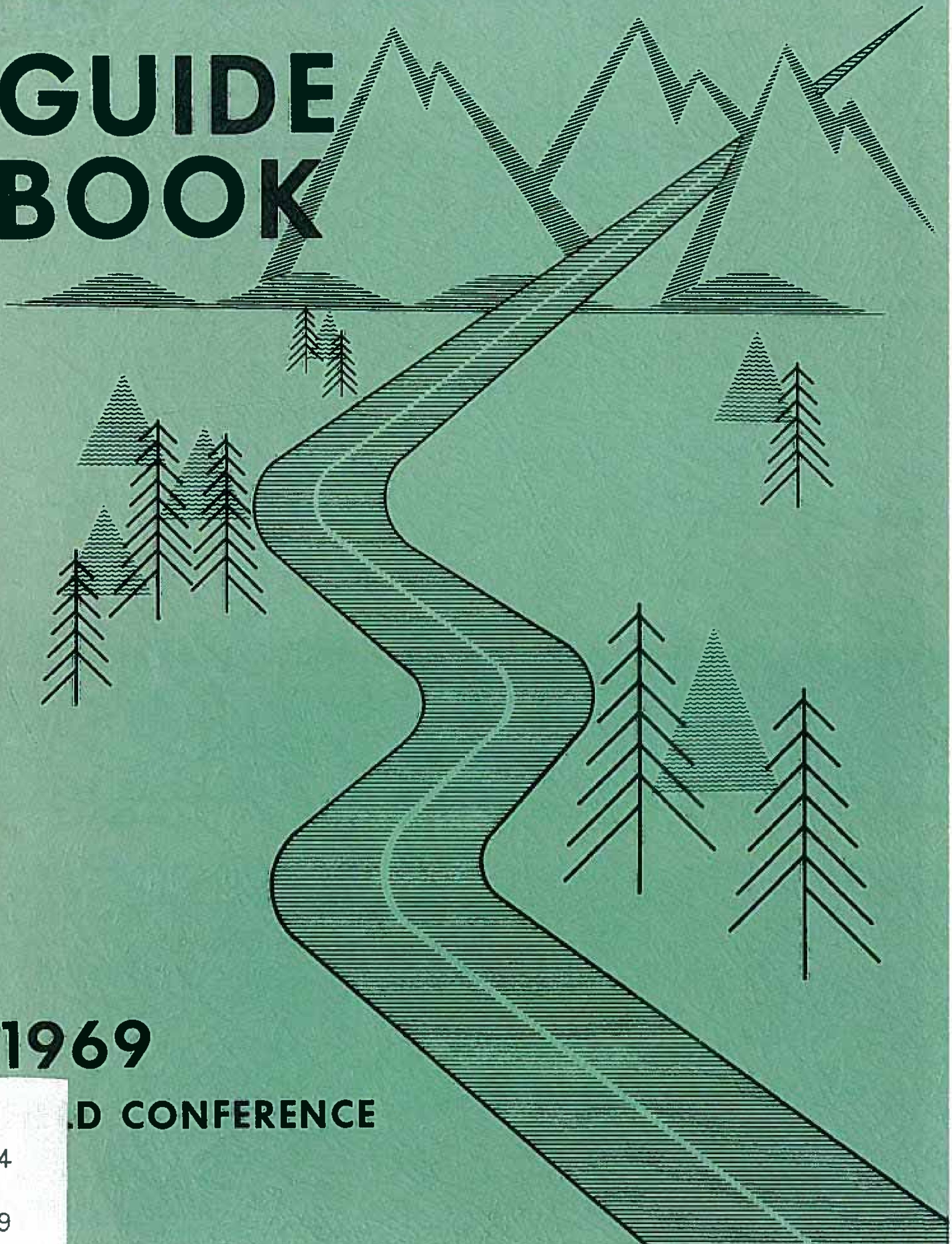
EDMONTON GEOLOGICAL SOCIETY

GUIDE BOOK



1969

[illegible]D CONFERENCE

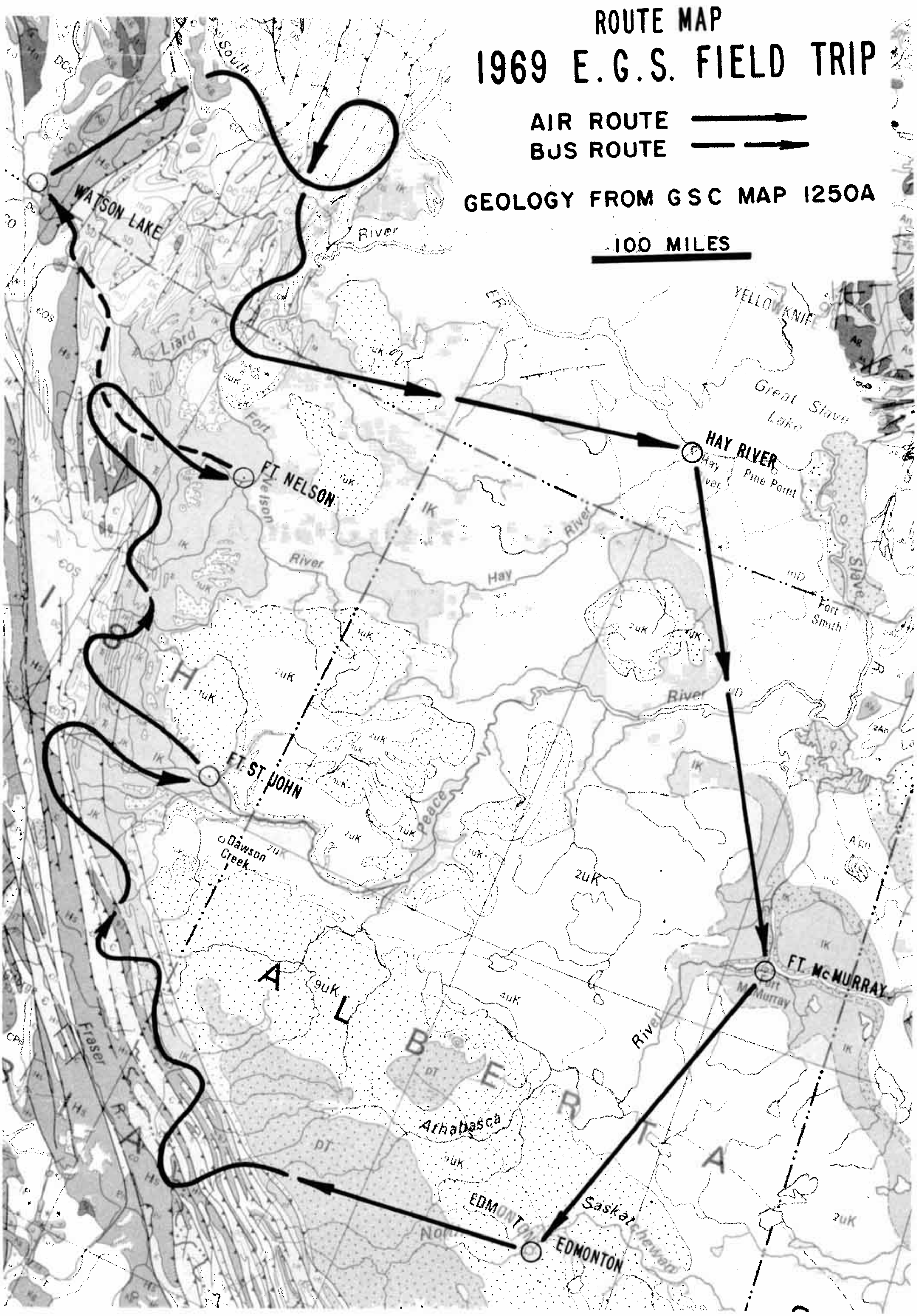
FIELD CONFERENCE

1969

EDMONTON GEOLOGICAL SOCIETY

EDITOR

PETER A. ZIEGLER


ROUTE MAP
1969 E.G.S. FIELD TRIP
AIR ROUTE
BUS ROUTE
GEOLOGY FROM GSC MAP 1250A
100 MILES
WATSON LAKE
FT. NELSON
FT. ST. JOHN
HAY RIVER
FT. McMURRAY
EDMONTON
YELLOWKNIFE
Great Slave Lake
Pine Point
Fort Smith
Dawson Creek
Liard
River
Hay
Peace
Athabasca
Saskatchewan
Fraser
ALBERTA

ACKNOWLEDGMENTS

On the occasion of the 1969 Edmonton Geological Society Field Conference, may I take the opportunity to thank the several organizations and individuals responsible for the success of this endeavor.

We are indebted to Consolidated Mining and Smelting for the kind co-operation in arranging the tour at Pine Point, and to Great Canadian Oil Sands Ltd. for the tour of the plant at McMurray.

We deeply appreciate the co-operation of Shell Canada Limited in allowing Dr. Peter A. Ziegler to serve as Guide Book Editor and Chief Conference Guide. The support of Chevron Standard Ltd in the compilation of the Alaska Highway Road Log west of Fort Nelson is very gratefully acknowledged. The assistance of Imperial Oil Ltd. in the preparation of the Guide book is very much appreciated. The Geological Survey of Canada was extremely helpful in support of the Alaska Highway portion of the Field Conference.

The contributors of papers to the Guide book are to be commended for their ready response and quality of papers. We are grateful as well to Dr. G.C. Taylor and Dr. D.F. Stott of the Geological Survey of Canada for their forthcoming lectures on the geology of the Alaska Highway at the various stops during the Conference.

Finally, may I add a personal word of sincere thanks to the members of the Field Conference Committee for their very capable and effective efforts.

H.W. Cummings
Chairman Field Trip Committee

ITINERARY

FIRST DAY: Flight by F-27 from Calgary to Edmonton to Jasper, following the Rocky Mountains northward to Lake Williston (W.A.C. Bennett Dam). Refuelling stop in Fort St. John. Continue flight northward over northeastern British Columbia Rockies. Overnight stop in Fort Nelson.

SECOND DAY: Drive by bus over Alaska Highway from Fort Nelson to Watson Lake. Overnight stop in Watson Lake.

THIRD DAY: Flight by F-27 from Watson Lake over Southern Mackenzie Mountains to Pine Point; visit to Lead-Zinc Mining operations of Cominco. Flight to Fort McMurray; visit to Tarsand Mining operations of Great Canadian Oilsands Ltd. Return flight to Edmonton and Calgary.

The approximate route of this Field Trip is outlined on Figure 1.

In case of adverse weather the route may be reversed.

EDMONTON GEOLOGICAL SOCIETY

1969 EXECUTIVE COMMITTEE

President	G.D. Williams	University of Alberta
Vice President	P.L. Gordy	Shell Canada Limited
Secretary	R.H. Edmunds	Shell Canada Limited
Treasurer	A.R. Clark	Chevron Standard Limited
Business Manager	P.A.T. Haines	Chevron Standard Limited

1969 FIELD TRIP COMMITTEE

Chairman	H.W. Cummings	Imperial Oil Limited
Treasurer & Registrar	J.G. Pairaudeau	Imperial Oil Limited
Guide Book Editor	P.A. Ziegler	Shell Canada Limited
Logistics	F.A. Schoennagel	Shell Canada Limited

1969 ROAD LOG COMMITTEE

H.R. Hovdebo (Editor)	Chevron Standard Limited
G.C. Taylor	Geol. Survey of Canada
D.F. Stott	Geol. Survey of Canada
P.A. Ziegler	Shell Canada Limited

TABLE OF CONTENTS

SUMMARY OF PRELIMINARY WORK ON THE QUATERNARY GEOLOGY OF THE LAKE WILLISTON AREA, B.C.

by

Nathaniel W. Rutter

Geological Survey of Canada, Calgary, Alberta

The Lake Williston area includes that part of the Rocky Mountain Trench which extends from about Deserters Canyon southeastward to near the John Hart Highway. This area encompasses parts of the former Parsnip and Finlay Rivers drainage basins. At Finlay Bay (formerly Finlay Forks) the area extends eastward crossing the Rocky Mountains along the former Peace River valley to Portage Mountain (W.A.C. Bennett Dam).

Pleistocene deposits are widespread in the Rocky Mountain Trench. Fortunately, Quaternary deposits are relatively well preserved because of the broad nature of the trench that has minimized mass wasting and erosion. Prior to flooding, a good cross-section of these deposits was provided by the widely meandering Parsnip and Finlay Rivers.

Along the Parsnip River, bluffs up to 200 feet high exposed a variety of glacial deposits. The deposits forming the surface today display for the most part typical deglaciation features such as kames, eskers, sand dunes, and lake and outwash plains. In the northern part of the area glaciolacustrine deposits are the most common. In the southern part, in the vicinity of the John Hart Highway, widespread drumlin fields are present. These units are generally unconformable with underlying glacial deposits. Some of the more important sections consist in part of two distinct till units separated by gravel. The lower contact of the underlying deposits is generally obscured but in a few places the deposits were seen to truncate Tertiary gravel or older bedrock. Prior to flooding, one of the most complete sections was located near the mouth of the Manson River on the Parsnip River. The section included:

Top	23.5 feet	Lacustrine silt and sand
	9.0	Fluvial sand
	10.0	Lacustrine clay
	46.0	Till and gravels
	15.0	Fluvial sand and gravel
Bottom	49.0+	Fluvial sand

Thick sections of surficial deposits crop out in many localities along the lake shore in the area of the former Finlay River. These consist for the most part of lacustrine silt and clay (some units over 150 feet thick) from Finlay Bay north to about Davis Creek. Locally, the lacustrine deposits are overlain and underlain by till and glacio-fluvial deposits. North of the Davis Creek area to Deserters Canyon thick glacio-fluvial deposits including outwash, kames and eskers, are the dominant deposits with some till and lacustrine sediments present.

North of Deserters Canyon (out of the Lake Williston area) to Ft. Ware the best stratigraphic sections occur. One section, about 1 1/2 miles southeast of Del Creek displays the following sequence:

Top	9.0 feet	Till 1
	45.5	Till 2
	18.0	Lacustrine silt
	1.5	Fluvial gravel
	3.5	Till 3
	67.0	Fluvial sand and gravel
	±50.0	Till 4
	±35.0	Fluvial gravel
Bottom	±50.0	Oxidized fluvial sand and gravel

In the narrow valley formally occupied by the Peace River, the surficial deposits are almost entirely of fluvial and glacio-fluvial origin. Prior to flooding, four major sets of terraces up to more than 500 feet above the uncontrolled river level could be traced, although not continuously, from Finlay Forks to Portage Mountain. Generally, the terraces are underlain by silty to gravelly material with some of the higher terraces pocketed by kettles. From about Carbon Creek down to Portage Mountain, the higher terraces are capped by lacustrine silt. The deposits beneath the terraces are partly aggradational, related to the terraces themselves, and are partly erosional, remnants of pre-existing deposits. Beneath at least the three lower major terraces a distinct unconformity separates overlying, fairly flat-lying, moderately well sorted gravel and sand from underlying, highly contorted steeply dipping beds of poorly sorted gravel interbedded with sand and silt. Within this lower unit, restricted unconformities are common. The implication of these two distinct units found beneath terraces is that subsequent to down-cutting of each terrace, there was a period of aggradation. Till of restricted extent was found interbedded with the contorted sediments in some localities. Till also occurs beneath the contorted sediments and overlies oxidized gravels. Little is known about the unconsolidated material below the former river level although over 1,700 feet of such material has been reported from borings near Portage Mountian.

An arcuate end moraine extends from Bullhead Mountain southward to Portage Mountain across the former route of the Peace River composed principally of fluvial gravel and sand, formed during final deglaciation of the area. The moraine at least in part, dammed water upvalley that formed a lake and deposited the sediments seen in the high terraces in the area. During the drainage of the lake, water flowed over a saddle to the south of Portage Mountain and eroded bedrock forming the present Peace River Canyon, the site of the W.A.C. Bennett Dam. Material from the moraine was used extensively during the dam construction.

Until further office and laboratory studies are made only a general glacial history can be presented for the Lake Williston area. Evidence is present for four glacial advances that flowed in the Finlay

River valley. The two thick till units represented by Tills 2 and 4 in the second lithologic section cited, may correlate with the two units observed in the Parsnip River valley. If this is so, the till units represent widespread advances and may have passed through the Peace River valley being evidenced in this area by till observed within and below the contorted sediments. Till 3 may represent a minor readvance of the glacier that deposited Till 4. Till 1, which is relatively thin, appears to mantle pre-existing surficial topography downvalley to about the area of Deserters Canyon. A third advance is indicated in the Parsnip River valley by certain till outcrops found in the uplands that may be higher stratigraphically than the two tills commonly found in succession along the former Parsnip River banks.

The four well preserved major terraces observed in the Peace River valley formed after ice withdrew from the valley. They may relate to three periods of glacier fluctuation outside the Peace River valley, or water level control from damming, perhaps when the Peace River changed course and cut the canyon adjacent to Portage Mountain.

Preliminary information suggests that at least the latest advances followed the natural drainage of the area (pebble orientation studies in till are not as yet analysed). The paucity of glacial erratics from sources west of the Rocky Mountain Trench and the poor preservation of striated and fluted surfaces on or near mountain summits in the Rocky Mountains, suggest that only early and extensive glaciations have crossed drainage routes and penetrated deeply into the Rocky Mountains.

Radiocarbon dating has given some insight into the age of the surficial deposits. A mammoth tusk found in the end moriane near Portage Mountain was dated at about 11,600 years B.P., suggesting that the last mountain ice was present in this area at about that time. Wood dated from surface deposits on the west bank of the Ospika River well up the Finlay River valley indicates that that part of the Rocky Mountain Trench was ice-free at least about 7,470 years B.P. (GSC-1069).

The oxidized sands and gravels found under Till 4 as indicated in the second lithologic section presented, may be the only interglacial deposits preserved in the area. Radiocarbon dates derived from several samples taken from these deposits indicate that they were deposited prior to 44,000 years age (GSC - 837,841,1057).

It is interesting to note that since flooding of the narrow Peace River valley large scale landsliding has taken place. The largest slides have resulted from failure of glacial gravel and sand (forming the major terraces) and overlying Post-glacial talus. Waves on the order of 40 feet in amplitude have been generated by the slides according to loggers working in the area.

(GSC-1069) etc. refers to publications of the Geological Survey of Canada. See index of publications of Geological Survey of Canada.

ORDOVICIAN AND SILURIAN BETWEEN PEACE AND TUCHODI RIVERS, NORTHEASTERN BRITISH COLUMBIA

E.J.L. Davies

SHELL CANADA LIMITED

ABSTRACT

Two facies are present in the Ordovician and Silurian of the northern Rocky Mountains. A western facies of open marine shales and siltstones is the lateral equivalent of an eastern facies of platform carbonates. The sequence is characterized by eastward thinning onto the platform and the distribution of rock units is also governed by an unconformity at or near the Silurian-Ordovician boundary.

INTRODUCTION AND ACKNOWLEDGEMENTS

Ordovician and Silurian rocks are widely distributed in the Rocky Mountains of northeastern British Columbia and this account describes the thickness and facies variations present between the Peace and Tuchodi Rivers based on fourteen measured sections and one subsurface control point - H.B.O.G.-Pan American, Muskwa a-6-G, 94-G-13 (Figure 1). Many of the sections discussed were measured by Shell Canada field parties in 1960 and thanks are extended to Shell for permission to publish these. The source of the individual sections is indicated in Figures 3, 4 and 5.

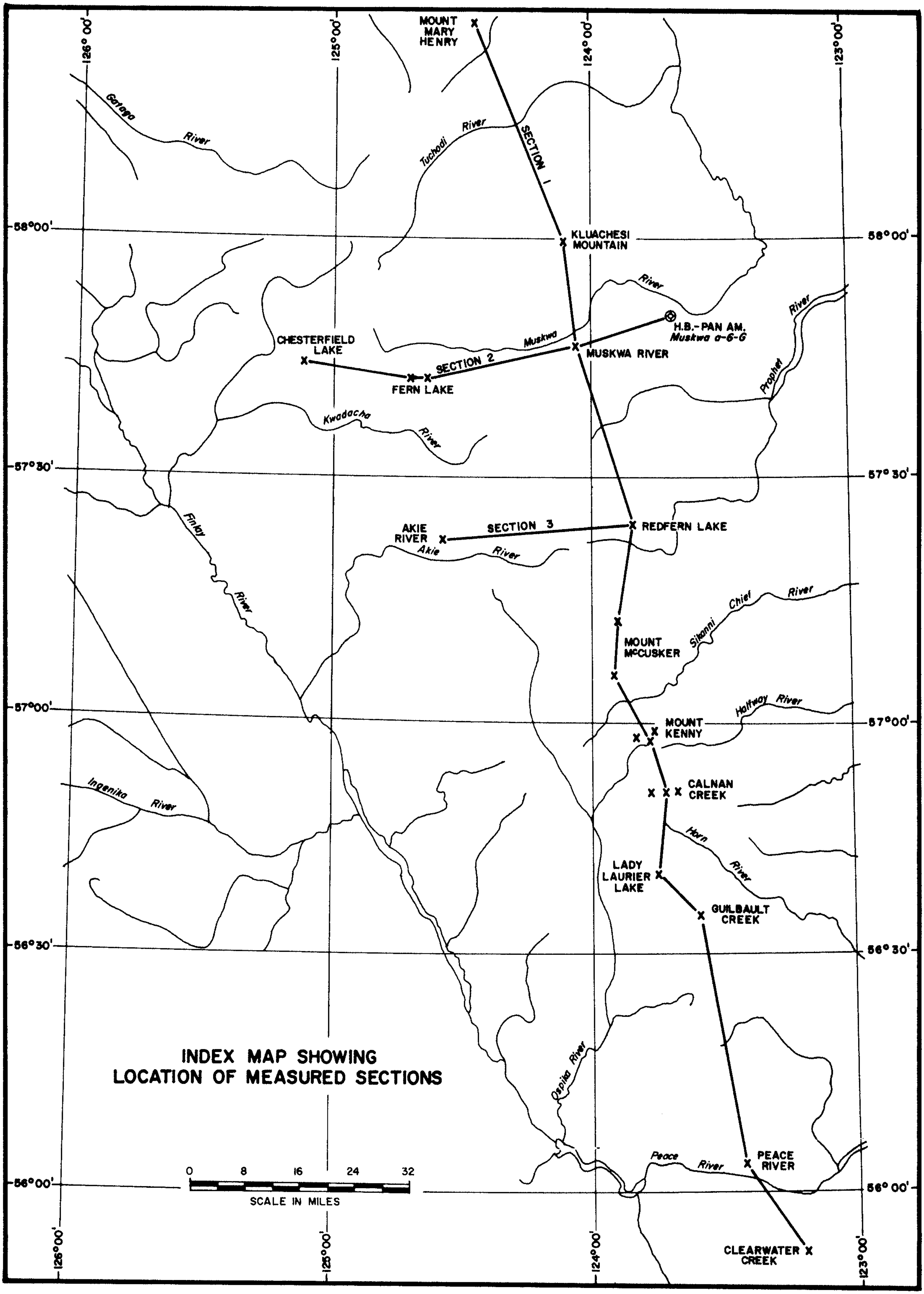
This report is partly summarized from a dissertation submitted to the University of Alberta and thanks are extended to Drs. D.E. Jackson and C.R. Stelck of the University and Dr. P.A. Ziegler of Shell Canada Limited for help and advice received.

PREVIOUS WORK

The first report of Ordovician and Silurian rocks in the area was by McConnell in 1896 who equated widespread grey limestones along the Finlay River with the Cambro-Ordovician Castle Mountain Group of the southern Rocky Mountains. McConnell also descended the Peace River for a short distance below the confluence with the Finlay River and collected the Silurian chain coral Halysites.

Dolmage explored the Finlay River area again in 1928 and further extended the known distribution of the grey limestones.

More recent accounts of Ordovician or Silurian in the area have been published by Sutherland (1958); Jull (1961); Tedrick (1962); Gallant (1962); Cosburn and Callan (1963); Irish (1963, 1964); Jackson, Steen and Sykes (1965); Taylor (1965, 1966); and Norford, Gabrielse and Taylor (1966).


MOUNT MARY HENRY
SECTION 1
KLUACHESI MOUNTAIN
CHESTERFIELD LAKE
FERN LAKE
SECTION 2
MUSKWA RIVER
H.B.-PAN AM. Muskwa a-6-G
AKIE RIVER
SECTION 3
REDFERN LAKE
MOUNT McCUSKER
MOUNT KENNY
CALNAN CREEK
LADY LAURIER LAKE
GUILBAULT CREEK
PEACE RIVER
CLEARWATER CREEK
Gataga River
Tuchodi River
Muskwa River
Prophet River
Kwadacha River
Finlay River
Akie River
Sikanni Chief River
Halfway River
Ingenika River
Horn River
Ospika River
Peace River
126° 00'
125° 00'
124° 00'
123° 00'
58° 00'
57° 30'
57° 00'
56° 30'
56° 00'
0 8 16 24 32
SCALE IN MILES
INDEX MAP SHOWING
LOCATION OF MEASURED SECTIONS

Jackson, Steen and Sykes (1965) published a detailed study of the graptolite faunas and erected a zonal scheme for the Silurian Sandpile and Ordovician Kechika Groups. Two new formation names were also proposed: the Mount April for a Lower Ordovician sequence of argillaceous limestones; and the Cloudmaker for a younger Ordovician sequence of graptolitic shales, siltstones and quartzites.

Norford, Gabrielse, and Taylor (1966) introduced the name Nonda Formation for a Silurian carbonate unit that can be traced from the Peace River northwards to the Yukon Border.

Ordovician and Silurian rocks have been mapped by Irish (1963) in the Halfway River area and by Taylor (1965, 1966) as part of Operation Liard. In addition, detailed geological maps of the Peace River area are included in the Edmonton Geological Society Guidebook for 1962.

STRATIGRAPHY

Two facies belts trending north of northwest are present in the Ordovician and Silurian of the northern Rocky Mountains. The western facies is basically comprised of shales, siltstones and calcareous mudstones. These open marine deposits are the lateral equivalents of argillaceous limestones and dolomites which constitute the eastern platform facies. Oscillations of the western limit of platform carbonate deposition are evidenced by an intervening mixed facies belt.

The nomenclature applied to the stratigraphic succession in the respective facies belts together with the correlation and age of these rock units is summarized in Figure 2.

Mount April Formation

The Mount April Formation is widely distributed in the area and at Fern Lake attains a thickness of approximately 9000 feet. Extremely rapid thinning takes place eastwards (Figure 4) and correlations suggest that this rapid thinning is primarily depositional.

Lithologically, the Mount April consists of an uniform sequence of argillaceous limestones passing westwards into calcareous mudstones. The argillaceous limestones are generally microcrystalline and thinly bedded and weather light brownish grey. They are commonly ripple-laminated and slightly silty. To the west the Mount April is more distinctive. The weathered profile comprises 6-foot units made up of alternating finely laminated mudstone bands, averaging 5 inches thick, and more calcareous nodular bands, averaging 1 inch thick. The rocks are medium dark grey in colour and weather medium light grey. Limestone bands and lenses may be developed. In the Chesterfield Lake area (Figure 4) the uppermost part of the formation is marked by 135 feet of cliff-forming argillaceous cryptocrystalline carbonate which is very finely laminated throughout.

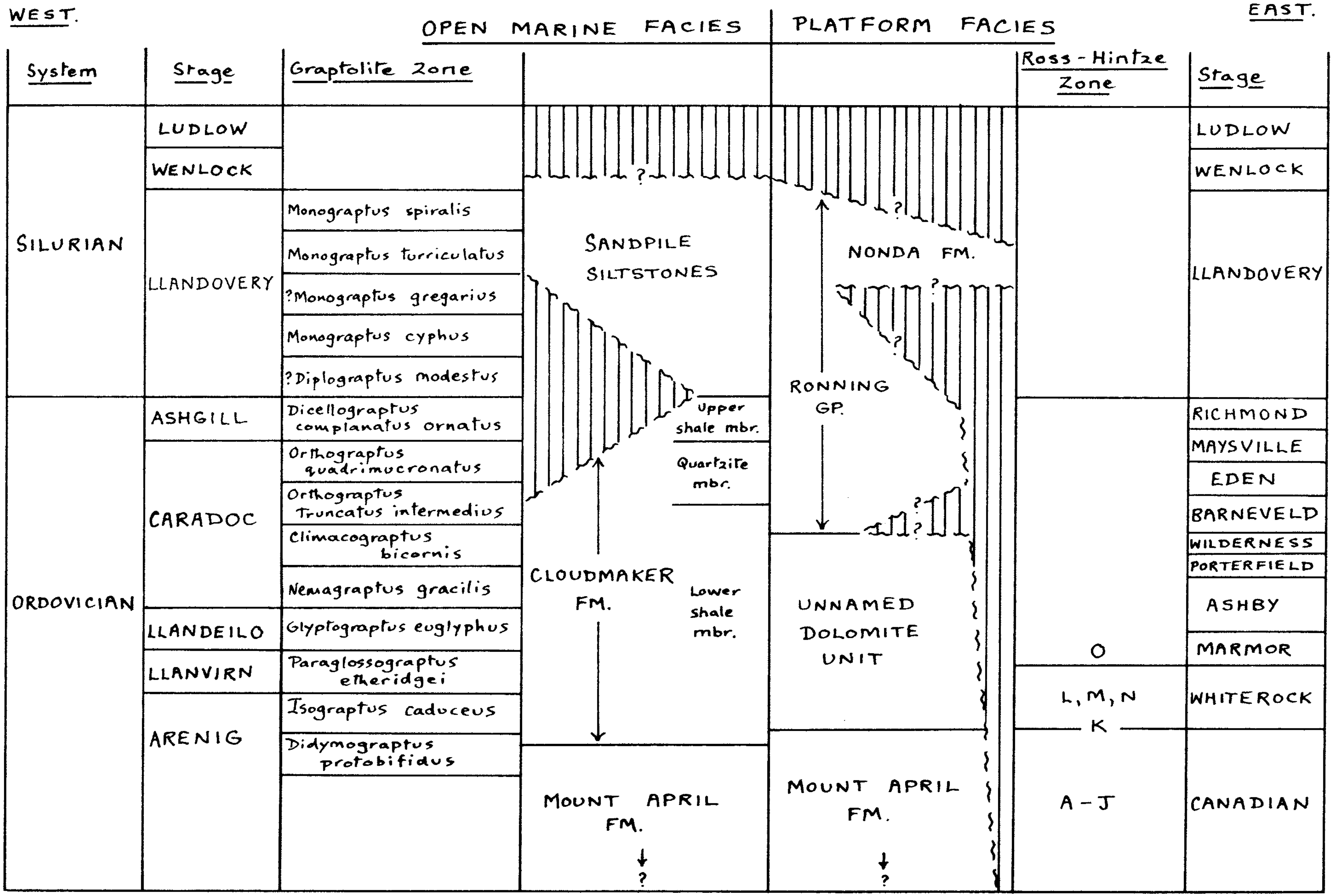


fig. 2.

NOMENCLATURE AND AGE OF ROCK UNITS. Correlation of Ordovician graptolite zones and shelly fossil stages after Berry, 1968.

The Mount April overlies Cambrian sandstones and shales and is conformably overlain by either the Cloudmaker Formation or an unnamed Ordovician dolomite unit. It is progressively truncated by the sub-Nonda unconformity northwards and eastwards from the Kluachesi Mountain area (Figure 3).

Fossils are not common in the Mount April. All the trilobite and brachiopod faunas collected to date are of Canadian age and range from Ross-Hintze Zone B to Zone H or J.

Cloudmaker Formation

A threefold division of the Cloudmaker Formation can be made into a lower shale member, a quartzite member, and an upper shale member.

The lower shale member can be traced from Chesterfield Lake southwards to Lady Laurier Lake (Figure 1). The maximum thickness measured is 1452 feet at Calnan Creek (Figure 3). It is probable, however, that the absolute maximum thickness occurs in the Kwadacha River area (Figure 1) where the member contains a large thickness of volcanics (Taylor, 1965, page 66).

The quartzite member can be traced from the Akie River area to the Lady Laurier Lake area. Over this distance its thickness is fairly constant: between 265 and 330 feet.

The upper shale member is presently known only from the Akie River area where its maximum thickness is 85 feet.

Lithologically, the lower shale member is recessive and consists primarily of grey shales and siltstones although dolomites and thinly bedded, very fine grained sandstones and quartzites are locally important. The siltstones are commonly laminated. The overlying quartzite member consists of massive, very light grey, fine grained quartzites. Interbeds of dark grey, fissile, silty shales are common in the lower part of the member. The upper shale member is composed of dark grey, silty shales and siltstones with subordinate argillaceous dolomite.

In the Akie River area, the upper shale member is preserved beneath the Silurian Sandpile and the Ordovician sequence is complete. To the north in the Chesterfield Lake area, however, the Sandpile unconformably overlies the lower shale member and the quartzite and upper shale members are missing.

The Cloudmaker Formation yields a prolific graptolite fauna and all graptolite zones from *Didymograptus protobifidus* through *Dicellograptus complanatus ornatus* are represented.

Unnamed Ordovician dolomite unit

This unit consists of resistant dolomites and is easily separated

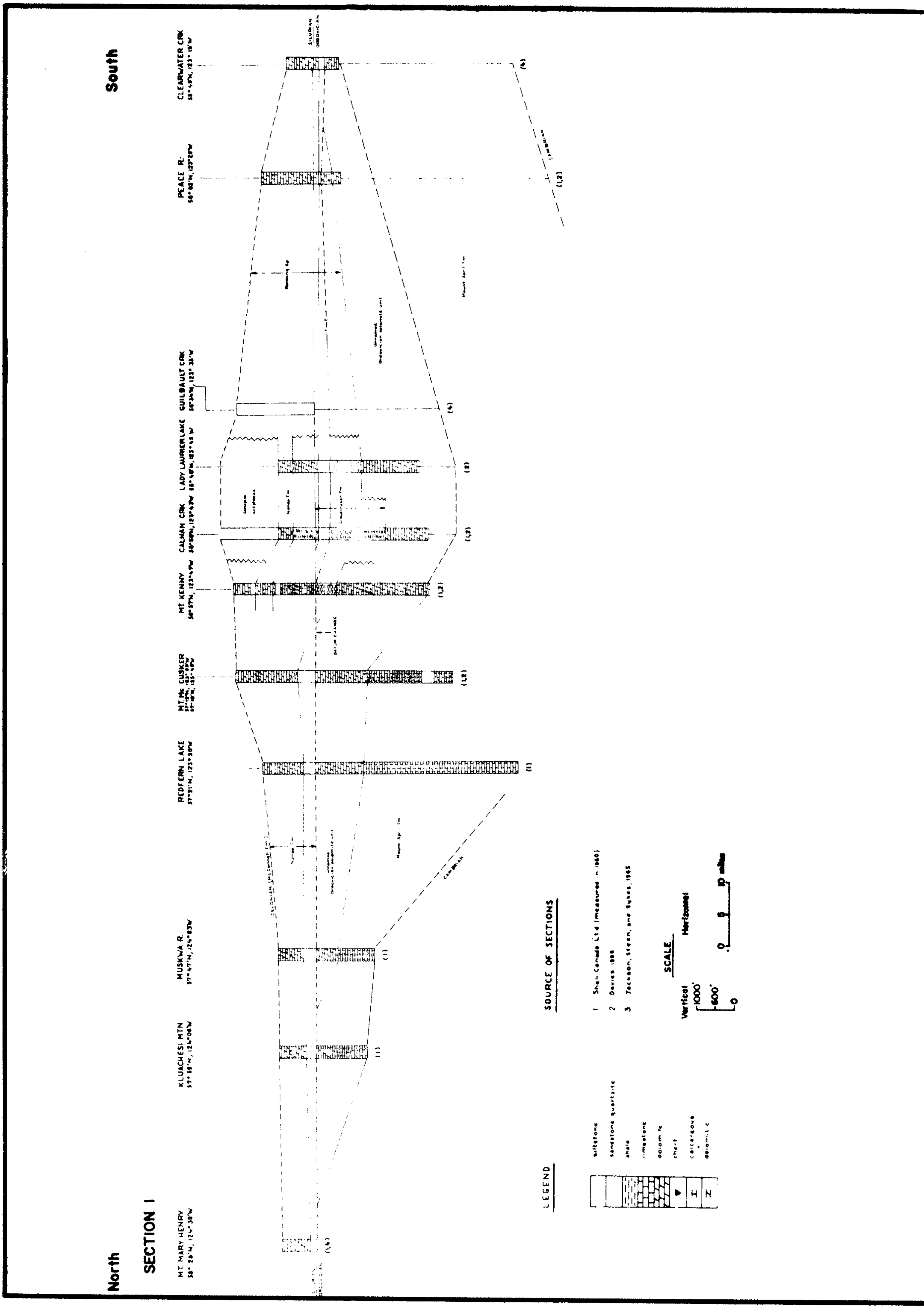

North
South
SECTION I
MT. MARY HENRY
KLUACHESI MTN
MUSKWA R.
REDFERN LAKE
MT. Mc CUSKER
MT. KENNY
CALNAN CRK
LADY LAURIER LAKE
GUILBAULT CRK
PEACE R.
CLEARWATER CRK
SILURIAN
ORDOVICIAN
CAMBRIAN
LEGEND
siltstone
sandstone quartzite
shale
limestone
dolomite
chert
calcareous
dolomitic
SOURCE OF SECTIONS
1 Shell Canada Ltd (measured in 1960)
2 Davies 1966
3 Jackson, Steen, and Sykes, 1965
SCALE
Vertical
1000'
500'
0
Horizontal
0 5 10 miles

fig. 3.

from the limestones of the underlying Mount April Formation. It is completely exposed along a ridge three miles northeast of the summit of Mount Kenny (56° 57'N, 123° 50').

This unit can be traced from the Peace River area northwards to the Muskwa River. At Mount Kenny the unit is 2373 feet thick but northwards from Mount McCusker the unit is progressively truncated by the Nonda Formation and is absent north of the Muskwa River (Figure 3).

The dolomite is microcrystalline to very finely crystalline. The beds are only slightly silty or argillaceous in the Halfway River area, but northwards the unit becomes sandy (Tedrick, 1962). Algal balls are particularly abundant at certain levels and pelletoid dolomite is also well developed in the Halfway River area. The weathered profile of the unit is massive but the individual beds are generally thin to medium.

The Ordovician dolomite unit is the lateral equivalent of part of the lower shale member of the Cloudmaker Formation and it is also overlain conformably by this formation in the Halfway River area (Figure 3). Further south in the Peace River area the unit is overlain by an unnamed calcareous mudstone unit (included here in the Ronning Group).

Apart from algae, fossils are not common. Those found include primitive corals, sponges, brachiopods, gastropods (particularly Maclurites), cephalopods and echinoderm fragments. The available collections suggest that the shelly fossil stages Whiterock through Wilderness are probably represented.

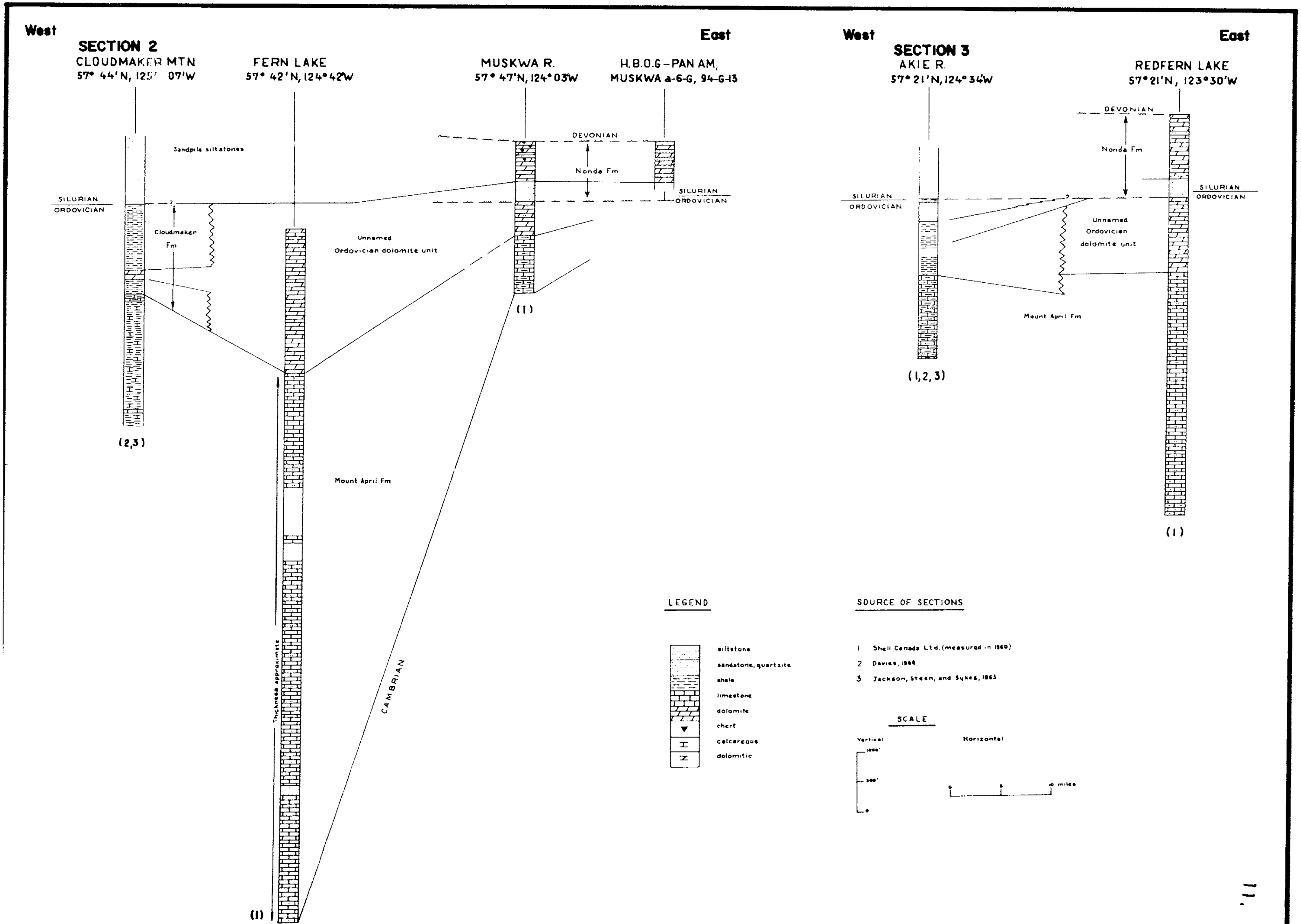
Sandpile siltstones

The Sandpile Group was proposed by Gabrielse (1954) for Upper Ordovician and Lower Silurian carbonates and sandstones in the McDame area. The definition of this group was later expanded by Norford (1962) and Gabrielse (1963) to include graptolitic siltstones. Jackson, Steen and Sykes (1965) referred Silurian siltstones outcropping between Akie River and Chesterfield Lake to the Sandpile Group.

The Sandpile siltstones can be traced from the Chesterfield Lake area through to the Halfway River area where they overlie Silurian dolomites. The maximum thickness of Sandpile siltstones measured is 1463 feet at Calnan Creek.

The Sandpile siltstone unit consists almost entirely of siltstones with only rare thin carbonate and quartzite beds. The siltstones weather light brown to rust, are generally cross-laminated, and may be slightly calcareous or dolomitic. Rare graptolites occur in the lower part of the unit but only worm trails and burrows are common in the upper part.

The Sandpile siltstones overlie the Cloudmaker Formation in


West
SECTION 2
CLOUDMAKER MTN
57° 44'N, 125° 07'W
FERN LAKE
57° 42'N, 124° 42'W
MUSKWA R.
57° 47'N, 124° 03'W
H.B.O.G - PAN AM,
MUSKWA a-6-G, 94-G-13
East
West
SECTION 3
AKIE R.
57° 21'N, 124° 34'W
REDFERN LAKE
57° 21'N, 123° 30'W
East
DEVONIAN
Nonda Fm
SILURIAN
ORDOVICIAN
Sandpile siltstones
Cloudmaker Fm
Unnamed Ordovician dolomite unit
Mount April Fm
CAMBRIAN
Thickness approximate
(2,3)
(1)
(1)
(1,2,3)
(1)
LEGEND
siltstone
sandstone, quartzite
shale
limestone
dolomite
chert
calcareous
dolomitic
SOURCE OF SECTIONS
1 Shell Canada Ltd. (measured in 1960)
2 Davies, 1966
3 Jackson, Steen, and Sykes, 1965
SCALE
Vertical
1000'
500'
0
Horizontal
0
5
10 miles

the Chesterfield Lake and Akie River areas whereas in the Halfway River area the siltstones transitionally overlie the Nonda Formation. This is because the Nonda carbonates and Sandpile siltstones are facies equivalents and the age of the base of the Sandpile decreases eastwards. In the Halfway River area the Sandpile siltstones are unconformably overlain by dolomites of the Devonian McConnell Formation.

In the Chesterfield Lake area, the oldest Silurian graptolite zone present is that of Monograptus turriculatus but in the Akie River area an additional two older zones are present. Graptolites found at the base of the Sandpile siltstones in the Halfway River area represent the Monograptus spiralis Zone. Only Llandoverian graptolites have been positively identified from the Sandpile to date but it is possible that very poorly preserved, stratigraphically higher collections are Wenlockian in age.

Nonda Formation

The Nonda can be traced throughout the eastern platform facies. The thickest section reported by Norford, Gabrielse and Taylor (1966) is at Guilbault Creek (Figure 3) where a thickness of 2008' was measured. The thickness of the Nonda is primarily a function of the sub-Devonian unconformity which has resulted in progressive eastward truncation of the Nonda.

The Nonda consists of dolomite with subordinate sandstones and quartzites. A basal sandstone-quartzite unit up to 450 feet thick is particularly well developed north of Mount McCusker (Figure 3). The dolomites are typically medium dark grey, weathering medium grey, microcrystalline to very finely crystalline and cliff forming. Sandy, silty or argillaceous dolomite beds are common and some beds, especially the sandy beds, contain abundant lithoclasts of argillaceous dolomite. Chert is common and most of the abundant fossils are silicified. Corals are the dominant fossils but locally brachiopods or encrinite banks are important.

The base of the Nonda is unconformable and truncates progressively older rocks northwards and southwards from the Halfway River area (Figure 3). In the Halfway River area the Nonda is overlain by the Sandpile siltstones but elsewhere by the Devonian McConnell Formation.

Although fossils are abundant in the Nonda the collections are difficult to date accurately. Norford et al. (1966, pages 512, 514) recognize four stratigraphical assemblages all of which are probably Late Llandovery in age although it is possible that the youngest assemblage may represent the Lower Wenlock. It is also possible that Richmondian fossils are present in dolomite beds in the basal sandstone-quartzite unit. Tedrick (1962, Figure 3) records a late Ordovician coral fauna from the Prophet River area.

Ronning Group

The Ronning Group is used here as a convenient term to include the Silurian rocks preserved beneath the sub-Nonda unconformity in the Halfway River area and the Silurian and Late Ordovician rocks of the Peace River area.

In the Calnan Creek section 655 feet of poorly exposed Silurian (and uppermost Ordovician?) calcareous and dolomitic mudstones and siltstones are present between the quartzite member of the Cloudmaker Formation and the Nonda. In the Mount Kenny area at least 1100 feet of pre-Nonda Silurian carbonates and siltstones are present. At Lady Laurier Lake a monotonous sequence of laminated flaggy dolomites underlies the Nonda.

Poorly preserved graptolites collected from Calnan Creek may represent the oldest Silurian zone of *Diplograptus modestus*. At Mount Kenny a more shelly facies is developed and a fauna of Llandoverian corals and brachiopods is present.

In the Peace River area, the Ronning Group may be subdivided into: an Ordovician argillaceous carbonate unit (oldest); an Ordovician sandstone unit, and a Siluro-Ordovician dolomite unit.

The argillaceous carbonate unit is 285 feet thick and consists of dark grey, argillaceous limestones and dolomites which contain abundant black chert nodules and stringers. The unit is very fossiliferous, yielding a rich Upper Ordovician fauna of brachiopods, gastropods, pelecypods and bryozoans.

The Ordovician sandstone unit varies between 55 and 110 feet thick and comprises very fine to fine grained, thick to massive bedded sandstones and quartzites.

The overlying Siluro-Ordovician unit which includes the Nonda Formation, is approximately 1500 feet thick just north of the Peace River but is truncated southwards into the Clearwater Creek area by the Devonian McConnell. Fossil collections from the base of this unit are of Richmondian age.

REFERENCES

BERRY, W.B.N.	1968	Ordovician paleogeography of New England and adjacent areas based on graptolites *in* Studies of Appalachian Geology (Eds. E-an Zen *et al*.).
DAVIES, E.J.L.	1966	Ordovician and Silurian of the northern Rocky Mountains between Peace and Muskwa Rivers, northeastern British Columbia: Ph.D. thesis, University of Alberta, Edmonton, Alberta.

DOLMAGE, V.	1928	Finlay River district, British Columbia: Geol. Surv. Canada, Summ. Rept., 1927, Part A, p. 19-41.
GABRIELSE, H.	1954	McDame, British Columbia: Geol. Surv. Canada, Paper 54-10.
GABRIELSE, H.	1963	McDame Map-area, Cassiar District, British Columbia: Geol. Surv. Canada, Mem. 319.
GALLANT, B.T.	1962	Brief notes on the Lower Paleozoic rocks of the Rocky Mountains along the Peace River, B.C.: Edmonton Geol. Soc. Fourth Annual Field Trip Guide Book, p. 102-108.
IRISH, E.J.W.	1963	Halfway River, British Columbia: Geol. Surv. Canada, Map 22-1963.
IRISH, E.J.W.	1964	Preliminary account of the Lower Paleozoic strata of a part of northeastern British Columbia: Bull. Canadian Petroleum Geology, v. 12, p. 808-830.
JACKSON, D.E. STEEN, G. SYKES, D.	1965	Stratigraphy and graptolite zonation of the Kechika and Sandpile Groups in northeastern British Columbia: Bull. Canadian Petroleum Geology, v. 13, p. 139-154.
JULL, R.K.	1961	Silurian Halysitidae of western Canada: M.Sc. thesis, University of Alberta, Edmonton, Alberta.
MCCONNELL, R.G.	1896	Report on an exploration of the Finlay and Omenica Rivers. Geol. Surv. Canada, Ann. Rept., New Series, v. 7 (1894), Part C, p. 1-40.
NORFORD, B.S.	1962	The Silurian fauna of the Sandpile Group of northern British Columbia: Geol. Surv. Canada, Bull 78.
NORFORD, B.S. GABRIELSE, H. TAYLOR, G.C.	1966	Stratigraphy of the Silurian carbonate rocks of northern British Columbia: Bull. Canadian Petroleum Geology, v. 14, p. 504-519.

SUTHERLAND, P.K. 1958 Carboniferous stratigraphy and rugose coral faunas of north-eastern British Columbia: Geol. Surv. Canada, Mem. 295.

TAYLOR, G.C. 1965 Operation Liard _in_ Report of activities: Field, 1964: Geol. Surv. Canada, Paper 65-1, p. 66, 67.

TAYLOR, G.C. 1966 Operation Liard _in_ Report of activities, May-October, 1965: Geol. Surv. Canada, Paper 66-1, p. 92, 93.

TEDRICK, R.L. 1962 Geology of the Prophet River Map-area, British Columbia: M.Sc. thesis, University of Alberta, Edmonton, Alberta.

REGIONAL GEOLOGY ADJACENT TO THE ALASKA HIGHWAY BETWEEN FORT NELSON AND MUNCHO LAKE, BRITISH COLUMBIA

G.C. Taylor(1)

INTRODUCTION

Reconnaissance studies of the geology of this part of northeastern British Columbia were initiated and facilitated by the construction of the Alaska Highway. Williams (1944)[2], the first to work the specific area, studied the geology along the Highway from Fort Nelson to Watson Lake. He was followed by Laudon and Chronic (1947, 1949) who attempted the first detailed stratigraphy. Since publication of the reports of these men a great many geologists have studied the area so that the present bibliography of published data concerning this area has become rather extensive.

Recently, the Geological Survey of Canada began an extensive reconnaissance study of this area in northeastern British Columbia and this background paper on the general geology adjacent to the Alaska Highway results from the work of many members of the staff of the Geological Survey. Work by E.W. Bamber, R. Bell, B.S. Norford, B.R. Pelletier, D.F. Stott and E.T. Tozer is included, but the author takes full responsibility for the data and interpretations presented in this report.

STRATIGRAPHY

With the exception of minor basic intrusives, all bedrock studied within the map-area is of sedimentary origin. The strata range in age from Helikian (Stockwell 1964) to Upper Cretaceous and have an aggregate thickness in excess of 60,000 feet. Strata representative of all systems except the Jurassic are known, and it is possible that erosional remnants of Jurassic formations, occurring to the south, are preserved locally.

PROTEROZOIC

Rocks of Proterozoic age in the vicinity of the Alaska Highway consist mainly of a sedimentary sequence in excess of 25,000 feet thick.

---

1 Address of author: Institute of Sedimentary and Petroleum Geology
Geological Survey of Canada
3303 - 33rd Street N.W.
Calgary 44, Alberta

2 Names, and/or dates in parenthesis refer to publications listed in the references.

TABLE OF FORMATIONS

EON	ERA	AGE	ROCK UNIT		THICKNESS
PHANEROZOIC	MESOZOIC	Cretaceous	Kotaneelee Formation		?
			disconformity		
			Dunvegan Formation		550+
			Fort St. John Group	Sully Formation	300
				Sikanni Formation	900
				Buckinghorse Formation	4,000
		angular unconformity			
		Triassic	Pardonet Formation		0-600
			Post Liard beds		0-1,000
			Liard Formation		0-600
			Toad Formation		1,200-2,500
			Grayling Formation		1,000-1,500
		angular unconformity			
	PALEOZOIC	Permian	Fantasque Formation		0-120
			disconformity		
			Kindle Formation		0-600
			disconformity		
		Mississippian	Stoddart Formation		0-535
			Prophet Formation		0-1,000
		Devonian upper	Besa River Formation		1,200
			Dunedin Formation		800
			local disconformity		
		Devonian middle	Stone Formation		1,035-1,935
			disconformity		
		Devonian lower	Wokkpash Formation		150-350
			Muncho-McConnell Formation		350-800
		disconformity			

TABLE OF FORMATIONS (continued)

EON	ERA	AGE	ROCK UNIT	THICKNESS
PHANERO.	PALEOZOIC	Silurian	Nonda Formation	600-1,200
			angular unconformity	
		Ordovician	Kechika Group	2,000-6,000
			angular unconformity	
		Cambrian	Atan Group	2,000-6,000
PROTEROZOIC	HADRYNIAN		unnamed succession	4,000+
			? ? ? ? ? angular unconformity	
	HELIKIAN		Gabbroic dykes	25-250
			Gataga Formation	4,500+
			Aida Formation	3,470-7,100
			Tuchodi Formation	5,000+
			Henry Creek Formation	700-1,500
			George Formation	1,170-1,750
			Tetsa Formation	1,030
			disconformity	
			Chischa Formation	3,100 +

Some of this sequence is unmetamorphosed and some shows the effect of low rank metamorphism. The strata have been separated into two successions tentatively assigned to the Helikian and Hadrynian eras.

Taylor (1963) published the first stratigraphic description of this lower part of the succession. Bell (1968) studied the complete succession, subdividing it into seven units and proposed the nomenclature followed in this report.

<u>Helikian</u>: The oldest strata exposed in the Tuchodi Lake map-area are shallow-water dolomites of the Chischa Formation. Approximately 3,100 feet of beds are exposed, but the base of the formation has not been seen. Unconformably overlying the Chischa Formation, are approximately 1,000 feet of thin-bedded, dark grey-weathering siltstones that comprise the Tetsa Formation and these are succeeded by 1,700 feet of shallow-water carbonate rocks, mainly limestone, of the George Formation. About 1,500 feet of calcareous mudstone and siltstone of the Henry Creek Formation overlie the George Formation and are gradational upward into the overlying Tuchodi Formation.

Only the Tuchodi Formation crops out along the Alaska Highway. It is composed of a thick (5,000 feet) succession of felspathic quartzites, siltstones, and silty, argillaceous dolomites. Sandstones and siltstones are crossbedded, ripple marked, and contain mud-cracked layers and local stromatolitic beds, all of which indicate deposition in shallow water. Dolomites are more common in the eastern exposures and the facies distribution suggests deposition in deepening waters westward.

Basic Intrusives: All formations assigned to the Helikian era are cut by steeply dipping gabbroic dykes composed of 40 to 50 per cent augite, 30 to 40 per cent labradorite (An_{55}), 4 to 8 per cent magnetite, and 2 to 4 per cent quartz. These dykes, commonly twenty to fifty feet thick but locally as much as two hundred and fifty feet thick, are not known to cut rocks assigned to the Hadrynian era. Several showings of copper mineralization are associated with these dykes. They are unconformably overlain by lower Cambrian strata, and pebbles of mineralized Proterozoic rock occur in the lower Cambrian conglomerates indicating that mineralization was also of Proterozoic age.

Hadrynian: Rocks assigned to the Hadrynian era are not exposed in the immediate vicinity of the Alaska Highway. Strata of this age have been recognized only to the west of the Gundahoo fault, where they lie paraconformably beaneath the Lower Cambrian Atan Group. To the west, in the Rabbit River and Kechika map-areas, Gabrielse (1962, a, b) has reported several thousand feet of beds of this succession. The western succession is unmetamorphosed, whereas the strata within the Tuchodi map-area have been weakly metamorphosed to low greenschist facies. To the south, within the Ware map-area, the sequence has been metamorphosed to low amphibolite facies. Farther south, within the Halfway map-area, equivalent beds have been mapped as part of the Misinchinka Group (Irish, 1963).

PALEOZOIC

Within the Paleozoic era, Cambrian to Middle Devonian rocks, dominantly carbonates, are succeeded by dominantly clastic rocks of Upper Paleozoic age.

Atan Group: Rocks assigned to the Atan Group unconformably overlie Helikian rocks in the eastern exposures and are paraconformable with Hadrynian strata west of the Gundahoo fault. Two main facies units have been mapped within the Atan Group; an eastern and lower clastic facies and a western, partly coeval carbonate facies. The clastic facies ranges in thickness from a zero edge to more than 5,000 feet. The succession apparently represents large fanglomerates deposited adjacent to active faults. Near the fault traces, the fanglomerates are sheared, polymictic, very coarse, with boulders as much as ten feet in largest dimension, and typically grey in colour. At distances in excess of two miles from the fault traces, maximum boulder size is markedly reduced, only the more resistant quartzites form the clasts, which are moderately well-rounded, and the strata are typically red in colour. The conglomerates pass laterally into siliceous quartzites with minor siltstone and argillaceous components. West of the Presidential Range small reef-like mounds of archeocyathid-bearing limestone mark the front of the carbonate (mainly limestone) facies unit of the Atan Group.

All fossils collected to date have been assigned an Early Cambrian age.

Kechika Group: An estimated 4,000 feet of strata occurring in the western part of the Tuchodi Lakes map-area have been assigned to the Kechika Group. Four facies units have been mapped but little in the way of detailed stratigraphy has been attempted in this area. East of the main drainage divide between the Trench and the Foothills, and occurring mainly to the south of the Alaska Highway, is a sequence of relatively clean, platform-type, shallow-water limestones with minor amounts of intercalated orthoquartzite. West of the divide, rocks of equivalent age occur in a graptolitic shale facies. The two units essentially equate to the Mount April and Cloudmaker Formations respectively of Jackson et al., (1965). Results of regional study suggest that the platform carbonates overlap to the west. The third facies, which crops out immediately to the northwest of Mount Churchill, consists of turbidites and separates the carbonates from the shale. North of the Alaska Highway and west of Muncho Lake the fourth facies unit, a thick sequence of argillaceous limestones, occurs as a very widespread unit replacing both the platform carbonates and the graptolitic shales. This is the typical Kechika lithology of the type area.

South of the Alaska Highway thick units of volcanic sediments occur within the lower part of the graptolitic shales. Thin dykes and sills have been observed cutting the carbonate facies south of Redfern Lake. Local prospectors have reported copper mineralization associated with some of these dykes.

In the vicinity of the Muncho Lake, and at several localities east of there, the base of the Kechika Group contains a lower Canadian fauna of Early Ordovician age. To the west of Muncho Lake, in the Rabbit River map-area, Gabrielse (1962a) reports a late Upper Cambrian age for the base of the Group suggesting transgression of the Ordovician seas to the east.

Nonda Formation: A sequence of dark grey-weathering, fine-crystalline, siliceous dolomites, thin orthoquartzites, and minor amounts of limestone has been described by Norford et al., (1966) and given the name Nonda Formation. The formation thins from 970 feet at its type section immediately west of the Toad River bridge, to 630 feet on Mount St. George, as a result of both stratigraphic condensation and post depositional erosion. West of the outcrop belt of the Nonda Formation, rocks of equivalent age occur in a graptolitic shale facies. The shale-carbonate facies front occurs as much as five miles east of the similar facies front of the underlying Ordovician Kechika Group. A major unconformity separates the middle Silurian Nonda Formation from the underlying rocks; the area of deepest down cutting being just south of the Alaska Highway near Summit Lake, where basal Nonda beds rest on strata of the Helikian Chischa Formation.

The structural pattern of much of the area includes numerous thrust faults. Their roots of decollement tend to be stratigraphically controlled by two intervals within the Nonda Formation: the first and more common, is the shaly beds within the basal sandstones of the formation; the second is a set of several zones near the top of the Nonda.

Muncho-McConnell Formation: Disconformably overlying the Nonda Formation is a sequence of fine-crystalline, well-bedded, medium grey dolomites with some interbedded sandy dolomite and argillaceous dolomite. The presence of dessication breccia, free-floating sand grains and other primary sedimentary structures indicate deposition in shoal water, above wave base, near an eastern shoreline. Taylor and Mackenzie (in press) have proposed the name Muncho-McConnell Formation for these dolomites, a revision of the original proposal of Laudon and Chronic (1949). The formation is 890 feet thick at its type sections where it overlies the type Nonda Formation, but thins to 345 feet near Mt. St. George. Fossils of Early Devonian age occur in this succession.

Wokkpash Formation: Conformably overlying the Muncho-McConnell Formation is a succession of distinctive yellow-to orange-weathering sandstone, dolomitic sandstone, dolomite and lesser amounts of shale for which the name Wokkpash Formation has been proposed by Taylor and Mackenzie (op. cit.). The Wokkpash ranges in thickness from 135 feet near Mt. St. George to 376 feet near Muncho Lake. Sandstone is more common in eastern sections whereas shales and argillaceous and anhydritic dolomites dominate western exposures. The Wokkpash has a transitional lower contact with the underlying Muncho-McConnell Formation and is considered to be a facies unit of the same sedimentary cycle and therefore of probable Early Devonian age.

Stone Formation: Unconformably overlying the Wokkpash Formation, a thick sequence of light grey, very fine-crystalline, dolomite and dolomite breccia has been named the Stone Formation by Taylor and MacKenzie (op. cit.). The Stone Formation ranges in thickness from 1,185 feet near Mt. St. George to 1,935 feet near Muncho Lake. Three facies units are recognized in northeast British Columbia; a sandy dolomite facies occurring south of Redfern Lake, a dolomite breccia and evaporitic dolomite facies occurring along the mountain front near Summit Lake, and a bedded dolomite and limestone facies typical of the succession near Muncho Lake. Fossils are rare in the Stone Formation but it overlies Lower Devonian strata and is overlain by Middle Devonian rocks. It seems likely that the Early-Middle Devonian time boundary occupies a position within the formation.

Dunedin Formation: Approximately 500 feet of fine-crystalline, dark grey limestones overlie the Stone Formation and have been named the Dunedin Formation by Taylor and MacKenzie (op. cit.). South of the Alaska Highway near Redfern Lake the Dunedin Formation unconformably overlies the Stone Formation with a well-developed regolith occurring at the base of the Dunedin. To the west, near Muncho Lake, the two formations are apparently conformable. Although the evidence is not incontroversial, it appears that in the vicinity of Summit Lake a disconformity separates the two formations. Fossils collected from the uppermost beds of the formation indicate that the unit is markedly dischronous, ranging in age from Eifelian in northern exposures to mid-Givetian in southern exposures. In the vicinity of the Alaska Highway the formation is an approximate correlative of the Hume and Nahanni Formations of the Northwest Territories.

Besa River Formation: Kidd (1962, 1963) defined the Besa River Formation as "... the thick black shale sequence which is present in northeastern British Columbia lying between Mississippian cherty limestone and Middle Devonian, "carbonates". Bamber et al., (1968) demonstrated the diachronous nature of both upper and lower contracts of the formation. In the vicinity of the mountains the Besa River is approximately 1,200 feet thick, though considerably thicker sections have been reported from wells to the east. The shales of the Besa River are believed to represent deposition in a sediment-starved basin, near the approximate site of the present exposure belt. No evidence for unconformities has been observed in the surface exposures and fossils from all stages have been reported, although admittedly not from one sequential succession. South of the area of study the Besa River shales are replaced by successive carbonate units representing Pine Point, Sulphur Point, Slave Point, and Beaverhill Lake equivalents which lie above the Dunedin Formation.

Prophet Formation: The Prophet Formation is a sequence composed of limestone, chert, and dolomite of Mississippian age. Bamber et al., (1968) describe an abrupt facies change from carbonate to chert and shale occurring across a north-northwest trending line lying within, but slightly oblique to, the structural trend of the Foothills. At the latitude of the Alaska Highway the carbonate facies does not crop out and only the extreme western remnants of the Prophet Formation are exposed. There, the Prophet is represented by 70 feet of dark grey chert with rare lenses of limestone. This thin chert of the western facies could be confused with the Permian Fantasque chert, but the latter lacks the carbonate lenses that characterize the Prophet Formation. The Prophet Formation is not recognized within the Racing River synclinorium.

Stoddart Formation: Only thin remnants of the Stoddart Formation are present in the vicinity of the Alaska Highway. The Stoddart is absent from the easternmost Paleozoic outcrops at the latitude of the Alaska Highway. Near the western edge of the Foothills the Prophet Formation is overlain by shale of Mississippian age, approximately 150 feet thick and equivalent in age to the Golata Formation of the Peace River Plains, succeeded by a sequence of sandstone, shale, limestone, and siltstone approximately 400 feet thick. The basal shales, equivalent to the Golata Formation, and the overlying beds are tentatively assigned to the Stoddart Formation. That succession is overlain by a similar but more resistant sequence, about 150 feet thick, assigned to the Permian Kindle Formation. North of the Alaska Highway the Prophet Formation is not developed, and shales equivalent to the Golata Formation are included in the Besa River Formation. In that region 578 feet of unfossiliferous sandstone and shale occur between the Besa River Formation and the overlying Permian rocks. The stratigraphic assignment of those rocks is in doubt. They are lithologically similar to the Mattson Formation to the north and change westward into Besa River shale which is directly overlain by the Permian Kindle Formation in the Racing River synclinorium.

Kindle Formation: Three lithologic units are recognizable within the Kindle Formation in the Racing River synclinorium. The lower unit consists of 130 to 200 feet of dark grey-weathering siltstone with thin shale and calcareous siltstone beds. The middle unit, 70 to 100 feet thick, has a banded appearance which results from an alternation of dark grey-weathering argillaceous siltstone and orange-weathering calcareous and dolomitic siltstone. The upper unit consists of dark grey-weathering siliceous mudstone, shales, and some chert. Farther southeast, in the Foothills north of Tuchodi River, the Permian sequence beneath the Fantasque Formation contains beds of sandstone and siltstone with some intra-formational conglomerate. Much of the sequence is very calcareous, and some coarse-grained fragmental limestone is present. The presence of these relatively coarse-grained rock types and the abundance of calcareous material characterize the eastern facies of the Kindle Formation.

The Kindle Formation is Permian in age. Bamber et al., (1968) report that the middle, and upper part of the lower unit contains a few horn corals and a sparse brachiopod fauna. This fauna includes Choristites associated with Permian representatives of the genera Pterospirifer, Waagenoconcha, Spiriferella, and Neospirifer.

The Kindle Formation rests disconformably on older rocks with the basal surface cutting down stratigraphically eastward.

Fantasque Formation: In the Foothills between Toad and Tuchodi Rivers, the Permian Fantasque Formation is composed of irregularly bedded, medium to dark grey chert, approximately 120 feet thick. The chert beds in the lower 10 to 15 feet of the Formation are separated by laminae and thin beds of dark grey shale. The chert is absent within the Racing River synclinorium, but the upper, dark grey, siliceous unit of the Kindle Formation may be a western facies equivalent of the Fantasque. In the eastern Foothills the Fantasque Formation rests unconformably on the underlying Kindle Formation.

MESOZOIC

Pelletier (1959, 1960, 1961, and 1962) and Stott (1967, 1968) have published on studies of the Triassic and Cretaceous rocks respectively that occur in the general region of the Alaska Highway.

Grayling Formation: Recessive, fine-grained sandstones and shales of the Lower Triassic Grayling Formation are rarely exposed near the Alaska Highway. Pelletier (1961) reports an almost complete section of the Grayling Formation exposed along the Dunedin River north of milepost 384, Alaska Highway, where 881 feet of beds were assigned to the formation. Fossils are rare in the Grayling but it has been dated by Tozer (1967) as being of Early Triassic age.

Toad Formation: The Toad Formation conformably overlies the Grayling Formation and is well exposed in draws on the higher ridges. Dark grey to black "sooty", fine-grained sandstones, siltstones, and intercalated shales comprise the formation, Pelletier (1960) has shown an east to west thickening of the Formation.

The Toad is of Early and Middle Triassic age (Tozer, 1967).

Liard Formation: The Liard Formation conformably overlies the Toad Formation and is well exposed capping most of the higher ridges of the Foothills. The lower beds of the Liard Formation are gradational with the finer, darker sandstone of the underlying Toad Formation. The contact rises stratigraphically to the west, where strata included in the Toad Formation are lateral equivalents of the Liard Formation. At the latitude of the Alaska Highway, post-Triassic erosion has removed much of the Liard from the eastern Foothills. The formation has a maximum thickness of about 600 feet near the headwaters of the Dunedin River. In the Racing River synclinorium the Liard loses its identity and is included in an unnamed sequence of strata equivalent in age to the Schooler Creek Group. That sequence, including strata that probably are equivalent to the Charlie Lake and Baldonnel Formations of the Fort St. John area, is present in synclinal remnants of Triassic occurring in the western Foothills near Mt. McLearn.

Pardonet Formation: Dark grey, fine-crystalline limestones of the Pardonet Formation are locally preserved in synclinal remnants along the western margin of the Racing River synclinorium. The eastern equivalents of this succession were removed during post-Triassic erosion. Outcrops of the Pardonet have been identified on Mt. McLearn and on a small, unnamed mountain immediately south of mile 428, Alaska Highway.

Cretaceous: Cretaceous rocks include two sequences of marine shales separated by coarse alluvial to deltic sediments. The Lower Cretaceous marine shales and sandstones are assigned to the Fort St. John Group and are overlain gradationally by shales and siltstones of the Dunvegan Formation. The latter lies disconformably below Upper Cretaceous marine shales of the Kotaneelee Formation.

STRUCTURE

The structural mode and stratigraphic successions of the northern Rocky Mountains are in marked contrast to those of the southern Rocky Mountains. It is axiomatic that the structural responses during deformation depend on the stratigraphic column that is being deformed. To understand the Laramide structure of this area it is necessary first to interpret the pre-existing elements. The pre-Laramide history of this area has been a complex one.

Helikian strata were folded and faulted along a trend more westerly than the later Laramide trend. Significant westward tilting resulted in downcutting to the east of the sedimentary column, a phenomenon that persists throughout much of the subsequent history. Postdating this deformation, basic igneous dykes were intruded into the sedimentary section, many of the dykes being injected along pre-existing faults and welding their walls. The relationship of the Helikian to the Hadrynian is uncertain. The two successions are presently separated by the Gundahoo thrust on which there has been significant laramide displacement. That displacement relative to the overlying Cambrian succession is, however, insufficient to eliminate the discontinuity of the Proterozoic successions so that major pre-Cambrian motion (sense ill-defined, though with a large strike-slip component) must be postulated for the fault.

Major faults involving the lower Cambrian strata are recognized. These faults are interpreted as having been formed contemporaneously with the deposition of the Cambrian clastic wedges. Prior to the deposition of the Ordovician, the Cambrian rocks were subjected, to erosion and eastward truncation.

Subsequent to the deposition of Ordovician strata and prior to the deposition of the overlying Middle Silurian strata, the Kechika was subjected to folding and to erosion with eastward truncation of the succession.

Following deposition of the Silurian Nonda Formation, the Lower Devonian Muncho-McConnell and Wokkpash couplet, and the Middle Devonian Stone Formation, minor westward tilting resulted in removal of eastern portions of the individual successions. Similarly, subsurface data to the east of the exposure belt of the Besa River Formation suggests that parts of equivalent strata to the east (shoreward on the depositional platform), have been removed.

Each of the succeeding marine transgressions onto the platform appear to advance farther east than the preceding one and the subsequent regression and erosion on the platform was, each time, limited to less of the basin.

The pattern of erosion was reversed to a degree following deposition of the Carboniferous Mattson Formation and Stoddart Formation. Erosion prior to Permian deposition truncated both east and west leaving a central remnant of Stoddart and Mattson sediments preserved. Although the evidence is fragmentary, thick isolated remnants of Mattson strata in the north seem to require tectonic activity.

The pattern of eastward truncation is repeated following deposition of the Permian Kindle Formation and again after Fantasque deposition. Similarly post-Triassic erosion has truncated the Triassic succession eastward.

Folds are the most prominent structural feature of the northern Rocky Mountain Foothills. Fitzgerald (1965, 1968) has described the box-like and disharmonic character of many of the folds. These structures are characterized by elongated doubly plunging, en echelon linked, fold axes. Many of these folds are asymmetric and more commonly oversteepened on the east limb than the west. Both flanks of the folds dip rather steeply though the structural relief rarely exceeds 2,500 feet. The combination of steeply dipping flanks, short wave length, and relatively small amplitude, suggests detachment of the strata at a relatively shallow depth. Where visible in vertical section the structures are observed to be disharmonic. Detachment occurs at several stratigraphic levels all within structurally incompetent strata. The main level occurs within the Besa River Formation and secondary detachment occurs within the lower Stoddart and the lower Grayling Formations.

Folding is also a prominent mode of deformation within the Rocky Mountains. The major folds are on a very large scale with wave lengths of six to eight miles and a structural relief of 5,000 to 10,000 feet. The folds are markely asymmetric with steepened east limbs which most commonly have overridden the adjacent synclines along thrust faults. However, few of these thrust faults have translation in excess of twice their stratigraphic separation.

A second type of thrust fault is typical of the flanks of the Tuchodi anticlinorium and the Stone anticlinorium, but also common where the Siluro-Devonian carbonate succession is present, as in the Sentinel Range. These thrusts develop out of decollement zones, generally near the base of the Nonda Formation, and rise stratigraphically, disappearing within the Besa River Formation. These thrusts have displacement of as much as two miles and stratigraphic throws of as much as 4,000 feet.

A study of these faults provided a conceptual model for the overall structure of the mountains and Foothills. If one accepts Bally's (1966) concept that the crystalline basement is not involved in the deformation, then from volumetric considerations, one must assume major deformation at depth below both the Foothills and Mountains. Since the decollement does not appear at the surface anywhere within the foothills it must be assumed that, at depth, the lower strata have translated relatively farther east than the strata at the surface. A zone of translation must therefore lie above the deeper rocks producing, in effect, a wedge of rock inserted at some level above the crystalline basement and beneath the surface strata. Major culmination within the Foothills belt probably reflects splaying off the lower decollement or downward deflection of the crystalline basement surface.

REFERENCES

BALLY, A.W. GORDY, P.L. STEWART, G.A.	1966:	Structure seismic data, and orogenic evolution of southern Canadian Rocky Mountains; Bull. Can. Petrol. Geol., Vol. 14, No. 3, pp. 337-381.
BAMBER, E.W. TAYLOR, G.C. PROCTER, R.M.	1968:	Carboniferous and Permian stratigraphy of northeastern British Columbia; Geol. Surv. Can., Paper 68-15.
BELL, R.T.	1968:	Proterozoic stratigraphy of northeastern British Columbia; Geol. Surv. Can., Paper 67-68.
FITZGERALD, E.L. BRAUN, L.T.	1965:	Disharmonic folds in Besa River Formation, northeastern British Columbia, Canada; Bull. Am. Assoc. Petrol. Geol., Vol. 49, No. 4. pp. 418-432.
FITZGERALD, E.L.	1968:	Structure of British Columbia Foothills, Canada; Bull. Am. Assoc. Petrol. Geol., Vol. 52, No. 4, pp. 641-664.
GABRIELSE, H.	1962a:	Rabbit River, British Columbia; Geol. Surv. Can., Map 46-1962.
GABRIELSE, H.	1962b:	Kechika, British Columbia; Geol. Surv. Can., Map 42-1962.
IRISH, E.J.W.	1963:	Halfway River, British Columbia; Geol. Surv. Can., Map 22-1963.
JACKSON, D.E. STEEN, G. SYKES, D.	1965:	Stratigraphy and graptolite zonation of the Kechika and Sandpile Groups in northeastern British Columbia; Bull. Can. Petrol. Geol., Vol. 13, p. 139-154.
KIDD, F.A.	1962:	The Besa River Formation; Edmonton Geol. Soc., Guidebook. Fourth Annual Field Conference, pp. 97-101.

KIDD, F.A. 1963: The Besa River Formation; Bull. Can. Petrol. Geol., Vol. 11, p. 369-372.

LAUDON, L.R., CHRONIC, B.J. 1947: Mississippian rocks of Meramec age along Alcan Highway, northern British Columbia; Bull. Am. Assoc. Petrol. Geol., Vol. 31, pp. 1608-1618.

LAUDON, L.R. 1949: Paleozoic stratigraphy along Alaska Highway in northeastern British Columbia; Bull. Am. Assoc. Petrol. Geol., Vol. 33, pp. 189-222.

NORFORD, B.S., GABRIELSE, H., TAYLOR, G.C. 1966: Stratigraphy of Silurian carbonate rocks of the Rocky Mountains, northern British Columbia; Bull. Can. Petrol. Geol., Vol. 14, No. 4, p. 504-519.

PELLETIER, B.R. 1959: Tetsa River map-area; Geol. Surv. Can., Map 29-1959.

PELLETIER, B.R. 1960: Triassic stratigraphy, Rocky Mountain Foothills, northeast British Columbia; Geol. Surv. Can., Paper 60-2.

PELLETIER, B.R. 1961: Triassic stratigraphy of the Rocky Mountains and Foothills, northeastern British Columbia; Geol. Surv. Can., Paper 61-8.

PELLETIER, B.R. 1962: Triassic stratigraphy of the Rocky Mountains and Foothills, northeastern District, British Columbia; Geol. Surv. Can., Paper 62-26.

STOCKWELL, C.H. 1964: Fourth report on structural provinces, orogenies, and time-classification of the Canadian Precambrian Shield; _in_ Age Determinations and Geological Studies, Geol. Surv. Can., Paper 64-17, Pt. 2, pp. 1-21.

STOTT, D.F.	1967:	Jurassic and Cretaceous stratigraphy between Peace and Tetsa Rivers, northeastern British Columbia; Geol. Surv. Can., Paper 66-7.
STOTT, D.F.	1968:	Cretaceous stratigraphy between Tetsa and La Biche Rivers, Northeastern British Columbia; Geol. Surv. Can., Paper 68-14.
TAYLOR, G.C.	1963:	MacDonald Creek, British Columbia; Geol. Surv. Can., Map 28-1963.
TAYLOR, G.C. MACKENZIE, W.S.	(in press):	Devonian stratigraphy of northeastern British Columbia; Geol. Surv. Can., Bull. 186.
TOZER, E.T.	1967:	A standard for Triassic Time; Geol. Surv. Can., Bull. 156.
WILLIAMS, M.Y.	1944:	Geological reconnaissance along the Alaska Highway from Fort Nelson, British Columbia, to Watson Lake Yukon; Geol. Surv. Can., Paper 44-28.

A SUMMARY OF THE GEOLOGY & EXPLORATION HISTORY OF THE "LIARD FOLD BELT"

by W.B. Richards

PAN AMERICAN PETROLEUM CORPORATION

INTRODUCTION

The terminology, and area names used in the following paper are compatible with those used in the published reports by the Geological Survey with one exception - the Liard Plateau - is referred to in this paper as the "Liard Fold Belt". The "Liard Fold Belt" is the name used in Pan American's reports and memorandums utilized as reference in compiling the data for this paper. While the exact reason for the change could not be isolated, it is suspected, that the name Plateau did not conform with management's image of an area where seismic shooting costs of $10,000.00 per mile, and road costs of $20,000 to $50,000 per mile were quoted. Thus the name "Liard Fold Belt", which from a description standpoint certainly describes the area.

The "Liard Fold Belt" extends from the South Nahanni River on the north for 150 miles south to the Rocky Mountains on the south side of the Liard River. It is bounded on the east by the Interior Plains and on the west by the Liard Plains and the Hyland Plateau (Figure 1).

The "Fold Belt" area encompasses approximately 10,000 square miles of some of the most beautiful scenery, challenging geology, expensive, and frustrating exploration conditions present anywhere in the world. The topography consists of high uplands in the north which change southward to long widely separated ridges with relatively uniform summits approximately 4000 feet in elevation.

Mesozoic and Paleozoic strata are involved in broad open folding and the structures have complicated sinuous axial trends with different fold symmetries. In general, the structures on the west side of the fold belt are asymetrical to the west while those on the east side of the belt are asymetrical to the east. This variance in structural symmetry is suggested to be representative of two periods of deformation.

The stratigraphy of the "Liard Fold Belt" for general purposes can be divided into four main divisions:

(1) Cretaceous and Triassic sandstones and shales, which occur as synclinal remnants.
(2) Permian-Mississippian cherts and sandstones, which are prominent as ridge formers and outline the anticlines.
(3) Mississippian-Devonian shales, which are exposed in the cores of many of the folds.
(4) Devonian-Ordovician carbonates, which occur in the subsurface and comprise the gas-producing horizon.

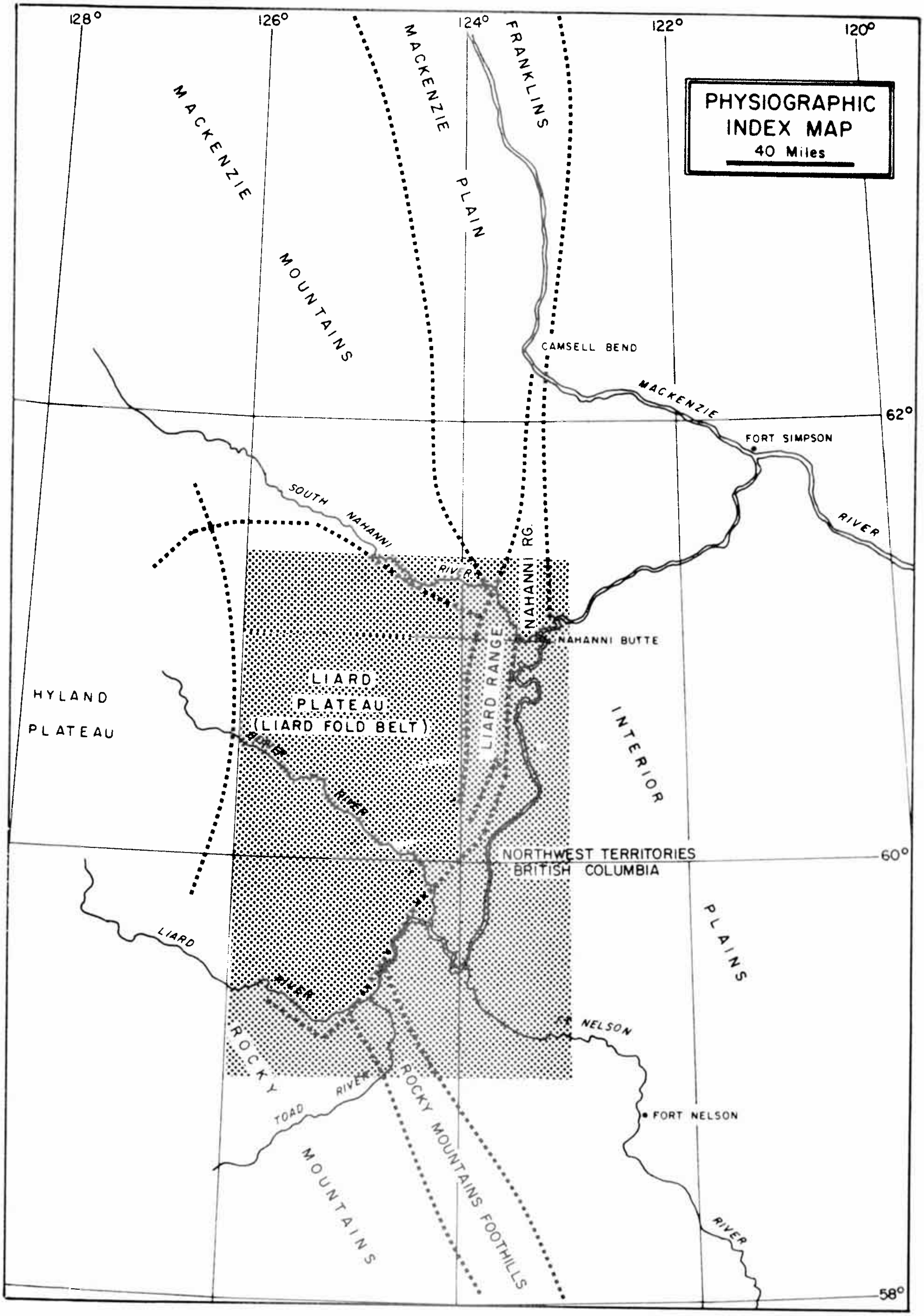

PHYSIOGRAPHIC
INDEX MAP
40 Miles
128°
126°
124°
122°
120°
62°
60°
58°
MACKENZIE
MOUNTAINS
MACKENZIE
PLAIN
FRANKLINS
CAMSELL BEND
MACKENZIE
FORT SIMPSON
RIVER
SOUTH
NAHANNI
RIVER
NAHANNI RG.
NAHANNI BUTTE
LIARD RANGE
LIARD
PLATEAU
(LIARD FOLD BELT)
HYLAND
PLATEAU
RIVER
RIVER
INTERIOR
NORTHWEST TERRITORIES
BRITISH COLUMBIA
PLAINS
LIARD
RIVER
NELSON
ROCKY
RIVER
TOAD
ROCKY MOUNTAINS FOOTHILLS
FORT NELSON
MOUNTAINS
RIVER

fig. 1.

STRATIGRAPHY

System	Formation	Lithology	Thickness
U. Cretaceous	Kotaneelee	Shale, sandstones	525'
	Ft. Nelson	Conglomerate and sandstone	500-800'
L. Cretaceous	Lepine	Shales, marine	2000'±?
	Scatter	Siltstones, marine, some shales	750'±
	Garbutt	Shales, marine, black, bentonite	1000'±
Triassic	Liard	Sandstones, with shales and silts (thickens W.)	0-800'+
	Toad	Silts, shales (thickens W.)	800-1800'
	Grayling	Shales with thin sandstone and silts	1000'±
Permian		Chert, sandstones, silts, siliceous shale	0-600'
		(variable) chert marker	0-200'
Carboniferous	Mattson	Sandstone, silts, shales, coals, limestones in lower part	0-4600'
	Miss.-Dev. shale unit	Shales, occasional thick silts	1200-7000'
U. Devonian			
Lower-Mid.Dev.	Nahanni	Limestone with shale facies	600-1200'±
	Lone Mountains	Dolomites with calc. shale facies and evaporitic facies	200-2700'
Silurian	Ronning	Dolomites with calc. shale facies and evaporitic facies	0-4400'
L. Sil.-Ord.		Limestones, silty, shaley, some dolomites and sandstones	6000'±
Cambrian		Sandstones with limestones	2500'±
Pre-Cambrian		Metasediments, pyroclastics, extrusive and intrusive rocks	?

HISTORICAL GEOLOGY

The "Liard Fold Belt" located in the miogeosyncline west of the Bekami Lake - Bovie Lake - Liard River structural hinge, underwent continuous subsidence and deposition throughout Cambrian, Ordovician and Silurian times. At the end of Silurian time, the Caledonian orogeny possibly caused the sea to withdraw from this area for a short time.

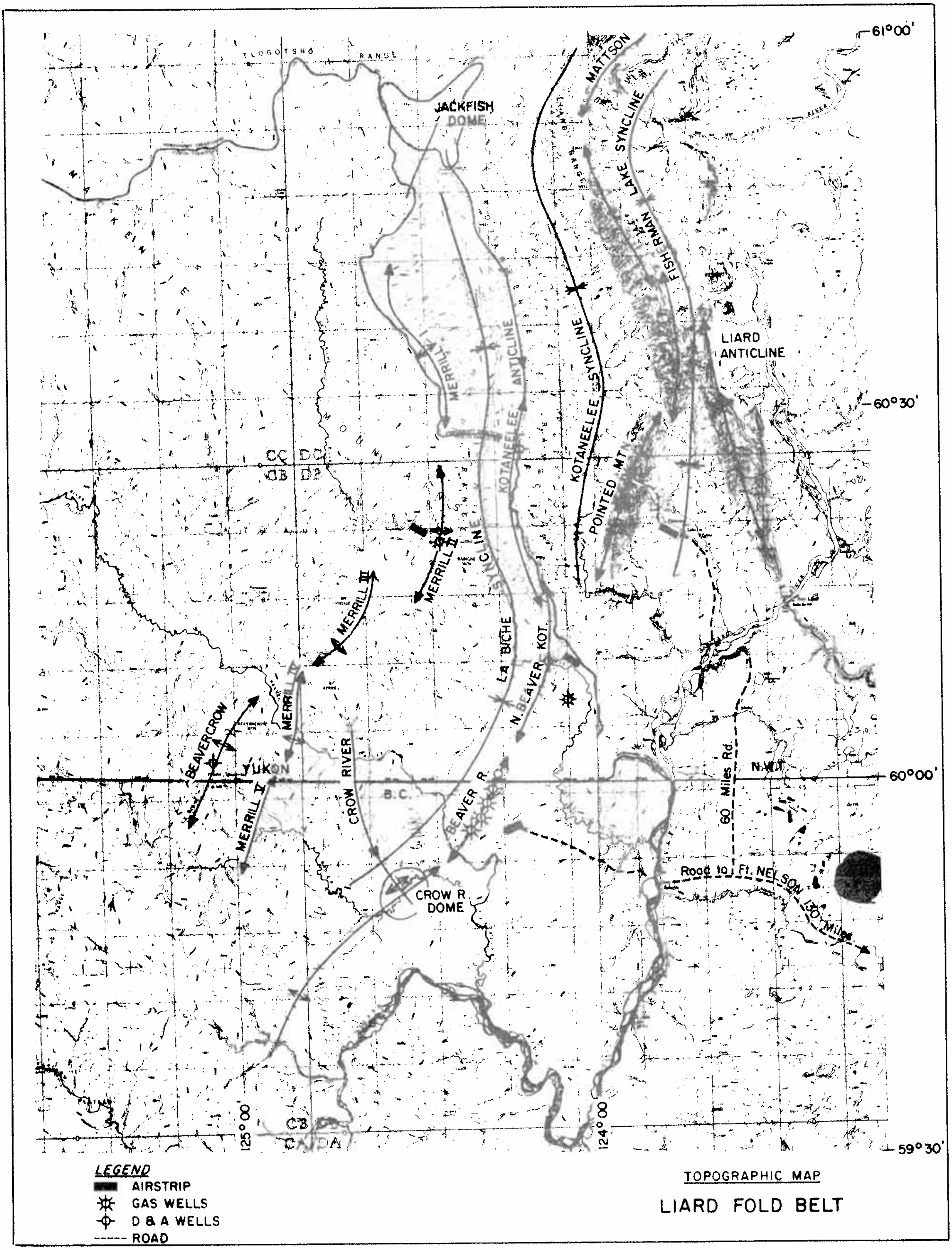
The sea returned early in Devonian time and continued to onlap to the east without a major break in shale and carbonate sedimentation throughout the Middle and Upper Devonian. It was during this depositional period that the Presqu'ile - Slave Point complex was deposited on the Interior Plains. In late Middle Devonian time, the Bekami Lake - Bovie Lake - Liard River feature no longer acted as a hinge. The entire area became submerged and a thick sequence of shales were deposited over a vast area. This deposition continued throughout most of the Upper Devonian time. Near the end of the Upper Devonian time, the area around Toad River was uplifted and eroded. This highland may have extended to the northwest and could be associated with the West Beaver River area. The late Devonian uplift in the west was associated with the deepening of the previous miogeosynclinal area.

Thick carboniferous shales associated with sands and silts of Banffian age, and carbonates of Upper Mississippian age were deposited. The clastics appear to have originated from the west, and are present only in the west-northwest half of the "Fold Belt". The Upper Mississippian carbonates (Prophet River), were deposited over the northeast corner of the "Fold Belt", while equivalent shales were laid down to the southwest. During middle and late Carboniferous great quantities of sand were laid down over the area. The sands thicken to the west suggesting a western source area. During Permian and early Triassic times, the area was inundated by a shallow sea in which a thin clastic sequence was deposited. The area was apparently positive during late Triassic and Jurassic time as no deposits of this age are known in the area.

The "Liard Fold Belt" was again inundated in Lower Cretaceous time, and a thick sequence of sands and shales were deposited throughout the Cretaceous period. Near the end of Upper Cretaceous, the Liard area was involved in orogenic uplift. Major west dipping faults occurred along the previous early Paleozoic hinge and formed the eastern margin of the "Fold Belt". The central portion was gently folded into anticlines and synclines with a minimum of faulting. The western margin was uplifted in a series of east dipping thrust faults.

REGIONAL TECTONICS

The "Liard Fold Belt" extends from the southern end of the Mackenzie Mountains as far as the Rocky Mountains and Foothills to the south. The Mackenzie Mountains strike predominantly north-northwest, and the Rocky Mountains have a similar trend. The "Liard Fold Belt", however, shows trends which at first glance appear to be anomalous. Evidence in the structure analysis of the "Liard Fold Belt" suggests the



JACKFISH DOME
MATTSON
LAKE SYNCLINE
FISH RMAN
LIARD ANTICLINE
MERRILL I
ANTICLINE
KOTANEELEE
KOTANEELEE SYNCLINE
POINTED MT
MERRILL II
MERRILL III
SYNCLINE
LA BICHE
N. BEAVER
KOT.
BEAVERCROW
YUKON
MERRILL V
CROW RIVER
B.C.
BEAVER R.
CROW R. DOME
N.W.T.
60 Miles Rd.
Road to Ft. NELSON 130 Miles
61°00'
60°30'
60°00'
59°30'
125°00'
124°00'
LEGEND
AIRSTRIP
GAS WELLS
D & A WELLS
ROAD
TOPOGRAPHIC MAP
LIARD FOLD BELT

fig. 2.

two mountain chains are distinct. The major structure of the "Liard Fold Belt" appears to be connected with the Mackenzie Mountain structural features which plunge south into the Liard Plains.

Two distinct lineations of the structures prevail in the "Liard Fold Belt" (Figure 2). These two distinct directions are clearly evident on the eastern side of the area where the Pointed Mountain structure shows the main axis in a northeast-southwest direction. The Flett Anticline and Liard Anticline located east and northeast of Pointed Mountain, exhibit axes oriented in a northwest-southeast direction, with the Liard Syncline between them sinuously trending in both directions. Centrally located in the "Fold Belt", the Kotaneelee structure trends primarily north-south, while on the west the Merrill structures trend northeast-southwest in the south, and swing in a northwest direction on the north end.

Regionally the Mackenzie Mountains appear as an eastern (forward) extension of the Rocky Mountain front, that during the mountain building process extended further east than the Rocky Mountains to the south. The extension results in an offsetting of the two mountain blocks (Figure 3). This offset places the Liard as a transitional zone between the two areas of different crustal shortening. If this explanation is correct, the Mackenzie Mountains would have underwent less crustal shortening and similarly less intense deformation than the Rocky Mountains. A comparison of the structures in both areas indicates the Rocky Mountains to be more intensely deformed than the Mackenzie Mountains.

The "Liard Fold Belt" positioned between the two areas of different crustal shortening exhibits variations in structural trends. These variations may be explained as resulting from two forces acting separately or in combinatior: horizontal compression, and/or a couple generated by the differential movement of the mountain front.

Horizontal compression would result in deformation in the form of folds and faults at right angles to the applied forces. This would result in folds trending northwest-southeast. A couple could result in folding oblique to the applied forces (i.e. northeast-southwest); while the two in combination could result in many variations in fold axial trends complicated by transcurrent faulting.

In theory during the widespread Laramide revolution the entire mountain front folded in response to compressional forces. During the later Rocky Mountain phase only the Rocky Mountains were subjected to the compressional forces while the Mackenzie Mountains remained static. In this situation the forces of a couple and their transcurrent nature were very likely developed in the "Liard Fold Belt" (Figure 3).

STRATIGRAPHY

The stratigraphy of the "Liard Fold Belt" has been described in detail by many authors of Geological Survey of Canada reports. (Reference 1-5). It will suffice here to include a Table of Formations with a brief description of the formations.

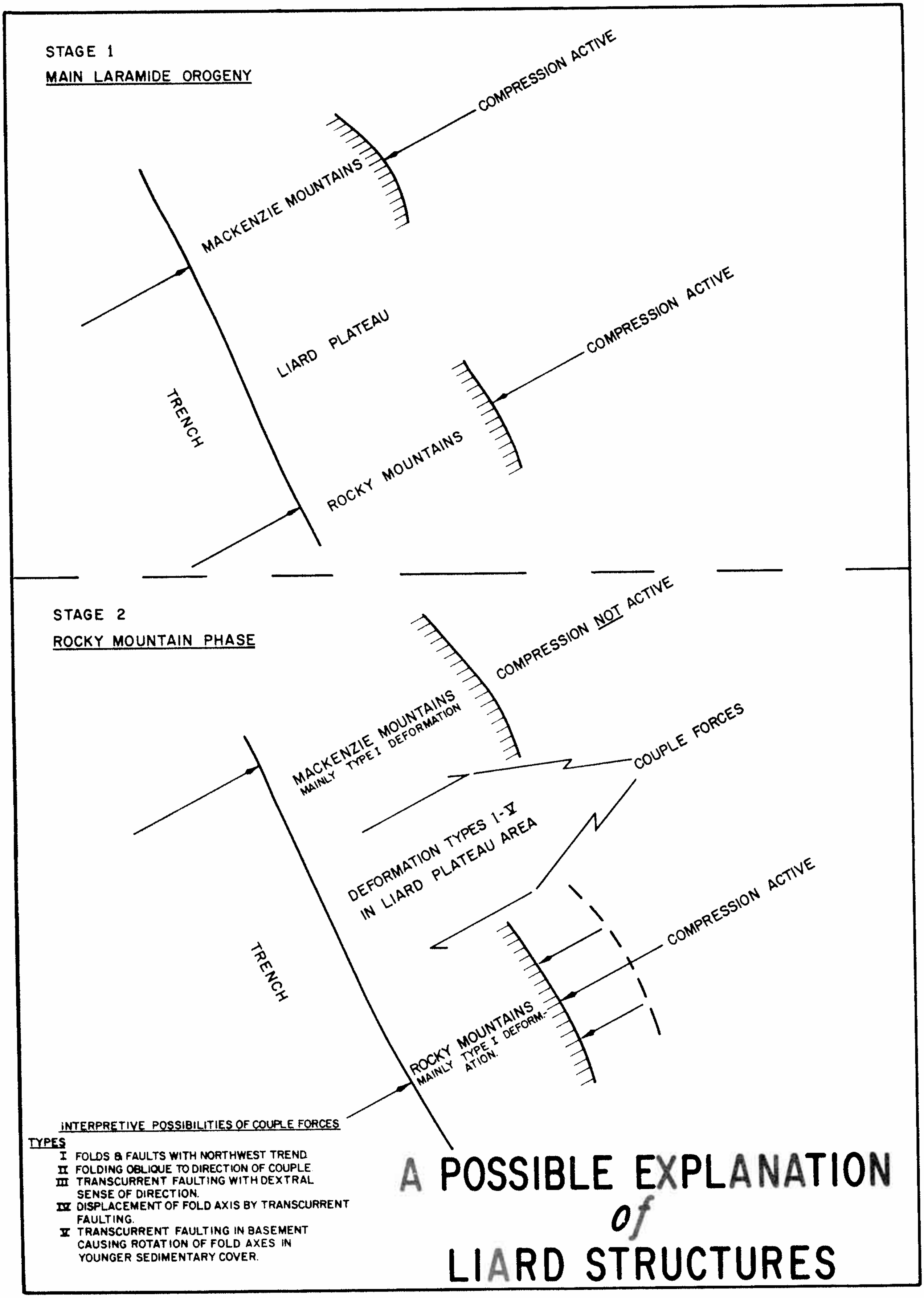

STAGE 1
MAIN LARAMIDE OROGENY
COMPRESSION ACTIVE
MACKENZIE MOUNTAINS
LIARD PLATEAU
TRENCH
COMPRESSION ACTIVE
ROCKY MOUNTAINS
STAGE 2
ROCKY MOUNTAIN PHASE
COMPRESSION NOT ACTIVE
MACKENZIE MOUNTAINS
MAINLY TYPE I DEFORMATION
COUPLE FORCES
DEFORMATION TYPES I-V
IN LIARD PLATEAU AREA
TRENCH
COMPRESSION ACTIVE
ROCKY MOUNTAINS
MAINLY TYPE I DEFORMATION.
INTERPRETIVE POSSIBILITIES OF COUPLE FORCES
TYPES
I FOLDS & FAULTS WITH NORTHWEST TREND
II FOLDING OBLIQUE TO DIRECTION OF COUPLE
III TRANSCURRENT FAULTING WITH DEXTRAL SENSE OF DIRECTION.
IV DISPLACEMENT OF FOLD AXIS BY TRANSCURRENT FAULTING.
V TRANSCURRENT FAULTING IN BASEMENT CAUSING ROTATION OF FOLD AXES IN YOUNGER SEDIMENTARY COVER.
A POSSIBLE EXPLANATION
of
LIARD STRUCTURES

fig. 3.

Scatter Formation (Lower Cretaceous). Its distribution over the Liard area is similar to the underlying Garbutt and Cretaceous-Triassic units. A thickness of 1400 feet is present south of the Liard, and thins to approximately 200 feet in the vicinity of Jackfish Dome on the north end of the area. There is a regional northward thinning of most Cretaceous formations and northward onlap on to the Permian-Mississippian surface is likely to have occurred.

Garbutt Formation (Lower Cretaceous). This unit thins from south to north over the Liard; approximately 2000 feet of strata have been recorded (Kindle, 1944) at the type section along Garbutt Creek. The unit thins to 1200 feet in the vicinity of Beaver River and to 700 feet at the Pointed Mountain structure.

Cretaceous-Triassic. This unit thins markedly to the southwest, and thins to zero in the vicinity of Pointed Mountain. Northwest of Merrill the Cretaceous-Triassic unit has not been differentiated from the overlying Cretaceous-Garbutt Formation.

Fantasque Formation (Permian). This formation lies unconformably below the Cretaceous-Triassic strata and is a distinctive marker east of the Merrill anticline, where it forms broad, gently dipping "outcrops". The unit appears to pinch out just south of Jackfish Dome on the north and west of the Merrill anticline on the west. The Fantasque reaches a maximum thickness of 950 feet in the Kotaneelee syncline west of Pointed Mountain.

Mattson Formation (Permian-Mississippian). The thickness of the Mattson is extremely variable. It varies from 0 to 5200 feet throughout the area. There is no control on the area west of Merrill II but the unit thins towards the southeast. A thickness of 5200 feet of Mattson strata is present in the vicinity of the Flett Anticline on the eastern edge of the "Liard Fold Belt".

Mississippian-Devonian Shale. A thick north-south lobe of 7500+ feet of Mississippian-Devonian shale is present over the central part of the Liard Fold Belt, and is termed the Beaver River Basin. Within this area local thickening along anticlinal crests may occur. The unit thins markedly to the east, south and west.

Nahanni Formation (Lower Middle Devonian). The type area for this formation is in the vicinity of the South Nahanni River. It is defined as the limestones (about 800 feet thick) which directly overlie the Lone Mountain dolomites and which in turn are overlain by shales of Middle and Upper Devonian age. Faunal evidence from this formation places the top of the formation approximately equivalent to the top of the Pine Point in the Slave Lake area, and definitely older than Slave Point. The Nahanni limestone is typically lithographic to fine grained, slightly argillaceous to silty, very often cherty and fossiliferous. In places it is pelletoidal and generally has the character of a shelf carbonate deposited under medium energy conditions. The Nahanni formation on the Toad River area is very similar lithologically to that in the South Nahanni River area. In the Beaver River area (central "Liard Fold Belt") the Nahanni formation as a limestone is not believed to exist. Shales rest directly on dolomites. There is no evidence for the Nahanni being present in a dolomite facies and it is suggested that the Nahanni formation shales out in the Beaver River area. Lithology studies indicate an increase in terrigenous material northward from the Toad River area, as well as a southward from the South Nahanni River area toward the central part of the "Liard Fold Belt". This increase in terrigenous material corresponds to a decrease in limestone percentage.

Lone Mountain Formation (Lower - Middle Devonian). It is this formation in combination with the Ronning below that is interpreted as being the gas producing formation in Beaver River and Pointed Mountain. The dolomites of the Lone Mountain are fine to coarse crystalline, dense to porous and generally devoid of terrigenous material. They are banded. Fossils are poorly preserved; brachiopods, corals, amphipora and stromatoporoids indicate a probable Devonian age.

The productive zones in Beaver River and Pointed Mountain have as a general rule fair to good porosity and permeability which is supplemented by fractures. The top, 600 to 800 feet of this formation, is clean, tan to buff color, coarse crystalline, secondary dolomite which is correlatable in most of the wells in the "Fold Belt" area. Below the clean coarse crystalline zone, the dolomite is finer crystalline, medium to dark grey color and becomes slightly argillaceous; the porosity in this zone is poorer and less effective.

EXPLORATION HISTORY

Geology

The exploration history of the "Liard Fold Belt" was initiated by the Geological Survey of Canada when reconnaissance mapping was conducted in 1944 by Kindle and in 1945 by Hage on the southern and eastern parts of the area.

In 1955 Pan American Petroleum Corporation (Stanolind, at that time) placed a geological field party in the general area of the Crow and Beaver Rivers.

Photogeologic studies were conducted in 1955, which defined the series of anticlinal structures from Jackfish Dome south through Merrill I, II, III & IV (Figure 2). The first geological field party Pan American put in the "Liard Fold Belt" area utilized photogeology plotted on planimetric base maps prepared from uncontrolled photo mosaics. Various photogeological studies, conducted by service companies, have been utilized to construct structure contour maps on the Base of Mattson sand, which conforms very closely to maps constructed today using seismic and well data for control.

Based on the findings of the field party in 1956, Pan American posted and purchased in excess of 500,000 permit acres located in both British Columbia, the Yukon and Northwest Territories. In subsequent years (1959 and 1961) Pan American conducted further and more detailed surface studies directed towards specific anticlinal structures within the "Liard Fold Belt". In 1959 and again as a direct result of surface studies Pan American purchased an additional 500,000 permit acres in the Yukon and Northwest Territories.

Seismic

In 1957 Pan American commenced seismic operations across the Crow River structure in the southwest part of the Liard area. Pan American and Shell jointly conducted a seismic program across the Merrill II structure in 1964, while shooting programs by Pan American over Beaver River, Pointed Mountain, Kotaneelee and Flett anticlinal structures were conducted in 1957, 1959, 1967 and 1968 respectively. The results of the seismic programs were plotted directly as footage structure contour maps on the base of the Mississippian Limestone Unit and the top of the Middle Devonian Carbonate.

Extreme variation in topography made seismic operations very difficult as well as expensive. Conventional track seismic operations used in early exploration of this area were restricted drastically by topography resulting in coverage over only those parts of the structures that were accessible. Total seismic (field) operating costs in the mountainous terrain in the Liard for track operations are approximately $2,500.00 per mile.

The frustrations of having limited seismic coverage governed by accessibility were overcome to a large degree in 1967 when Pan American initiated the use of portable seismic equipment which could be moved by helicopters in mountainous terrain. Areas previously considered inaccessible were shot with no loss in quality of data. Total seismic field operating costs in the mountainous terrain for heli-operations are approximately $10,000.00 per mile.

The utilization of portable seismic equipment, which could be moved by helicopters, made it possible to define the critical structural closure at Middle Devonian Carbonate level.

Drilling

Drilling operations in the Liard started in 1958 when Pan American drilled the A-1 Beaver River well, which was the discovery well on the Beaver River anticline. The drilling of the first well in this area confronted Pan American with many problems, a few of which were: hard drilling, hole deviation problems, high water flows, and high pressure gas pockets. In fact, while the Beaver A-1 well was the discovery well, it had to be abandoned when a high pressure gas zone in the Mississippian caused a blowout and fire, which destroyed the rig and regrettably killed two men.

Since the discovery of gas in 1959 the chronological drilling exploration in this area is as follows:

	Well Name	Date Completed	Structure	Status
1)	Pan American A-1 Mattson	1961	Mattson	D&A
2)	Pan Am A-2 Beaver River	1962	Beaver River	Gas
3)	S.O.B.C.-Shell Beavercrow	1963	Beavercrow	D&A
4)	Canada Southern et al N.Beaver River	1964	N.Beaver-Kootaneelee	Gas
5)	Pan Am-Signal Kotaneelee A-1	1964	N.Beaver-Kotaneelee	D&A
6)	Pan Am A-1 Pointed Mountain	1966	Pointed Mountain	Gas
7)	Pan Am A-3 Beaver River	1967	Beaver River	Gas
8)	Pan A A-2 Pointed Mountain	1968	Pointed Mountain	Gas
9)	Pan Am B-1 Beaver River	1969	Beaver River	Gas
10)	Pan Am-Shell A-1 Merrill	1969	Merrill II	D&A
11)	Pan Am B-1 Kotaneelee	1969	Kotaneelee	D&A
12)	Pan Am A-3 Pointed Mountain	1969	Pointed Mountain	Gas
13)	Pan Am C-1 Beaver River	Drilling	Beaver River	
14)	Pan Am B-1 Pointed Mountain	Drilling	Pointed Mountain	

While drilling time for wells in the Liard initially took about one year; familiarity with conditions has reduced the drilling time to approximately six to seven months. The cost for a well to approximately 14,000 feet is in excess of $2,000,000.00.

The high exploration costs involved in the search for hydrocarbons in this area, necessitates the possibility of large potential reserves in order to make the venture commercial. While the Middle Devonian Carbonate reservoir rock is a relatively low porosity dolomite supplemented by fractures, the Absolute Open Flow Capacity for the average well in either Pointed Mountain and Beaver ranges upward from 35.95 Mmcf/d with the majority of wells testing over 75 MMcf/d Absolute Open Flow. The Gross pay thicknesses range from a minimum of approximately 800 feet to a maximum of approximately 3000 feet.

Beaver River Anticline

The Beaver River anticline (Figures 4 and 5) is essentially symmetrical with surface dimensions 13 miles long and 3-3/4 miles wide. Seismic control indicates the presence of a high angle fault on the east flank of this northeast-southwest striking structure.

Four wells have been drilled on this structure, with a fifth currently drilling to further define the north plunge. The average gross pay encountered in the four wells is approximately 2300 feet. The reservoir rock while variable, can be described briefly as three basic lithologies, namely:

(1) Mottled grey-white dolomite with vuggy porosity developed in the coarse white crystalline dolomite.
(2) Dense, dark grey, fine grained dolomite.
(3) Light grey, fine, to medium grained dolomite with pin-point porosity in combination with small vugs. The vugs in many cases are completely infilled with coarse crystalline dolomite.

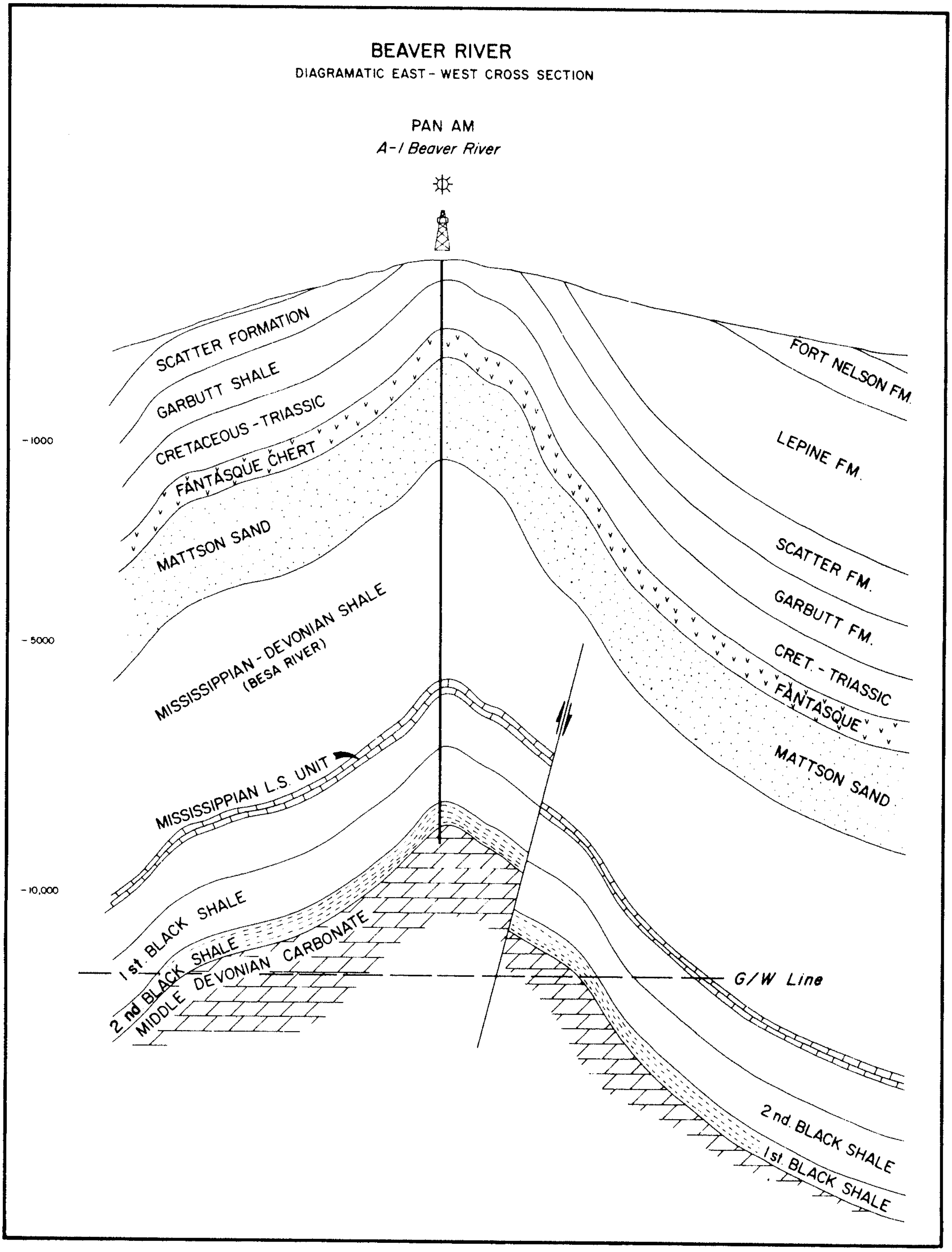

BEAVER RIVER
DIAGRAMATIC EAST - WEST CROSS SECTION
PAN AM
A-1 Beaver River
SCATTER FORMATION
GARBUTT SHALE
CRETACEOUS - TRIASSIC
FANTASQUE CHERT
MATTSON SAND
MISSISSIPPIAN - DEVONIAN SHALE
(BESA RIVER)
MISSISSIPPIAN L.S. UNIT
1st BLACK SHALE
2nd BLACK SHALE
MIDDLE DEVONIAN CARBONATE
FORT NELSON FM.
LEPINE FM.
SCATTER FM.
GARBUTT FM.
CRET. - TRIASSIC
FANTASQUE
MATTSON SAND
G/W Line
2nd. BLACK SHALE
1st. BLACK SHALE
-1000
-5000
-10,000

fig. 5.

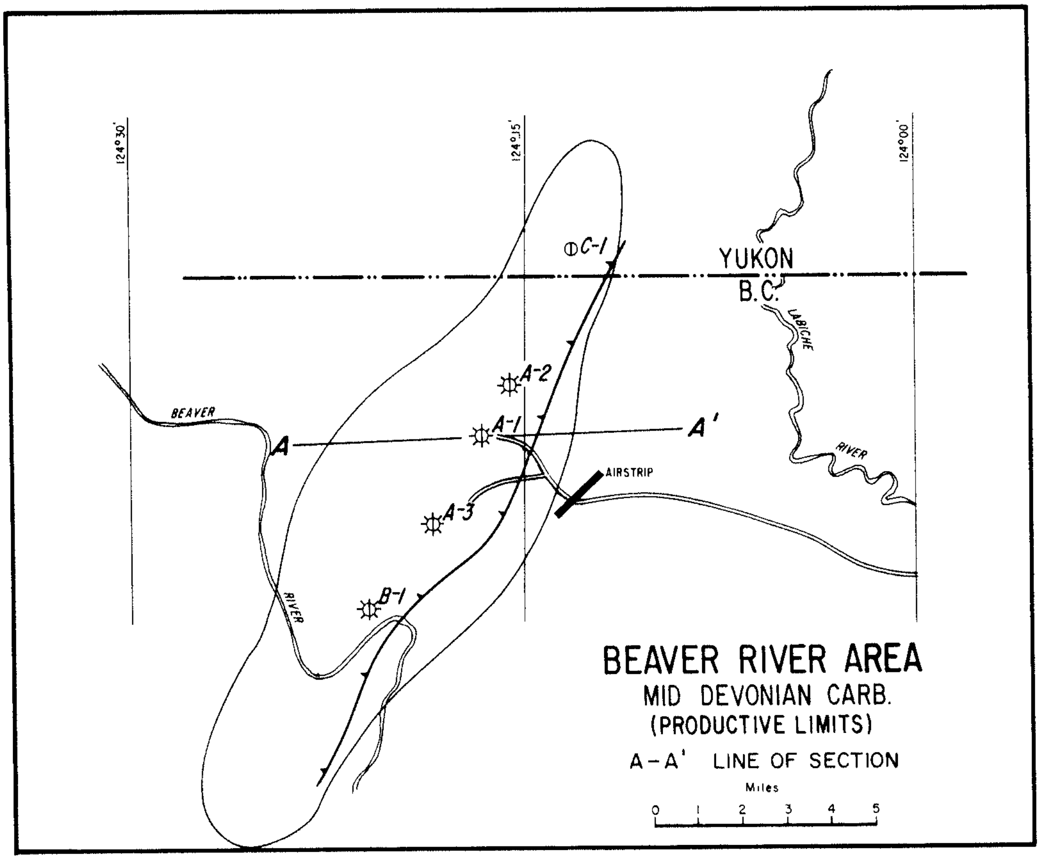


fig. 4.

In many instances the three basic lithologies are cut vertically and horizontally with fractures which grade from open to completely closed. Fracturing in some cases was of such intensity that a breccia was created which supplemented the intercrystalline and vuggy porosity and permeability considerably.

All of the wells drilled on this structure have encountered lost circulation or gas blow-out problems in the Mississippian silty-shale section. The current drilling well drillstem tested one of these gas zones at the rate of 40 Mmcf/d. A further evaluation of this potential zone is underway.

Pointed Mountain Anticline

The Pointed Mountain anticline is doubly plunging and asymmetrical to the east with surface dimensions approximately 15 miles long and 4 1/2 miles wide (Figures 6 and 7). The east limb of the structure shows a pronounced steepening with bedding dips up to 60° while the west limb has relatively gentle dips in the order of 10° - 20°. The steep dips on the east side of the structure reflect a thrust fault which strikes northeast-southwest. This fault which cuts the Middle Devonian Carbonate seems to mark the eastern

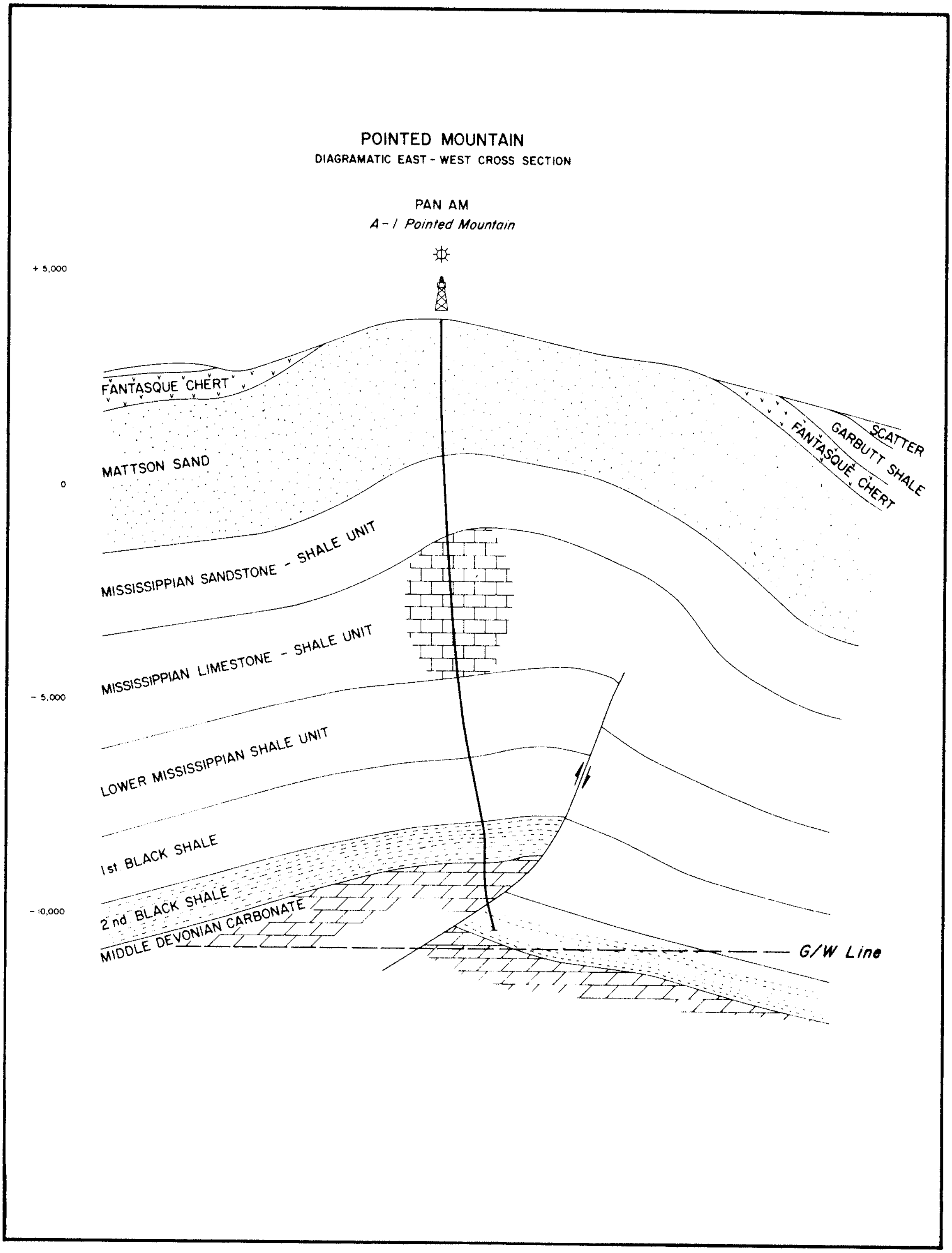

POINTED MOUNTAIN
DIAGRAMATIC EAST - WEST CROSS SECTION
PAN AM
A-1 Pointed Mountain
+ 5,000
0
- 5,000
- 10,000
FANTASQUE CHERT
MATTSON SAND
MISSISSIPPIAN SANDSTONE - SHALE UNIT
MISSISSIPPIAN LIMESTONE - SHALE UNIT
LOWER MISSISSIPPIAN SHALE UNIT
1st BLACK SHALE
2nd BLACK SHALE
MIDDLE DEVONIAN CARBONATE
SCATTER
GARBUTT SHALE
FANTASQUE CHERT
G/W Line

fig. 7.

limits of production in this reservoir. The lithology of the Middle Devonian Carbonate is similar to the ones at Beaver River. It is noteworthy that the Mississippian (Prophet) limestone which was non-existent at Beaver River to the south is approximately 2000 feet thick in the Pointed Mountain area. A facies change from 2000 feet of limestone to essentially a total shale section occurs between the Pointed and Beaver structure.

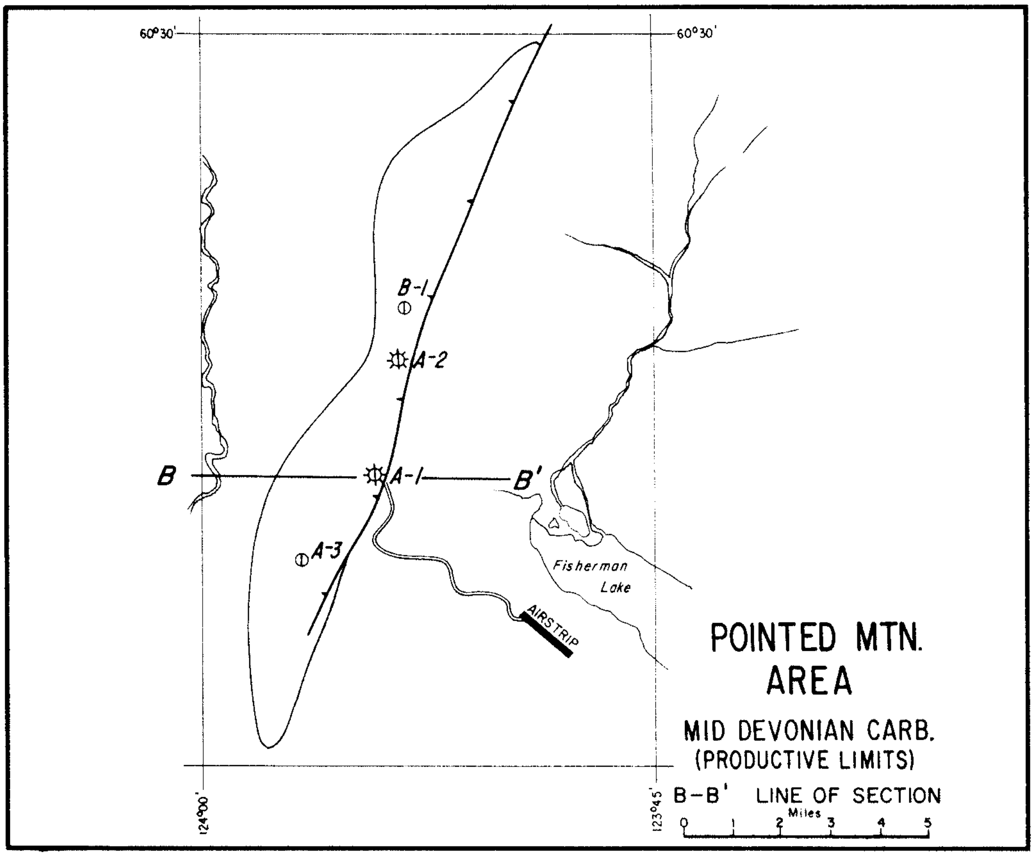


fig. 6.

A third structure which was proven to be productive was drilled, and completed, with a shut-in gas well in 1964 by a group headed by Canada Southern, Dome, and Pan American. The Canada Southern et al North Beaver River well is a marginal gas well from the Middle Devonian carbonate. Since the Liard "Fold Belt" has recently received considerable attention as a large potential gas sales area, it is expected that follow-up exploration to the North Beaver gas discovery will take place in the near future.

In January, 1967, Pan American announced the signing of a gas sales contract with Westcoast Transmission Co. Ltd. The gas contract was for 1.5 trillion cubic feet of gas, with daily rates which could reach 205 Mmcf/d.

Sale of gas for this area is slated to commence late 1971, which means by that date Westcoast will have to complete 110 miles of pipeline from Fort Nelson to the Beaver River Field, in order to take delivery of the unprocessed gas. The current drilling program on both Beaver River and Pointed Mountain is being conducted to insure delivery rates called for under the gas contract. Construction of the necessary field gathering lines and processing facilities are scheduled to start in early 1970 for completion coincident with gas sales in late 1971.

The many frustrations presented by exploration in the Liard area present compensations in the form of a unique challenge to geologists, geophysicists, and engineers alike, but more important than the challenge are the possibilities of large reserves of hydrocarbons. The increasing demand, compounded by the depletion of gas reserves in the United States, make gas reserves of the magnitude of those in the Liard extremely important not only to the company that finds them, but to the economy of the country as a whole. There are many more structural reservoirs with large gas and oil reserves as yet undiscovered, just waiting for the explorationist worthy of the challenge.

REFERENCES

A good deal of the information in the paper has evolved from a "paper search" of reports and memoranda in Pan American's files; it therefore is fitting that the following names be acknowledged: W.G. Ayrton, E.R. Michaelis, N.G. Koch, J.P.A. Noble, S.A. Antoniuk.

DOUGLAS, R.J.W., NORRIS, D.K. 1969 Fort Liard and LaBiche Map-Areas, Northwest Territories and Yukon; Geol. Survey, Canada, paper 59-6.

KINDLE, E.D. 1944 Geological Reconnaissance along the Fort Nelson, Liard & Beaver Rivers, Northeastern British Columbia and Southwestern Yukon; Geol. Survey, Canada, paper 44-16.

HAGE, C.O. 1945 Geological Reconnaissance along Lower Liard River, Yukon Territory and British Columbia; Geol. Survey, Canada, paper 45-22.

BAMBER, TAYLOR & PROCTOR 1968 reported on the Carboniferous and Permian stratigraphy of Northeastern British Columbia; Geol. Survey, Canada, paper 68-15.

PATTON, W.J.H. 1958 Mississippian succession in the South Nahanni River Area, Northwest Territories; in Jurassic and Carboniferous of Western Canada, Allan Memorial Volume, Am. Assoc. Petrol. Geol. PP 309-326.

AN OCCURRENCE OF CHALCOPYRITE, LIARD RIVER, N.W.T.

by *Murray A. Roed

ABSTRACT

Chalcopyrite, pyrite and quartz mineralization carrying minor amounts of chromium, nickel and silver has been discovered in a fracture zone located 20 miles east of the Mackenzie Mountains along the Liard River in the Northwest Territories. The fracture zone is in miogeosynclinal shale and siltstone of the Simpson Formation of Upper Devonian age. A number of dikes, possibly igneous in origin, are associated with the fracture zone at the locality. The occurrence of chalcopyrite in this particular geologic setting is new for western Canada. This discovery has served to focus attention on the possibility of economic accumulations of base metals on an as yet unproductive part of the western Canadian Sedimentary Basin.

INTRODUCTION

Chalcopyrite has never been recorded in the western Canadian Sedimentary Basin east of the front ranges of the Cordillera. During the summer of 1967 the author was given the opportunity to examine a reported occurrence of chalcopyrite exposed in a fracture zone in shale associated with carbonate-rich dikes. The outcrop was examined during a period of low water on the Liard River. This report is a summary of subsequent geologic studies on the samples collected from the surface and those recovered from a diamond drill hole at the site.

LOCATION AND PHYSIOGRAPHY

The chalcopyrite deposit is on the southeastern side of the Liard River (Figure 1) approximately 30 miles downstream from Nahanni Butte in the Interior Plains physiographic division (Bostock, 1948). It is situated 20 miles east of the Nahanni Range of the Mackenzie Mountains, 80 miles southwest of Fort Simpson, Northwest Territories and 150 miles north of Fort Nelson, British Columbia.

The topography of the general area is one of low relief characterized by outwash, alluvial terraces and patches of muskeg. The rocks at the locality are a resistant mass which forms conspicuous rapids at high water and extends nearly 1,000 feet into the Liard River from the southeastern shore. The elevation of the locality is approximately 500 feet above sea level.

PREVIOUS WORK

The area has been mapped by Hage (1945) and Douglas and Norris (1960). Several regional studies have made reference to the area (Sikabonyi,

*M.A. Roed Geological Explorations Ltd., Edmonton, Alberta

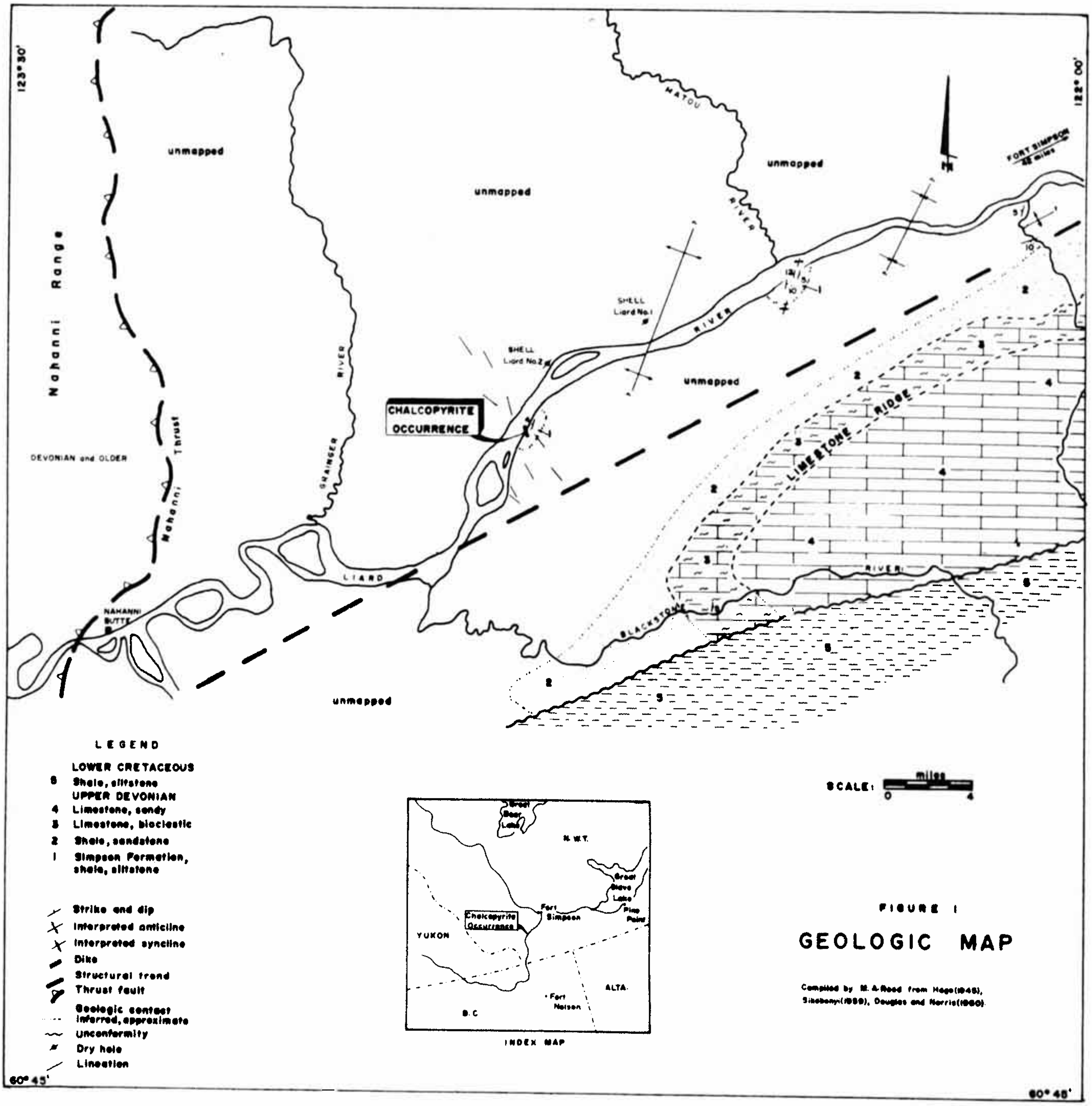


FIGURE 1

GEOLOGIC MAP

Compiled by M. A. Reed from Hage (1945), Sikabonyi (1959), Douglas and Norris (1960).

1959; Baadsgaard *et al.*, 1961; Harker, 1963; Burwash, 1965; Craig, 1965) and considerable exploration has been carried out by oil companies. Aerial magnetometer surveys have been run over the area by Imperial Oil Ltd. and Socony-Vacuum (Imperial Oil Ltd., 1954 and Reford, 1954). Two dry holes, Shell Liard Nos. 1 and 2, have been drilled near the locality (Figure 1). Hage (1954, p.31) discovered the silicified zone and reported only a trace of gold from one assay; presumably no other metals were analyzed.

REGIONAL GEOLOGY

Stratigraphy

The locality is in an area of gently folded miogeosynclinal shales and siltstones belonging to the Simpson Formation of Upper Devonian age (Douglas and Norris, 1960). Ordinarily the entire Lower Paleozoic section of carbonates and shales would be expected in the subsurface near the locality, however, this is not the case. In Shell Liard No. 2 (Figure 1) only 1,885 ft. of the Lower Paleozoic section was encountered before reaching basement rocks of Proterozoic age. The Lower Paleozoic rocks are, in descending sequence, the Nahanni, Headless, Mattson and Arnica Formations, some chert and unspecified rocks above the basement (Department of Northern Affairs and Natural Resources, 1964). Shell Liard No. 1 bottomed in the Nahanni Formation (Middle Devonian age) at a depth of around 400 ft.

The Proterozoic rocks encountered in Shell Liard No. 2 have been dated by the K/A method from a biotite separate giving an age of 1,100 m.y. (G.S.C. 60-35, Lowden, 1961, p.2). Baadsgaard *et al.* (1961) obtained a K/A date of 600 m.y. ± 300 on the same rocks.

Structure

The regional structure in the Paleozoic rocks along the Liard River near the copper occurrence is an homocline forming the northwest flank of a broad shallow basin. Information from published reports plus photogeologic information has been compiled in Figure 1 and a general structural interpretation is presented. Along the Liard River a series of open anticlines and synclines trend in a north-easterly to east-northeasterly direction, discordant to the northwesterly to northerly trend of the Nahanni Range of the Mackenzie Mountains. Numerous northwest trending and a few northeast trending lineations can be identified on aerial photographs near the locality (Figure 1) and may represent either fractures or faults within the bedrock.

Faults in the area are of two distinct classes: (1) those which have affected the Paleozoic rocks, and (2) structural trends which may be faults within the basement Precambrian rocks. The Nahanni thrust fault defines the eastern structural boundary of the Mackenzie Mountains 20 miles to the west. Other faults affecting Paleozoic rocks have not been identified in the vicinity of the locality, however, the sudden termination of the limestone ridge of Upper Devonian age (Figure 1) may be the result of a northerly trending fault. The Liard River basement structural trend (Figure 1) has been mentioned by several authors including Sikabonyi (1959), Douglas and Norris (1960), Lowden (1961) and Burwash (1965). It is presumably developed within the basement rocks, but this can not be substantiated from total intensity aeromagnetic maps (Imperial Oil Ltd., 1954, and Reford, 1954). Sikabonyi (1959, Figure 4), however, shows the pre-Middle Devonian Liard River structural trend to have a strike length of 150 miles. The trend marks the northern boundary of the Liard High as shown by Douglas et al. (1963, Figures 4 and 23).

A fracture zone at the subject locality forms an important structure which carries the sulphides and quartz described in this report. Minor contortions in the shale occur in association with the fracture zone.

Mineralization

Mineralization reported in the general area includes silificed Silurian rocks at the base of Nahanni Butte carrying small amounts of chalcopyrite, chalcocite, pyrite and galena (Hage, 1945, p.31). Hage also mentioned the silicified zone at the locality of the present report. Douglas and Norris (1960, p.26) observed azurite and malachite in a gangue of fine grained quartz and dolomite in a 70 foot-wide zone of vertical fracturing at the south end of the Nahanni Range. Minor amounts of bornite and chalcopyrite occur at a depth of 1,300 to 1,320 feet in cuttings from Shell Liard No. 2. Also, cuttings from other intervals of this drill hole contain an unusual amount of pyrite and numerous authigenic quartz crystals.

GEOLOGY OF THE CHALCOPYRITE OCCURRENCE

General Remarks

The general geology of the locality is shown in Figure 1. The main surface structure is a resistant northwesterly trending, steeply dipping fracture zone associated with intensely carbonatized dikes with the same general attitude as the fracture zone. The country rocks are gently dipping fissile shales and siltstones of the Simpson Formation of Upper Devonian age (Douglas and Norris, 1960). Locally, however, adjacent to and within the fracture zone, the shales and siltstones are slightly contorted and have been silicified.

Surface Mineralization

The mineralization occurs in a silicified fracture zone. The fracture zone, which is approximately 900 feet long and up to 80 feet wide, contains pods of quartz breccia and discontinuous dikes which range from several inches to two feet thick. Nine well-defined breccia pods containing sulphide minerals have been mapped. They are composed of angular fragments of silicified shale enclosed in a matrix of quartz. Most of the pods appear to be steeply-dipping and trend N23°W. The most continuous band of breccia is 220 feet long and 3 to 5 feet wide. A series of chip samples from the surface of this zone result in a weighted average value of 2.24 percent copper over a width of 3.5 feet. The other breccia bands sampled are about 80 feet long and 3 to 5 feet wide and contain similar amounts of copper.

Chalcopyrite and pyrite occur as blebs between crystals of quartz, as veins and in scattered pods and stringers throughout the breccia pods. Pyrite and minor amounts of chalcopyrite are also found in the silicified shale and siltstone in veins parallel to bedding and disseminated throughout the outcrop within one or two feet of the mineralized breccia bands. Numerous discoidal concretions rich in disseminated pyrite occur in the shale. Most commonly chalcopyrite has partly filled vugs between quartz crystals, but some quartz veins cut chalcopyrite masses; a small amount of calcite has replaced quartz in some places. A little black hydrocarbon occurs as a coating on quartz crystals and as amorphous masses in some vugs.

A spectographic analysis performed on a selected sample of "high-grade" mineralization revealed small amounts (0.01 to 0.1 percent) of nickel, chromium and vanadium, and one assay indicated up to 0.2 ounces of silver per ton. The nickel, chromium and vanadium indicate that the copper and silica mineralization was likely derived from mineral-bearing solutions of an igneous source.

Subsurface Mineralization

Core recovered from one of the diamond drill holes at the locality revealed some thin intervals which contain euhedral barite, chalcopyrite and galena crystals within what appears to be quartz veins and breccia. Some specks of sphalerite were also collected from a siltstone and quartz interval. Samples of these sulphides and samples collected from the outrop were analyzed for sulphur isotope ratios.

Sulphur Isotopes

The sulphur isotope analyses on certain representative sulphide samples were carried out by Dr. A. Sasaki, Physics Department, University of Alberta. A general account of the results is given in Table 1.

In general a clustering of δS^{34} values near the meteoritic standard of 0.0 is assumed by Jensen (1967) and others to favor a magmatic source (White, 1968, p.305). The values obtained in this study for the chalcopyrite, galena and sphalerite are not inconsistent with a magmatic origin, but conclusive evidence of a magmatic source is lacking. It may be that if the sulphide-bearing solutions were magmatic in origin some dilution by sulphate solutions from underlying

Table 1 — Sulphur Isotopes

Sample	Description	S^{34}	Remarks
LRD-1	Chalcopyrite in quarts breccia	+10.2	Sample from surface quartz breccia pod
LRD-2	Galena from quartz vein at depth of 159'	+ 7.6	Diamond drill core
LRD-3	Sphalerite from siltstone with quartz veins at depth between 212' to 220'	+ 6.7	Diamond drill core
LRD-4	Euhedral barite in vug of quartz breccia	+43.2	Same sample as LRD-2
LRD-5	Pyrite in nodule	+24.0	Nodule collected from along bedding plane in siltstone of Simpson Formation in indurated zone of locality

carbonate and/or evaporite rocks has occurred. The S^{34} value for the pyrite is more in agreement with sulphur isotope values of the Pine Point area (Evans, et al, 1968), whereas, the high value for the barite remains difficult to explain.

Dike Rocks

The main part of the mineralized zone sampled occurs on the east side of a dike. A dike at this locality was first noticed by Hage (1954, p.31) who described a silicified zone 56 feet wide on the west side of a dike that is not presently exposed. During the present work a number of dikes have been outlined. The dikes are discordant (Strike North 18° West, dip 84° West) with the enclosing shales which have a general strike northeast, dip 4 to 8° West, but the attitude of the shale varies at the locality because of the contortions. The shale adjacent to the dikes is indurated but it is not clear whether this is related directly to the dikes or to silicification associated with fracturing. In thin-section typical igneous crystalline texture is almost entirely lacking in the dike rocks. Chilled contacts were not detected, but minor apophyses of the dike material extend into the shale.

The main component of one of those dikes which were studied in detail appears to be finely crystalline siliceous dolomite (result of x-ray diffraction analysis) with scattered pellet-like structures and minor inclusions of angular black siltstone and shale fragments; pods of a light green carbonatized (?) mineral are common. Altered feldspar crystals are rare. Under a high-power petrographic microscope the pellet-like structures appear highly shattered which suggests a cataclysmic origin. An x-ray fluorescense for strontium was run on one sample in order to determine whether or not the rock was carbonatite (carbonatites average 0.4 percent strontium), but the rock showed only a trace of strontium, more typical of sedimentary rocks. Disseminated pyrite is abundant in some samples of the dikes.

CONCLUSIONS

Recognition of chalcopyrite and associated mineralization which occurs on the Liard River, has served to focus attention on the possibility of economic accumulations of base metals in this part of the western Canadian Sedimentary Basin. The presence of a major northeasterly trending basement structural trend, the occurrence of a Precambrian basement high, and the presence of heavy metals in the samples suggests an igneous source for the mineralization. The results of the sulphur isotope analysis of the chalcopyrite, galena and sphalerite, although inconclusive, are not incompatible with a magmatic origin of these sulphides.

On the basis of the microscopic shattered structure it is concluded that the dikes have been intruded from below with cataclysmic force. They have probably been metasomatized as a result of entry into a chemical environment dominated by carbonate minerals of the Lower Paleozoic rocks in the sub-surface. The indurated country rocks are not inconsistant with a magmatic source but conclusive evidence of an igneous origin for the dikes is lacking.

The existance of dikes in this part of the sedimentary basin may have to be considered in the interpretation of geophysical data.

ACKNOWLEDGEMENTS

Permission to publish this account has been kindly granted by Mr. G. Bory of Ramada Mines Ltd. and Mount Hyland Mines Ltd., whose cooperation and financial aid is here gratefully acknowledged. Suggestions and advise were generously given by colleagues at the University of Alberta, by Dr. B. Mellon and Dr. M. Carrigy of the Research Council of Alberta and by J.Y. Smith. Thanks are extended to Dr. R.E. Folinsbee of the Department of Geology, University of Alberta, who read parts of the manuscript and offered advise during preparation. Dr. A. Sasaki supplied all of the isotope data and Mr. Stewart Jackson offered valuable suggestions during the course of this study. However, it is emphasized that the ideas and conclusions presented are the sole responsibility of the author.

REFERENCES

BAADSGAARD, H., CAMPBELL, F.A., CUMMINGS, G.L., EVANS, T., KANASEWICH, E., KROUSE, R.H. ROBERTSON, D.K.	1965	Isotopic data from the Cordillera and Liard Basin in relation to the genesis of the Pine Point lead-zinc deposits: unpublished, Department of Geology, University of Alberta, Edmonton.
BAADSGAARD, H., FOLINSBEE, R.E., LIPSON, J.	1961	Caledonian or Acadian granites of the northern Yukon Territory: Geology of the Arctic, p. 458-465.
BOSTOCK, H.S.	1948	Physiography of the Canadian Cordillera, with special reference to the area north of the fifty-fifth parallel: Geol. Survey Canada, Mem. 247.
BURWASH, R.A.	1965	Basement architecture of Western Canada: Alberta Soc. Petrol. Geol., 15th Annual Field Conference Guidebook, Part 1, Cypress Hills Plateau, p. 280-288.
CRAIG, B.G.	1965	Glacial Lake McConnell and the surficial geology of parts of Slave River and Redstone River map-areas, District of Mackenzie: Geol. Survey Canada, Bull. 122.
DEPARTMENT OF NORTHERN AFFAIRS AND NATIONAL RESOURCES	1964	Northwest Territories, Yukon Territory and Canada Lands not within the Province, Schedule of Wells 1920-1963, Schedule No. 3: Queen's Printer, Ottawa.
EVANS, T.L., CAMPBELL, F.A. KRAUSE, H.R.	1968	A reconnaissance study of some western Canadian lead-zinc deposits: Econ. Geol., V.63, No. 4, p. 349-359.
DOUGLAS, R.J.W., NORRIS, D.K.	1960	Virginia Falls and Sibbeston Lake map-areas, Northwest Territories: Geol. Survey Canada, Paper 60-19.
DOUGLAS, R.J.W. NORRIS, D.K. THORSTEINSSON, R. TOZER, E.T.	1963	Geology and petroleum potentialities of Northern Canada: Geol. Survey Canada, Paper 63-31.
HAGE, P.	1945	Geological reconnaissance along the lower Liard River, Northwest Territories, Yukon, and British Columbia: Geol. Survey Canada, Paper 45-22.

HARKER, P. 1963 Carboniferous and Permian rocks, southwestern District of Mackenzie: Geol. Survey Canada, Bull. 95.

JENSEN, M.L. 1967 Sulphur isotopes and mineral genesis, P. 143-165 in Barnes, H.L., Editor, Geochemistry of Hydrothermal Mineral Deposits: New York, Holt, Rinehart, and Winston, Inc., p. 670.

IMPERIAL OIL LTD. 1954 Airborne magnetometer survey, Mackenzie River Area: Unpublished, Department of Northern Affairs, Calgary.

LOWDEN, J.A. 1961 Age determinations by the Geological Survey of Canada, Report 2-Isotopic Ages: Geol. Survey Canada, Paper 61-17.

REFORD, M.S. 1954 Report on airborne magnetometer survey carried out by Canadian Aero Service Limited, Liard-Fort Simpson area, for Socony Vacuum: Unpublished, Department of Northern Affairs, Calgary.

SIKABONYI, L.A. 1959 Paleozoic tectonics and sedimentation in the northern half of the West Canadian Basin: Journal of Alberta Society of Petrol. Geol. Vol. 7, No. 9, p.

WHITE, DONALD E. 1968 Environments of generation of some base-metal ore deposits: Econ. Geol., V.63, No. 4, p. 301-335.

LEAD-ZINC DEPOSITS OF THE PINE POINT AREA, NORTHWEST TERRITORIES, CANADA

by S.A. Jackson, Dept. of Geology,

University of Alberta, Edmonton

Participants on this field excursion will have the opportunity to examine a mining district which has developed recently into one of the richest lead-zinc producing areas of the world. Since production began late in 1964 sales of ores and concentrates up to the end of 1968 generated income of $131 million with net profits of about $112 million. Shipments of high grade ore totalling approximately 1.4 million tons which graded in excess of 47% combined lead-zinc have generated nearly half of the sales income to date. Shipments of high grade ore were discontinued in late 1968 when rated mill capacity was expanded from 5000 tons/day to 8000 tons/day. At the end of 1968 published reserves were 39.3 million tons averaging 2.6% lead and 6.8% zinc. This figure represents a total from over 30 separate orebodies. A summary of the history of development of the Pine Point ores is given in a paper by Campbell (1966).

The ores are located mainly within the Middle Devonian Pine Point and Presqu'ile dolomites which are underlain by evaporites and overlain by limestones (Table 1). These dolomites developed as parts of a barrier carbonate complex that stretched from the Precambrian Shield southwesterly across the Pine Point area to immediately north of and beyond the Rainbow and Zama Lake areas of northwestern Alberta (McCamis and Griffith, 1967; Bassett and Stout, 1967). This barrier carbonate complex separated the Mackenzie shale basin to the north from the Elk Point evaporite basin to the south.

The Pine Point Formation developed within a fore-reef shale, reef carbonate complex, and back-reef evaporite configuration (Figure 2). The Presqu'ile Formation developed in a more shallow water environment with patchy, erratic reef development along the northern margin of a zone of shallow lagoons, supratidal mudflats, sebkhas, and salinas. More open-marine conditions prevailed during deposition of the Sulphur Point Formation but periodic exposure and brackish water conditions prevailed during deposition of the Watt Mountain shale. A period of exposure followed, then the shallow water to evaporitic deposits of the Fort Vermilion Formation, including the Amco marker bed, covered the area. Following this, the area was blanketed by the limestones of the Slave Point Formation.

The Presqu'ile and Pine Point sediments were dolomitized during sedimentation by refluxing of magnesium-rich brines; the Presqu'ile was later recrystallized by warm brines to a coarsely crystalline dolomite with abundant white and grey vug-lining sparry dolomite.

The orebodies occur as a series of isolated elongate lens-shaped bodies ranging from 100,000 tons to several million tons in size. Mineralogy is relatively simple. Sphalerite, both crystalline and colloform, and galena are the only ore minerals. Marcasite and pyrite are abundant and pyrrhotite and fluorite occur occasionally. Native sulphur and bitumen are

Table 1: Summary of Middle Devonian stratigraphy, Pine Point area, N.W.T., (modified after Norris, 1965, and Rice, 1967).

	Formation	Approximate thickness (feet)	Lithology
MIDDLE DEVONIAN	Slave Point	170	Brown stromatoporoid-limestone and laminated limestone
	Fort Vermilion (includes Amco marker bed)	75	Laminated limestone, dolomite and anhydrite
	Sulphur Point (includes Watt Mountain shale)	up to 170	Pelleted and bioclastic limestone, green shale lenses near top (Watt Mountain)
	Presqu'ile	up to 200	Coarsely crystalline dolomite
	Pine Point	300	Brown medium crystalline dolomite; bituminous argillaceous fine-grained limestone; dark green shale
	Chinchaga	300	Very finely crystalline dolomite interlaminated with anhydrite
	Cold Lake Equivalent	34-51	Brecciated anhydrite, and red dolomitic mudstone
	Fitzgerald	40	Brownish grey, crypto-crystalline dolomite
CAMBRIAN? & ORDOVICIAN	Mirage Point	100-131	Dolomitic, evaporitic red beds. Shale and breccia
	Old Fort Island	0-108	Basal sandstone
	Precambrian Basement		Granites and Metamorphics

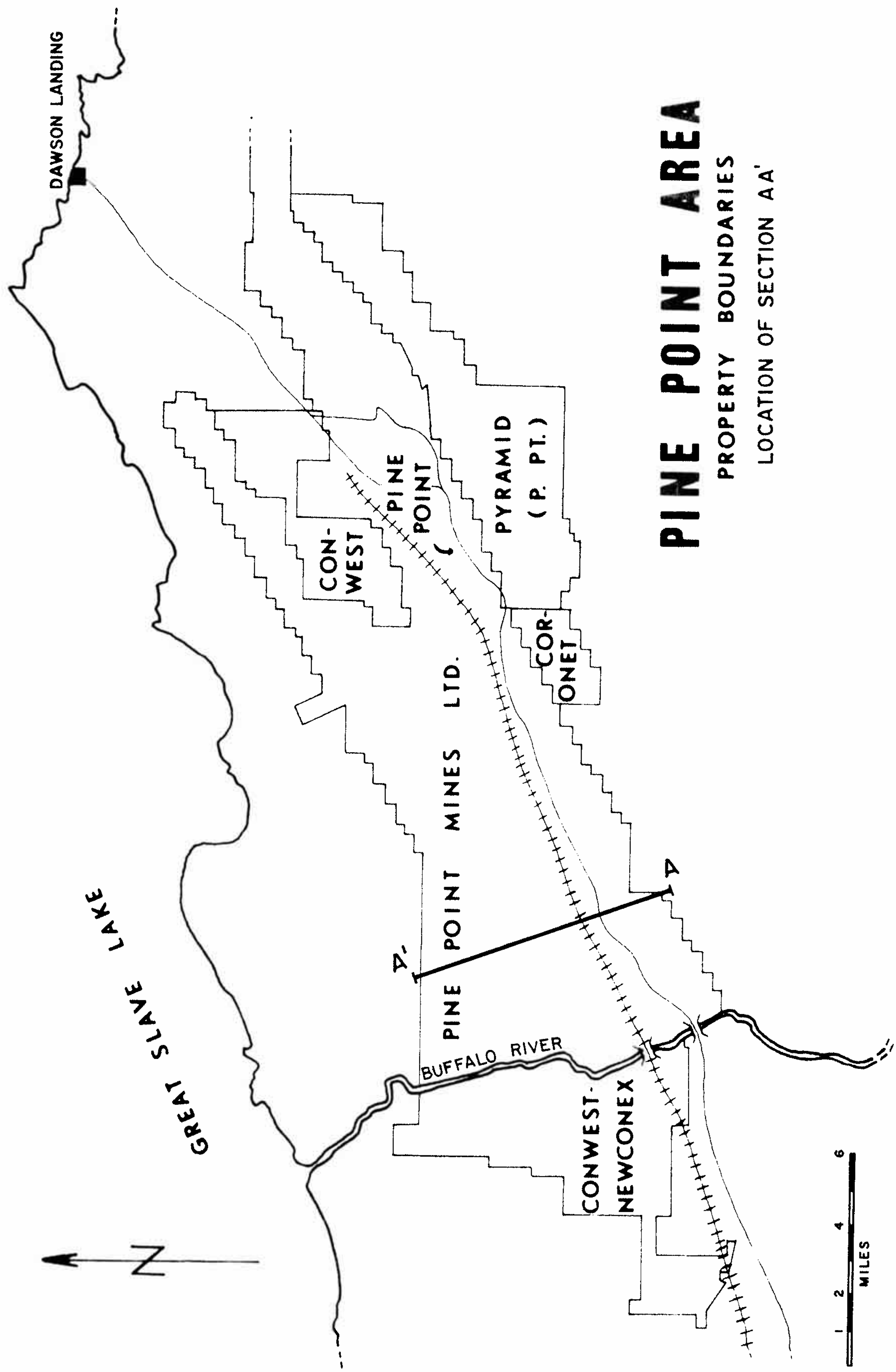

PINE POINT AREA
PROPERTY BOUNDARIES
LOCATION OF SECTION AA'
DAWSON LANDING
GREAT SLAVE LAKE
PYRAMID
(P. PT.)
PINE POINT
CON-WEST
COR-ONET
PINE POINT MINES LTD.
A
A'
BUFFALO RIVER
CONWEST-NEWCONEX
N
1 2 4 6
MILES

Fig. 1

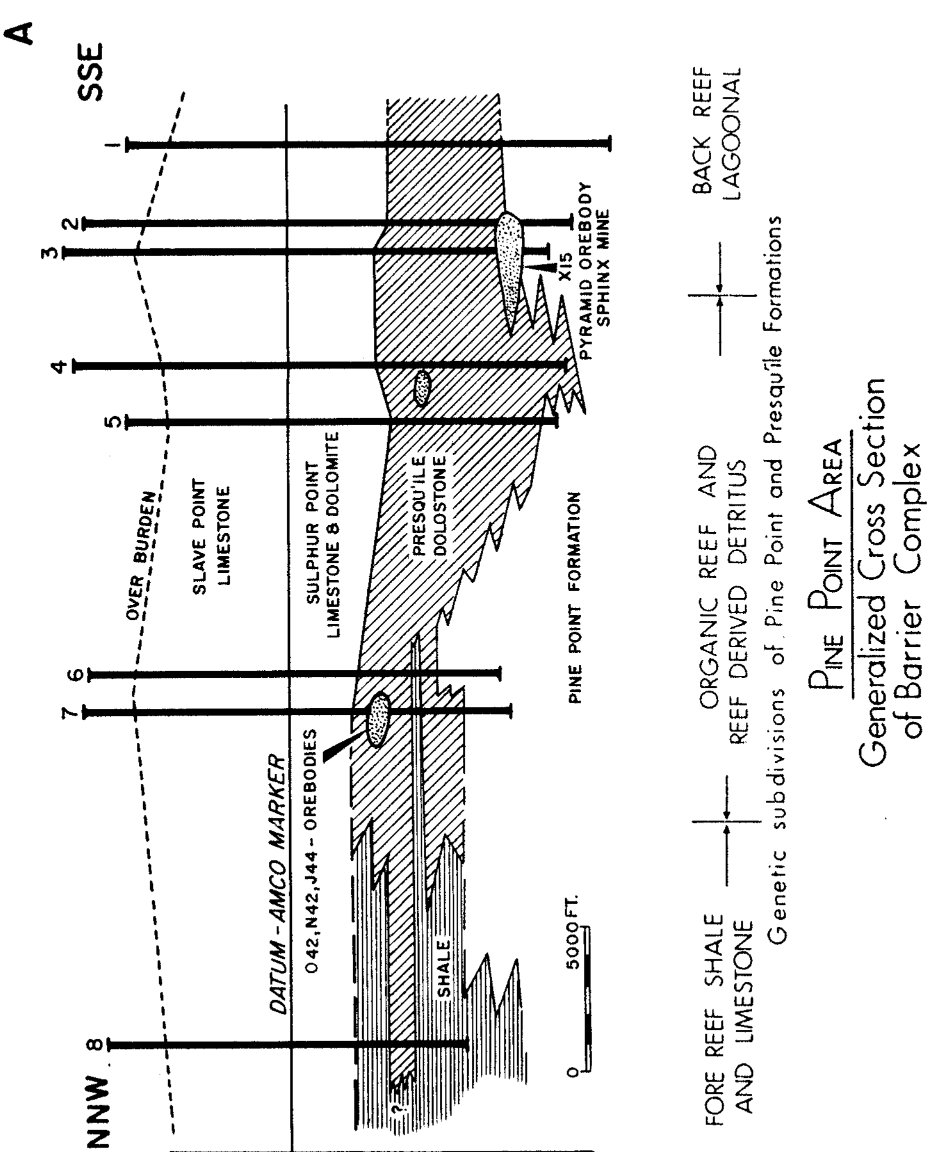

A'
NNW
A
SSE
1
2
3
4
5
6
7
8
100'
50'
0
50'
100'
150'
200'
250'
OVER BURDEN
SLAVE POINT LIMESTONE
SULPHUR POINT LIMESTONE & DOLOMITE
PRESQU'ILE DOLOSTONE
PINE POINT FORMATION
DATUM - AMCO MARKER
O42, N42, J44 - OREBODIES
SHALE
X15
PYRAMID OREBODY SPHINX MINE
0
5000 FT.
FORE REEF SHALE AND LIMESTONE
ORGANIC REEF AND REEF DERIVED DETRITUS
BACK REEF LAGOONAL
Genetic subdivisions of Pine Point and Presqu'ile Formations
PINE POINT AREA
Generalized Cross Section of Barrier Complex

FIG. 2

found in vugs and pores in the wall rock near the orebodies, but are more common away from the immediate vicinity of ore zones.

The orebodies appear to be localized by a combination of fault zones, porosity, and breccia zones. Evaporite solution appears to have played an important role in porosity development. Sharp margins on the orebodies can be explained by a model involving a sharp interface between two fluids, one bearing metals while the other carried sulphur, with ore precipitating only where they mix (Jackson and Beales, 1967; Beales and Jackson, 1968).

Sulphur in the ore sulphides has an average del S^{34} value of +18 compared with +16 to +17 for Elk Point anhydrites, +14 to +21 for native sulphur, and -15 to +10 for sulphur in syngenetic pyrite in the host dolomite (Sasaki and Krouse, 1969). The sparry white "vein" dolomite probably formed by dissolution and precipitation of the early diagenetic dolomite since both carbon and oxygen isotopes are similar for both types of dolomite (Fritz, 1969).

Open pits display the bedded nature of the Presqu'ile and Pine Point dolomites. The interbedding of both the Sulphur Point limestone and the Watt Mountain shale with the Presqu'ile dolomite can be seen in some pit ramps (N42 and 042 pits).

REFERENCES

BASSETT, H.G. STOUT, J.G.	1967	Devonian of Western Canada, in International Symposium on the Devonian System, Vol. 1, Alta. Soc. Petroleum Geologists, Calgary, p. 717-752
BEALES, F.W. JACKSON, S.A.	1968	Pine Point - A stratigraphical approach: Can. Inst. Min. Met., V. 61, No. 675, p. 867-878
CAMPBELL, N.	1966	The lead-zinc deposits of Pine Point: Trans. Can. Inst. Min. Met., V. 69, No. 652, p.288-295
JACKSON, S.A. BEALES, F.W.	1967	An aspect of sedimentary basin evolution: the concentration of Mississippian Valley-type ores during late stages of sediment diagenesis: Bull. Can. Petroleum Geol., V. 15, No. 4, p. 434-468
NORRIS, A.W.	1965	Middle Devonian and older rocks, Great Slave Lake region: Geol. Surv. Canada, Mem. 322

ISOTOPE PAPERS: presently in manuscript form, to be published as a group in Economic Geology

CUMMING, G.L. ROBERTSON, D.K.	1969	Isotopic composition of lead from the Pine Point deposit
FRITZ, P.	1969	The oxygen and carbon isotopic composition of carbonates from the Pine Point lead-zinc deposits
JACKSON, S.A. FOLINSBEE, R.E.	1969	The Pine Point lead-zinc deposits, N.W.T., Canada. Introduction and paleoecology of the Presqu'ile reef
SASAKI, A. KROUSE, H.R.	1969	Sulfur isotopes and the Pine Point lead-zinc mineralization

SULPHUR ISOTOPES AND THE PINE POINT LEAD-ZINC DEPOSITS, N.W.T., CANADA

R.E. Folinsbee, R. Krouse and A. Sasaki
Departments of Geology and Physics,
University of Alberta, Edmonton

S^{34}/S^{32} ratios were determined on about 80 specimens of sulphides (galena, sphalerite, pyrite and marcasite), sulphates (gypsum and anhydrite) sulphur and pyrobitumen, in and contiguous to the major ore bodies of the Pine Point area, and from the evaporitic Elk Point basin which the ore-bearing dolomitized Presqu'ile reefs rim. Sulphur in the sulphides of the major ore bodies is consistently heavy with S^{34} enriched in the range +13 to +20%, with an average δS^{34} value of +18%. This is remarkably similar to sulphur values in the anhydrite of the Elk Point basin from which three anhydrite samples returned δS^{34} values ranging from +16 to +17%. The anhydrite highest in the section is richest in S^{34}, suggesting that the brines from which it was precipitated were changing isotopically as evaporation proceeded. Sulphur in minor syngenetic or diagenetic sedimentary sulphides away from the ore bodies appears unrelated to sulphur in the ore and returns widely scattered δS^{34} values ranging from +10 to -15%. Sulphur in pyrobitumens in and near the ore bodies is also depleted in S^{34} as compared with the sulphur in the anhydrite and ore, with δS^{34} values of +4%. Within the ore bodies contiguous sphalerite-galena pairs show the sphalerite consistently enriched in S^{34} over the galena by +2%. These data, remarkably similar to the results of Buschendorf *et al.* for Meggen, Germany, suggest that connate brines, highly enriched in S^{34}, were the source of the sulphur in the Pine Point ore deposits, and that ore deposition took place during some hydrothermal event subsequent to the formation of the Elk Point evaporite basin.

PINE POINT, N.W.T., CANADA

A LEAD-ZINC DEPOSIT FORMED FROM HYDROTHERMAL CONNATE BRINES?

R.E. Folinsbee, G.L. Cumming, P.D. Fritz,
R.H. Krouse, S.A. Jackson, A. Sasaki and R.N. Singh
Departments of Geology and Physics,
University of Alberta, Edmonton

Oxygen, carbon, sulphur and lead isotope studies on the Pine Point ore deposit yield the following data:

1. Lead isotopic composition of galenas in the ore deposit is very uniform; galena crystals formed about 275 m.y. ago, some 100 million years after the middle Devonian Presqu'ile reef, host to the ore deposit.

2. Sulphur in the sulphide ore minerals is quite uniform, highly enriched in sulphur 34 (δS^{34} + 18.7), quite different from syngenetic sulphur in sulphides away from the ore deposit (δS^{34}-16.8 to +8.5), and very similar to sulphur in the evaporitic anhydrites (δS^{34} + 17.9) and down dip connate brines (δS^{34} + 17.9).

3. Oxygen and carbon isotopes in the primary limestone, the dolomite host and from gangue calcite and dolomite intergrown with the ore minerals indicate formation of the ore at temperatures of less than 100°C, probably in the range 50-100°C.

The lead data, and absence of Devonian volcanic centres in this part of the basin, rule out a volcanic exhalative origin; the sulphur data do not support a sedimentary syngenetic origin for the sulphides, though it appears certain that the sulphur in the ore deposits came without fractionation from the same sulphur reservoir as the evaporites and connate brines. A hydrothermal origin for the ore deposits under telethermal conditions seems to be the most attractive theory of ore genesis. Source of the ore forming solution appears to have been large, homogeneous, and down dip in a more deeply buried part of the sedimentary basin.

ATHABASCA TAR SANDS

by E.E. Sanford

SUN OIL COMPANY

INTRODUCTION

In 1778 Peter Pond, an American fur trader, for the Northwest Company, reached the junction of the Athabasca and Clearwater Rivers, where the town of Fort McMurray now stands. Here he found the Indians using a sticky substance which was oozing from the banks to water proof their canoes.

It was a century later before the Geological Survey of Canada instituted plans for a survey of the area. This survey revealed that the oil sands extended for 118 miles along the Athabasca River and cover an area of approximately 13,000 square miles.

The Alberta Oil and Gas Conservation Board has estimated that the oil sands contain over 700 billion barrels of oil in place.

CHARACTERISTICS OF TAR SANDS

The McMurray tar sands are a series of deltaic sand deposits impregnated with varying amounts of bitumen. The source of the sand was probably the Pre-Cambrian Shield, located one hundred miles to the northeast. The sands are highly cross-bedded with cross-bedding varying from 5° to 45° and dipping in a northwesterly direction. The general attitude of the beds is almost flat, but there is a small inclination of 7 to 8 feet per mile to the southwest.

The tar impregnation is not homogeneous, and varies in richness from zero to 18% by weight. There appears to be a direct relationship between the coarseness of the material and the bitumen impregnation. There is generally less bitumen in the finer material. This does not always hold true, however, since there are very fine grain sediments in several areas with high bitumen content. The deposit also contains numerous thin beds of clay which are barren of bitumen. Pockets of combustible gas occur in the tar sands, but these are spotty and low pressured wherever encountered in the property.

There is a noticeable increase in coarseness of the sediments and in bitumen saturation toward the base of the formation.

GEOLOGY

The McMurray tar sands are deposited on an irregular erosion surface of limestone or shale, or on clays filling hollows on the erosion surface. The sands in turn are covered by shales, glacial debris or a thin lamination or organic soil.

The tar sands consist of heterogeneous mixture of sands and silts impregnated with a heavy highly viscous bitumen. They also contain beds of clay up to 5 feet thick, lenses of siltstone, and thin to massive lenses of sandstone.

The Mine at Tar Island consists of two mining benches, which expose a maximum vertical section of 150 feet, and horizontal north-south sections of 3500 feet and 2200 feet in two benches. East-west sections at the north end of the Mine provide some three dimensional control.

The sand exposed in these benches is divisible into three groups.

1. Basal Sand - this was deposited on the limestone floor. It is coarser than the overlying sands, with grain size varying from pea-sized to coarse silt. Bitumen content is high. Clay beds are thin and discontinuous, with a dip of 5° to 8° to the north. Fragments of wood up to a few cubic inches in size are common, but occasional logs and stumps occur. Silt lenses up to 6 inches thick are present. Occasional rock "pods" of black, tough oil impregnated sandstone up to 4 x 1 1/2 x 1 feet occur.

Transition of the Basal Sand to the overlying "Lagoonal" Deposition is gradational.

2. "Lagoonal" Deposits - this type of deposits are exposed along the southeastern third of No. 1 Mining Bench. The sand here is fine-grained to silty. Clay bands vary from 1 inch to an occasional 6 inches in thickness. The bands are relatively continuous, some being traceable for 100 - 200 feet along the face. Dip of the clay beds is variable, from 5° to the north, to flat. An examination of the tar sands south of the south end of No. 1 Bench for a further 1800 feet indicates that lagoonal sediments extend at least to this point. Occasional silt bands also occur in this environment as do pods of oil-saturated sandstone.

3. Scoured Area - all major sandstones lenses have occured within this environment. The "Scour" is believed to be an old river or flood channel that cuts across the Lagoonal deposition. The original tar sands have been swept out and other tar sands and clays have been transported in and deposited in the new channel. The north dipping base of the Scour cuts off the thin lagoonal clay beds to the south, while the massive (to 60 inches thick) clay beds within the scour dip to the north at steeper angles than the "Lagoonal" clay beds.

Sedimentation within the Scour differs from that of the other 2 groups. The clay beds are thick, and can be traced for hundreds of feet.

Within the Scour are 3 types of rock lenses.

a. Siltstone - a colloquial expression used by the Mining group to describe a light brown-grey rock which is sometimes totally surrounded by tar sands. At other times clay beds are found to grade laterally into siltstone, and the contact can only be detected by careful examination. The siltstones are rarely more than 12 inches thick. Microscopic examination shows they are composed chiefly of quartz grains ranging in size from silt to fine sand cemented by limestone and siderite (from carbonate, sometimes called "bog iron"). The siltstone can grade into hard, oil-saturated sandstone.

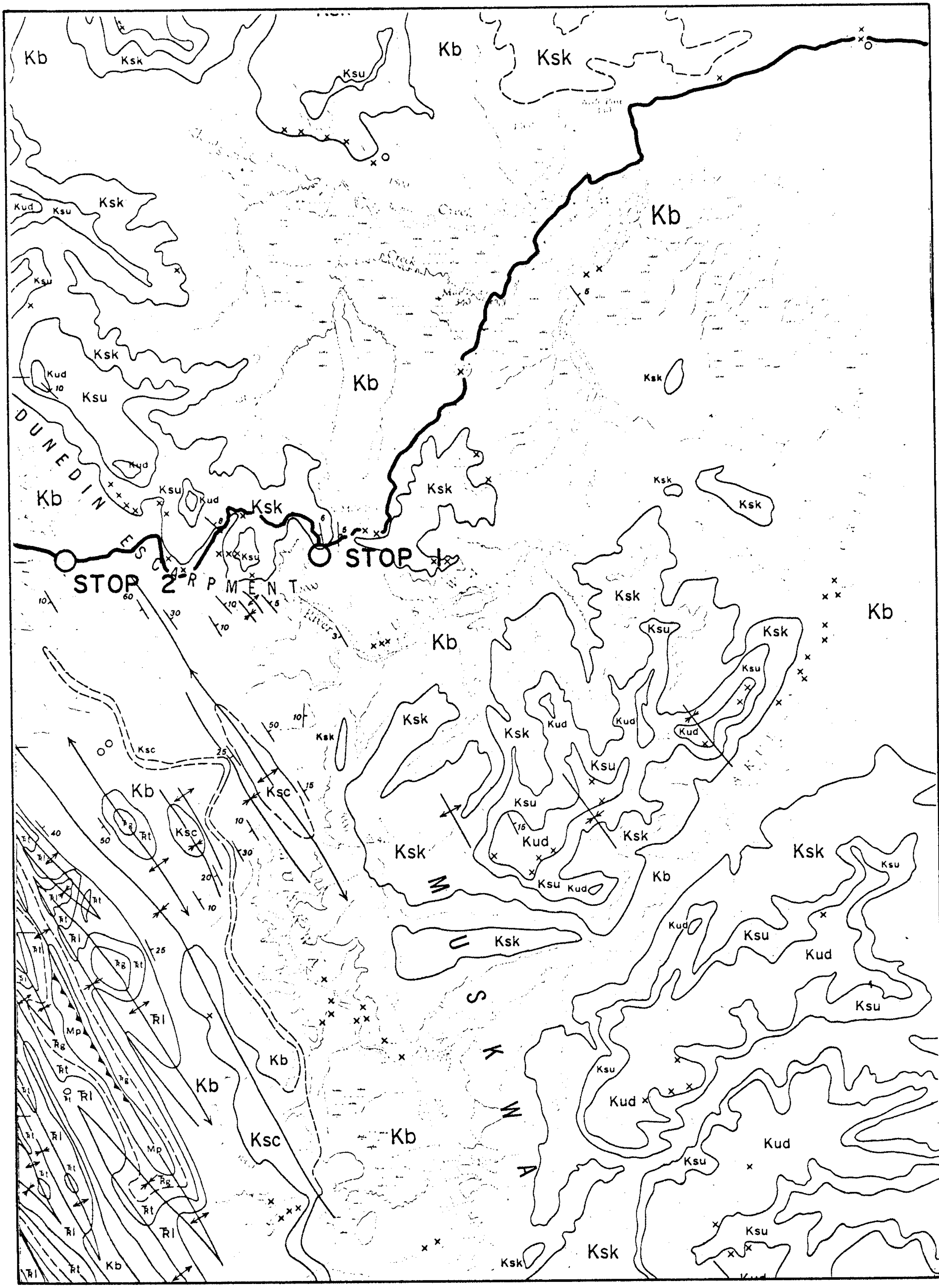
b. Sandstone - grey, thin-bedded, hard. It is composed of silt to fine sand-sized quartz grains cemented with limestone and siderite. The bedding planes are coated with carbonaceous material (plant remains).

c. Sandstone - black, massive, very hard. It is composed of silt to medium sand size quartz grains cemented by siderite and limestone. It occurs in lenses from 3 inches to 42 inches thick. It is impregnated with oil, and so is the same color as the tar sands.

Personal observation at the mining faces has established that the rock lenses are almost invariably associated with irregularities in the clay deposition. These irregularities are either minor scours within the major scour; or undulations in the clay beds in the mining face. Many irregularities did not have rock lenses, but rock lenses almost without exception, occurred in these irregularities.

I wish to thank and acknowledge the help of W.H. Tisdall and G.M. Steene of Sun Oil Company towards compiling the above information.

Road Log



Map No. 1

ROAD LOG FORT NELSON TO WATSON LAKE

by H.R. Hovdebo

CHEVRON STANDARD LTD.

Odometer zero reading from Ft. Nelson Liquor Store. Mileage on left side corresponds to mileage out of Fort Nelson, mileage on right side of page corresponds to the Alaska Highway signpost mileage. The signpost mileage intervals do not necessarily agree with the other mileage because of changes in the Alaska highway route since it was first built.

Cumulative		Signpost
00.0	Fort Nelson Liquor Store.	
00.6	- correlative mileage -	304.0
06.6	Lower Cretaceous Buckinghorse shale to right, on hillside north of highway.	
08.5	Royalite service station on north side of highway. Buckinghorse shales crop out behind buildings.	308.0
12.0	Buckinghorse shales to right in creek	-
19.6	Buckinghorse shales at right	319.0
22.0	Buckinghorse shales at right. Entering Map #1.	-
24.8	Raspberry Creek and bridge.	323.2
26.9	Buckinghorse shale outcrop.	-
35.1	Kledo River bridge.	335

This is an area of gentle folding in the Cretaceous. The Kledo well was drilled about 6 miles west of here by Phillips in 1959-60 and recovered gas at a depth of 9964 feet in dolomites

---

LEGEND TO MAP NO. 1. Scale: 1 inch = 4 miles
From: Geol. Survey of Canada. Map 3-1968, Fort Nelson, by G.C. Taylor, D.F. Stott & E.W. Bamber.

Kvd	Dunvegan	TRl	Liard
Ksu	Sully	TRt	Toad
Ksk	Sikanni	TRg	Grayling
Kb	Buckinghorse	Mp	Prophet, Fantasque and Kindle
Ksc	Scatter	o	Well Locations

equivalent to the Stone Formation in the mountains to the west. This well was drilled on a broad anticlinal area at Cretaceous level as seen by surface outcrops.

40.0 Steamboat Creek 340.2

43.1 Buckinghorse shale on both sides of the road. -

49.4 Climbing up Steamboat Mountain. To the north are mesas capped by upper Cretaceous Dunvegan (Fort Nelson) sandstones and conglomerates. The intermediate cliff former at a lower level is the Sikanni Formation, also Upper Cretaceous, composed of sandstones interbedded with shales.

50.6 Buckinghorse shales crop out along cut bank to right. 351

51.6 Both Buckinghorse and Sikanni can be seen in this area. The Sikanni has at least three sandstones developed in this area. 352

52.5 The second Sikanni sandstone can be seen here. It is in a delta fringe facies. 353

54.0 Summit of Steamboat Mountain. 354.5
STOP #1 at viewpoint on left side of highway.

The Cretaceous section here is approximately as follows:

Dunvegan (Fort Nelson) 600 feet thick, composed of three main conglomerates and underlain by a basal sandstone. Cenomanian plant fossils are present in this unit.
Sully - 300 feet of shale.
Sikanni - 800 to 900 feet of interbedded sandstone and shale. Three main sands are present here.
Buckinghorse - The underlying Lower Cretaceous shale unit.

From viewpoint, looking south, the ridge with the west facing escarpment is capped by Sikanni sands. The mesas to the extreme south and southeast are all formed by Dunvegan Formation.

Proceed on along Highway.

54.3 Looking northwest - a steep cliffed knob called Indian Head consists of Dunvegan sandstones and conglomerates.

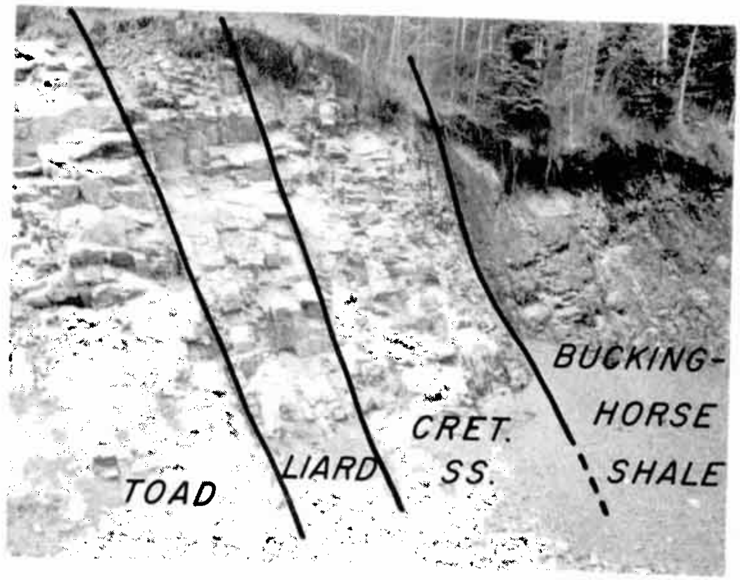


Figure 1 - Stop No. 3

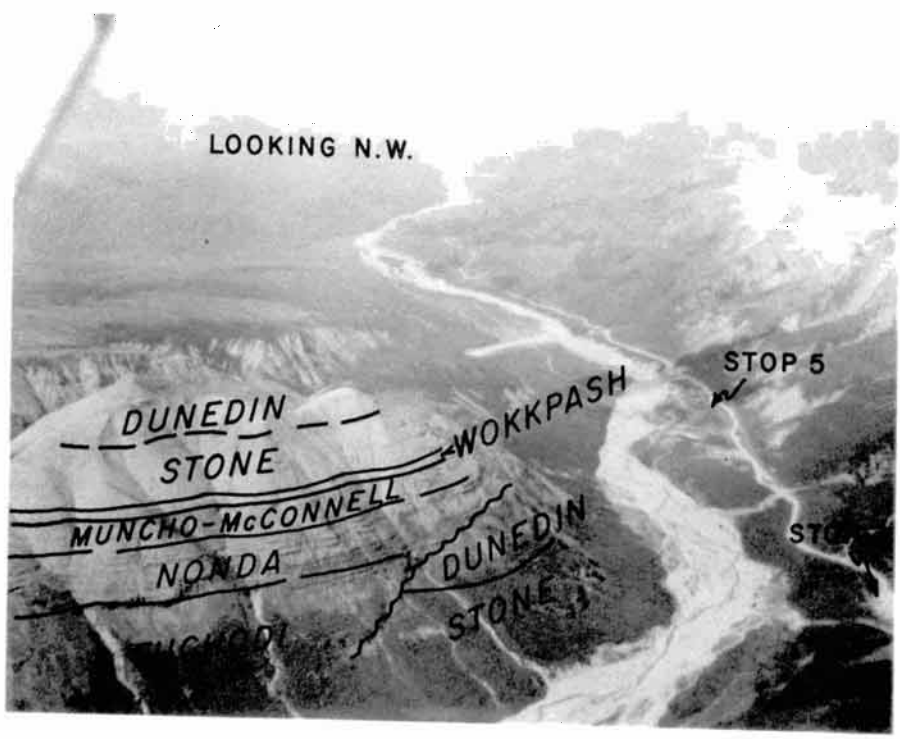


Figure 2 - Stops No. 4 and 5

55.8 Outcrop of Sikanni Formation along roadcut.

56.5 Drinking water sign at curve in highway. Sikanni at road level and Dunvegan Formation to north at top of ridge. 357

59.9 A good view of "Indian Head" profile, with Sully Formation and Sikanni Formation below.

62.3 STOP #2 Looking north is "Teetering Rock". Teetering rock is a balanced rock of Dunvegan sandstone and conglomerate in an area of slumped rock. The escarpment to the immediate right is composed of Sikanni sandstones. 364.2

Looking south, the anticline on the horizon is the Chlotapecta anticline. The smaller anticline immediately to the east of this is the Chischa (Sheep) anticline. This anticline was tested in 1955-56 by the Stanolind Sheep Creek #1, 95-D 94-J-12 NTS well, which was abandoned after bottoming in Devonian shales at a depth of 8244 feet.

In 1965 Pan American drilled a well about one mile southwest of the old location at c-86-D 94-J-12 and encountered the first Devonian carbonates at 8152 feet and drilled a normal sequence from here down to a T.D. of 10,307 feet. The surface anticlines and structures at Devonian carbonate level are disharmonic. This well is also dry and abandoned.

The valley in the foreground marks the boundary between the Plains and Rock Mountain Foothills as defined by Bostock in his outline of the physiographic subdivisions of western Canada. This valley is underlain by soft, easily eroded Buckinghorse shales.
Leaving map #1, entering map #2.

63.8 Mill Creek 363.1

74.0 Crossing east flank of first Triassic anticline.

75.1 First good exposure of Triassic at road level.

STOP #3 Figure #1

At this stop an excellent exposure of the Triassic-Cretaceous contact can be examined (see Figure 1). In this outcrop, Toad Formation dolomitic siltstones and silty dolomites are overlain by 9 1/2 feet of Liard sandstone, which in turn are unconformably overlain by 12 feet of basal sandstones and black shales of the Buckinghorse Formation.

An important locality for ammonites in the Toad Formation occurs 100 yards to the west, up the ridge above the highway traffic sign. There is good exposure through the core of this anticline. The contact discussed above is on the east limb of this anticline.

75.7 Driving through a syncline with Buckinghorse shale in the core. 376

76.1 On the right side of the highway exposure of Triassic Toad siltstones which are quite massive to blocky in appearance in this locality.

77.2 Exposure of Buckinghorse shales, lying on Liard sandstones which in turn lie on Toad dolomitic siltstones.

80.1 Up the cliff to right (north) and at road level, the Permian Fantasque chert is repeated by faulting. The beds in both cases are vertical with tops to east.

81.1 Laudon's highway section which he called 381.5 was measured here.

81.8 To the north again outcrops of Fantasque, now on the west limb of a complex, faulted anticlinorium which has the 80.1 locality on its east limb.

82.4 Area is now again underlain by Triassic.

82.8 Small exposure of Toad Formation.

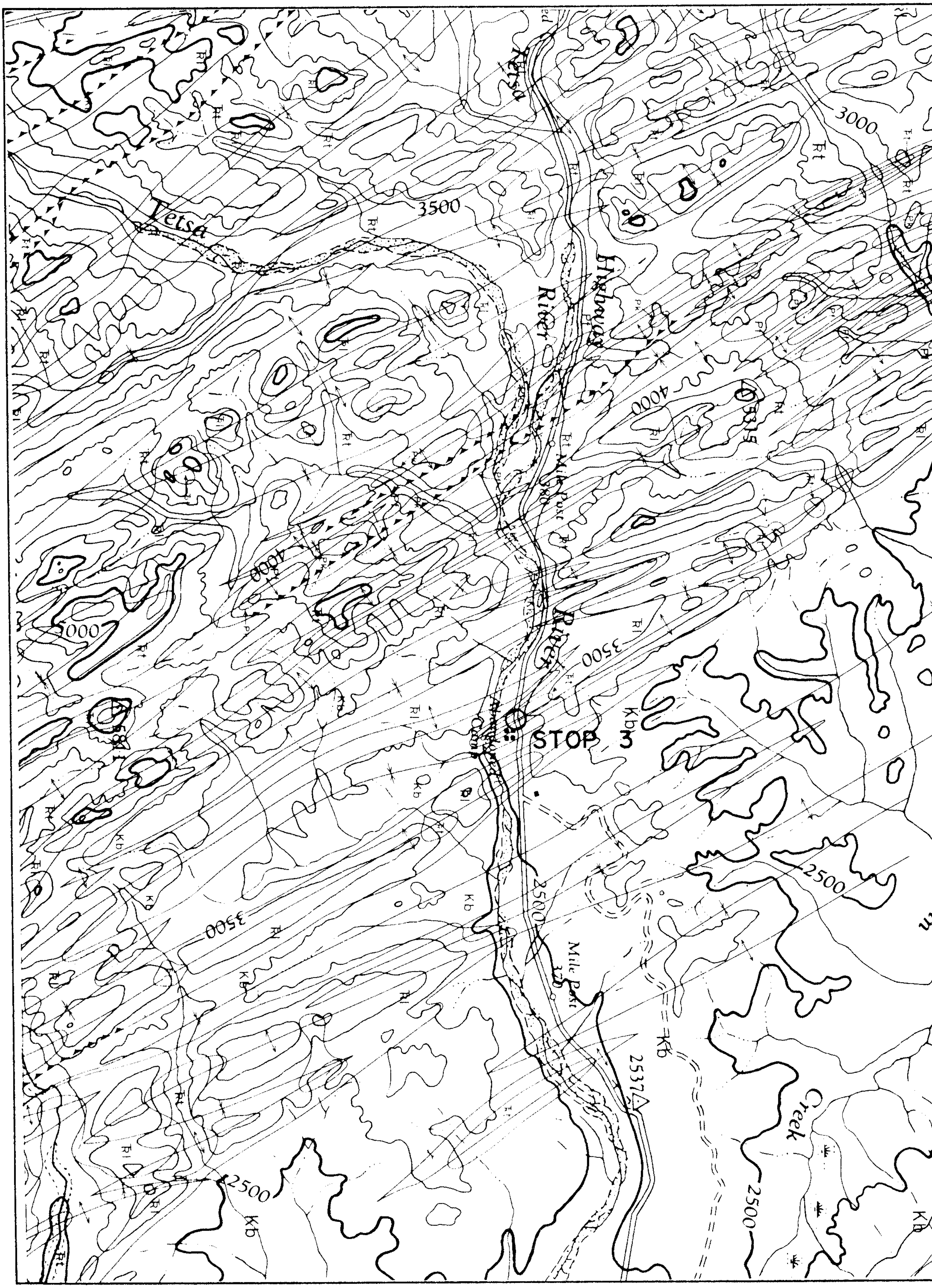
83.2 Tetsa River bridge, exposure here is all Triassic. Leaving map No. 2. 383.3

85.5 Bridge crossing on the Tetsa River for the second time. Entering map No. 3. 384.9

88.1 Exposure on the left side of highway is attributed to the Grayling Formation.

88.5 Permian Fantasque exposed here.

88.9 Permian Kindle (slightly older than Fantasque) exposed here.



Map No. 2

LEGEND TO MAP NO. 2. Scale 1: 125,000
Compiled by: G.C. Taylor, Geological Survey of Canada

Kb	Buckinghorse	Pf	Fantasque
TRl	Liard	Pk	Kindle
TRt	Toad-Grayling		

89.3 Fantasque exposure.

89.7 Crossing Prophet chert and moving into area underlain by Besa River shales. These black shales can be seen to the west.

90.4 First exposures of Dunedin limestone in canyon adjacent to highway, forming the steep east limb of an anticline, the leading edge (or east limb) of which is in fault contact with the Besa River shales.

This point marks the boundary between the Rocky Mountain Foothills and Rocky Mountains, as defined by Bostock.

90.7 Nonda (Silurian dark dolomites) faulted onto Dunedin.

91.4 Highway Maintenance Camp and Restaurant. View to north shows a fairly flat lying succession. The section here, from the mountain peak down, consists of thin bedded light grey weathering Dunedin limestone, slightly blockier, light to medium grey weathering Stone dolomite, Wokkpash yellow-orange weathering dolomitic sandstone, Muncho-McConnell light grey weathering lower Devonian dolomite, and dark grey weathering Nonda dolomite.

92.9 Basal quartzites of the Nonda present at road level here. From this point on we are moving up section again.

94.5 Entering canyon of 195 Creek. Stone Formation dolomites present on both sides of highway. 395.2

95.3 <u>STOP #4</u> at this point. The Stone Formation in cliff at roadside is brecciated and shows a slight similarity to the Bear Rock breccia, its time equivalent in the North West Territories.

Looking due west, across the valley, from top to bottom the succession is: Dunedin, Stone, Wokkpash, Muncho McConnell, Nonda, thrust fault, Dunedin, Stone at base of mountain. (See figure 2).


STOP 5
STOP 4
Rhododendron
MacDonald
One Eighteen
One Thirteen
One Ten
Mile Post 400
Mile Post 390
Summit Lake
Summit Pass
Summit Lake
Alaska
North
Abandoned Camp
Abandoned Camp
Maintenance Camp
STONE MTN
ST PAUL
ST GEORGE
5000
5000
5000
5000
4500
4500
4500
3500
3500
6000
5500
3000

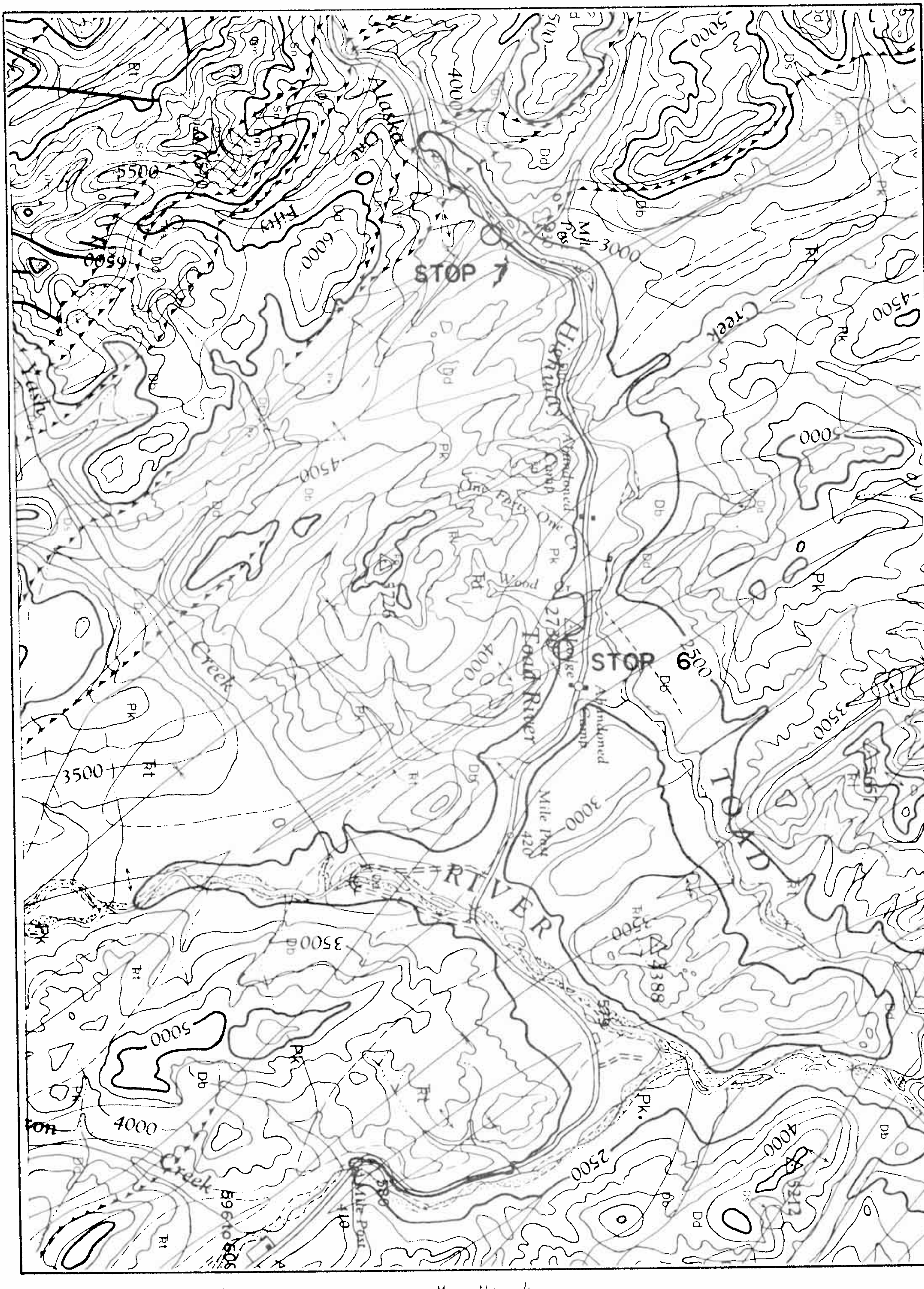
Map No. 3

LEGEND TO MAP NO. 3. Scale 1: 125,000
Compiled by: G.C. Taylor, Geological Survey of Canada

TRt	Toad-Grayling	Ds	Stone
Pf	Fantasque	Dw	Wokkpash
Pk	Kindle	Dm	Muncho-McConnell
Mp	Prophet	Sn	Nonda
Db	Besa River	P	Helikian Series
Dd	Dunedin		

Looking southwest, the Nonda directly overlies red weathering Proterozoic rocks.

96.6	Gulf gas station	397
98.4	STOP #5 at 110 Creek. We will walk 200 yards upstream to the east to examine a section through the Besa River shale. Their contact with the Dunedin limestone is exposed at the mouth of a narrow gorge.	
100.0	Good exposure of Kindle Formation consisting of southwest dipping siliceous siltstones which form the east flank of the Racing River synclinorium.	400
108.6	Texaco service station. Siliceous mudstones of the Kindle crop out in the ditch to right of the highway. Leaving map No. 3, entering map No. 4.	408
110.5	MacDonald Creek and bridge. Rock directly ahead is Kindle Formation, outcrops of Kindle Formation on riverbank upstream from bridge.	410.3
111.9	Resistant bands of outcrop on hillside on east side of valley are siliceous Kindle Formation.	
114.3	Looking north into MacDonald river gorge, resistant Stone dolomites and Dunedin limestones form the steep walls of the gorge. They are overlain by the recessive Besa River shales which are capped by the resistant ledge of the Kindle Formation. The MacDonald Creek and Toad River confluence marks the north plunge of the Stone Range anticlinorium which we have crossed at Summit Lake from where we followed its west flank. From here we will cross the Racing River synclinorium.	
115.4	Highway turns west here. All exposures to the north are formed by complex folded rocks of the Toad and Grayling Formations.	



STOP 7
STOP 6
Alaska
Highway
Toad River
RIVER
TOAD
Creek
Mile Post 420
Abandoned Camp
One Fifty One
Wood
3000
3500
4000
4500
5000
5500
6000
2500
5726
4388

Map No. 4

LEGEND TO MAP NO. 4. Scale 1: 125,000
Compiled by: G.C. Taylor, Geological Survey of Canada

TRp	Pardonet	Ds	Stone
TRl	Liard	Dw	Wokkpash
TRt	Toad-Grayling	Dm	Muncho-McConnell
Pk	Kindle	Sn	Nonda
Db	Besa River	Ⴒt	Helikian, Tuchodi
Dd	Dunedin		

117.9	Directly north is a good view of the Toad and upper part of the Grayling series.	
118.9	Racing River bridge.	418.7
119.2	On strike with highway (to north), outcrops of near vertical Kindle Formation, formation, top is to the east. From this point westward we are again in an area underlain by Besa River shales.	
120.3	Besa River shales exposed at right.	
122.9	Toad River Lodge.	422
123.7	STOP #6, at gravel pit on left side of the highway (climb embankment) view of complexly folded Kindle to north, capping the ridges. The folding at Kindle level is disharmonic and is only indirectly related to the folding at the Dunedin-Stone level.	
124.1	Dunedin cropping out on both sides of highway, forming the leading edge of a thrust element involving Dunedin and older carbonates.	
125.6	Kindle at this point nearly vertical on the west limb of an anticline.	
126.0	Outcrop of Grayling Formation on right side of road.	
126.8	Outcrop of Toad Formation.	427
127.9	The type section of the Kindle Formation was measured on the ridge to the south of this point. Directly ahead can be seen what is locally called "Thumbprint Mountain"; tight folds in the Dunedin cause this appearance.	428
129.4	Dunedin crops out in road cut.	
129.8	STOP #7 at Gravel Pit to left. To the south can be seen crenulated and folded Dunedin. To the north: crenulated Dunedin at river level	

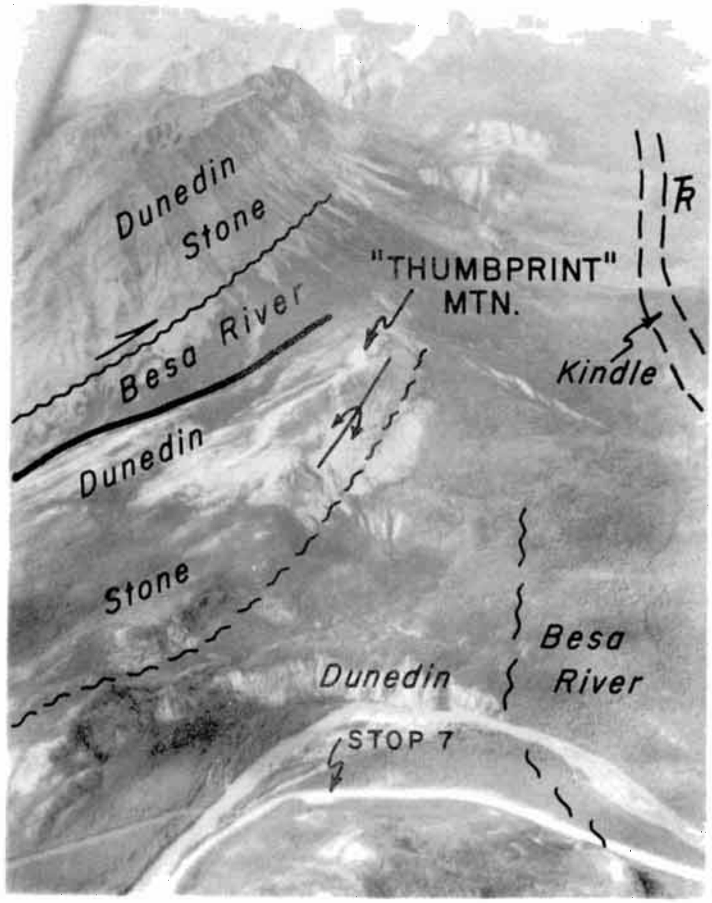


Figure 3 - Stop No. 7

Figure 4 - Stop No. 9

is fault overlain by a recumbent Dunedin Stone sequence which also forms the "print" of Thumbprint Mountain. This is overlain, by a further thrust element consisting of Dunedin and older rocks. (Figure 3).

131.9 Dunedin - Stone contact to north. Leaving map No. 4, entering map No. 5.

132.4 Stone thrust over Dunedin.

133.8 150 Creek. 433.6
Dunedin - Stone contact can be seen to north.

135.9 STOP #8
Looking at cliff to southwest the Muncho-McConnell and a thin sliver of underlying dark grey Nonda dip to the west and are thrust over a Dunedin and Stone sequence. The fault plane is very sharp, and has a dip that is nearly parallel to the Nonda - Muncho-McConnell contact. Looking north, across the river, the same fault can be seen, faulting Nonda onto Stone.

136.9 Entering the east side of a large anticline exposing in its core Precambrian sediments of the Tuchodi Formation which are unconformably overlay in by the Silurian Nonda Formations. This anticline forms the backbone of the Sentinel range.

138.2 Toad River bridge. 437.6

STOP #9 on west side of bridge outcrops of a dyke intruding the Tuchodi Formation.

138.9 The type section of the Nonda was measured on hillside above and to the right (see Figure 4). 440

143.5 Peterson Creek bridge. 441.8
Looking south here, a normal fault (shear zone) places Devonian rocks on the west against Cambrian and older on the east.

143.7 Village Inn 442

143.9 Entering the Muncho Lake longitudinal valley. This valley is to a certain extent controlled by a zone of shearing and normal faulting. (Fault mentioned above can be included in this). These normal faults are interpreted to be of late orgenic age and may play a comparable role


Muncho Lake
Mile Post 460
Cabin
2680
STOP 10
Muncho Lake
Maintenance Camp
Repeater Station
River
1552
Eight Mile
5000
6000
Muncho
Cr
Mile Post 450
Abandoned Camp
Drogheda L
6749
6547
5681
565
Peterson Cr
Moose L
4000
5500
STOP 9
STOP 8
Mile Post 440
Cabin
Creek
Creek

Map No. 5

LEGEND TO MAP NO. 5. Scale 1: 125,000
Compiled by: G.C. Taylor, Geological Survey of Canada

TRt	Toad-Grayling	Dm	Muncho-McConnell
Pk	Kindle	Sn	Nonda
Db	Besa River	Ok	Kechika
Dd	Dunedin	Ɛs	Atan
Ds	Stone	Ꝑt	Helikian Tuchodi
Dw	Wokkpash		

---

as the normal faults associated with the Rocky Mountain Trench.

145.8 Kechika Formation (early Ordovician) on left faulted onto Dunedin on right. Dunedin outcrops from this point on, show many small scale "kink" folds. 444

146.8 Contact between the Dunedin and Stone Formations. We are now emerging into the more open part of the Muncho Valley. 446

148.8 The highway is now leading from outcrops of the Stone Formation, through the Wokkpash Formation and into Muncho-McConnell sediments in the vicinity of Drogheda Lake. (Small lake which highway half circles). From this lake on for the next 1/2 mile the highway is nearly at the Stone-Wokkpash contact, with Stone to the west. 450

151.7 Kechika on left, Cambrian quartzite on right at Creek level.

154.1 Cambrian orange colored carbonates on right. 455

154.9 Construction camp. 456

155.9 Muncho Lake. Dark Nonda dolomites form outcrops to the east side of highway. Across the lake to the west can be seen a slab (dip slope) of east dipping Nonda lying on a thin layer of Kechika. 457

156.9 STOP #10 458

Turn off onto gravel flat west of highway. Outcrop at road is Muncho-McConnell Formation. Looking southeast up "underground Creek" towards the unnamed peak on the horizon, Chevron folded Dunedin limestone overlies smoother folded Stone dolomites.

Continuing on north along highway from this point, the Muncho-McConnell crops out continuously along the road cut.

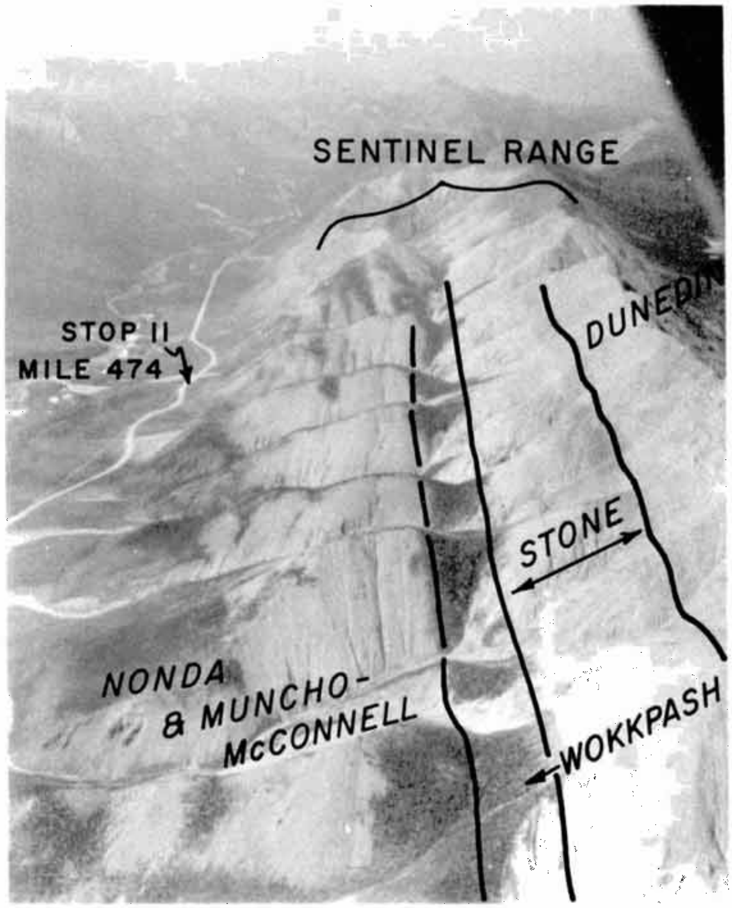
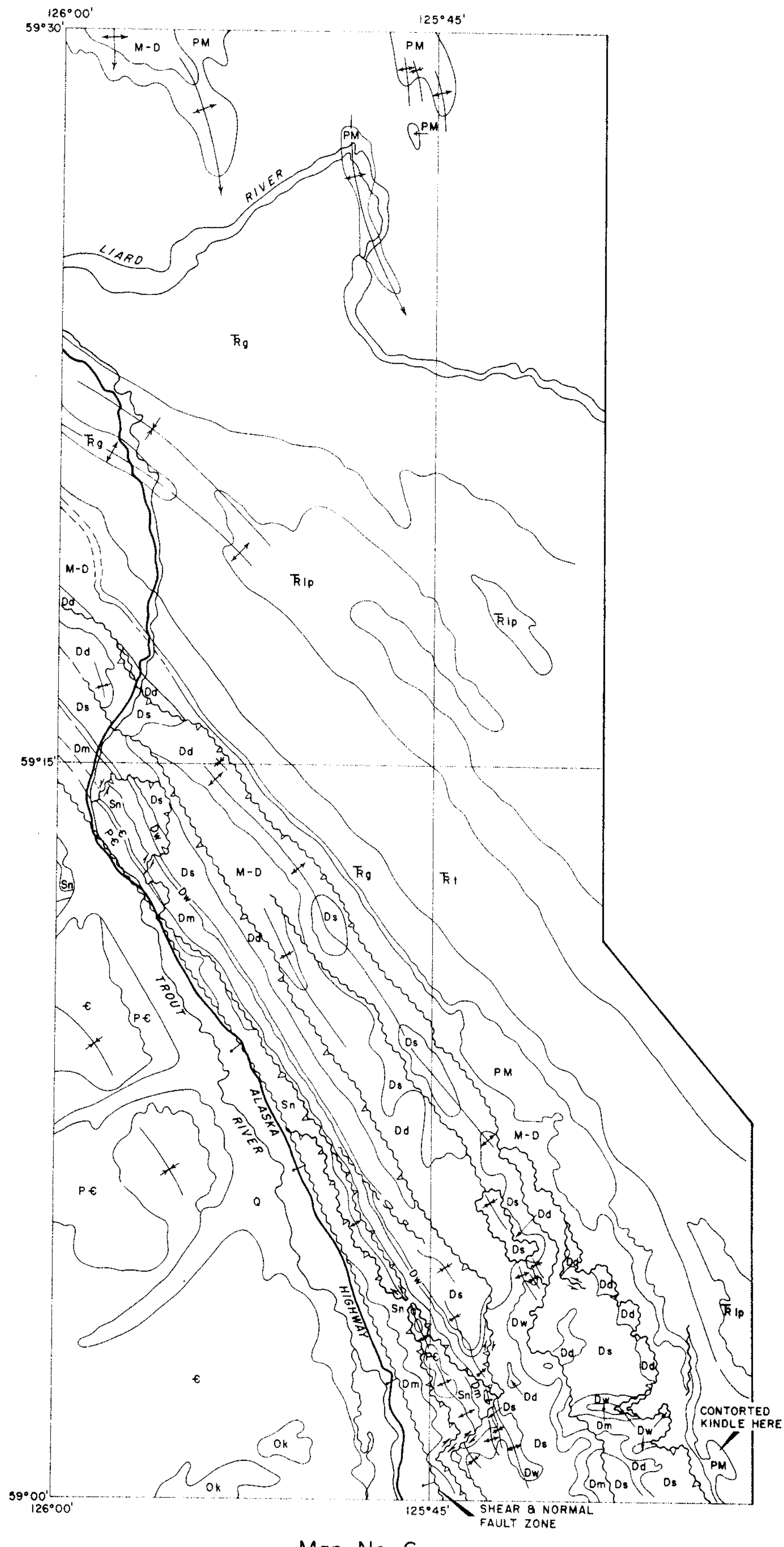


Figure 5 - Stop No. 11

LEGEND TO MAP NO. 6 Scale 1 inch = 4 miles
By: H.R. Hovdebo, Chevron Standard Limited

Q	Quaternary	Ds	Stone
TRlp	Liard-Pardonet	Dw	Wokkpash
TRt	Toad	Dm	Muncho-McConnell
TRg	Grayling	Sn	Nonda
M-P	Kindle, Flett, Mattson	Ok	Kechika
M-D	Besa River Shale	Є	Cambrian Clastics
Dd	Dunedin	PЄ	Precambrian


126°00'
59°30'
125°45'
M-D
PM
PM
PM
PM
LIARD
RIVER
₸Rg
₸Rg
M-D
₸Rlp
₸Rlp
Dd
Dd
Dd
Ds
Ds
Dm
Dd
59°15'
Sn
Ds
Dw
P€
Sn
Ds
M-D
₸Rg
₸Rt
Dw
Dm
Ds
Dd
TROUT
€
P€
Ds
PM
Ds
ALASKA
Sn
Dd
M-D
RIVER
P€
Q
Ds
Dd
Ds
Dd
Dw
HIGHWAY
Ds
Dd
Dd
₸Rlp
Sn
Dw
Dd
Ds
Dd
P€
€
Dm
Sn
Dm
Dd
Ds
Dw
Dm
Dw
CONTORTED
KINDLE HERE
Ok
Ds
Dd
PM
Ok
Dw
Dm
Ds
Ds
59°00'
126°00'
125°45'
SHEAR & NORMAL
FAULT ZONE

Map No. 6

158.8 Rock exposures from this point to beginning of rock fan are Nonda.

159.4 At this point the highway crosses a normal fault zone and rocks exposed along road cut on north side of fan are yellow-orange weathering Cambrian carbonates. A short way along the highway crosses to the west side of the fault into Nonda outcrop.

159.9 Highway cuts back through normal fault into sheared and shattered Cambrian again. 461

160.2 The normal fault is crossed again and the outcrops from here on are Nonda.

160.9 Highland Glen Cabins and service station-cafe. Driving along to north from this point the flat iron dipslopes to the right are Muncho-McConnell. Cambrian rocks are present directly across the lake to the west. Leaving map No. 5, entering map No. 6. 462

165.9 Double flat iron dipslope (west dip) to right. The upper flat iron is Muncho-McConnell and the lower one is Nonda. Across the lake to northeast the Green slope below ridge-top cliff former is underlain by Precambrian. 466

170.0 Yellow-grey phyllitic appearing rock on peak to west is the Cambrian Kechika limestone. 470

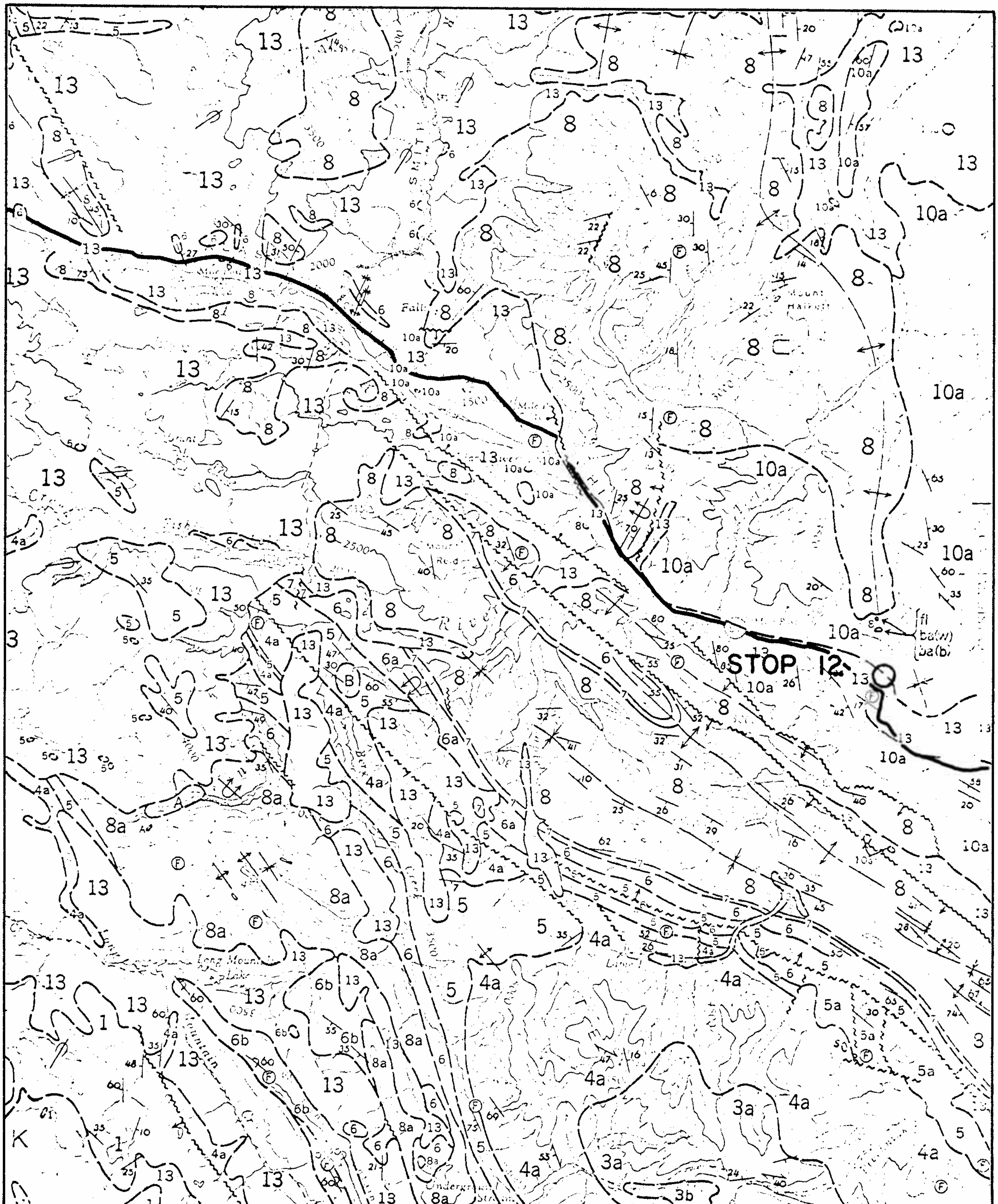
172.0 To the right orange-yellow weathering Proterozoic clastics can be seen. They are overlain by Nonda. 472

173.7 <u>STOP #11</u> 474

From this point one can walk upstream to examine the Nonda-Tuchodi unconformable contact. See Figure 5 for aerial view of Sentinel Range.

174.5 Yellow weathering Pleistocene lake sediments can be seen across the Trout River to northwest.

175.6 On the shoulder to the east Nonda lies on red weathering Cambrian - just above and east of the Trout River bridge. Along this stretch of highway the rapid downcutting of the pre-Nonda unconformity is demonstrated since Nonda lies on Cambrian quartzites to the east (right side of valley) and Nonda lies on



LEGEND TO MAP NO. 7 Scale 1 inch = 4 miles
From: Geol. Survey of Canada. Map 46-1962, Rabbit River
By: H. Gabrielse

13. Pleistocene & Recent
9. Undivided Cambrian to Middle Devonian Carbonates
8. Dunedin and Stone Carbonates
7. Wokkpash
6. Muncho-McConnell
5. Nonda (may include some 6)
4a. Kechika
1. Cambrian and older

Kechika, which lies on Cambrian quartzites to west (left side of valley).

178.6 Prochniak Creek bridge. The near vertical shear and normal fault zone extending the length of the Muncho valley trends to the northwest from this point. The highway now begins to cut through the Sentinel Range, which has been forming the east side of Muncho Valley for the last 30 miles. 479.3

181.3 Kindle cherts can be seen forming low cliffs to southeast.

181.7 The highway has now crossed the frontal fault marking the eastern edge of the Sentinel Range. Tree-covered hills in the area are underlain by Besa River, Kindle and Triassic rocks.

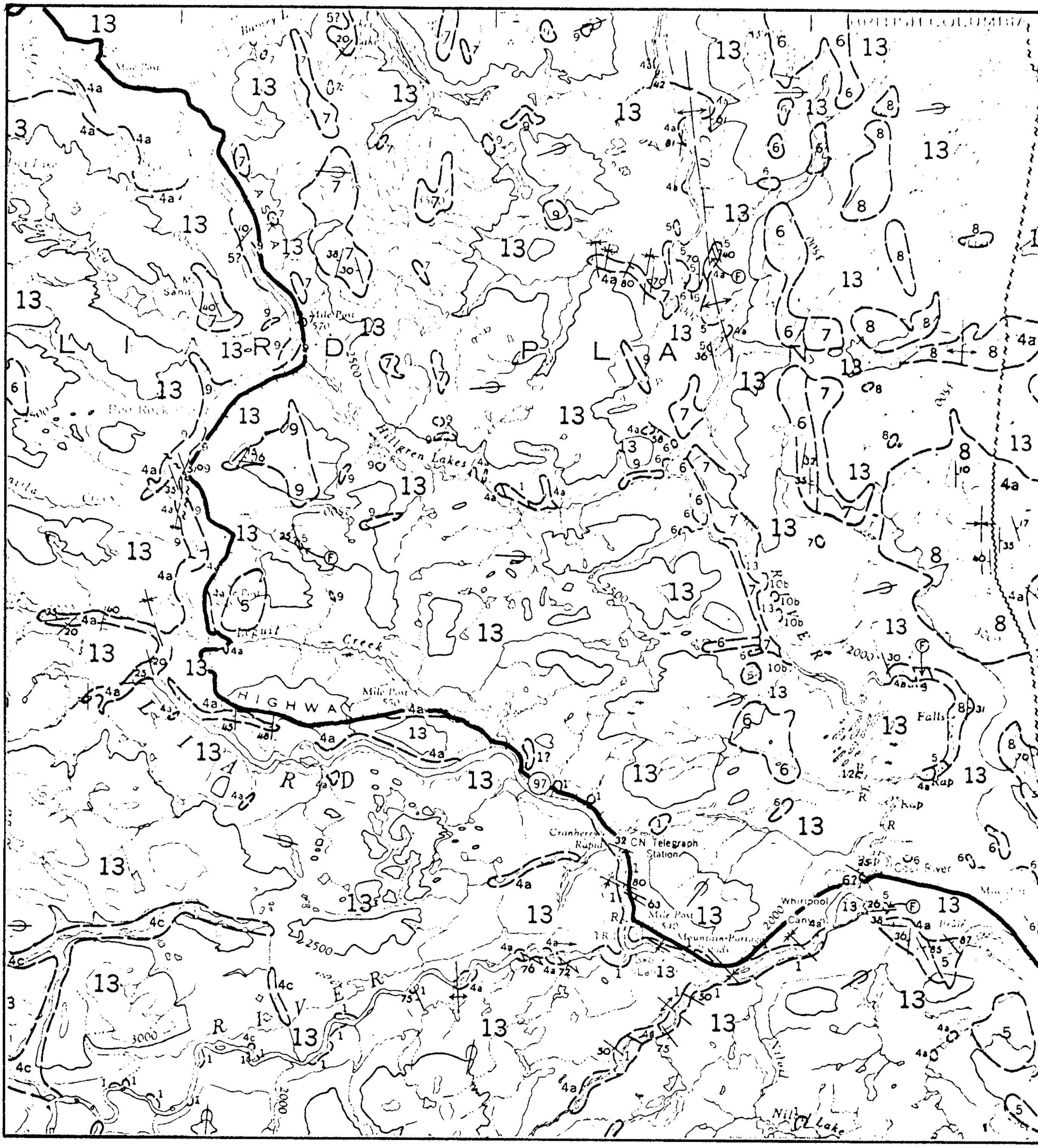
184.6 River cut below highway level to the right has a Kindle exposure in it. 486

187.6 Outcrop of Grayling on left side of highway. Sediments of the Pardonet Formation (upper Triassic) cap the mountain peaks to the east. 489

188.8 Road sign: "Bad Corner". At top of grade we have a good view to the north across the Liard River into the south plunging structural elements of the Mackenzie Mountains. Note terrace system on river banks to the east. Leaving map No. 6.

192.1 Mountain across Liard River exposes small scale folds in the Kindle Formation which form the east limb of a large anticline (Liard anticline) in the core of which Dunedin carbonates are exposed (not visible from here). The Dunedin Core strikes north south and is part of the Mackenzie Mountains system. In contrast to this the axes of the small scale folds in the Kindle parallel the strike of the Rocky Mountains (northwest-southeast). Entering map No. 7.

194.6 Liard River and bridge. 495.8
Looking due north, when on the bridge, one can see the low, tree-covered hill forming the core of the north-south trending steeply south plunging Liard anticline. The hill is composed of Dunedin limestones with Besa River-Kindle shales on the flanks. The steep south plunge is demonstrated by the presence of siliceous shale-mudstone of the Kindle under the bridge



LEGEND TO MAP NO. 8 Scale 1 inch = 4 miles
From: Geol. Survey of Canada. Map 46-1962, Rabbit River
By: H. Gabrielse

13. Pleistocene & Recent
10a. Besa River shale and Kindle, includes some Grayling.
8. Dunedin and Stone Formation
7. Wokkpash
6. Muncho-McConnell
5. Nonda (may locally include some 6)
4a. Kechika
3a. Lower and Middle Cambrian
1. Cambrian or older

on the north bank of the Liard River.

STOP #12
Turn off to left into Gulf service station and cafe area.

This area is in the zone separating the Rocky Mountains from the Mackenzie Mountain structural province. There are no great apparent fault zones separating these two provinces. To the east the "foothills" structures merely swing gently from the north western Rocky Mountains trend to the north trend of the Mackenzie Mountains. In the area of the Liard bridge there are north west trending faults separating the "leading edge" of the Rockies from the south plunging Mackenzies. At no place is there any great stratigraphic throw.

This point also marks the physiographic boundary between the Rocky Mountains and the Liard plateau as defined by Bostock.

194.9 Continuing on from Stop #12, there is a turn-off to the north from the highway at about mile 194.9 which leads to the Liard Hot Springs. These warm mineral waters emerge from the Dunedin-Besa River contact and flow over a considerable area (bathing facilities).

196.7 To the right is the Kindle Formation, dipping west at about 30°. It forms the west limb of the Liard anticline.

197.8 View from this point across the Liard River towards the Terminal Range of Rockies.

200.7 Teeter Creek and bridge. 501.7
In this vicinity the highway roughly parallels the strike of the Terminal Range.

203.5 Mt. Halkett Range. Middle Devonian Stone and Dunedin in a complex south plunging anticlinorium.

205.1 Continuing along in the Halkett structure. 506

205.8 Carbonates of Middle Devonian age crop out at highway level.

212.8 Smith River bridge. On river banks good out- 513.9
crops of "Besa River" shale which contain concretions with Goniatites of Chesterian age (time equivalents of the Stoddart).

The Smith River marks the physiographic boundary between the Liard plateau to the east and the Liard plain to the west.

215.9 Mountain ahead formed of Middle Devonian carbonates (Dunedin and Stone). The Stone Formation about 40 miles southwest of here is limestone, limestone facies which renders it difficult to differentiate it from the Dunedin limestones.

224.2 Outcrops of Devonian carbonate in road cut. Entering map No. 8.

231.8 Coal River bridge. Gravel banks here are glacial outwash deposits. Coal deposits some miles to the north are of Tertiary age (post-orogenic deposits). 533.2

237.2 Whirlpool Canyon. (off highway to south). These rapids are formed by the Liard River flowing over. Kechika? dark shales and shaly limestones.

241.5 Road maintenance camp and Fireside Inn hotel.

243.1 Across river is a small outcrop of Cambrian rocks (Kechika?).

244.1 Road cut has outcrops of Cambrian or possibly older rocks.

246.1 Army Creek. 547.1

249.0 to 249.5 Scattered outcrops of dolomitic siltstones of Cambro-Ordovician age.

252.0 More Cambro-Ordovician rocks.

256.6 Leguil Creek. The hill to the north of Leguil Creek valley has middle Silurian dolomite outcrops. 558

258.5 Outcrops of shattered Cambro-Ordovician dolomites. 560

259.8 View over Liard Plain to the west. Rivers in this area are quite deeply incised.

265 Hill to the north formed by Lower Devonian carbonates. 567

266.7 Cut bank here exposes Lower Devonian carbonates.

268.1	Allan's lookout. Carbonate outcrops in hill-side across the Liard River are of probably Lower Devonian age.	570
285.0	Contact Creek.	558.1
286.2	Crossing from British Columbia into the Yukon. The southern limit of the Hyland Plateau area is only ten miles north of the border here. The highway continues to traverse the Liard Plain physiographic subdivision. Leaving map No. 8.	558.3
286.8	Outcrops of Besa River shales.	
289.1	Outcrops of Besa River shales.	
291.7	Iron Creek.	594.3
293.7	Iron Creek Lodge.	
296.8	Quarry in Besa River shales. These siliceous shales are used for road metal.	
301.0	View across the flat, low lying Liard Plain, onto the slightly higher Dease plateau, into the Cassiar Mountains. The light colored rocks forming the horizon are mainly lower Paleozoic in age. Scattered outcrops of black Mississippian-Devonian shales along the highway for the next 1/2 mile.	
303.0	Hyland River bridge.	605.9
316.0	Lower Post.	619
322.1	Shales and carbonates here could range from Mississippian to Silurian in age (Besa River and Road River Formations).	
331.5	Watson Lake. Signpost display and liquor store mark the final mileage here.	635