outcrop or lie beneath glacial drift along the lowlands adjacent to the Athabasca River, and underlie much of the highlands in the southern and western parts of the region. Shale is most abundant in the Cretaceous succession overlying the oil sands (Clearwater and La Biche Formations) but also is found in the Devonian Waterways Formation as units of calcareous shale with interbedded argillaceous limestone up to 170 feet thick (Firebag Member).

The Clearwater Formation is a succession of marine, grey silty shales, laminated siltstones and sandstones averaging 275 feet in thickness. The mineral composition of the shaly beds is principally illite with subordinate amounts of montmorillonite, kaolinite, chlorite, and quartz (silt). Shales of the Waterways Formation are typically green in color and strongly calcareous, grading frequently into argillaceous limestones. The clay content comprises illite, with lesser amounts of kaolinite and minor chlorite. Chemical analyses of selected shale samples are given in table 3.

No physical tests of these shales have been made, but on the basis of lithologic and chemical characteristics several potential uses are indicated. Either shale would be quite suitable for cement-making. Clearwater Formation shale has indications also of being an excellent bloating material for lightweight aggregate (although the need for lightweight aggregate in this region seems remote at present). The Waterways shale has a composition close to ideal for the manufacture of mineral rockwool -- as insulation for pipelines, buildings, etc. As ceramic raw materials, however, neither of these shales is likely to be suitable owing to poor plasticity, poor drying and firing characteristics, and a tendency to bloat.

Gypsum

Gypsum is found in the subsurface of the Fort McMurray region (Fig. 6) in shallow deposits believed to be the water-insoluble remains of the leached Prairie Evaporite Formation of Middle Devonian age, the thick salt section of which is preserved downdip in the western part of the region. A deposit 30 to 50 feet thick underlies the Clearwater River valley over a distance of 18 miles at depths from near-surface to 300 feet; another is postulated to exist beneath the Athabasca River valley about 60 miles north of Fort McMurray (Hamilton, 1969). Gypsum -- apparently younger than that found along the Clearwater River (Fort Vermilion Member) but possibly including some equivalent beds -- outcrops at Peace Point on the Peace River (Govett, 1961) and was encountered recently in shallow test borings on the west shore of Lake Claire (Bayrock and Root, 1972). Both the Peace Point and Lake Claire deposits lie in Wood Buffalo National Park (Fig. 6).

The average grade of the Clearwater River valley gypsum measured in continuous cores from two test holes is 84 percent. A higher grade for the

Table 3. Chemical Analyses of Shales from the Fort McMurray Region

Constituent	Composition (weight percent) 1	2
SiO_2	66.97	31.47
Al_2O_3	12.73	7.11
Total iron as Fe_2O_3	5.81	2.84
TiO_2	0.52	0.51
CaO	1.20	28.19
MgO	2.39	2.37
Na_2O	1.07	0.20
K_2O	2.74	1.81
L.O.I.	6.13	24.97
Total	99.56	99.47

Key:

1. Clearwater Formation -- sample from Socony Vacuum Hole No. 27, located in Lsd.7, Sec.22, Tp.91, R.10, W.4th Mer., depth 91-92 Feet (Alberta Research files).
2. Waterways Formation (Firebag Member?) -- sample from Richfield Pony Creek No. 2, located in Lsd.9, Sec.1, Tp.80, R.8, W.4th Mer., depth 1502-1503 feet (Alberta Research files).

Athabasca River valley deposit is inferred from the wildcat well data of the region, in which core analyses show a northerly increase in the grade of the gypsum, and from the presence of high grade gypsum (95 percent purity or better) outcropping at Peace Point.

The chief use of gypsum is as raw material for the manufacture of plasterboard; it also finds major use as a component of Portland cement (accounting for 30 percent of the gypsum market in Alberta). A wide variety of minor uses exist both for calcined and the raw gypsum: for various types of plasters, in filtering, as a filler, as a base for paints, etc.

Gypsum is one of the few industrial mineral commodities in the region having an outside market potential. In 1972, all of Alberta's gypsum requirements of approximately 180,000 tons (valued at $1.5 million) were shipped in at heavy cost from outside the province. The Fort McMurray gypsum deposits thus hold considerable promise for development in the near future.

Granite

Granite with good potential for use as building and ornamental stone is found in northeastern Alberta in plutonic masses which outcrop on the Precambrian Shield near Fort Chipewyan (Fig. 6). Although distant from Fort McMurray (and outside the area of the study proper), the granite deposits are mentioned here, because any future development presumably would use Fort McMurray as the main distribution center.

The granite is massive in outcrop (i.e., not extensively cleaved or fractured), uniform in grain size and color, with a pleasing deep red tone and texture that takes a high polish. Preliminary studies on the economic feasibility of producing granite from this area have given encouraging results (J. D. Godfrey, pers. comm.).

Granite is used in Alberta chiefly for monumental stone and for facing commercial buildings. The Fort Chipewyan granite would have to rely on both the Alberta and more distant markets for development, and must compete with granites quarried in Manitoba and eastern Canada. Nevertheless, the Fort Chipewyan granite is the only known source of high quality ornamental stone in Alberta, fitting all the requirements of a quality dimension stone, and therefore appears to have a solid potential for future use.

Ceramics

The primary raw materials for ceramics are clay and silica sand, large tonnages of which are required to produce clay products and glassware, respectively. Ceramics are, by and large, materials of construction, so that the industry tends to be closely tied to the construction industry. However, the potential market area for ceramics can extend well beyond the sphere of local construction activity.

The outlook for ceramics in the Fort McMurray region appears bright for certain materials. Refractories, for example, needed in high-temperature installations of industrial plants, can be manufactured from local kaolinite-base clays, as well as from silica sand. Stoneware and pottery are local industry possibilities for any region. Glass products are essential for a wide range of industrial purposes, and raw glass sand itself has potential for long-distance marketing. New and improved kinds of structural clay products are possibilities for the region, although the outlook for products such as common brick and tile is not particularly encouraging.

Clay

Clays with ceramic potential are present at several stratigraphic levels in the Fort McMurray area. The so-called oil sands "underclays" are clay deposits underlying the Cretaceous McMurray Formation and overlying the

Devonian limestones, apparently infilling depressions on the pre-Cretaceous erosion surface. Within the McMurray Formation itself, the clay fraction of the oil sands forms up to 17 percent of the bulk rock (Carrigy, 1962), and where it accumulates in the tailings pond as a waste byproduct of oil sands processing, it may represent a potential economic deposit of ceramic clay. Finally, clays of lacustrine origin are present in the glacial drift overlying bedrock throughout much of the area.

Comparative compositions of the main types of clays described above are summarized in table 4, selected from analyses as nearly representative as possible of the different types. Ceramic properties are summarized in table 5.

The oil sands underclay crops out in the Athabasca River valley and undoubtedly can be found in other localities along the trace of the basal McMurray Formation boundary (Fig. 6). However, the clay is not everywhere present beneath the oil sands nor is it of the same quality wherever found; considerable further work is needed to assess fully its potential. The clay was first reported and tested by Ells (1915), subsequently by Hume (1924) and Halferdahl (1969), giving indications of possible stoneware or higher grade clays to be found in this type of deposit (Table 5).

The clay fraction from the McMurray oil sands is similar in composition to the underclay (Table 4) but gives preliminary indications of being a more consistent and better grade of clay. Many mineralogical analyses show only kaolinite and illite present (Carrigy, 1963), in approximately equal amounts or with kaolinite slightly in excess. In some samples, minor amounts of chlorite may be present. Although no ceramic tests are available, the clay should possess properties as good as or superior to the best of the underclays. The clay fraction (minus 4 microns) averages only about 1 percent of the high grade oil sands (i.e., those selected for mining) but, for an average-sized operation of 100,000 tons per day, this amounts to 1,000 tons of clay accumulating daily as waste material at a single plant. If more detailed testing proves that the clay is consistent in its composition and properties and potentially useful as a ceramic raw material, then its recovery for commercial use becomes a possibility.

The glacial clays of the region are found in widespread lacustrine deposits (Fig. 3) generally 3 to 5 feet thick, in places up to 10 feet thick. However, the only ceramic data available are for a thin, lenticular bed of pink clay buried beneath 80 feet or more of sandy outwash sediments on the Firebag River (L. A. Bayrock, pers. comm.). Ceramic tests (Ells, 1926; Halferdahl, 1969) indicate this clay has suitable properties for the production of structural clay products (Table 5).

The potential for clays in the Fort McMurray region is primarily for those of stoneware grade or better. Such clays are scarce in Alberta, and a good supply would be a valuable long-term asset for the region, perhaps even with prospects for immediate development as a raw material source for established

Table 4. Comparative Chemical and Mineralogical Analyses of Clays Representative of Different Types of Deposits in the Fort McMurray Region

Constituent	Composition (weight percent) 1	2	3
Chemical analysis:			
SiO_2	68.93	63.26	85.02
Al_2O_3	16.32	20.43	7.45
Total iron as Fe_2O_3	3.18	3.08	2.70
TiO_2	.93	1.17	.30
CaO	.50	0.57	.67
MgO	.65	1.28	.86
Na_2O	.33	.56	.28
K_2O	1.38	1.68	1.13
H_2O^+	5.49	7.92 L.O.I. (H_2O^+, CO_2, C)	1.63
CO_2	.97		.00
C	.96		.28
Total	99.64	99.95	100.32
Mineralogical analysis:			
Quartz	45.0	not measured	69.5
Clay minerals			
Kaolinite	major	major } approx.	-
Illite	minor	major } equal	minor
Chlorite	minor	minor	major
Halloysite	present	-	-
Vermiculite	present	-	-

Key:

1. Oil sands underclay, sampled from testhole at Abasand pit near Fort McMurray (Halferdahl, 1969).
2. McMurray Formation clay, representative of the clay fraction of McMurray oil sands, sampled from ROC Pony Creek No. 1 in Lsd.1, Sec.33, Tp.79, R.7, W.4th Mer., at depth of 1130 feet (Alberta Research files).
3. Glacial clay, sampled from outcrop on Firebag River (Halferdahl, 1969).

Table 5. Ceramic Properties of Clays from the Fort McMurray Region

Type and Description of Deposit	Unfired Properties	PCE	Range of Fired Properties			
			Cone No.	Shrinkage	Absorption	Color
Oil sands underclay; light to dark grey (Ells, 1915, 1926)	good plasticity and workability, water of plasticity 24 to 28%, *dries safely*, drying shrinkage 6 to 8%	Cone 3 (1170°C) to Cone 8 (1260°C)	010-03 (895°-1115°C)	0.0-4.6	14.1-4	buff to reddish brown
Oil sands underclay; light grey, noncalcareous, beds 6 to 15 feet thick (Hume, 1924)	fair plasticity, good workability, water of plasticity 17 to 19%, *dries safely*, drying shrinkage 5 to 6%	Cone 14 1/2 (1410°C) to Cone 18 1/2 (1500°C)	012-5 (875°-1205°C)	0.0-4.6	11.0-0 (vitrified)	cream to buff
Oil sands underclay; brownish grey to dark grey, noncalcareous, in lenticular beds up to 8 feet thick (Halferdahl, 1969)	good plasticity and workability, water of plasticity 23 to 25%, *cracks badly in drying*, drying shrinkage 7 to 8%	Cone 15 1/2 (1440°C) to Cone 18 (1490°C)	06-5 (1015°-1205°C)	0.5-3.1	16.6-3.9	light to medium brown
Oil sands underclay; light grey, 10-foot bed (Ells, 1915)	good plasticity and workability, *dries safely*	27 (1670°C)	3 (1170°C)	9 *total* (includes drying shrinkage)	"dense"	cream
Glacial clay; pink, noncalcareous, slightly calcareous in some deposits (Halferdahl, 1969)	good plasticity and workability, water of plasticity 28 to 33% *cracks moderately with fast drying*, drying shrinkage 6 to 7%	16 (1460°C)	06-5 (1015°-1205°C)	0.9-6.3	19.8-2.3	salmon to red
Glacial clay; grey, slightly calcareous, carbonaceous (Ells, 1926)	poor plasticity, water of plasticity 21%, *dries safely* (scums), drying shrinkage 6.3%	Cone 3 (1170°C)	06 (1015°C)	1.7	16.9	reddish brown

plants outside the region. Stoneware clays are used in the manufacture of vitrified structural ware, stoneware, and pottery, and are blended with other clays to produce a wide range of ceramic products. Refractory clays of the type with PCE of cone 27 found in the oil sands underclay (Table 5) are used mainly for making firebrick, which in turn is used for refractory linings of high-temperature installations. For these clays, which have relatively high alumina contents (Table 4), a possibility for the distant future is the production of alumina and metallic aluminum (Peters *et al.*, 1967).

Quartz (Silica) Sand

Sand exists in great abundance in the Fort McMurray region. Four different sources can be recognized in which the sands have a quartz content high enough to be classed as silica sand. The most obvious of these is the tailings sand from the oil sands extraction process, known from earliest research efforts in extracting the oil to be very high in silica. Another less well recognized source is an alluvial sand deposit of excellent quality found in a buried (possibly preglacial) river channel of the Clearwater River valley east of Fort McMurray. The McMurray Formation itself -- where the sands are not impregnated with oil -- is yet another potential source. Lastly, widespread glacial and postglacial sands of outwash and aeolian origins, although virtually untested, are regarded as a possible source for lower grade silica requirements.

For this paper, only the first two sources warrant more detailed consideration. The tailings sand is of primary importance because of its availability, accumulating in potentially enormous tonnages as a waste byproduct of oil extraction plants. An investigation of tailings sand quality was made by Lilge (1945), who used tailings from two experimental plants which operated at Fort McMurray (Abasand Oils Limited) and at Bitumount (Oil Sands Limited). Results of the study indicate that, with beneficiation, sand of a suitable quality for glass-making can be obtained from the tailings. The main impurities include mica, "fines," and a residual oil film. Chemical and textural properties of the sand are summarized in table 6 and figure 7.

From Lilge's (1945) study, and from other data subsequently obtained, it is apparent that tailings sand is far from consistent in quality from plant to plant, perhaps even from day to day for a single plant, and that further research is required to assess fully its industrial potential. Generally, silica sand quality is shown to be a direct function of grain size: the finer the sand, the greater is the content of accessory mica, "fines," and other contaminants such as iron and titanium. Wide variations undoubtedly reflect conditions in the original rock being mined, the grain size of which may range from coarse sand to very fine sand and silt (Carrigy, 1963, 1966). Thus, the finer grades of tailings sand, such as the one reported by Lilge (1945) from the Abasand plant, will be unsuitable for glass sand use because of excessive fineness.

The alluvial "channel" sand is known in at least three localities along the Clearwater River. At Fort McMurray, in the Alberta Goverment Salt Well No. 1

Table 6. Comparative Chemical and Physical Analyses of Sands from Potential Silica Sand Sources in the Fort McMurray Region

Chemical Analyses:

Constituent	Composition (weight percent) 1	2	3A	3B	4
SiO_2	99.14	98.83	97.54	98.30	97.24
Al_2O_3	0.52	0.81	0.94	0.68	1.02
Total Iron as Fe_2O_3	0.08	0.04	0.11	0.05	0.13
TiO_2	0.03	0.06	0.10	0.07	0.03
P_2O_5	-	-	0.02	0.02	-
MnO	-	-	0.01	0.01	-
CaO	0.00	0.22	0.06	0.06	0.34
MgO	0.00	0.04	0.06	0.04	0.73
Na_2O	-	-	<0.01	<0.01	0.22
K_2O	-	-	0.43	0.41	0.25
L.O.I.	-	-	0.66	0.27	0.50
Total	99.77	100.00	99.93	99.91	100.46

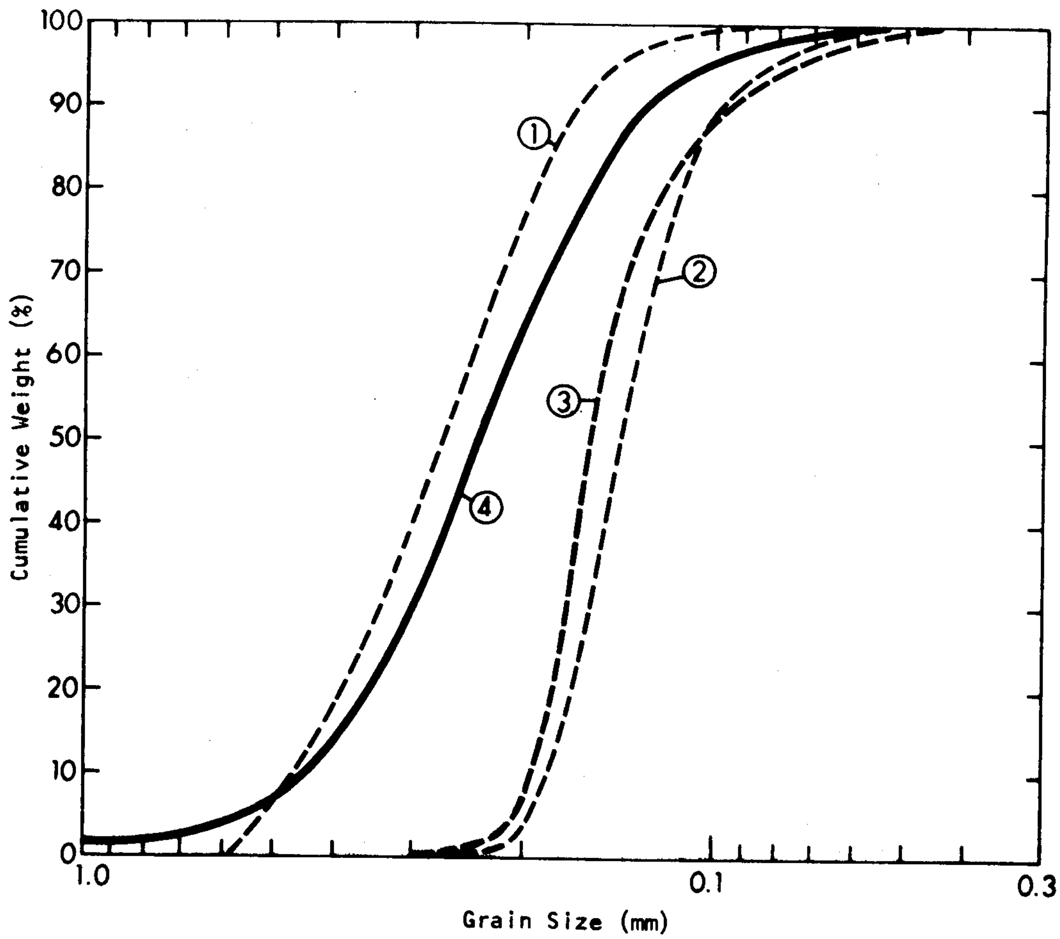
Grain Size Analyses:

US Standard Sieve No.	Opening (mm)	Composition (percent retained) 1	2	3A	3B	4
5*	4.00	-	-	-		0.38
10	2.00	-	-	-		0.20
18*	1.00	-	-	-		0.72
30	0.595	-	-	-		
35*	0.50	6.0	0.0	-		5.17
40	0.42			0.02		
50	0.297	35.0	0.4	0.12		
60	0.25					38.00
70	0.210	32.0	1.3	3.66		
100	0.149	21.0	39.0	57.00		
120	0.125					47.26
140	0.105	5.3	45.0	25.62		
200	0.074	0.6	11.3	8.73		
<200		0.1	3.0	4.88		
230*	0.062					7.83
<230						0.44

*Tyler Screen Sieve No.

Key:

1. Tailings sand sample from experimental extraction plant (Oil Sands Limited) at Bitumount (Lilge, 1945).
2. Tailings sand sample from experimental extraction plant (Abasand Oils Limited) at Fort McMurray (Lilge, 1945).
3. Tailings sand sample from GCOS plant 20 miles north of Fort McMurray (analyses by Alberta Research).
   3A. Raw tailings sample.
   3B. Modal size fraction of tailings (-70+100 mesh) with "heavy" minerals removed (0.20 wt %).
4. Alluvial "channel" sand sample from buried channel in the Clearwater River valley, 35 miles above Fort McMurray (in RCA Gypsum Test Hole B; Lsd.13, Sec.9, Tp.89, R.5, W.4th Mer.) (analyses by Alberta Research).
   Note: Chemical analysis is for -60+230 mesh size fraction, with "heavy" minerals removed (0.32 wt %).



Key:

1. Tailings sand sample from experimental extraction plant (Oil Sands Limited) at Bitumount (from Lilge, 1945).
2. Tailings sand sample from experimental extraction plant (Abasand Oils Limited) at Fort McMurray (from Lilge, 1945).
3. Tailings sand sample from Great Canadian Oil Sands plant 20 miles north of Fort McMurray (analysis by Alberta Research).
4. Alluvial "channel" sand sample from buried channel in the Clearwater River valley, 35 miles upstream from Fort McMurray in RCA Gypsum Test Hole B, 13-9-89-5 W.4 (analysis by Alberta Research).

FIGURE 7. Comparative textural properties of sands from potential silica sand sources in the Fort McMurray region.

(Lsd. 3, Sec. 21, Tp. 89, R. 9, W.4 Mer.), "heavy white silica sand" was logged by Allan (1921) between depths of 42 and 55 feet in a buried channel extending to 95 feet. In a nearby well, Industrial Minerals Salt Well No. 1 (Lsd. 1, Sec. 10, Tp. 89, R. 9, W.4 Mer.), Allan (1937, p. 120) reports "a bed of quite pure white, fine-grained sand" in the unconsolidated material filling a channel overlying bedrock to a depth of 100 feet. Thirty-five miles upstream, in the Research Council Gypsum Testhole B (Lsd. 13, Sec. 9, Tp. 89, R. 5, W.4 Mer.), the deepest part of the channel yet penetrated (142 feet) was found to be filled largely with clean, fine-grained sand. A grain size analysis of a sample of this sand is plotted on figure 7, and a chemical analysis given in table 6. Based on only a single sample, these data are far from conclusive, but they point to the possibility of a source of silica sand potentially superior in quality to the oil sands tailings.

The nature of the channel sand suggests it to be a reworked derivative of the Precambrian Athabasca Sandstone lying on the Shield area to the northeast. The depth of the channel indicates a preglacial origin, although the Clearwater River valley is generally considered a postglacial feature (Carrigy, 1959). Clearly, the valley and alluvial deposits therein have a complex history which remains to be worked out.

Silica sand has its main large-tonnage use in glass-making. For sands of the Fort McMurray region, this is the major market to be anticipated for the future, although the possibility of a glass industry for the region may be unrealistic. More likely, the raw sand would be transported to major population centers for use in glass factories near the larger markets. However, local requirements could be quite substantial in support of the numerous secondary industries bound to spring up as oil sands development progresses.

Silica sand for refractory use (e.g., furnace sand, silica brick), including foundry sand, is a possibility. Various uses in the chemical and metallurgical fields and for building products (McLaws, 1971) also hold promise for future application in the region.

Chemical and Metallurgical Uses

Minerals of this category include salt, sulfur, and limestone, traditionally regarded as the basic raw materials of chemical processing, plus certain important byproduct materials of oil sands processing (coke, fly ash, accessory [heavy] minerals), the principal use of which is foreseen in the chemical and metallurgical industries. Excepting salt and limestone, which are low-value comcommodities that normally rely solely on local industrial markets, these materials possess good capability for long-distance marketing. However, their real potential for the region is as raw materials for locally based industries in the chemical, petrochemical, and metallurgical fields.

It is generally acknowledged that these will be the major secondary industries to materialize from large-scale development of the oil sands; thus, the prospects for commercial utilization of supportive mineral resources for the medium- to long-term future (10 to 25 years) appear excellent.

Salt

Salt (halite) beds of commercial thickness and purity underlie part of the Fort McMurray region (Fig. 6) at depths as shallow as 625 feet. The salt beds are found in the Prairie Evaporite Formation of Middle Devonian age, the same unit that hosts the gypsum beds discussed in a preceding section. Older and deeper salt beds (the Cold Lake and Lotsberg Salts) also underlie part of the region but have little economic significance. The Prairie Evaporite Salt is the deposit of primary importance, particularly because its presence at shallow depths in the vicinity of Fort McMurray townsite makes this the only place in the province where conventional underground mining of rock salt is considered practical (Hamilton, 1971).

The area underlain by salt is shown in figure 6 and includes generally the western half of the region. In the eastern half, the salt is absent as a consequence of erosion and subsurface solution. The solution edge, trending north-northwest, passes just to the east of Fort McMurray townsite. From this edge the Prairie Evaporite salt deposit thickens rather rapidly to the south-west, across its solution subcrop, regaining full thickness of 500 to 600 feet over a distance of about 20 miles (Hamilton, 1971). Beneath Fort McMurray townsite, the salt bed is about 200 feet thick.

The quality of the salt generally is excellent. Representative chemical analyses of rock salt cores are given in table 7. The only significant impurity is $CaSO_4$ (anhydrite), a ubiquitous constituent of rock salt easily contended with by most salt-consuming industries. Reserves of salt in the region are virtually inexhaustible -- certainly ample for any needs that might arise in the future. For example, a single quarter-section of land underlain by a salt thickness of 200 feet will contain nearly 100 million tons of salt.

Commercial exploitation of the salt has taken place at two separate times in the past. It has been known to exist since about 1912 and was the first salt deposit to be discovered in Alberta. The history of its exploration and development is documented by Allan (1937, 1943) up to the latest event, the building of a salt recovery plant in 1937 which operated until 1950. Although the salt beds are shallow enough for underground mining, all production was by brining and surface evaporation methods, and the salt was shipped by rail to Edmonton for distribution throughout the province. Prior to 1948, this was the only commercial source of salt on the Prairies west of Manitoba.

Salt is one of the basic raw materials of the chemical industry, and accordingly its prospects for utilization in the Fort McMurray region appear excellent for the future. The principal use of salt is in the manufacture of

Table 7. Selected Chemical Analyses of Rock Salt Cores from the Fort McMurray Region

Constituent	Composition (weight percent)			
	1	2	3	4
NaCl	99.09	99.45	97.24	94.78
$CaSO_4$	0.53	0.31	2.00	4.74
$CaCl_2$	0.06	0.14	0.07	-
$MgCl_2$	0.02	tr	0.06	0.00
KCl	0.04	-	0.02	0.00
Water Insolubles	0.26	-	0.74	0.24
Total	100.00	99.90	100.13	99.76

Key:

1. Bear Vampire No. 1 (Lsd.7, Sec.28, Tp.87, R.12, W4th Mer.); sample depth 1489 to 1496 feet, from total rock salt interval 1293 to 1881 feet (Hamilton, 1971).
2. Industrial Minerals Salt Well No. 1 (Lsd.1, Sec.10, Tp.89, R.9, W.4 Mer.); sample depth 855 to 860 feet, from total rock salt interval 694 to 893 feet (Allan, 1937).
3. Bear Rodeo No. 1 (Lsd.8, Sec.20, Tp.89, R.9, W.4th Mer.); sample depth 761 to 833 feet, from total rock salt interval 625 to 834 feet (Hamilton, 1971).
4. Alberta Government Salt Well No. 1 (Lsd.3, Sec.21, Tp.89, R.9, W.4th Mer.); sample depth 648 to 662 feet, from total rock salt interval 631 to 662 feet (Allan, 1921).

chloralkali chemicals (NaOH, Cl_2) and soda ash (Na_2CO_3), both basic commodities for a number of major industries (e.g., pulp processing, glass-making) as well as being the starting point for many manufactured chemicals.

One direct application of salt in the Fort McMurray region could be in the manufacture of caustic soda (NaOH) for use in oil sands processing. In the hot water separation process, caustic soda is required in amounts of about 70 tons per 100,000 barrels of oil per day. At the projected peak development of 1 million barrels per day production, caustic requirements alone will be more than enough to support a major chloralkali industry. However, a plant producing 700 tons of caustic daily also will produce 700 tons of chlorine, for which an industrial market would have to be found in the region. Some possibilities exist in chlorinating processes for treatment of certain metallic ores (e.g., titanium-zirconium), for petrochemicals manufacture (e.g., chloro-carbons, chloro-hydrocarbons), and in converting it to hydrochloric acid for chemicals manufacture (e.g., $CaCl_2$) and general industrial purposes.

Salt has a wide range of industrial uses other than in chemicals manufacture, although few have potential application in northeastern Alberta. However, an indirect use of the salt beds that seems very likely for the future is for underground storage of petroleum products, in artificially created caverns.

Sulfur

Sulfur is present in the bitumen fraction of the Athabasca oil sands in amounts of approximately 5 percent by weight. In oil sands processing the sulfur is recovered from the upgraded crude oil product of the bitumen, with a proportionate amount remaining in the residual coke (Fig. 5). Thus, about 80 percent of the total sulfur content is recovered as a byproduct.

The output of sulfur from the existing GCOS plant is in the range of 335 to 350 tons per day. When oil sands development reaches a production rate of 1 million barrels per day, the output will amount to about 7,500 tons per day, and possibly larger by as much as 20 percent if the sulfur left in residual products also should become recoverable. Accordingly, at peak development, the quantity of byproduct sulfur could very well exceed 3 million tons annually.

The traditional large-tonnage uses for Alberta-produced sulfur are in pulp processing and in fertilizer manufacture. Among many other lesser uses are the manufacture of chemicals, rubber products, plastics and synthetic resins, explosives, insecticides, in petroleum refining, and uranium ore processing. The long-term growth rate of these markets is not expected to increase substantially (Raymont, 1972), certainly not rapidly enough to accommodate the rapidly-rising sulfur inventories of the province. Thus, the future for Fort McMurray sulfur does not look overly bright, inasmuch as a state of oversupply which now exists appears likely to persist for years to come.

This oversupply situation could be reversed with the development of new large-scale uses, in which case the Fort McMurray sulfur could become a very valuable resource. As a basic raw material of chemical processing, sulfur has some traditional use potential for the Fort McMurray region by the expected development of chemical industries. However, its best hope for total utilization lies in such new applications as outlined by Raymont (1972). Some of these of particular relevance for the region include uses as construction materials, such as foamed sulfur for ground and building insulation; sulfur-asphalt compositions for road construction; sulfur-aggregate concrete; and sulfur building blocks. Plastics and polymers are another possibility. One such product now coming into commercial production, polyphenylene sulfide, contains 29.6 percent sulfur (Raymont, 1972). Other possibilities include its use as sulfur dioxide for waste treatment, for plant and soil treatment (to correct alkalinity and add plant-nutrient sulfur), and in petrochemical processes.

Limestone and Dolomite

Limestone and dolomite are found in Devonian strata of the Fort McMurray region. Being geologically similar rock types, and having uses in the chemical and metallurgical industries for which they are interchangeable to a certain extent, they are discussed together here.

The limestone resources of the region are described elsewhere in the paper under the category of construction materials. Physical characteristics summarized in table 2 point out that the Devonian limestones of the region tend to be argillaceous, a fact which downgrades their potential for chemical and metallurgical use inasmuch as the tolerance for argillaceous or siliceous impurities is quite low in limestone specifications for lime-making. Nevertheless, an analysis presented in table 8 indicates that fairly high purity limestone can be found in selected intervals of the Waterways Formation. This limestone probably would be acceptable for lime-making, although its commercial potential would depend on whether selective quarrying of the high purity bed(s) were practical, and whether sufficient tonnages could be outlined.

Dolomites of the region are found mainly in the Middle Devonian Methy Formation, a unit with a reefal aspect that crops out between Cascade Rapids and Whitemud Falls on the Clearwater River, and lies near the surface along the lower stretch of the Athabasca River (Fig. 6). Outcrops at Whitemud Falls form thicknesses up to 80 feet (Plate 1 in Norris, this volume), consisting of massive, vuggy, reefal dolomite for which a chemical analysis is given in table 8.

For many of its chemical and metallurgical uses, limestone is consumed in the calcined form as lime (CaO). In lime-making, magnesium is normally not as critical an impurity as it is in limestones used for cement-making. In fact, high-magnesium limestones grading into dolomites are used for making special-purpose types of magnesian lime. The need for lime in the Fort McMurray region will arise with the expected future development of chemical, petrochemical, and metallurgical industries. Lime also has other general industrial uses such as in glass-making. Limestone and dolomite have potential use in their raw state as fluxing stone, in chemicals manufacture, in pollution control (neutralizing wastes, etc.), and in desulfurizing crude oils. With respect to the latter, limestone or dolomite as a sulfur-removing commodity in oil sands processing facilities could be important in the future. Dolomite may have possibilities in the future as a refractory material ("dead burned" dolomite) for metallurgical furnaces.

Table 8. Selected Chemical Analyses of Limestone and Dolomite from the Fort McMurray Region (Carrigy, 1959)

	Composition (weight percent)	
Constituent	1	2
SiO_2	1.66	0.30
Al_2O_3	1.28	1.49
Total iron as Fe_2O_3	0.21	1.03
CaO	53.33	33.12
MgO	0.53	16.32
L.O.I.	42.74	46.26
Total	99.75	98.52
$CaCO_3$	95.18	59.11
$MgCO_3$	1.11	34.13

Key:

1. Waterways Formation -- limestone sample from north bank of Clearwater River at junction with Athabasca River.
2. Methy Formation -- dolomite sample from Whitemud Falls, Clearwater River.

Petroleum Coke

In oil sands processing, one of the basic steps involves thermal coking of the separated bitumen to produce an upgraded distillate crude, leaving a residual product of bitumen coke (Fig. 5). At the existing GCOS plant about 20 percent by weight of the bitumen is formed into coke, which for a daily crude oil production of 45,000 barrels amounts to about 2,750 tons per day.

The amount of byproduct coke to be expected from future oil sands development is uncertain, for it depends upon the upgrading method chosen. If all new plants were to continue with the delayed coking process now in use, the output at peak development of 1 million barrels of oil per day would reach 60,000 tons per day. However, methods that utilize hydrogenation processes, converting more of the carbon to saleable petroleum products and leaving less residue, probably will come into increasing use with future development.

Analyses of coke residues from the bitumen are given in table 9. The coke has a relatively high ash content (about 3 percent) plus a sulfur content of

Table 9. Analyses of Coke Residue from Bitumen of the McMurray Oil Sands

	Composition		
	1	2	3
Proximate Analysis:			
Moisture (wt %)	0.35	0.31	0.30
Ash (wt %)	3.12	2.94	2.95
Volatile Matter (wt %)	10.59	10.41	10.85
Fixed Carbon (wt %)	85.94	86.34	NA
Sulfur (wt %):	5.80	5.12	6.42
Heating Value:			
BTU/lb	NA	14,711	NA
Cal/gm	NA	8,173	NA

Key:

1,2. Coke residue from GCOS extraction plant (Alberta Research files).

3. Coke residue from pilot-plant "delayed coking" experiments on Athabasca Oil Sands (Sterba, 1951).

NA. not analyzed.

5 percent or higher, which renders it unsuitable for metallurgical coke or for electrode carbon (Pasternack, 1963). The sulfur content limits its usefulness even for fuel, for on burning it releases objectionable sulfur dioxide to the atmosphere. About 75 percent, or 2,100 tons per day, of the coke produced at the GCOS plant is burned for steam power generation releasing 220 tons of SO_2 daily into the atmosphere. If at peak development a proportionate amount of coke continued to be burned for fuel, release of SO_2 could total 5,000 tons per day, vastly in excess of what might be tolerable to the regional environment.

The impure nature of byproduct coke suggests its only value for the region is as low-grade fuel. Clearly, however, its use in the future must depend on effective control of SO_2 emissions, either through stack gas removal of the sulfur, or through gasification of the coke and standard desulfurizing treatment to produce a clean, low-BTU gas fuel.

Improvements in process technology may make it feasible in the future to produce low-ash, metallurgical grade coke from the bitumen residues. Pasternack (1963) described experimental methods by which coke with ash contents as low as 0.07 percent could be obtained (while ostensibly allowing also for sulfur removal).

Coke Ash (Fly Ash)

Virtually all of the mineral solids and most of the trace metals present in the bitumen accumulate in the residual coke product of thermal cracking, constituting 3 percent of the coke by weight. These solids accumulate as fly ash and bottom ash where the coke is burned for boiler fuel at the existing GCOS plant, and represent a potential mineral resource principally for the vanadium and nickel concentrations.

An analysis of ash obtained from the coke produced at the GCOS plant is given in table 10. The ash is similar in composition to fly ashes of power plants in general -- largely silica, alumina, and iron oxide -- except for a remarkably high content of vanadium and nickel oxides. This reflects trace concentrations of the two metals found in the bitumen (Scott *et al.*, 1954), primarily in the asphaltenes. Upon thermal cracking of the bitumen most of the metals content reports to the coke and is further concentrated by reducing the coke to ash.

The amount of coke ash produced at the GCOS power plant is not large -- no more than 65 tons per day. However, at a projected production of 1 million barrels of oil per day, the total for the region could amount to 1,400 tons daily, representing about 48 tons and 16 tons of metallic vanadium and nickel, respectively. According to a recent press report (Oilweek, April 9, 1973), recovery of these two metals by a pyrometallurgical process developed at the Department of Energy, Mines and Resources would become economically feasible when synthetic oil production facilities reach 200,000 barrels per day.

With respect to other, more conventional uses for fly ash (Capp and Spencer, 1970), few appear to hold much promise for the Fort McMurray material. Some fly ash produced in Alberta (from coal combustion) is marketed for use as pozzolan and for making brick. These uses, and others such as mineral filler, soil stabilization, and base course construction may have some future potential for the region. The toxic effect of high vanadium and nickel contents seems to rule out the use of ash in agriculture and reclamation schemes, although non-toxic tailings from pyrometallurgical processing may eventually be available.

Accessory (Heavy) Minerals

The McMurray oil sands composed mainly of quartz with minor feldspars and muscovite also contain trace amounts of accessory, or "heavy" minerals ($sg > 2.95$), which constitute approximately 0.3 percent by weight of the solid mineral matter of the sands. These "heavy" minerals include titanium-bearing minerals [rutile (TiO_2), anatase (TiO_2), "leucoxene"] and zircon ($ZrSiO_4$), along with a number of others of less significance such as tourmaline and garnet. "Heavy" minerals become concentrated in the froth as an incidental effect of the flotation process in bitumen extraction. Preliminary studies

Table 10. Chemical Analysis of Coke Ash from Bitumen Coke, GCOS Plant, Fort McMurray (analysis by Alberta Research

Constituent	Composition (weight percent)
SiO_2	43.00
Al_2O_3	27.07
Total iron as Fe_2O_3	8.60
TiO_2	3.70
P_2O_5	0.11
MnO	0.26
CaO	4.12
MgO	1.43
Na_2O	0.99
K_2O	2.14
V_2O_5	6.25[1]
NiO	1.53[2]
Total	99.20

1 3.5% metallic vanadium (V)

2 1.2% metallic nickel (Ni)

indicate that these minerals form up to 30 percent by weight of the froth solids. This "heavies" fraction in turn assays up to 25 percent metallic titanium by weight, and, in addition, contains significant amounts of zircon (possibly as much as 10 to 20 percent metallic zirconium by weight). Thus, the froth solids are a potential source of these two transition elements and their oxides.

Despite the almost negligible percentage of accessory minerals in the raw sand, the amount becomes significant in consideration of the enormous tonnages of sand handled in the extraction process. Thus, for a 100,000 barrels per day operation involving 140,000 tons of raw oil sand, approximately 350 tons of accessory minerals are being put through the process each day. A substantial (but as yet undetermined) portion of these will collect in the bitumen froth, and therefore may be available for subsequent beneficiation and treatment.

Market possibilities for concentrated titanium-bearing and zircon sands are world-wide. Titanium and zirconium are highly valued "space-age" metals used in specialized alloys, although the principal industrial use of titanium today is in the form (TiO_2) for pigment, used in the production of paints, paper, and many other products requiring a chemically stable white pigment. The principal use for zirconium metal is in nuclear reactors, but most zircon ($ZrSiO_4$) is used directly as sand in refractories, particularly foundry sand, and in abrasives and ceramics. Whether the zircon found in the bitumen froth solids falls within commercially specified size grades is yet to be determined.

SUMMARY

The Fort McMurray region in northeastern Alberta is rich in mineral resources, which include a wide variety of industrial minerals in addition to the huge Athabasca Oil Sands deposits. The oil sands -- now in the initial stages of large-scale commercial development -- are the key to realization of the potential of the industrial minerals, some of which are byproducts of oil sands processing, some are bedrock deposits found in rocks of Precambrian, Devonian, and Cretaceous ages, and some are surficial deposits of glacial and postglacial origin.

The mineral resources are summarized in figure 8 (in pocket) according to their potential industrial uses and in relation to the possible sequence of development in northeastern Alberta. These development possibilities are forecast largely on the basis of current use trends in mineral raw materials, which could alter considerably in the future. Nevertheless, the picture presented in figure 8 gives a reasonable indication of trends in industrial activities to be expected for the region.

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CONVENTIONAL OIL POSSIBILITIES IN THE FORT McMURRAY AREA

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INTRODUCTION

Oil has been extracted from the McMurray Formation since prehistoric times by the native population, who used it for tarring canoes. Gas seeps were also known, e.g., the Boiler Rapids were so named because of gas bubbles rising from the bed of the Athabasca River (Bell, 1884). The first attempt at finding conventional light gravity oil was made by the Geological Survey of Canada in 1897. It was believed that by drilling downdip from the tarry seeps of the outcrop area, light oil would be discovered. A cable tool rig was used to drill in the vicinity of Pelican Rapids (Tp. 78, R. 17, W.4 Mer.), but the well encountered only tar (maltha) and natural gas. It was not until 60 years later that follow-up work resulted in the discovery of the Marten Hills and Calling Lake gas fields.

In 1905 a German entrepreneur, Count Alfred Von Hammerstein, conceived the idea of drilling through the tar sands and into the underlying Paleozoic section. It was hoped that the light gravity source of the oil sands might be found there. A cable tool rig barged through the Grand Rapids was lost with all hands except for the redoubtable Count Von Hammerstein himself, who swam ashore and walked back to civilization for a second rig. Eventually Von Hammerstein drilled a series of deep tests downstream from Fort McMurray. No light oil was discovered; however, the presence of porous reservoir beds in Middle Devonian Keg River reefs and in Granite Wash was established.

There is a tendency to be condescending towards these early efforts, and to overlook the fact that the exploration concepts were basically sound. The presence of the tar seeps and possible reservoir beds should have warranted continuing exploration programs. If the search had persisted through the inevitable disappointments, carrying geologic knowledge from the outcrop areas deeper and deeper into the basin, the oil industry in Alberta may have developed at an earlier date.

Following the discovery of Upper Devonian oil at Leduc in 1947, the possibilities of downdip light oil were once more raised. The Meadowbrook D3 reef trend was traced northward by the drilling of wells and seismic operations to its subcrop at the downdip edge of the oil sands. The regional Grosmont biostrome, which also subcrops in the same general area, led many writers to speculate that these Upper Devonian formations might be the source of the McMurray tar. Subsequently, it became apparent that the pre-Cretaceous unconformity truncated the geologic column from Precambrian to Jurassic and extended over most of Alberta. Porosity above and below the unconformity provided excellent aquifers, making it theoretically possible for oil to reach the oil sands from many sources.

In 1965 the discovery of oil in Middle Devonian Keg River reefs at Rainbow Lake revived interest in the Keg River equivalents of the McMurray area. Numerous deep tests subsequently were drilled which encountered reefs, some with porosity and light gravity oil staining. However, no commercial accumulations were found, and the search continues.

REGIONAL STRATIGRAPHY

The Paleozoic section begins with coarse and arkosic Granite Wash type sands in the Precambrian erosional lows. They become finer, better sorted, and more quartzitic higher in section. These sands drape over the crests of Precambrian highs, or onlap against their flanks, thus forming potential traps. Porosities are usually good, reaching 30 percent or more, and large salt water recoveries are common. To date no oil has been found updip from the Red Earth Field in township 88, range 7, west of the 5th meridian, about 140 miles west of Fort McMurray.

At Contact Rapids, on the Clearwater River, Saskatchewan, (Tp. 89, R. 23, W.3 Mer.) the basal sands and shales of the Contact Rapids Formation grade upward without any apparent break into carbonates with Middle Devonian (Methy) fossil assemblages. At Pine Rapids (Tp. 89, R. 1, W.4 Mer.) the outcrop contains Middle Devonian Keg River reefs with a few minor quartz sand partings, the underlying section being unexposed.

The Muskeg (Prairie Evaporite) Formation west of the town of Fort McMurray occurs as a salt and anhydrite section, which is missing in a zone about 40 miles west of its projected subcrop position as a result of salt solution.

The Upper Devonian Meadowbrook reef chain subcrops at the downdip edge of the McMurray oil accumulation. Possible traps may be present at breaks in the Meadowbrook reef chain, or in isolated Golden Spike or Redwater type reefs lying off the main chain. To the east, such traps would ultimately be breached by the pre-Cretaceous unconformity. A secondary post-Cretaceous accumulation could occur on erosional highs. These are controlled by a northwest-trending pre-Cretaceous drainage system developed on alternating hard limestone and soft shale formations of the Upper Devonian.

REGIONAL STRUCTURE

The base of Keg River to Precambrian isopach (Fig. 1), shows the well-known Peace River Arch dipping eastward into the Elk Point and Mikkwa Basins. A saddle extends northeastward toward a feature herein called the "Athabasca Arch." This feature can be interpreted as a tectonic high similar to the Peace River Arch, or, alternatively, the thinning could be due to salt collapse caused by the solution of the Middle Devonian Cold Lake Evaporites which are present to the west.

If the theory of a tectonic arch is accepted, then shoreline fringing facies should be expected in Middle Devonian strata. In addition to the sand-carbonate facies at Contact Rapids, interfingering sand laminations are present in the Keg River Formation as far west as the Pine Rapids outcrops (Tp. 89, R. 1, W.4 Mer.). These outcrops contain a number of indications of a relatively

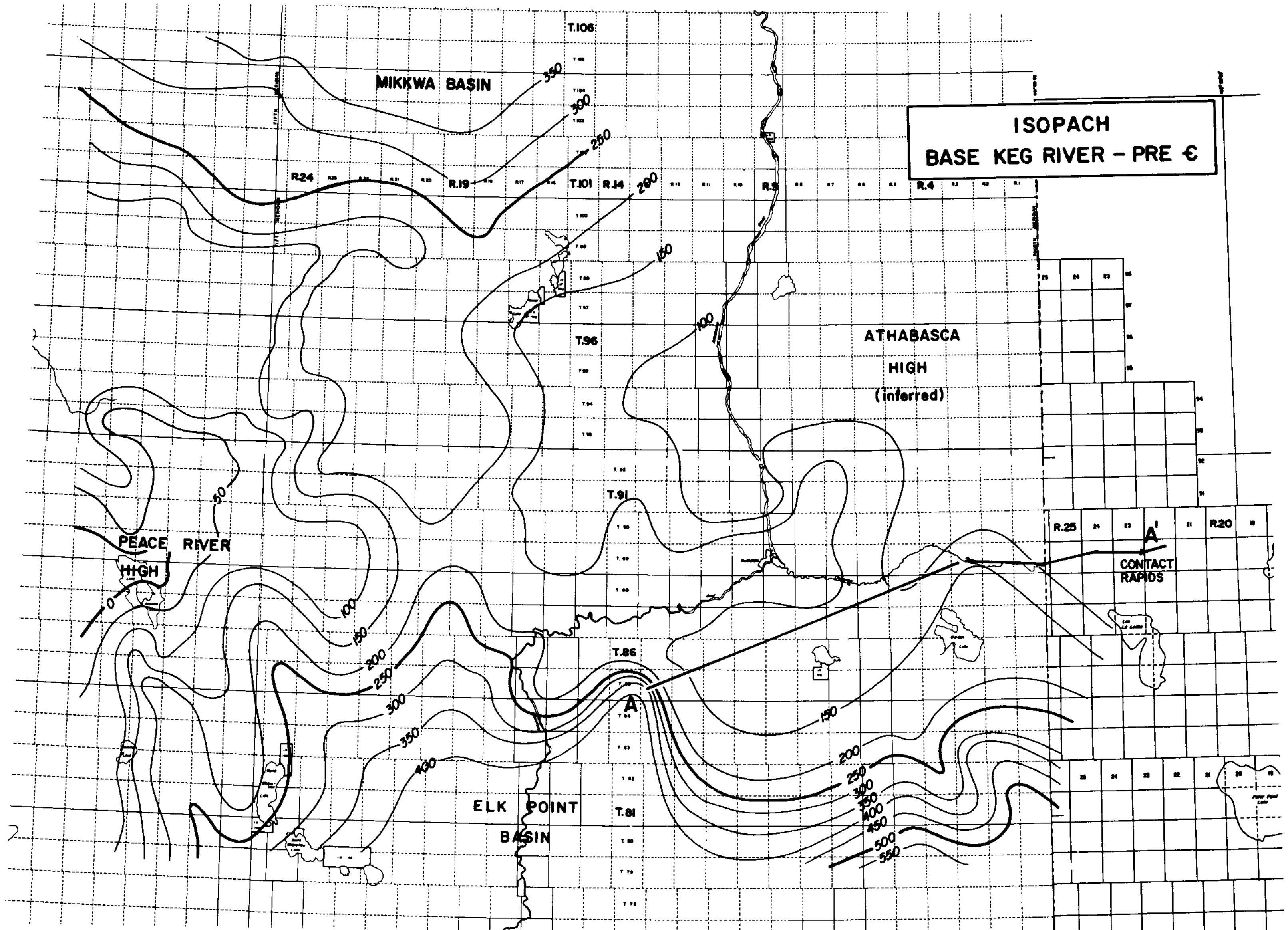

FIGURE 1. Base of Keg River to Precambrian isopach, northeastern Alberta.

shallow near-shore environment. Dolomite muds and sands show evidence of extensive reworking, with some high energy zones and minor patch reefs.

The possibility of Cold Lake salt solution thinning is negated by the Precambrian to Keg River outcrop section at Contact Rapids, Saskatchewan (Tp 89, R. 23, W.3 Mer.). This section shows a normal gradation from scour and fill basal sands to carbonates without any disconformity or any facies which might represent the missing Cold Lake salt (Fig. 2; Plate 1). Also, all Middle Devonian outcrops along the Clearwater River are essentially flat lying. In contrast, the Upper Devonian of the Fort McMurray area, which is known to be effected by solution of the underlying Muskeg Formation, shows a characteristic undulating structure (Plate 2).

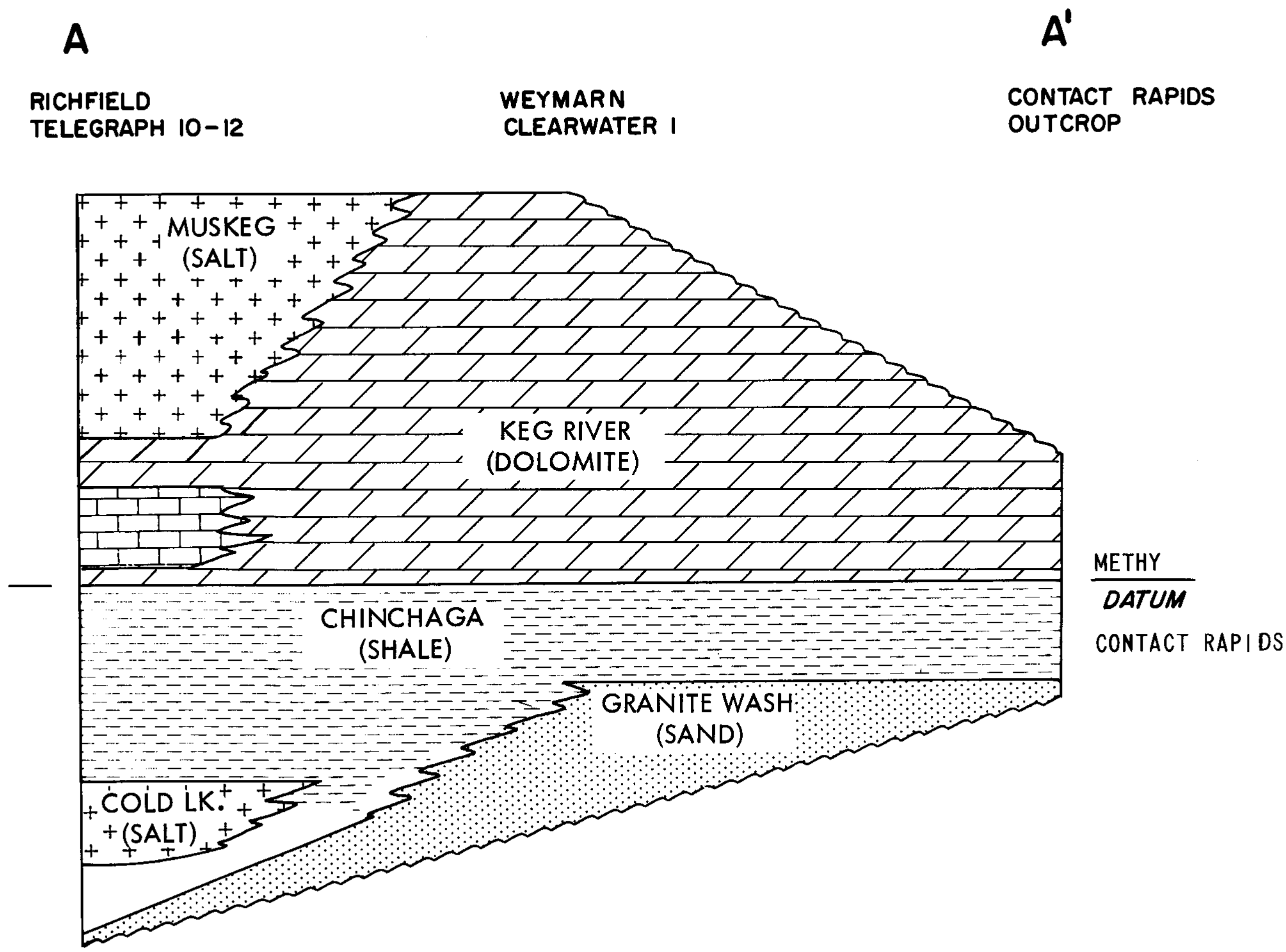

FIGURE 2. Facies and isopach trends toward the inferred Athabasca High.

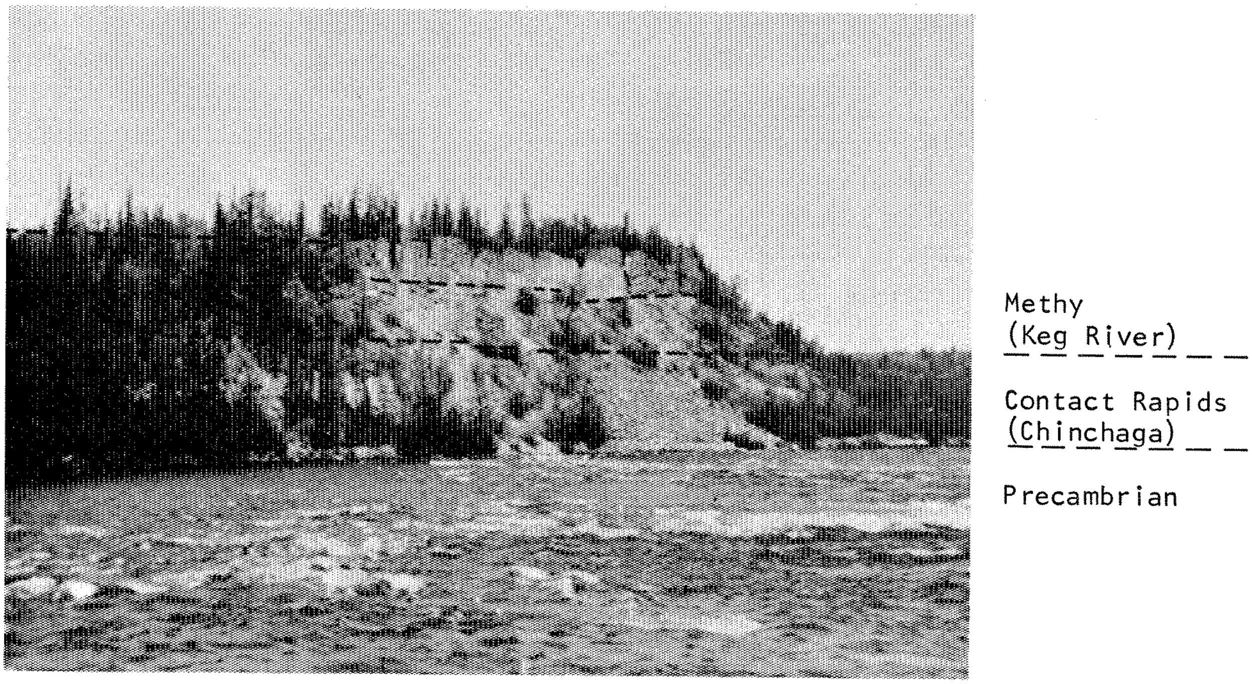

PLATE 1. Contact Rapids, Saskatchewan. A continuous Middle Devonian section (Precambrian to Keg River) with no evidence of salt collapse.

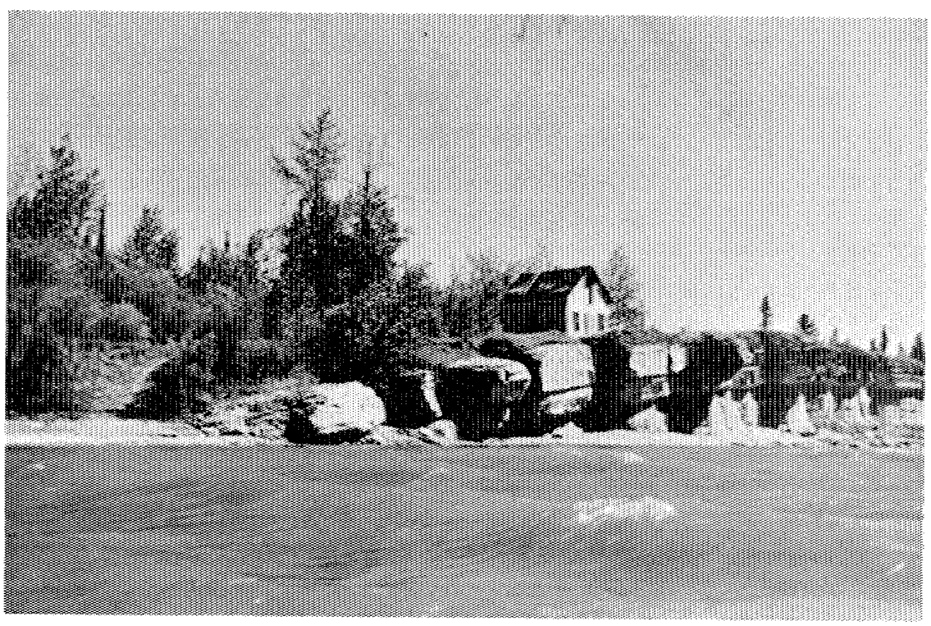

PLATE 2. East bank of the Athabasca River opposite Fort MacKay. Drape in the Upper Devonian Waterways Formation resulting from solution of the underlying salt beds.

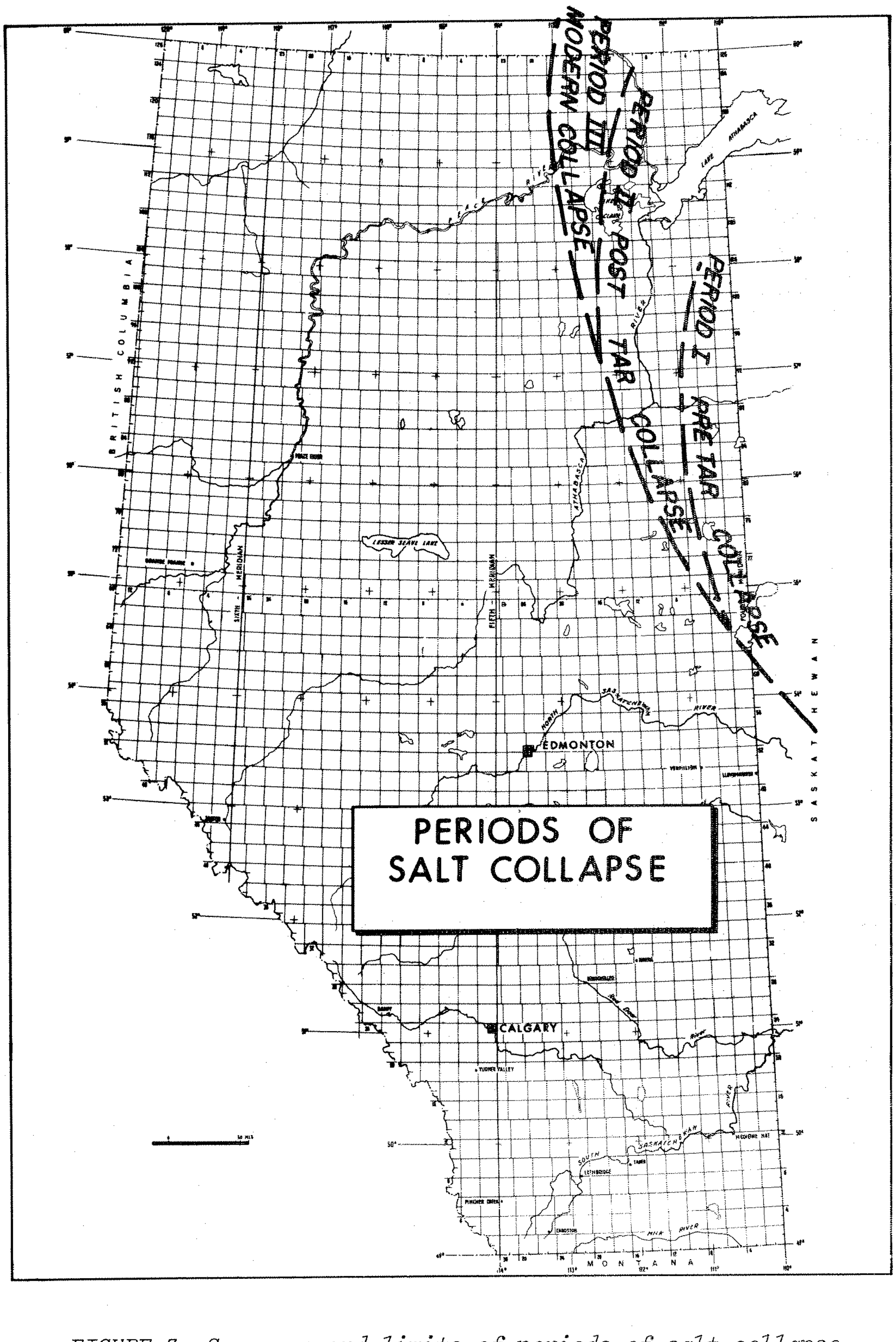

FIGURE 3. Sequence and limits of periods of salt collapse.

Evidence for a possible landmass to the northeast is found in a number of wells in the greater Fort McMurray area. For example, the Middle Devonian Watt Mountain Formation is overlain by quartz/silts, very fine-grained sands, and traces of silts. The regional configuration of the Grosmont reefs is a further indication of the presence of a landmass. Finally, a broad downdip nosing on McMurray Formation structure maps, together with one of the worlds largest hydrocarbon accumulations, the Athabasca oil sands, suggests that the high might still have been active in Cretaceous time.

Salt solution of the Middle Devonian Muskeg (Prairie Evaporite) Formation has created updip reversal in the overlying beds along a front of several hundred miles. A solution stage may have occurred prior to the McMurray bitumen accumulation. This is suggested by a general absence of bitumen updip from the main collapse front. Collapse continued in post-accumulation times as shown by tilted and varying oil-water contacts in the main deposit. There are post-Pleistocene or modern collapse sink holes as far south as the Bitumount area in Tp. 97, R. 10, W.4 Mer.

The presence of multistage collapse (Fig. 3), Paleozoic erosional relief, and probable tectonic structure, together with potential reservoir beds such as the Granite Wash, Middle and Upper Devonian reefs, and porous erosional highs on the pre-Cretaceous unconformity, will provide challenges to petroleum geologists working in the greater Athabasca oil sands area for many years to come.

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HISTORICAL HIGHLIGHTS

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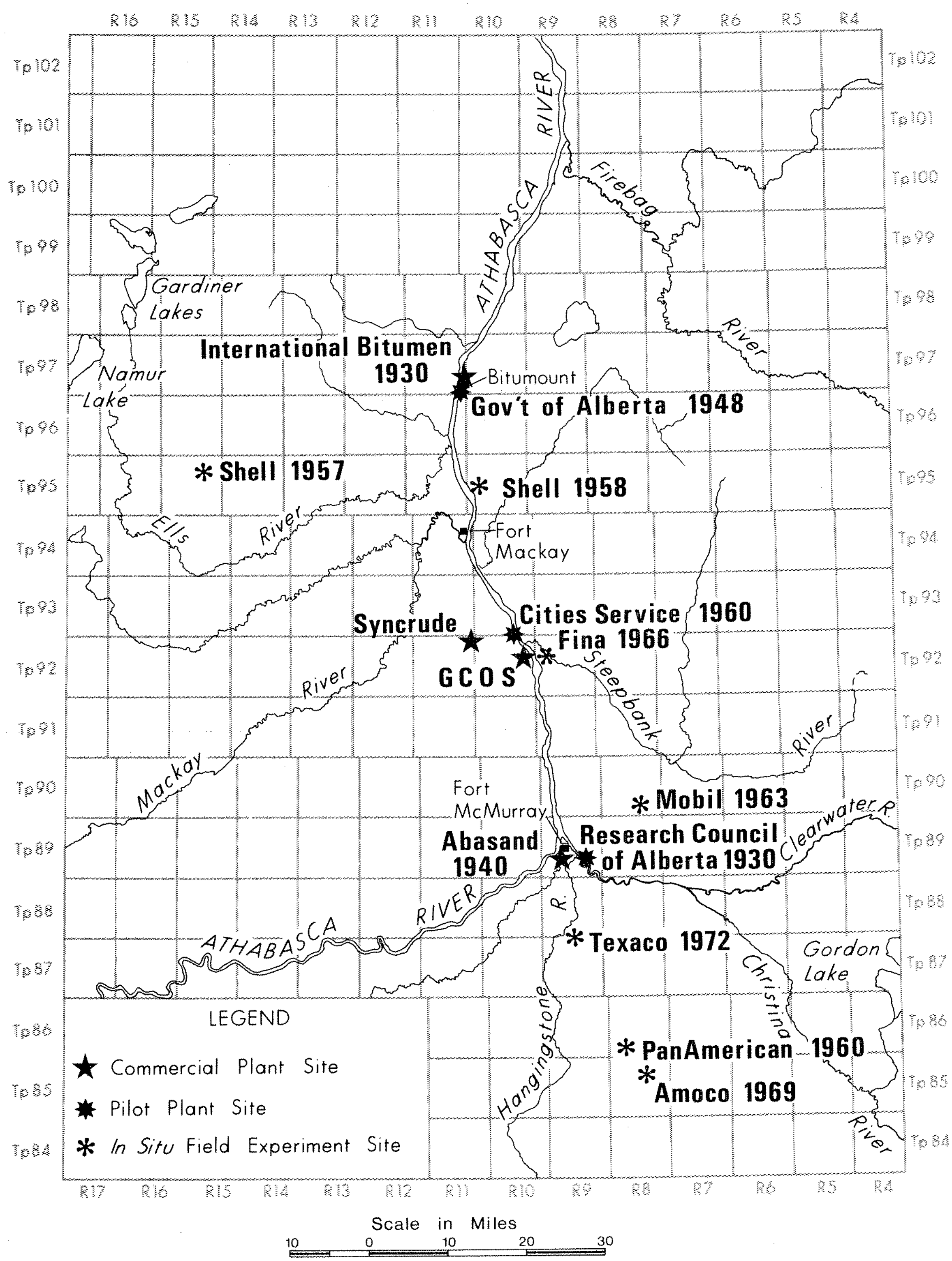


Locations of experimental and commercial plant sites in the Athabasca Oil Sands area.

HISTORICAL HIGHLIGHTS
LOG OF MAJOR EVENTS IN THE HISTORY OF THE ATHABASCA OIL SANDS

Year	No. of years ago	Event
1778	195	• Peter Pond, a fur trader with the North-west Company, reaches the Athabasca River by way of Methy Portage and becomes the first European to see the tar sands outcrops.

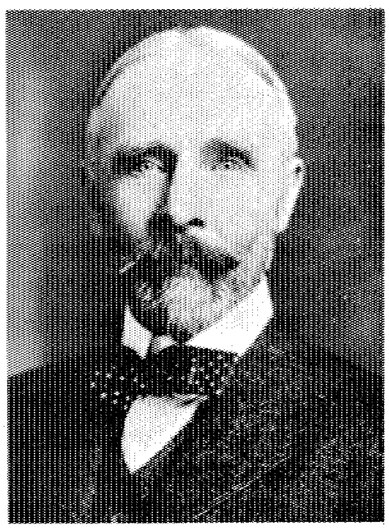
Alexandre MacKenzie (Photograph courtesy of the Public Archives of Canada, Ottawa).

Year	No. of years ago	Event
1792	181	• Alexandre MacKenzie enters the Clearwater-Athabasca River system *via* Methy Portage and describes the tar sands.
1799	174	• David Thompson makes a track survey of the Athabasca River from the Clearwater forks to Lake Athabasca.
1819	154	• Sir John Franklin examines the Athabasca River between Lake Athabasca and the mouth of the Clearwater River.
1848	125	• Sir John Richardson makes geological notes on a journey to the Arctic in search of Franklin. Correlates the tar sands with the Marcellus shales of the New York State Devonian sequence.
1882	91	• Dr. Robert Bell of the Geological & Natural History Survey of Canada examines the tar sands area in detail. Recognizes the Lower Cretaceous age of the tar sands strata, proposes a Devonian origin for the bitumen, and reports that hot water extraction of the bitumen might be feasible.

Dr. Robert Bell (Photograph courtesy of the Geological Survey of Canada, Ottawa).

He also proposes building a pipeline from the east end of Lake Athabasca to Hudson's Bay to transport the oil to foreign markets.

1884 89 • William Ogilvie D.L.S. makes a new track survey of the Athabasca River.



R. G. McConnell (Photograph courtesy of the Geological Survey of Canada, Ottawa).

1888 85 • Mr. R. G. McConnell of the Geological & Natural History Survey of Canada gives the first modern geological description of the tar sands, and correlates them with the Dakota sandstones of the U.S. western interior. Estimates the area underlain by tar sands to be in excess of 1,000 square miles and the reserves of bitumen at not less than 4.2 million long tons. Suggests that lighter oil might be found in the same strata down dip at Pelican Rapids.

Count Alfred von Hammerstein (Photograph courtesy of the E. Brown collection, Provincial Museum and Archives of Alberta, Edmonton).

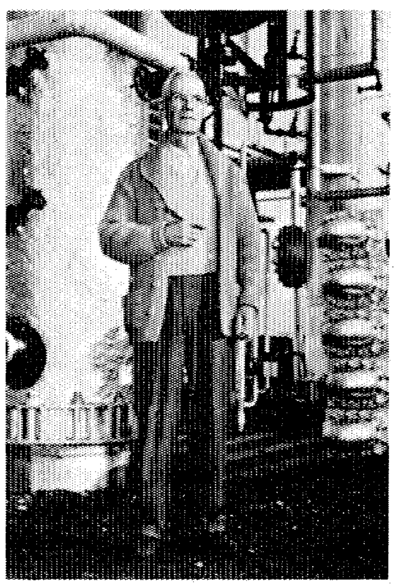
1906	67	• Count Alfred von Hammerstein follows up Robert Bell's suggestion and drills for oil in the Devonian limestones along the banks of the Athabasca River. He does not find oil but discovers salt in a well drilled at the mouth of the Horse River.
1911	62	• G. H. Blanchette completes a survey of the 23rd base line.

Sydney Ells at Waterways, 1931. (Photograph courtesy of the Public Archives of Canada, Ottawa).

1913	60	• Mr. Sydney C. Ells, an engineer with the Mines Branch in Ottawa, begins a detailed survey of the tar sands exposures on the lower Athabasca River.
1915	58	• Mr. Ells lays a demonstration bituminous pavement in Edmonton using tar sands from near Fort McMurray.
1916	57	• Northern Alberta Railway track reaches the junction of the Christina and Clearwater Rivers, 12 miles southeast of Fort McMurray.

Dr. F. H. McLearn (Photograph courtesy of the Geological Survey of Canada, Ottawa).

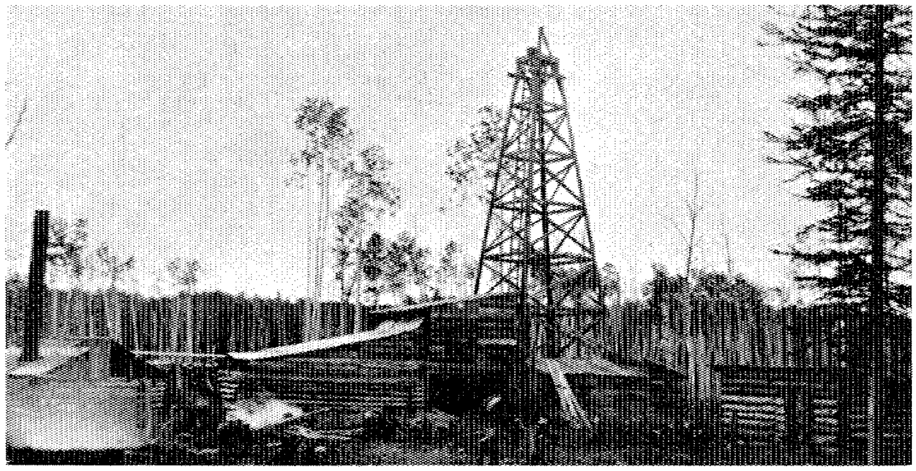
1917 56 • Dr. F. H. McLearn of the Geological Survey of Canada gives the name McMurray Formation to the strata containing the tar sands.



Dr. Karl Adolf Clark at Bitumount, 1948. (Photograph courtesy of the Government of Alberta, Edmonton).

1920 53 • Dr. Karl Adolf Clark joins the Alberta Scientific and Industrial Research Council in Edmonton to study the use of Athabasca tar sands as a road paving material.

• Mr. D. Diver makes the first attempt at production of oil by an *in situ* method. He tries to distill oil from the bituminous sands by lowering a heating unit to the bottom of a well drilled in Sec. 9, Tp. 89, R. 9, W.4th Mer. near Fort McMurray.



Diver's in situ *operation, 1920. (Photograph from J. A. Allan collection, courtesy of Alberta Research, Edmonton).*

1922	51	• A group of New York city policemen form the Alcan Oil Company to drill for oil near the tar springs found along the Athabasca River in townships 96 and 97.
1923	50	• Dr. K. A. Clark and Mr. S. M. Blair build the first hot water extraction pilot plant at the University of Alberta.
1924	49	• Clark and Blair erect a larger hot water pilot plant at the Dunvegan Railway yards in northeast Edmonton.
1926	47	• Mr. S. C. Ells successfully drills and cores tar sands. Northern Alberta Railway completed to Waterways.
1927	46	• Mr. R. C. Fitzsimmons forms the International Bitumen Company for commercial development of the tar sands.

Mr. R. C. Fitzsimmons, ca. *1934. (Photograph courtesy of the Provincial Museum and Archives of Alberta, Edmonton).*

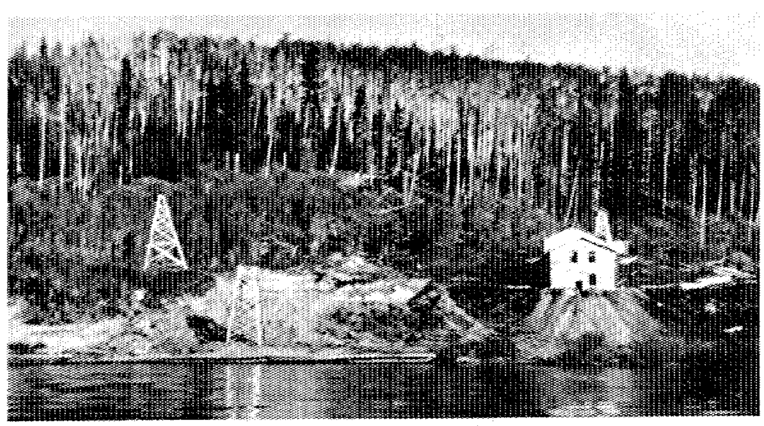
First commercial tar sands separation plant (Fitzsimmons' plant) at Bitumount. (Photograph courtesy of the Provincial Museum and Archives of Alberta, Edmonton).

- Mr. S. C. Ells lays tar sands pavement in Jasper National Park, from the CNR railway to Jasper Park Lodge.

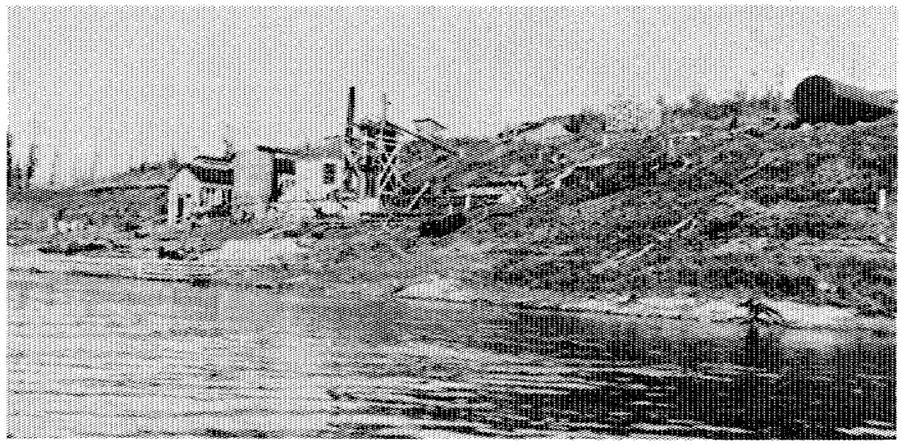
1928 45
- Dr. K. A. Clark is awarded a Canadian Patent for his hot water process.

1929 44
- Mr. J. O. Absher attempts *in situ* distillation near Fort McMurray. Tries to ignite the tar sands at the bottom of a well to induce production.
- Mr. S. C. Ells conducts blasting experiments to soften the tar sands for easier digging.

1930 43
- The Research Council of Alberta hot water extraction plant is moved from the Dunvegan yards to the Clearwater River near Waterways, and uses tar sands mined by the Mines Branch of Canada.



Research Council of Alberta pilot plant, Waterways, ca. *1930. (Photograph courtesy of the Public Archives of Canada, Ottawa).*



International Bitumen Company plant at Bitumount, ca. *1930. (Photograph courtesy of the Provincial Museum and Archives of Alberta, Edmonton).*

- Mr. R. C. Fitzsimmons produces 8,400 gallons of bitumen at the Bitumount plant of the International Bitumen Company.

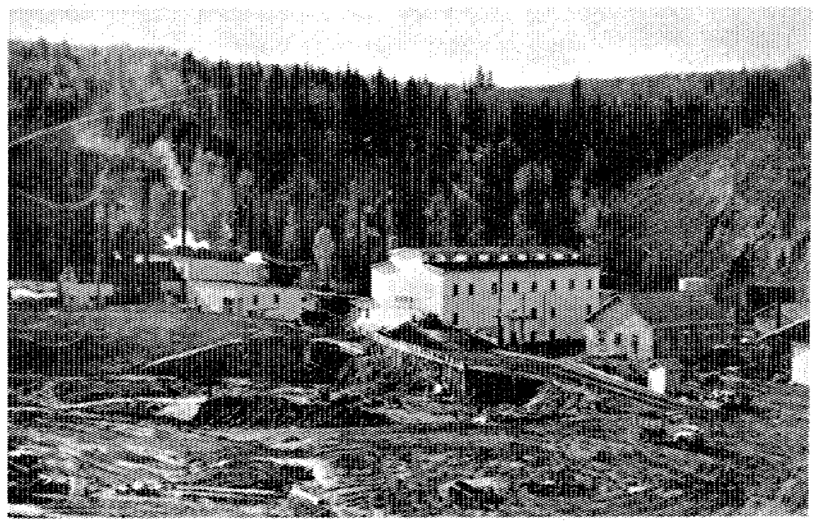
Max Waite Ball (Photograph courtesy of Wallace E. Pratt and the American Association of Petroleum Geologists, Tulsa).

- Max Waite Ball forms Abasand Oil Company to extract oil commercially from the tar sands.
- Mr. B. F. Haanel of the Mines Branch in Ottawa begins hydrogenation experiments on Athabasca bitumen.

1936 37

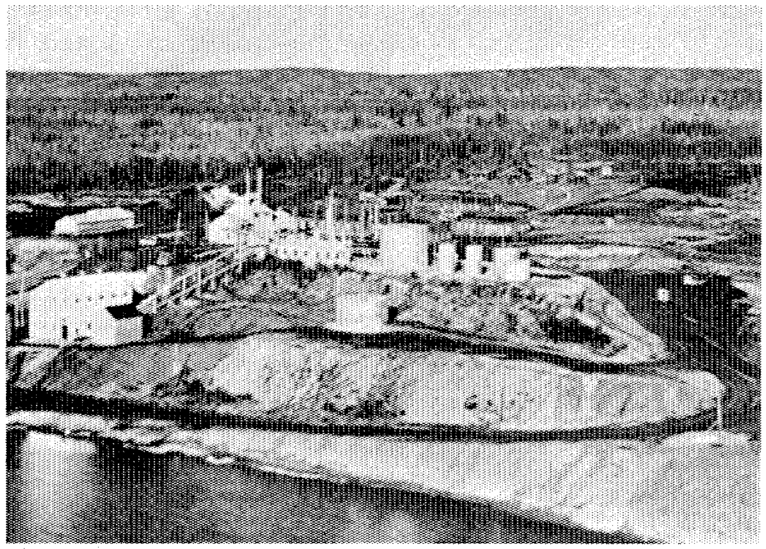
- Dr. K. A. Clark awarded a U.S. patent for the hot water process and apparatus.
- Abasand Oil Company Ltd. completes construction of a 400 ton per day plant on the Horse River site.
- International Bitumen Company enlarges its plant at Bitumount to 350 barrels per day and adds a distillation unit.

1938	35	• International Bitumen Company produces 4,500 drums of asphalt and 2,000 barrels of fuel oil at Bitumount.
1941	32	• Abasand Plant is destroyed by fire.
1942	31	• Mr. L. R. Champion acquires control of International Bitumen Company and renames it Oil Sands Limited. The Abasand plant is rebuilt.
		• Government of Canada begins an exploratory drilling and coring program to outline the tar sands reserves for war-time emergency use.
1943	30	• Mines Branch takes over the Abasand property and begins to redesign and reconstruct the plant.



Abasand plant. (Photograph courtesy of the Public Archives of Canada, Ottawa).

1945	28	• Rebuilt Abasand plant is again destroyed by fire.
1947	26	• Dr. P. E. Gishler begins investigation of a fluidized solids process for bitumen recovery at the National Research Council of Canada.
		• Canada Mines Branch drilling is completed after proving up reserves of 1.75 billion tons of commercial grade tar sand and discovering the rich deposit near Tar Island, now being exploited by Great Canadian Oil Sands Ltd.
1948	25	• Government of Alberta builds a 500 ton per day plant at Bitumount to demonstrate the commercial feasibility of the Clark hot water process.



Government of Alberta demonstration plant at Bitumount. (Photograph courtesy of Alberta Research, Edmonton).

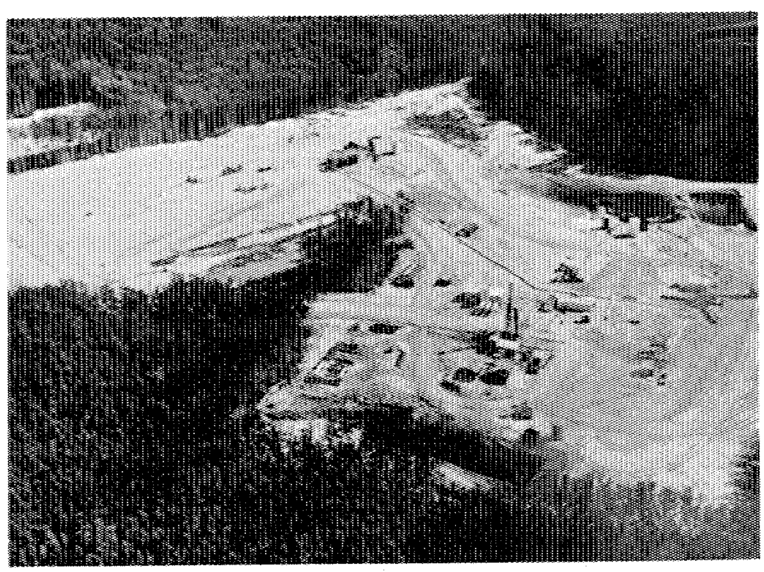
1950	23	• Mr. S. M. Blair publishes a report indicating that large-scale economic development of the tar sands is now feasible. He estimates the cost of producing one barrel of synthetic oil and delivering it to Edmonton by pipeline at $2.36.
1951	22	• First Athabasca Oil Sands Conference is held in Edmonton. Alberta Government publishes its bituminous sands leasing policy and issues the first permits to oil companies.
1954	19	• Great Canadian Oil Sands Ltd. is formed to take over the interests of Oil Sands Ltd.
1957	16	• Shell Oil Company of Canada begins *in situ* steam drive experiments on lease 26.
1959	14	• Cities Service Athabasca Inc. builds a pilot plant near Mildred Lake to test various separation methods.
		• Pan American Petroleum Company begins *in situ* combustion experiments near Gregoire Lake.
		• Atlantic Richfield and partners propose an experiment to release oil by exploding a nuclear device beneath the oil sands.
1960	13	• Great Canadian Oil Sands Ltd. applies to the Alberta Oil and Gas Conservation Board for permission to produce 31,500 barrels per day from the oil sands.
1962	11	• Great Canadian Oil Sands Ltd. receives permission from the Alberta Oil and Gas Conservation Board to build a 31,500 barrel per day plant at Tar Island.

- The Shell Oil Company of Canada applies to the Alberta Oil and Gas Conservation Board for permission to produce 130,000 barrels per day of bitumen by an *in situ* steam drive process.
- A consortium of companies consisting of Atlantic Richfield, Cities Service Athabasca Inc., Imperial Oil Ltd., and Royalite Oil Company apply to the Alberta Oil and Gas Conservation Board for a permit to produce 100,000 barrels per day of synthetic crude oil by a mining and hot water process.

1963 10
- Second Athabasca Oil Sands Conference is held in Edmonton.
- The Alberta Oil and Gas Conservation Board publishes the first comprehensive estimate of bitumen reserves in the Athabasca deposit at 626 billion barrels of bitumen in place.
- Sun Oil Company of Philadelphia acquires a controlling interest in Great Canadian Oil Sands Ltd.

1964 9
- The Alberta Oil and Gas Conservation Board increases Great Canadian Oil Sands Ltd. production allowable to 45,000 barrels per day. The Syncrude consortium (Atlantic Richfield, Cities Service, Imperial Oil and Gulf Oil) is incorporated to operate oil sands projects for member companies.

1967 6
- Great Canadian Oil Sands Ltd. plant goes on stream.



Amoco in situ *experimental site south of Gregoire Lake. (Photograph courtesy of Amoco Canada Petroleum Company Ltd., Calgary).*

1968	5	• Muskeg Oil Company (Amoco) applies to the Alberta Oil and Gas Conservation Board for permission to produce 8,000 barrels per day of bitumen by a modified *in situ* combustion process.
1969	4	• Syncrude's application is amended to 80,000 barrels per day.
1972	1	• Great Canadian Oil Sands Ltd. applies for permission to increase production to the 50-60,000 barrels per day range.
		• Alberta Energy Resources Conservation Board gives conditional approval for Syncrude to build a 125,000 barrels per day plant at Mildred Lake.
1973	0	• Shell Canada Limited applies to the Alberta Energy Resources Conservation Board for approval of a mining operation to produce 100,000 barrels per day from the Athabasca oil sands.
		• Canadian Association of Petroleum Geologists Oil Sands Symposium is held in Calgary.

ROAD LOG,
FORT McMURRAY TO FORT MacKAY

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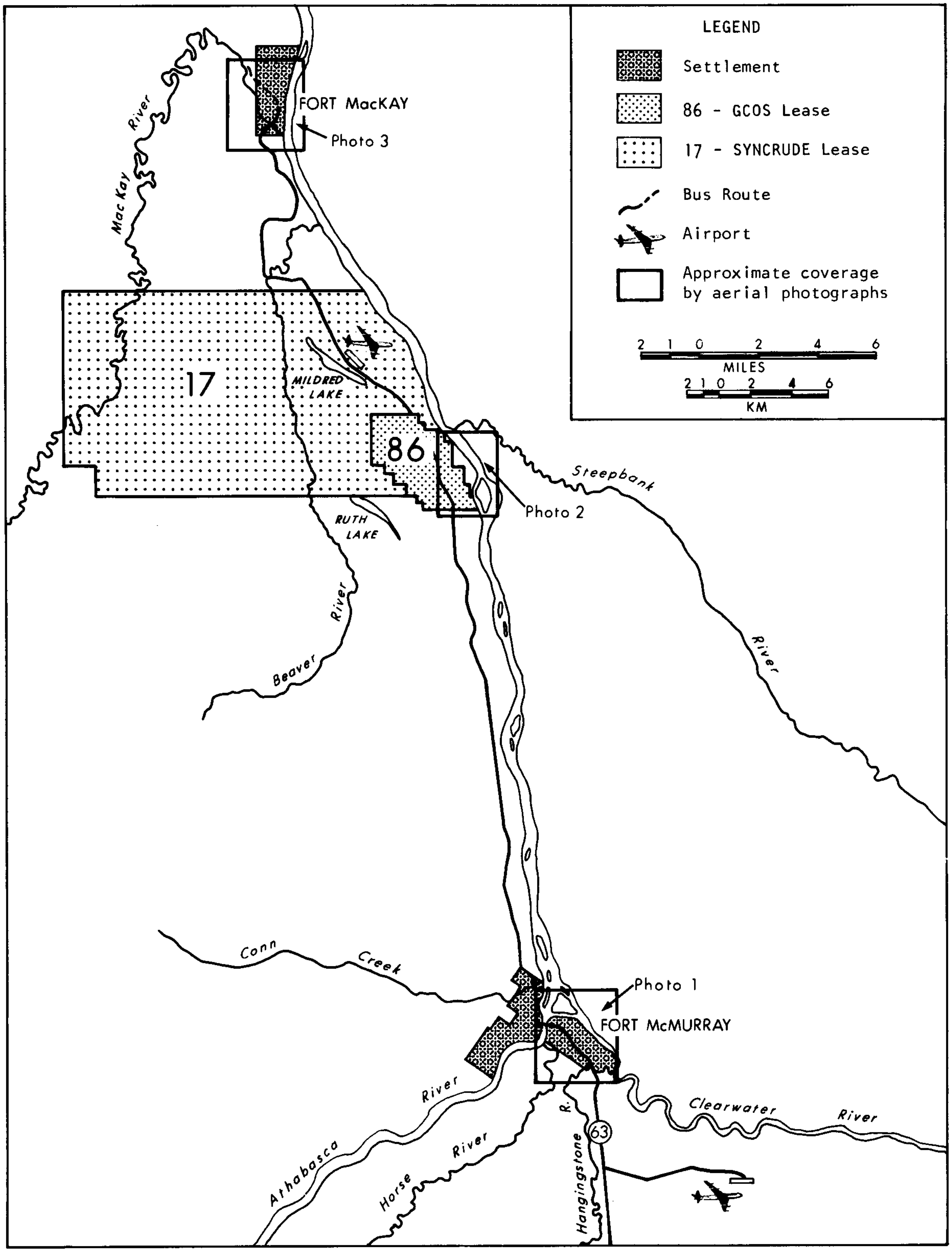
Alberta Research, Contribution No. 632



Route map for the CSPG Oil Sands Symposium field trip, September 1973.

ROAD LOG
1973 CSPG OIL SANDS SYMPOSIUM
FIELD TRIP

The road log presented here is a general road log from the airport at Fort McMurray to a viewpoint along the MacKay River just northwest of Fort MacKay, as shown on the route map. Immediately following are three aerial photographs taken in August 1972: the coverage of these photographs is shown on the route map. The main stops of the field trip are indicated on the photographs by circled numbers and are also shown on the road log where the stops are described.

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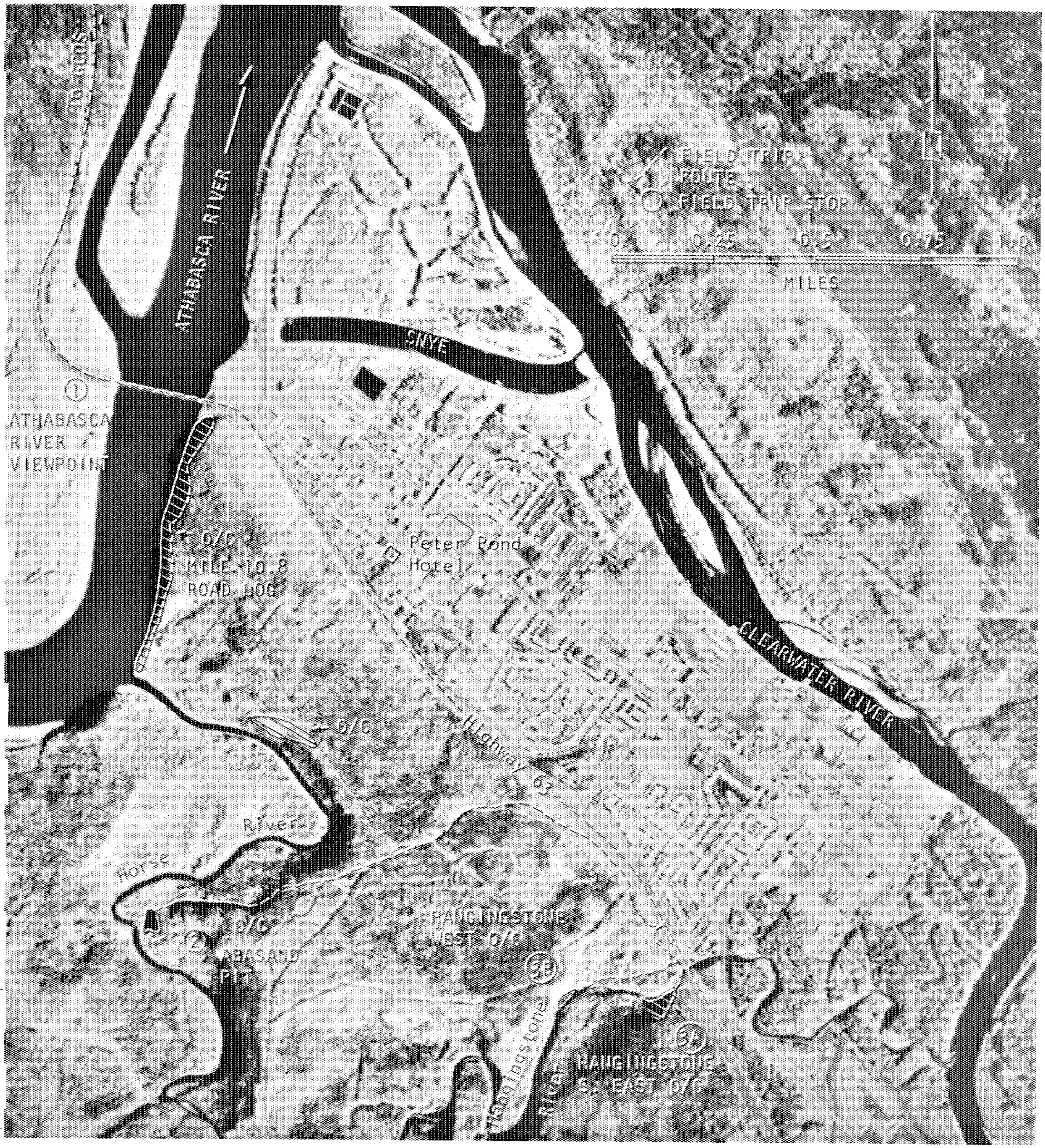
W. B. (Bill) Gallup	Gallup Exploration and Services Ltd., Calgary
J. W. (John) Kramers	Alberta Research, Edmonton
I. J. (Jean) McLaws	Alberta Research, Edmonton
A. W. (Willy) Norris	Institute of Sedimentary and Petroleum Geology, Calgary
E. R. (Gene) Sanford	Great Canadian Oil Sands Limited, Fort McMurray

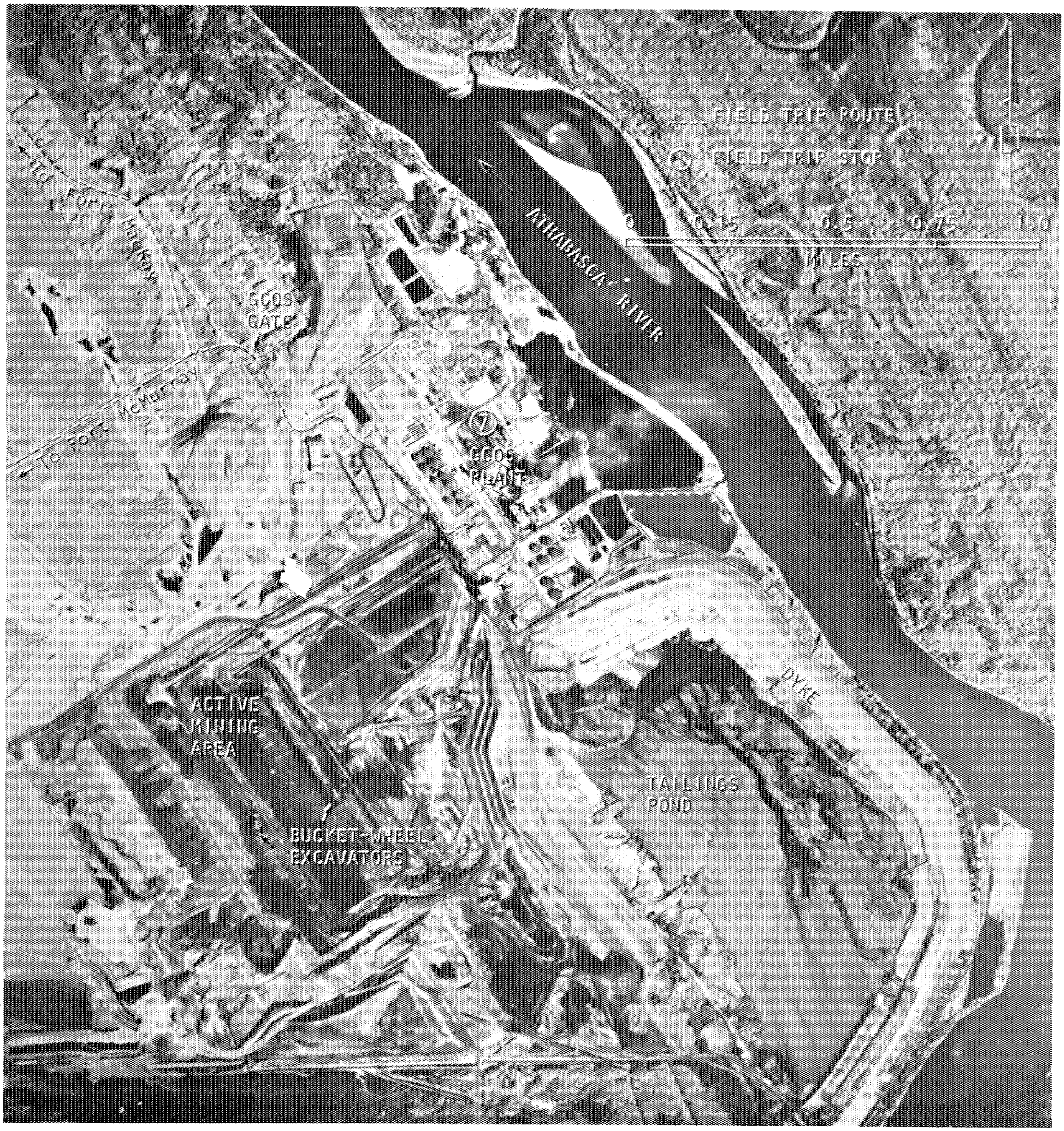
NOTES

Aerial photographs courtesy of the Technical Division,
Department of Lands and Forests, Government of Alberta



Aerial Photo 1. Fort McMurray and vicinity.

NOTES



Aerial Photo 2. Aerial view of the Great Canadian Oil Sands operation. A visit to the plant will be made on the second day of the field trip.

NOTES

Aerial Photo 3. Settlement of Fort MacKay and vicinity.

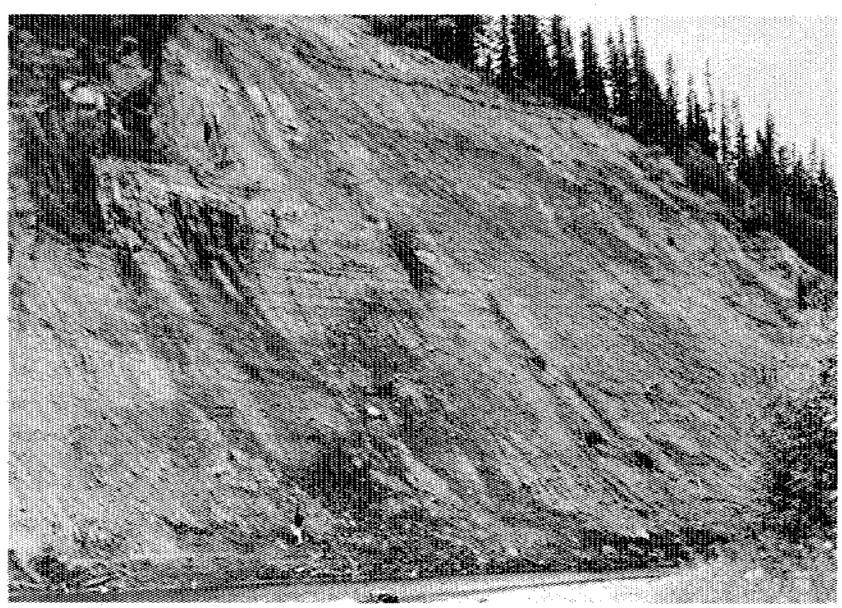
NOTES

ROAD LOG:

Fort McMurray Airport to Fort MacKay Settlement

Mileage	Distance	
0.0	0.0	Fort McMurray Airport terminal.
4.4	4.4	Junction Highway 63 (turn right).
4.8	0.4	Gravel pits in glacial drift (on left).
5.2	0.4	Gravel pits in glacial drift (on right).
6.1	0.9	Alberta Vocational Center training area.
6.8	0.7	Gravel pits in glacial drift (on left).
7.0	0.2	Road cut on left exposes the Clearwater Formation. Section consists of green glauconitic siltstones, overlying a thin fossiliferous ironstone bed, overlying grey fossiliferous shale.
7.5	0.5	Corporate limits of the town of Fort McMurray.
8.0	0.5	Road on right is the first turnoff for Waterways and Fort McMurray.
8.1	0.1	Bridge over Hangingstone River. High bank on left shows olive green sandstone (Wabiskaw Member) of the Clearwater Formation at the top overlying the thin-bedded, silty, oil-impregnated beds of the McMurray Formation (Athabasca oil sands).

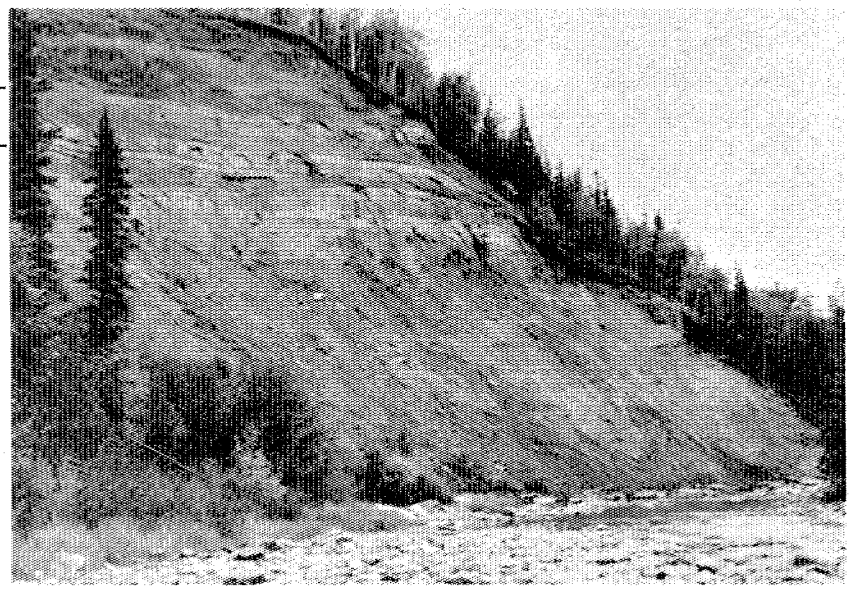
(3A)



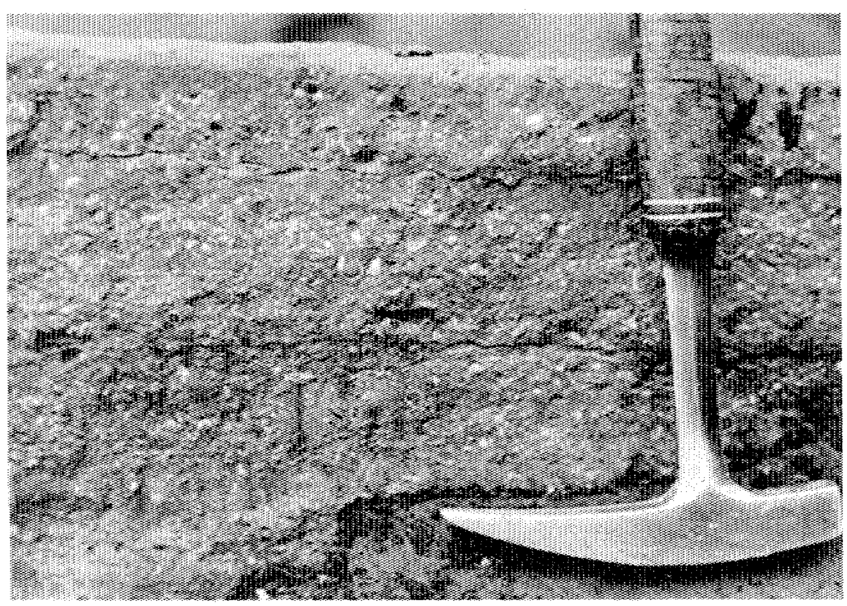
Hangingstone River southeast bank outcrop. Oil-impregnated McMurray Formation overlain by the Wabiskaw Member of the Clearwater Formation.

NOTES

A section of oil-impregnated McMurray Formation, overlain by the Wabiskaw Member of the Clearwater Formation, is located a short distance (approx. 600 yards) upstream on the west bank of the Hangingstone River.



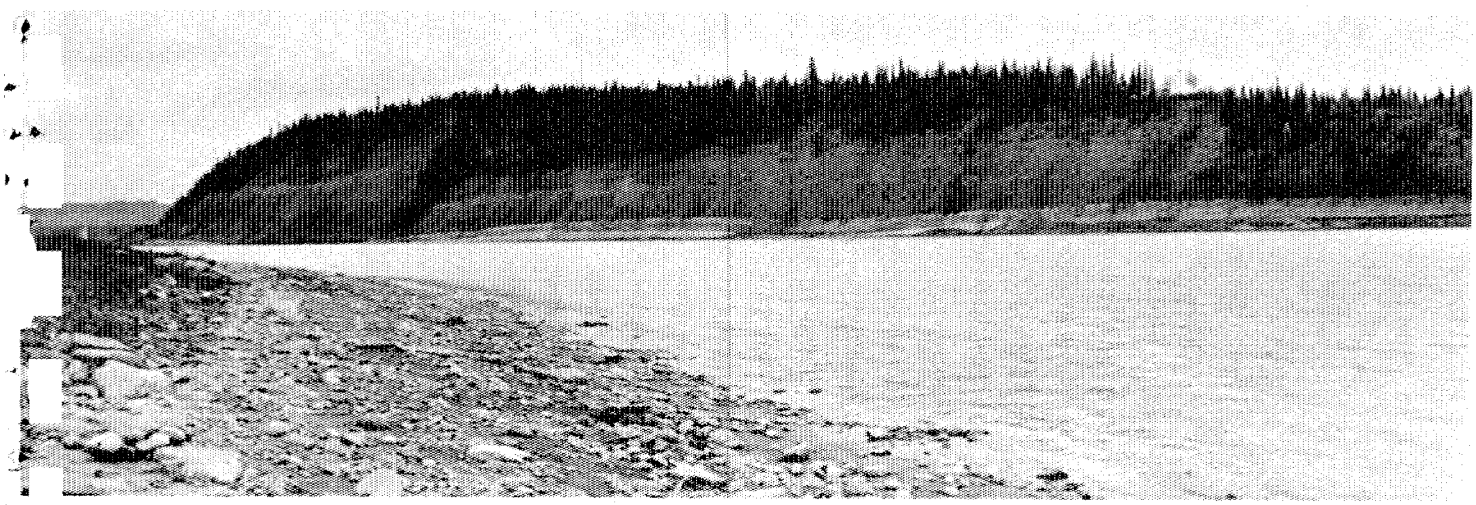
Hangingstone River about 1/3 mile upstream from Highway 63, west bank outcrop. Oil-impregnated McMurray Formation overlain by the Wabiskaw Member of the Clearwater Formation.



Close-up of shell bed from the Upper McMurray Formation, Hangingstone River outcrop above.

NOTES

8.25	0.15	Road on left, turnoff to Abasand (see supplementary road log, Abandoned Abasand Operation).
10.3	2.05	Bridge over Athabasca River. High bank on left exposes a complete section of the oil-impregnated McMurray Formation, overlain by the olive green glauconitic sands of the Clearwater Formation at the top and underlain by the cream-colored, undulating limestones of the Moberley Member of the Waterways Formation at the base.
(1) 10.8	0.5	End of bridge, road on left at the end of the guard rail leads down to the river flats for a good view of the section exposed on the other side of the river. The Moberly Rapids outcrop described by Norris and Carbone (this volume) is 0.7 miles south of the bridge on the west bank of the Athabasca River.



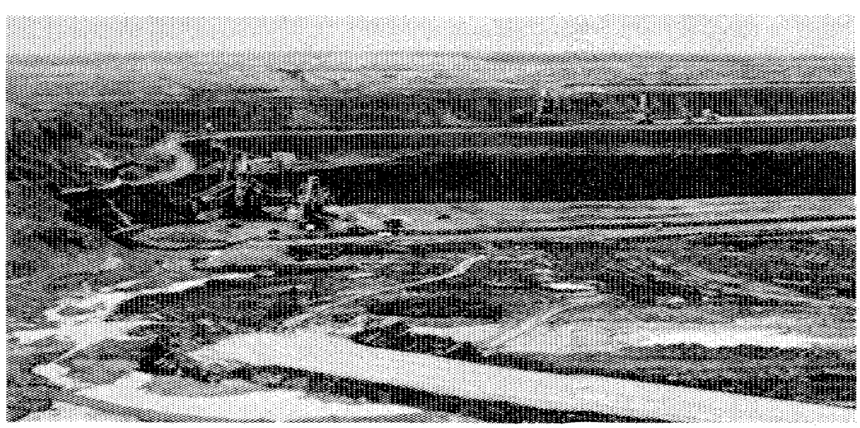
Panoramic view south of the Athabasca River bridge, showing the oil-impregnated McMurray Formation, overlain by the olive green glauconitic sands of the Wabiskaw Member of the Clearwater Formation and underlain by gently undulating limestones of the Moberly Member of the Waterways Formation.

10.9	0.1	Gravel road on left leads to Thickwood Hills.
11.9	1.0	Culvert over Conn Creek. The Moberly Member of the Waterways Formation is exposed in the banks of the Creek to left and right of the road. The limestone here is very fossiliferous and many fine brachiopod specimens can be collected in the cleared area on the roadside to the right. See Conn Creek section description by Norris and Carbone (this volume) for a more detailed description.
12.8	0.9	Dirt road on left leads to a good exposure of oil sands of the McMurray Formation. This outcrop is comprised of thin-bedded, fine-grained strata with some thin layers of interbedded ironstone. The outcrop is cut by an access road and has slumped in places. Careful examination shows sedimentary features such as animal burrows and ripple bedding.
14.2	1.4	Small oil sands outcrop on left.

NOTES

17.9	3.7	Outcrop of oil sands off highway to the left (200 yards). The section here consists of light-grey, poorly-impregnated beds with many burrows. There are several thin ironstone beds in the outcrop and some fossil wood. The richer oil sands occur in the lower part of the section.
20.6	2.7	Roadside exposure of rubbly limestone on right is richly fossiliferous and contains most of the representative shelly fauna of the Moberley Member of the Waterways Formation. Crinoid heads have been found in this outcrop. See Norris and Carbone (this volume) for a more detailed description.
20.75	0.15	Outcrop of oil sands (McMurray Formation) on left.
21.60	0.85	Dirt road on left leads to small outcrop of oil sands.
22.0	0.4	Road cut on left exposes the greenish argillaceous beds of the Moberly Member of the Waterways Formation. Excellent brachiopod specimens can be found in this outcrop. See Norris and Carbone (this volume) for more description.
22.2	0.2	For the following 1.3 miles there are several exposures of rubbly limestones of the Waterways Formation.
24.1	1.9	Supertest Hill. Road cut on left shows oil sands overlain by a thick section of glacial drift.
24.9	0.8	Top of hill, clearing to the right gives a good view of the Athabasca River valley to the south.
28.0	3.1	Sand pit in postglacial dune field.
31.0	3.0	Entering Great Canadian Oil Sands lease.
31.5	0.5	Gravel pit in glacial drift.
32.5	1.0	Hill on the right is the waste dump from the GCOS open pit mine. Turn left off pavement to Fort MacKay. Pavement leads to gate at the entrance of the GCOS operation (0.3 miles).

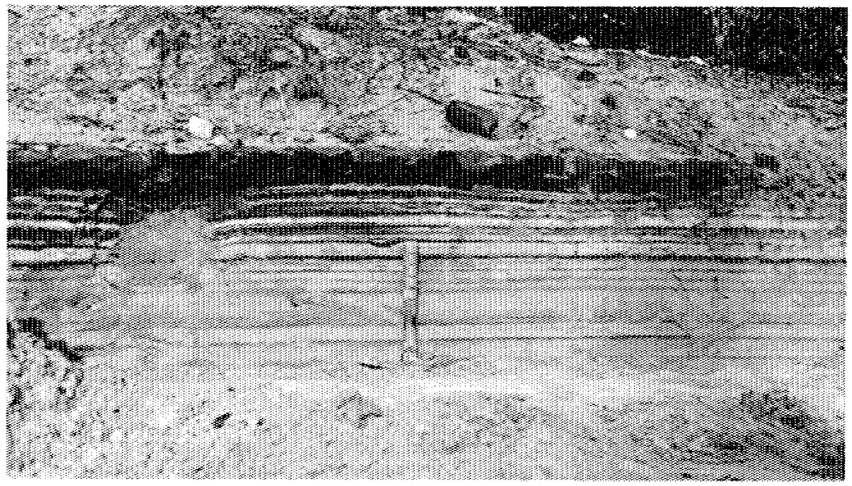
(7)



Bucketwheel excavators mining oil sands on the upper and lower benches in the Great Canadian Oil Sands pit.

NOTES

33.9	1.4	Sand pit in postglacial dune (on left).
34.25	0.35	Access road to Syncrude operation (on left).
34.30	0.05	Access road to Syncrude camp and pilot plant (on right) (see supplementary road log, Syncrude Pilot Plant).
36.7	2.4	Access road to Mildred Lake landing strip (on right).
39.8	3.1	Road cut with glacial sand containing thin beds of reworked oil sands (on right).

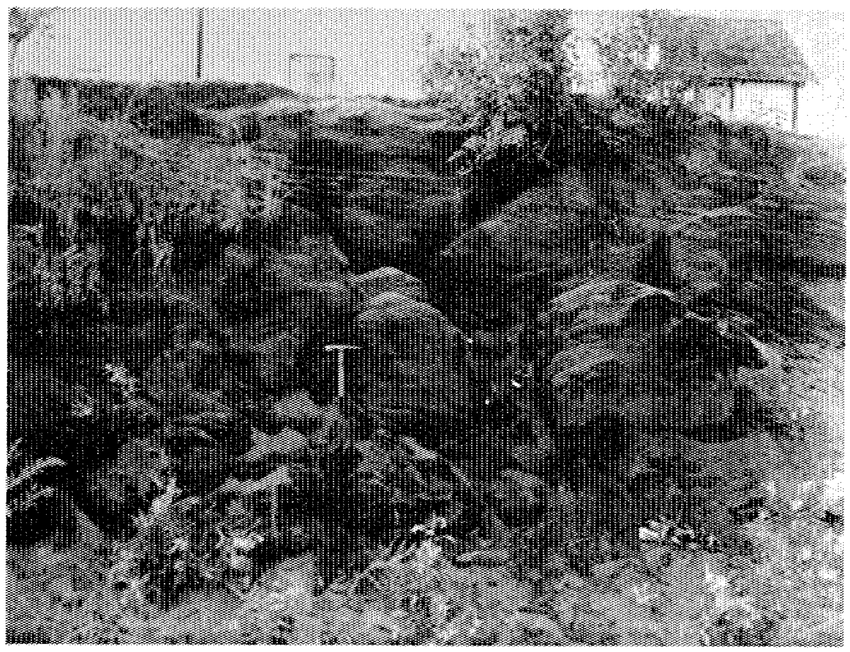


Thin interbeds of reworked oil sands in surficial deposits.

40.9	1.1	Road cuts in postglacial dune sand.
41.9	1.0	Beaver River bridge. Provincial campground to the right. River bank shows rich oil sands overlain directly by glacial sand.
43.0	1.1	On both sides of the road, beyond the creek, road cuts have exposed green sand and shale of the Clearwater Formation overlying poorly impregnated oil sands of the Upper McMurray Formation. The contact between these formations is exposed in the drainage ditch on the left side of the road.
44.4	1.4	In the gravel pit on right hand side of the road heavy oil from the oil sands has been incorporated into the gravel as oil conglomerate pockets. Oil sands in place are exposed in the roadside ditch to the north of the gravel pit.
46.5	2.1	Oil sands exposed on surface on both sides of the road.
47.3	0.8	Road cut through knoll containing a mixture of local bedrock including many blocks of ironstone.
47.4	0.1	Small stream.
48.0	0.6	Outcrop showing 20 feet or so of poorly-impregnated oil sands. Some beds show shale-chip conglomerates.

NOTES

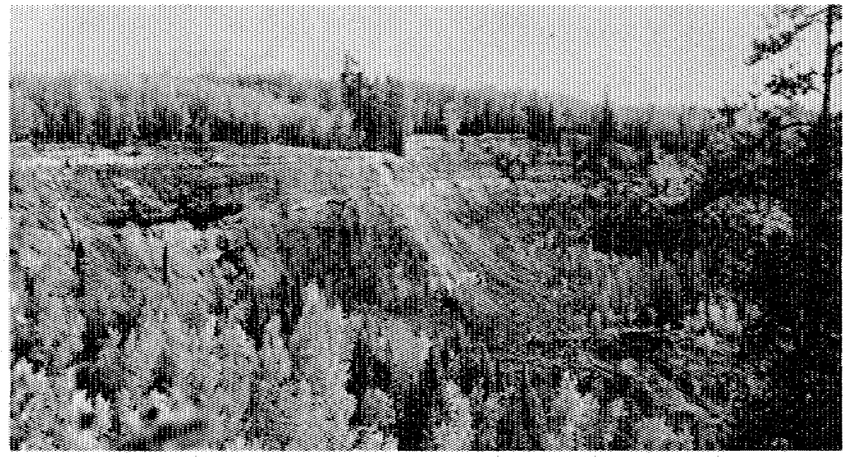
	48.2	0.2	Rich oil sands in road cuts on both sides of the road.
	48.4	0.2	MacKay River bridge. A small outcrop of basal McMurray Formation overlies limestones of the Moberly Member of the Waterways Formation about 500 yards upstream.
	49.15	0.75	Fort MacKay settlement. Take road to the right, proceed towards Athabasca River.
(5)	{49.30 49.45	0.15 0.15	Low outcrops of coarse-grained, poorly-saturated oil sands are present on the left side of the road. The sands are cross-bedded on a large scale and contain many clay-ironstone pellets.



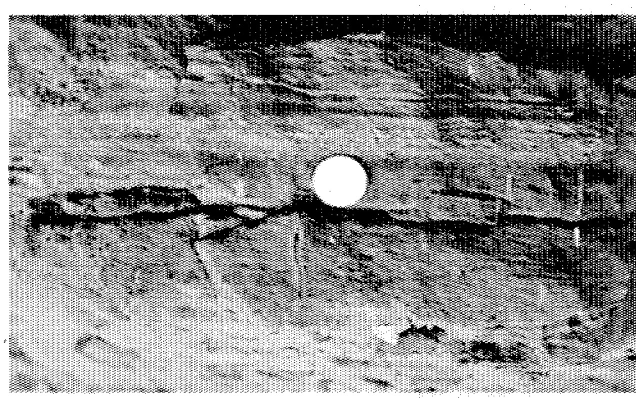
Coarse-grained, poorly-saturated oil sands of the basal McMurray Formation showing large scale cross-bedding, Fort MacKay settlement.

(6)			Less than 1/2 mile north of these outcrops, the Moberly Member of the Waterways Formation is exposed along the river banks. See Fort MacKay section description by Norris and Carbone (this volume).
	49.6	0.15	Return to main road, turn right.
	49.7	0.1	Turn left off main road onto sand track towards the MacKay River.
(4)	51.3	1.6	Viewpoint overlooking extensive outcrops of oil sands. Waterways limestone is visible at the base. The Upper McMurray beds containing many small-scale sedimentary structures are exposed beneath a thin layer of sandy soil.

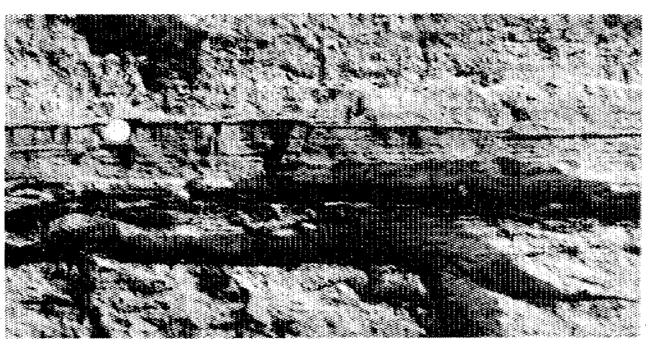
NOTES

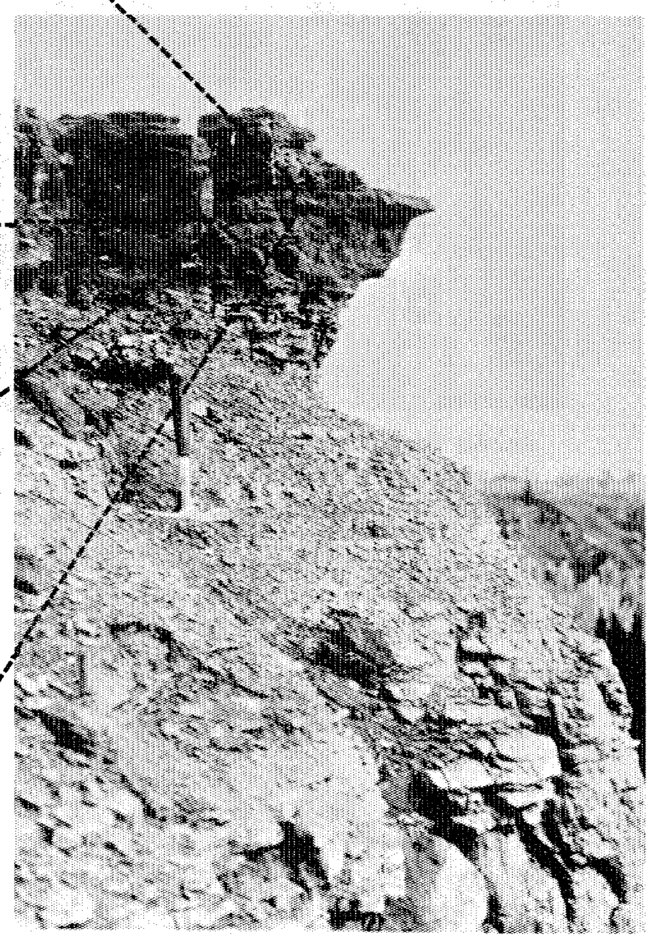


View of oil-impregnated Upper McMurray Formation from the viewpoint, looking toward the south.



Detailed views of burrows and small sedimentary structures at viewpoint (on right).





NOTES

SUPPLEMENTARY ROAD LOG

ABANDONED ABASAND OPERATION

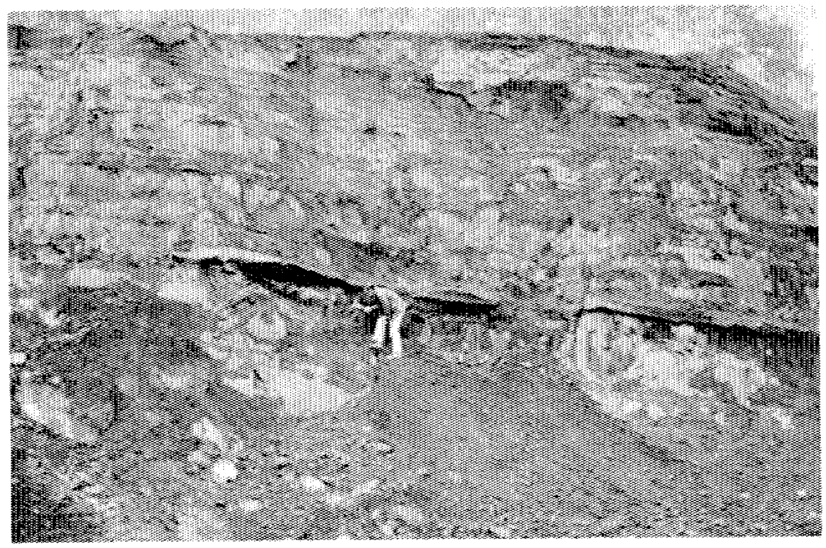
Mileage	Distance	
0.0	0.0	Turn left off Highway 63. Mileage 8.25 on Fort McMurray Airport to Fort MacKay Settlement Road Log.
0.3	0.3	View of Fort McMurray townsite to the right.
0.9	0.6	Fork in road, take the left fork. The right fork leads to the Fort McMurray Ski Hill.
(2) 1.1	0.2	Fork in road. Walk down the right fork in the road down the hill to the site of the abandoned Abasand operation, in the Horse River valley. Outcrops on the left of the road are oil-saturated sands of the McMurray Formation. The pit in the river flats is the old mine of the Abasand operation. Foundations of several of the plant buildings are still visible.

Aerial view of the ruins of the Abasand plant which was destroyed by fire in 1945. (Photograph taken in 1960, courtesy of Imperial Oil Limited.)

NOTES

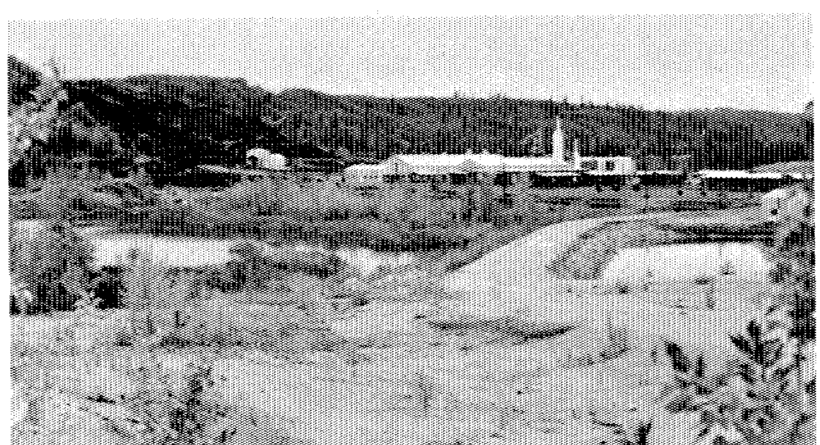
SUPPLEMENTARY ROAD LOG
SYNCRUDE PILOT PLANT

Mileage	Distance	
0.0	0.0	Turn right off Fort MacKay Road. Mileage 34.3 on Fort McMurray Airport to Fort MacKay Settlement Road Log.
0.3	0.3	Outcrops of rich oil-impregnated McMurray Formation on the right. Some small oil seeps can be seen approximately halfway up the outcrop (see photograph below).

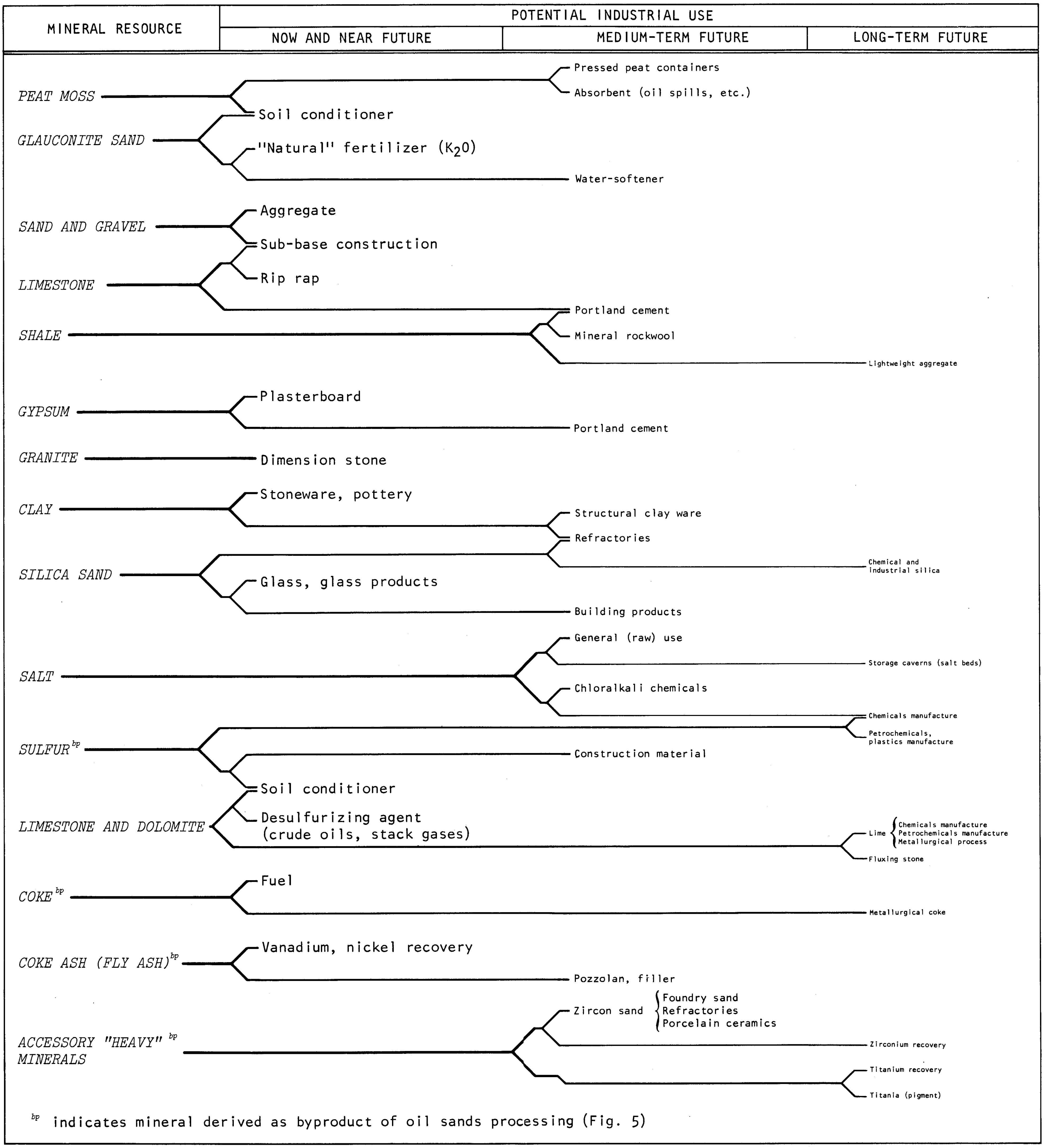


0.6	0.3	Mine area on the right. Tailings pond ahead and to the right. Turn right between tailings ponds and mine area and follow road along the pilot plant to the camp.
0.85	0.25	Limestones of the Waterways Formation exposed on an island to the right.
1.05	0.2	Syncrude camp. Turn right on road over dyke.
1.5	0.45	End of road. Rubbly limestones of the Waterways Formation are exposed from here to the Athabasca River, which can be seen straight ahead.

For a description of the Devonian limestones in this area, see Norris and Carbone (this volume).



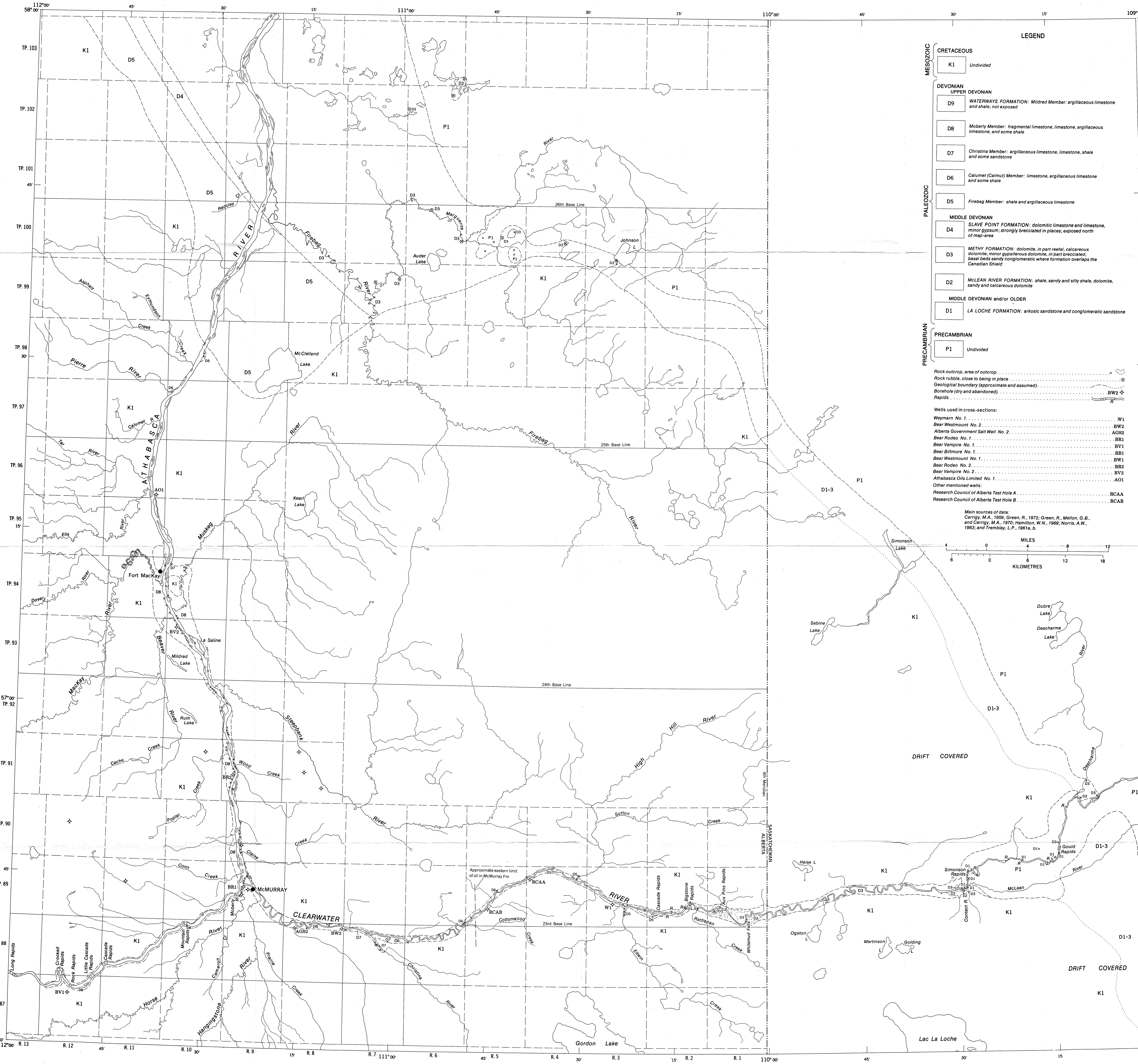
View of abandoned Cities Service Athabasca Ltd. (Syncrude) pilot plant with mining area in background.



To accompany Alberta Research Information Series 65
by M. A. Carrigy and J. W. Kramers

Industrial Mineral Resources of the Fort McMurray area: W. N. Hamilton and G. B. Mellon

FIGURE 8. POTENTIAL USES AND POSSIBLE SEQUENCE OF DEVELOPMENT OF INDUSTRIAL MINERAL RESOURCES



Paleozoic (Devonian) Geology of Northeastern Alberta and Northwestern Saskatchewan: A. W. Norris

FIGURE 4. DISTRIBUTION AND MAIN OUTCROPS OF PALEOZOIC (DEVONIAN) ROCKS ALONG THE ATHABASCA AND CLEARWATER RIVERS AND ADJACENT AREAS

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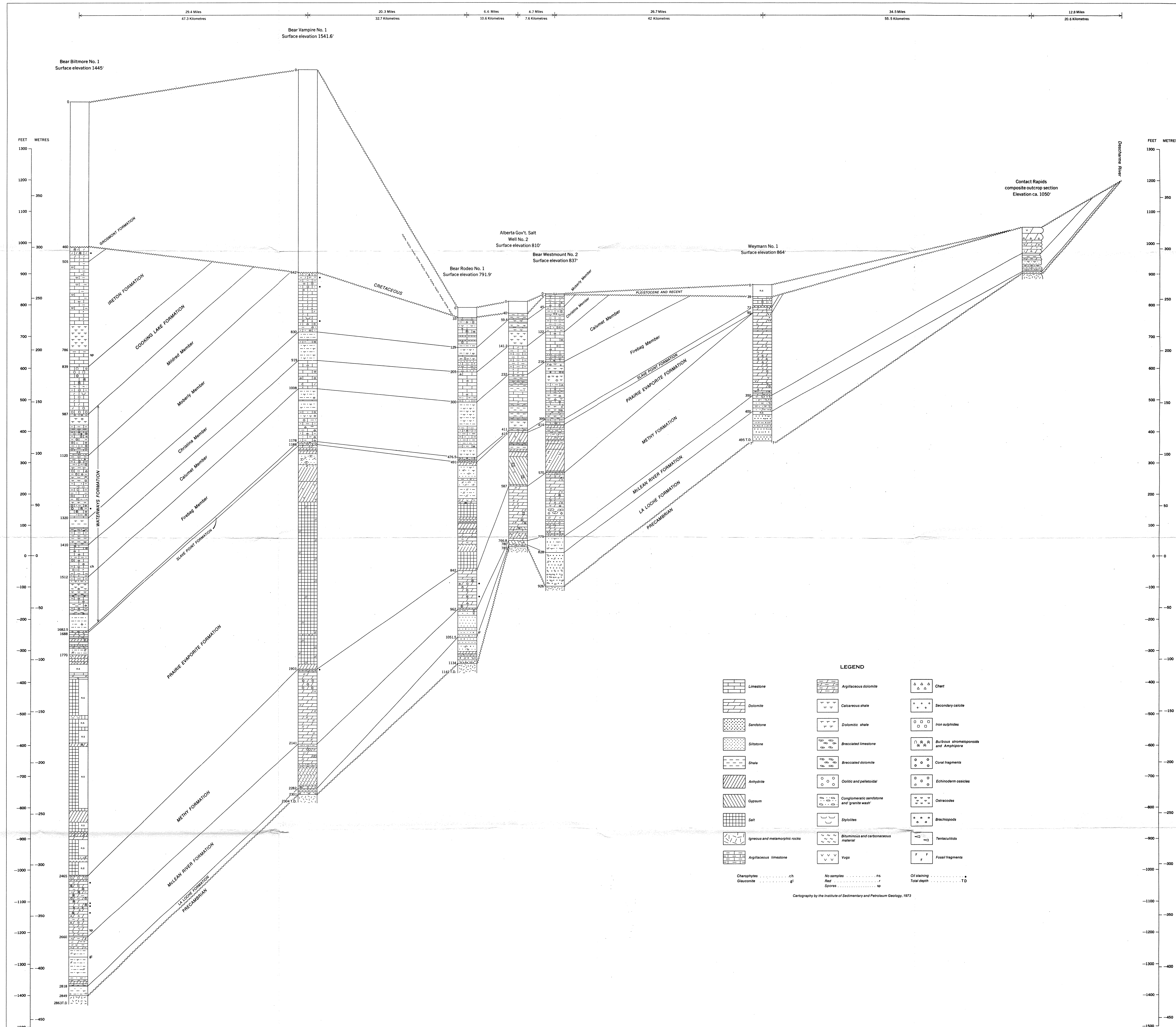

Paleozoic (Devonian) Geology of Northeastern Alberta and Northwestern Saskatchewan: A. W. Norris

FIGURE 5. COLUMNAR SECTIONS OF WELLS FROM BEAR BILTMORE NO. 1 TO COMPOSITE OUTCROP SECTION AT CONTACT RAPIDS

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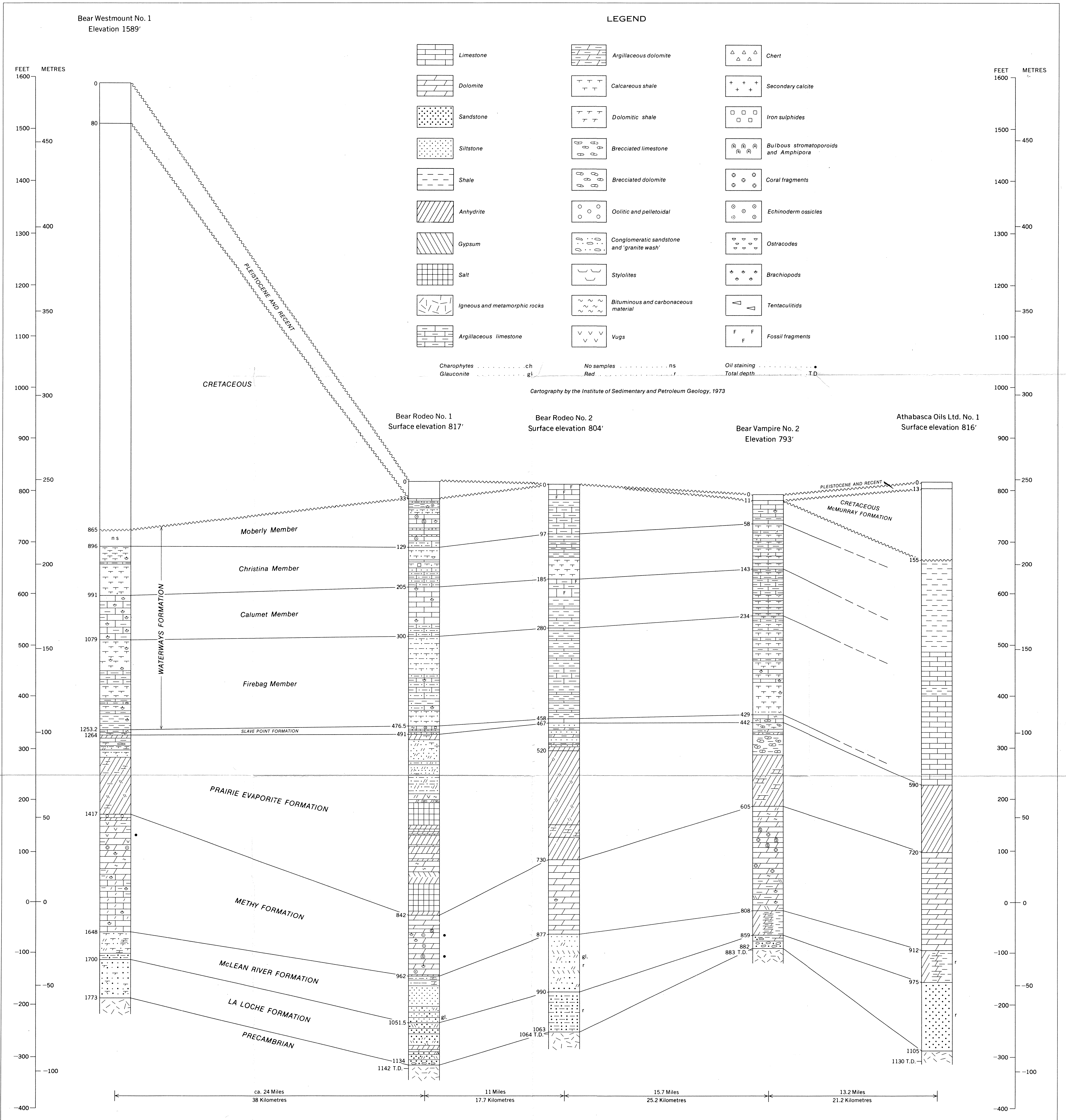

Paleozoic (Devonian) Geology of Northeastern Alberta and Northwestern Saskatchewan: A. W. Norris

To accompany Alberta Research Information Series 65
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FIGURE 7. COLUMNAR SECTIONS OF WELLS FROM BEAR WESTMOUNT NO. 1 TO ATHABASCA OIL LIMITED NO. 1

AGE	ROCK UNIT	ROCK TYPE	INDUSTRIAL MINERALS — Principal Potential Use: Agricultural and Related Uses	Construction Materials	Ceramics	Chemical and Metallurgical Uses
PLEISTOCENE-RECENT	DRIFT	aeolian sand organic soils lake clays and silts till outwash gravels alluvial sand	*peat moss*	*sand and gravel*	*quartz (silica) sand* *clay* *quartz (silica) sand*	
CRETACEOUS	CLEARWATER FORMATION	marine shale		*shale*		
	WABISKAW MBR.	glauconitic sandstone	*glauconite sand*			
	McMURRAY FORMATION	nonmarine sandstones and shales (oil-impregnated) oil sands underclay			*quartz sand* [bp] *(silica)* *clay* [bp] *clay*	*sulfur* [bp] *coke* [bp] *fly ash* [bp] [*vanadium*, *nickel*] *accessory "heavy" minerals* [*titanium*, *zirconium*]
DEVONIAN	WATERWAYS FORMATION	marine limestones and shales		*limestone* *shale*		*limestone*
	SLAVE POINT FM. FT. VERMILION MBR. WATT MOUNTAIN FM.	limestone evaporites shale				
	PRAIRIE EVAPORITE FORMATION	evaporites-salt, gypsum, anhydrite		*gypsum*		*salt*
	METHY FORMATION	dolomites				*dolomite*
		clastics and evaporites				
PRECAMBRIAN CRYSTALLINE COMPLEX		granite		*granite*		

[bp] indicates mineral derived as byproduct of oil sands processing (Fig. 5)

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Industrial Mineral Resources of the Fort McMurray area: W. N. Hamilton and G. B. Mellon

FIGURE 4. INDUSTRIAL MINERALS OF THE FORT McMURRAY REGION IN STRATIGRAPHIC CONTEXT