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GEOLOGIC FACTORS AFFECTING LAND DEVELOPMENT AT FORT MCMURRAY, ALBERTA

by

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Abstract

The near-surface geologic deposits in the Fort McMurray area can be subdivided into bedrock and unconsolidated surficial deposits. Bedrock outcrops include the Beaverhill Lake limestones, the McMurray oil sands, and the Clearwater Formation which consists of the Clearwater shale and the Wabiskaw glauconitic sandstone. Surficial deposits are comprised of gravelly till, outwash sand and gravel, colluvium, glaciolacustrine and recent lacustrine silts and clays, and alluvium along stream valleys.

A survey of the geologic factors affecting land development indicated that many of the deposits are susceptible to erosion, slumping, and landslides. The Clearwater Formation and surficial deposits are subject to gullying by surface water runoff when vegetative cover is absent. Undercutting on the inside of stream meanders contributes to bank erosion and instability. The Clearwater shales which are overconsolidated clay shales are prone to massive slumping and landslides on steep slopes in the area.

The following recommendations are made concerning land development in the area: (1) Vegetative cover should be left undisturbed to curtail gullying; if vegetation is removed it should be replaced as quickly as possible. (2) Developers should avoid areas where active stream undercutting is occurring. (3) Developments should not be placed on or near steep slopes composed of Clearwater shale because of their susceptibility to slumping and landslides. (4) The highlands above the stream valleys are suitable for development in terms of erosion hazards and slope stability; however, before any development occurs additional information pertaining to groundwater conditions, sulphate content of soils, mineral resources, suitability of sites for solid waste disposal, and geotechnical properties of the various deposits would be essential to assess properly all geologic factors that may effect land development in the area.

INTRODUCTION

Geology is applicable to many aspects of land development because in any physical environment, the overall interdependent natural systems are built on a geologic framework. Mineral resources, water supply, waste disposal, landslides, construction conditions, flood control, and transportation systems are all related to the distribution of geologic materials.

Due to extensive development of the Athabasca Oil Sands, which are located in the vicinity of Fort McMurray, rapid expansion of the townsite is presently in progress and is also projected for the future.

At the request of Dr. G.B. Mellon[1], Research Council of Alberta, a survey of geologic factors affecting land development at Fort McMurray was conducted, in particular an evaluation of landslide hazards along stream banks. The information obtained from the survey is outlined in this report; however it should be stressed that the study was a reconnaissance survey meant to illustrate geologic factors that may have an affect on land development.

LOCATION AND ACCESS

Fort McMurray is situated at the junction of the Athabasca and Clearwater Rivers in northeastern Alberta, approximately 275 miles northeast of Edmonton (Fig. 1). Highway 63 provides access to Fort McMurray from southern Alberta, rail service is provided by Northern Alberta Railways, and air service by Pacific Western Airlines.

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[1] Presently Deputy Minister of Mines and Minerals, Province of Alberta

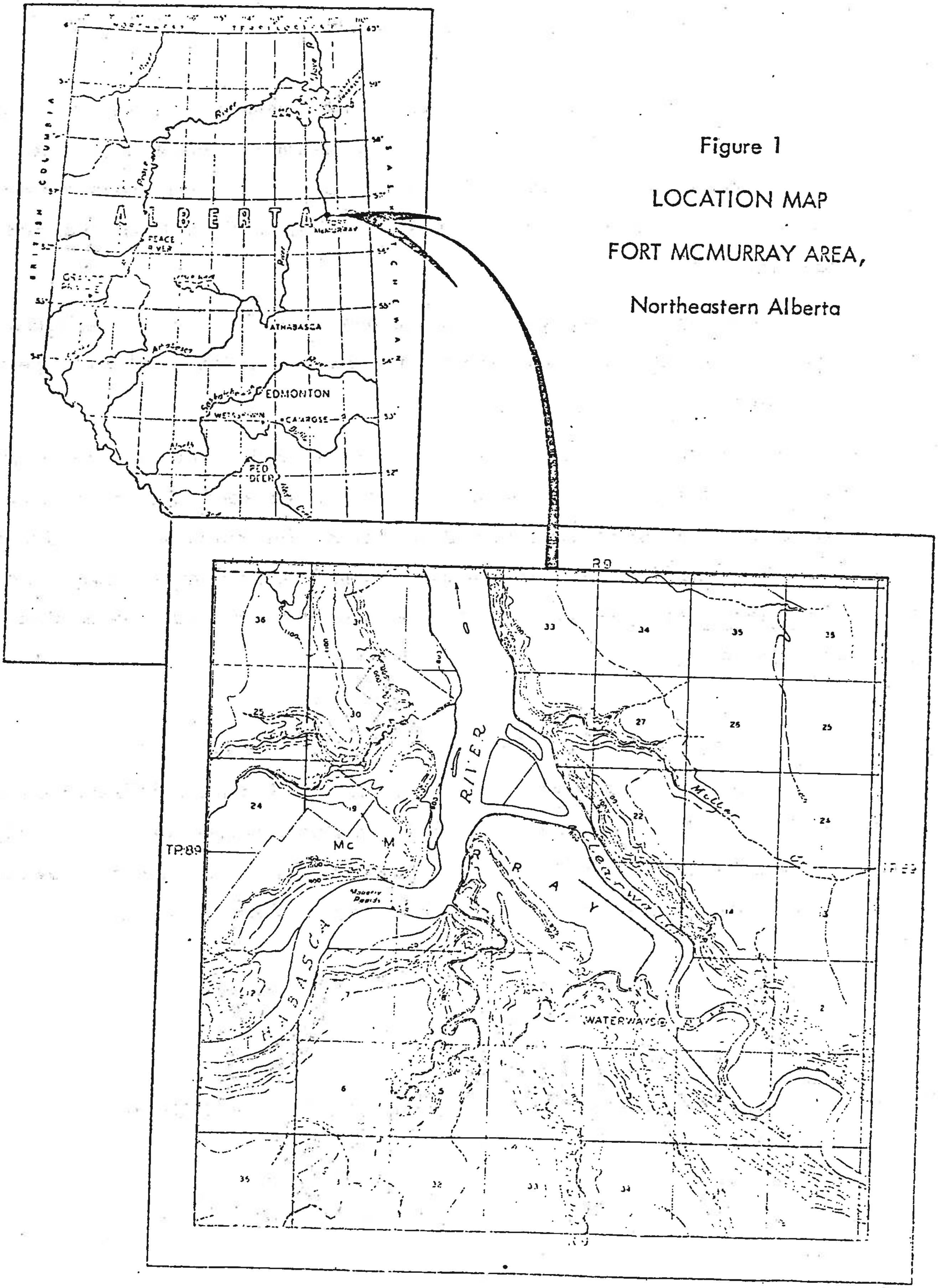

Figure 1

LOCATION MAP

FORT MCMURRAY AREA,

Northeastern Alberta

PHYSICAL GEOGRAPHY

The townsite is situated on a relatively flat lying terrace of the Clearwater River where it joins the northward flowing Athabasca River (Fig. 2). Tributaries of the Athabasca River in the area include the northward flowing Horse River and the eastward flowing Conn Creek. Tributaries of the Clearwater River include Hangingstone River and Saline Creek south of the town and Miller Creek to the north (Fig. 1). The Athabasca and Clearwater Rivers have broad U-shaped valleys with well developed terraces (Fig. 3) whereas their tributaries have V-shaped valleys which are deeply entrenched into the adjoining uplands. Terraces on the tributaries are narrow and discontinuous.

The climate of the McMurray area is similar to that of the central plains of Alberta. The normal winter temperatures are very low and the snowfall is light. Summer is warm with occasional thunderstorms and rainy periods.

Climatic data for Fort McMurray is tabulated below.

TABLE I*

Standard 30-year (1921-50) Normals of Temperature and Precipitation for Fort McMurray

Temperature				Precipitation
January Mean Daily		July Mean Daily		Mean Annual
Max	Min	Max	Min	Inches
4	-17	76	47	16.32

*data from Alberta Facts and Figures, 1954

Muskeg, slough, and swamp growth cover a large part of the uplands. In stream valleys and on well drained uplands and hillsides, heavy growths of poplar, spruce, jackpine and birch are common.

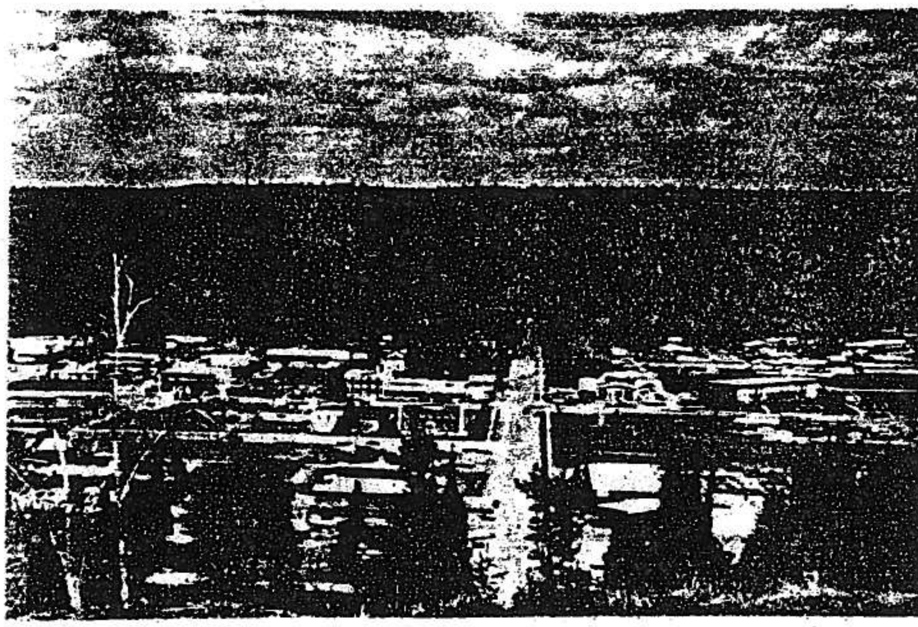

Figure 2. Townsite of Fort McMurray which is situated on a relatively flat terrace at the mouth of the Clearwater River (looking east).

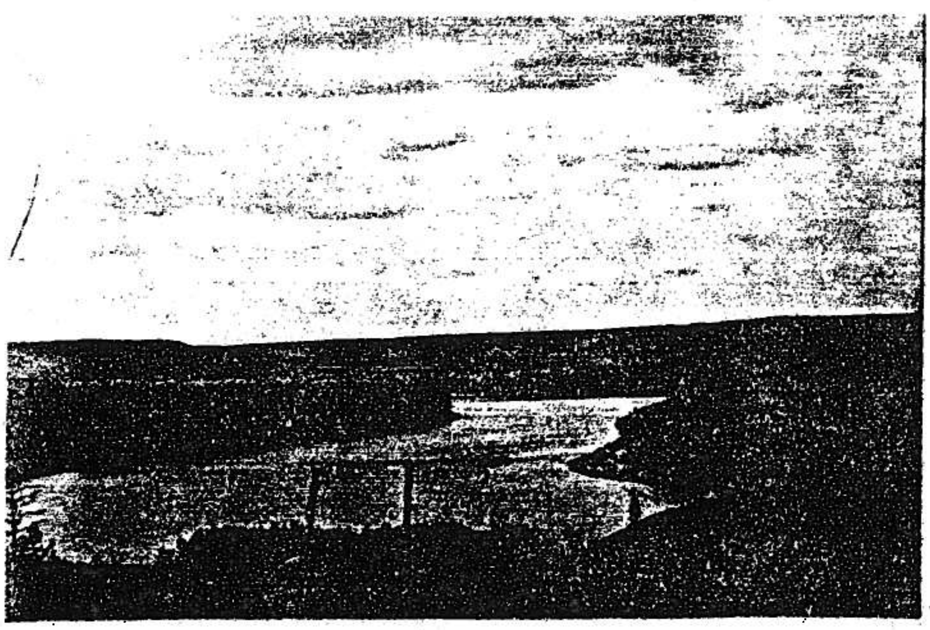

Figure 3. The Athabasca River valley west of Fort McMurray with vegetated valley walls and well developed terraces.

GENERAL GEOLOGY

The description of the general geology is confined to the near surface deposits which will have an effect on land development and is divided into two sections: bedrock and surficial geology.

Bedrock Geology

The bedrock geology of the area has been mapped by Carrigy and Collins (a copy of the map is included in the back pocket). Table II provides a summary of the near surface stratigraphy of the McMurray area.

TABLE II*

General Stratigraphy in the McMurray Area

System or Series	Formation	Member	Lithology
Pleistocene and Recent			Glacial and post glacial deposits of till, sand, gravel, silt and cla
Erosional unconformity			
Cretaceous	Clearwater		Shale and sandstone
		Wabiskaw	Sandstone, glauconitic
	McMurray	No. 3 (Upper)	Fine-grained quartz sands, oil cemented
		No. 2 (Middle)	Medium-grained quartz sand, oil cemented, lenses of siltstone, shale, and coal
		No. 1 (Lower)	Conglomerate, detrital clays and shales, siltstone and coarse-grained sands
Erosional unconformity			
Devonian	Beaverhill Lake		Argillaceous limestone

*modified from Carrigy (1959)

The Beaverhill Lake Formation, which is composed primarily of limestone, is exposed near water level along the valleys of the Athabasca and Clearwater Rivers. The limestones are generally grey and thin bedded with shaly limestone interbeds. The rocks are well jointed and fractured; some of the joints and fractures are filled with bitumen. The upper surface of the limestone is an erosional unconformity but it is also deformed (Fig. 4), perhaps due to collapse caused by solution of water soluble evaporite beds of the underlying Elk Point Group (Carrigy, 1959).

Figure 4. Deformed contact between the Beaverhill Lake Formation and the overlying McMurray Formation.

The McMurray Formation outcrops extensively along the Athabasca and Clearwater River valleys as well as along tributary stream valleys (Fig. 4). There is a wide variation in particle size distribution of the oil sands in the McMurray Formation and the deposits have been subdivided on lithologic evidence into three stratigraphic units (Carrigy, 1959).

No. 1 (or the lower member) is a conglomerate with detrital clays and shales, siltstones, and coarse-grained sands containing minor wood, lignite and coal. No. 2 (middle) is a medium-grained quartz sand that is oil cemented. Lenticular beds of siltstone, shale, and coal are common as are beds containing ironstone, cemented sandstone, vegetable remains and pyrite nodules. No. 3 (upper) is a fine-grained, oil cemented quartz sand which is generally horizontally bedded.

The Clearwater Formation outcrops along all the stream valleys in the McMurray area and is exposed in road cuts on the uplands where surficial deposits are relatively thin.

A thin bed of glauconitic sandstone generally less than 20 feet thick is present at the base of the formation (Carrigy, 1959). It is composed of a fine-grained well-sorted sand with varying proportions of silt and clay. This lower glauconitic sandstone has been called the Wabiskaw member by the Alberta Oil and Gas Conservation Board (Badgley, 1952).

A grey shale containing marine fauna is the characteristic lithology of the Clearwater Formation in the McMurray area. It is estimated to vary between 200 and 250 feet in thickness (Carrigy, 1959). Thinner beds of silty sandstone were also observed in the upper portion of the formation.

Surficial Geology

The surficial geology of the area has not been mapped in detail but is scheduled to be completed this summer by the Research Council of Alberta. The following description of the surficial geology is based on air photograph interpretations supplemented by limited field observations.

Most of the uplands have a thin mantle of surficial deposits consisting of gravelly till and scattered deposits of outwash sand and gravel overlying the Clearwater Formation (Fig.

Outwash sand and gravel forms outwash plains on the highlands southeast of Fort McMurray. The land surface is level to gently undulating except where the outwash is overlain by scattered sand dunes.

Figure 5

Surficial Geology

(1) Alluvium; river terrace and floodplain gravel, sand and silt.

(2) Eroded slope: mainly bedrock with colluvium in places, slumping very common.

(3) Outwash sand and gravel: forms outwash plains; surface level to gently undulating; fine sand to coarse gravel.

(4) Thin outwash gravel and thin gravelly till over bedrock; surface level, organic material in the lows.

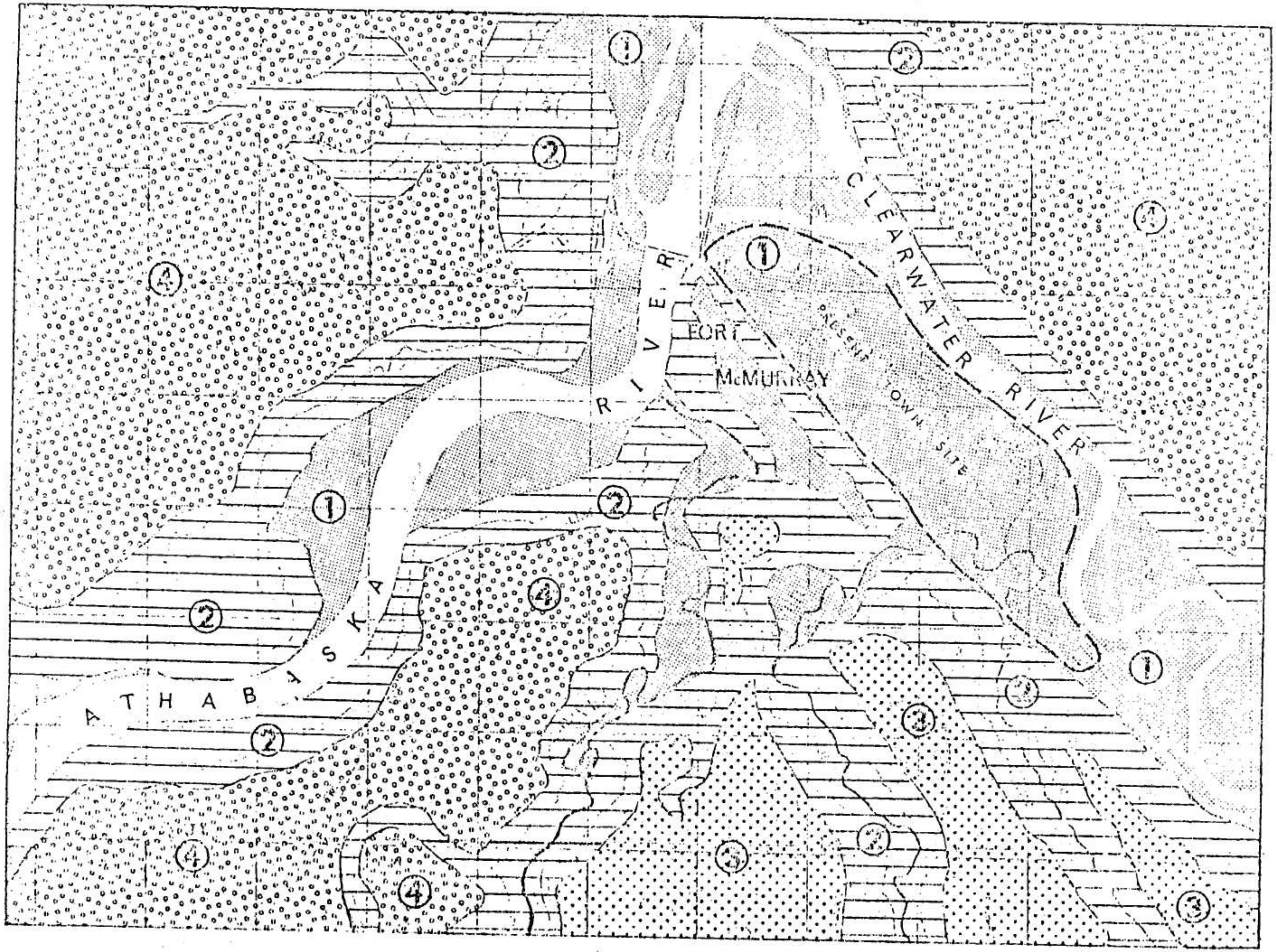

Figure 5. Surficial geology of the Fort McMurray Area (Scale 1:50,000)

Thin glacio-lacustrine and/or recent lacustrine deposits, as well as organic materials, occupy many of the depressions.

Along all the major slopes and valley sides, bedrock, slumped bedrock, and colluvium consisting of eroded bedrock and surficial deposits is common. Alluvium consisting of gravel, sand, silt, and clay is present along most of the streams in the area. The terrace on which the present townsite is located is composed primarily of silts as are most of the terraces of the Clearwater and Athabasca Rivers. Deposits along the tributary streams are variable over short distances and terraces are discontinuous and poorly developed.

EROSION HAZARDS AND SLOPE STABILITY

Three types of hazards associated with instability of near surface geologic deposits were observed in the Fort McMurray area. These include: (1) surface erosion where vegetative cover is absent, (2) undercutting along stream valleys, and (3) landslides and slumping.

Surface Erosion

Wherever vegetation was absent along slopes, erosion of the surface deposits was prevalent. Extensive gullying was observed throughout the area and appeared to be most common in unconsolidated sands. An example is shown on Figure 6 where surface runoff has eroded a major gully in river terrace sands on the west bank of the Athabasca River.

Gullying also occurs in exposures of Clearwater shale and colluvium composed primarily of glacial till. The Beaverhill Lake Formation, the McMurray Formation, and coarse gravel deposits do not appear prone to active surface erosion even where vegetation is absent.

Figure 6. Extensive gullying in river terrace sands along the Athabasca River caused by surface runoff (west side of bridge on the Athabasca River – north of Fort McMurray).

Undercutting Along Stream Valleys

Undercutting is common along the inside of meanders on all the streams in the area. Stream erosion of material at the toe of the slopes results in instability of the overlying banks. Generally these areas are predominated by bedrock outcrops because active erosion prevents the development of vegetative cover. Areas where active undercutting is taking place are outlined on Figure 7. The McMurray Formation does not appear susceptible to massive slumping and landslides and usually forms steep banks (Fig. 8).

In contrast, steep exposures of the Clearwater Formation are usually absent where the streams are undercutting because the shale is prone to massive slumping and landslides.

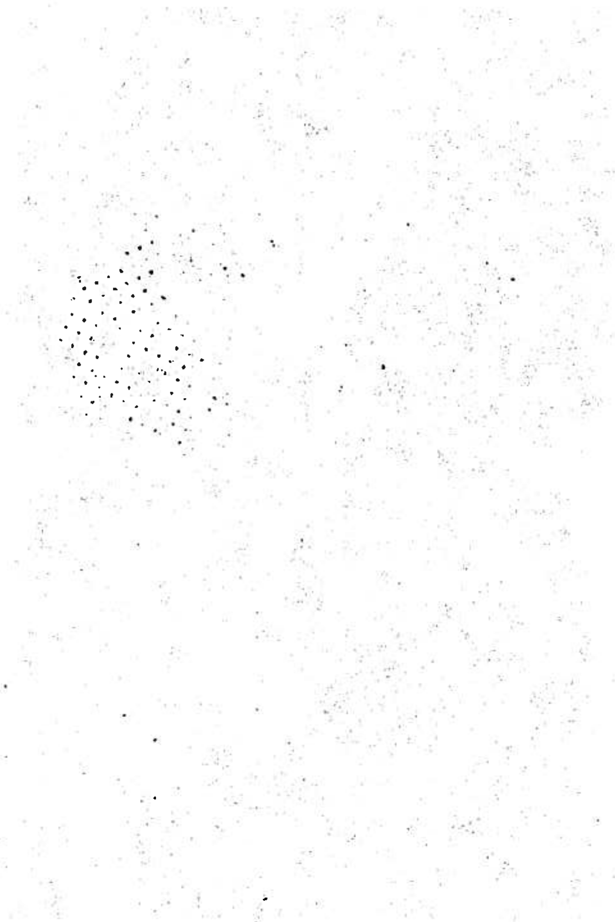

Figure 7

Erosional Features

Extensive slumping present: bank is generally unstable.

Individual slump: not within an extensive slump area; bank appears to have more stability.

Active undercutting taking place: steep unstable banks above.

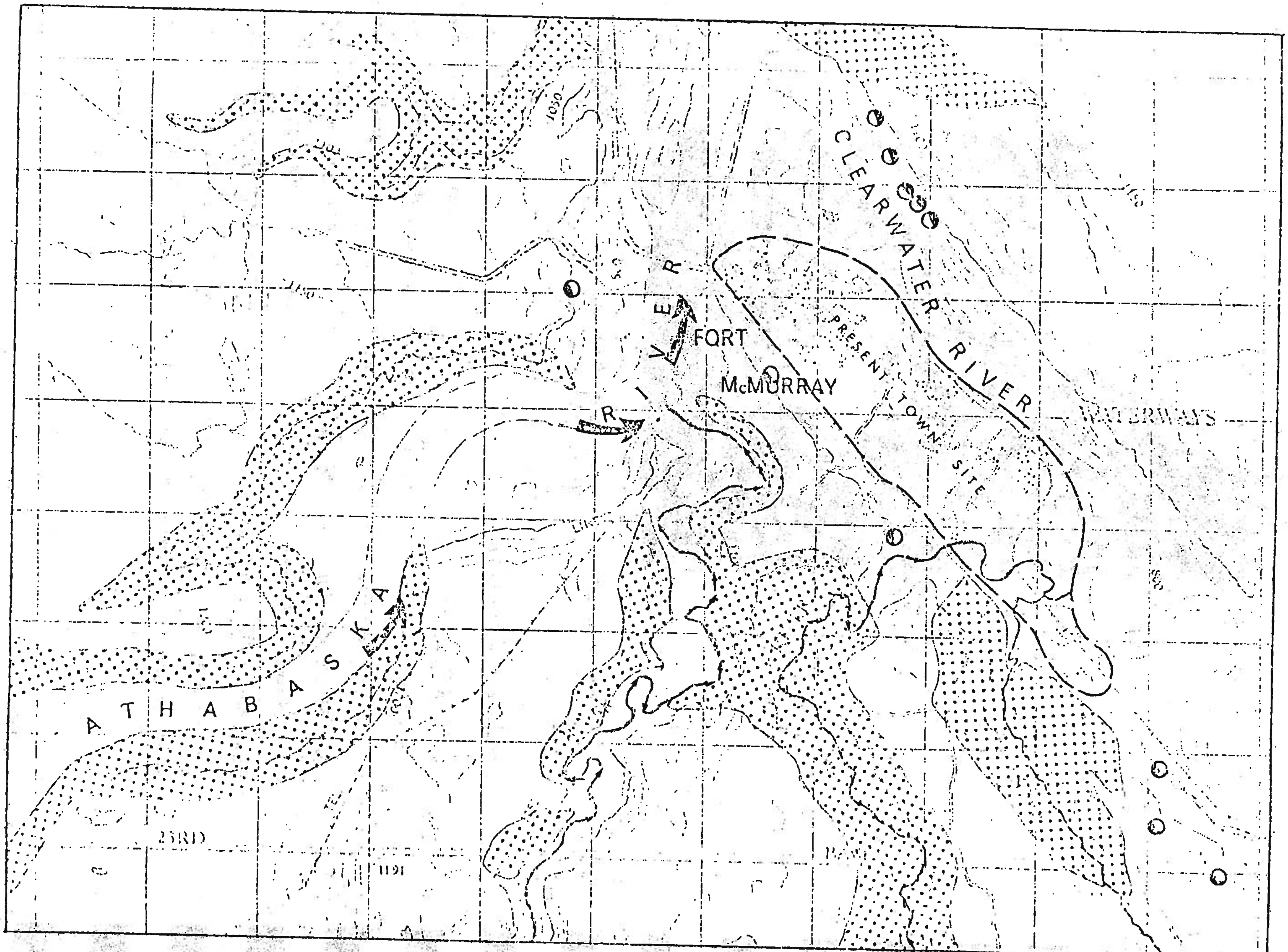
CLEARWATER RIVER
FORT
McMURRAY
PRESENT TOWN SITE
WATERWAYS
ATHABASKA
R I V E R
1030

Figure 7. M...

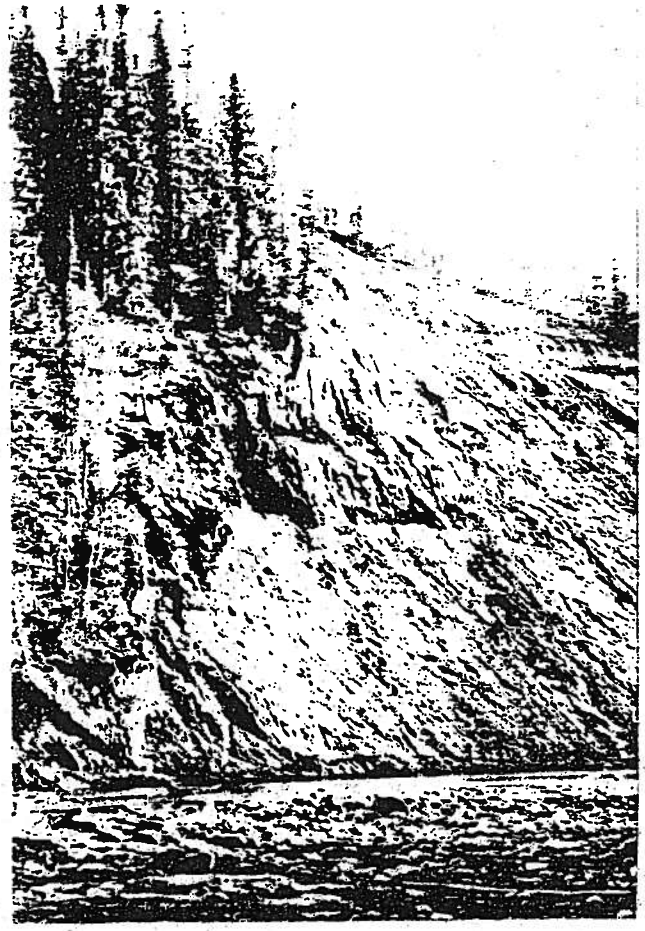

Figure 8. Steep exposure of McMurray Formation being undercut by the Hangingstone River at Fort McMurray.

Landslides and Slumping

Landslides and slump features are common along stream banks in the Fort McMurray area. Many relatively old features have been subsequently covered by vegetation. They are often not readily apparent on the ground but can be delineated on air photographs as series of arcuate lines. A portion of the slides and slumps appear to have occurred recently because trees both large and small have been bent in various directions by downslope movement. Field observations revealed that all the slumps and landslides have occurred in the Clearwater shales. No groundwater springs were observed at any of the slides. Areas of extensive slumping as well as individual slumps are outlined on Figure 7.

Landslides are present on Highway 63 along the bank of Saline Creek south of Fort McMurray. An air photo stereopair of the slides (Fig. 9) shows major arcuate slip faces in the bedrock and fallen and bent trees caused by downslope movement of a large landslide. A smaller slide has occurred on the opposite side of the highway as well. Removal of vegetation and oversteeping of the bank during road construction appears to have caused the slide. Failure has occurred in the Clearwater shale as illustrated on Figures 10, 11, and 12. Slumping is apparent near the top of the slide and flowage is present at the toe. No groundwater springs were observed in the vicinity of the slide. Gullying of the shale caused by surface water runoff is also prevalent in the roadcuts because vegetative cover is absent.

Another well developed series of landslides occurs along a road between the Horse and Hangingstone Rivers south of Fort McMurray (Fig. 13). All the slides occur in the Clearwater shales and no groundwater springs are present. At one locality, the road has been constructed on a major slump block; a second slump block also occurs above the elevation of the road (Fig. 14). Below the roadcut, the trees are fallen and bent because of downslope movement toward the Hangingstone River (Fig. 15).

Another landslide, immediately to the south has exposed and bent a gas pipeline because of downslope movement toward the Horse River (Fig. 16).

There are numerous other slumps and landslides along all of the stream valleys in the area. Areas where they have been observed on air photographs or in the field are outlined on Figure 7.

GENERAL ENGINEERING CHARACTERISTICS OF GEOLOGIC DEPOSITS

A discussion of the geotechnical properties and expected behavior of the geologic deposits in the area is included in the following section.

Figure 9. Stereopair of landslides on Highway 63 south of Fort McMurray. Note arcuate slip faces and bent and fallen trees associated with the slide.

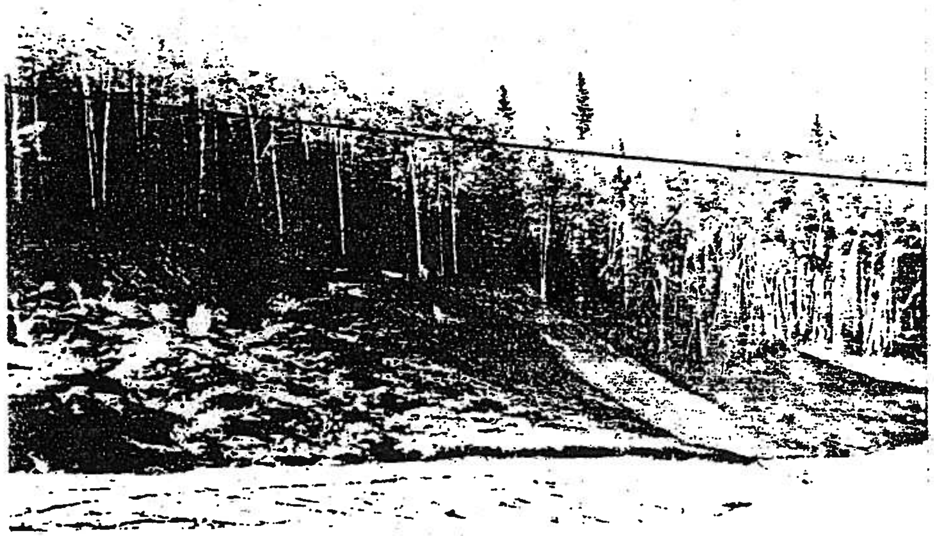

Figure 10. Landslide in Clearwater shales on Highway 63 road cut south of Fort McMurray.

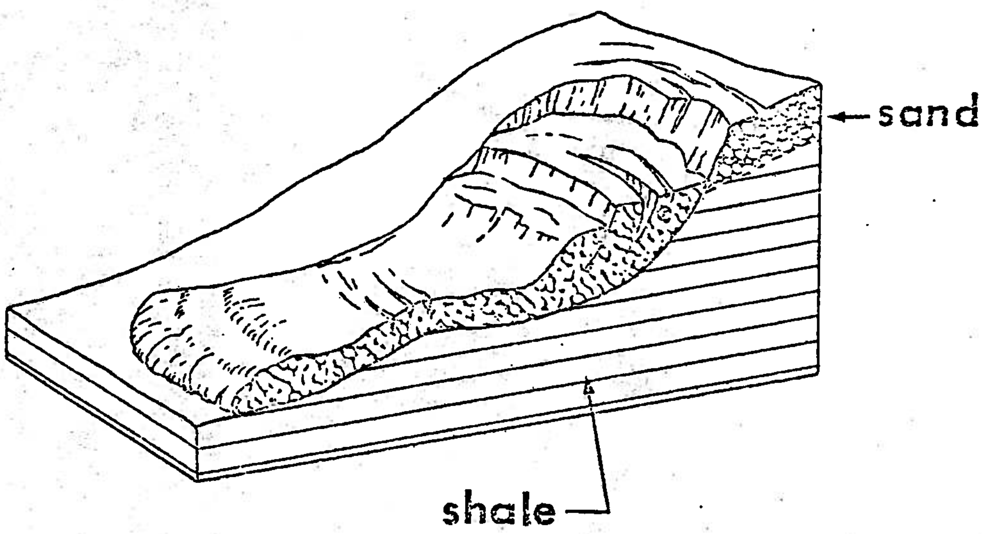

Figure 11. Schematic diagram of landslide shown in figures 10 and 12.

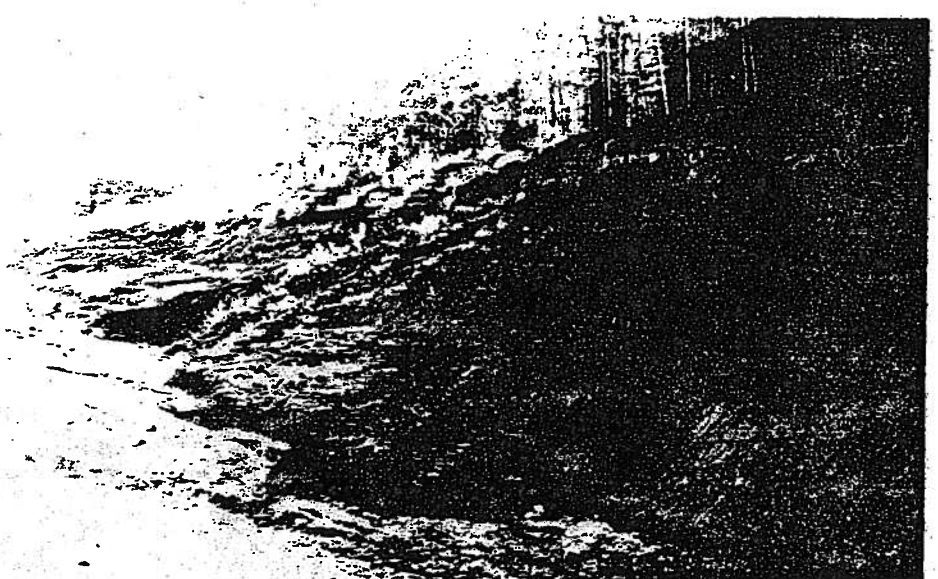

Figure 12. Landslide in Cretaceous shales on Highway 63 road cut south of Fort McMurray. Note the slip scars at the top of the landslide and the flowage at the toe. Also observe the gullying below the toe of the slide.

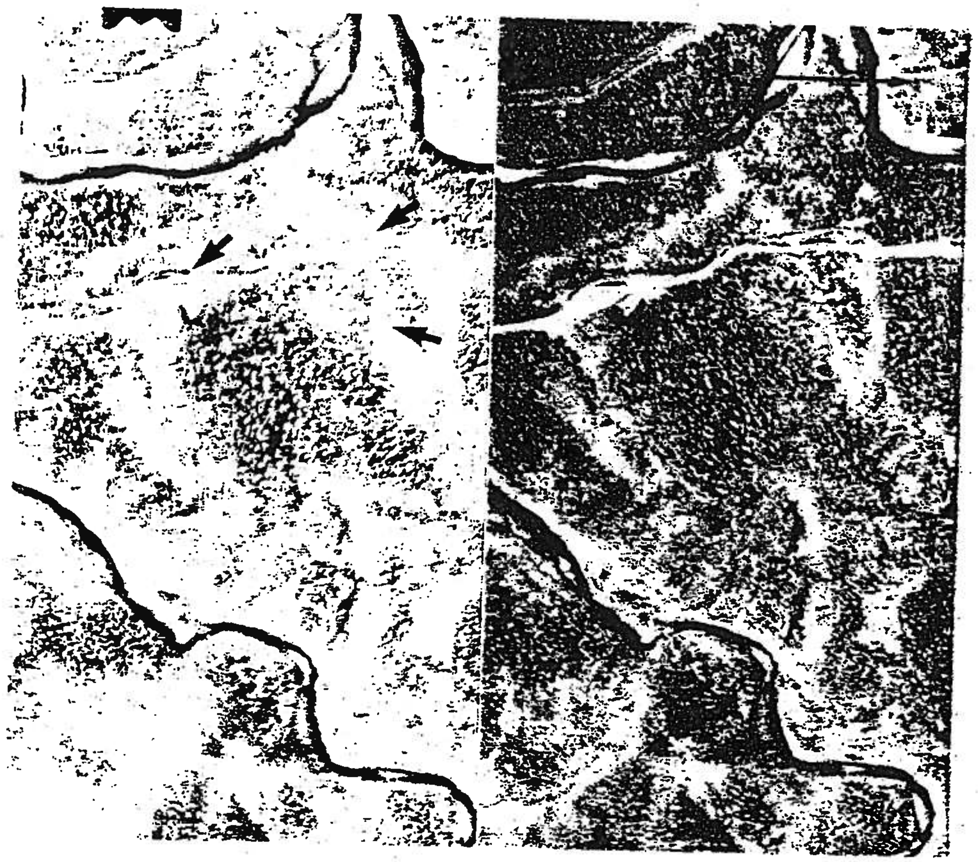

Figure 13. Stereopair illustrating landslides on a road between the Horse and Hangingstone Rivers south of Fort McMurray.

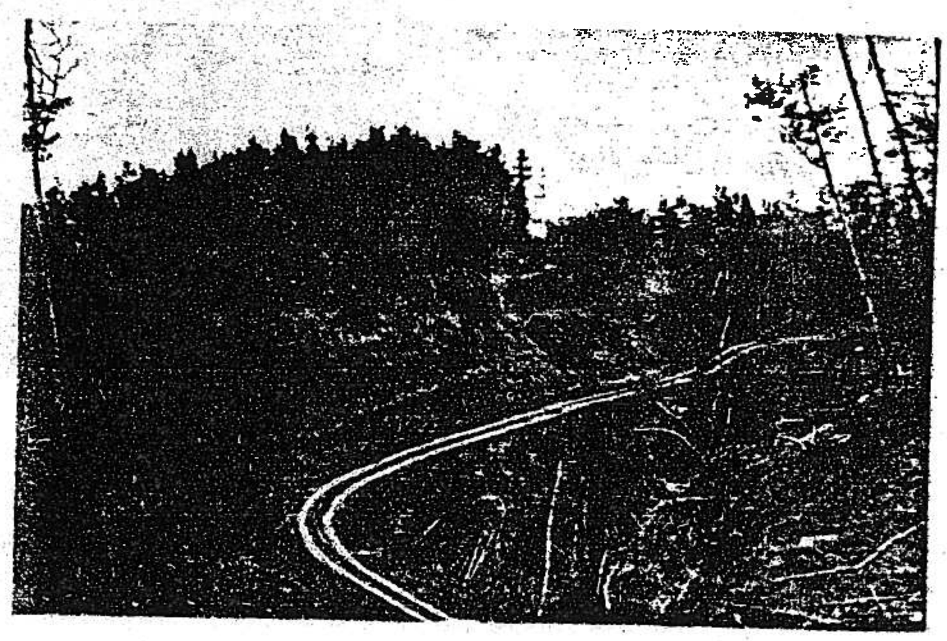

Figure 14. Landslide in Clearwater shales; the road is built on a slump block

Figure 15. Fallen and bent trees caused by downslope movement caused by a landslide in Clearwater shales. The slump block shown in figure 14 is to the right of the photograph.

Figure 16. [illegible] caused by [illegible] along the [illegible] of the [illegible]

Beaverhill Lake Formation

The Beaverhill Lake Formation is composed of argillaceous limestone and is exposed only a short distance above water level along the Athabasca and Clearwater Rivers. Although it is jointed or fractured in places, it is not expected to cause major problems with development because of its relatively competent nature and limited exposures in stream valleys.

McMurray Formation

The McMurray oil sands form steep banks which appear relatively stable and are not prone to gullying. Carrigy (1967) described the bulk properties of the oil sands and based on laboratory analyses concluded that they behave as soft sandstones and that the conventional concepts of effective stress used in soil mechanics are applicable. Analyses also indicate that the oil sands behave essentially as a non-cohesive material; however, strength tests and natural slope angles both exceed expected values (M. Dessault[1], personal communication). Research on the cause of these phenomena is currently being conducted. Although slope stability does not appear to be a problem, further research is required to determine their long term stability when exposed to erosion and subjected to loading (because of construction).

Clearwater Formation

The Wabiskaw member of the Clearwater Formation consists of a glauconitic sandstone. It is not expected to present any major problems of slope stability because it is generally less than 20 feet thick and is seldom exposed. Only where vegetative cover is removed would there be a danger of gullying by surface water runoff.

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[1] M. Dessault, Department of Civil Engineering, University of Alberta.

Most of the problems with slope stability are expected to occur in the Clearwater shale. Clay shales of Upper Cretaceous age occur extensively in Western Canada where they cause stability problems for foundations and slopes. They are referred to as 'overconsolidated clay shales' which are defined as sedimentary deposits composed primarily of silt and clay-sized particles dominated by members of the montmorillonite group of clay minerals, that have been subjected to consolidation loads in excess of those provided by the present overburden. In the Fort McMurray area, this load was provided by glacial ice as well as additional shale that has subsequently been eroded. Considerable research has been conducted on the behavior of these materials (Hardy et al., 1962; Scott and Brooker, 1968); however predictic of the engineering performance of overconsolidated clay shales either on a short or long term basis cannot be made with reasonable confidence in spite of proven statistical theory and modern laboratory testing techniques. Studies by Scott and Brooker (1968) concluded that the prime geologic factors affecting the engineering behavior of overconsolidated shales are depositional environment, lithology and stratigraphy, stress history, structure, climate, geomorphology, and groundwater. The effects of these factors on slope stability are outlined in Table III.

Atterberg limit tests on two samples of Clearwater shales from landslides at Fort McMurray show that they are comprable to limits on shales from landslides in the Puskwaskau shales near Peace River.

TABLE IV

Atterberg Limits of Clearwater Formation and Puskwaskau Formation

Physical Property	Formation	
	Clearwater Formation	Puskwaskau Formation*
Liquid Limit %	53-65	51-60
Plastic Limit %	26-30	19-34
Plastic Index %	27-35	24-25

*data from Hayley, 1968

TABLE III

Geological Factors Controlling Slope Stability and their Engineering Consequence*

GEOLOGICAL FACTORS		INFLUENCE	ENGINEERING CONSEQUENCE
1. Depositional Environment	(a) Marine deposition	High sodium conc. in pore fluid.	High osmotic swelling potential.
	(b) Fine-grained clastic sediments and volcanic ash.	Clay sizes dominant, montmorillonite abundant.	High plasticity soils.
	(c) Slow rate of sedimentation.	Sediments generally of uniform texture and structure.	Low permeability.
	(d) Relatively shallow depth of burial.	Lithification incomplete, interparticle bonds weak.	Low shear strength, high rehydration swelling potential.
2. Lithology and Stratigraphy	(a) Bentonite layers interstratified with clay shales.	Retards downward movement of groundwater; leaching along top of bentonite layers.	Zones of high plasticity, high swelling pressure, low shear strength.
	(b) Fine-grained sandstone layers widely spaced.	Drainage layers widely spaced.	Layers of relatively high shear strength related to distribution of sandstone.
3. Stress History	(a) Loading by younger sediments.	Consolidation.	Increase in shear strength with loading.
	(b) Diastrophism and preglacial erosion.	Removal from marine environment, leaching, dilatancy, sediments in condition of overconsolidation.	Residual stresses relieved only in near surface zone.
	(c) Glacial erosion and loading.	In some areas consolidation loads may exceed those imposed by sediments.	May cause increase in O.C.R.
	(d) Glacial unloading.	Initiation of residual stress relief; sediments in condition of over-consolidation.	Residual stress concentrations.
	(e) Postglacial rebound.	Terrain uplift – erosion base level lowering, increase in groundwater gradients.	Stream erosion accelerated, downcutting exceeds rate of residual stress relief.
	(f) Valley erosion.	Exposure of zone of high residual stress. Fracture development parallel with the valley.	High lateral stresses in valley walls.
4. Structure	(a) Attitude of bedding.	Controls outcrop width of formation.	Older beds of formation may occur below near-surface zone of stress relief.
	(b) Fracture development.	Vertical planes of weakness.	Loss in mass shear strength.
5. Climate	(a) Precipitation.	Affects rate of groundwater movement and leaching.	Seasonal pore pressure fluctuations leaching may decrease shear strength.
	(b) Temperature.	Alternate wetting and drying produces fractures. Freeze/thaw action in fractures.	Decrease in shear strength in near-surface fracture zone.
6. Geomorphology	(a) Position of base level.	Controls depth of valley and in part, rate of erosion.	Failures occur only where base level of erosion is below critical height of slope. Critical height, however, is not constant.
	(b) Stream channel configuration.	Asymmetrical cross valley profile, steep undercut slopes, toe erosion.	Decrease in shearing resistance of slope.
	(c) Terrace development.	Reduction in effective slope height.	Decrease in shear stresses.
	(d) Rate of erosion.	Rate of downcutting may exceed rate of residual stress relief in valley walls.	Increase in shear stresses.
	(e) Slope exposure.	Exposure to insolation may depress groundwater flow regimen.	Increase in effective stress due to decrease in neutral stresses.
7. Groundwater	(a) Quantity.	Seasonal variations in flow may increase leaching and pore pressures.	Decrease in shear resistance.
	(b) Quality.	Differences between groundwater chemistry and pore water chemistry can create osmotic swelling pressures.	Decrease in shear resistance.

*(from Scott and Brooker, 1968)

In summary, it will be difficult if not impossible to predict the behavior of slopes consisting of Clearwater shales. However, it is readily apparent that steep slopes along stream valleys have been subjected to extensive slumping in the past. Furthermore recent landslides have also occurred especially where road construction and undercutting by streams has resulted in oversteepening of slopes. Removal of vegetation from shale slopes contributes to their instability and results in active gullying by surface water runoff.

Surficial Deposits

The surficial deposits which were outlined on Figure 5 are not expected to cause serious slope stability problems. The exception would be locally thick deposits of glacial lake clays that might be exposed during construction. However, all the deposits would be subject to gullying on steep slopes if the vegetative cover is removed.

RECOMMENDATIONS

Based on information obtained from air photo interpretations, spot field checks, and investigations by others on the geologic deposits as well as on similar deposits elsewhere, the following recommendations are made concerning future land development in the Fort McMurray area.

(1) All types of geologic deposits in the area, with the exception of the Beaverhill Lake Formation and Athabasca oil sands, are susceptible to erosion and gullying on steep slopes when the vegetative cover is removed. Therefore, when any development is planned near any slopes, vegetative cover should not be removed if possible. Roadcuts, etc. should be revegetated as soon as possible.

(2) Development should be avoided near banks presently being undercut by streams. These areas have been outlined on Figure 7.

(3) A generalized map of areas that are suitable for future development in terms of slope stability is provided on Figure 17. Area (1) consists of unstable areas susceptible to undercutting by streams, landslides, and slumping.

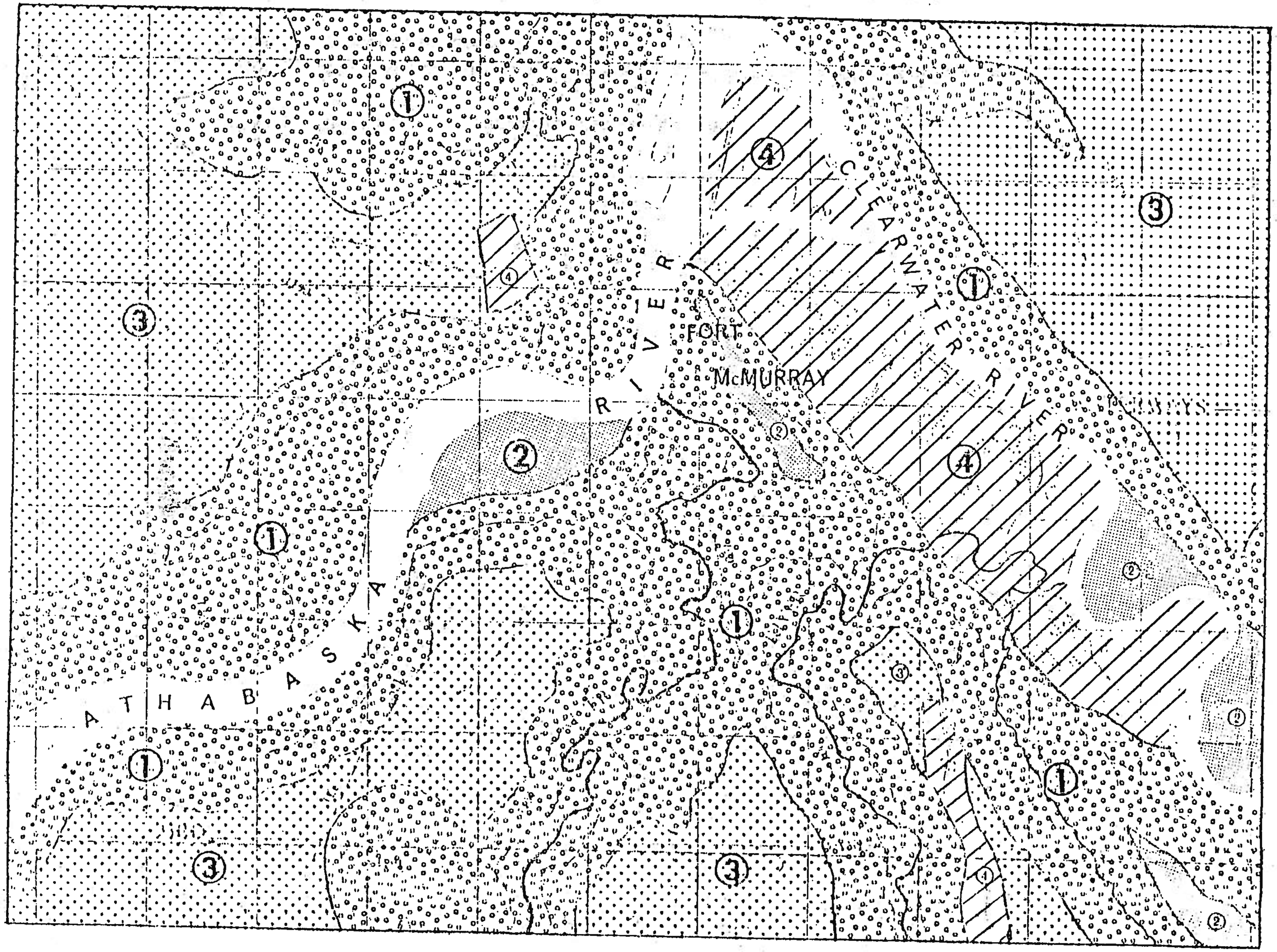
Both the time of occurrence and size of landslides in the Clearwater shales is impossible to predict, and extensive field work and laboratory investigations would be necessary to establish a realistic safety zone along the tops of these slopes. The up slope boundary of zone (1) has been arbitrarily set at a minimum distance of 500 feet from any unstable area in an attempt to provide an adequate margin of safety.

Area (2) consists of terraces along the Athabasca and Clearwater Rivers. These areas should not have slope stability problems; however they are relatively small and inaccessible from the present townsite.

Areas labelled (3) are stable uplands that appear suitable for land development in terms of slope stability. However, a survey of other potential geologic problems in these areas would be required to determine their suitability for development. In addition, most of these areas are underlain by potentially economic oil sands deposits and the alternatives of oil sand exploitation or land development would have to be considered.

Areas labelled (4) are currently developed and appear stable in terms of slope stability. There is limited space for further development in these areas. The practice of building along the unstable slopes of the Clearwater River above the present townsite (as has occurred in a few instances) should be clearly avoided.

(4) This report is a reconnaissance survey only and outlines geologic factors that may effect future land development in the Fort McMurray area, in particular erosion hazards and slope stability. Considering the expected rapid development of the area, it would be desirable to conduct further studies in the area to provide data to determine the location of aquifers, sulphate content of the soils, sites suitable for solid waste disposal, aggregate supplies, and geotechnical properties of the various geologic deposits. In this manner, proposed land uses of any areas could be properly assessed.



1
3
4
CLEARWATER RIVER
3
1
3
RIVER
FORT McMURRAY
2
2
4
1
2
1
ATHABASKA
3
2
1
3
3
2

Figure 17

Land Use Map

1. Unstable area: should remain undisturbed.
2. Stable area: unsuitable for development because of other geological or economic reasons.
3. Stable area: suitable for future development in terms of erosion hazards and slope stability.
4. Area presently being used for residential and industrial purposes.

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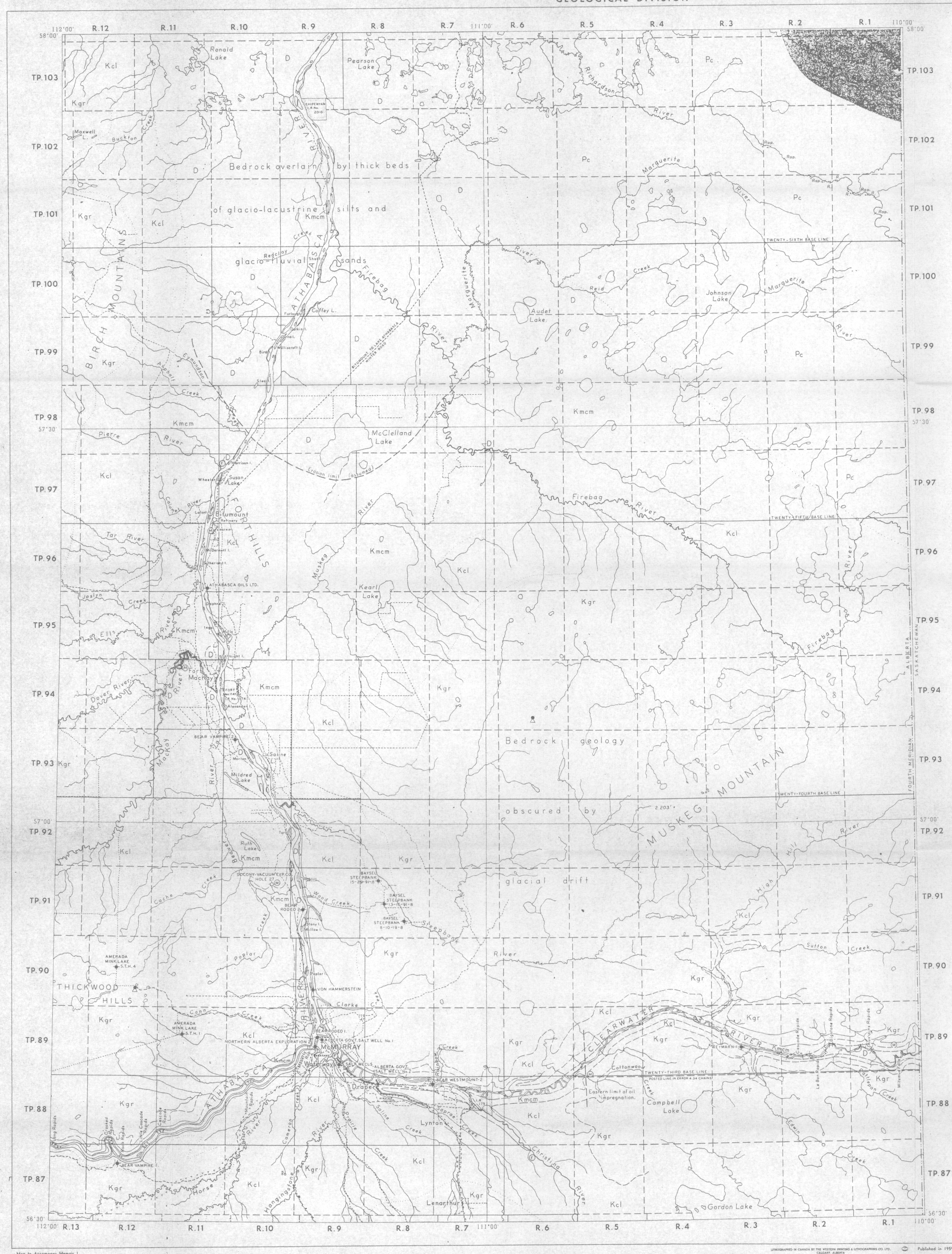
GEOLOGICAL DIVISION



Map to Accompany Memoir 1

LITHOGRAPHED IN CANADA BY THE WESTERN PRINTING & LITHOGRAPHING CO. LTD. CALGARY, ALBERTA

Published in 1959

MAP 26

GEOLOGY OF McMURRAY AREA, ALBERTA

WEST OF FOURTH MERIDIAN

Scale 1 inch to 4 miles

5 0 5 10

LEGEND

MESOZOIC

CRETACEOUS

LOWER CRETACEOUS

Kgr — *GRAND RAPIDS FORMATION: white to yellow fine-grained lithic sand and sandstone.*

Kcl — *CLEARWATER FORMATION: grey-black marine shale, grey and green glauconitic sandstone.*

Kmcm — *McMURRAY FORMATION: shale, siltstone, fine to coarse-grained quartz sand, in part oil-saturated.*

PALEOZOIC

DEVONIAN

D — *BEAVERHILL LAKE and METHY FORMATIONS: calcareous shale, limestone and dolomite.*

PRECAMBRIAN

Pc.a — *ATHABASCA FORMATION: orthoquartzite.*

Pc — *UNDIVIDED: basement complex, mainly granite gneiss and schist.*

Geological boundary (defined)
Geological boundary (approximate)
Geological boundary (assumed)
Locality (macrofossils)
Locality (microfossils)
Saltwell
Oil-sand test hole
Wildcat well

Geology by M. A. Carrigy, 1957, 1958 and G. A. Collins, 1953, 1954, 1955.

Winter and summer road (condition unknown)
Railway
Railway (abandoned)
Telephone or telegraph line
Forestry lookout tower
Interprovincial boundary
Township boundary (surveyed)
Township boundary (unsurveyed)
Indian reserve boundary
Boat landing
Stream (permanent, intermittent)
Rapids
Waterfall
Height in feet above mean sea-level 2203'

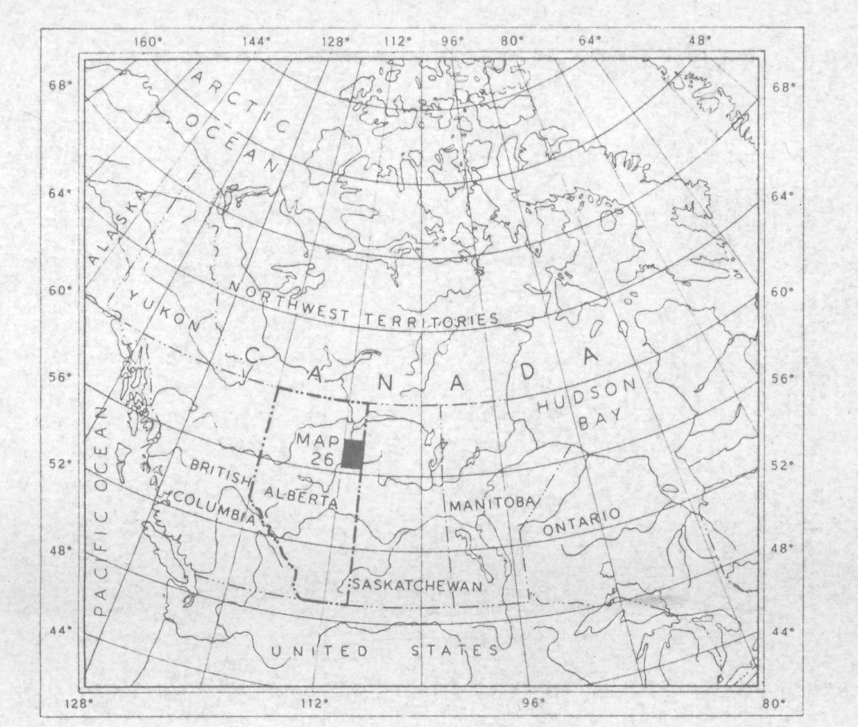
Magnetic declination over the area was 25°00′ E. to 27°00′ E. in 1954. The declination of the compass needle is decreasing 6′ annually.

Boundaries of Athabasca formation after Blake. D. A. W., (1956), Geological Survey of Canada, Paper 55-33.

Base map compiled from planimetric sheets 74 D/NW, NE, and 74 E/SE, SW, NW, NE, published by Government of Alberta, Department of Lands and Forests; Scale One Inch to Two Miles, (1952).

Road information supplied by Government of Alberta, Department of Highways, Shell Oil Company of Canada Ltd., and Bailey Selburn Oil and Gas Ltd., (1958).

INDEX MAP



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