GEOLOGICAL SURVEY OF CANADA
COMMISSION GÉOLOGIQUE DU CANADA

MEMOIR 401

PRE-MESOZOIC GEOLOGY IN THE SUBSURFACE OF PEEL RIVER MAP AREA, YUKON TERRITORY AND DISTRICT OF MACKENZIE

D.C. PUGH

Canada

1983

MEMOIR 401

PRE-MESOZOIC GEOLOGY IN THE SUBSURFACE OF PEEL RIVER MAP AREA, YUKON TERRITORY AND DISTRICT OF MACKENZIE

D.C. PUGH

1983

Available in Canada through

authorized bookstore agents
and other bookstores

or by mail from

Canadian Government Publishing Centre
Supply and Services Canada
Ottawa, Ontario, Canada K1A 0S9

and from

Geological Survey of Canada
601 Booth Street
Ottawa, Canada K1A 0E8

A deposit copy of this publication is also available
for reference in public libraries across Canada

Cat. No. M46-401E   Canada: $50.00
ISBN 0-660-11468-2   Other countries: $60.00

Price subject to change without notice

Critical readers

J.D. Atiken (Precambrian, Cambrian)
E.W. Bamber (Upper Paleozoic)
M.P. Cecile (Cambrian to Silurian)
M.O. Fuglem (Economic Geology)
L.V. Hills (Devonian)
D. Morrow (Silurian, Devonian)
G.K. Williams (manuscript review)

Scientific editor

E.R.W. Neale

Layout

L. Machan-Gorham

Word Processing

P. Greener
H. King

Artwork by Cartography Section
Institute of Sedimentary and
Petroleum Geology

Author's address:

Geological Survey of Canada
Institute of Sedimentary and Petroleum Geology
3303 - 33rd Street N.W.
Calgary, Alberta T2L 2A7

Original manuscript submitted: 80-04-08
Approved for publication: 81-02-20

Preface

The thick sequences of sedimentary rocks, occurring in two structural basins in the Peel River area, have long been a target of economic interest, owing to their hydrocarbon and mineral potential. As a result of exploratory drilling, surface mapping, and many local studies, the need has developed for a broad regional synthesis of the stratigraphy and geological history of the area. This report is intended to satisfy this need, thereby assisting in the evaluation of the economic potential. Subsurface data have been used to compile a series of maps and cross-sections, illustrating the stratigraphy and structure of the area; nomenclature has been reviewed and the geological history elucidated.

OTTAWA, June 1983

R.A. Price
Director General
Geological Survey of Canada

Préface

Les épaisses séries de roches sédimentaires observées dans deux bassins structuraux dans la région de la rivière Peel font, depuis longtemps déjà, l'objet de considérations économiques en raison des hydrocarbures et minéraux qu'ils renferment. Suite aux forages d'exploration, aux travaux de cartographie de la surface et aux nombreuses études locales entrepris, on sent maintenant le besoin de produire une synthèse générale de la stratigraphie et de l'histoire géologique de la région. Le présent rapport tente de répondre à ce besoin, contribuant du fait même à l'évaluation du potentiel économique de la dite région. Des données recueillies en profondeur ont servi à la compilation d'une série de cartes et de coupes illustrant la stratigraphie et la structure régionale; l'auteur a d'ailleurs révisé la nomenclature stratigraphique de la région et en a expliqué l'évolution géologique.

OTTAWA, juin 1983

R.A. Price
Le directeur général de la
Commission géologique du Canada

CONTENTS

Table

Illustrations

Figures (in pocket)

Abstract

Terrace wedge deposits of Helikian age, the oldest rocks drilled so far in the Peel River map-area, appear to be related to the inception of major continental separation. Hadrynian rocks, which are preserved as a very thick succession southwest of the Mackenzie Arch, are probably absent in the subsurface to the northeast.

During the Cambrian period the Mackenzie Arch and its northern extension provided a barrier to open marine circulation. Clastic and evaporitic sediments were deposited to make up the Mount Clark, Mount Cap and Saline River Formations behind this barrier in the hypersaline water. The Saline River is divided into three informal units: Lower clastic, Salt and Upper clastic members. West of the northern extension of the Arch during Cambrian time, thick carbonate and clastic sediments built up in the Richardson Aulacogen. This rift continued to dissect the regional shelf environment until mid-Devonian time, giving rise to the thick basinal facies succession of the Road River Formation, deposited contemporaneously with shelf carbonates on the Mackenzie and Porcupine Platforms. The platform equivalents of the Road River Formation are grouped into the Upper Cambrian to Lower Devonian Ronning Group and the Lower and Middle Devonian carbonates assemblage, the two being separated by a regional unconformity extending into at least part of the Road River succession. The Ronning Group consists of three formations: Franklin Mountain Formation, in which a cherty member in the upper part appears to be a time-transgressive unit; Mount Kindle Formation, which on the Porcupine Platform is present only as a transitional unit; and Peel Formation (new name). The Devonian carbonates assemblage consists of four formations: Tatsieta Formation (new name) of shallow marine limestone and shale; Arnica and Landry Formations, which are facies equivalent units; and Hume Formation. The top Devonian carbonate unit on the Porcupine Platform is the upper part of the Ogilvie Formation.

A Givetian interlude is represented by the Horn River Group of Formations: Hare Indian shale with its basal Bluefish Member (new name); Ramparts reef complex, comprising a Siltstone lentil, a Platform member, a Reef member and a Sandy member; and Canol black shale.

The Canol veneer was the regional "ground state", or the floor, during late Paleozoic time, of immensely thick wedges of detrital material derived mostly from a roughly northern orogenic source. The southward transportation of this material appears, at least initially, to have followed the line of the old aulacogen rift valley. During Late Devonian time thick clastic wedges with turbidite lobes were deposited over a wide area straddling the present day Richardson Mountains. To the southeast, homotaxial with these deposits, somewhat finer clastic rocks of Late Devonian age are known

Résumé

Les sédiments de terrasses en biseau d'âge hélikien, les roches les plus anciennes forées jusqu'à présent dans la région de la riviere Peel, sembient avoir une relation avec le début de la principale séparation continentale. Les roches d'âge hadrinien qui ont été conservées sous forme d'une succession très épaisse au sud-ouest de l'arche de Mackenzie, sont probablement absentes sous la surface vers le nord-est.

Durant le Cambrien, l'arche de Mackenzie et son extension vers le nord formaient une barrière pour la circulation marine. Les sédiments clastiques et évaporitiques qui se sont déposés derrière la barrière dans de l'eau hypersaline ont donné les formations de Mount Clark, de Mount Cap et de Saline River. On divise la formation de Saline River en trois unités informelles: membres clastiques inférieur, Salt et supérieur. À l'ouest de l'extension nord de l'arche, des sédiments carbonatés et clastiques se sont accumulés pendant le Cambrien, dans l'aulacogene Richardson. Le fossé d'effondrement continuait à disséquer le plateau continental régional jusqu'au milieu du Dévonien, donnant ainsi naissance à la succession épaisse de facies de bassin de la formation de Road River, déposée en même temps que les carbonates du plateau continental sur les plate-formes de Mackenzie et de Porcupine. Les équivalents de plate-forme de la formation de Road River sont réunis dans le groupe de Ronning du Cambrien supérieur au Dévonien inférieur et l'ensemble des carbonates du Dévonien inférieur et moyen, les deux étant séparés par une discordance régionale qui se prolonge du moins en partie, dans la succession de Road River. Le groupe de Ronning comprend trois formations: la formation du Franklin Mountain dans laquelle un membre formé de chert de la partie supérieure semble être une unité de trangression; la formation de Mount Kindle qui forme, sur la plate-forme de Porcupine seulement, une unité de transition; et la formation de Peel (nouveau nom). L'ensemble des carbonates du Dévonien comprend trois formations: la formation de Tatsieta (nouveau nom) formée de calcaires marins et de schistes argileux peu profonds; les formations d'Arnica et de Landry qui sont des unités de faciès équivalents; et la formation de Hume. L'unité supérieure de carbonate du Dévonien, se trouvant sur la plate-forme de Porcupine constitue le sommet de la formation d'Ogilvie.

L'intermède du Givétien est représenté par le groupe des formations de Horn River: les schistes argileux de Hare Indian et son membre Bluefish (nouveau nom); le complexe récifal de Ramparts, comprenant une lentille de siltstone, un membre de plate-forme, un membre récifal et un membre de sable; et les schistes argileux noirs de Canol.

Le placage de Canol représente "l'état fondamental" de la région ou le socle à la fin du Paléozoïque constitué de biseaux très épais formés de matériaux détritiques dérivant surtout d'une source orogénique d'orientation plus ou moins nord. Le transport vers le sud de ces matériaux semble, du moins au début, avoir suivi la ligne de l'ancienne vallée d'effondrement aulacogene. Au Dévonien supérieur des biseaux clastiques épais avec des lobes de turbidite s'étaient déposés dans une vaste région chevauchant les chaînons Richardson actuels. Vers le sud-est, des roches un peu plus

as the Imperial Formation. Overlying the thick Imperial equivalents, the Tuttle Formation (new name) attests to the continuation into the Early Carboniferous of the growth of turbidite and probably deltaic sequences south- and southwestward. This depositional pattern of prograding shoreline behind basin fill changed during Early Carboniferous time. Marine transgression accompanied a flexing of the continental margin, and the new pattern was one in which shoreward coarse clastic facies graded seaward through skeletal and cherty limestone shoals into dark basinal shale facies. From late Early Carboniferous through Early Permian time three main pulses of clastic-carbonate wedge deposition gave rise to the Hart River, Ettrain and Jungle Creek Formations. Basinal equivalents of the wedges are black shales which make up the Ford Lake Shale and Blackie Formation (new name).

The Peel River area is interpreted as favourable for hydrocarbon accumulation, with the added possibility of deposits of important minerals.

finement clastiques du Dévonien supérieur et homotaxiques avec ses dépôts sont connues sous le nom de formation d'Impérial. Couvrant les équivalents épais d'Impérial, la formation de Tuttle (nouveau nom) confirme la continuation dans le Carbonifere inférieur de la croissance des séquences turbiditiques et probablement deltaïques vers le sud et le sud-ouest. Le type de sédimentation du rivage progressant vers le large et se trouvant derrière le remplissage de bassin a changé pendant le Carbonifère inférieur. Une trangression marine a accompagné une flexure de la marge continentale et le nouveau type de sédimentation était constitué de faciès clastiques et grossiers qui, du côté du rivage, devenaient des sédiments classés au large, passant par des haut-fonds squelettiques de calcaires à silex vers un faciès de schistes argileux noirs de bassin. De la fin du Carbonifère inférieur au Permien inférieur, trois phases de sédimentation en biseau de carbonates clastiques ont donné naissance aux formations de Hart River, d'Ettrain et de Jungle Creek. Les équivalents de bassin des biseaux sont constitués de schistes argileux noirs qui groupent les schistes argileux de Ford Lake et la formation de Blackie (nouveau nom).

On pense que la région de rivière Peel est favorable à l'accumulation d'hydrocarbures et aussi à la présence possible de dépôts de minéraux importants.

PRE-MESOZOIC GEOLOGY IN THE SUBSURFACE OF PEEL RIVER MAP AREA, YUKON TERRITORY AND DISTRICT OF MACKENZIE

CHAPTER I

INTRODUCTION

Study area

Peel River map-area, bounded by the 64th and 68th parallels north latitude and by the 128th and 144th meridians west longitude, embraces the Mackenzie, Ogilvie, Richardson and Selwyn Mountains and plains and plateaux crossed by the lower Mackenzie, Peel, Porcupine and Yukon Rivers. The study area for this report, controlled primarily by drilling for oil and gas, is restricted to that part of the map-area north of 65° latitude and east of the international border on 141° longitude. Subsurface geology of the study-area is illustrated on twenty-two isopach, lithofacies, subcrop and superimposed structure contour maps, and eleven stratigraphic, and one time-lithostratigraphic, cross-sections.

Previous work

The earliest geological investigations pertinent to the present work date back to McConnell (1889) and Cairnes (1914). The discovery of oil in Norman Wells in 1920 was followed by the work of Kindle and Bosworth (1921), Williams (1922, 1923) and Hume (1923).

World War II provided the next boost to exploration by way of the Canol Project, which resulted in a set of unpublished reports, of which those of Laudon (1944) and Nauss (1944) are referred to herein, followed by those of Hume and Link (1945). Later, Hume's (1954) timely report, summarizing the thirty years prior to 1954, of geological work in the lower Mackenzie area, became the forerunner of many studies by industry geologists. Those pertinent to the present work were subsequently studied and summarized by Tassonyi (1969) in his report on the subsurface geology of the region, which included detailed discussions on the problems of stratigraphic nomenclature that had arisen through the years.

Meanwhile, the Geological Survey of Canada had launched a new mapping program of helicopter-supported field work, beginning with Operation Mackenzie (1957) and followed by Operation Porcupine (1968) and Operation Norman (1968-69). Most of the more recently published geological maps and stratigraphic studies referred to herein were the result of these three Operations, and further maps and papers have been in the course of preparation while this report was being finalized.

Present study

Subsurface studies during 1975 and 1976 aimed at establishing a regional correlation network based on radioactivity well logs and examination of all drill cuttings available. Emphasis was primarily on obtaining an overall view, leading, at a later stage, to more detailed studies as found necessary in order to provide as complete an understanding of the regional geological history as possible on the raw data so far.

All wells drilled within the study area and released from confidential status, as reported in Schedule of Wells by Canada Department of Northern Affairs and National Resources, were considered, and in addition, data from 14 wells north, east and southeast of the area were included. All 132 wells are listed in Appendix III along with basic geological data.

Acknowledgments

The writer gratefully acknowledges an introduction by F.G. Young in 1974 to the stratigraphic problems in the subsurface west of the Richardson Mountains. It was from these first discussions that the need became evident for a more regional comprehensive study. Some studies in the subsurface had been begun in the eastern part of the area by W.S. Mackenzie, whose published papers are referred to herein, and whose unpublished work gave a firm direction for research in the initial stage of this project.

During the preparation of the manuscript in 1978 and 1979, many hours of invaluable discussion were spent with colleagues, J.D. Aitken (Proterozoic and Cambrian stratigraphy), E.W. Bamber (upper Paleozoic stratigraphy), M.P. Cecile (Road River stratigraphy), D.G. Cook (stratigraphic and structural concepts and rock-unit nomenclature), J. Dixon (Cambrian and Devonian stratigraphy), N.C. Meijer Drees (lower Paleozoic stratigraphy), D. Morrow (Silurian-Devonian nomenclature), B.S. Norford (lower Paleozoic biostratigraphy), A.W. Norris (Devonian stratigraphy), D.K. Norris (surface to subsurface correlations), A.E.H. Pedder (Devonian biostratigraphy), T.P. Poulton and J.H. Wall (pertaining to P-34 borehole), and G.K. Williams (on many occasions especially helpful guidance in lower Paleozoic and Devonian regional correlations and nomenclatural problems).

Bruce I. Clardy of the Louisiana Land and Exploration Company in Denver, Colorado, kindly donated well logs and useful stratigraphic charts from east-central Alaska. L.V. Hills of the University of Calgary gave generously of his time to discuss stratigraphic problems related to the Imperial Formation. R.J. Kirker of Arjay Kirker Resources Ltd., Calgary, Alberta, brought to the writer's attention the economic possibilities of metalliferous deposits within the Middle Devonian. Most recently, J.H. Lichtenbelt, of Time-Stratigraphic Correlations Ltd., Calgary, Alberta, renewed the writer's interest in the oil and gas prospects of the study area.

Fossils were examined by N.S. Ioannides (Devonian, Carboniferous and Cretaceous spores from K-04[1]), A.W. Norris (Devonian crinoid from G-31), R.S. Tipnis (Ordovician conodonts from H-71), and T.T. Uyeno (Ordovician conodonts from D-77, G-31, I-50, K-35 and N-49). The resulting reports, together with previously unpublished paleontological reports by A.P. Audretsch, M.S. Barss, T.P. Chamney, W.H. Fritz, D.M. Loranger, B.S. Norford, A.W. Norris, A.E.H. Pedder, Robertson Research (North America) Ltd., R. Thorsteinsson, T.T. Uyeno and J.B. Waterhouse are included in Appendix I.

Also in Appendix I are reports by G.P. Michael and J.N.Y. Wong on X-ray diffraction analysis of samples from K-15t and N-05.

Finally, for their many valuable comments and suggestions the writer is indebted to critical readers, J.D. Aitken, E.W. Bamber, M.P. Cecile, M.O. Fuglem, L.V. Hills, D. Morrow and G.K. Williams.

Borehole reference

Well names have conventionally taken the form of a tripartite union of commercial interests, geographical flavouring and a trivial number. For the sake of clarity and conciseness and an unsponsored presentation and discussion of geological data, borehole sections, which necessarily are referred to continually throughout this report, have been designated brief reference numbers. These references are the "unit-section" locations (Canada Department of Indian Affairs and Northern Development, 1965), a useful feature of well identification "north of 60". Unit-section references, being a part only of the "Unique Well Identifiers" (Canada Department of Indian Affairs and Northern Development, 1967), although not unique to a specific location, very adequately fulfill the purpose of repeated reference to borehole locations, with the occasional duplications easily handled.

Figure 1 includes well locations with the unit-section references. In Appendix III all wells are listed in alphabetical and numerical order of well references (A-05, A-22, A-23, . . .), and information includes well name and location by latitude-longitude and by Y.T. and N.W.T. Land Survey System.

Metric conversion

The desire of the subsurface geologist to conform with what may even be felt to be a long overdue conversion, is frustrated by his source of raw data. For the many thousands of boreholes drilled before 1979, measurements were in feet. All drill cuttings and cores are labelled in feet. All mechanical logs are printed in feet. Direct reference to any of this raw data, therefore, may be usefully stated only in feet, and nothing can be gained even by adding metric equivalents in parentheses. This means that, somewhere in the modern "metric" report on subsurface geology, a link must be provided between exclusively metric text and maps on the one hand, and the footage on pre-1979 borehole logs and samples on the other.

In the present report, this necessary provision has been included in the "Logs of wells", (Appendix II), by stating all relevant subsea elevations and thicknesses in both metric and British systems. This dual "m (ft)" designation relates directly both to metric numbers in the text and on the maps (Figs. 3-23), and also to borehole footage of the samples described (in Appendices I and II) and borehole footage intervals on the logs shown on stratigraphic cross-sections (Figs. 24-34).

It is hoped that this provision will adequately bridge the gap between raw data footage and metric presentation for future scientific reference, while at the same time leaving the text and maps unencumbered by obsolete terms for general reading.

[1]Borehole reference number - see under following heading.

CHAPTER II

STRATIGRAPHY

General

The subsurface stratigraphy of Peel River map-area straddles the north-south range of the Richardson Mountains. These mountains, a present day structural boundary between Eagle Plains to the west and Mackenzie Plains to the east, also mark the site of an ancient sedimentary division between two areas of similar depositional history. Marker beds, within a carbonate succession of Cambrian to Middle Devonian age, are readily traceable, from Mackenzie River westward almost to the Alaska border, across the band of black shales and carbonates which comprise much of the Richardson Mountains outcrop. These marker beds have been the keys to the stratigraphic interpretation in this report.

Nomenclature

Arising from more than a century of geological field work and mineral exploration in the northern Yukon and lower Mackenzie River area, some fifty names have been published which, at one time or another, have been applied to pre-Mesozoic rock stratigraphic units found either within, or extending into the subsurface of, Peel River map-area. Many of the older names have been superseded or their definitions modified as new data have become available. An excellent account of part of this nomenclatural evolution was given by Tassonyi (1969), whose comprehensive treatment of the subsurface geology of the Lower Mackenzie River area provided a firm platform from which to launch a westward tracking of rock units.

In the absence, so far, of any published comprehensive regional study to determine east-west stratigraphic relationships, particularly across the Richardson Mountains, new names inevitably were proposed for "new" rock units in the western part of the area. Most of these were formal names for mountain type sections, with a few informal names introduced for upper Paleozoic strata encountered in drilling for oil and gas in the Eagle Plain area. The present study has clarified east-west relationships, with the result that, by retaining twenty-one formal stratigraphic names and introducing five new names, one set of twenty-six formal and fifteen informal names may now be meaningfully applied to the regional pre-Mesozoic stratigraphy. Stratigraphic relationships within this nomenclatural system are illustrated diagrammatically on a time-lithostratigraphic cross-section, Figure 2. For easy reference to formation names, see Table 1 (Table of Formations) which follows.

Precambrian stratigraphy

Only fourteen of the boreholes considered in this study provided data on Precambrian stratigraphy in the Peel River map-area. Of these, five are in isolated locations, one of them (G-31[1]) close to the Alaska border, and four outside the area to the north (D-54) and east (E-15, K-24 and M-63). The remaining nine holes are fairly widely distributed east of the Richardson Mountains (see Fig. 3), but they have provided enough information from which, in the light of work in the Mackenzie Mountains (Aitken et al., 1973), to at least recognize four distinct lithologic units below the sub-Cambrian unconformity and their probable correlations with known outcrop units. However, because work is in progress to formalize Proterozoic nomenclature and, also, because of insufficient well control to permit correlations with confidence, the lithologic units recognized are referred to informally: Shale, Dolomite, Argillite and Orthoquartzite units.

Proterozoic

Shale unit

Shale unit refers to siliceous fine clastic rocks underlying a dolomite-siltstone-shale sequence, and is represented by one incomplete borehole section (D-40) in the northeastern corner of the map-area.

The shale unit, from the bottom of the borehole, may be subdivided into: a lower brown brittle shale with very siliceous siltstone and orthoquartzite; a middle member of siliceous microcrystalline limestone, 8 m thick; and an upper grey siliceous shale with some siliceous siltstone, 76 m thick.

The incomplete shale unit is 198 m thick in D-40. The underlying beds are unknown. The overlying beds probably represent the lower part of what is herein referred to as Dolomite unit, which as discussed under that heading, is probably correlative with some part of Unnamed unit H-1 of Aitken et al., 1973. The beds of Shale unit at the bottom of borehole D-40 are therefore probably the oldest rocks drilled in the study-area.

Dolomite unit

The informal name, Dolomite unit, is used in this report for varicoloured dolomite found below the sub-Cambrian unconformity in five wells (A-73, I-11, H-34o[2], L-26 and N-39) in the Lower Mackenzie River area (see Fig. 3).

The Dolomite unit is easily recognized. In all five boreholes it consists almost entirely of microcrystalline to aphanitic dolomite, coloured pink, yellow, buff, pale green, grey or white, and in part with characteristic blood-red streaks. Chert was found in three of the sections, in one of which (L-26) the chert replaces oolite. Minor variations to the above were noted in two sections: in the upper part in A-73 there is some siltstone; and in L-26, the top 34 m consists of coarsely crystalline dolomite with some black splintery shale.

All five boreholes bottomed in the Dolomite unit with a maximum incomplete thickness, 257 m, drilled in A-73. Consequently, underlying beds, in these four sections are not

[1]Borehole section reference number (see Appendix III) = G-31-66-30-140-00 Y.T. and N.W.T. Land Survey System.
[2]Borehole section reference number (see Appendix III) = H--34-66-10-132-00 Y.T. and N.W.T. Land Survey System.

TABLE I

Table of Formations

Basinal facies equivalent rock unit (name, author and thickest borehole)	System or Stage	Rock unit name, author and thickest borehole section (m): Group	Formation	Lithology: Member
Shale and siltstone	Middle Permian		Unnamed shale and sandstone unit	Dark silty and sandy shale and fine-grained quartzose sandstone
	Lower Permian		Jungle Creek Formation Bamber and Waterhouse (1971) 719 at M-55[1]	Limestone, sandstone, conglomerate, shale and siltstone
?	Unconformity			
Blackie Formation (new name) 682 at M-59; shale and siltstone; some limestone and sandstone	Pennsylvanian		Ettrain Formation Bamber and Waterhouse (1971) >257 at N-58	Limestone, skeletal, silty and sandy; chert; calcareous shale and coarse-grained sandstone
			Blackie Formation (new name)	Shale, black silty, locally with limestone, sandstone, siltstone
	Middle Pennsylvanian ↑ Upper Mississippian		Hart River Formation Bamber and Waterhouse (1971) 811 at M-08	Limestone, chert, shale, siltstone and sandstone: limestone skeletal and spicular. Chance Sandstone Member (Martin, 1972): sandstone, chert-rich, conglomerate
Ford Lake Shale	Upper Mississippian ↑ Upper Devonian		Ford Lake Shale Brabb (1969) 975 at G-31	Shale, dark grey to black; siliceous siltstone, sandstone and orthoquartzite
?	Lower Mississippian ↑ Upper Devonian		Tuttle Formation (new name) 1421 at O-22	Sandstone, conglomerate rich in varicoloured chert, siltstone, shale; rare coal; deltaic
Imperial Formation	Upper		Imperial Formation Hume and Link (1945) and Bassett (1961) 1909 at B-25	Shale and siltstone, dark grey; locally coarse-grained sandstone (north) and very fine-grained sandstone (southeast)
Canol Formation	Devonian		Canol Formation Bassett (1961) 157 at A-73	Shale, black bituminous, pyritic
			Allochthonous limestone unit	Reef debris and graded echinoderm

[1]Borehole section reference number (see Appendix III) = M-55-66-00-140-15 Y.T. and N.W.T. Land Survey System.

TABLE 1 (cont'd)

Basinal facies equivalent rock unit (name, author and thickest borehole section)		System or Stage	Rock unit name, author and thickest borehole section (m): Group	Formation	Lithology: Member
Ogilvie Formation (Norris, 1968; 923 at D-61 Porcupine Platform limestones: Black bituminous shale		?	Horn River Group Whittaker, 1922 477 at C-31	Hiatus - reef top erosion	
		Middle Devonian		Ramparts Formation Kindle and Bosworth (1921) 393 at L-24	Sandy member: siltstone and very fine-grained sandstone. Reef member: 263 at L-24 reef and bioclastic limestones. Platform member: bioclastic and fragmental limestone, siltstone and shale. Siltstone lentil: calcareous siltstone and shale
				Hare Indian Formation Kindle and Bosworth (1921) 260 at K-60	Grey shale member: shale, grey, variably calcareous, micro-micaceous, silty in the upper part. Bluefish Member (new name). Shale, black, bituminous, non-calcareous with locally black argillaceous limestone at base
Black shale and dark chert	Road River Formation Jackson and Lenz (1962) 1382 at N-25: Black graptolitic shale, carbonate and chert		Devonian carbonates assemblage 1181 at N-05	Hume Formation Bassett (1961) 389 at A-42	Limestone, bioclastic, argillaceous, silty, fossiliferous; interbedded calcareous shale
Black shale and some argillaceous limestone		Middle Devonian ↑		Landry Formation Douglas and Norris (1961)	Limestone, brown aphanitic and pelletoid
				Arnica Formation Douglas and Norris (1961) Arnica + Landry 1048 at N-05	Dolomite, brown, finely crystalline, in part sucrosic
		Lower Devonian		Basal Fort Norman tongue	Pale dolomite and green micropyritic shale
Black shale and limestone breccia		Lower Devonian ↑		Tatsieta Formation (new name) 183 at F-57	Limestone, pale buff, aphanitic; shale, pale green, micropyritic; locally some dolomite in upper part
Porcupine Platform equivalents			Unconformity		
Peel Formation dark dolomite facies		Upper Silurian	Ronning Group Stewart, 1944, 2040 (est.) at N-53	Peel Formation (new name) 388 at B-25	Dolomite, pale grey and pale buff, in part microsucrosic, locally silty or argillaceous
Mount Kindle-Road River transitional unit: dark limestone, dolomite and chert		Upper Silurian ↑ Upper Ordovician		Mount Kindle Formation Williams (1922) 440 at G-55	Unconformity. Dolomite, brown, very finely to medium crystalline, in part sucrosic; locally some chert

TABLE 1 (cont'd)

Basinal facies equivalent rock unit (name, author and thickest borehole section) / Porcupine platform equivalents	System or Stage	Rock unit name, author and thickest borehole section (m): Group	Formation	Lithology: Member
Unconformity Franklin Mountain Formation limestone in the upper part	Upper Ordovician ↑ Upper Cambrian		Franklin Mountain Formation Williams (1922) >1222 at N-53	Unconformity Dolomite, creamy white to pale buff and brown, micro- to coarsely crystalline. Cherty member: dolomite with chert, silicified oolites and clear quartz
↓ ?	?Upper Cambrian	Cambrian clastics-evaporites assemblage, 421 at N-39	Saline River Formation Williams (1922) 304 at N-39	Upper Clastic member: varicoloured shale; some siltstone, sandstone, dolomite, anhydrite. Salt member: halite, 265 m at N-39. Lower clastic member: shale, siltstone, sandstone, dolomite and chert
	Middle Cambrian ↑ Lower Cambrian		Mount Cap Formation Williams (1922, 1923) 196 at D-40	Varicoloured shale; silicified siltstone, dolomite and oolite; sandstone; orthoquartzite; chert; glauconite
	Lower Cambrian		?Mount Clark Formation Williams (1923) 92 at H-34o	Varicoloured orthoquartzite and silicified siltstone
	Unconformity			
Tindir Group Cairnes (1914) >133 at G-31. Shale, varicoloured, hard; some orthoquartzite	EAST → ← WEST		Orthoquartzite unit >167 at N-25	Orthoquartzite
			Argillite unit 876 at H-34o	Argillite; some orthoquartzite
	Helikian (?)		Dolomite unit >257 at A-73	Varicoloured dolomite; locally some siltstone and shale
			Shale unit >198 at D-40	Upper shale, grey, siliceous; some siltstone; Middle limestone; Lower shale, brown, brittle, with siliceous siltstone and orthoquartzite.

known. Overlying the Dolomite unit in A-73, I-11 and L-26 are Cambrian strata, separated from it by the sub-Cambrian regional unconformity. In H-34o the upper contact is non-gradational with the base of the Argillite unit.

Recent workers in the area (Aitken et al., 1973; Norford and Macqueen, 1975) have placed the Little Dal Formation (currently the Upper carbonate sub-unit of Little Dal Group, Hoffman and Aitken, 1979) at the top of the Proterozoic (Helikian?) succession below the sub-Cambrian unconformity northeast of the Mackenzie Arch. This upper sub-unit has recently been described (Aitken et al., in press) as being, in the Upper Ramparts River and Sans Sault Rapids map-areas, "dominated by carbonate rocks that are almost entirely dolomite" and "everywhere thinned by pre-Rapitan erosion". However, to correlate the Dolomite unit, as the above evidence might suggest, with the Upper carbonate sub-unit of the Little Dal Group, necessarily places the overlying Argillite unit (at H-34o) into the Hadrynian succession. J.D. Aitken (pers. comm., Jan. 1979) considers this to be highly improbable and suggests that the Dolomite unit has features in common only with the Unnamed unit H-1, the oldest of the Helikian(?) units exposed in the Mackenzies. This means, therefore, that progressively older Proterozoic rocks subcrop northeastward from the Mackenzie Arch, which modifies the diagrammatic cross-section of Aitken et al.

(1973, p. 9) but strengthens their alternative argument (*ibid.*, p. 37) with reference to the Arch that "the absence of known derived deposits to the east suggests a hinge-line rather than an 'arch' ".

An apparent anomaly occurs in borehole D-40. Only 25 km from I-11, where red-streaked, pale yellow, pale buff and pale pink dolomite makes up the 160 m that were drilled into the Dolomite unit, the same position in D-40 below the regional unconformity is occupied by 244 m of silicified dolomite and siltstone and some red and dark grey shale and one 6 m-bed of black argillite. The fact that some siltstone is found in the upper part of the Dolomite unit in A-73, 55 km from D-40, might lend some support to equating the beds at D-40 to the Dolomite unit and in turn to postulating a rapid local facies change between I-11 and D-40. Alternatively, erosion might have removed the upper part of the Dolomite unit in D-40, leaving a dolomite-siltstone-shale lower part, a part not yet revealed by sufficiently deep drilling in other boreholes (see cross-section, Fig. 24). For the latter suggestion to be correct, resistant dolomite strata would appear to have been cut through very locally and this would possibly be a result more of a channelling process, rather than of erosion of a structural feature and if that were so, the resulting topographical "low" could be verifiable by its reflection in the overlying Cambrian deposits. The overlying Mount Cap Formation at D-40 is, in fact, exceptionally thick and, moreover, the excess thickness of 100 m approximates the thickness of its lower unit of glauconitic, oolitic dolomite and interbedded shale which at D-40 is a unique local feature (see cross-section, Fig. 24 and, p. 9). A tentative model then for D-40 is localized exposure at the pre-Cambrian surface of a lower dolomite-siltstone-shale member of the Dolomite unit in a paleo-depression (as opposed, for example, to the eroded core of an anticlinal structure) by the beginning of Mount Cap sedimentation.

Argillite unit

The reference section for the Argillite unit is in H-34o, one of only two boreholes in which it has been drilled within the study-area.

The Argillite unit in H-34o consists predominantly of black siliceous argillite, whose monotonous continuity through 876 m is broken by two relatively thin members:

> 146 m above the base, a varicoloured cherty member, 114 m thick, comprising pale grey, grey-green and grey-yellow argillite which is very siliceous and grades to chert; and 633 m above the base, 79 m of dark grey, green and some red-brown orthoquartzite, some silicified siltstone and argillite.

The contact of the Argillite unit with the underlying Dolomite unit appears to be sharp with no evidence of gradation. The Argillite unit is here considered to be overlain unconformably by the Lower Cambrian Mount Clark Formation (or equivalent) rather than the alternative possibility of a Proterozoic assignment of the overlying beds. While the evidence so far from the subsurface (p. 9) indicates that these overlying beds may overlie only the Argillite unit, thereby suggesting that they could feasibly correlate with the lithologically similar orthoquartzites of the lower part of the Katherine Group, this would mean that the sub-Cambrian unconformity would have to cut down abruptly through probably very much more than a 1000 m of section in less than 20 km between K-04 and L-26 (see cross-section, Fig. 24). The Mount Clark assignment, therefore, is preferred because of both its simpler structural implications and also the closer lithological similarity of these beds to the Mount Clark Formation, as described from outcrop (see p. 8).

Sixty-two kilometres from the reference section of the Argillite unit, borehole K-04 bottomed 98 m below the base of Mount Clark Formation in interbedded grey orthoquartzite and black argillite, which are assumed to correlate with part of the Argillite unit at H-34o.

The Argillite unit appears to correlate with the Tsezotene Formation (Aitken, pers. comm., Jan. 1979).

Orthoquartzite unit

Borehole A-22 was completed having drilled 24 m into orthoquartzite immediately below dolomite of the Franklin Mountain Formation. A-22 is located within the "crestal region of Mackenzie Arch" (Aitken et al., 1973, p. 14), where the Franklin Mountain Formation has been shown to rest unconformably on orthoquartzite of the Katherine Group (*ibid.*, p. 9, restored stratigraphic cross-section). On a reasonable projection northwestward of the crest of the Mackenzie Arch (see Fig. 3), a second borehole N-25, penetrated 167 m of similar orthoquartzite beds below the Paleozoic succession. It is, therefore, tempting to assign the lowest beds encountered in these two wells to the Katherine Group. However, because these two incomplete borehole sections tell nothing of the underlying beds, the beds will be referred to in this report as simply Orthoquartzite unit.

The Orthoquartzite unit in A-22, as already indicated consists, at least in the top few metres penetrated, of only orthoquartzite in which traces of pyrite were noted. The thicker section (in N-25) is also almost entirely orthoquartzite, composed of coarse silt to fine sand size grains of quartz but variably dolomitic. In the top 20 m, the orthoquartzite is noticeably more dolomitic grading to a siliceous silty dolomite.

Overlying the Orthoquartzite unit in both wells are 650 and 680 m respectively of dolomite beds, which undoubtedly belong to Franklin Mountain Formation. Of these, in N-25, the basal 57 m are unusually silty and sandy. Similarly in a third borehole, A-42, situated between the other two, traces of very sandy dolomite occur about 30 m above borehole bottom, which at 685 m into the Franklin Mountain dolomite, may well be very close to formation base.

Little as it is, the above data fits the picture presented by Aitken et al. (1973), in their restored stratigraphic cross-section through Mackenzie Arch: borehole A-22 may have bottomed in the lower unit of Katherine Group; N-25 may also have penetrated Katherine Group with some of its upper unit preserved below the unconformity; sand and silt in the basal beds of the overlying dolomite (N-25 and A-42) would also be an expected feature close to the crest of the Arch, as indicated on the restored section (*ibid.*, p. 9).

If correlation with the Katherine Group turns out to be correct, the age of Orthoquartzite unit would be Helikian(?) (Aitken et al., in press).

Tindir Group

The Tindir Group, whose rocks were first noted by McConnell (1889) was later named and mapped along the Yukon-Alaska International boundary by Cairnes (1914) who described it (*ibid.*, p. 45) as "composed dominantly of sedimentary rocks, but includes also, in most places, some basic volcanics . . .". The sedimentary rocks were stated (*ibid.*) to include, "mainly, quartzites, dolomites, shales, slates, phyllites".

Forty kilometres east of the International boundary, borehole G-31 penetrated 133 m of mainly varicoloured shales before drilling was completed. These shales are hard and range in colour, in order of abundance, from purple-red and brick-red to purple, dark grey-green and green. At the top is a 4 m bed of clear to pale green-grey, slightly pyritic orthoquartzite. These beds apparently belong to the Tindir Group, of which at the nearest outcrops, "north of Orange Creek in places, varicoloured slates and phyllites are the most conspicuous members" (Cairnes, 1914, p. 45).

As at the International boundary, so at G-31, the Tindir Group is overlain by Lower Paleozoic carbonates, in the subsurface section by white and grey dolomite assigned in this report to Franklin Mountain Formation (p. 15). The basal beds of this overlying dolomite at G-31 include some interbedded orthoquartzite and shale reminiscent of the Proterozoic-Cambrian relationship along the Mackenzie Arch (Aitken et al., 1973, p. 9 and this report, p. 16), some 300 km to the east.

Cairnes (1914, p. 56) considered the Tindir Group to be "entirely of Pre-Cambrian age, or . . . includes both Lower Cambrian and Pre-Cambrian members". Brabb (1967, p. A3), in drawing a compromise between paleontology and "stratigraphic discontinuity", stated, "The top of the Tindir Group is, therefore, provisionally and arbitrarily considered the top of the Precambrian in east-central Alaska". Similarly, Gabrielse (1967, p. 272, 273, Figs. 2-4; 1972, p. 522, Fig. 1) has indicated a Proterozoic (Helikian and Hadrynian) age for the Tindir Group.

Lower Paleozoic stratigraphy

The Lower Paleozoic succession of rocks in the subsurface of Peel River map-area consists of a lower clastics-evaporite series comprising three rock units and referred to as "Cambrian clastics-evaporites assemblage", an upper thicker carbonate series comprising a further three rock units grouped under the name "Ronning", and an equivalent succession of dark shales and carbonates included within the Road River Formation. Whereas the clastics-evaporites assemblage is known only in the eastern half of the study-area, the Ronning Group extends across the whole area, with the "western Ronning" including, in part, rocks transitional to Road River basinal facies whose domain is roughly the north-south belt of the Richardson Mountains.

Cambrian clastics-evaporites assemblage

In addition to nine boreholes which reached Precambrian strata east of the Richardson Mountains, a further six wells within the study-area were completed in the basal Paleozoic clastics-evaporite succession. Data from these fifteen boreholes have sufficed for recognition of two, possibly three, previously described Cambrian formations, and these are illustrated on two isopach and lithofacies maps (Figs. 4 and 5) and a scenario of the Precambrian subcrop presented in Figure 3.

The stratigraphic interval under consideration was referred to as Macdougal Group by Tassonyi (1969, pp. 13-14) who, in reviewing the historical development of the name, beginning with T.A. Link in 1921 (cited in Hume and Link, 1945), and its subdivisions both by Williams (1923) and Nauss (1944), adopted, as formal divisions of the Macdougal Group, Mount Clark, Mount Cap and Saline River Formations. Although at that time only two wells (southeast of the present study-area) had penetrated these strata, Tassonyi (*ibid.*) considered that the Macdougal Group was present in the subsurface within the entire Lower Mackenzie River and Anderson River area west of the Precambrian edge.

During the past decade the three formational names have proved their value in geological mapping of the Lower Mackenzie River area, while the group name has continued to have, as Tassonyi stated (*ibid.*), "only limited application". The term made its last appearance in print in Aitken et al. (1973), in which (p. 28) it was stated ". . .the term Macdougal Group is regarded herein as obsolete".

An aggregate of nearly 600 m of sediments is embraced by the three formations which constitute the Cambrian clastics-evaporites assemblage, including more than 250 m of Saline River halite. Complete sections of possibly all three formations together are found in only two boreholes, H-34o and K-04, and at those locations little more than two hundred metres of sediments make up the assemblage.

?Mount Clark Formation

At the base of the subsurface Cambrian clastics-evaporites assemblage east of the Richardson Mountains a relatively thin and apparently discontinuous deposit of orthoquartzite and varicoloured silicified siltstone is assigned with reservations to the Mount Clark Formation[1].

Mount Clark Formation was named by Williams (1923, p. 76B) at its type section on Cap Mountain. This same section was measured and described by J.D. Aitken and R.W. Macqueen in 1972 (Section AC-541 in Aitken et al., 1973, p. 148) and was summarized (*ibid.*, p. 34) as consisting of "orthoquartzitic sandstone and subordinate quartzite, white to yellow at the base, with purplish and reddish grey intervals increasing upward. . .", having a thickness in excess of 215 m.

Two complete sections of possible Mount Clark Formation have been drilled within the area of present study. The thicker section, in H-34o, is made up of a lower pale pink to grey orthoquartzite, 20 m thick; a middle green, red and yellow silicified siltstone, 61 m thick; and an upper 11 m of pink orthoquartzite, for a total formation thickness of 92 m.

In borehole K-04, 62 km east of the above section, the same interval is occupied by 76 m of orthoquartzite coloured mainly pink and purple, also some clear with red streaks. The only other borehole to penetrate this unit was G-55, 62 km northwest of H-34o, where an incomplete section, 21 m thick, consists of orthoquartzite and grey, dark grey, buff, red, pink, purple and pale green silicified siltstone.

Mount Clark Formation is certainly absent in L-26 (where, uniquely, the Mount Cap Formation also is missing), only 20 km from the section at K-04, and it is not recognized at four other locations (A-73, D-40, I-11 and N-39) farther to the east and northeast.

[1]Closer study to determine grain size within the orthoquartzite might be of help in making a more definite assignment, either to Mount Clark Formation which typically "should contain at least some medium-grained sand or coarser" (J.D Aitken, pers. comm., April 1980), or to Proterozoic Orthoquartzite unit, in which, if it is equivalent to Katherine Group, "very fine-grained sand should dominate absolutely, and there should be next to nothing coarser than fine sand" (J.D. Aitken, pers. comm., April 1980).

If assignment to Mount Clark Formation is correct, its lower contact with the Proterozoic Argillite unit would be unconformable at both H-34o and K-04. At these locations, as well as at G-55, the unit assigned to Mount Clark Formation is overlain by Mount Cap Formation, from which it is distinguished by its much greater degree of silicification, its lack of shale and by qualitative differences in the sonic logs (see cross-section, Fig. 24). This upper contact is clearly non-gradational at the three locations. In describing a Mount Cap Formation section in the Franklin Mountains (Section U-15 in Aitken et al., 1973, p. 118), Usher and Macqueen suggested a possible disconformity with the underlying Mount Clark Formation, adding "as though the Mount Cap basal units overlapped northward or eastward onto the underlying Mount Clark Formation quartzites". Confirming this in the subsurface is the areal discontinuity of Mount Clark Formation, which may be viewed as initial Paleozoic sediments filling depressions in the Precambrian landscape until the time when the general area was inundated and Mount Cap sediments buried both Mount Clark deposits and most or all of the remaining features of the earlier landscape. This view of localized accumulation of basal Paleozoic sediments is by no means novel. To the east of Peel River map-area, the deposition of penecontemporaneous clastic sediments was similarly explained by Macqueen and Mackenzie, 1973: ". . .the Old Fort Island is discontinuous, occupying paleo-depressions between knobs and ridges on the Precambrian erosion surface and thinning to the vanishing point where the unit abuts against Precambrian high areas".

Within the limitations of widely scattered borehole control, it appears that possible Mount Clark beds are restricted to an area coincident with the Precambrian subcrop of Argillite unit and that it is absent both over the crestal region of Mackenzie Arch to the southwest and over the subcrop area of Dolomite unit to the northeast. Given that the deposits here assigned to ?Mount Clark are, in fact, Cambrian and not Proterozoic the inference is that any paleo-depression on the Precambrian surface, in which Mount Clark sediments were deposited must have been the result either of minor crustal sagging or of deeper erosion of the less resistant Argillite unit. The latter model would more readily accommodate the absence of both Mount Clark and Mount Cap sediments at L-26 as the site of a resistant paleotopographic feature (discussed under Mount Cap Formation).

An Early Cambrian age was considered to be the most likely for the Mount Clark Formation in the Franklin Mountains (Aitken et al., 1973, p. 25). Because the basal Paleozoic sands are likely diachronous, the ?Mount Clark beds in the subsurface, though strikingly similar to, are not necessarily contemporaneous with, those in the outcrop. However, because they are similarly overlain by the Lower and Middle Cambrian Mount Cap Formation, the ?Mount Clark beds in the subsurface are probably Early Cambrian.

Mount Cap Formation

The name, Mount Cap Formation, was proposed and later redefined by Williams (1922, 1923) for "100 feet or more of green and rusty, thin-bedded sandstones and overlying grey and rusty shale or phyllites", overlying the Mount Clark Formation at the type locality on Cap Mountain. Subsequently, thicker sections were found which included carbonate. In 1968, Mount Cap Formation was measured at the Macdougal Group type section in Dodo Canyon by R.W. Macqueen, whose description of it (in Aitken et al., 1973, pp. 125-128 and 175) included dark grey shale and varicoloured quartzose sandstone, micritic limestone and dolomite, with a formation thickness of more than 100 m.

Within the present area of study, eight boreholes have penetrated strata which are here assigned to Mount Cap Formation. Of these, seven have complete sections. In addition, Mount Cap beds were found to be absent in three other wells (see Fig. 4). The subsurface Mount Cap Formation is characterized by varicoloured shales with variable, areally controlled, amounts of silicified siltstone, dolomite, oolite, sandstone, orthoquartzite and chert, most of which may be glauconitic. Figure 4 illustrates the distribution of Mount Cap deposits east of the Richardson Mountains, showing the boundary between a westerly sandstone facies and an easterly carbonate facies.

An anomalous maximum thickness for the Mount Cap Formation in the subsurface of 153 m was recorded in D-40. Dolomite, both pale buff and dark brown, is the dominant rock; oolite and glauconite are common, though mainly in the lower 100 m, the ooids mostly dolomitized or silicified. Varicoloured shale and siliceous siltstone make up only the upper 16 m of the section. As discussed in a previous section (p. 7), this lower glauconitic, oolitic dolomite unit at D-40 may represent early Mount Cap sedimentation in a localized pre-Cambrian topographical "low". Twenty-five kilometres to the northeast of this section at D-40, similar lithology to the upper beds at D-40 is found in the 57 m section at I-11, with significantly similar thicknesses of individual units up to the contact with overlying Saline River. About 40 km southeast of D-40, an incomplete section of 30 m above total depth in borehole J-42 shows almost identical lithology with the upper 30 m of Mount Cap beds in D-40. This similarity between the upper beds at D-40 and J-42 and the above-noted similarity of thicknesses of upper beds between D-40 and I-11, suggest that there is probably little or no erosional break at the Mount Cap-Saline River contact in that area. One other complete section in Mount Cap carbonate facies was drilled near to the eastern border of the map-area, at N-39 where 72 m are made up of mostly grey, green and black shales and aphanitic limestone, with a thin glauconitic dolomite at the base.

Three of the other four complete sections, which were assigned to the sandstone facies of Mount Cap Formation (G-55, H-34o and K-04) were distinguished from underlying Mount Clark(?) orthoquartzite and silicified siltstone on the basis of the presence in Mount Cap beds of both shale and glauconite and the absence of these in Mount Clark Formation. These three sections are located towards the westerly pinch-out of the overlying Saline River Formation (see cross-section, Fig. 24), in an area, therefore, where pin-pointing the top of the Mount Cap Formation might present problems. In the case of K-04, though drill cuttings from the Saline River evaporite member are missing, the sonic log indicates halite, probably with interbedded fine clastics, down to a borehole depth of 8211 ft. This leaves 51 m of siltstone, glauconitic sandstone and shale, above Mount Clark orthoquartzite, readily assignable to Mount Cap Formation. West of the limit of Saline River evaporite, at H-34o, Mount Cap beds, consisting of orthoquartzite (questionably glauconitic), purple and pink siltstone and purple and green-grey silty micaceous shale, are overlain by some 20 m of red beds, which, in turn, being overlain by grey-green and purple silty shale, are considered to be close-to-depositional-edge equivalent of Saline River evaporite, as discussed under that heading. Less straightforward is the most westerly section at G-55, where 15 m of shale, sandstone, orthoquartzite and siltstone occur between underlying 21 m of characteristic Mount Clark orthoquartzite and varicoloured silicified siltstone at the bottom of the borehole and Franklin Mountain dolomite above. The assignment of these beds to Mount Cap Formation is based on the presence of traces of glauconite throughout and of varicoloured shale and on the assumption that this location is west of the Saline River pinch-out. However, overstepping of Saline River Formation on Mount Cap Formation in the Mackenzie Mountains has been documented by Aitken et al. (Memoir 388, in press), so that at G-55 the 15 m of beds, here assigned to Mount Cap, may include Saline River shale in the upper part (6 m of green, red and purple shale and varicoloured orthoquartzite with a questionable trace of glauconite).

As mentioned above both Mount Clark and Mount Cap beds are missing at L-26, where Saline River halite rests directly on the Proterozoic Dolomite unit. It could be argued that this constitutes evidence of pre-Saline River truncation of Lower and Middle Cambrian beds at L-26, contrasting with the evidence of non-erosion at the three locations to the northeast (p. 9). However, if removal by erosion is to account for the absence of Lower and Middle Cambrian deposits at L-26, it is necessary to postulate post-Mount Cap uplift and truncation of strata down to Proterozoic at L-26, located between uneroded Mount Cap sediments to the northeast and those to the immediate southwest (as at K-04, 20 km away). Although we might invoke block faulting or folding, associated with renewed activity in the nearby Mackenzie Arch prior to Saline River deposition, a much simpler model is suggested by the nature of the rocks constituting the Precambrian erosion surface. As noted in the previous chapter, beds which are herein tentatively assigned to the Mount Clark Formation and which therefore, would represent initial Paleozoic sedimentation, accumulated in a limited area, a postulated paleo-depression, which area coincided with previously outcropping beds of the Argillite unit. Furthermore, these beds have not been found above the subcrop of Dolomite unit to the northeast. This should not be at all surprising. Differential erosion would be expected to have scoured out depressions in the relatively soft rocks of the Argillite unit, while leaving topographic highs of resistant dolomite to the northeast and possibly also the orthoquartzite core of the Mackenzie Arch to the southwest. Was borehole L-26 drilled on a seismic profile of one of the more conspicuous dolomite knobs of the Precambrian landscape? Could this not have survived as, say, an off-shore island, its shores sand-protected through Middle Cambrian time? A similarly resistant land feature may also explain why Mount Cap sediments are missing in the two boreholes, A-22 and N-25, which penetrated the Proterozoic Orthoquartzite unit in the crestal region of the Mackenzie Arch (see p. 7). Neither Mount Clark nor Mount Cap sediments had to be deposited and truncated over the Arch in order for Saline River Formation to overstep the edge of Mount Cap Formation, as clearly documented by Aitken et al. (in press). Cecile (in prep.) postulates a carbonate cover on the Mackenzie Arch, separating Mount Cap sediments from the Selwyn Basin to the southwest, with subsequent erosion before deposition of Franklin Mountain beds. Reasons given by Cecile (*ibid.*) are: (1) presence of transitional facies of Middle Cambrian age at location MPC-1 (see Fig. 4, this report); (2) preservation of Middle Cambrian carbonates on the southern Mackenzie Arch; (3) abundance of basinal limestone beds in Middle Cambrian shales in Misty Creek Embayment. Though further relevant comment is included in discussing the nature of the Mount Cap - Saline River contact, (see under "Saline River Formation-Lower clastic member); all in all, the model of non-deposition, rather than removal by erosion, of Mount Cap sediments at the three localities, is preferred, both for its simplicity and for its compatibility with the non-erosion evidence from the northeast boreholes (D-40, I-11, J-42).

The contact of Mount Cap Formation with the underlying Mount Clark beds appears to be disconformable, Mount Cap beds extending beyond the Precambrian topographically restricted depositional limits of Mount Clark clastics. The upper contact of Mount Cap with Saline River Formation, discussed on page 11, seems to be essentially conformable, with no reason to postulate more than a depositional break.

The age of the Mount Cap Formation is Early and Middle Cambrian, according to Aitken et al. (1973, p. 29), who summarized identifications of several collections of fossils from outcrops and boreholes in the Lower Mackenzie River area.

Saline River Formation

The term "Saline River Formation" was first used by Williams (1923, p. 77B) for beds, about 30 m thick, of red and green shale containing salt casts and gypsum, poorly exposed on Saline River near its confluence with Mackenzie River. Tassonyi (1969, p. 17) suggested that the Saline River Formation "would include all evaporites and evaporitic associations which are underlain by the Mount Cap Formation and overlain by the massive dolomites of the Ronning Formation, or by any continuous carbonate sequence". Tassonyi gave the Vermilion No. 1 well (see location on Fig. 1, this report) as reference section, in which he recognized (*ibid.*) "two distinct lithologies: a lower, thick salt and evaporite unit referred to as the salt member and an upper shale member that is partly evaporitic". Tassonyi stated (*ibid.*) that no data existed at that time "to verify the presence of the formation north of latitude 65°30'". Meijer Drees (1975, p. 12 and Fig. 12, p. 19) recognized a threefold division of the Saline River Formation in the Blackwater E-11 well south of latitude 64°: "a lower clastic member consisting of shale and anhydritic siltstone", shown (*ibid.*, p. 19) to lie unconformably on the Mount Cap Formation; "a middle evaporitic member comprising salt and anhydrite"; "and an upper clastic member consisting of shale and anhydritic salt and anhydrite". Because this same threefold division can be traced over a wide area with good well control north of latitude 64° and east of the present study area (J. Dixon, pers. comm., Sept. 1979), and because this division is clearly seen in only four borehole sections within the report area, formal naming of any of the sub-units will await future documentation of the Cambrian in the subsurface of Great Bear River map-area.

Within the Peel River map-area, twelve boreholes drilled into the Cambrian clastics-evaporites sequence have exposed eight complete sections of Saline River Formation, north to latitude 68° and west to about longitude 133° (see Fig. 5 for isopachs and lithofacies).

Lower clastic member. In four well sections near the eastern boundary of the map-area, a distinct unit of shale, siltstone, sandstone, dolomite and chert, underlying the salt member, is assigned to Meijer-Drees's (*op. cit.*) Lower clastic member on the basis of recognition of this member throughout the adjoining area to the east by J. Dixon and of his observation (pers. comm., Sept. 1979) of a depositional hiatus or minor disconformity at its base.

In three of the sections, to the northeast (D-40, I-11, J-42, see cross-section A22-A73, Fig. 24) this lower unit of the Saline River Formation displays a further threefold subdivision into a lower 6-12 m thick sub-unit of brown and dark brown siliceous dolomite, a middle 3-9 m thick chert zone, and an upper 18-27 m thick sub-unit of varicoloured shale, brown and buff dolomite, pale green and pale buff siliceous siltstone and minor amounts of white quartzitic very fine-grained sandstone and (at I-11) white "chalky" limestone. To the southeast at N-39, the Lower clastic member has a comparable overall thickness of 45 m but consists entirely of argillaceous dolomite with interbedded shale and traces of dark brown chert. The Lower clastic member at L-26 is absent below the Salt member possibly because of non-deposition over a Precambrian topographic "high" (see below and under "Mount Cap Formation").

J. Dixon's (pers. comm., Sept., 1979) placement of the Mount Cap-Saline River contact and his recognition of a minor disconformity or depositional break between the two formations thus defined are valuable contributions toward determining the regional nature of this stratigraphic boundary. In the northeastern part of the study-area, a near constant thickness of the upper beds of Mount Cap Formation (see p. 9) indicates that, at least in that area there was no substantial sub-Saline River erosional break, in agreement with Dixon. Seemingly in contradiction to that is the fact that at L-26 halite rests directly on beds which are assigned to the Proterozoic Dolomite unit, but as discussed in the preceding chapter, non-deposition of pre-Saline River Cambrian sediments, rather than removal by erosion, is a preferred interpretation at L-26. Preference for a near-conformable contact relationship is in agreement with several earlier authors (Williams, 1922; Hume, 1959; Bell, 1959; Douglas and Norris, 1962; cited by Tassonyi, 1969, p. 15), but contradicts with recent conclusions based on observations of this contact along Mackenzie Mountain front east of longitude 129°. Concerning that area, which proximates the zero edge of the Saline River Formation, Aitken et al. (1973, p. 31) reported, "Usher observed evidence of an unconformity at the Saline River -Mount Cap contact at Loretta Canyon[1] and subsequent mapping has provided incontrovertible evidence for this unconformity by demonstrating that in the Mackenzie Mountains the Saline River successively overlies formations ranging downward from Mount Cap to the Katherine Group". The same authors stated (*ibid.*, p. 28) "The Mount Cap Formation is encountered relatively rarely within the Mackenzie Mountains, owing to sub-Saline River or sub-Franklin Mountain erosion". In more detail, Aitken and Cook (1974, p. 9) have stated, "In the Mackenzie Mountains, erosion along the Mackenzie Arch has resulted in truncation of all Precambrian formations down to the lower unit of the Katherine Group by the base of the Mount Cap Formation (Fig. 2). The unconformity locally displays visible angularity. The Arch was reactivated as a positive element following deposition of the Mount Cap, because the Mount Cap is, in turn, truncated at the unconformity beneath the Saline River and Franklin Mountain Formations". They continue that at Imperial River the Mount Cap is overlain by the Saline River "at a clearly erosional contact". Further evidence for this unconformity is given (*ibid.*, p. 10) "the Saline River is unaffected by the Katherine Fault, which displaces the Mount Cap and older formations", adding that their observations "record a period of significant deformation and erosion along Mackenzie Arch that intervened between the deposition of the Mount Cap and Saline River Formations".

On the other hand, evidence indicative of a Saline River receding shoreline is provided in Usher's description (in Aitken et al., 1973, p. 100) of the Loretta Canyon (Imperial River) section that the basal unit of the Saline River Formation, "appears to thin to the west along strike", thereby inferring that the Mount Cap-Saline River unconformity, recorded in the mountains may disappear "basinwards" to the northeast.

It seems reasonable, therefore, to conclude from the assembled evidence that the strong angular unconformity below the Saline River may be restricted only to that area which in Cambrian time was high on the flank of Mackenzie Arch. Allowing for reactivation of the arch to accompany rising of a western land barrier (p. 12), in the absence of compelling evidence from subsurface data to suggest more than a depositional hiatus between Mount Cap and Saline River Formations, likely no more than relatively minor truncation at the depositionally-thinned edge of the Mount Cap took place before burial beneath the first Saline River sediments in earliest Late Cambrian or, as suggested by Aitken et al. (*ibid.*, p. 31) possibly even as early as latest Middle Cambrian time.

Salt member. The salt member is well developed at ten borehole locations with a maximum thickness of 265 m at N-39. Figure 5 includes data from three additional boreholes (E-15, K-24 and M-63) east of longitude 127°, allowing approximate isopachs to be drawn which indicate an elongated, rather than circular, shape to the body of halite, with axis trending W.N.W. between latitudes 66° and 67°. Such a shape, if correct, supports the concept of Tassonyi (1969, p. 18) that the salt member "is not a circular-shaped, basin-centre evaporite. Rather, the loci of the salt deposition may have been a trough-like depression with a Norman Wells-Fort Good Hope trend, brought about by compressional forces acting normal to the present Precambrian outcrop-edge". This concept is further supported by a recently published study by Matthews (1977, pp. C-42, 43) in the Lower Mackenzie River area, indicating that the salt member was deposited in graben troughs.

Aitken et al. (in press) have found that "the thick intervals containing halite encountered in the subsuface do not outcrop" in Mackenzie Mountains where "the Saline River is composed of red mudstone (commonly silty and sandy), red and green shales and siltstones, pale pink to grey gypsum (anhydrite in the subsurface) and grey, microcrystalline dolomite", but that "the abundant layers of calcareous, gypsiferous breccia of red bed fragments seen in outcrop may be a record of salt beds removed by solution". Mackenzie Mountain outcrop sections are records of sedimentation along the northwestern flanks of the ancestral Mackenzie Arch. Significantly, similar lithology was recorded in two borehole sections: at A-73, the most northerly well location in the map-area, where Saline River beds consist of a lower 17 m of siltstone shale and anhydrite, 20 m of anhydrite and an upper 49 m of grey, green and red shale with traces of siltstone, anhydrite and dolomite; and at H-34o west of longitude 132°, where a lower 20 m of red siliceous siltstone, orthoquartzite and coarse sand and pink, red and pale purple shale, are overlain by 19 m of varicoloured shale. The two 20 m sections of anhydrite and red beds, respectively, are considered to represent westerly near-shore sediments equivalent to the Salt member, indicating proximity to a western land barrier (see also p. 16) which, together with or as northern extension of, the Mackenzie Arch, were needed to inhibit marine circulation and thereby to give rise to the hypersalinity necessary for halite precipitation.

Upper clastic member. All twelve boreholes, which penetrated Saline River Formation, have complete sections of the upper member. In all but one section, this member overlies evaporite and varies in thickness from a maximum of 54 m to 30 m, with no obvious correlation with the underlying salt member isopachs.

Within the present area of study varicoloured shale, brick-red, green, olive-green, purple, brown and grey, constitutes the predominant and characteristic rock type in the Saline River upper member. Also characteristic of this unit east of longitude 131° are buff microcrystalline dolomite and minor amounts of anhydrite and locally, varicoloured siltstone and very fine- or fine-grained quartzose sandstone (see lithofacies map, Fig. 5). To the west, at H-34o, only grey-green and purple silty shale was observed in the upper

[1]Southeast corner of study-area, for location see Figure 5 of this report.

19 m of the Saline River Formation, which upper part is assigned to the Upper clastic member with the underlying 20 m of redbed clastics considered to be Salt member equivalent (see above)[1]. The westerly depositional edge is drawn to the east of G-55, although, as discussed on page 9, the section which has been assigned to Mount Cap Formation may include some Saline River shale in the upper part.

The Upper clastic member in all subsurface sections is overlain by the Franklin Mountain Formation. The relationship is conformable and gradational, although no difficulty was found in pin-pointing the contact with the aid of gamma-ray logs where predominantly shale beds change to predominantly argillaceous dolomite, the gradation, therefore, being less a feature of the contact than one of upward decreasing argillaceous content of the basal part of the Franklin Mountain Formation. An additional criterion was helpful for picking the contact at N-32, where 13 m of pale buff, microcrystalline to aphanitic dolomite and limestone are placed at the top of the Saline River Formation because they include interbedded grey-green, olive-green and maroon shales. This should not exclude the possibility of having minor greenish colouring in the otherwise normally grey shales interbedded with dolomite at the base of the Franklin Mountain Formation.

Road River Formation

Before considering the lower Paleozoic platform carbonates, it will be useful first to outline the nature and distribution of the basinal facies into which both lower and middle Paleozoic carbonates pass laterally. These approximately time-stratigraphic shale and limestone equivalents of the platform carbonates outcrop principally in Richardson and Ogilvie Mountains. There they were studied by Jackson and Lenz (1962) who proposed that they be called the Road River Formation, informally subdivided into lower and upper members. Some previous studies, cited by these authors and dating from 1905, had recorded the presence of graptolitic shales in the northern Yukon Territory. Jackson and Lenz were the first to zone them and described them (*ibid.*, p. 32) as "a thick sequence of alternating dark-coloured graptolitic shales, argillaceous limestones and subordinate amounts of chert, dolomite, siltstone and sandstone". A type section was designated on a tributary (Tetlit Creek) of the Road River, slightly north of the Arctic Circle in northwestern Richardson Mountains. Of special interest there from Jackson and Lenz's (1962) study are (*ibid.*, p. 32):

1) "This formation contains all the stages and sub-series of the Ordovician and Silurian of Britain";

2) In the Richardson Mountains the lower boundary was placed "where a thick sequence of limestones generally present in the lower part of the formation is apparently conformably underlain by shale, siltstone and sandstone of Cambrian Age" and the upper boundary where "the formation is unconformably overlain by Upper Devonian Fort Creek Shale" (Note: "Fort Creek" referred probably to Canol. At Trail River, about 35 km south of Road River, the Road River Formation is reported by Norris (1968b, p. 239) to be overlain unconformably by some 265 m of Middle Devonian Prongs Creek Formation);

3) In the Ogilvie Mountains the lower boundary was recorded as "abrupt . . .located where graptolite-bearing shales overlie a thick sequence of dolomites of probable Cambro-Ordovician Age" and "the upper part of the Road River Formation becomes gradually more calcareous and appears to grade into the overlying Devonian argillaceous limestones" (Note: Road River in Ogilvie Mountains overlain by Middle Devonian and older beds, Norris, 1967, pp. 106-119).

Although these boundaries for the type Road River seem to have been adequately and unambiguously defined, the subsequent recognition of Lower Devonian graptolitic shales (e.g. Lenz, 1966, 1968) and recognition of a distinct unit of Devonian shale (Prongs Creek Formation of Norris, 1968b, p. 23) above the graptolitic shales and below the Canol, have raised queries about the Road River upper boundary and have resulted in the name Road River being used to include all of the basinal shale succession below Canol (e.g. Norris, in press), this at the expense of acceptance of the name Prongs Creek. The technicalities concerning the legitimacy of including Prongs Creek within the Road River Formation appear to have been overshadowed by common practice dictated by systemmatic mapping. Although now there can be no reasonable doubt (see p. 23-25) that Devonian carbonate units pass laterally into three equivalent shale units in the Richardson Trough and that these shale units are in fact, the three informal divisions of the Prongs Creek Formation, as described by Norris (*ibid.*), yet the imperfectly defined boundaries of the type Prongs Creek (see discussion, p. 23-25), coupled with shadows of doubt about the precise upper limit of type Road River, seem to weigh heavily against retention of the name Prongs Creek. It is the consensus among the writer's colleagues that the beds which have been referred to as Prongs Creek be included within the Road River Formation and that the name Prongs Creek be regarded as obsolete. This suggested procedure is adopted in this report and the Road River upper boundary defined accordingly.

Future work on the Cambrian-Devonian basinal facies succession of the Richardson Trough may well delineate several mappable sub-units of the Road River Formation. From the results of work already directed to this end (Cecile, 1978, in press; Norford, 1979), it is considered likely (M.P. Cecile, pers. comm., Nov. 1979) that some divisions recognized within the mid-basinal sequence will turn out to be the homotaxial equivalents of the carbonate units of the Mackenzie Platform. Therefore, it would be premature at this point to introduce any formal nomenclature for sub-units of the Road River. Instead, the results of the present subsurface study are slotted into easily recognizable informal basin facies equivalents of defined platform carbonate units. The equivalents of the Franklin Mountain, Mount Kindle and Peel Formations are discussed below under "Lower Paleozoic basinal facies" and those of the Tatsieta, Arnica-Landry and Hume Formations are discussed under "Road River Formation - Devonian carbonates equivalents." Under the latter heading the upper boundary of the Road River Formation is also discussed.

Norford (1964, p. 3) gave a Late Cambrian (Dresbachian) age to the lower part of Jackson and Lenz's lower member of the Road River Formation at Trail River outcrop and place the Cambro-Ordovician boundary within

[1]The possibility of related redbeds at the base of the Franklin Mountain Formation on the southwest flank of the Mackenzie Arch is discussed briefly under "Franklin Mountain Formation - 2) Sand in the lower part", p. 16 this report.

the lower member. Norford (*ibid.*, p. 6-7) found that the lower member seemed to be restricted to Richardson Mountains, "but the upper member was deposited over much of northern Yukon Territory, progressively encroaching upon the carbonate banks during Ordovician and Silurian time".

The Road River Formation has wide regional distribution. Road River beds, outcropping at the Alaska International boundary at latitude 65°, were described by Churkin and Brabb (1965), as a predominantly shale and chert sequence, 120 to 270 m in thickness, ranging in age from Early Ordovician to Late Silurian, lying disconformably on a Middle and Upper Cambrian limestone sequence and separated by erosional disconformity from overlying Middle and Upper Devonian McCann Hill Chert. In Mackenzie Mountains, Road River Formation mapped by Aitken et al. (in press), "overlies the thick carbonates of the [Lower Cambrian] Sekwi and is overlain by Devonian carbonate formations". South of the present study-area in the Misty Creek Embayment, the Road River Formation has been found to comprise four mappable units (Cecile, 1978): lower shale; argillaceous limestone; chert-shale; and upper Grey limestone. All these four units now have formation status (Gabrielse, Blusson and Roddick, 1973; Cecile, in press). Southward again the Road River has been mapped (Gordey, 1978, 1979) in the Nahanni area, and Gabrielse (1975) introduced its usage into northeastern British Columbia where more recently the platform to basin facies transition has been studied by Cecile and Norford (1979). Norford (1979), in describing Lower Devonian graptolites within the Road River Formation in British Columbia, mentions that this belt of rocks extends as far south as Idaho, and states that the "various stratigraphic names [which] have been used for these rocks" and the "several rock-units [which] can be discriminated ---can be regarded as members within the Road River Formation or as formations within the Road River Group".

Due to structural deformation of the strata, thicknesses of the Road River Formation within the study-area have mostly been estimated and figures differ very widely. Jackson and Lenz (1962) gave thicknesses varying from roughly 1700 to 2700 m across the Richardsons, a distance of some 20 km and stated (p. 32), "Such differences in thickness are believed to be partly the result of faulting rather than vagaries in deposition". Norford (1964, p. 3) gave a total Road River thickness of more than 3000 m on the west flank of the Richardsons "where faulting is also present but less important". Recently reported measurements of the Road River south of the present study-area (Cecile, 1978, p. 376) show thicknesses "in excess of 2800 m --- at the basin centre".

Lower Paleozoic basinal facies

Road River equivalents of the Ronning Group of carbonate formations have been drilled within the study-area at six localities, between longitudes 134°30' and 138°, with complete sections in four of these boreholes. The six sections are widely spaced, from Ogilvie Mountains (D-77)[1] in the south, to north (I-51, K-35), east (N-25) and west (N-05, F-72) of the Richardsons. Thicknesses range from 236 m to more than 873 m. All six sections are lithologically divisible into two parts on the basis of darker colouring of, and presence of chert in, the lower part.

The fortuitously located borehole sections at H-71 and N-25 (see cross-section, Fig. 26) demonstrate the physical continuity of the Mount Kindle and Peel Formations as they pass into the upper part of the lower Paleozoic division of the Road River Formation. The two basinal units, therefore, are labelled as equivalents of the Mount Kindle and Peel Formations, and are discussed separately under those formation headings.

Included on Figure 26 is a composite Road River section from the type area, between N-05 and N-25. That part of the subsurface sections assigned to Franklin Mountain/Road River transition facies (see below, p. 16) (which may include Middle Ordovician equivalent of the Sunblood Formation, see p. 17) appears to equate to all of the Lower, and part of the Upper members of the type Road River.

Ronning Group

The name "Mt. Ronning" was published by Stewart (1944, p. 163) in a stratigraphic column for the Carcajou River area (after T.A. Link, Imperial Oil Limited), and applied to 488 ± m of "Limestone in thick and thin beds, hard, marble-like; also cherty in places", as a formation of Silurian age. Later it was reported (Tassonyi, 1969), "This formational name was originally given by Link, in an unpublished report [dated 1921, according to Norford and Macqueen, 1975, p. 3], to a section on Mount Ronning, in the vicinity of Macdougal Canyon".

Hume and Link (1945, p. 11) "---proposed to use the name Ronning Group for the succession of Silurian beds generally regarded as resting on Cambrian strata and overlain by the brecciated and non-bedded dolomites and limestones of the Bear Rock Formation ---". These authors continued (*ibid.*), "The upper limits of the Ronning Group are sharply delineated by a marked disconformity---, but the lower limits are somewhat more indefinite". Hume and Link on faunal evidence stated (*ibid.*, pp. 6, 13-16) that the Ronning Group included Franklin Mountain and Mount Kindle Formations and perhaps higher beds.

Tassonyi (1969, p. 23) used the name "Ronning" in the subsurface for "a carbonate sequence, consisting principally of dolomites, that occupies the stratigraphic position below the brecciated or evaporitic facies of the Bear Rock Formation, or the non-brecciated facies of the Gossage Formation (new name)[2] and the shaly, semi-evaporitic facies of the shale member of the Saline River Formation". The same author (*ibid.*) considered that the use of the term Ronning as a group was unjustified and gave it "formational status, pending recognition of mappable units within the carbonate sequence". Tassonyi (*ibid.*) gave a maximum thickness of Ronning, drilled in borehole A-37g of 943 m, which section was considered to be "almost complete". The present study, which, incidentally indicates an estimated total Ronning thickness of 1371 m at A-37g, shows that Tassonyi included in his "Ronning Formation" at A-37g all strata which in this report are included in Franklin Mountain, Mount Kindle and Peel (new name) Formations.

Macqueen (1970, p. 225) used the term Ronning Group "only in a reconnaissance sense", stating that "the four distinct stratigraphic units which comprise the type 'Ronning Group' on the south side of Dodo Canyon along the Mackenzie

[1] Borehole section reference number (see Appendix III) = D-77-65-50-137-00 Y.T. and N.W.T. Land Survey System.

[2] Name obsolete, this report, replaced by Tatsieta, Arnica and Landry Formations.

Mountain front can be mapped separately wherever they occur throughout most of the Operation Norman area". Macqueen's units were described (*ibid.*) as "Four, widespread, lower Paleozoic shelf carbonate units", including, from the base, "the informal 'cyclic', 'rhythmic', and 'cherty' units and the overlying Mount Kindle Formation".

Some 250 m north of Mackenzie Mountain outcrops, Lower Paleozoic carbonates were continuously cored in the A-73 borehole. The cores were examined by MacKenzie (1974) who recognized within this carbonate sequence eight units and sub-units: Franklin Mountain Formation, comprising Macqueen's 'cyclic', 'rhythmic' and 'cherty' units plus an uppermost 'porous dolomite' unit; Mount Kindle Formation; Lower Devonian and Upper Silurian carbonates; and (*ibid.*, p. 266) "Tassonyi's (1969) lower limestone member of the Gossage Formation [which] probably should be included in this sequence of [Lower Devonian and Upper Silurian Carbonates]".

Norford and Macqueen (1975, pp. 1-5) have outlined the 1921-1974 historical development of correlation of type sections of Franklin Mountain and Mount Kindle Formations and have assigned to the Lower Paleozoics in the District of Mackenzie: Upper Cambrian and Lower Ordovician Franklin Mountain Formation; Upper Ordovician and Lower Silurian Mount Kindle Formation; and "unassigned beds", placing an unconformity at the top of each of these three units.

Although the term "Ronning" has evidently limited application in surface mapping, the name, widely known if not widely used and having historically consistent definition, provides a ready and useful handle with which to refer to the Lower Paleozoic carbonate sequence, which, in the subsurface at least, is widespread and well-defined westward to Alaska (see note below). It is proposed to revive the name "Ronning Group", retaining the well-established and accepted definition which has positioned it in the post-Saline River, pre-Bear Rock/Gossage stratigraphic interval. For the upper sub-unit of the Ronning - the "higher beds" of Hume and Link (1945), the "Lower Devonian and Upper Silurian Carbonates" of MacKenzie (1974) and the "unassigned beds" of Norford and Macqueen (1975) - the new name, Peel Formation, is proposed (p. 20). For reasons stated elsewhere (p. 26), Tassonyi's Lower limestone member of the Gossage Formation, although treated as a separate formation in this report, is not included in the "Ronning" package.

Of the 71 boreholes, from which data was used to construct the maps (Figs. 6-9) and cross-sections (Figs. 25, 26) pertaining to the Ronning Group and its constituent formations and equivalents, 20 were drilled through the "Ronning" to sub-Franklin Mountain strata and 51 bottomed within the Ronning or its equivalent Road River facies. The isopach map (Fig. 6) of the Ronning Group was compiled using, in addition to raw data from the 20 complete Ronning sections, projected data from Figure 7 (mostly) and Figures 8 and 9, to arrive at reasonable estimates of Ronning thickness at 45 other locations. The Ronning isopachs, therefore, are somewhat speculative, but they have served both to illustrate for the entire area at least the major trends in thickness variations and to carry down-section structure contours to produce a scenario (Figs. 3, 5) of Cambrian and Pre-Cambrian surfaces.

Note: The use of the names Franklin Mountain, Mount Kindle and Peel Formations over the Porcupine Platform raises the question as to whether this is stratigraphically legitimate or desirable, when lithological continuity cannot be demonstrated between the Mackenzie and Porcupine Platforms. To decide this on whether or not the carbonate units to the east are somewhere physically continuous with similar litho-units to the west of the Richardson, is to miss what the writer feels is a highly important aspect of lithostratigraphy, namely, that within the bounds of practicality, the assignment of rocks units should be such that the name alone reflects a mental picture of the regional tectonic framework and depositional environment. Very similar sequences of lower Paleozoic carbonates built up on the Mackenzie and Porcupine Platforms and to obscure this picture by introducing a second package of names is felt to defeat a major purpose of rock-stratigraphic nomenclature. This is particularly true in the present case, in view of the probability (see Chapter III) that the Richardson Trough was a Paleozoic aulacogen, whose significance as a rift extending into one continental shelf would be lost in the mental image engendered by two separate packages of names.

A further question might now arise as to whether or not the use of one set of stratigraphic names is inconsistent with using separate tectonic names (Mackenzie and Porcupine Platforms) for the two areas of the one continental shelf. Apart from the need for separate names for two distinct geographical areas, perhaps, too, the nomenclatural distinction of the two areas of the shelf serves to emphasize that the Richardson Trough was more than a simple downwarping, but that (if, in fact, it was an aulacogen) it bissected the shelf with faults extending into the asthenosphere.

The argument for one set of rock unit names for the two separately named platforms will apply similarly to the Devonian carbonate sequence (see p. 26).

It should also be noted that, the priority of Mackenzie Platform names over those of the Porcupine Platform is sanctioned by Article 4b of the Code of Stratigraphic Nomenclature (American Commission on Stratigraphic Nomenclature, 1961) which states: "Extension of a defined unit to separated bodies of rock is permissible only where they are homotaxial". In this case, physical continuity can be traced through equivalent sub-units within the intervening Road River Formation (see under "Road River Formation" and "Devonian basinal shales").

Franklin Mountain Formation

The name Franklin Mountain was originally applied by Williams (1922, 1923) to 100 m of calcareous shale and limestone lying between the Saline River Formation below and the Mount Kindle Formation above, outcropping on the eastern slope of Mount Kindle in the Franklin Mountains. Douglas and Norris (1963, p. 11) reported nearly 400 m of Franklin Mountain Formation on the northeast face of Mount Kindle and described in this measured section (in ascending order): limestone and calcareous shale; dolomite; brown, green and red shales with subordinate sandstone and dolomite; and upper two-thirds mainly pale grey dolomite with minor chert lenses.

Tassonyi (1969, p. 20) considered that the lower shale and dolomite sequence of Douglas and Norris (*op. cit.*) were equivalent to the Shale member of the Saline River Formation and that the upper dolomite part was equivalent to the lower part of the Ronning Formation. Because of the uncertain definition of the Franklin Mountain Formation, Tassonyi (*ibid.*) omitted the name in his subsurface study in favour of "Ronning". On the other hand, in surface work Macqueen (1970, p. 225) used "Ronning" only in a reconnaissance sense in the plains east of the Lower Mackenzie River. Macqueen (*ibid.*) described three distinct stratigraphic units below the Mount Kindle Formation and referred to these informally as: Cyclic unit, 50-80 m of very finely crystalline dolomite and argillaceous dolomite, the latter disappearing upward; Rhythmic unit, 150-400 m of rhythmically alternating very finely crystalline dolomite and finely to medium crystalline dolomite, the rhythms disappearing westward; Cherty unit, "sporadically distributed as remnants from pre-Mount Kindle erosion" (*ibid.*, p. 229) up to about 170 m thick, of finely to medium crystalline dolomite "generally with lesser amounts of drusy quartz, chert, silicified stromatolites and silicified oolites".

Later as drilling began to expose the subsurface strata below the Lower Mackenzie River area, the "Ronning" sub-units of Macqueen (*op. cit.*) were recognized in borehole sections. Macqueen and MacKenzie (1973, p. 183) reported, "It is now clear that the Franklin Mountain and Mount Kindle Formations, as seen at the type sections in the Franklin Mountains near Wrigley, are recognizable over a large part of the Lower Mackenzie River region, including much of the subsurface and the original 'Ronning Group' type locality at Dodo Canyon along the Mackenzie Mountain front. . .". In the same paper these authors identified the Cyclic, Rhythmic and Cherty units in the cored borehole section at E-15 (by Colville Lake, east of the present study-area, see Fig. 7) where Franklin Mountain beds are at the present day erosion surface (see Fig. 26 for nearby section at M-63). Macqueen and MacKenzie (*ibid.*) gave a Late Cambrian age to the Cyclic and Rhythmic units and a ?Late Cambrian-Early Ordovician age to the Cherty unit.

The following year MacKenzie (1974) carried the three Franklin Mountain sub-units to another cored borehole section, far from outcrop sections, at A-73 near Tenlen Lake. MacKenzie included a "zone of floating sand grains" within the Cherty unit and added a "porous dolomite unit" above the Cherty unit. MacKenzie (*ibid.*) published a columnar section of the Lower Paleozoic carbonates (Ronning Group) at A-73, the lower part of which is included here as the overlying beds in the Proterozoic-Cambrian cross-section (Fig. 24).

The present study extends the Franklin Mountain Formation as a rock-stratigraphic unit westward almost to Alaska (see discussion under "Ronning Group", p. 14) and north into the Mackenzie Delta area (see Ronning Group Stratigraphic cross-sections, Figs. 25 and 26). Figure 7 illustrates the distribution of the Franklin Mountain Formation throughout the Peel River map-area, showing isopachs of and facies fluctuations within both the whole formation and the Cherty unit. Also shown are the western limit and eastern isopachs and lithofacies of the upper "porous dolomite unit" of MacKenzie (1974) and the postulated extent of the roughly equivalent Lower member of the Road River Formation, for which part there is no direct subsurface data. Correlation of the Franklin Mountain Formation was facilitated primarily by the areal persistence of cherty carbonate above the typical crystalline dolomite. It is readily apparent that delineation of the Cherty unit automatically delineates both the overlying non-or sparsely cherty "porous dolomite unit" and the underlying thick "Rhythmic-Cyclic" sequence. Because of this and because the rhythms characterizing the Rhythmic unit, which in any case are difficult to trace in the subsurface, disappear westward (Macqueen, *op. cit.*) and because furthermore, the Cyclic unit, equated by MacKenzie (1974) to the basal argillaceous beds in the subsurface, also disappears westward, therefore, the informal names, other than Cherty unit, have been omitted in this report. However, for the purpose of future reference, the basal argillaceous beds are traced on the cross-sections (Figs. 25 and 26) as far west as practical and they appear naturally as a separate descriptive unit in the well logs (Appendix III). The Franklin Mountain Formation, therefore, in the subsurface of the Peel River map-area is essentially a sequence of crystalline dolomites that includes a distinctive Cherty member at or near the top in almost every section.

The correlative value, however, of the Cherty member is restricted due to the presence westward of chert both in the upper part of the Franklin Mountain and throughout the overlying Mount Kindle, a problem which is discussed later under "Cherty member".

East of the Richardson Mountains, the unit overall is pale. Creamy white and pale buff predominate with some brown-coloured intervals and grey or brown-grey is common in the lowest beds especially where these are argillaceous and interbedded with subordinate grey or greenish-grey shales. Again very generally, the higher in the section, the paler the colours and the coarser the crystallinity.

West of the Richardson Mountains, as far as may be determined from mostly incomplete sections, the Franklin Mountain Formation, though very much thicker than, is lithologically almost identical to its eastern counterpart, except for a relatively thin upper cherty limestone and dolomite unit (discussed fully in the following section). Six boreholes in the west have penetrated deep into the Franklin Mountain beds with maximum incomplete thicknesses of greater than 1222^+ m at N-53 and 1200^+ m at D-77. The only complete western borehole section, at G-31, is a much reduced 779 m thick and, although farthest from, has the same overall lithological pattern which characterizes the subsurface Franklin Formation to the east: in the lower part, pale grey to dark grey, micro- to very finely crystalline dolomite and at the base some interbedded orthoquartzite and shale; in the upper 500 m, white to grey, very finely to coarsely crystalline dolomite. In a similar way, in all five incomplete sections west of the Richardsons, colours range from pale buff, buff and grey to white and brown and crystallinity from fine or very fine to coarse.

Variations within these generalized descriptions throughout the study-area fall into three main categories:

1) Franklin Mountain/Road River transition.

   At A-42, a probably near-to-complete section (685± m) consists predominantly of brown-grey, dark grey and black, silty and argillaceous, microcrystalline dolomite. Only traces of smoky chert and possibly some silicified oolite are present near the top of this section and below this the dark dolomite sequence is broken by two intervals, 50 and 150 m thick, of typical creamy white to grey-buff, finely and medium crystalline dolomite. Overlying this transitional section is a typical Mount Kindle dolomite sequence.

   At N-25, the transition is different. The Cherty member is well developed, made up of nearly 300 m of dark brown-grey to black, argillaceous and silty, microcrystalline dolomite with chert throughout ranging in colour from milky and mottled white, translucent, pale smoky with dark specks and pale buff, to brown and black and also some silicified oolite and clear quartz. Below this, the lower 300 m of dolomite are mostly "Franklin Mountain" except for a few silty and argillaceous intervals in its lower half. Above the Cherty member are 50 m of brown-grey and black argillaceous dolomitic siltstone and some dolomite with traces of buff, brown and black chert, which seem to be equivalent to the uppermost non-cherty dolomite elsewhere. The transitional Franklin Mountain at N-25 is overlain by black silty calcareous shales with traces of black chert, which are assigned to Mount Kindle equivalent.

The two sections at A-42 and N-25, demonstrate clearly both the generally fluctuating nature of the carbonate/shale front, and at two locations 100 km apart, opposing overall trends of receding and advancing carbonate banks across the Franklin Mountain-Mount Kindle boundary. These two sections constitute a northwestward extension of the "Transitional unit" of Aitken et al. (in press), which to the west of Arctic Red River in the Mackenzie Mountains "has been mapped only where the Mount Kindle Formation is recognizable above it; thus, it occupies the position of the Franklin Mountain and must be at least partly time equivalent". At K-35, in Mackenzie Delta area, an incomplete Franklin Mountain section consists of an upper 228 m of Cherty member, typical but for dark colouring and a lower 500 ± m of dark argillaceous and silty limestone and black silty calcareous shale and traces of grey finely to medium crystalline dolomite. This demonstrates the probable existence below the delta area of Road River facies equivalent to the lower part of the Franklin Mountain and, therefore, of the Lower member of the Road River. Confirming the presence of lowest Road River shale more than 150 km north of the Richardson Mountains outcrop section, borehole D-54 at Inuvik exposed an 815 m section of typical Franklin Mountain dolomite, complete with upper Cherty member, but including at its base 56 m of dark shales, underlain by Cambrian clastics on Precambrian.

2) Sand in the lower part.

Four borehole sections of Franklin Mountain carry quartzose sand in the lower part, at A-42, G-31, I-50 and N-25 (see Fig. 7). The basal sandy, silty dolomite beds at A-42 and N-25 have been discussed elsewhere (p. 7) in connection with the Orthoquartzite unit (?Katherine Group) on which they rest unconformably. At those locations, within a northerly projection of the crestal region of the Mackenzie Arch, quartzose clastic impurity is expected in the basal Franklin Mountain dolomite. A similar relationship exists at G-31 (already cited, p. 8) where orthoquartzite and shale are found interbedded with basal Franklin Mountain dolomite immediately overlying orthoquartzite and varicoloured shales of the ?Precambrian Tindir Group. In the fourth section, I-50, in the south Mackenzie delta area, typical Franklin Mountain dolomite is very sandy (fine to medium, quartz) throughout the 42 m at the bottom of the borehole. This sandy zone is 300-350 m below the top of the Franklin Mountain, which, according to the formation isopachs as drawn in Figure 7, would be about 350 m above the base of a "normal" Franklin Mountain section. If, on the other hand, the sandy zone is at the base of an anomalously thin Franklin Mountain, deposition may have been over a pronounced paleo "high", from which also the sand may have been derived. In either case, whether at the base of the formation or at mid-section, the abundance of fine and medium quartz sand content certainly indicates proximity to a source area, and one of similar nature to the Mackenzie Arch. One candidate for such an area is the postulated Cambrian western land barrier of the Saline River "basin" (see p. 12). Location I-50 represents about the northwesterly limit of probability for this Cambrian "high", beyond which as indicated by the Franklin Mountain transition beds at K-35, the earliest of the deeper water Road River shales were being deposited. Moreover, it perhaps would not be unlikely that the I-50 borehole was located over a paleo-structure similar to that which lies below the three locations to the south at N-25, A-42 and A-22.

In the Mackenzie Mountains, sand in the lower part of Franklin Mountain Formation has been noted by Aitken et al. (in press), "where the 'cyclic' unit is missing (notably across the crest of Mackenzie Arch), the basal few tens of feet of the 'rhythmic' unit normally contain at least a few beds of sandstone and sandy dolomite. . .". This sandy zone was stated (*ibid.*) to correspond to the "basal redbeds" unit, a discontinuous unit mapped at the base of, or below, the Franklin Mountain and overlying Proterozic beds in the Arctic Red River area (locations plotted on Fig. 7, this report). Because of similar stratigraphic positions, the basal Franklin Mountain sandy zone and the "basal redbeds" unit on the southwestern flank of the Mackenzie Arch may relate in some way to redbeds considered (see p. 12) to be shoreward equivalent of the Saline River Formation northeast of the Arch. More evidence, however, is required before Upper Cambrian relationships across the Arch can be determined.

3) Sand and colouring in the upper part.

In the southeastern part of the map-area eight borehole sections carry sand and shale and pink, red and green colouring in the uppermost Franklin Mountain dolomite (see lithofacies, Fig. 7). The eroded remnants of the upper non-cherty fine, medium and coarsely crystalline dolomite at G-26, N-39, K-68 and F-57 m are creamy white and pale buff with pink and at G-26 also with pale green. The topmost beds of the underlying Cherty member in most easterly sections are also coloured, much pink and red at K-68, traces of pink at N-39. The top non-cherty beds are sandy at three locations: fine to coarse rounded quartz sand and sandstone at K-68 and L-24; and medium sand and sandstone at G-26. At L-61 the Cherty member is in part very sandy (fine to medium grains). Green shale is common to all eight sections, but particularly so at K-68 where green-grey, olive-green and pale green shale is interbedded with and fills intercrystalline and intergranular spaces of the dolomite and sandstone. The red and green colouring of the dolomite and the green shale between grains and crystals is a feature of weathering that has been commonly observed below unconformities all along the Cordillera, according to J.D. Aitken (pers. comm., April, 1980) who considers that the quartz sandstone as well as the shale may also have been introduced from above. Supporting this view is the fact that the sand and colouring was seen only in the upper 40 m or less of the Franklin Mountain beds. Meijer Drees (1975) has, in fact, found the Franklin Mountain Formation thinning southward to a zero edge below a regional unconformity. However, the possibility is not ruled out that part of the clastic material, for example, sand grains in dolomite at four locations, is depositional, attesting to shoreline proximity toward the end of Franklin Mountain deposition. The westward migration of coloured beds, as shown on Figure 7, means that time of exposure to weathering may have been less in a westerly direction, inferring that the sea regressed slowly during the time of deposition of the Cherty member and uppermost Franklin Mountain sediments in that area.

Cherty member. East of the Franklin Mountain/Road River transition the Cherty member consists typically of finely to coarsely crystalline dolomite with chert and silicified oolites, all either milky white or pale buff, and some quartz. The unit reaches a maximum thickness of about 400 m over a wide area in the northeast part of the study area and it is particularly rich in chert and silicified oolites in the area of Manuel Lake. By contrast, the Cherty member is only about 60 m thick in two sections to the south, at A-22 and A-42, on either side of the pale to dark colour transition.

West of the Richardson Mountains, the Ronning Group is clearly distinguishable by the characteristic sequence of typical Franklin Mountain dolomite, topped by a cherty unit in turn overlain by two distinct units in the same stratigraphic position as the Mount Kindle and Peel Formations below characteristic aphanitic limestone and green micropyritic shale of the Tatsieta Formation (new name for Lower limestone member of Gossage Formation). A cherty sequence, therefore, is recognized as a rock stratigraphic mappable unit at, or near, the top of the Franklin Mountain Formation west to 139° latitude (it is absent at G-31). In a representative section of the "western Ronning", at N-53, this cherty unit is 179 m thick and consists of brown aphanitic limestone, some buff finely to medium crystalline dolomite and brown to brown-black and smoky translucent chert abundant in the top 30 m. Very little change in lithology was noticed between the four sections where the "western" cherty unit is present. Macrofauna from cored upper beds of the Cherty unit at both D-77 and N-05 have been assigned a Late Ordovician age by B.S. Norford (in Norford et al., 1971, p. 22-23). At N-49, the position of the Cherty unit is occupied by a non-cherty, dark argillaceous limestone unit, from which similar macrofauna have been dated as Late Ordovician by B.S. Norford (in Norford et al., 1973, p. 25-26) and also from which conodonts were identified by R.S. Tipnis (in Appendix I, 4-TTU-1978) who dated them as possibly late Middle to early Late Ordovician age.

Previous datings of the Cherty member have been not younger than Early Ordovician (Macqueen and MacKenzie, 1973; Norford and Macqueen, 1975; Aitken et al., in press). However, from the upper dolomite, 100 m above the top of the Cherty member at N-02 to the north, coral was dated by B.S. Norford (in Norford et al., 1973, p. 25) as "probably Late Ordovician to Devonian" - Late Ordovician or Silurian (B.S. Norford, pers. comm., April, 1980). If, therefore, the western cherty unit were taken to be the Cherty member of the Franklin Mountain, the result would be a time-transgressive unit, of Early Ordovician (or older) age in the east to Late Ordovician age in the west, a unit which was possibly still being deposited on the Porcupine Platform when Mount Kindle deposition was beginning on the Mackenzie Platform. The alternative assignment of the western cherty unit to Mount Kindle equivalent was under consideration until evidence in favour of a time-transgressive Cherty member came from the recently completed borehole at H-71, on the western edge of the Mackenzie Platform. R.S. Tipnis's conodont dating (see Appendix I, 9-RST-1979) indicates a Middle Ordovician (or younger) age for the Cherty member, at a point roughly midway between outcrops of Early Ordovician age and the western cherty unit of Late Ordovician age.

If, as the paleontological data suggest, conditions favourable for chert development migrated westward across the Mackenzie Platform during Early to Middle Ordovician time, then the migration might be expected to continue on to the Porcupine Platform by Late Ordovician time. One objection, that such a migration would cross the sub-Upper Ordovician unconformity to the east is not considered valid in the face of the continuous deposition in the Richardson Trough (see p. 12). Another objection, that the Porcupine Platform chert is dark-coloured in contrast to the very pale, commonly oolitic chert characteristic of the Cherty member is not in itself a valid criticism when, in fact, the chert of the Cherty member, as it is traced westward (see cross-section, Fig. 26), becomes dark-coloured within transitional facies, as at H-71, N-25, etc. On the other hand, in favour of assigning the western cherty unit to Cherty member, rather than to lower Mount Kindle equivalent, is the evidence (discussed under "Mount Kindle-Road River transitional unit", p. 19) pointing to erosional unconformity above, not below, the western cherty unit. Until such time that definite placing of this unconformity in the subsurface and the physical relationship between the eastern and western cherty units can be established, it is proposed to hang on the Porcupine Platform cherty unit a temporary label of ?Cherty member of the Franklin Mountain Formation[1].

The probability of Early Ordovician marine regression and subsequent weathering of Franklin Mountain beds has been discussed (p. 16) and below it is argued that the unconformity at the top of the Franklin Mountain must disappear toward the Richardson Mountains. In summary, therefore, the Franklin Mountain marine shelf, which during Late Cambrian time extended from the present Alaskan border east and south to Fort Simpson area, may have been restricted by Late Ordovician time to either side of the Road River shale trough, with chert still forming only over part of the Porcupine Platform. A general pattern of retreating marine waters was probably reversed from time to time as a result of "minor epeirogenetic events" (Meijer Drees, 1975, p. 20), giving rise to local disconformities within the Franklin Mountain Formation (e.g. an "apparently minor unconformity" below the Cherty member in the Franklin and Mackenzie Mountains, reported by Norford and Macqueen, 1975, p. 9).

Mount Kindle Formation

This term was first used by Williams (1922, p. 60B) for an estimated 150 m of Middle Silurian "grey magnesian limestone", exposed at Mount Kindle in the Franklin Mountains. This incomplete type section was supplemented from another outcrop south of Mount Kindle (Williams, 1923, p. 79B).

[1]It should be noted too, that recognition of the Cherty member at H-71 and its dating as Middle Ordovician at that location introduces the possibility that the Cherty member may be found to correlate southward with the Middle Ordovician Sunblood Formation, a map-unit overlying the Franklin Mountain Formation in the Mackenzie Mountains. This correlation therefore may become a factor in the determining of Cherty member limits.

Douglas and Norris (1963) described the Mount Kindle Formation from both outcrops and subsurface. The Mount Kindle in the type area was stated (*ibid.*, p. 11-12) to be about 270 m thick, estimated from two overlapping sections: one on Mount Kindle of the lower 160 m of "massive to thickly bedded dolomite medium grey, fine to medium grained, sugary and finely vuggy", of which "the basal beds are reefy and contain large colonial corals dated Late Ordovician (Richmondian) by Sinclair and Norford"; the other on Smith Ridge of about 230 m of "medium bedded, fine to medium grained, light brownish grey to light grey dolomites", in which "Fossils from beds near the top are of early Silurian age according to Norford". The Mount Kindle Formation was considered (*ibid.*) to rest, "apparently conformably", on the Franklin Mountain Formation and to be separated by unconformity from the overlying breccias of the Middle Devonian Bear Rock Formation. The same authors (*ibid.*, pp. 32-34) published a log of Imperial Redstone No. 1 well, in which the bottom 113 m were assigned to Mount Kindle Formation and described as brown, finely crystalline limestone and dolomite.

Macqueen (1970) reporting on Mount Kindle Formation in the northern Franklin and eastern Mackenzie Mountains, where its thickness, ranging from less than 90 m to about 450 m, is "related to pre-Devonian erosion" (*ibid.*, p. 229) described the formation as "a monotonous succession of uniform, medium to dark brownish grey, fine to medium crystalline dolomites" with abundant chert and silicified fossils.

MacKenzie (1974) in describing Lower Paleozoic rock units in the cored A-73 borehole section at Tenlen Lake, reported (*ibid.*, p. 266) that the Mount Kindle there consisted of 240 m "mainly of dark brown argillaceous and siliceous dolomite, commonly with silicified solitary and colonial corals, crinoids, gastropods, and bryozoans and the presence of nodules and thin beds of brown and white chert. The formation is conspicuously siliceous and fossiliferous throughout".

The subsurface Mount Kindle Formation, east of about 134° longitude, is of a uniform lithology consistent with previous descriptions. In 45 borehole sections of the Mount Kindle, 31 of which are complete, there is very little variation from brown, buff, grey, pale buff and dark brown, very finely to finely and medium crystalline dolomite, with some sucrosic texture and some intercrystalline and vuggy porosity. Pale-coloured chert occurs locally (see Fig. 8 for isopachs and lithofacies). In the northeastern corner of the map-area the Mount Kindle dolomites are in part very siliceous at K-15c and, as stated above, are siliceous throughout at A-73. In the southeastern corner the dolomite is in part paler in colour at N-39, G-26, K-68 and particularly so at A-53. At the easternmost of these sections, K-68 drill cuttings include some green-grey, pale grey and pale green waxy shale.

A fringe of limestone (see Fig. 8) borders the western edge of the Mount Kindle Formation, beyond which carbonates give way to the basinal facies of the Road River Formation. The section at J-80 exposes clearly the dolomite-limestone transition: the lower 151 m consist of dark brown-grey to grey-buff, micro- to finely and medium crystalline dolomite, with traces of mottled brown and grey chert; the upper 93 m are mainly limestone, brown, pale buff and white, aphanitic and finely crystalline and variably dolomitized, with subordinate brown, buff, fine to medium crystalline dolomite. Within the limestone fringe, the sections at B-25 and I-50 consist of pale buff and white aphanitic, micro- and finely crystalline, partly dolomitized limestone and some pale buff, fine and medium crystalline dolomite. This western "fringe" is consistent with surface observations: Aitken et al. (in press) report, "Pale grey weathering limestone occurs in the Mount Kindle in the vicinity of the facies change to shale of the Road River Formation". Near to the limestone fringe in the north, the Mount Kindle sections at A-05 and C-78 include at their top about 100 m of grey-brown, microcrystalline argillaceous dolomite, which at A-05 has been dated "Silurian", probably Late Llandovery (late early Silurian) by B.S. Norford (in Norford et al., 1973, p. 25) and which indicates transition northward to Road River facies.

The thickness of the Mount Kindle Formation in the subsurface ranges from zero at the truncated edges, both to the east of the study-area and also flanking the Aklavik "high", to a maximum recorded 440 m at G-55. However, more representative of Mount Kindle distribution is the fairly uniform thickness of around 200-250 m which is maintained over much of the area. Westward in contrast, the Mount Kindle appears to thin rapidly into the limestone "fringe", as evidenced by the sections at I-50 (135 m) and B-25 (60 m). The picking of the Mount Kindle top at these locations is dealt with under Peel Formation, limestone fringe (see p. 21). To attribute this thinning to subsequent erosion of Mount Kindle would be to place an unconformity between the Mount Kindle and Peel Formations in an area adjacent to the Road River shale "trough", in which deposition has been shown (p. 12) to have been continuous throughout the Lower Paleozoic. It means therefore, that the limestone fringe simply marks the basinward zone of reduced carbonate build-up. By reason again of continuous deposition of the Road River shales, both lower and upper contacts of the Mount Kindle may be assumed to be conformable in the immediate vicinity of the Road River shale belt. Eastward in the subsurface no direct evidence was noted of disconformable relationships below or above the Mount Kindle, but indirectly the irregularity of Mount Kindle isopachs in the easternmost part of mapping (see Fig. 8) may reflect either a sculptured surface of the underlying Franklin Mountain Formation (a hint of this appears in the Upper dolomite isopachs, Fig. 7), or erosion of the Mount Kindle itself prior to subsequent Peel deposition, or both. Consistent with these suggestions are the results of surface mapping (Aitken et al., in press) which indicate that the lower contact with the Franklin Mountain is regionally unconformable, and the upper contact with "undifferentiated Siluro-Devonian" is probably disconformable. Westward, both these stratigraphic gaps below and above the Mount Kindle must close. Precisely where they close may not be possible to map from present data, but one avenue of investigation is suggested by results of paleontology to date, namely the early(?) Late Ordovician age of topmost Franklin Mountain in the subsurface (see above) and the recorded Latest Ordovician age of basal Mount Kindle at the type area (in Douglas and Norris, 1963, p. 11-12).

Mount Kindle[1] *- Road River transitional unit.* In three subsurface sections west of the Richardson Mountains, a dark argillaceous limestone unit occupies the same mid-Ronning position as the Mount Kindle Formation between the Franklin Mountain and Peel Formations.

At N-53, herein designated the representative section of the "western Ronning", the Mount Kindle transitional unit consists of: a lower 57 m of dark grey-brown and buff-grey, micro- and very fine-grained argillaceous limestone, some black shale in the lower half and much black and brown-black chert in the upper half; a middle 50 m of mostly brown and pale buff, micro- and very finely crystalline limestone and some pale buff, medium and coarsely crystalline dolomite; an upper 16 m of dark brown and brown-black argillaceous microcrystalline dolomite with some dark brown-grey shale.

[1]See discussion under "Ronning Group" for use of name west of Richardson Trough (p.).

Compared to the 123 m section at N-53, the slightly thicker (147 m) section to the south at B-62 is significantly more transitional to Road River: a lower 74 m of black and dark grey argillaceous and silty limestone, in part grading to dolomite, some black calcareous shale in the lower half and much brown-black, pale brown and smoky chert in the upper half; an upper 73 m of black calcareous shale with some brown and buff-grey argillaceous limestone.

The third and most northerly section of the transitional unit, at N-49, consists of 201 m of dark grey calcareous shale and brown-grey, argillaceous limestone in the lower part, grading upward to buff "earthy-textured" argillaceous limestone, dark brown microcrystalline dolomite and black calcareous shale. No chert was recorded.

The vertical and horizontal relationships within and between these three and other sections are illustrated on the Ronning stratigraphic cross-section G31-M63 (Fig. 26) and the lithofacies map (Fig. 8).

Age determinations (for details see B.S. Norford in Norford et al., 1971, p. 22; B.S. Norford in Norford et al., 1973, p. 25-26; T.T. Uyeno, Appendix I, 4-TTU-1978) are as follows: at B-62, Middle Silurian for the middle of the lower half; at N-49, Middle(?) to Late Silurian for the upper half. The latter age validates distinguishing this unit at N-49 from the underlying, somewhat similar argillaceous limestone dated Late Ordovician (B.S. Norford and T.T. Uyeno, *ibid.*) and, in addition, these datings at N-49 indicate that Lower Silurian rocks may be absent there. In contrast, 75 km away at N-05, a late Early to Middle Silurian age was assigned (B.S. Norford in Norford et al., 1971, p. 22) to the basal bed of a 92 m section of brown shale and earthy and chalky-textured limestone (very similar to the Mount Kindle transitional unit at N-49). This rests on black shale and limestone of the Mount Kindle equivalent of the Road River Formation which in turn overlies Late Ordovician Franklin Mountain beds (see p. 17). The Silurian section at N-05, therefore, consists of both Road River shales and Mount Kindle transitional limestones. The implied absence of Lower Silurian beds at N-49 and the presence of basinward Lower Silurian shale at N-05 indicate the appearance of a stratigraphic discontinuity en route from "trough" to shelf, discussion of which is continued below. N-05 is also unique among the borehole sections to date in that the Lower-Middle Silurian transitional beds are overlain unconformably by Tatsieta limestone and micropyritic shale, Peel or equivalent Road River beds being absent.

A hint of other interesting facies changes within the "western Ronning" is provided by the westernmost subsurface section at G-31, where the mid-Ronning position is occupied by 26 m of grey-buff, grey, purple-red, pale purple, green, pink and pale buff mudstone, in part very sandy grading to orthoquartzite and in part very pyritic (up to 50% pyrite) and with traces of buff microcrystalline dolomite. The lithology indicates shoreward facies, presumably of a shoreline of uncertain age to the west. The only (indirect) paleontological evidence from G-31 is an Early-Middle Devonian age (A.W. Norris, see Appendix I, 1-AWN-1977) for beds within a thick sequence of grey dolomites, below which a thin dark argillaceous dolomite is considered to be dark dolomite facies of the Peel Formation (see p. 21), overlying the even thinner sandy mudstone, which in turn overlies typical Franklin Mountain dolomite. The Cherty member of the Franklin Mountain is missing at G-31 and the contact with the mudstone unit is sharp. Indication of a Lower Silurian stratigraphic break appearing westward between N-05 and N-49 is discussed above. The reflection of this on gamma ray-sonic logs (see Ronning cross-section, Fig. 26), while not very convincing between N-05 and N-49, is very clear further westward to N-53, B-62 and G-31. At G-31, on the other hand, the upper contact of the sandy mudstone unit appears to be gradational with the overlying argillaceous dolomite. Correlating from G-31 to B-62 (Fig. 26), the mudstone unit equates to the Mount Kindle transitional unit and, if not to the whole of it, then, by virtue of the indicated gradational nature of the upper contact, probably to the upper part. Given the recorded Middle Silurian age for the lower part of the transitional unit at B-62, the implication to be drawn from all the above data is that the Franklin Mountain to sandy mudstone contact at G-31 represents missing sediments of age ranging from pre-Late Ordovician to possibly Late Silurian, with the further implication that an emergent Franklin Mountain was re-submerged only gradually throughout Silurian time, the shoreline having receded to a little west of G-31 by possibly the Late Silurian.

This is compatible with Norris's (1968b, p. 180-208) section 24, part of which is sketched on cross-section G-31-M-63 (Fig. 26, this report). It shows a Middle Ordovician to Lower Devonian interval occupied by only 20 m of chert pebble conglomerate and varicoloured shale, beds which were included by Norris (*ibid.*) in his "Gossage" (Arnica Formation), but which may alternatively be related to the red sandy mudstone unit at G-31. Either way, a significant Lower Paleozoic unconformity on the Porcupine Platform has been demonstrated. The model of transgression throughout the Silurian of marine waters in which, west of the Richardsons, shales and argillaceous limestones were deposited over an increasingly wider area, is consistent with previous conclusions that Road River deposition reached its greatest areal extent during Late Silurian time (Norford, 1964, p. 7; Gabrielse et al., 1973, p. 72).

Road River Formation - Mount Kindle equivalent. Four complete sections at (D-77, K-35, N-05 and N-25) of lower Paleozoic basinal shales, underlain by Franklin Mountain Formation carbonates, have been found (see p. 13) to be lithologically divisible into two parts and because the lower part is demonstrably (at N-25 to H-71, see Fig. 26, and also at J-80 to I-51 and K-35) homotaxial with the Mount Kindle Formation, it is referred to as Mount Kindle equivalent. Lithofacies and tentative isopachs are shown, therefore, on the same map as Mount Kindle Formation (Fig. 8).

The Mount Kindle equivalent consists generally of black or very dark-coloured shale and chert and locally, some argillaceous dolomite or limestone. Chert content varies (see Fig. 8) from abundant in the south at D-77, through only traces to the east and west of the Richardsons at N-05 and N-25, to abundant in the north at I-51 (incomplete section) and K-35. In the latter two most northerly sections significant amounts of dark grey and dark brown argillaceous dolomite are present in a predominantly black shale and chert sequence. The least shaly section is at D-77, close by the Ogilvie Mountains, where grey to dark brown-grey argillaceous limestone predominates, with black calcareous shale and black shale as minor constituents.

The Mount Kindle equivalent appears, from the four complete sections available, to be remarkably uniform in thickness, from 144 and 145 m respectively at N-05 and D-77 to a maximum of 210 m at K-35, a variation of only 65 m over a distance of 250 km[1]. At these four locations, the underlying beds are thick Ordovician carbonates assigned to

[1]Note, however, that at N-05 this is overlain by 92 m of Mount Kindle - Road River transitional unit.

Franklin Mountain Formation. The Mount Kindle equivalent is overlain, apparently conformably, by the Peel equivalent in all but one borehole section, namely at N-05 where it lies below Mount Kindle-Road River transitional unit, above which Peel equivalent is absent. The basal few centimetres of the Mount Kindle equivalent at N-05 have been dated as probably Late Llandovery (B.S. Norford in Norford et al., 1971, p. 22). Therefore the age of the Mount Kindle equivalent at N-05 is probably no younger than Early Silurian and, because the underlying Franklin Mountain Cherty member has there been assigned a Late Ordovician age (B.S. Norford, *ibid.*), is probably no older than latest Ordovician.

Upper Silurian and Lower Devonian carbonates

A sequence of carbonate rocks, overlying the Mount Kindle Formation and overlain by Bear Rock or Arnica Formation in the Lower Mackenzie River area, has so far remained unnamed because of uncertainty of age, contact relationships and physical continuity with rock units to the south. In their mapping of the Carcajou Canyon area, Aitken and Cook (1974, p. 12-13) stated, "An easily mapped rock unit basal to the Devonian succession --- is treated here, with some reservations, as the Delorme Formation". MacKenzie (1974), in describing Lower Paleozoic carbonates in the A-73 well (at Tenlen Lake), referred (*ibid.*, p. 266) to 231 m of "Lower Devonian and Upper Silurian carbonates" overlying the Mount Kindle Formation, stating, "They may be wholly or in part lateral equivalents of the Delorme Formation of Douglas and Norris (1971, p. 10)", and added, "The name Delorme Formation is used frequently by industry for this part of the stratigraphic sequence". MacKenzie (*ibid.*) considered, "Tassonyi's (1969) Lower limestone member of the Gossage Formation --- probably should be included in this sequence of carbonate rocks". Cook and Aitken (1975), mapping areas of the plains north of the Mackenzie Mountains, referred briefly to a subsurface Upper Silurian "Unnamed unit" between the Mount Kindle and Gossage Formation, citing MacKenzie's (1974) description from A-73. Most recently (Aitken et al., in press), the "post-Mount Kindle, pre-Arnica interval --- is dealt with simply as containing an unnamed mappable unit, 'SD' ". The use of the term "Delorme" was discontinued (*ibid.*), partly because this name "has been extended to rocks far from the type section, different from the Delorme of the type area, and largely unfossiliferous" and partly because the Mount Kindle to Arnica interval to the south was occupied by both Delorme and Camsell Formations. The Camsell, a distinctive but discontinuous unit in the type area, was not recognized by Aitken et al. (*op. cit.*), and its equivalent, if any, was mapped as "part of Map-unit SD in the Upper Ramparts and Sans Sault map-areas".

The present study of the subsurface of the Peel River map-area identifies two distinct stratigraphic units, separated by unconformity, within the "Upper Silurian-Lower Devonian" interval and are referred to as Peel Formation, at the top of the Ronning Group and Tatsieta Formation, basal to the Devonian succession.

Peel Formation

The upper of the three sub-units of the Ronning Group throughout the Peel River map-area is clearly distinguishable in 56 borehole sections drilled to date. Of these 50 are complete sections, of which four are located west of the Richardson Mountains.

The name Peel Formation is proposed for the pale-coloured, generally micro- to finely crystalline dolomite sequence overlying the Mount Kindle Formation and overlain by the Tatsieta Formation. The type section designated is Pacific Peel Y.T. F-37, borehole footage interval, 10940-9793. F-37, located at 66°56'26"N latitude, 134°51'54"W longitude, KB elevation 55 m (179 ft), completed drilling 4th November 1972 at total depth 3368 m (11050 ft). Drill cutting samples are stored at the Institute of Sedimentary and Petroleum Geology of the Geological Survey of Canada in Calgary, Alberta. A descriptive log of the type section is shown in Appendix II, and sonic-gamma ray logs of this and other sections of the Peel Formation are included on Ronning stratigraphic cross-sections A37-N39 (Fig. 25) and G31-M63 (Fig. 26). The distribution of the Peel Formation in the Peel River map-area is illustrated on the isopach and lithofacies map, Figure 9.

The Peel Formation type section consists of 350 m of pale buff, pale grey and grey-buff aphanitic and microcrystalline dolomite, some of which is calcareous. The basal 50 m are in part argillaceous or finely silty and include some interbedded very dark grey shale. Pale grey and pale buff colouring and microsucrosic texture are characteristic features of the Peel Formation by which it is easily distinguished from underlying brown, less finely sucrosic dolomites of the Mount Kindle Formation and from overlying aphanitic limestone and pale green micropyritic shale of the Tatsieta Formation, or, where the latter is absent to the east, from overlying brown sucrosic dolomite of the Arnica Formation. Dark shales in the basal beds of the type section are not characteristic of the Peel Formation and at this location may represent uncommonly far eastward-reaching interfingering of Road River shale. The type section is located (see Fig. 9) bordering an area of transition to a limestone fringe (represented by sections at G-06 and I-50) adjacent to the Road River shale equivalent. However, there is also some evidence of limestone in the upper part only of some of the thicker sections of Peel Formation, as at O-27 (top 120 m of a 275 m section), at G-55 (top 50 m of 273 m section) and at H-37 (top 100 m), indicating that an upper dolomite-limestone member may have been more widely distributed than at present and have been removed by erosion, or alternatively could have been the result of localized facies variations. Thickness of the Peel Formation ranges from zero at eroded edges to the east and north to a maximum recorded 388 m at B-25. The Peel thickness variation is discussed mainly under the heading Sub-Devonian unconformity. However, a marked difference in thickness and variation of lithology between the two almost adjacent three wells demands separate treatment. F-57t and H-57 are about a kilometre apart, yet the Peel Formation in the westerly borehole (F-57t) is the thicker by 40 m and lithology changes from silty and argillaceous dolomites interbedded with some dark silty dolomitic shale at F-57t to typical Peel dolomite with a mid-section 60 m limestone and dolomite interval at H-57. In the latter section the upper part includes a minor amount of dark silty shale. The overlying Tatsieta Formation (see Fig. 11) similarly is thicker at F-57t by 36 m and identical Tatsieta lithology in three distinct sub-units has shown (p. 26) that the sudden east-to-west thickening is contained entirely within the thin basal unit (see Tatsieta Formation, stratigraphic cross-section, Fig. 29, and Appendix II for details). This indicated faulting in the Tree River area is referred to herein as Tree Fault. It is possibly also reflected in Peel Formation. The presence of darker clastic sediments in the thicker and more westerly of the two Peel sections (F-57t) might reflect a downthrown westerly block, conceivably even a miniature shale trough with a limestone-dolomite "fringe" on the eastern side. The relationship of Peel and Tatsieta Formations with respect to Tree Fault is discussed below (Sub-Devonian unconformity).

Important variations from type lithology fall into two categories:

1) Limestone fringe.

Occupying the stratigraphic interval of the combined Mount Kindle and Peel Formations at G-06 and I-50 is a sequence of limestones which offer no conspicuous changes in lithology (see Appendix II) or in sonic-gamma ray characteristics (see Ronning stratigraphic cross-section A37-N39, Fig. 25) on which to base an obvious subdivision. However, in this same interval a little to the south at B-25, 60 m of pale buff to white, finely crystalline limestone (thin for Mount Kindle) is overlain by 388 m of typical Peel dolomite and limestone. Projecting this to I-50, 135 m of pale buff, microcrystalline limestone with some dolomite are assigned to Mount Kindle, leaving for the Peel Formation 232 m of buff to white, mainly microcrystalline, with some very finely crystalline and some aphanitic, limestone, which in solution leaves a black bituminous residue. Correlating this to G-06 (where drill cutting samples below borehole footage 7350 are missing), the most reasonable assignment allows 177 m of Mount Kindle, overlain by 360 m of Peel Formation, which, from samples available, consists of limestone with black residue, identical to that of the Peel at I-50. Given the data from B-25, therefore, differentiating Mount Kindle from Peel within the limestone fringe turns out to be reasonably straightforward. Picking the Mount Kindle tops in this way shows rapid westward thinning of the Mount Kindle into its limestone fringe which is considered in this case (p. 18) to be a depositional feature. It also shows rapid changes in Peel thickness in the lower Peel River area (see Fig. 9). The 232 m section at I-50, for example, is very thin compared to the nearby 388 m section at B-25, 360 m at G-06 and 350 m at F-37, providing as discussed below, supporting evidence of erosion at a sub-Devonian unconformity.

2) Dark dolomite facies[1].

The top sub-unit of the "Western Ronning" as observed in four borehole sections west of the Richardson Mountains (see cross-section G31-M63, Fig. 26) consists of typical Peel dolomite, atypical dark-coloured dolomite and some argillaceous dolomite transitional to Road River shales. Typical Peel lithology comprises the entire 241 m Peel section in the "Western Ronning" representative section at N-53: creamy white to pale buff dolomite, with traces of pale buff-grey; finely to coarsely crystalline in the lower, micro- to medium crystalline in the upper part; traces of green and pale green shale in drill cutting samples. To the south at B-62, 169 m of mainly micro- to medium crystalline dolomite is buff to brown in the lower and pale buff and buff-grey in the upper part, with a mid-section interval of dark brown and black microcrystalline and argillaceous dolomite. The small and apparently isolated area of pale-coloured Peel, as shown by the above two sections, is bounded by darker beds: to the north at N-49, 80 m of dark brown, slightly calcareous, microcrystalline dolomite; to the west at G-31, 55 m of brown-grey to black, micro- to very finely crystalline dolomite, variably argillaceous and siliceous and in the lower part interbedded with black and dark grey dolomitic siliceous shale; southeastward the Peel passes into a dark limestone-shale transition, as observed in the 473 m section of Road River Formation, Peel equivalent at D-77 (see p. 22). These widely differing thicknesses of the "western" Peel Formation and the absence of equivalent Road River shales at N-05 (see p. 20) provide evidence of a post-Peel erosional discontinuity west of the Richardsons. Some dark dolomite facies was recorded also in wells on the Mackenzie Platform: in the northeast at A-73, I-11, K-15c and H-34w, dark-coloured argillaceous and silty dolomite and dolomitic shale is present in minor amounts in otherwise normal Peel sections; on the western edge of the Mackenzie Platform at H-71, the Peel Formation consists of both pale coloured and dark brown-grey to black argillaceous dolomite and includes a 38 m interval of black silty shale, indicating transition to equivalent Road River beds 14 km away at N-25.

Contact relationships. The lower contact of the Peel formation with Mount Kindle Formation is apparently conformable. However, because of the recognized (Aitken et al., in press) sub-Late Silurian (=sub-Map unit SD or sub-Delorme) unconformity, and the time equivalence (see below, p.) of the lower part of the Peel and the "SD" unit, the Mount Kindle-Peel contact may be in part disconformable. The upper boundary of the Peel Formation is a paleo-erosional surface at the sub-Devonian unconformity (see also under "Tatsieta Formation").

Age and Correlation. Paleontological data from three widely spaced locations point to a Late Silurian age: from mid-section at A-73, "probably Late Silurian, Ludlovian or Pridolian" (R. Thorsteinsson, see Appendix I, S-1-RT-1973); from mid-section at I-50 (limestone fringe), "Silurian" (B.S. Norford in Norford et al., 1971, p. 22); from top section at N-49 (dark dolomite facies), "probably Silurian" (T.T. Uyeno, Appendix I, 4-TTU-1978 - note that, because Uyeno dates the underlying Mount Kindle-Road River transitional unit "probably Wenlockian? to Ludlovian", the age of the Peel Formation at N-49 is probably no older than Late Silurian). Because the top of the Peel Formation is at a regional unconformity (see below), in which Peel beds younger than Silurian may have been removed and because of the Early Devonian age of equivalent transitional beds at D-77 (see below), the age of the Peel Formation may range from Late Silurian to Early Devonian. This confirms, therefore, that the Peel Formation is at least partly time-correlative with Map-unit SD of Aitken et al. (in press).

Road River Formation - Peel equivalent. Five complete sections of the Peel equivalent were recognized in the subsurface. Lithofacies are shown in Figure 9 in relation to the Peel Formation. Dark coloured shale is, as a rule, a major constituent of the Peel equivalent and is predominant in three of the borehole sections:

at N-25 - shale, dark brown-grey, calcareous; silty in the lower part;

at F-72 - shale, very dark to black, silty, grading to argillaceous siltstone; rare coarse-grained siltstone;

[1]See discussion under "Ronning Group" for use of name west of Richardson Trough (p. 14).

at K-35 - shale, pale grey to black, dolomitic; dolomite, argillaceous; rare siltstone and chert.

Peel equivalent in the other two sections consists predominantly of argillaceous carbonates with shale:

at I-51 - dolomite, mostly very dark to black, argillaceous and siliceous; shale, black, dolomitic; rare chert;

at D-77 - limestone, argillaceous, very fossiliferous; shale, black, calcareous.

Peel equivalent is thought to be absent at N-05 where typical Tatsieta beds rest directly on what appear to be Mount Kindle equivalents.

The Peel equivalent at D-77 and at N-25 is overlain by brown aphanitic limestone and by limestone breccia, respectively, which are assigned to transitional facies of the Tatsieta Formation. To the north, at F-72 and I-51, the Peel equivalent is overlain directly by undifferentiated Devonian basal shales, which may include at their base a Tatsieta dark shale equivalent.

The areal extents of the Peel equivalent and of the overlying Devonian part of the Road River Formation appear to be much the same (compare Figs. 9, 10), which might suggest a continuing stability within the shale trough, this more so to the north where the shale sequence is unbroken by Tatsieta limestone equivalents. The randomly variable thickness of the Peel equivalent (ranging from zero at N-05 to 786 m at F-72, see Fig. 9), while suggestive of a sub-Devonian erosional break (see following heading) extending into the shale trough, in part may be explained alternatively by depositional variations, such as varying detrital supply at a time of crustal movements affecting neighbouring areas. Such depositional continuity within the trough had been the regional pattern (demonstrated by Jackson and Lenz, 1962), along with erosional discontinuities within Ronning shelf carbonates, since Cambrian time. Postulation of areally variable rates of clastic supply to explain in part the thickness variations of the Peel equivalent is compatible with a noticeable increase of silt content in the Peel equivalent (compared with the underlying equivalents), and by the fact that by far the thickest section of Peel equivalent (at F-72) contains by far the greatest proportion of silt. This is further discussed under the following heading.

Conodonts from the middle of the Peel equivalent at D-77 have been given a late Lochkovian to early Pragian (Early Devonian) age by T.T. Uyeno (see Appendix I, 4-TTU-1978). A questionable Silurian age has been suggested for the top part of the Peel equivalent at F-72 (see Appendix I, RRNA-059-1973).

Sub-Devonian unconformity.[1] Isopachs of the Peel Formation and its Road River equivalent (see Fig. 9) illustrate throughout the map-area a very irregular pattern of thickness distribution. This is probably due to erosion of Peel strata rather than to tectonic events during deposition, although Tree Fault (p. 26), may have been a factor. The erosional implications of the widely varying Peel thicknesses within its limestone fringe and also west of the Richardsons have been mentioned above and further evidence of erosion is as follows:

1) In their mapping of the Sans Sault Rapids area, Aitken et al. (in press) observed "no change to a shoreline facies in unit SD as its feather-edge is approached, as would be expected if that edge were a depositional pinchout", and added, "This suggests that the feather edge is a result of erosional truncation at a sub-Arnica/Gossage (restricted) /Bear Rock unconformity".

2) The thicker Peel sections tend to include limestone in the upper part, a feature missing in thinner sections, indicating, as mentioned above (p. 21) that an upper dolomite-limestone member may have been truncated by subsequent erosion. If so, this would imply that the area of thickest Peel (in the lower Peel River area) suffered little or no erosion, even that that area remained submerged, a possibility which is compatible with a relatively thick overlying Tatsieta carbonate build-up (see p. 26).

3) The thickness distribution of the overlying Tatsieta Formation is considered to reflect deposition over paleotopographical relief (see p. 26) and this is indicated especially by the relationship of the Peel and Tatsieta Formations in the area of Tree Fault. The postulated "deep" on the west side of the fault was either not filled before the end of Peel deposition or the fault was reactivated before subsequent re-submergence, either way resulting in a paleo-escarpment which reflects in the Tatsieta thickness difference between the two Tree wells. Moreover, the fact that the Tatsieta is exceptionally thick in the Tree River area and the fact that only the upper of the three Tatsieta sub-units in the Tree boreholes is found in sections nearby (at F-79, M-05, A-05 to the west), indicate that the Tree escarpment topography was part of a broader depression, some 150 m or more in relief, which was submerged and filled with lime deposits probably before neighbouring localities were flooded.

   The presence of some dark silty shale in the upper part of the Peel section at F-57t (p. 20) suggests that this broader depression may have been initiated before the end of Peel deposition.

4) The absence of Peel or its equivalent Road River beds at N-05 and the evidence of generally deeper rather than shallower marine conditions west of the Richardsons, suggested by the western darker-coloured Peel sections, together indicate deposition and subsequent removal of the upper Ronning/Road River unit at N-05. Supporting this is Norris's (1968, p. 24) report of "an erosional unconformity with a relief on top of the Road River of 2 to 3 feet" at his section 35 on Trail River, 55 km east of N-05. In the northern part of the shale trough unbroken continuity of shale deposition is favoured (see above). To the south: at N-25, Landry/Arnica equivalent shales are separated from Peel equivalent shales of the Road River Formation by only 23 m of limestone breccia and black shale assigned to a Tatsieta-Road River transitional unit (see p. 26); at D-77, Road River transitional beds are overlain by Devonian carbonates. These data, together with the possibility that the widely varying recorded thicknesses of the Peel equivalent sub-unit of the Road River Formation may in part be explained by varying rates of detrital supply (see discussion

[1]"Sub-Devonian" is used in an approximate sense only, because the age of underlying Peel Formation may extend into Early Devonian.

under Peel equivalent, p. 22), indicate that, although the Road River shale belt evidently suffered truncation in the central part (N-05), it remained submerged, probably in the north and possibly also in the south.

In summary, a sub-Devonian regional unconformity is well documented for the study-area with evidence of differential crustal movements, faulting and general emergence and erosion of the Peel Formation and of at least part of the Road River Formation.

Lower and Middle Devonian stratigraphy[1]

The succession of Lower and Middle Devonian rocks in the subsurface of the study-area is represented to date by 59 complete borehole sections, one fault-repeated section and also 24 incomplete sections from wells in which drilling terminated within the Devonian succession. In addition, for the purpose of isopach and structure contour compilations, data has been used from 12 borehole sections to the north, east and southeast of the map boundaries. Nomenclature used is based on that recommended by Tassonyi (1969, pp. 32-40) who, in reviewing the complex history of Devonian nomenclatural development "since Kindle and Bosworth (1921) laid down the foundations of the formational framework", proposed a modified Devonian terminology most of which has continued to be acceptable in recent mapping. Norris (1968b, p. 11) found that all but two of the formations "typically developed in the central Mackenzie River region can be recognized" in the northern Yukon and northwestern District of Mackenzie and, in order to accommodate facies changes, named (*ibid.*) "four new distinctive rock units", which are discussed in the following pages. Seven Devonian carbonate and shale units within the study-area are packaged into two distinct sequences, "Devonian carbonates assemblage" and Horn River Group. Basinal shale equivalents within the Road River Formation are considered first.

Road River Formation - Devonian carbonates equivalents. The Road River Formation is taken to include in its upper part a basinal shale sequence which has been referred to as Prongs Creek Formation. The following discussion will provide a background for the proposal (see p. 12) to regard the name Prongs Creek as obsolete and at the same time will demonstrate the passing of Devonian carbonate units into equivalent shale units within the Road River Formation.

The name Prongs Creek Formation was proposed by Norris (1968b, p. 23) for "the sequence of Devonian dark grey to black shales with thin interbeds of black argillaceous limestones and black chert, which overlie graptolitic shales of the Road River Formation and are overlain by dark grey silty shales of the Canol(?) and Imperial Formations". Norris considered (*ibid.*, p. 23) the Prongs Creek Formation "to be confined to a relatively narrow north-trending belt --- to coincide roughly with part of the Richardson Mountains uplift", and showed (*ibid.*, Fig. 2) the Prongs Creek Formation to be time-equivalent of the succession Bear Rock/Gossage, Hume, Hare Indian and Ramparts Formations of the Mackenzie River area.

Norris's (*op. cit.*) definition of Prongs Creek Formation did not clearly satisfy Article 5 of the Code of Stratigraphic Nomenclature[2] which begins, "Boundaries of rock-stratigraphic units are placed at positions of lithologic change". Definitions of both lower and upper boundaries of the Prongs Creek Formation have remained in need of clarification:

- lower contact: In the type area, Norris (*ibid.*, p. 24) reported that this contact "is within shales and is for the present arbitrarily and tentatively drawn immediately above the highest occurrence of monographids", adding, "A detailed study of the rich faunas from immediately above and below will no doubt provide a more accurate placement of this boundary at a later date". As a result, the contact has remained obscure and, although Devonian basinal shales are more extensive than earlier believed (as documented in the present report), Prongs Creek beds have been included within the Road River Formation (see Norris, in press).

- upper contact: In the type area this was (Norris, *ibid.*, p. 24) "arbitrarily drawn at the disappearence of chert and change of colour of shales from dark grey or black to brownish-grey varieties generally containing orange-brown weathering clay ironstone nodules of the Canol(?) or Imperial "Formation". A conflict arises. If the Canol(?) was not intended to be included in the Prongs Creek Formation, as the original definition may imply, then the upper contact will necessarily lie where a thin black shale unit ("Canol") is found resting on the thick succession of black shales with thinly interbedded black argillaceous limestone. However, Norris's (*op. cit.*) description for the type area indicates that the overlying beds of brownish-grey shales are at the base of the Imperial Formation, in which case the "Canol" (if present as expected) was included, intentionally or otherwise, in the Prongs Creek Formation.

With the proposed inclusion of Prongs Creek within the upper part of the Road River Formation, our concern is to define unambiguously the upper boundary of the Road River. In surface mapping (D. Morrow, D.K. Norris, pers. comm., Nov. 1979), the "Canol" is seen as a widespread unit, easily distinguished, even in the trough area, from underlying basinal shales, however, it is not always so readily separated from the overlying Imperial shales. The "Canol" therefore, has been mapped (Norris, in press) as a separate unit overlying Road River Formation. The results of the present subsurface study show that the Canol Formation is indeed a widespread unit, but what has been referred to as "Canol" in the western half of the study-area represents, at least in part, a condensed basinal (lagoonal?) equivalent of the threefold Horn River Group to the east. Close to the eastern side of the Richardson Trough, the Horn River consists entirely of black Canol-like shale but includes at its base an identifiable Bluefish Member of the Hare Indian Formation (see p. 34). Therefore, to be clearly and precisely stated, the Road River Formation should be defined as overlain by the Horn River Group or its condensed basinal equivalent commonly referred to as "Canol".

The present study traces Devonian rock units through the subsurface from Mackenzie River westward to the Alaska

[1]The author recognizes and respects the views of colleague Dr. A.W. Norris who disagrees with the application of Devonian nomenclature presented in this report. In particular, Dr. Norris is opposed to extending the use of names northward from type areas in the southern Mackenzie Mountains. For example, Arnica and Landry have been carried through the mountains into the Peel River area by several workers, and are herein used west of the Richardson Mountains. Reasons for this and other applications of Devonian names are given in this report. Dr. Norris's treatment of Devonian stratigraphy will appear in a forthcoming report.

[2]American Commission on Stratigraphic Nomenclature, 1961.

border and shows that, in several boreholes along the eastern edge of the Richardson Mountains, all three Devonian carbonate units (Tatsieta, Arnica-Landry, and Hume Formations; see isopach and lithofacies maps, Figs. 11, 12 and 13) pass transitionally into basinal dark shale equivalents (see also cross-section, G31-F57, Fig. 27). The study shows also that the Horn River Group (Hare Indian, Ramparts and Canol Formations) condenses westward from a reef-shale assemblage into a relatively thin black shale ("Canol" of Norris, in press, and others). The belt of transition of Devonian carbonates to Road River shale facies to the east of the Richardsons follows roughly the underlying transition belt of Ronning carbonates to Road River shales. This is especially well demonstrated in the borehole section at H-71 where two of the three Ronning Formations and all Devonian carbonate units are clearly in transition through that area (see also under formation headings and Appendix II). Westward a little into the shale trough from H-71, the three Devonian carbonate units pass, at N-25, into clearly distinguishable equivalents within the thickest recorded subsurface Devonian shale section. There, 1069 m of Devonian shale facies consist, in ascending order, of a basal 23 m of limestone breccia and black shale (Tatsieta-Road River transitional unit; see p. 26), 857 m of grey, brown-grey and black calcareous shale, some argillaceous limestone and traces of buff aphanitic limestone (Arnica-Landry equivalent), and 189 m of black shale, white-speckled black chert and grey very silty limestone (Hume equivalent). Thus the upper (Devonian) part of the Road River Formation at N-25 consists of three distinct sub-units and it turns out that this threefold division is very closely correlative with Norris's original description (1968, p. 23) of his Prongs Creek Formation:

- "A lower division consists mainly of dark grey to black shales with widely spaced, thin interbeds of limestones and argillaceous limestones, some of which show brecciation and graded bedding suggesting deposition by turbidity currents" (Tatsieta-Road River transitional unit at N-25);

- "a middle division consists of interbedded shale and limestone, in part argillaceous and slightly cherty" (Arnica-Landry equivalent at N-25);

- "an upper division consists of interbedded shale and black chert" (Hume equivalent at N-25).

This similarity between Norris's divisions and the demonstrated shale unit equivalents of Devonian carbonate units provides an obvious basis for any future attempt to formalize mappable rock-units within the upper part of the Road River Formation.

Four other subsurface sections of Devonian shale facies are available from within the study-area. Roughly "on strike" with and 35 km from, N-25, the borehole at N-77 completed drilling 951 m into shales below the basal siltstone of the Imperial Formation. Of this incompletely drilled section, the lower 640 m of black and dark grey shale and interbedded argillaceous limestone are assigned to the Arnica-Landry equivalent sub-unit of the Road River and 311 m of black siliceous shale and white-speckled black chert to Hume equivalent (which may here include undifferentiated Horn River beds at the top).

Another section east of the Richardsons is in the south Mackenzie Delta at I-51, where Road River subcrops at the sub-Mesozoic unconformity. There, the lower 682 m of hard, black, micromicaceous shale (very sparsely fossiliferous, given a possible Devonian age by A.W. Norris, Appendix I, D-5-AWN-1972) and the upper 117 m of black siliceous shale, are interpreted, respectively, as the Arnica-Landry and Hume equivalents. The section overlies Peel equivalent, Tatsieta equivalent, implying that Tatsieta equivalent, if present, is included within Arnica-Landry equivalent.

On the Porcupine River at F-72, 115 km west of I-51, the upper (Devonian) part of the Road River Formation consists of a monotonous 467 m of dark grey to black, silty, micromicaceous shale; argillaceous siltstone; and rare coarse-grained siltstone (reported to be ?Lower to ?Middle Devonian, Appendix I, RRNA-059-1973). Contact with the underlying Peel equivalent at F-72 is pin-pointed on the basis of change in neutron log trace, supported by paleontological results (RRNA-059-1973). The insignificant lithological change across the contact would explain the failure to recognize the Prongs Creek Formation as a mappable unit west of the Richardsons, even though Norris (1968, p. 24) reported a 65 m-thick section of Prongs Creek black shales and chert, sub-cropping below the sub-Pennsylvanian unconformity 12 km from F-72.

The most westerly subsurface record of dark shale facies assignable to Devonian carbonates equivalents is at G-31 where 417 m of dolomite with some black shale, considered to be Arnica-Road River transitional unit (see p. 29), is overlain by 273 m of very siliceous black shale and chert. This shale-chert sequence appears to be an undifferentiated equivalent of upper Ogilvie and "Canol" (see cross-section G31-F57 m, Fig. 27) and is probably correlative with the McCann Hill Chert (Churkin and Brabb, 1965) of east-central Alaska.

Devonian Carbonates assemblage

Devonian carbonates assemblage refers to the succession of rocks comprising what has been called Gossage Formation (Tassonyi, 1969) plus the overlying Hume Formation. In the subsurface this assemblage comprises three distinct and mappable shelf carbonate units, which westward become an entirely limestone succession before passing transitionally into a threefold upper part of the Road River Formation. The assemblage is bounded below by a regional unconformity at its contact with the underlying Ronning Group and above by black shale at the base of the Hare Indian Formation.

A need was felt for a group name to refer to this neatly bounded assemblage of platform carbonates within the study-area, but because a formal grouping within this stratigraphic interval might conflict with Devonian nomenclature currently being developed to the south (D. Morrow, pers. comm., Nov. 1979; Meijer-Drees, in prep.), the informal designation, Devonian carbonates assemblage, is preferred. If, however, a formal group name turns out to be regionally desirable for this stratigraphic interval, it should be noted that the identical interval in the Mackenzie River valley area was named sixty years ago. The following discussion summarizes the technicalities behind reviving the name and gives reasons why the Devonian carbonates assemblage should not be referred to as "Gossage-Hume".

The name Bear Mountain Formation was used by Kindle and Bosworth (1921, p. 45B) for "beds which are composed chiefly of limestones with some gypsum and shale", outcropping near Fort Norman and placed (*ibid.*, p. 44B) stratigraphically above "Lone Mountain dolomite"[1] and below "Hare Indian River shales".

---

[1]It would seem from later work that this referred to what is now Ronning, not to Arnica which now superseded Lone Mountain (D. Morrow, pers. comm., November 1979).

Following the practice of Canol geologists, Hume and Link (1945, p. 16) used the name, Bear Rock Formation, "to describe the brecciated and non-bedded dolomites and limestones lying below Middle Devonian strata and above a sharp disconformity with well-bedded Silurian limestones below it". In fact, a new name, Bear Rock Formation, had come into common usage, undoubtedly growing out of, but applying to only part of, the old Bear Mountain Formation. More detailed work in the early 1940's had revealed, as stated by Tassonyi (1969, p. 34), "that a distinct limestone and shale unit intervenes between the Bear Rock Formation and Kindle and Bosworth's (1921) Hare Indian River shale", a unit which subsequently (Bassett, 1961) was named Hume Formation.

The type sense of the term Bear Mountain Formation, as originally intended by Kindle and Bosworth (1921) remained unchanged when the earlier term was superseded jointly by the Bear Rock and Hume Formations.

The name Gossage Formation was proposed by Tassonyi (1969, p. 48) "for limestones and dolomites representing open-shelf associations, overlying the Ronning Formation and overlain by limestones of the Hume Formation and which are thought to be partly or entirely time-equivalents of the Bear Rock Formation". Tassonyi (*ibid.*, p. 49) divided the Gossage Formation informally into three lithological units: a Lower limestone member, a middle Dolomite member and an upper Pellet limestone member. For reasons discussed below Tassonyi's Lower limestone member is treated as a separate unit with formational status (Tatsieta) and the Dolomite and Pellet limestone members are found to be precisely the Arnica and Landry Formations, respectively, as used by Aitken et al. (in press) at the adjoining Mackenzie Mountain front. The possibility of retaining the name Gossage, by raising it to group status to contain the three formations, is not recommended because of misuse of the name which has led to three different meanings from that intended by Tassonyi (1969):

1) "Gossage" = Lower limestone + Dolomite members of Tassonyi's Gossage.

This is illustrated on cross-section G31-F57 m (Fig. 27), showing that Norris (1968b), using the term "Gossage", removed from it the Pellet limestone member which (a) becomes the lower part of the Ogilvie Formation in the type section of the Ogilvie Formation (Norris, *ibid.*, section 24) and which (b) becomes in part the Cranswick Formation in the type section of the Cranswick Formation (Norris, *ibid.*, section 6).

2) "Gossage" = Dolomite + Pellet limestone members of Tassonyi's Gossage.

Aitken et al. (in press), following the suggestion of MacKenzie (1974, p. 266) to include Tassonyi's Lower limestone member in the "Lower Devonian and Upper Silurian Carbonates", have applied the term "Gossage Formation (restricted)" to the remaining two members. The term Gossage was not used by these authors in surface mapping in order to emphasize the fact that the Arnica and Landry Formations could be traced completely around the Carcajou Salient.

3) "Gossage" = Silurian-Devonian unnamed unit (Peel Formation, this report).

Norris (1967, p. 42-44) applied the name Gossage Formation to some 300 m (incomplete) of pale grey siliceous dolomites, overlying 234 m of "Mount Kindle Formation equivalent" in his section 5, which is located 23 km from borehole section A-42 where 232 m of Mount Kindle Formation are overlain by 220 m of Peel Formation pale grey dolomite.

For these reasons, the name Gossage is regarded as obsolete and, therefore, the three units to which it originally referred plus the overlying Hume Formation make up an unnamed Devonian carbonate assemblage.

A representative subsurface section of the Devonian carbonate assemblage is designated in the R.O.C. Grandview Hills No. 1 (A-37) borehole where it consists of Tatsieta Formation (type section, borehole footage 3462-3262), Arnica Formation (borehole footage 3262-2676), Landry Formation (borehole footage 2676-1874) and Hume Formation (borehole footage 1874-1578), giving a total Devonian carbonate thickness of 574 m. The Devonian carbonate assemblage is developed over both the Mackenzie and Porcupine Platforms[1] and reaches a maximum recorded thickness of 1181 m in the west at N-05. Between the platforms, the carbonates pass totally into the upper part of the Road River Formation (see p. 24).

Tatsieta Formation

A thin sequence of limestone and green shale at the base of the subsurface Devonian system has been known as the Lower limestone member of the Gossage Formation (Tassonyi, 1969, p. 49). It is overlain with sharp contact by the brown Dolomite member of the Gossage and it was because of this "conspicuous change in sedimentary regime from a relatively shallow to an appreciably deeper water environment" (MacKenzie, 1974, p. 266) that MacKenzie suggested (*ibid.*) that the Lower limestone member should be included in the unnamed Silurian-Devonian carbonate unit (Peel Formation, this report). The present broader study of the subsurface, however, in demonstrating an erosional surface at the top of the Peel Formation favours recognition of the Lower limestone member as a distinct stratigraphic rock unit between an unconformity below and a sharp depositional change above. It is proposed, therefore, to give this unit formational status, referring to it as Tatsieta Formation.

The type section selected is across the Mackenzie River from Tatsieta Lake in R.O.C. Grandview Hills No. 1 (A-37) borehole footage interval, 3462-3262. A-37g, located at 67°06'12"N latitude, 130°52'30"W longitude, K.B. elevation 369 m (1212 ft), completed drilling 27 March 1960 at total depth 1998 m (6555 ft). Drill cutting samples and cores are stored at the Institute of Sedimentary and Petroleum Geology of the Geological Survey of Canada in Calgary, Alberta. A descriptive log of the type section is shown in Appendix II. The radioactivity log of the type section and sonic-gamma ray logs of other sections of the Tatsieta Formation are included on Devonian stratigraphic cross-sections B25-P75 (Fig. 29), A37-N39 (Fig. 30), G31-F57 m (Fig. 27) and K60-J42 (Fig. 28). The distribution of the Tatsieta Formation in the Peel River map-area is illustrated on the isopach and lithofacies map, Figure 11.

The Tatsieta Formation type section consists of 61 m of pale buff aphanitic limestone, some white "chalky" limestone and some pale green micropyritic shale and it includes in the top 10 m pale grey very silty dolomite. A cored interval is discussed separately below. The type section limestone and

[1]Argument in favour of extending carbonate unit names from Mackenzie to Porcupine Platforms (see under "Ronning Group") similarly applies to Devonian units, but with less import, with the use of name "Hume" not recommended west of the Richardsons (see p. 31).

green shale are characteristic features which permitted easy recognition of the Tatsieta Formation in 38 of the 41 boreholes in which it, or its equivalent, is present. The presence of dolomite, which occurs only northeastward from Peel River (see lithofacies, Fig. 11), was noted at 17 locations and, among the thicker of these sections, pale grey silty dolomite is found only in the upper part, as in the type section. This is particularly significant in the case of the two Tree River wells at H-57 and F-57t, where the Tatsieta Formation is subdivisible into three units (see cross-section, Fig. 29 and also discussion below of Tree Fault.

> The basal sub-unit is pale buff, aphanitic limestone and some pale green and pale green-brown shale, 47 m thick at H-57, 79 m at F-57t; the middle sub-unit is creamy white to buff calcareous dolomite grading upward to microcrystalline dolomitic limestone, 79 m thick at H-57, 81 m at F-57t; the uppermost sub-unit consists of buff dolomitic limestone, pale grey silty calcareous dolomite and pale green micropyritic shale, 21 m thick at H-57, 23 m at F-57t.
>
> The top sub-unit in the Tree River wells seems to equate with the top 10 m of the type section to the east and also to be equivalent to the entire Tatsieta immediately to the west, as for example 13 m at M-05 (type limestone-dolomite-green shale lithology) and 15 m at F-79 (limestone-dolomite-black shale, transitional facies discussed below).

The evidence, therefore, from sections east of the Richardson Mountains clearly indicates that thickness variations of the Tatsieta Formation are largely, if not entirely, depositional, reflecting paleotopographic relief on the underlying Peel surface. Deposition appears to have begun, east of the Richardsons, in a paleo-depression from the present Tree River area north-northeastward (see isopachs, Fig. 11). Within this depression there existed at least one fault-generated escarpment, that of Tree Fault, as evidenced by the 50 m difference in thickness in the basal Tatsieta sub-unit between H-57 and F-57t. Only the top sub-unit in the Tree River area and type section is common to most of the area east of the Richardsons, demonstrating that thin areas in the Tatsieta isopachs are not a result of removal or non-deposition of the upper beds, but of non-deposition of the lower beds.

Distribution. Type lithology, generally without dolomite, extends westward to the Porcupine River area and the Tatsieta attains thicknesses far in excess of most of those around the type area. The thickest of the westerly sections, at B-25, is made up of 165 m of buff and pale buff aphanitic, partly pyritic, limestone with traces only of pale green-grey shale. Westward from B-25, green micropyritic shale increases and all sections in the western part contain some white "chalky" limestone. At N-53, on the Porcupine River, a 118 m section includes some pale grey and pale buff microcrystalline dolomite in the lower part. It is possible that the westerly Tatsieta carbonate build-up, especially at B-25, represents a longer period of sedimentation, being the initial deposition of Tatsieta shallow marine carbonate in a localized area that had remained submerged since Peel deposition, an idea arising from discussion of the Sub-Devonian unconformity (see p. 22).

Northwestward, at F-72 and I-51, no trace of Tatsieta equivalent was found at the base of the undifferentiated upper (Devonian) part of the Road River Formation. At N-25 a Tatsieta-Road River transitional unit, consists of 23 m of limestone breccia (basin slope?) and black calcareous shale. This transitional unit, which at N-25 separates the Peel equivalent from the Arnica/Landry equivalent, becomes in 15 km northeastward at H-71, a clearly distinguishable Tatsieta section between a transitional Peel and a transitional Arnica/Landry. The H-71 Tatsieta section consists of a lower 14 m of type limestone with traces of breccia and pale grey very calcareous shale and an upper 4 m of black calcareous shale and argillaceous bituminous bioclastic limestone. This upper dark unit at H-71 correlates northeastward again with an upper limestone-dolomite-black shale sub-unit (seen at H-37, F-37, C-60, L-50 and G-55), which comprises the entire 15 m section at F-79 and which itself represents a partially transitional facies of the upper limestone-dolomite-green shale sub-unit of the Tree River and type areas. Along the line of the present Arctic Red River, therefore, (see Fig. 11) where the Tatsieta isopachs indicate a continuously thin belt, the inferred underlying paleotopographical high probably had remained emergent throughout much of "Tatsieta" time. A later rise in sea-level and consequent flooding of at least part of the Arctic Red "high", may have resulted in a spread of basinal dark shales northeastward from N-25 which until then had probably been flanking the Road River basin.

On the opposite, northeastern, side of the Arctic Red "ridge" lay the paleo-depression in which, as discussed above the earlier Tatsieta sediments had been deposited. Evidence from the cored interval in the type section at A-37g (see description in Appendix II and Tassonyi, 1969, p. 191) of breccia, limestone sand and varicoloured shale suggests both collapsed evaporitic facies and proximity to land surface. Similar evidence was reported at A-73, from which MacKenzie (1974, p. 266) described limestone conglomerate and breccia and interbedded silty and sandy green waxy shale in Tatsieta core. Thus, the suggested paleo-"ridge" along the line of the present Arctic Red River may have acted as a barrier to open marine conditions giving rise to hypersaline waters to the northeast, and the subsequent deposition of the top sub-unit of the Tatsieta followed the breaching of the Arctic Red barrier between A-05 and G-55. Additional evidence of easterly land proximity was noted in the most southeasterly Tatsieta section at A-59, from which drill cuttings contain traces of white calcareous siltstone.

Contact relationships. The lower contact of the Tatsieta Formation with the Peel Formation is at the sub-Devonian erosional unconformity (see discussion, p. 22). The aphanitic limestone of the Tatsieta is readily distinguished from the microsucrosic dolomite of the Peel in drill cuttings. Because sonic log characteristics of the two units are similar (see Ronning Group and Devonian cross-sections, Figs. 25-30), the contact between them cannot be picked reliably without recourse to drilling samples.

There is no compelling evidence to suggest more than a depositional hiatus at the top of the Tatsieta. The absence of an uppermost limestone-dolomite-shale unit to the south, while suggesting the possibility of removal by erosion, alternatively, may well be the result of non-deposition and/or continuing limestone-shale deposition. The area in question, straddling the southern part of the postulated Arctic Red River "ridge", may have maintained an unchanged depositional environment when the "ridge" was breached to the north and the limestone-dolomite-shale unit was deposited in a belt northeastward from the shale "basin". The questionable zero edge of the Tatsieta near to O-65 (see isopachs, Fig. 11), if correct, similarly could indicate local non-deposition over the "ridge". The Tatsieta-Arnica/Landry contact, therefore, is considered to represent simply a significant change from a shallow and locally restricted, to an open marine, environment.

Age and correlation. Because of similar stratigraphic position, it is possible that the Tatsieta was deposited contemporaneously with a basal part of the Fort Norman Formation.[1] Either the Fort Norman tongue (see p. 28 and cross-section, Fig. 27) or its basal dolomite and green shale unit alone, are possible candidates for correlation with the Tatsieta, but borehole data at present is insufficient to establish physical continuity. Therefore, it remains to be worked out whether the indicated land area to the east of the Tatsieta "basin" was merely a narrow lowland separating it from the Fort Norman "basin", or even that there was some marine connection between the two depositional areas south of present latitude 67°N. Either of these latter two alternatives to a mainland Tatsieta shoreline would explain why a more pronounced shoreline facies has not been observed in Tatsieta sections close to its depositional edge.

The age of the Tatsieta Formation, from its stratigraphic position is not younger than and probably not older than, Early Devonian. Aitken and Cook (1974, p. 15) considered the Camsell Formation to correspond with the Lower limestone member of the Gossage (i.e. with the Tatsieta), but reported (*ibid.*) that contact relationships of the Camsell with underlying and overlying units do not correspond with those of Lower limestone member (Tatsieta). D.W. Morrow (pers. comm., May, 1980) considers that Tatsieta may be equivalent to Camsell and Delorme, but that nothing definite can be stated because the Delorme-Camsell relationship is not understood.

The Tatsieta-Michelle relationship also needs consideration. The Michelle Formation (Norris, 1968b) was described by Norris (*ibid.*, p. 16) as "a basal Devonian recessive shale and argillaceous limestone and dolomite unit unconformably(?) overlying Silurian graptolitic shales of the Road River Formation and sharply underlying Middle Devonian carbonates . . . .". At D-77, only 10 km from the nearest outcrops of the Michelle Formation, 9 m of brown, buff, micrograined to aphanitic limestone lies between Lower Devonian strata of the Road River Formation (see p. 22) and the Arnica Formation. This thin limestone at D-77, therefore, would seem to be in the same stratigraphic position as both the Tatsieta Formation (50 km from the Tatsieta zero edge as drawn on Fig. 11) and the Michelle Formation (10 km from outcrop section reported to be 187 m thick, Norris, 1968, p. 17), but because, according to Norris (*ibid.*, Fig. 2), the Michelle Formation is time equivalent of the "Gossage" (see p. 25, for discussion of misuse of name Gossage), the D-77 limestone is not clearly Michelle - yet it is not clearly homotaxial with the Tatsieta. Because it is, however, clearly below the Arnica Formation, it is referred to here as Tatsieta(?) equivalent. The possibility also exists that the D-77 limestone could represent deposits transitional between a shallow Tatsieta environment and deeper water Michelle environment.

Arnica and Landry Formations

The Arnica and Landry Formations, whose names were originated by Douglas and Norris (1961) in the Camsell Bend and Root River map-areas, have been mapped northward by Gabrielse et al. (1973) and by Aitken and Cook (1974, in press) to the northern Mackenzie Mountains and the Upper Ramparts River and Sans Sault Rapids map-areas (Aitken et al., in press).

Aitken et al. (*ibid.*) have described the Arnica Formation as "alternating thin sequences of beds of pale brown and dark brown dolomite, --- The dark brown dolomite is commonly argillaceous and very finely crystalline, while the pale dolomite is medium crystalline, sucrosic and commonly porous". The Landry Formation was described (*ibid.*) as "brown and dark brown limestone, --- mainly lime-mudstones within which scattered granular and pelleted areas are distinguishable". The Arnica-Landry contact was found by these authors to be interbedded and gradational, and the Landry Formation to thicken continuously westward along the Mackenzie Mountain. The top of the Landry Formation was drawn (*ibid.*) at the abrupt appearance of dark grey, fossiliferous limestone of the Hume Formation rich in skeletal particles.

The above descriptions by Aitken et al. (in press) of the Arnica and Landry Formations characterize, in the adjoining subsurface, the Dolomite and Pellet limestone member, respectively, of the Gossage Formation (Tassonyi, 1969). For reasons discussed elsewhere (see p. 25), the name Gossage is rejected and the names Arnica and Landry are carried into the subsurface where characteristic lithologies and contact relationships extend throughout both the Mackenzie and Porcupine Platforms.

The representative subsurface section of the Devonian carbonates assemblage in R.O.C. Grandview Hills No. 1 (A-37) well, which includes at its base the type section of the Tatsieta Formation, serves also to represent the subsurface Arnica and Landry Formations which occur in the borehole footage interval, 3262 to 1874. A brief descriptive log is included in Appendix II, a detailed description having been published by Tassonyi (1969, Appendix, p. 174-190). The radioactivity log of the A-37g section and the sonic-gamma ray logs of other sections of the Arnica and Landry Formations are included on Devonian stratigraphic cross-sections, B25-P75 (Fig. 29), A37-N39 (Fig. 30), G31-F57M (Fig. 27) and K60-J42 (Fig. 28). The distribution of the Arnica and Landry Formations in the subsurface is illustrated on the isopach and lithofacies map, Figure 12, compiled from data from a total of 83 boreholes, including 57 complete and 18 incompletely drilled Arnica-Landry sections within the map-area.

The twofold interval in the subsurface may be described concisely as comprising the Arnica dolomite which is generally brown and buff, finely crystalline and characteristically in part sucrosic with common intercrystalline and vuggy porosity, and the Landry limestone which varies from generally pale buff in the lower part to chocolate brown at the top and is aphanitic, variably argillaceous and pelletal. In the representative section at A-37g the contact is placed at borehole footage 2676, a natural choice on the radioactivity log (see cross-section B25-P75' Fig. 29) and one which follows Tassonyi's (1969, p. 51) original proposal to include "a transition zone of alternating limestone and dolomite" in the Pellet limestone member (Landry). When this criterion of Tassonyi is applied to other sections throughout the Mackenzie Platform (see particularly cross-section A37a-N39, Fig. 30), the "transition" may take the form of tongues and possibly lentils of Arnica brown dolomite within Landry pellet limestone. Tassonyi's criterion, therefore, in the light of the more regional study, turns out to be the most straightforward means of specifying the Arnica-Landry contact and can be re-stated as placing the contact at the base of the stratigraphically lowest limestone. However, it is the nature of the contact rather than its precise placing that is stratigraphically significant. Clearly such a transitional contact can hardly be conceived as recording anything other than a pulsating, but overall

---

[1]Fort Norman Formation (Meijer-Drees, in prep.) is the lower anhydrite unit, which together with Arnica and Landry Formations, makes up the Bear Rock Group.

easterly, migration of the dolomite-limestone depositional boundary and thus demonstrates that the Arnica and Landry Formations are largely, if not entirely, contemporaneous units. It is for this reason that they are considered jointly.

No attempt is made in this report to reproduce Tassonyi's (1969, p. 51-54) detailed accounts of his Dolomite and Pellet limestone members, which serve adequately to describe the Arnica and Landry Formations throughout most of the present area of study. Additional features are discussed in the four sections which follow.

I. Relationship of the Fort Norman Formation to the Tatsieta, Arnica and Landry Formations.

Toward the southeastern corner of the map-area, the Tatsieta-Arnica-Landry interval occupied by carbonates changes to the Fort Norman interval occupied mainly by evaporites (Fort Norman Formation, Meijer-Drees, in prep.). The area over which this transition takes place displays some significant features. East of the depositional edge of the Tatsieta Formation and south of latitude 67°N, the Arnica Formation, instead of lying directly on the sub-Devonian unconformity, as it does in three boreholes (J-42, I-11, K-15c) in the northeast, is found overlying a northwesterly projecting basal wedge of the Fort Norman Formation. Isopachs[1] of this wedge are included on Figure 12 and relationships between all of the rock units involved are illustrated on cross-section G31-F57 (Fig. 27). Thickening of the Fort Norman anhydrite at the expense of the Arnica and Landry Formations reaches its maximum within the study-area in F-57m where typical Arnica dolomite and Landry limestone have thinned to 44 m and 9 m, respectively. The Arnica and Landry jointly are evidently in part contemporaneous with the Fort Norman, the carbonate-to-evaporite boundary having migrated southeastward.

Of particular interest is a thin unit of pale, very finely to medium crystalline dolomite and green micropyritic shale at the base of the Fort Norman Formation (12 m thick at F-57m) and similarly also at the base of the Fort Norman anhydrite wedge (13 m thick at C-31). The same unit at the base of a 205 m-thick Fort Norman section at L-24 includes some chert in addition to dolomite and green shale and the shale is sandy. In seven borehole sections immediately northwest of the depositional edge of anhydrite (see map, Fig. 12), the Arnica rests upon pale, finely to medium crystalline dolomite (maximum thickness 63 m at A-23), with some green micropyritic shale mainly near the base and at A-53 the green shale was observed to be sandy (rounded medium sand grains of quartz). Sonic-gamma ray log correlation between C-31 and H-47m (see Fig. 27) supports the idea that this pale dolomite unit below the Arnica is a northwesterly extension of the basal anhydrite wedge of Fort Norman complete with its shaly dolomite basal bed. For this reason it is referred to as Fort Norman tongue and is, therefore, neither included in the Arnica Formation, nor is it taken to be an erosional remnant of the Peel Formation. The latter assignment to Peel Formation could reasonably be made on the basis of lithological similarities alone, but the error of this, by which the unit would be placed below the regional sub-Devonian unconformity, becomes quickly apparent when attempting to trace this unconformity on the cross-section (Fig. 27).

The thin dolomite and green sandy shale at the base of the Fort Norman Formation and of the Fort Norman tongue, may correspond to a lithologically similar, but very much thicker, unit mapped as Tetsoe Formation (Meijer-Dress, in prep.) below the Fort Norman Formation to the south. Likewise because of similar stratigraphic position, either this same thin basal unit alone, or the total Fort Norman tongue, may also correlate northwestward with the Tatsieta Formation. Whether they are physically continuous or not cannot be shown due to lack of well control (see cross-section, Fig. 27, A-59 to A-23). It may be of value to note for future resolution of this problem that, in the formations being considered, green shale seems to be confined to only the Tatsieta and basal Fort Norman. Two exceptions are some olive-green waxy shale in Arnica drill cuttings at N-39 and traces of green micropyritic shale throughout the Landry at K-15c, both locations close to the eastern edge of the map-area.

II. Limestone "fringe" and transition to shale.

The Arnica zero isopach (see Fig. 12) immediately east of the Road River shale trough, drawn on the basis of absence of Arnica in four borehole sections (B-25, H-37, I-50 and J-80, see Appendix II), indicates the initial position of the dolomite-limestone depositional boundary, or the initial extent of dolomitization. The total absence of dolomite in the Landry at B-25 and the recording of only traces of dolomitization at H-37 and J-80, indicate a narrow belt of continuous limestone deposition on the eastern margin of the shale trough. Thus, a limestone "fringe" to the Mackenzie Platform carbonates, similar to those described for the Mount Kindle and Peel Formations (p. 18 and 21), was re-established as an Arnica-Landry feature, but broadened through time as the area of dolomitization diminished eastward.

Evidence of the proximity of the Landry limestone "fringe" to the Road River shale trough was recorded in seven sections, on the basis of which was drawn the approximate extent of transitional facies on the map, Figure 12. The Landry transitional unit of argillaceous limestone and dark calcareous shale at H-71 has been discussed under "Road River Formation-Devonian carbonates equivalents".

At I-21, 27 km distant from H-71, an incompletely drilled section of similar transitional Landry consists of grey calcareous silty shale and limestones varying from aphanitic and pelletal to fine grained, silty, argillaceous and brecciated. At M-69, 15 km from I-21 and on the edge of the transitional belt, the Landry Formation includes 100 m of presumably slope breccia and this overlies a thin Arnica dolomite which is brown, microcrystalline and argillaceous. At H-37, 30 km north of H-71, a 700 m section of Landry consists of atypically darker limestone with minor amounts of interbedded black and grey shales. Farther north, at B-25, I-50 and J-80, Landry sections are in part darker and include some dark shales.

Transitional shale facies in the area of the Porcupine River are discussed below.

III. Porcupine Platform.

The Arnica and Landry Formations of the Porcupine Platform are lithologically very similar to those on the Mackenzie Platform. The combined stratigraphic interval, although very much thicker, exhibits a somewhat similar

[1]It should be noted that, in drawing Fort Norman isopach, reasonable assumptions were made that at H-73, 116 m of Fort Norman anhydrite are missing due to structural deformation (see Appendix III, p.), and that in the multifault-repeated section at K-68 (see Appendix II, p.) the Fort Norman anhydrite has suffered deformations ranging from exaggerated formational thickness to complete elimination at fault planes.

eastward irregular thickening of Arnica at the expense of Landry. An exception to the Arnica-Landry contact rule (developed above, p. 27) is necessary for the Porcupine sections N-05 and N-49, in which the Arnica carries minor amounts of limestone. Most Porcupine sections include some darker carbonate colouring and have some thin dark shales, mainly in the Arnica.

Two sections are chosen to represent the development of the Arnica and Landry Formations on the Porcupine Platform (see Appendix II for borehole descriptions):

At N-05, close to the eastern margin of the platform a maximum recorded Arnica-Landry thickness of 1048 m consists of 863 m of Arnica, buff brown, pale buff, buff-grey, micro- and very finely crystalline dolomite, in part sucrosic, with some brown aphanitic limestone in the basal part and with some interbedded very dark grey micromicaceous shale in the uppermost part; and 185 m of Landry, pale buff, white, brown, aphanitic and micrograined limestone, in part "chalky".

At N-53, in a central platform location, a total thickness of 626 m consists of both Arnica and Landry. The Arnica is only 135 m, brown, buff, pale buff, pale grey, micro- and very finely crystalline dolomite, in part sucrosic and with some pale green and pale grey shale in the basal part. The 491 m of Landry is brown, buff and white limestone, largely aphanitic, but also in part "chalky", fragmental and "earthy" and with minor amounts of brown chert and, in the lower half, much brown to brown-black microcrystalline and argillaceous dolomite. The increase of dark sediments at N-53 may mark the beginning of a westerly "shaling out" to Road River Formation, the transition to which is evident in G-31 where the Lower and Middle Devonian interval consists of 417 m of dark grey, grey and pale grey micro- to very finely and finely crystalline dolomite with some breccia and some black shale.

IV. Relationship to the Ogilvie Formation.

The transitional section at G-31 yielded, from core, about 100 m above the base, an echinoderm ossicle which has been dated by A.W. Norris (see Appendix I, 1-AWN-1977) as mid-Emsian to early Eifelian and probably from the "Ogilvie Formation". The name Ogilvie was proposed by Norris (1968b, p. 28) for "the Devonian carbonate succession overlying the Michelle and Gossage Formations", occurring from the Mackenzie Mountains to the Ogilvie Mountains and appearing "also to underlie the southwestern part of the Porcupine Plateau and the southern part of the Eagle Plain". The lower part of the Ogilvie Formation yielded fossils which "are pre-Hume in age and indicate a lower Middle Devonian (Eifelian) age", and "correlates roughly with the middle part of the Prongs Creek Formation" (*ibid.*, p. 31). The relationship of the Ogilvie type section to the closest Devonian subsurface sections is illustrated on cross-section G31-F57 (Fig. 27). Norris's "Gossage" and lower Ogilvie are apparently the Arnica and Landry Formations, respectively. Arnica is preferred to "Gossage" (see p. 25) and the use of the names Arnica and Landry in the Porcupine area emphasizes the very broad areal extent of a consistent shelf carbonate unit. The correlation of the Landry section at B-62 with the lower Ogilvie allows the possibility of referring to the latter as the Landry Member of the Ogilvie, thereby linking Ogilvie to the regional picture. The relationship of the upper Ogilvie with the Hume Formation is discussed under the following heading.

In addition to the paleontological evidence of "mid-Emsian to early Eifelian" (Early to early Middle Devonian) age (A.W. Norris, *op. cit.*) for the Arnica to Road River transitional facies at G-31, age determinations have been made on fossils from two other sections assigned to Arnica: at I-06, a mid-section age of "probably Early Devonian" by A.E.H. Pedder (in Norford et al., 1973, p. 22); at N-05, from near the base, a "probably Late Silurian, Ludlow" age by B.S. Norford (in Norford et al., 1971, p. 22) revised to Silurian or Devonian (B.S. Norford, pers. comm., March 1979).

Hume Formation and upper Ogilvie Formation

The term Hume Formation was proposed by Bassett (1961, p. 486) "for a succession of fossiliferous Middle Devonian limestone and, in places, shale which overlies the Bear Rock Formation and underlies the Hare Indian Formation". Bassett designated a type section "exposed at the front of the Mackenzie Mountains on the east branch of Hume River" (see map, Fig. 13 this report), which was described (*ibid.*, p. 486-487) as grey and brown-grey limestones, shaly limestones and calcareous shales. The limestones southeastward from the type locality were reported (*ibid.*, p. 287) to "contain numerous corals (but are not biostromal)". The thickness of the Hume Formation was stated by Bassett (*ibid.*, p. 488) to range from 122 m at its type locality to 168 m in the central Mackenzie River country and to increase southward and westward to more than 300 m in the mountains west of Fort Simpson. Bassett's (*ibid.*, p. 487) description of the Hume type section indicated a five-fold division, in ascending order: 8 m of limestone and interbedded calcareous shale; 73 m of argillaceous, very fossiliferous limestone and calcareous shale; 27 m of very fossiliferous limestone; 5 m of shaly limestone and calcareous shale; and 9 m of fossiliferous limestone.

Tassonyi (1969, p. 62) also recognized that in the Hume Formation "A five-fold division is clearly discernible in the subsurface in the Norman Wells area and consists of three predominantly limestone members and two intervening shale members". The thicknesses were reported (*ibid.*, p. 64-65) in ascending order: 11 m, 12 m, 15 m, 18 m and 60 m. Tassonyi considered that three informal members should be recognized by treating the lowermost three lithological divisions as one sub-unit member because of facies changes.

A five-fold division may be seen in borehole sections of the Hume Formation in the southeastern corner of the map-area. Cross-section G31-F57 (Fig. 27) illustrates this divisibility on sonic-gamma ray logs, carried from C-31 westward through H-47m, A-23 and A-59 to I-77. Thicknesses of five sub-units closely resemble those of Bassett's five lithological sub-units of the type section 25 km away. Eastward from C-31 the lower two divisions in the suburface seem to lose their distinction and, westward from I-77, the upper three divisions merge into one limestone unit. The five-fold division of the type area has very different relative thicknesses from those reported by Tassonyi (*op. cit.*) 100 km to the southeast and also differs from the three- or four-fold division 100 km to the north, as seen on cross-section A37-N39 (Fig. 30). Therefore, because of evidently rapid facies changes, sub-units of the Hume Formation appear to have only local significance and do not justify formal recognition. Informal recognition of localized sub-units may prove useful, as for example in the correlation of the lower shaly part of the Hume at A-22 with the black shale tongue in the transitional section at A-42 (illustrated on cross-section, Fig. 27, and discussed below).

Hume lithology is traceable in the subsurface westward and northward. With the exception of reef development over part of the Porcupine Platform, characteristic lithology was observed in the Landry-to-Horn River stratigraphic interval in all borehole sections studied. The most consistent lithological Hume characteristic is bioclastic, highly fossiliferous and argillaceous limestone and in addition most sections on the Mackenzie Platform include much typical grey or green-grey calcareous shale, generally in the lower part. Exceptionally, at D-61 and O-22 on the Porcupine Platform, the "Hume" consists entirely of stromatoporoid, amphiporoid and coral reef limestone. Reef facies appear to extend from D-77 to N-49, for nearly 150 km.

The previous pattern of transition from limestone to basinal black shales, observed in borehole sections along the western margins of the Mackenzie and Porcupine Platforms, continued during the deposition of the Hume Formation. Although the "limestone fringe" of earlier formations cannot be similarly delineated for the Hume, a tendency to cleaner limestone deposition on the western edge of the Mackenzie Platform is evident, notably in the total limestone section at B-25 and in the near absence of shale at C-78 and D-08. Similarly, although the belt of transitional to basinal black shale is equally poorly defined from present data, transitional facies occur in the same areas as in the older formations (see lithofacies, Fig. 13). Notable among these is the Snake River area where a tongue of Road River shale may be seen to extend northeastward to the Ontaratue River area. At H-34o the lower 75 per cent of the Hume interval consists of dark grey calcareous shale, black bituminous shale and fossiliferous limestone. Sonic-gamma ray log correlation eastward from H-34o is illustrated on cross-section A37-N39 (Fig. 30). Very dark grey splintery shale occurs in the lower part of otherwise typical Hume lithology at O-65. Although no atypical shales were observed at either D-64 or K-15t, the dark shales at H-34o and O-65 are probably a narrow tongue extension of a 118 m-thick black shale unit at A-42. This was cited above with reference to its correlation to the lower shaly part of the Hume at A-22 (see Fig. 27). The shale unit at A-42, consisting of black, very calcareous pyritic shale and some argillaceous limestone, is a sub-unit of a 389 m section of otherwise typical Hume limestone and shale. Below and above the black shale are 45 m and 226 m respectively of argillaceous, bioclastic, fossiliferous limestone with some shale in the lower portion. The whole unit, lying above brown aphanitic and microcrystalline limestone assigned to the Landry Formation and overlain by black pyritic shale of the Horn River Group, evidently represents a pronounced thickening of the Hume carbonate interval as it passes southwestward through transitional facies into the Road River Formation. The figure of 389 m for the Hume transitional unit at A-42 is comparable to Bassett's (*op. cit.*) reported 300+ m of Hume west of Fort Simpson and also compares favourably with 311 m of Road River (Hume equivalent) at N-77 (see under "Road River Formation-Devonian carbonate equivalents"). The Hume transitional unit at A-42 is tentatively correlated with two of Norris's (1968) sections: at section 6 (Snake River) with most (about 550 m) of the "Hare Indian"; at section 4 (Cranswick River) with "Ogilvie Formation" (above "Cranswick Member"), about 372 m.

The thickness of the Hume Formation (see isopachs, Fig. 13) throughout a broad band from the type area to the Peel River varies only from about 90 m to 140 m. Similar thicknesses were recorded in non-reef areas of the Porcupine Platform. Within the reef belt, thicknesses range from 160 m in the south (D-77) to 326 m at N-49. On the Mackenzie Platform northward from 67° latitude the Hume Formation thins steadily to 45 m in the Crossley Lakes area, but an anomalous 27 m occurs in the Tree River well H-38, where it consists of a lower 15 m of bioclastic argillaceous limestone and an upper 12 m of limestone and grey calcareous shale. In nearby Hume sections of normal thickness (about 100 m, see cross-section B25-P75, Fig. 29), particularly at F-79 and H-57, a well-developed 15 m thick limestone is part of a middle limestone member between lower and upper shaly members. If the middle limestone at F-79 and H-57 is, in fact, related to the lower limestone of the thin Hume at H-38, it would indicate that the lower shaly member in that area is absent at H-38. However, the thin Hume at H-38 may alternatively be explained by erosion or non-deposition of upper, rather than lower beds, suggested by the fact that the Bluefish Member at H-38 is absent at the base of the overlying Horn River Formation which also is anomalously thin there. Localized warping or faulting toward the end of Hume deposition would accommodate both anomalies at H-38.

The lower contact of the Hume Formation seems to be in part unconformable. Bassett (1961, p. 487) stated that the Bear-Rock-Hume contact "is sharp and probably disconformable" and noted, "At Rouge Mountain River, a disconformity showing ten to fifteen feet of relief --- at the top of the Bear Rock Formation and fragments of the Bear Rock occur in the basal beds of the Hume". Bassett (*ibid.*) further noted that at the type locality the basal contact is sharp, marked by a thin bed of brown shale and "At the Arctic Red River, this shale appears to fill cracks in the underlying bed of Bear Rock limestone".[1] Tassonyi (1969, p. 65) reported that the Landry-Hume contact zone "is generally marked in the subsurface by the presence of dark shales, probably partings, that are brownish grey, semi-bituminous and marked by increased radioactivity". In the present study, darker shales in basal Hume samples were observed in only a few scattered sections in the Grandview Hills to Peel River area. The thin Hume at H-38, as noted above, is perhaps better explained by a sedimentary break at the top, rather than at the base, of the Hume Formation. To the west, particularly in the predominantly limestone sections at the edge of the Mackenzie Platform and on the Porcupine Platform, the Hume appears to rest conformably on the Landry.

The upper contact of the Hume with the overlying Hare Indian Formation was considered by Bassett (1961, p. 487) to be sharp but showing no evidence of erosion. Tassonyi (1969, p. 66) favoured a generally conformable contact, but added that during the sudden change of depositional environment, indicated by the sharp lithological change from limestone to black shale, "Erosional surfaces may have developed locally on the top of limited coralline-stromatoporoidal accumulations". Evidence from the present study confirms these earlier conclusions, extending them across the study-area. In the southeastern part, the thin top limestone unit of the Hume maintains a constant thickness (see cross-section, Fig. 27) and similar evidence of uneroded Hume may be seen on the other Devonian cross-sections (Figs. 28, 29, and 30). Tassonyi's suggestion of localized erosional surfaces over bioherm top may apply also to the Hume lithological equivalent interval on the Porcupine Platform: at D-61, where 236 m of reef limestone are covered by black pyritic silicified sandy mudstone at the base of the Horn River; at N-05, 13 km from D-61, off-reef "Hume" is overlain by black shale, orthoquartzite and argillaceous silicified siltstone and breccia which might indicate erosion on reef flanks. In the east, at L-61, where locally the Ramparts limestone rests directly on the Hume, a topographic high on the Hume surface may explain the absence there, of Hare Indian shale (for alternative explanation, see under Hare Indian Formation, p. 34).

---

[1]Bear Rock Formation was restricted by Tassonyi (1969) to include only evaporites and brecciated dolomites and therefore "Bear Rock limestone" probably should read "Landry limestone".

A mainly early Middle Devonian age for the Hume has been well documented, as in Lenz and Pedder (1972, p. 7), who, on the evidence of conodonts, gave an Eifelian age to all of the Hume except for a few feet of Givetian beds on top. An Eifelian age is given to fossils from sections assigned to Hume Formation in the northern part of the Mackenzie Platform (at I-06 and K-60), by A.E.H. Pedder (in Norford et al., 1973, p. 21), but limestones occupying the Hume stratigraphic interval on the Porcupine Platform appear to be younger (see below).

Established correlatives of the Hume to the south are the Headless and Nahanni Formations, roughly equal to the lower more shaly and upper less shaly parts, respectively, of the Hume Formation. On the western edge of the Mackenzie Platform, through borehole sections H-71 and N-25 (see under "Road River Formation-Devonian carbonates equivalents", p. 71-72) the Hume Formation correlates with Norris's (1968b) Prongs Creek upper division of interbedded shale and black chert (Road River-Hume equivalent, this report). On the Porcupine Platform, correlating from borehole B-62 a distance of 45 km to Norris's (1968b, p. 180-204) type section of the Ogilvie Formation on Mount Burgess, the 137 m of bioclastic, fossiliferous limestones between "Landry" brown aphanitic limestones and Horn River ("Canol") black shale at B-62, seem to equate to the "Recessive medium to thin bedded, light grey weathering limestone unit" forming the upper part of the Ogilvie Formation. This upper zone was considered by Norris (1968b, p. 32) to span "much of the Upper Eifelian and Givetian Stages of the Middle Devonian", and a recent biostratigraphic study by A.E.H. Pedder (see Appendix I, AWN-97-AEHP-79 and note) has shown that the upper Ogilvie is Givetian post-Hume in age; in fact, Hume-age equivalent beds in type Ogilvie are roughly at mid-section within the lower part of the Ogilvie, "Ramparts-forming limestone unit", which part seems (see cross-section G31-F57, Fig. 27) to equate to the Landry lithological interval at B-62. Because of this pronounced east-west time-transgression of rock stratigraphic units, the question arises as to whether the names Landry and Hume may usefully be applied to their lithological equivalents over the Porcupine Platform. The use of the names Arnica and Landry across the study-area serves to give nomenclatural expression to the wide areal extent of a long-enduring platform environment. This is not invalidated by finding that Landry limestone continued to be deposited on the Porcupine Platform contemporaneously with the accumulation of Hume and even Hare Indian sediments on the Mackenzie Platform. In contrast, however, the use of the name Hume on the Porcupine Platform, because of the very pronounced time-transgression involved, would tend to obscure the important fact that the subsequent Horn River black shale interlude, which marked a great regional change from platform carbonates to clastic rocks, began over the old Mackenzie Platform and spread westward. During this time, continuing deposition of upper Ogilvie limestone and reef build-up were taking place on the Porcupine Platform prior to final burial beneath a regional blanket of black shale. It is suggested, therefore, that the name Hume not be used west of the Richardsons and that, pending further study of the post-Landry interval in the Porcupine area, it be known as the upper Ogilvie limestone and reef.

Horn River Group

The name Horn River[1] was first used stratigraphically by Whittaker, 1922 (p. 51-52) for an informal "Horn River shale" unit, of which only a few metres were exposed on the Horn River northwest of Great Slave Lake. Overlying these shales is Middle Devonian limestone which Whittaker (*ibid.*) referred to the Pine Point Formation.

Douglas and Norris (1960, p. 18-19) used the term Horn River Formation to include both Whittaker's (1922) "Horn River shales" and his overlying "Pine Point" limestone and assigned a Middle Devonian age to the redefined unit. It appears that the base of the Horn River Formation was not defined until Belyea and Norris (1962) used the name in the subsurface and the formation was stated (*ibid.*, p. 15) to be "present in all wells north and west of the Tathlina 'high' and west of the carbonate platform in northeastern British Columbia" and to vary from a black shale to "a sequence consisting of black shale, greenish grey shale and black shale". In their logs of wells, Belyea and Norris (*ibid.*, p. 20-21) referred to the three-fold shale sequence as the Evie, Otter Park and Muskwa Members, names proposed and defined by Gray and Kassube (1963, p. 473) in a subsurface section of the Horn River Formation in northeastern British Columbia.

Northward the name Horn River was used provisionally in the Dahadinni River map-area (62° to 64°N latitude) by Douglas and Norris (1963, p. 20-21) for 220 m of dark grey to black shale and interbedded shale, siltstones and sandstones, "lithologically similar to those referred to the Horn River Formation in adjacent map-areas". Douglas (1970, p. 407) described the Horn River Formation as 30 to 90 m of "brownish grey bituminous shales, interbedded with dark brown, fine-grained limestones and greenish grey calcareous shales", thickening into the three-fold Evie-Otter Park-Muskwa Membership. The Middle-Upper Devonian boundary was stated (*ibid.*, p. 407) to lie "within the Horn River Formation, possibly at the base of the Muskwa Member". On correlation Chart III (by R.J.W. Douglas, H. Gabrielse, D.F. Stott and H.R. Belyea) of Douglas (1970) the Horn River Formation is shown as a "black pyritic shale" unit equated to the Evie-Otter Park-Muskwa sequence in Fort Nelson area of British Columbia and to the Hare Indian-Ramparts/Kee Scarp-Canol sequence in Norman Wells area. The implied equivalence of the two threefold sequences had already been indicated by Bassett and Stout (1967) in their use of the Hare Indian-Canol terminology southward, Canol for Muskwa and Hare Indian for the remainder of the Horn River Formation. Tassonyi (1969, p. 90), on the other hand, recognized the value of carrying the term Horn River Formation northward, suggesting that it "should be extended into those areas where the Ramparts Formation is absent and where the dark shales of the Canol Formation are inseparable from similar shales of the Hare Indian Formation and used to include both formations", and expressed (*ibid.*) preference for this name over the term Hare Indian-Canol Formation which had been proposed by Bassett (1961).

Wider adoption of the name Horn River, particularly to the north and a precise and consistent meaning of it, have been inhibited by an uncertain belief in a regional unconformity below the Canol and Muskwa units. The case against a sub-Canol unconformity is considered under "Canol Formation" (p. 128-134). Griffin (1965, p. 43), postulating an unconformity at the base of the Muskwa Member, separated the Muskwa from the Horn River Formation and raised it to formational status. The consequent fate of the name Horn River was not mentioned, although, according to the Code of Stratigraphic Nomenclature (Article 14), Horn River should not have remained with formational status.

[1] This discussion of the Horn River draws heavily on a historical review of the nomenclatural evolution of the name, being prepared by G.K. Williams, November 1978.

In summary, the name Horn River has been given a variety of seemingly different meanings:

Whittaker (1922) - shales only at type locality;
Douglas and Norris (1960) - redefined to Whittaker's shales plus overlying limestone;
Belyea and Norris (1962) - a) black shale;
b) threefold, black shale-greenish grey shale-black shales;
Gray and Kassube (1963) - threefold, Evie-Otter Park - Muskwa Members in British Columbia, spans Givetian-Famennian boundary;
Douglas and Norris (1963) - dark grey to black shales, siltstones, sandstones, 62°-64°N;
Griffin (1965) - reduced to twofold, Evie-Otter Park in British Columbia (unacceptable according to Code);
Douglas (1970) - bituminous shales, dark limestones and greenish grey shales;
- black pyritic shale = Evie + Otter Park + Muskwa = Hare Indian + Ramparts + Canol Formations, 65°N.

The present study removes the problematic unconformity in the study-area (see under Canol Formation, p. 39-41) and demonstrates that the threefold sequence, Hare Indian (with its basal black shale Bluefish Member)/Ramparts-Canol, condenses westward into an undifferentiated basinal black shale. This provides the missing link to tie together the valid work of previous authors by raising the name Horn River to group status. The Horn River Group, which to the north consists of the Middle Devonian Hare Indian Formation (black and grey shales), with its lateral facies equivalent, the Ramparts Formation (platform and reef limestones, siltstone, sandstone) and the Upper Devonian Canol Formation (black pyritic shale) and which group is, in effect, a formation for the condensed basinal equivalent, satisfies:

Belyea and Norris's (1962) dual description;
Gray and Kassube's (1963) threefold division;
Douglas and Norris's (1963) Horn River clastics;
Griffin's (1965) objection to an unconformity within a formation;
Douglas's (1970) dual description; and
Tassonyi's (1969) preference over "Hare Indian-Canol Formation".

The proposed use of Horn River Group is important nomenclatural recognition of a depositional environment which, not only was essentially unvaried for at least a 1000 km of the continental shelf, but also represents one unique sedimentary interval of regional transition from long-enduring deposition of shelf carbonates (Ronning Group and Devonian carbonates assemblage) to equally long-lasting accumulation of Upper Devonian to Permian clastics.

The Horn River Group, thus defined, was identified and studied in 79 borehole sections within the study-area. Of these, 39 sections were assigned to the condensed and mostly undifferentiated basinal facies. In addition, data from 7 wells outside the map-area were used in compiling the map (Fig. 14) showing isopachs of the Horn River Group and isopachs and lithofacies of the Ramparts Formation.

Hare Indian Formation

The name Hare Indian Formation derives from the original "Hare Indian River Shale" of Kindle and Bosworth (1921, p. 456) who described the upper 30 m at the type section at the lower end of the Ramparts gorge as "bluish-grey calcareous shale in strata 1 inch to 3 inches thick".

Bassett (1961, p. 490), in his Devonian Stratigraphy, applied the name as used by Kindle and Bosworth and cited exposures of the entire formation along the Mackenzie Mountain front. The shales were stated to be "calcareous, contain thin argillaceous limestone interbeds and, with the exception of a dark grey basal interval which is commonly bituminous, are characterized by their greenish-grey colour". Bassett (*ibid.*) reported the Hare Indian to extend "as far north as Anderson River and to the west at least as far as Snake River", and "is present above the Hume Formation at least as far south as the Ram River area of Fort Simpson". The lower contact with the Hume Formation was stated to be commonly sharp but representing no more than a minor depositional hiatus. Bassett provided criteria for selecting the top of the Hare Indian Formation: 1) where overlain by Ramparts limestone, the upper boundary, stated (*ibid.*) to be "somewhat diachronous", was "arbitrarily placed where limestones are predominant"; 2) where overlain by Canol Formation, "The contact is sharp and easily recognized where the Hare Indian shales are limy and/or light grey or greenish grey in colour", with the added note that the contact was difficult to place where the Hare Indian shales were dark and slightly bituminous.

Tassonyi (1969, p. 71) noted that the Hare Indian Formation was present in the subsurface in all wells within his study-area (Lower Mackenzie and Anderson River area) with the exception of the Point Separation well (A-05), where (*ibid.*) "the Canol Formation is interpreted as resting on a shaly facies of the Hume Formation". Tassonyi (*ibid.*) separated the Hare Indian Formation into two lithologically different, shale units, referring to the basal dark bituminous shale as the "spore-bearing member".

The more recent inclusion of sandstone (MacKenzie, et al., 1975) at the top of, and the finding of siltstones within, the Hare Indian/Ramparts stratigraphic interval have brought about the need to reconsider the criterion for the Hare Indian-Ramparts contact and how best this could portray the interval's depositional history. From the subsurface, Devonian cross-sections G31-F57 (Fig. 27) and A37-N39 (Fig. 30) illustrate very clearly that, although the localized vertical view in any one section is of Ramparts overlying Hare Indian, the overall lateral view at any one time is of contemporaneous deposition of limestones, siltstones and shale. This same model was envisaged by MacKenzie, Pedder and Uyeno (1975, p. 550), namely, that "carbonate banks were developing close to shore at the same time as shales were being deposited farther seaward" and quartz clastic material "laid down on seaward parts of the Ramparts Formation carbonate bank and still farther seaward on adjacent marine shale of the Hare Indian Formation". Therefore, because the two well-established names, Hare Indian and Ramparts, already carry a meaning of facies equivalency, it would be undesirable to set up additional independent rock-units within this interval.

It is proposed that, primarily because the quartz clastics belong more to the regime of the nearshore carbonate banks, the required criterion be to assign all quartz siltstone and sandstone to members of the Ramparts Formation, with the provision that Hare Indian shales locally may be very silty, grading to argillaceous fine-grained siltstone in the upper part (as found, e.g., at A-37g and K-04). In practice in the subsurface, this has proved to be a straightforward means of picking the Hare Indian-Ramparts facies contact consistently from drill cuttings and mechanical logs. The Hare Indian Formation, then, may continue to be commonly referred to as "Hare Indian shales". At the base, the importance of Tassonyi's (*op. cit.*) "spore-bearing member", as outlined below, warrants its recognition as a formal sub-unit, for which the name Bluefish Member is proposed. The upper part of the Hare Indian Formation, referred to by Tassonyi (*ibid.*) as the Unnamed part, is referred to herein informally as "Grey shale member".

Bluefish Member. All 38 borehole sections of the Hare Indian Formation within the map-area and two sections located north of 68° latitude, have at their base the thin distinctive black bituminous shale unit, for which, as stated above, Tassonyi (1969, p. 71) proposed the informal name "spore-bearing member". Tassonyi noted (*ibid.*) that R.J. Kirker referred to this distinct rock unit as the 'Bluefish member' in his presidential address in 1962 to the Alberta Society of Petroleum Geologists, but considered, because "the type section of this member at Bluefish Creek, a tributary of Hare Indian River, is a poor exposure" and because "Moreover, in the Norman Wells-Fort Good Hope area there are two Bluefish Creeks", that "Pending the selection of an appropriate type section, it seems advisable to postpone the introduction of formal nomenclature". Tassonyi used the name "spore-bearing member" because of the presence of "well-preserved, commonly trilete, spore cases", but noted that "Spore cases are apparently absent from this member in similar lithology" in two wells on the southeast flank of the Norman Wells reef.

Since Tassonyi's (1969) work, the basal beds of the Hare Indian Formation assumed a new importance when MacKenzie (1972) reported beds of fibrous calcite with cone-in-cone structure within the "spore-bearing member", describing them as remarkably persistent throughout the Lower Mackenzie and Anderson River area and drawing a probable western limit at about 132°W longitude. The calcite beds were demonstrated to be of stratigraphic significance because of their widespread predictable occurrence and their presence in the bituminous "spore-bearing member" was considered to delineate petroleum source beds. Due to the thinness of the calcite beds, MacKenzie noted that they constitute a geological marker which, although evident in outcrops and in borehole cores, probably could not be determined from drill cuttings or geophysical logs. The only subsurface occurrence in a cored section was stated (*ibid.*, p. 1432) to be "in core No. 7 from Imperial Canol Mac No. 1 well, near Norman Wells", core which was noted to be "badly broken". The importance of the fibrous calcite beds within the "spore-bearing member", the absence of suitable borehole sections and "A scarcity of good exposures of this part of the Hare Indian Formation" (MacKenzie, 1972, p. 1432) limit candidacy for type section to those cited by MacKenzie, among which, the reported Powell Creek section is an obvious choice. In order to preserve the geographic name proposed by R.J. Kirker (*op. cit.*) and because the Powell Creek section is within the same general area of the "two Bluefish Creeks" (Tassonyi, *op. cit.*), the name Bluefish Member is proposed.

Bluefish Member, therefore, refers to a thin but widespread unit of dark bituminous shales, known informally as the "spore-bearing member", at the base of the Hare Indian Formation. The type section designated is located at 65°16'30"N, 128°46'30"W, at the Mackenzie Mountain front on Powell Creek, 4.5 km upstream from its confluence with Mountain River (see map, Fig.). MacKenzie (1972, Fig. 1) showed only three other outcrops of the Bluefish Member (see also Fig. 15 this report), two of them in the Carnwath River area at 68°N and the other west of Lac à Jacques at 66°N. A representative subsurface section is chosen at C-31, 60 km north of the type locality. The sonic-gamma ray log is included on cross-section G31-F57 (Fig. 27) and logs of many other sections are shown on all four Devonian cross-sections (Figs. 27, 28, 29 and 30). Borehole sample descriptions of the Bluefish Member are included in Appendix II and distribution of the unit is illustrated on the isopach and lithofacies map, Figure 15. An important reference section outside the present study-area is at the Imperial Mac No. 1 borehole, south of Norman Wells, from which core samples of fibrous calcite were studied by Mackenzie (*op. cit.*).

The type area lies within the Sans Sault Rapids map-area, where the member is reported (Aitken et al., in press) to consist of "extremely fissile, brown-black bituminous shale containing abundant fossils, notably **Styliolina, Tentaculites** and the algocysts **Leiosphaeridia** and **Tasmanites** (the "trilete spore cases" of Tassonyi, 1969)". The member was stated (*ibid.*) to be typically about 15 m thick. The fibrous calcite beds with cone-in-cone structure, in the basal part of the Bluefish Member, were reported by MacKenzie (*op. cit.*, p. 1432), in the Powell Creek (type) section, to be 5 cm, 1.9 cm and 7 cm thick, occurring at 1.8 m, 2.1 m and 3.6 m, respectively, above the base of the member. MacKenzie documents the fibrous calcite at Powell Creek and other sections by an acetate peel print and five photomicrographs.

The Bluefish Member in the subsurface is characteristically black or brown-black and often non-calcareous except for a basal bed or beds of highly calcareous black shale and locally, argillaceous bituminous limestone. The area throughout which basal calcareous beds occur and a belt in which the entire member is calcareous, are shown in Figure 15. The basal limestone may be locally well developed, as at C-31, which has been selected as a representative subsurface section in order to emphasize the inclusion of the basal limy beds within the Bluefish Member, rather than at the top of the underlying Hume Formation. At C-31 (see cross-section, Fig. 27) where these basal beds clearly overlie the top thin limestone unit of the Hume in that general area, the Bluefish Member consists of a lower 13 m of dark brown-grey and black calcareous shale, grading to argillaceous limestone and some buff bioclastic limestone and an upper 16 m of black non-calcareous shale. The basal limy beds are typically very thin, probably equating to MacKenzie's (*op. cit.*) basal beds with fibrous calcite. The 15 m typical thickness of the Bluefish along the Mackenzie Mountain front (Aitken and Cook, *op. cit.*) seems to be a rough average thickness for the entire area east of 131°W longitude. The member thins and basal limy beds seem to be absent west of that line and, as mentioned above, MacKenzie (*op. cit.*) suggested a probable western limit of fibrous calcite beds at about 132°W. The only well core from this part of the section was taken near the base of the Horn River Formation at A-05 (134°W), borehole depth 5168-5191 feet, which shows non-limy black shale down to 1 m above the base (the basal 3 m are assigned to Bluefish Member on the basis of gamma-ray correlation, see below).

The lower contact of the Bluefish Member with the Hume Formation appears almost everywhere to be conformable. The possibility of localized erosion of the Hume surface is discussed under "Hume Formation" (p. 96). Aitken et al. (in press) report no evidence of a break in deposition at this contact in the Sans Sault Rapids and Ramparts map-area, stating the contact varies from abrupt to gradational.

The top of the Bluefish Member is not so readily specified in order that it may be distinguished consistently from the overlying unnamed part of the Hare Indian Formation, both in surface and subsurface. The placing of this contact would seem to be dependent upon colour change from black or brown-black of the bituminous Bluefish to the characteristic non-bituminous grey or green-grey of the unnamed member. However, experience with the many subsurface sections in this study-area shows the colour change to be very gradual and reports of surface exposures (e.g. Bassett, 1961, p. 490; Tassonyi, 1969, p. 72) indicate that in some areas Hare Indian shales may be atypically dark grey throughout and even may include bituminous zones. Tassonyi (1969, p. 72) noted that, "In the subsurface, in every case where the identity of the (Hare Indian) Formation is firmly established by the presence of the Ramparts Formation, the bituminous facies is restricted to the lowermost part of the formation and thus is included in the spore-bearing member". This observation of Tassonyi, applied throughout the present study-area, has proved to be a reliable criterion only if expressed in terms of sonic-gamma ray characteristics and, in so doing, has additionally provided a means whereby the Bluefish Member appears to be traceable into the condensed black shale facies of the Horn River Formation. The proposed criterion for consistency and most practical stratigraphic use in the subsurface is therefore to place the contact at the top of the zone of ultra high sonic-gamma ray log trace and where the upward change from bituminous to non-bituminous is gradual, the contact is at the base of the gradation, a 'pick' which is easily pin-pointed on radioactivity logs. Almost invariably, it turns out that this gamma-ray 'pick' coincides perfectly with colour change from black to brown-grey as indicated by drill cuttings. In fact, the only observed exception to this coincidence was found in the K-04/L-26 (Ontaratue River) area where the gradational nature of the contact seems to be the most developed, to the extent that a 100 m-thick zone of colour gradation includes some black, non-calcareous shale at its base.

Probably the most significant stratigraphic result of recognizing the Bluefish Member in the subsurface and identifying it by the radioactivity criterion, is that the unit is thereby traceable westward into the otherwise undifferentiated black shale facies of the Horn River. This is illustrated on all four Devonian cross-sections (Figs. 27, 28, 29, 30) on which the gamma-ray kick indicates a gradual thinning west of 131° longitude to less than 5 m west of 132°. The most westerly gamma-ray indication of Bluefish beds is a 2 m kick at B-25 at 135°34'. This very pronounced feather edge of the soft fissile shale of the Bluefish Member at the base of the Horn River Formation, illustrated more clearly in the isopachs (Fig. 15), is important evidence in the case against a "sub-Canol regional unconformity" to be considered under "Canol Formation" (p. 39-41).

Within its area of distribution the Bluefish Member is missing in two boreholes. At H-38, its absence above an anomalously thin Hume Formation may indicate (as discussed, p. 31) localized eroded topography on the Hume surface. At L-61, where a very thin "platform" below a thick "reef" of Ramparts limestone lies directly on Hume limestone, the absence of Bluefish and of the entire Hare Indian may also indicate a local positive feature on the Hume surface (see also p. 30), but in this case is a subsea topography on which early reef build-up occurred contemporaneously with Bluefish shale deposition elsewhere.

The Bluefish Member, as part of the Hare Indian Formation, is of Givetian (late Middle Devonian) age (see under "Grey shale member) and it correlates with the Bituminous member of the Horn River Formation in the Great Slave Lake area and with the Evie Member of the Horn River Formation in northeastern British Columbia.

The economic significance of the Bluefish Member in the search for petroleum, reported by MacKenzie (1972), is mentioned above. The Bluefish Member may also prove to be important in connection with exploration for other minerals. From a thin Bluefish Member at the base of the Horn River Formation at K-15t drill cuttings of black shale contain white crystals. Random samples of these crystals were analyzed by X-ray diffraction (see Appendix I, 79-XR-10) as calcite, fluorite, quartz and barite. The possibility that this (fluorite, in particular) may indicate proximity to interesting mineralization is significant in view of a recent finding (Macqueen et al., 1975) that several samples from the Bituminous member at the base of the Horn River and Pine Point Formations in the Pine Point area, yielded high values of zinc, lead and uranium oxide. The mineralization of the Bluefish Member at K-15t is not the only example at this horizon in the Peel River map-area. West of the Richardsons, barite occurs in chert breccia at the base of the Horn River Formation ("Canol") at N-05 (see Appendix I, 79-XR-10) on the flank of the underlying upper Ogilvie reef. The same horizon is reported (R.J. Kirker of Arjay Kirker Resources Ltd., pers. comm.) to be heavily mineralized in test holes near the Alaska border.

Grey shale member. The characteristic feature of the Grey shale member, as recorded in drill cuttings from more than thirty borehole sections, is its gradation from dark brown-grey, rarely black, at the base immediately above the Bluefish Member, upward through brown-grey, progressively paler to grey, green-grey or buff-grey and, in the thicker sections, to pale grey at the top. The shales are micromicaceous, often very micaceous in the upper part. They generally grade upward also from non-silty and slightly or non-calcareous at the base to calcareous and silty at the top of the thicker sections. In two sections, at A-37g and K-04, argillaceous fine-grained siltstone, interbedded with the shale in the upper part, was easily distinguishable from the overlying coarse-grained calcareous siltstone assigned to the Ramparts Formation. The western limit of the Grey shale member, shown on the Horn River Group map, Figure 14, approximates the depositional edge, rather than a truncated edge (see under Canol Formation). On the same map are drawn the Ramparts Formation isopachs which may be taken to represent inversely the thickness distribution of the facies equivalent Hare Indian shale.

The gamma-ray criterion for the lower contact and the facies criterion for the upper contact are discussed under Bluefish Member and Hare Indian Formation headings, respectively. The Hare Indian Formation at Powell Creek was given a Givetian (late Middle Devonian) age by Lenz and Pedder (1972, p. 35) on the basis of brachiopod and conodont dating. The Grey shale member correlates with the Otter Park Member of the Horn River Formation in northeastern British Columbia.

Ramparts Formation

The term "Ramparts limestone" was used by Kindle and Bosworth (1921, p. 443-463) "because of the excellent exposures of it in the Ramparts section (Plate IIIB) just above Good Hope, where it lies between the Hare Indian River shales below and the Cretaceous shales above". A photograph and lithological description of the "Ramparts Section" were included in their report.

In the course of development of Devonian stratigraphy of the Lower Mackenzie River area, the "Ramparts Section" became part of a nomenclatural controversy which was subsequently analyzed by Caldwell (1964, p. 615-619) and Tassonyi (1969), who both advocated the use of the name Ramparts Formation in its type sense. Caldwell (*ibid.*, p. 619) concluded, "Ramparts is valid, appropriate and concise, the unit it designates is magnificently exposed and richly fossiliferous in type section and this section is coincident with one of the best known geographical features on the Mackenzie River". Tassonyi (*ibid.*, p. 78) summed up his discussion of the controversy in the statement, "the Ramparts Formation, as it was defined originally by Kindle and Bosworth (1921, p. 45B-46B) is a perfectly legitimate and valid stratigraphic unit and it should be retained, exactly in the original sense as it was defined in the type section". The Ramparts Formation in its type sense was shown (Tassonyi, *ibid.*) to have been built up during the same carbonate cycle, and that two phases could be distinguished in the development of the reef-complex. On this basis, Tassonyi (*ibid.*) recognized two informal members, the bedded platform member and the overlying, more massive reef member and stated (*ibid.*, p. 78), "In most cases the carbonate lithology of these two members is separated by a thin (maximum 21 ft thick) dark shaly and limy sequence, that is recognized here as the 'Carcajou marker' and is included in the platform member".

A quartzose sandstone unit (Unnamed map-unit D4) mapped in the Grandview Hills area (Cook and Aitken, 1975, p. 6) was reported by MacKenzie, Pedder and Uyeno (1975, p. 547) to be of Middle Devonian age and a part correlative of the Ramparts. The present subsurface study shows that calcareous siltstones are closely associated with Ramparts limestones throughout most of the Hare Indian/Ramparts stratigraphic interval. Because the siltstone and sandstone beds pertain more to the Ramparts than to the Hare Indian and, as discussed under "Hare Indian Formation" (p. 32), in order not to confuse the stratigraphic picture of facies equivalency by trying to delineate separate rock-units of formational status, it is proposed to include the silty and sandy facies as informal sub-units of the Ramparts Formation. The Ramparts, therefore, will comprise four sub-units, referred to herein as Siltstone lentil, Platform member, Reef member and Sandy member.

Isopachs and lithofacies of the Ramparts Formation are included on the Horn River Group map (Fig. 14) and the complex relationships between sub-units is illustrated on cross-sections G31-F57 (Fig. 27) and A37-N39 (Fig. 30). Borehole section A-23 (Candel Mountain River A-23) is suggested for a reference section because of its straightforward sequence of Siltstone lentil-Platform member (and Carcajou marker)-Reef member. In the subsurface the Sandy member has so far been encountered only beyond the depositional limit of the other members. The thickness of the Ramparts Formation varies widely across the reef-complex and ranges from 5 m of Siltstone lentil at I-77 to a maximum recorded 393 m of Siltstone-Platform-Reef sequence at L-24.

The age of the Ramparts has been documented as Givetian (late Middle Devonian) (MacKenzie, Pedder and Uyeno, 1975; Pedder, 1975) and the upper part of the Reef member at D-72 was referred by A.E.H. Pedder (in Norford et al., 1971, p. 17-18) to the "Late Devonian, **mackenziense** Zone", showing that reef growth continued into Late Devonian time. As stated above, the Ramparts Formation is, at least in part, a facies equivalent of the Hare Indian Formation which in turn correlates with the Evie and Otter Park Members of the Horn River Formation in northeastern British Columbia (see under "Bluefish Member", p. 34, and "Grey shale member", see above).

Siltstone lentil. The informal name, Siltstone lentil, is applied to a possibly discontinuous deposit of calcareous siltstones occurring either as the lowest sub-unit of the Ramparts Formation, or as interfingering or lenticular beds within, or grading laterally into, the Platform member. Any predominantly siltstone interval within the Ramparts Formation has been assigned to Siltstone lentil, except where coarse-grained siltstone may be placed more reasonably in the Sandy member.

Siltstone lentil has been recognized in 15 borehole sections. Its major characteristic is predominance of siltstone, generally pale in colour, varying from fine-grained and calcareous to very calcareous grading to silty limestone, and commonly argillaceous, grading to silty calcareous shale. Darker coloured siltstones occur locally at A-23 and H-73 (see map, Fig. 14) and brown oil-stained siltstone was recorded at G-26 on the shoreward side of the reef. A westward (seaward) trend to apparently deeper water facies is evidenced by the change from a thin reefoid limestone at L-09, to 14 m of black calcareous siltstone and limestone at A-59, to 5 m of brown, very dolomitic and calcareous, argillaceous siltstone at I-17. Northward, on the other hand, coarser-grained siltstone and silty limestone grade laterally into the shallow water Sandy member between L-26 and K-04.

Where Siltstone lentil occurs as the lowermost sub-unit of the Ramparts, overlying the Hare Indian Formation, picking the shale-to-siltstone facies contact is generally straightforward. Contacts between Siltstone lentil and Platform member are always on the basis of siltstone predominance. Siltstone lentil is widely and very unevenly distributed. Maximum thickness of 154 m was recorded at H-24, only 10 km from a local absence of siltstone at C-31, D-53 and O-62 (see map. Fig. 14). Siltstone is absent also at L-61 where the Ramparts interval is entirely platform and reef limestones.

Siltstone lentil seems to have been deposited mostly at the periphery of carbonate build-up. As the platform in time became more extensive, silty material continued to be spread around its edges, giving rise to a highly diachronous sequence of siltstones, generally underlying, and locally within, diachronous platform limestones. The expanding platform and its peripheral silts progressively overlapped grey shales of the Hare Indian Formation with maximum areal spread of silts towards the end of the Ramparts cycle.

Platform member. Tassonyi (1969, p. 80) recognized within the Ramparts Formation two informal members which were referred to as platform member and reef member. The Platform member was stated to consist of "brown, or brownish-grey limestones, having a range of textures owing to different proportions of lime-mud and very fine to very coarse bioclastics". A 6 m thick "sequence of interbedded dark limestone and shales on Carcajou Ridge" (*ibid.*, p. 81), for which Tassonyi suggested the name "Carcajou marker", separates the two members at that outcrop locality and was included by Tassonyi in the Platform member.

In the present study-area the Platform member is recognized in 18 borehole sections. Although a variety of limestones characterize the unit, buff, brown, white and grey bioclastic limestones are the most common, occurring in 7 sections and found in association with fragmental limestone in 4 of those sections. Lime-mud ratios vary from a clean, buff-coloured, microcrystalline to aphanitic limestone at the base of the unique, all-carbonate Ramparts at L-61, to commonly buff-grey and brown, very argillaceous and silty. In the Ramparts reference section at A-23, the Platform member, with a total thickness of 132 m consists of 108 m (below the Carcajou marker) of grey-brown to buff, microcrystalline, variably silty limestone which in part grades to very calcareous siltstone. Interbedded thin calcareous shales and siltstone are common and in some sections Siltstone lentil and Platform limestones are interfingered or intergradational (see Appendix II and cross-sections).

In 12 of the 16 borehole sections in which the Platform member is overlain by reef development, a 9 m to 27 m thick sequence of dark grey to black shale and dark limestone, at the top of the Platform member, has been tentatively labelled "Carcajou marker". The writer is uncertain that this identification does justice to the importance given to this marker by Tassonyi (1969, p. 81) in the statement, "The understanding of the nature and correlation of the unit is essential for correlation within the reef-complex" and in his placing (*ibid.*, Fig. 5) the Carcajou marker 15 m below the top of the Platform member in the Ramparts type section. In the subsurface a dark shale interval between the Platform and Reef members is certainly conspicuous in drill cuttings and logs, but more detailed study of this marker and of its stratigraphic significance should be required before definitive assignments and correlations are made.

Reef member. Tassonyi (1969, p. 80) reported the Reef member to consist "generally of massive, clean, light grey to light buff limestones, characterized by digitate and tabulate corals and stromatoporoids" and that (*ibid.*) "In the cores of the Norman Wells Pool great variations of lithology can be observed". Bassett (1961, p. 493) had reported measured maximum thicknesses of about 90 m and 150 m for the platform and reef parts, respectively.

In the present study Reef member is taken to include, in addition to reef core, reef detritus and reef flank interfingering of reefoid and other limestones and calcareous shale. The practicality of this is illustrated on cross-section, G31-F57 (Fig. 27) where fragmental and bioclastic limestones and some shale occupy the same stratigraphic interval at C-31 as does the entire reef core 14 km away at H-47. Defined, then, in this way, the Reef member reaches thicknesses in excess of 200 m in 3 of the 16 borehole sections, with a maximum 236 m at L-24. The latter section consists of buff, brown and white reefoid beds, which grade upward into dark brown, microcrystalline limestone and is underlain by black calcareous shale and bioclastic, fragmental limestone assigned to the Carcajou marker at the top of the Platform member. Reef member thicknesses and porosities are extremely variable. In the reference section at A-23, the Reef member is only 37 m thick and has good porosity, pores filled with black bituminous material.

For the purposes of this study the lower contact with the Platform member has been placed at the top of a dark shale-limestone break wherever such a break could reasonably be referred to as the Carcajou marker. Where this marker is absent, as at D-72, H-73 and L-61, the pick is based on difference of lithology alone. It must remain yet to be determined whether these criteria for the Platform-Reef contact will be valid in the light of more detailed work which lies outside the scope of this regional study.

The upper contact of the Ramparts Formation, which for the most part, is the upper contact of the Reef member, was first described by Kindle and Bosworth (1921, p. 46B) at the type section where the Ramparts Formation is truncated at the sub-Cretaceous unconformity. A similar contact occurs in the subsurface at L-61 (see Fig. 30b this report). Subsequently to Kindle and Bosworth, however, the nature of the Ramparts contact below Upper Devonian beds became a fertile field for differing opinions. Tassonyi (1969, p. 83-85), concerned with historical development of the stratigraphy, devoted a sub-heading specifically to "Discussion of Upper Contact". His suggestion (*ibid.*, p. 84) of "different contact relations between the Ramparts Formation and younger Devonian rocks in different parts of the study-area" is supported by the present more regional study and is discussed in detail under "Sub-Canol contact" (p. 39).

Sandy member. "The presence of arenaceous sediments between the Middle Devonian Ramparts Limestone and equivalent beds and the Upper Devonian Canol Shale has long been known" (MacKenzie, Pedder and Uyeno, 1975, p. 547). Their documentation (*ibid.*, p. 547-552) of faunal evidence showed that the hitherto generally accepted view of an Upper Devonian age for these beds was incorrect and, therefore, that informal references to them such as "basal Canol Formation Sandstone" were invalid. Indicating intention to name this unit at a later date, these authors stated (*ibid.*, p. 547) "for the present, they wish to stress that it is a part correlative of the full Ramparts Formation and pre-dates the Middle/Upper Devonian disconformity". The faunal evidence was obtained from an outcrop by Lac Charrue, 20 km north of Little Chicago (Fig. 1). The eligibility of the sandy unit for formation rank had already been given by Cook and Aitken (1975, p. 6) who mapped it over "a relatively small area (240 x 80 km)" of distribution, north from Ontaratue River area, designating it "Unnamed map-unit D4". Cook and Aitken (*ibid.*) reported it to overlie Ramparts limestone but also to extend "beyond the northern limit of Ramparts development to overlie Hare Indian shale".

The present study confirms the distribution of the sandy unit, as shown by MacKenzie, Pedder and Uyeno (1975, Fig. 1). Correlation with the Ramparts Formation is supported by cross-section A37-N39 (Fig. 30b) which demonstrates that southward from K-04, through K-47 and A-37c, to D-72, the sandy unit could be lithologically correlated with Siltstone lentil and probably time-correlated with Platform and Reef members (Pedder, 1975, equated the sandy unit to bedded platform on the basis of megafossil zonation). What, however, is important to note is that "Map-unit D4" was mapped (Aitken and Cook, *op. cit.*) overlying Ramparts limestone "in the southern part of its area of occurrence", which is compatible with nearby subsurface evidence (cross-section, K-04 to A-37c, Fig. 30) which strongly suggests that limestone intervenes between Siltstone lentil and the southward disappearence of a sandy or silty unit at the top. This shows that it would be unwise to correlate the sandy unit with Siltstone lentil and supports its recognition as a separate unit. To give to the sandy unit formation rank, particularly in view of its earlier erroneous inclusion within the Canol Formation, would not reflect its true stratigraphic status as well as would member status within the Ramparts Formation. The latter alternative, therefore, is preferred and because of the informal status of the other three sub-units of the Ramparts, it is proposed to refer to the sandy unit, also informally, as the "Sandy member" of the Ramparts Formation.

The reader is referred to MacKenzie et al. (1975) for "type" descriptions and interpretations of principal outcrop sections (Fig. 14, this report) near Lac Charrue (located at 67°23'N, 130°10'W). The unit was reported (*ibid.*, p. 547) to consist "mainly of detrital quartz siltstone and very fine-grained sandstone with intervals of silty shale containing interbeds of siltstone and discontinuous beds and lenses of silty bioclastic limestone". A maximum known outcrop thickness (near Lac Charrue) was given as 18 m.

In the subsurface, the Sandy member is recognized at three locations, at A-37g and K-04 west of the outcrop areas and at J-42 very close to outcrop. At A-37g (see cross-section B25-P75, Fig. 29), in the Grandview Hills area, the Sandy member consists of 19 m of slightly calcareous micaceous siltstone, oil-stained brown. At K-04 (see cross-section, A37-N39, Fig. 30), near Ontaratue River, 15 m of buff to pale grey, in part coarse-grained, calcareous and very micaceous siltstone, in part grading to very silty limestone, occupy the same interval between the Hare Indian and Canol Formations.

East of the Lac Charrue area, at J-42 (see cross-section B25-P75, Fig. 29), 37 m of pale grey siltstones, grading to silty shale and to very silty and sandy bioclastic limestone, make up the Sandy member lying between the Hare Indian Formation and the sub-Cretaceous unconformity. Mica, which is a conspicuous component of the more westerly sections at A-37g and K-04 is virtually absent at J-42. A lithofacies boundary is drawn (see Fig. 14) arbitrarily between the section of predominantly coarser-grained Sandy member siltstone at K-04 and a 67 m section of siltstone, limestone and shale at L-26 which is assigned to Siltstone lentil.

The lower contact at A-37g and K-04 is placed where argillaceous calcareous siltstone and grey shale change to calcareous, coarse-grained siltstone and silty limestone. It is not only technically acceptable to confine, in this way, grey shale to the Hare Indian Formation and to make for a smooth cross-section correlation (see A37-N39, Fig. 30), but it also emphasizes the fact that increasingly more silty material began to flow into the same northerly off-reef area as later received the coarser silt and sand of the Sandy member. The implication from this is that the earlier fine silts and the later coarse silts and sands were genetically related. MacKenzie, et al. (1975, p. 550) reported the arenaceous parts of the Sandy member to "consist of supermature siltstone and very fine-grained sandstone, the degree of maturity being indicated by an almost complete absence of less stable accessory minerals such as feldspar and mica and by the sparse occurrence of such ultra-stable heavy minerals as zircon and tourmaline", and suggested (*ibid.*) that the sands were recycled "from sandstone formations of Cambrian age --- themselves mature quartz arenites --- probably exposed to erosion in late Middle Devonian time". This finding, together with the record (this report) of abundant mica in more westerly sections of the Sandy member (at A-37g and K-04) and also in Siltstone lentil and the Grey shale member (at K-04, K-47, A-37c, D-72, see cross-section A37-N39, Fig. 30), indicate a secondary source of clast supply from which mica was possibly selectively transported to settle as a major accessory mineral of the northerly off-reef sediments. Mica would not have settled close to shore for the same reason that "Turbulence in the relatively shallow, more agitated water that prevailed during this period of deposition carried away easily-eroded fragments from the carbonate bank and mixed them with the sand" (MacKenzie et al., 1975, p. 550) .

Allochthonous limestone unit

Reporting microfaunal assemblages in the Middle and Upper Devonian rocks of the Norman Wells area, Braun (1966) identified a distinctive limestone and shale unit of Frasnian (Upper Devonian) age, which had previously been included by Bassett (1961, p. 494) in his "lower Kee Scarp Formation" at the type section of his Canol Formation on Powell Creek. Braun (*ibid.*, p. 254) referred to this limestone and shale unit as "Unnamed beds" because they belonged neither lithologically nor faunally to the "Kee Scarp" (Ramparts Formation) and lithologically they were "not typical of the Fort Creek shales" (Fort Creek shales = Canol Formation, see Tassonyi, 1969, p. 90). "Unnamed beds" were reported (Braun, *ibid.*) also on Carcajou Ridge (see Index map. Fig. 1).

MacKenzie (1970) made a detailed study of the "Unnamed beds" at Powell Creek and referred to them as "allochthonous reef debris and limestone turbidites", which corresponded directly to a twofold lithological division into (*ibid.*, p. 485) "Lower thin-bedded argillaceous and silty limestone with black shale interbeds, black chert and blocks of coral and stromatoporoid-bearing limestone (18 ft) and overlying dark grey, calcareous shales with graded echinoderm beds (35 ft)". Subsequently, MacKenzie (1973) identified Upper Devonian beds of echinoderm debris between the Ramparts and Canol Formations in cored section from borehole G-56 and concluded that they were genetically similar to the reef debris beds outcropping at Powell Creek.

Pedder (1975) assigned an early Frasnian megafaunal zone to the debris beds, stating (*ibid.*, p. 575) "In the lower and middle Mackenzie Valley, the time of the zone was essentially one of non-deposition or active erosion. The only locality known at present where the existence of the zone can be demonstrated is in the allochthonous beds on Powell Creek".

Aitken et al. (in press) did not map the "Allochthonous limestones" in the Upper Ramparts River and Sans Sault Rapids map-areas, because, (*ibid.*) "Although they are undeniably important to the interpretation of the geological history of the region, these beds lack the thickness, continuity and ease of field identification necessary to permit being mapped at the scale of 1:250,000".

The present study provides some additional evidence from the subsurface, but, because this is considered insufficient to justify formalizing the debris beds as a mappable unit, they are referred to herein, informally, as "Allochthonous limestone unit". Within the study-area the distribution of the unit, in relation the 200 m and 250 m isopachs of the Ramparts Formation, is shown on the Canol Formation map, Figure 16. In addition to previously recorded occurrences of the Allochthonous limestone unit, namely at Powell Creek (Braun, MacKenzie, *op. cit.*) in the south, at Carcajou Ridge (Braun, *op. cit.*) and at G-56 (MacKenzie, *op. cit.*) on the east side of the reef complex, debris beds appear also to be present in six borehole sections on the west (seaward) flank of the reef, according to evidence from drill cuttings and sonic logs. At one location, D-53, drill cuttings, supported by sonic log trace, indicate that the entire interval (6 m) between the Reef member of the Ramparts Formation and the overlying Imperial Formation consists of brecciated limestone and black shale with free bitumen. The basal metre or so was cored and this shows coarse-grained reef debris and thin black shale partings, similar to the debris beds described at G-56 (MacKenzie, *op. cit.*). The same interval, 3 km away at O-62, is occupied by 8 m of siliceous pyritic siltstone and buff and white limestone and chert.

MacKenzie's (*op. cit.*) twofold division of the unit at Powell Creek may extend to L-09, 40 km away, where, although drill cuttings from a borehole through steeply dipping strata show no more than limy streaks in black shale, the interval of reef debris is determined and divisible into two parts, on the basis of sonic log trace.

The evidence certainly points to the distribution of debris beds along the Ramparts reef flanks, but more detailed work is required before all the possible occurrences can be related to the Powell Creek section with sufficient certainty to warrant recognition as a bona fide map-unit. For the purpose of this study the important fact is that debris beds do occur and that in two localities, at least, they are of early Frasnian age.

Canol Formation

The term Canol Formation was proposed by Bassett (1961, p. 494) and defined as the black shale unit directly overlying the Kee Scarp Formation or, where the latter is absent, directly overlying the Hare Indian Formation. Bassett (*ibid.*) stated, "The Canol Formation is completely exposed at its type locality situated on the northwest side of Powell Creek at the Mackenzie Mountain front (65°16'30"N, 128°46'30"W)". The name was derived "from Camp Canol on the Mackenzie River opposite Norman Wells".

Tassonyi (1969, p. 90) stated that, although the validity of the Canol Formation had not been tested by surface mapping "the practicability in subsurface mapping is beyond doubt". Using the name Canol Formation "with the same stratigraphic meaning as proposed by Bassett", Tassonyi recognized a threefold division in the Norman Wells area: "an upper, a middle and a lower member".

Aitken et al. (in press) mapped the Canol Formation as a distinctive unit "that overlies the Ramparts and Hare Indian Formations", consisting of mostly "dark grey to black, hard and siliceous" shale and some "fissile and sooty" shale.

A distinctive unit intervenes between the Ramparts and Canol Formations (see under previous heading) which Bassett included in the Kee Scarp (Ramparts) Formation at Powell Creek and which Tassonyi (1969, p. 92-93) seems to have included in his lower member of the Canol Formation and which Aitken et al. (in press) found lacking the thickness and continuity required for surface mapping. This unit demands a refinement of the original definition of the Canol Formation to ensure the continuing clarity of its type sense of a "black shale unit". Restated, the Canol Formation in its type stratigraphic meaning directly overlies the Ramparts Formation or its reef-derived Allochthonous limestone unit, or, where these are absent, directly overlies the Hare Indian Formation. The present report recognizes the Canol as the uppermost formation of the Horn River Group as far west as the Hare Indian Formation can be delineated and beyond that as undifferentiated within the Horn River Formation. In view of the very fine feather edge of the Bluefish Member of the Hare Indian (see p. 34 and, map, Fig. 15) and, therefore, of an indicated depositional edge to the west which might imply non-deposition in the western part of the study-area and moreover in view of the Givetian age (p. 31) of the underlying upper Ogilvie limestone, it seems probable that, in at least some areas west of the Richardsons, the Horn River Formation consists entirely of Canol black shale. However, it is important to note that, if the starved basin model presented in this report is correct, the Horn River to the west represents an interval of initially little or no deposition followed by Canol deposition, not, it is emphasized, of Canol deposition alone. It would therefore probably be more technically correct to refer to this interval regionally as Horn River Formation, but, west of the Richardsons, the use of the name Canol Formation is now firmly established (Norris, in press) and this, more so than Horn River, does give the desirable nomenclatural recognition of the regional veneer of black bituminous shale at the beginning of Upper Devonian time.

The Canol Formation is delineably present within the study-area in 18 borehole sections and was also recorded in two wells north of 68° latitude. In the subsurface it is readily identified on gamma-ray logs by its high radioactivity and is recognized in drill cuttings as dark grey to black, bituminous shale, commonly siliceous and pyritic. Distribution is shown, relative to the main area of Ramparts reef, on Figure 16, which also includes, west of 131°30' longitude, some thicknesses of the Horn River Formation where the Bluefish Member (see p. 34) can be identified at the base. In the latter (Horn River) sections, the "Canol" forms part or all of that portion above the Bluefish Member and therefore the thicknesses shown represent more than the Canol alone. Figure 16 thereby illustrates that there must be a belt of maximum depositional thickness of Canol shale of close to 100 m in an arc from Crossley Lakes , north of the study-area, to Arctic Red River at the Mackenzie Mountain front (I-77) in the south. The actual maximum recorded Canol thickness is an exceptional 157 m at A-73. Canol thicknesses indicate an inverse relationship to the thicknesses of the Ramparts Formation, as illustrated (Fig. 16) by the Canol isopachs and the 200 m and 250 m Ramparts isopachs. Because the upper contact of the Canol Formation is conformable (Bassett, 1961; Tassonyi, 1969), the eastward thinning of the Canol is evidently reef-controlled. The overlying Imperial Formation is found resting directly on Middle Devonian Ramparts Reef member at H-47m, indicating that Canol shale probably never covered the reef in that area. Interestingly, at D-53, the Imperial Formation rests directly on Upper Devonian Allochthonous limestone unit, whose significant content of black shale suggests that the slumping and turbidity flows, associated with the debris beds (MacKenzie, 1970), took place during deposition of the Canol shales. However, the fact that the Allochthonous limestone unit has elsewhere been found overlain by Canol shale shows that the debris beds generally were deposited before the end of Canol deposition. Faunal zonations of early Frasnian age (Lenz and Pedder, 1972; Pedder, 1975) indicate that the allochthonous beds at Powell Creek were deposited at the very beginning, or prior to, deposition of Canol shales.

The Canol Formation is truncated below the sub-Cretaceous unconformity (see map, Fig. 16), which has removed any evidence of eastern shoreward facies. The Canol shale which is preserved below the Imperial Formation is devoid of significant content of silt or coarser clastic material. To the west, however, where Canol is indistinguishable as an upper part of the Horn River Formation, siltstone was recorded in two sections of otherwise typical black bituminous pyritic shale (see map, Fig. 16): at F-37, near the top, a 6 m thick bed of coarse-grained argillaceous and non-calcareous siltstone; at I-21, some brown calcareous siltstone in the upper part. No silt was observed in any of the eight sections of Horn River Formation west of the Richardson Mountains. The "new" material at F-37 and I-21, therefore, arrived neither from the east nor the west, nor could it have been locally derived from reworked older strata. It is tempting, at this point, to speculate, admittedly on the slim objective evidence of coarser material at the more northerly of only two locations, that the arrival of silt toward the end of a period during which the lagoonal basin had been starved of sediments, heralded the early development of a new drainage system which subsequently was to carry into this very same area increasingly coarser material from the north during the deposition of the Imperial Formation (see p. 42) and to culminate in the thick conglomeratic sequences of the Tuttle Formation (see Fig. 18). However, serious objection to a northerly source lies in the line of six normal black shale sections from I-50 to I-06 (see map, Fig. 16). Probably related to the atypical Canol silts, are the two atypical Horn River sections of shale and limestone (see map, Fig. 14): at B-25, the Horn River interval is occupied by black shale and buff and white limestone which is chalky, argillaceous, and in part finely and medium granular; at C-60, the same interval consists of black shale and brown, bioclastic limestone. Sonic log trace (see cross-section A37-N39, Fig. 30) indicates interbedding of the shale and limestone and limestone increasing upsection. A trend to locally shallow marine environment may be suggested and this at the same time and in the same general area as the deposition of silt material. The question of the source rocks, from which the "new" clastic material was transported, remains open.

The Canol Formation, as stated above, is of early Frasnian age, and it occupies the same stratigraphic interval as, and is lithologically identical to, the Muskwa Member of the Horn River Formation in northeastern British Columbia.

The lower contact of the Canol Formation remains to be discussed and is dealt with under the following heading.

Sub-Canol contact. Citing earlier work of Nauss (1944), Hume and Link (1945, p. 25) reported, "north of the Ramparts in the Lower Mackenzie River area, the Middle Devonian beds are bevelled off, and northward Upper Devonian progressively rests on older Middle Devonian beds". This concept was expanded by Warren and Stelck (1949) who, on the basis of fossil collections, postulated "The Late Middle Devonian Unconformity in Northwestern Canada". The unconformity in the Mackenzie Valley was defined "In the field the Fort Creek shales are found directly overlying three different formations, the Beavertail Formation, Ramparts Formation and Hare Indian River Formation", and (*ibid.*, p. 144), "This bevelling below the unconformity is most marked below Fort Good Hope on the Mackenzie River and elsewhere on the Arctic slope, in which area both the Beavertail and Ramparts limestones are missing". From the Mackenzie Valley, the unconformity was traced to Great Slave Lake and into Alberta and the Canadian Rockies. It should be noted that Hume and Link (1945, p. 21-29) had given detailed reasons for discarding the name Beavertail, which was later to receive the support of Bassett (1961, p. 492) in the statement "Hume and Link (1945, p. 21) correctly considered that the names Ramparts and Beavertail were synonymous".

Bassett (1961), reporting on the upper contact of the Ramparts Formation, left the nature of the sub-Canol open by stating "It is likely that the thicker sections are the direct result of reef growth, although information available at present does not preclude the possibility that the overlying Canol Formation was deposited on an erosional surface with many hundreds of feet of erosional relief".

Sub-Canol contact relationships in the Mackenzie Valley were obscured throughout the history of confused Devonian nomenclature by miscorrelations of outcrops (see Tassonyi, 1969), as, for example, (*ibid.*, p. 40), "In fact, the basal shales of the Hare Indian Formation were frequently mistaken for the Canol Formation in outcrops". After outlining the results of previous work regarding the Ramparts-Canol contact, Tassonyi stated (*ibid.*, p. 84), "This controversial data does not help to solve the nature of the upper contact of the [Ramparts] Formation or to interpret the magnitude of any assumed unconformity". From "subsurface data, the evaluation of the Canol reports and the geometrical relationships of the reef", Tassonyi (*ibid.*, p. 84-85) suggested that contact relations differed in different areas, summarized as follows: ranging from "Unconformity: Limited in areal extent and magnitude due to limited lowering of the sea-level", through "Disconformity: the Canol Formation disconformably overlies the progressively thinning formation, owing to bevelling probably by marine abrasion", to "Continuous deposition" in off-reef areas.

Bassett and Stout (1967, p. 744) had declared "there can be no debate regarding the regional proportions and significance of the [unconformity] at or near the Middle-Upper Devonian boundary", and published a cross-section to illustrate "gradual truncation of the entire Middle Devonian and the upper part of the Lower Devonian between Norman Wells and the axis of the Richardson Mountains". Similar opinions were subsequently published by Gilbert (1973, p. 220), "LATE DEVONIAN". A short period of regression and uplift in certain areas resulted in removal of considerable thicknesses of Middle Devonian beds", and by Kunst (1973, p. 265), "The Canol Formation lies with disconformity or unconformity on progressively older strata from east to west. Beginning on the east overlying the Kee Scarp, it progressively overlies the Hare Indian, the Hume and eventually Silurian beds".

The basis, it seems, for Bassett and Stout's (*op. cit.*) pronouncement of a significant regional unconformity was two sections in the Richardson Mountains and these will now be considered in the light of other measured sections both in outcrop and from the subsurface. Letters A to N refer to plotted locations on the Canol Formation map, Figure 16, this report.

A - Bassett and Stout (1967, cross-section A-A, p. 724, see also p. 722) outcrop section 10, Road River, at 66°36'45"N, 135°26'30"W, - "Canol" unconformably on "Lower and Middle Devonian" pre-Hume.

B - Jackson and Lenz (1962, p. 34) section 3 (type section of Road River Formation) at 66°44'N, 135°46-48'W, - Fort Creek Shale (only basal part measured) unconformably overlying Ordovician and Silurian Road River Formation.

NOTE: Norris's (1968) later work (loc. C) suggests that Jackson and Lenz's section 3 may include at the top, or be overlain by, Prongs Creek Formation[1].

C - Norris (1968b, p. 239-273) section 35, Trail River, from 66°24.5'N, 135°31'W to 66°27.5'N, 135°22'W, - Upper Devonian (early to middle Frasnian) Imperial Formation overlying about 265 m thick Middle Devonian Prongs Creek Formation[1], in turn overlying unconformably Silurian Road River Formation, the sub-Prongs Creek unconformable contact being suggested by (*ibid.*, p. 272) "Erosional relief of between 2 and 3 feet at top of unit [Road River]".

D - Bassett and Stout (1967, p. 744), outcrop section located on the Peel River at 65°54'N, 135°56'W, "the Canol Formation -- carries an Upper Devonian conodont assemblage, including the genus **Palmatolepis**, which lies within 300 stratigraphic feet (91 m) above Lower Devonian shales with **Monograptus yukonensis**, indicating the absence here of earliest Frasnian, the complete Middle Devonian and the upper part of the Lower Devonian".

E - Lenz and Pedder (1972, p. 23-30), Upper Canyon of the Peel River at 65°52'N, 135°37-46'W, confirmed an unconformity above the Road River Formation, dating the topmost beds Gedinnian (earliest Devonian), but did not indicate what overlies the unconformity.

F - Lenz and Pedder (*ibid.*, p. 23), cited "a magnificent exposure of the unconformity at the base of the Late Cretaceous-early Tertiary Bonnet Plume Formation -- on the Wind River, approximately one mile (1.6 km) upstream from its junction with Peel river - gently dipping basal conglomerate of the Bonnet Plume Formation resting with marked unconformity on upturned beds of the pre-Middle Devonian Road River Formation".

G-N Norris (1968, 1969) - stratigraphic thicknesses of Road River equivalents of Devonian carbonates, 302 m to 971 m.

D-77, N-05, N-25 - stratigraphic thicknesses of Road River equivalents of Devonian carbonates ranging from 1069 m to 1181 m.

---

[1]Upper part of Road River Formation (this report).

H-71, N-25 - (see p. 71-72, this report) complete sections of the Lower and Middle Devonian strata clearly demonstrating transition from the formations of the Devonian carbonate assemblage to equivalent shale subunits within the upper part of the Road River Formation.

The thicknesses of the Lower and Middle Devonian beds in the above sections have been plotted, Figure 16, enabling isopachs of this interval to be drawn, guided by the more regional data from the Devonian isopachs map (Fig. 10). Pronounced thinning of the Lower and Middle Devonian strata roughly along the axis of the Richardson Mountains is undeniable. Erosional thinning, however, is not the only possible explanation. Norris (1968, p. 24-27) recognized the thinning of his Prongs Creek Formation, but did not attribute it to erosion; in fact, with reference to his section 35 (loc. C above), specific mention was made of "the condensed sequence of the Prongs Creek Formation along the eastern flank of the Richardson Mountains". Research concerning the above quoted sections shows that there is no evidence whatsoever of truncation of the Lower and Middle Devonian beds below the Canol (or Horn River Formation) in any one of the subsurface sections flanking or within the shale basin and no stated evidence of sub-Canol erosion in any of the outcrop sections other that at A and D, the sections upon which Bassett and Stout (*op. cit.*) founded their regional unconformity. It turns out that application of Norris's (*op. cit.*) concept of condensed sequence of Prongs Creek to the sections at A and D removes the sub-Canol unconformity while leaving all the reported factual data intact: at location A, Canol may lie, not on an eroded pre-Hume, but on a condensed Prongs Creek (upper part Road River, this report); at location D, part or all of the 91 m of undated sequence between dated Lower Devonian and Upper Devonian beds may also be a condensed basinal sequence of Devonian shales. The evidence to date favours a starved basin model and is not at all weakened by the locally pronounced thickening of this same sequence along part of the eastern edge of the basin or trough (at N-25 to N-77, see both maps, Figs. 10 and 16). The suggested model is certainly a more pleasing alternative to the intuitively dissatisfying concept of a short period of uplift and removal of some thousand metres of beds, catastrophically confined within the ancestral shale trough. Moreover, a condensed sequence of Devonian basinal sediments is more compatible with the immediately subsequent starved basin conditions of the Horn River Formation and also with the demonstrated (see p. 34) very fine feather edge of the Bluefish Member at its base. A detailed re-examination of the Lower to Upper Devonian interval in the Peel River Canyon section would therefore be expected to substantiate the starved basin model.

What of the lower contact of the Canol Formation in the Mackenzie Valley? The most recently published work bearing on this is by Pedder (1975), who, with reference to the early Frasnian fossil **billingsi** Zone, stated "In the lower and middle Mackenzie Valley, the time of the zone was essentially one of non-deposition or active erosion. The only locality known at present where the existence of the zone can be demonstrated is in the allochthonous beds on Powell Creek". This is illustrated (*ibid.*, Fig. 1, p. 57) diagrammatically as breccia below the base of the Canol Formation deriving from erosion of the Ramparts reef complex. The allochthonous beds are made up of subaqueous debris flows, turbidites and black shale (see also p. 37-38) indicating that active reef erosion took place at a time when surrounding areas remained flooded, but, as suggested by the absence there of the **billingsi** Zone, with little or no deposition. Therefore, bottom scouring and marine abrasion of the softer basin sediments could be expected. The latest evidence therefore, validates Tassonyi's (1969, *op. cit.*) earlier conclusions regarding the sub-Canol contact. That any hiatus in deposition between Ramparts and the Allochthonous limestone unit was of minor dimension is exemplified by the section at D-72, where allochthonous beds lie on Reef member dated near the top as Late Devonian, **mackenziense** Zone (A.E.H. Pedder <u>in</u> Norford et al., 1971, p. 17) (cited also under "Ramparts Formation", p. 35).

The validity of the thirty year old concept of a "Late Devonian Unconformity in Northwestern Canada" is thus seriously questioned for the northern area, the area, in fact from whence the idea first arose. Future work may well query its validity to the south, particularly in view of Griffin's (1965, p. 46) postulation of considerable pre-Muskwa erosion suggested by regional stratigraphic trends, and in light of the striking similarity between the Hare Indian-Ramparts-Canol and the Evie Lake-Otter Park Slave Point-Muskwa complexes, within which the proposed unconformity was supposedly located and within which its validity is now questioned in the north.

Upper Paleozoic stratigraphy

Within the Peel River map-area, the geological record of the upper Paleozoic is dominated by deposits of thousands of metres thickness of mainly marine clastic debris, of which the greater part was transported from a northern orogenic source. It is a very different record from that of most of the lower and middle Paleozoic, when shelf carbonates and basinal black shales were dominant. The interlude between these two great episodes of the Paleozoic, of which the Horn River Group alone is representative, spanned the Middle-Upper Devonian boundary. For ease of presentation, therefore, discussion of the upper Paleozoic begins with the Upper Devonian Imperial Formation and equivalents. Lower units in the Upper Devonian geological interval belong naturally to the interlude.

The Imperial Formation and equivalents were succeeded by the Tuttle Formation and its western basinal equivalent, Ford Lake Shale, both spanning the Devonian-Mississippian boundary and these were in turn followed by the Hart River, Blackie, Ettrain and Jungle Creek Formations. All of these formations subcrop beneath the sub-Mesozoic regional unconformity (see subcrop map, Fig. 23), the oldest in the eastern part of the area, and successively younger formations toward the southwest. Thus, the Imperial Formation has been studied mainly in the eastern half and the Jungle Creek Formation only in the southwestern corner of the map-area.

Imperial Formation and equivalents

The name Imperial Formation was formally introduced by Hume and Link (1946, p. 34-39) for a sequence of beds which had originally been named Bosworth Formation by Kindle and Bosworth (1920). Hume and Link (*ibid.*, p. 34) recounted, "In 1921 Bosworth called these same beds Camp Creek series" and "In 1936, Kindle renamed the formation "Carcajou Mountain Beds", because of prior use of the name Bosworth. The change to Imperial Formation was made because of better known sections and a type section was designated (Hume and Link, 1945, p. 34), "on the northeast flank of Imperial Mountain Range on Imperial River, -- 10 miles southwest of the junction of Imperial and Carcajou Rivers". The location was given by Bassett (1961, p. 495) as 65°07'00"N, 127°51'00"W (see map, Fig. 17, this report). The formation was described by Hume and Link (*ibid.*, p. 35), "In the Norman Wells area the Imperial Formation consists of green and fine grained silty sandstones and shales. Some of these beds carry marine fossils whereas others carry plant fragments and carbonaceous materials". Laudon's (1944) description of the section on Imperial River, which was reproduced by Hume and Link (*ibid.*, p. 34) indicated that the lower half of the Imperial Formation in the type locality was the more sandy and that the upper half was predominantly shale with some interbedded sandstones and very fossiliferous limestone. The thickness of the type Imperial, defined by Hume and Link (*ibid.*) as underlain by "Fort Creek shales", was about 610 m.

Bassett (1961, p. 496) proposed to modify the definition of Imperial Formation to include, at the type section, 110 m of "upper non-bituminous shales of the Fort Creek Formation", a modification which had been anticipated by Hume and Link (1945, p. 34). Having renamed the lower bituminous member of the Fort Creek Formation, Canol Formation, Bassett's (*ibid.*) revised definition of the Imperial Formation was stated, briefly "as the sequence of Devonian clastics and minor interbedded limestones, which overlies the Canol Formation and is unconformably overlain throughout the region by Cretaceous strata". Tassonyi (1969, p. 97) divided the Imperial Formation into two informal members in the subsurface, but noted, "Facies changes make it difficult to subdivide the formation in a regionally valid manner".

Facies variability in the Mackenzie River area alone is evident from the following statements:

Hume and Link (1945, p. 34)
Norman Wells area - "fine-grained silty sandstones and shales"; Imperial River (type section, after Laudon, 1944) - sandstone and shales in the lower part and shales, sandstones and limestones in the upper part;

Bassett (1961, p. 496)
"Light to medium grey shales commonly predominate in the lowermost 1,000 feet, greenish grey siltstones are prominent in the succeeding 600 to 800 feet and at many localities, grey shales occur at the top of the formation. This sequence is highly idealized and does not hold true everywhere. In fact, at some sections the siltstones are prominent at the bottom and at the top and are separated by a thick interval of shale";

Tassonyi (1969, p. 97)
"Based on gross lithology, supported by electric log characteristics, the formation can be divided informally in the subsurface into a lower member, consisting predominantly of marine shales and into an upper member, consisting of interbedded marine siltstones, sandstones, shales and a few intercalated limestone beds. The Jungle Ridge limestone lentil and the Canyon Creek sandstone lentil are positioned within the lower member and have limited extent in the Norman Wells area";

Aitken, Cook and Yorath (in press)
"The formation is dominated by shale --- Siltstone is prominent --- Sandstone forms a subordinate part of the formation; the amount and position of sandstone units within the formation vary from place to place in a manner that has yet to be worked out, but they are clearly more prominent in the upper part of the formation".

More recent work on the Imperial Formation (Hills and Braman, 1978) included outcrop data from the type area, the Arctic Red River area and Trail River. These suggest (*ibid.*, p. 36) "that the Imperial Formation consists of at least four discrete sedimentation units within the study area". Subdivision of the Imperial was recommended. In view of this and of further more detailed study of the Imperial Formation currently in progress (L.V. Hills, pers. comm., July, 1980), no name changes are proposed at this time for western equivalents of the Imperial Formation. The informal term "Imperial" in this report will refer to the Upper Devonian sequence of clastics lying between the Canol and Tuttle Formations, thereby indicating that these rocks are homotaxial with the Imperial Formation of the type area.

Within the study-area 69 boreholes have penetrated beds assigned to the Imperial Formation and equivalents and all but six of these are completely drilled sections. Twenty-five sections represent the Imperial Formation, preserved below conformably overlying beds. The major components of most sections are grey and dark grey shales, silty shales and argillaceous siltstones. Minor amounts of coarse-grained siltstones and very fine- and fine-grained sandstones occur in many areas and to the northwest increasingly significant amounts of coarser-grained sandstones. Because of important facies and thickness variations, a reference cross-section (Fig. 31), rather than one or two representative sections, is proposed. Regional distribution is illustrated on the isopach and lithofacies map (Fig. 17) and drill cuttings are described in Appendix II.

From the type area on Imperial River in the extreme southeast corner of the map-area, the shales, sandstones and limestones which have been recorded (Hume and Link, 1945; Bassett, 1961) as major interbedded constituents of the type Imperial Formation, seem to persist northwestward for about 80 km where, at the nearest borehole sections (L-09, H-73, L-24), drill cuttings contain fine grained siltstones, grading to silty, very fine grained sandstone and silty micromicaceous shale, with one 4 m thick bed of microcrystalline limestone recorded at H-73. From there, overall grain size decreases to the north and west (see lithofacies, Fig. 17). Westward along the Mackenzie Mountain front relatively coarser material reappears at the base. At A-22 the lowermost 79 m consist of coarse-grained siltstone; very silty, very fine grained sandstone and silty shale; the uneroded formation thickness of 865 m is by far the thickest recorded in the south. It is at A-22 that the reference cross-section begins (Fig. 31).

The cross-section illustrates two different directions of clastic transport, a major inflow from the north and a minor one from the west or south[1]. The latter is represented by the already cited basal unit of siltstone and sandstone at A-22, a unit which is traceable through D-64 as far as D-08 and possibly also into the Ontaratue area (I-38). Northward from I-21, formation thickness and sandstone grain size both increase (see also lithofacies, Fig. 17), reaching at C-78 respective values of 1863 m and beds of fine- to medium-grained sandstone carrying coarse and very coarse angular sand grains of grey, black and green chert. Sandstone in the northern sections is dominant in the upper part of the formation, siltstone and shale in the lower part. At G-06, coarse and very coarse chert and quartz sand was observed also in a dark grey siliceous argillaceous matrix in a 3 m thick interval about 170 m below the sub-Cretaceous unconformity.

[1]According to Hills and Braman, 1978, the lower part of the Imperial Formation in the Arctic Red River area (A-22) comprises turbidites in which "paleocurrent measurements indicate a west to east direction of transport (*ibid.*, p. 36).

The Imperial Formation almost everywhere lies conformably and non-gradationally on black bituminous shale, of the Canol Formation. The only exceptions to this rule occur over the top of the Ramparts reef core at H-24 and H-47m and on reef-flank Allochthonous limestone unit at D-53, where at all three locations the Canol Formation is missing. The Canol-Imperial contact is easily determined in the subsurface by the change in lithology from black radioactive shale to dark grey micromicaceous silty shale, siltstone or silty sandstone.

The Imperial Formation, where not truncated below sub-Permian, sub-Mesozoic or recent erosion surfaces, is overlain conformably by the Tuttle Formation or its basinal facies equivalent, Ford Lake Shale. The Imperial-Tuttle contact is conformable and time-transgressive (see below) but does not seem to be gradational. The contact can be defined, for consistent lithological pin-pointing, at the base of either the lowest conglomerate, or lowest silicified beds, or lowest brown-black shale, according to locality. These criteria are discussed more fully under "Tuttle Formation". The definition can be extended to the Imperial-Ford Lake contact to the southwest using the criterion of the base of brown-black shales with thin orthoquartzites or siliceous sandstones. At the sub-Mesozoic unconformity, eroded Imperial is in contact with a basal transgressive clean quartzose sandstone quite distinct from any Imperial sandstone. East of the Richardson Mountains, this basal sandstone, marking the base of the Lower Cretaceous, is also generally glauconitic, but is locally very thin and separates similar-looking Devonian and Cretaceous grey shales. In such cases, where the sandstone is not well represented in washed drill cutting samples, picking of the Imperial-Lower Cretaceous contact may involve a time-consuming search for one or two diagnostic sand grains to match the correct thin kick on well logs. In one well only (F-72) eroded "Imperial" is overlain by limestone of Mississippian to Permian age (see Appendix I, RRNA-059-1973).

Distribution of the Imperial Formation and equivalents (see Fig. 17) extends over most of the study-area, but Imperial beds are truncated over much of the eastern half by sub-Mesozoic and recent erosion, in the northwest at the sub-Permian and sub-Mesozoic unconformities and along the Mackenzie, Richardson and Ogilvie Mountain fronts at present-day outcrops. Isopachs in the southwest indicate thinning to a zero edge below the Ford Lake Shale, but because the "Imperial" in that direction (as evidenced at D-77 and B-62) consists mainly of uncharacteristically dark shale (dark brown-grey to black at B-62), the thinning probably represents decreasing volume of basinward sediments. Black shales, homotaxial with the "Imperial", may continue southwestward as an undifferentiated lower part of the Ford Lake Shale. Hence, the arbitrary zero edge drawn on Figure 17 would be depositional, the only depositional zero edge of the Imperial Formation and equivalents to be preserved within the study-area. A similar situation of non-erosional thinning is found in the Snake River area, with very dark grey and black shale (see lithofacies, Fig. 17). The possibility that this localized area may also have been "starved" of sediments during Imperial deposition is supported by its situation between a northern major and a southern minor clastic wedge, as illustrated in the reference cross-section (Fig. 31). In sharp contrast, the Imperial Formation attains a maximum recorded thickness of 1909 m at B-25, for a complete uneroded section below Tuttle beds. Even greater thicknesses may have accumulated north of the Tuttle zero edge where present-day eroded sections reach a recorded 1863 m thick (at C-78). These thicknesses in the north are clearly a depositional feature, as is the southward thinning with decreasing grain size. The same must be true to the west of the Richardsons, in the Cranswick River area and probably elsewhere.

The indicated Imperial model is one of transportation of clastic debris, varying in volume and grain size, from north, northwest and to lesser degrees from the west (Hills and Braman, 1978) and southeast (type area nearshore sediments), deposited as wedges into a "background" of marine basinal dark grey to black shale. The model is in accord with earlier opinions: Ziegler (1969, p. 7-15) depicted the Upper Devonian Imperial Formation as mainly greywacke and eugeosynclinal sequences deposited to the south of a rising landmass; Lerand (1973, p. 353, 355-357) postulated the Imperial to be the debris from geanticlinal highlands of igneous intrusions, metamorphosed Paleozoic rocks and perhaps volcanism, deposited as nonmarine and marine clastics; Glaister and Hopkins (1974) cited Ziegler and Lerand in support of their description of basin intermediate turbidity-current deposits in cored Imperial strata from the Tuktoyaktuk Peninsula, stating, "The setting is typically that of the synorogenic flysch facies found in narrow troughs adjacent to rising welts. Turbidity-current deposits are common in the flysch facies".

The suggested model for the study-area is of an Imperial "background" or "ground state" of basinal shale. Locally between wedges and southwestward beyond wedges, the basinal shale was unalloyed with coarser clastic materials. It is, in fact, the sedimentary expression of the same "ground state continuity" of a marine basin which previously had been "Canol" without any wedges and subsequently was to be "Ford Lake", shifted southwestward by advancing Tuttle wedges.

The age of the Imperial Formation has been established: at the type section (Chi and Hills, 1973) to range from Frasnian (but not earliest Frasnian) to early middle Famennian; at Powell Creek (Lenz and Pedder, 1972, p. 8-9, 37-38) as Frasnian and Famennian. Within the study-area nine borehole sections, assigned to Imperial Formation and equivalents, carry confirmatory age determinations (see Appendix II, A-37g, F-72, I-21, K-04, K-47, K-63, L-19, L-26, N-25). Four of these are for the upper part of the Imperial (non-truncated below overlying Tuttle) in the lower Peel River area:

I-21 (40-100 m below Tuttle contact) reported on palynomorphs, "Strunian or very latest Famennian" (D.C. McGregor in Norford et al., 1970, p. 7-8);

K-63 (uppermost Imperial and lowermost Tuttle) palynological results, "probably Strunian" (A.P. Audretsch; see Appendix I, APA-1972);

L-19 (500 m below Tuttle contact) report on palynomorphs, "late Frasnian or Famennian" (D.C. McGregor in Norford et al., 1970, p. 4-7);

N-25 (40-100 m below Tuttle contact) report on conodonts, "Late Devonian, Famennian" (T.T. Uyeno; see Appendix I, 16-TTU-1974).

These reports indicate that the top of the Imperial is younger southward, and similar reports (see under "Tuttle Formation") confirm that the base of the Tuttle likewise is younger from north to south. The contact is demonstrably time-transgressive over the interval from late Frasnian or early Famennian to very latest Famennian or Strunian. Deposition of the marine sediments of the Imperial Formation probably continued into Strunian, i.e. post-Famennian, time, contemporaneously with the deposition of southward-advancing Tuttle basin-fill sediments.

The "Imperial" is the same as Norris's (1968b, p. 41 and Fig. 2) "Unnamed Shale unit" in the Ogilvie Mountains. The Imperial Formation is roughly equivalent to the Fort Simpson

Formation to the south and it is time-correlative with the nonmarine clastic sequence of the Nation River Formation in east-central Alaska (Brabb and Churkin, 1967) plus part of the Ford Lake Shale at its type section (Brabb, 1969).

Tuttle Formation

A thick sequence of sandstones, conglomerates and shales, overlying the Imperial Formation in the lower Peel River area, has been referred to simply as "Mississippian" in well history reports of some two dozen wells and as "Mississippian clastic wedge" by Lutchman (1977). Norris (in press) has recognized and mapped these strata along both eastern and western flanks of the Richardson Mountains and has referred to them informally as "Tuttle" (D.K. Norris, pers. comm., June 1979). This name derives from Tuttle Hill (approximately at 66°30'N, 136°48'W) on the west side of the Richardsons where this rock sequence appears originally to have been recognized in outcrop. A little to the west of Tuttle Hill, D-61 borehole was drilled through 305 m of sandstone and conglomerate which were called "Tuttle" in the D-61 well history report of 1972 and "Tuttle sandstone" by Graham (1973, p. 164, Fig. 3).

The present study shows that this sequence of rocks is very important to regional stratigraphy and, potentially, to the oil and gas industry and therefore should be recognized as a formal rock stratigraphic unit. The sequence is typically and also most completely developed and preserved in the subsurface of the lower Peel River area. This is considered to be sufficiently near (75 to 100 km) to Tuttle Hill to permit continued use of the term "Tuttle" and therefore is the most logical candidate for the type area. "Tuttle" is probably the only geographical name to have been used for, and only for, these strata either in surface or subsurface. It is proposed therefore that the sequence of upper Paleozoic clastic rocks overlying the Imperial Formation and equivalents be called "Tuttle Formation". The type section selected is the Pacific Peel Y.T. F-37 borehole footage interval, 3216-350. F-37, located at 66°56'26"N, latitude 134°51'54"W, longitude, K.B. elevation 55 m (179 ft), completed drilling 11 April 1972 at total depth 3368 m (11050 ft). Drill cutting samples are stored at the Institute of Sedimentary and Petroleum Geology of the Geological Survey of Canada in Calgary, Alberta. A descriptive log of the type section is shown in Appendix II. The sidewall neutron porosity log of the type section and sonic-gamma ray logs of other sections of the Tuttle Formation are included on the upper Paleozoic stratigraphic cross-sections O18-A59 (Fig. 32), F72-D77 (Fig. 33) and G31-G55 (Fig. 34). Distribution of the Tuttle Formation is illustrated on the isopach and lithofacies map, Figure 18. Of the thirty-six sections described (Appendix II), six have palynomorph datings and of these L-19 and I-21 are suggested as useful reference sections. The thickest section, at O-22 and the most northerly section, at N-50, are two good reference sections west of the Richardsons.

The Tuttle Formation type section consists of 874 m of chert conglomerate, very poorly sorted quartz/chert sandstone, siltstone and grey and dark grey-brown shale; the conglomerate material is predominantly chert, coloured white, buff, grey, yellow, orange and pale green; much of the sandstone is kaolinitic; orthoquartzite beds occur in the top 100 m; most of the rock types from sandstone to shale are micaceous. Carbonates are absent.

The most common features of Tuttle lithology, whereby it is distinguished from the underlying Imperial Formation and equivalents, are: kaolinite and quartz infill of sandstone pores; thin orthoquartzite beds (quartz cement becoming more common southward); varicoloured chert conglomerate in the north; finer-grained, better sorted and more quartzose sandstone to the south; brown-black shale; carbonaceous fragments and locally coal; absence of carbonate cement. Near absence of glauconite in Tuttle lithology facilitates distinguishing these beds from the overlying, characteristically very glauconitic and well sorted quartzose sandstones at the base of the Mesozoic, but even so caution may be needed in locating the sub-Mesozoic unconformity in some areas (discussed below).

Overall clastic grain size distribution is illustrated in Figure 18. Coarsest clastics observed were from the lower Peel River area (pebble and larger at F-37 and L-19). Southward from there the trend is to better sorting, and there is a progressive decrease in maximum grain size down to coarse-grained siltstone at the Mackenzie Mountain Front (A-22, A-59). West and northwest from the lower Peel River area of coarsest clastics, Tuttle sandstones are very immature and this is especially evident in the most northerly section, at N-50, where very poorly sorted conglomeratic greywacke consists of angular fragments of chert, sedimentary rock (including dolomite) and subordinate quartz. At variance with an implied north to northwesterly derivation of clastics is the shaling out of the Tuttle Formation into Ford Lake Shale to the southwest (see discussion below), which would suggest northeasterly derived sediments, in agreement with the regional NW-SE alignment of the continental margin during late Paleozoic time (Bamber et al., 1980). The observed southeasterly decrease in grain size within Tuttle sediments is probably therefore only a part of the total picture and may represent the southeastern side of a major deltaic-turbidite wedge system.

Lutchman (1977) made a litho/environmental facies analysis of the Tuttle Formation from study of cores, logs and drill cuttings, finding the rocks to be apparently of fluvio-deltaic origin and by cross-section correlation suggested (*ibid.*, p. M-5) "the Mississippian clastic wedge can be subdivided into seven impulses of sandstone deposition". These were referred to as "M-1 sandstone" to "M-7 sandstone" units and each of these were illustrated on areal facies distribution maps. All seven sandstone unit designations after Lutchman are included in this report in the descriptive logs (Appendix II) and on the cross-sections O18-A59 (Fig. 32) and G31-G55 (Fig. 34), partly to illustrate a conflict between Lutchman's correlations and palynological evidence and to present collected data and interpretations as a basis from which future study may proceed. Lutchman's overall model is of successive delta systems, initially "confined to the northern section of the wedge area" (*ibid.*, p. M-5) and advancing progressively southward. The model of southward advancing basin-fill is confirmed by palynomorph dating of late Frasnian or early Famennian to late Famennian or Strunian (early Late to latest Devonian) age range for the units designated as M-1 to M-7 at L-19 and of Strunian to Tournaisian (latest Devonian to early Carboniferous) age range for similarly designated sandstones M-1 to M-7 to the south at B-06 and H-59 and for M-4 to M-7 at I-21. However, a logical expectation that individual delta systems would be roughly time-correlative units, is contradicated by several palynological datings. For one example, the M-2 sandstone unit, which at L-19 has been dated "late Frasnian or early Famennian (D.C. McGregor in Norford et al., 1970, p. 4-7), only 37 km away at B-06 lies between shales above and below dated "Strunian" (M.S. Barss, see Appendix I, CRS-5-MSB 1969). At variance with an entirely fluvio-deltaic model for Tuttle beds is an observation by L.V. Hills, (pers. comm., July, 1980) that in outcrop on Trail River, sandstone units within the Tuttle Formation are turbidites.

Very pronounced thickness variations of the Tuttle Formation reflect a combination of clastic wedge-type deposition, pre-Mesozoic erosion and present-day truncation along both flanks of the Richardson Mountains. The Tuttle Formation is bounded everywhere by erosional edges, except in the southwest corner where, based on the section at D-61, it is assumed to terminate at a depositional edge between the "Imperial" and Fork Lake Shale. Tuttle isopachs, reconstructed across the Richardsons belt (see Fig. 18) show clearly the rapid thickening from a depositional zero edge in the southwest to preserved thicknesses in excess of 1250 m north of 66°30' latitude. A maximum thickness of 1421 m was recorded in the Eagle Plains at O-22. Less than 40 km to the west, at N-49, a recorded anomalous thickness of only 105 m suggests pre-Mesozoic truncation on strike with the SW-NE trending Aklavik Arch. At N-49, the "Imperial"-Tuttle contact was picked on the basis of characteristically distinct sandstone lithologies. Northward from N-49, these lithological differences helped determine the Tuttle zero edge (see Fig. 18) in an area where boreholes have not reached the base of the "Imperial". For example, at F-48, 231 m of shale, chert-rich wacke and siltstone, designated "Upper Devonian? (Frasnian/Famennian)" underlaying "Probable Jurassic (undef.)" (see Appendix I, WHR-F-48-1973), are assigned to the Tuttle. The Late Devonian dating suggests that these beds at F-48 are in the lowest part of the Tuttle, similar to the Late Frasnian or early Famennian "M-2 sandstone unit" at L-19. That caution is needed in these assignments is shown at another location, P-34, where drilling was completed 218 m below what was earlier thought to be the base of Jurassic beds (Young, 1975, p. 309; Norford et al., 1971) in a sequence of shale, siltstone and sandstone: Young (*ibid.*) referred to this sequence as Imperial; it could reasonably be assigned to Tuttle on the basis of a chert-rich fine- to very coarse-grained sandstone and black shale lithology; it was dated by T.P. Chamney (Norford et al., 1971, p. 13) as Middle to Early Jurassic; and on recent re-examination of microfossils it is now considered (J.H. Wall, pers. comm., Aug. 1979) to be probably of Early Cretaceous age!

The contact between the Tuttle and the underlying Imperial Formation seems to be conformable and is certainly diachronous, and these two formations probably intertongue. Tuttle wedges were being deposited in the Road River (L-19) during late Frasnian or early Famennian time (D.C. McGregor in Norford et al., 1970, p. 4-7), while Imperial marine shales were continuing to be deposited a hundred kilometres to the south (I-21) until very latest Famennian or Strunian time (D.C. McGregor, *ibid.*, p. 7-8). The Tuttle is generally overlain by Lower Cretaceous strata. The rarity of glauconite in Tuttle beds facilitates recognition of this unconformable contact below characteristically very glauconitic and well sorted basal Mesozoic quartzose sandstone. Southeastward, where Tuttle sandstone tends to be more quartzose and better sorted and Tuttle thicknesses are down to 100 m and less, their presence below Lower Cretaceous beds of similar mechanical log trace can be determined confidently only by inspection of drilling samples in order to differentiate kaolinitic buff-coloured quartzose sandstone or siltstone from glauconitic white quartzose sandstone. The kaolin/glauconite criterion for the upper contact is a useful rule of thumb - but must be used with caution. Locally, near the eastern zero edge, distinctively glauconitic sandstone may overlie younger Lower Cretaceous beds. For example, in the Ontaratue River area at K-04, a 49 m interval of partly kaolinitic coarse-grained siltstone, with coal at the base, was considered at first to be probably an erosional outlier of Tuttle, underlain by Imperial shale and overlain by quartzose sandstone and glauconitic shale assumed to be at the base of the Lower Cretaceous. However, a careful palynological study by N.S. Ioannides (Appendix I, 3-NSI-1978) indicated the coal to be of probable Early Cretaceous age, overlying Frasnian(?) Imperial shale. The coal-siltstone interval at K-04 may be part of a thin nonmarine unit associated with an Early Cretaceous (Aptian) drainage system from the east (see Yorath and Cook, in press). Westward, into the lower Peel River area, chert conglomerate of Aptian age has been mapped (Norris, in press), and it is pointed out by D.K. Norris (pers. comm., Nov. 1979) that the type Tuttle may include this conglomerate at the top. Palynomorph datings throughout the 1039 m thick Tuttle section at L-19, 25 km southwest from the type section, give a Late Famennian or Strunian age about 200 m below the top (D.C. McGregor in Norford et al., 1970, p. 4-7). By virtue of its being conglomerate and especially so if derived from eroded Tuttle, the Aptian beds in question, if present in the Tuttle type locality, would not easily be distinguishable lithologically. This means that any Lower Cretaceous (pre-Albian) chert conglomerate will fall unavoidably into the same lithostratigraphic unit as the Upper Paleozoic chert conglomerate, the Tuttle Formation. It is in accord with the Code of Stratigraphic Nomenclature (Article 5d) that, if the boundary of an obscure unconformity (in this case, the sub-Mesozoic unconformity) cannot be lithologically defined, one unit be recognized, "even though it may include rocks deposited in different epochs, periods or eras".

Only in the southwest is the upper contact of the Tuttle Formation conformable, where it is part of the facies boundary with Ford Lake Shale. Using the model of progressively southward advancing Tuttle sediments, the farthest southwesterly extension of uneroded Tuttle sandstone, as represented in the subsurface of 308 m of conglomeratic sandstone at D-61, might be expected to be the youngest preserved Tuttle strata. Tendency toward younger Tuttle to the southwest is supported by a Tournaisian dating of outcropping Tuttle beds on the west flank of the Richardsons (D.K. Norris, pers. comm., June 1979). Further south, in the Peel River Canyon, "Unit 1" (Ford Lake Shale, this report), of Bamber and Waterhouse, 1971, p. 43, "is conformably underlain by approximately 30 feet of interbedded, fine grained, quartzose sandstone and dark grey shale of Viséan age". This sandstone-shale unit has not so far been correlated with beds elsewhere, but it could belong to the Tuttle Formation. Similarly, again at D-61, a 10 m thick unit of Tuttle-type, poorly sorted, chert-rich sandstone with siliceous cement and some kaolin, occurs high in a 924 m thick section of Ford Lake Shale, designated "Upper Mississippian (cf. Meramec)" (well history report, paleontological determination). Important, however, is the fact that the Tuttle Formation at D-61 is overlain by Ford Lake shale in which a tongue of Tuttle-type sandstone occurs. The presence of this tongue indicates that, following maximum southwesterly spread of Tuttle sandstone, basinal shale onlapped Tuttle beds through Viséan time, intertonguing with a possibly waning supply of coarse clastic material. The Tuttle section at D-61, therefore, appears to mark a turning point from basinward progression with marginal basin infill to a phase of shoreward progression accompanying reduced clastic supply and relatively rising sea-level. This suggestion is compatible with the Bamber and Waterhouse (1971, p. 95) statement that a northerly marine transgression during the Mississippian, postulated for northeastern Alaska, "appears to have continued toward the northeast, during Middle and early Late Viséan time ---" (see also Bamber et al., 1980). The generally grey and dark grey silty shales that were deposited until the Tuttle "turning point", belong lithologically to the rock unit, "Imperial"; during the subsequent phase of marine transgression, dark grey and black shales and very thinly interbedded quartzitic siltstone and sandstone, that were deposited basinward, are assigned to Ford Lake Shale. The Tuttle Formation, therefore, can be viewed as one overall wedge-type system, intertonguing with both "Imperial" shale below and Ford Lake Shale above. The thin edge of the wedge separates the "Imperial" and Ford Lake Shale and pinpoints the contact between them beyond the Tuttle depositional edge. Thus, the "Imperial"-Ford Lake contact is defined by a change from dark grey shale and argillaceous siltstone below to black pyritic shale with orthoquartzite and sandstone above (discussed in more detail below).

Presence of Tuttle-type sandstone of Viséan age [within Ford Lake Shale at D-61, (*op. cit.*) and see also under "Hart River Formation"] indicates that the age of the Tuttle Formation could range from Frasnian/early Famennian (as dated at L-19, *op. cit.*) through Tournaisian, with the possibility of some Viséan Tuttle preserved and yet to be recorded, below the sub-Mesozoic eroded surface. As discussed above, the Tuttle Formation could also include beds of coarse clastic rocks of Early Cretaceous (pre-Albian) age.

Ford Lake Shale

Brabb (1969, p. 12) introduced the name "Ford Lake Shale" ---for exposures in the type section - the east and west banks of the Yukon River (Fig. 19) from about 3.2 km east of Ford Lake to about 3.2 km northeast of Ford Lake. The Ford Lake Shale was given formation status and reported (*ibid.*) to consist "predominantly of greyish-black siliceous shale and laminated greyish-black chert that splits with a slabby parting". The contact with the "underlying Nation River Formation of Late Devonian age" was reported to be concealed at the type locality and the top of the Ford Lake Shale to be exposed at Calico Bluff, "where it grades vertically upward into limestone of the overlying Calico Bluff Formation of Late Mississippian age". Brabb (*ibid.*, p. 17) considered, "The few fossils found in the lower part of the Ford Lake Shale and the gradational relations of the Ford Lake to its underlying and overlying units indicate that the Ford Lake is Late Devonian to Late Mississippian in age". The type section location about 10 km west of the Alaska-Yukon border is at about 64°55'N latitude, 141°12'W longitude (see Fig. 19). Brabb gave a Ford Lake Shale thickness of "about 2000 feet" (about 610 m).

Bamber and Waterhouse (1971, p. 42-45) correlated Brabb's (1969) Ford Lake Shale and Calico Bluff Formation with their "Unit 1" shale and Hart River Formation carbonates, respectively, in the Northern Ogilvie Mountains-Peel River area. E.W. Bamber (pers. comm., June 1979) considers that "Unit 1" and "Ford Lake Shale" are one stratigraphic rock unit and therefore that the introduction of a new name for "Unit 1" is unnecessary. On the basis of similar lithology and stratigraphic position, it is proposed to extend use of the name Ford Lake eastward and to define it for the Northern Yukon Territory as a thick sequence of very dark shales, previously known informally as "Unit 1", underlying the Hart River Formation and overlying the "Imperial Formation" ("Unnamed shale unit" of Norris, 1968). In the subsurface, the Ford Lake Shale has been penetrated in 11 boreholes and completely drilled in 5 of these (at B-62, D-61, D-77, G-31 and O-18). The Ford Lake in the subsurface has been referred to more often as "Mississippian-Devonian shale", but also the name "Parkin Creek" was used in three well history reports for approximately the same interval.

Suggested reference section of Ford Lake Shale in the Yukon subsurface is Socony North Cath Y.T. B-62 well, 184 km northeast of the type section. There, the interval between the top of "Imperial" and bedrock at the base of drift (borehole footage interval, 2297-20?) consists of 694 m of predominantly dark brown-grey to black, carbonaceous shale, partly silty, with some thinly interbedded siliceous siltstone. Some poorly sorted siliceous chert-rich sandstone occurs in the lower 100 m+; about 420-400 m from the top, an interval of black silty shale and black bedded(?) chert; in the top 170 m, two 50 m intervals of conglomeratic, chert-rich, kaolinitic sandstone. Sonic log trace at the B-62 and other sections are shown on stratigraphic cross-sections O18-A59 (Fig. 32), G31-G55 (Fig. 34) and F72-D77 (Fig. 33), illustrating correlation to southwest, north and east. Postulated distribution is illustrated on the isopach and lithofacies map (Fig. 19).

There is one complete subsurface section of Ford Lake occupying the interval between the "Imperial" and Hart River Formations, at D-77. It consists of 352 m of brown-black, bituminous, pyritic shale, in part silty, rarely sandy, with some thin beds of orthoquartzite and very poorly sorted argillaceous to very coarse-grained sandstone and, at approximately mid-section (173 m above base) some buff, fine grained, porous, quartzose sandstone.

Ford Lake Shale thickens rapidly northeastward as it changes facies into the laterally equivalent part of the Tuttle Formation (see p. 45 and Fig. 2). At D-61, the Ford Lake, which is unconformably overlain by the Mesozoic, is 924 m thick and consists mainly of black splintery shale with some poorly sorted quartzitic sandstone and siltstone in the lower part and some brown ironstone; 85-94 m below the top is an interval of poorly sorted, silty, medium-to coarse-grained, chert-rich sandstone with siliceous cement and some kaolin, a unit which is probably a Tuttle tongue.

The Ford Lake thickens northwestward with the thickest recorded section west of the depositional edge of the underlying "Imperial" at G-31, where 975 m of black siliceous and pyritic shale overlie the Devonian Road River transitional unit. The Ford Lake at G-31 may include undifferentiated "Imperial" equivalent at the base (see discussion, p. 43). Similar thickness and lithology was recorded at O-18 where 952 m of black, silty, siliceous, partly pyritic Ford Lake Shale, which at this location may include basinal shale equivalent of Hart River Formation (according to E.W. Bamber, pers. comm., June 1979), is overlain probably by Ettrain Formation. The Ford Lake Shale in the O-18 borehole is fault repeated.

Isopachs shown on Figure 19 are based on the above figures and on reported (Brabb, 1969; Bamber and Waterhouse, 1971, *op. cit.*) approximate thicknesses at the type locality and Peel River Canyon. The latter provides a minimum value which would be an actual value only if the sandstone-shale unit of Viséan age reported (Bamber and Waterhouse, 1971, p. 43) to underlie "Unit 1" is found to correlate with the Tuttle Formation.

The contact between the Ford Lake Shale and the underlying "Imperial" is pinpointed to the northeast by the depositional zero edge of the Tuttle Formation (see under previous heading), which has allowed recognition of lithological criteria by which to pick the contact farther southwestward, or basinward. In the only two boreholes (B-62, D-77) in which the "Imperial"/Ford Lake contact has been drilled, the criteria are better exemplified at D-77 where a distinct change in sonic log, at borehole footage 2688, from "smooth" to "ragged" trace results from lithology change from dark and very dark grey micromicaceous shale with some brown-grey argillaceous siltstone, to brown-black bituminous pyritic shale with some thinly interbedded orthoquartzite and poorly sorted "Tuttle type" sandstone. Westward, at the B-62 reference section, "Imperial" micromicaceous shale is darker (dark brown-grey to black) so that the main distinguishing criterion seems to be the high silica content of Ford Lake shale, which at B-62 appears as thin beds of siliceous siltstone and sandstone and some bedded(?) chert.

The Ford Lake Shale is overlain by the Hart River Formation. Several wells have been drilled through the Hart River limestones and sandstones and into Ford Lake Shale. The lithology of the upper part of the Ford Lake in these sections indicates a gradational and/or intertonguing contact with the Hart River. At M-08, the 595 m of drilled Ford Lake shows a black shale, similar to the section 27 km away at D-61, with a 2 m interval of chert-rich conglomeratic sandstone 145 m below the top. In other incompletely drilled sections (B-34, K-56p, M-59), quartzitic siltstone and sandstone are characteristically very thinly interbedded with dark grey to black shale. The 35 m drilled at B-34, assigned to the top of Ford Lake, also includes some interbedded argillaceous and fossiliferous limestone, a feature similar to the type locality where the Ford Lake-Calico Bluff contact was reported (Brabb, 1969, *op. cit.*) to be gradational. A completely conformable Ford Lake-Hart River contact is further indicated by age determinations from the uppermost Ford Lake: Chesteran or late Viséan age at M-59, 20-25 m below the top (J.B. Waterhouse, see Appendix I, 716-928-2011-JBW-1970), sharing the same faunal zone as the lower Hart River Formation (see also Bamber and Waterhouse, 1971, p. 110); a Viséan age for palynomorphs 550 m below the top of the Ford Lake at M-08 by M.S. Barss (Appendix I, CRS-5-MSB-1969); a Late Mississippian, (approx. Meramec) (late Viséan) age for the upper 146 m of the Ford Lake at D-61 ("Paleontological Determinations", well history report, 1972); a suggested Viséan to Namurian age 4 m below the base of the Hart River Formation at N-26 (M.S. Barss in Norford et al., 1971, p. 10).

The above ages for the Ford Lake postdate reported ages of the Tuttle Formation. An intertonguing facies contact relationship with the Tuttle to north and east is discussed under the previous heading (p. 44). It is not known if the entire Ford Lake Shale shares, or ever did share, this lateral facies change to Tuttle Formation, because of missing upper Tuttle beds at the sub-Mesozoic truncation. For the same reason, it may not be possible to determine the northeastern depositional limit of the Ford Lake Shale, beyond which the Tuttle Formation would be overlain directly by Hart River Formation (see under following heading).

Hart River Formation

The name Hart River Formation was proposed by Bamber and Waterhouse (1971, p. 45-51) for a "sequence of recessive, light and dark brownish grey-weathering, laminated, silty, skeletal-micritic and micritic limestone, silty, calcareous dolomite and chert", overlying "Unit 1" (Ford Lake Shale, this report) and overlain by the Ettrain Formation in the Ogilvie Mountains and by "Unit 2" (Blackie tongue, this report) in the Eagle Plain. The type section is located on the north bank of the Peel River (Section 116H-1B of Bamber and Waterhouse, 1971), approximately 14.5 km east of its confluence with the Hart River, at approximately 65°53'N, 136°05.5'W. At the type locality, the Hart River Formation is 242 m thick and is overlain there by the reference section of "Unit 2".

Martin (1972) recognized northward thickening of the Hart River Formation and divided the Hart River into three members, named "the Birch, the Canoe River and the Chance Sandstone" Members. Subsequently, Martin (1973, p. 292) modified this subdivision, because of "new information, based on seismic data of excellent quality and additional drilling activities in 1971 and 1972", stating that "Of the proposed members, only the Chance Sandstone, a conglomeratic sandstone unit near the top of the formation in the south-central Eagle Plain, is retained". The type-section for the Chance Sandstone Member had been designated by Martin (1972, p. 22) in Western Minerals Chance No. 1 well (M-08), borehole footage interval, 4856-4258. The Chance Sandstone at M-08 formed the reservoir rock in Yukon Territory's first potential hydrocarbon producer.

Graham (1973, p. 161), summarized "results of integrated stratigraphic, paleontologic, petrographic and seismic studies", confirming northward thickening of the Hart River Formation both in the subsurface and in outcrop on the west flank of the southern Richardson Mountains and reported (*ibid.*, p. 166) "Where it is thickest, the Hart River consists mainly of limestone that is characteristically siliceous to cherty, skeletal, micritic and spicular; minor siltstone and coarse sandstone beds are present". Graham interpreted "Convergence of seismic markers within the Hart River Formation" to be the result of slope deposition and the Hart River to be "the thick sediments of a limestone shelf to the north and the thinner deposits of the flanking slope and basin to the south". Seismic profiles were used to correlate the Chance Sandstone Member to the D-51, C-18 and I-13 wells from the M-08, J-19 and G-08 boreholes, where it "is conglomeratic in part and is composed of medium and light grey, subangular to subrounded chert pebbles in a fine to coarse matrix of subangular to subrounded chert and quartz grains" with varying degrees of calcite cement. Correlation by Graham (*ibid.*, p. 168) "of the Chance Sandstone Member identifies a shelf and depositional slope within the Hart River Formation". The Chance Sandstone was not recognized in outcrop to the east and was considered to be represented by shale and bituminous limestone equivalents at K-56 and N-26 (see cross-section O18-A59, Fig. 32).

The present study adds little to Graham's work. The Hart River Formation was recognized in 14 borehole sections, in 8 of which the formation was incompletely penetrated. Of the 6 complete subsurface sections underlain by Ford Lake Shale, three are overlain by the Blackie Formation (or tongue) (B-34, D-77, M-59) and three by Mesozoic strata (K-56r, M-08, N-26). Distribution is illustrated on isopach and lithofacies map (Fig. 20), constructed using data from subsurface sections and outcrops (Bamber and Waterhouse, 1971; Graham, 1973). Maximum recorded thickness, at M-08, is 808 m, but because, according to Graham (1973, p. 166), this includes 120 m of section repeated by thrust faulting, a 691 m thickness is used on the map. Slope deposition, demonstrated in detail by Graham (*op. cit.*), is reflected graphically by southward thinning with corresponding decrease of sandstone and southward change to predominantly limestone-dolomite-shale facies. Correlations within the Hart River Formation, after Graham (1973), are included on cross-sections, O18-A59 (Fig. 32) and F72-D77 (Fig. 33) and in Appendix II.

The colour of the chert in the Hart River limestone ranges from brown, through buff and grey, to pale grey and white, commonly with characteristic brown specks and streaks. Similar colours and brown specks were observed in the clastic cherts of the Chance and other sandstone units, but also with some black and rare pale green, suggesting affinity both with Hart River bedded chert and with the chert conglomerates of the Tuttle Formation. Part of the clastic material in the Hart River sandstone, therefore, may have been derived from source rocks similar to those from which the Tuttle chert clasts originated.

The lower contact with the Ford Lake Shale and the upper contact with the Blackie Formation are conformable. North of the zero edge of the Blackie, the Hart River

Formation is truncated below the Mesozoic. Evidence of an erosional surface appears in borehole samples from the Hart River at three locations, D-51, K-56p and N-26, where pale grey, pale buff and white chert occupy the top 2 to 16 m with evidence of pebbles and weathering at D-51. In addition, at D-61, 27 m of conglomerate of black, grey and pale brown chert pebbles in a red brown sandstone matrix, occur above Ford Lake Shale and below Mesozoic glauconitic quartzose sandstone. If not belonging to Ford Lake Shale, this conglomerate at D-61 could be either an erosional remnant of the Hart River Formation or part of a sub-Mesozoic regolith.

The age of the Hart River Formation, based on macrofossils (Bamber and Waterhouse, 1971, p. 51) and on Foraminifera (Graham, 1973, p. 167) is mainly Late Viséan and Early Namurian and "ranges as high as Moscovian (Middle Pennsylvanian) in the southwestern Eagle Plain" (Bamber and Waterhouse, *ibid.*). The Hart River is equivalent to the Calico Buff Formation (Brabb, 1969), which at its type section in eastern Alaska lies between the Ford Lake Shale and the Mesozoic.

Blackie Formation

Lying between the Hart River Formation and a regional unconformity at the base of the Permian Jungle Creek Formation, there is a sequence of rocks of heterogeneous lithologies, parts or all of which, according to facies, have been referred to as "Unit 2" and Ettrain Formation (Bamber and Waterhouse, 1971, p. 51-53) and "Unnamed Pennsylvanian shale and siltstone" (Graham, 1973, p. 172). Assisted by seismic data, Graham (*ibid.*, p. 169, 173) presented cross-sections illustrating within this interval "southerly prograding sedimentary wedges", and stated "The term 'unnamed Pennsylvanian shale and siltstone' applies to the rocks in an area south of the Ettrain shale-out and includes equivalents of Unit 2, Ettrain Formation and younger Pennsylvanian fine-clastic rocks".

The name Blackie Formation is proposed for the basinal facies equivalents of Unit 2, Ettrain and Jungle Creek Formations, for the following reasons. The term "Unit 2" had been used (Bamber and Waterhouse, 1971, p. 51) for a sequence of sandstone, conglomerate and limestone, bounded below by the Hart River Formation and above by the Ettrain Formation or its eastern equivalents. Due to poor exposures, "Unit 2" could not be clearly delineated and Graham's subsequent documentation of Ettrain Formation shale-out southward has shown that "Unit 2" has a limited area of application. Graham (*ibid.*, p. 168) described "Unit 2" as "composed of calcareous shale and siltstone, beds of spicular and skeletal limestone and coarse-grained sandstone and conglomerate". Stratigraphic cross-sections (*ibid.*, p. 169-170) illustrated "Unit 2" to be predominantly of "shale, siltstone, limestone" lithology and within this to include sandstone bodies associated with the depositional slope at the basin edge. In addition, Graham stated that a major spore zone boundary had been defined. This was drawn on the cross-section in the upper part of "Unit 2" and carried through the lower part of "Unnamed Pennsylvanian shale and siltstone". It is clear, therefore, that "Unit 2" is a lateral equivalent of the lower part of the shale and siltstone unit. Furthermore, because the shale and siltstone unit was defined (Graham, *op. cit.*) to include fine-clastic rocks younger than the Ettrain, the Ettrain Formation intertongues or grades laterally into the "Unnamed Pennsylvanian shale and siltstone". It will be logical and most meaningful, therefore, and also consistent with the shelf-basin nomenclature of underlying units, to give formal recognition to the shale and siltstone unit with "Unit 2" recognized as a tongue below the Ettrain. In the absence in outcrop of complete exposures of either the shale and siltstone unit or "Unit 2", it is proposed to describe the new unit in the subsurface, using the complete section drilled in Socony Blackie M-59 borehole as type section and naming it "Blackie Formation".

The Blackie Formation is defined as the sequence of shale, siltstone and subordinate limestone and sandstone, overlying the Hart River Formation in the southwestern part of the study area. The term Blackie Formation, so defined, replaces the informal "Unnamed Pennsylvanian shale and siltstone", and also includes the "shale and siltstone facies of the overlying Jungle Creek Formation" (Graham, 1973, p. 172) from which the Pennsylvanian shale and siltstone was stated (*ibid.*) to be "separable with difficulty".

The type section designated is in the Socony Blackie Y.T. M-59 well, in which it is bounded above by the Jungle Creek Formation and in which it occurs in the borehole footage interval, 5164-2926. M-59, located at 65°58'55"N latitude, 137°11'11"W longitude, K.B. elevation 562 m (1844 ft), completed drilling 17 March 1964 at total depth 1931 m (6338 ft). Drill cutting samples and cores are stored at the Institute of Sedimentary and Petroleum Geology of the Geological Survey of Canada in Calgary, Alberta. Sample descriptions are included in Appendix II. The sonic-gamma ray log of the type section and of the section at D-77 are shown on Upper Paleozoic stratigraphic cross-section, F72-D77 (Fig. 33). The distribution of the Blackie Formation is indicated on the isopach and lithofacies map, Figure 21.

The type Blackie Formation is made up of a lower 294 km of black, bituminous shale, in part silty or sandy, with rare argillaceous limestone, and an upper 388 m of dark brown-grey, argillaceous, slightly calcareous or dolomitic siltstone, very dark brown-grey, partly silty shale and some thin beds of argillaceous limestone. Sonic-gamma ray trace suggests possibility of sandstone beds in the lowermost 75 m of the upper part (immediately above the 4200 ft borehole depth) coincident with Graham's (1973, p. 169, Fig. 3) inclusion at that depth of the edge of a "basinal sandstone" equivalent of the Ettrain Formation. The Blackie Formation thins from 682 m at the type section to 221 m at D-77, 23 km to the south. At D-77, a twofold division is still evident, with the lower part consisting of 121 m of brown-black bituminous shale and some dark brown, dolomitic siltstone and with an upper 100 m of brown-grey micromicaceous shale. The base of the upper part contains some beds of siliceous siltstone and sandstone.

To the west of the type section, drilling at D-63 was completed 231 m into the Blackie Formation in black and dark brown-grey, silty calcareous shale grading upward into brown-grey calcareous siltstone and shale with traces of glauconite. East of M-59, at E-53 only 47 m of Blackie were drilled, the cuttings indicating interbedded dark brown-grey to buff-grey shale and grey-buff siltstone. More data will be needed in order to determine the lateral extent of the twofold division recognized at M-59 and D-77.

The lower contact of the Blackie with the Hart River Formation is apparently conformable. Basinward beyond the shale-out of the Hart River, the Blackie Formation is expected to overlie the Ford Lake Shale (Fig. 2) and, in fact, the Ford Lake and Blackie are considered to be in contact in one well, M-55, near to the Alaska border. The contact there has been placed where characteristic Ford Lake black siliceous shale is overlain by black calcareous shale, calcareous siltstone and very calcareous sandstone assigned to the Blackie Formation (see Appendix II, M-55). Further basinward, however, the Ford Lake and Blackie may not be so easily separated. The upper contact with the Permian Jungle

Creek Formation may in places be unconformable. A sub-Permian regional unconformity, between the Ettrain and Jungle Creek Formation is documented by Bamber and Waterhouse (1971, p. 91) and supported by seismic evidence of angular discordance (Graham, 1973, p. 174). However, the reported (Bamber and Waterhouse, 1971, p. 55) "gradational lithologic change" at the Ettrain-Jungle Creek contact in the southwestern corner of the map-area, suggests that the sub-Permian unconformity may disappear basinward. Therefore, the contact between the Blackie, which is a basinal deposit, and the Jungle Creek may be conformable.

The Blackie Formation, as stated above, is seen to extend in part below the Ettrain Formation, as a mainly shale-siltstone unit which, in its shoreward limestone-sandstone-conglomerate facies, was referred to as "Unit 2" (Bamber and Waterhouse, 1971, p. 51-52). On the basis of seismic data, lithology and "a major spore zone boundary --- believed to lie at the base of the Middle Pennsylvanian Desmoinesian [Late Carboniferous Moscovian] --- within the upper one-half of Unit 2", Graham (1973, p. 168-172) demonstrated correlation of Unit 2 with the lower part of "Unnamed Pennsylvanian shale and siltstone" at D-77. Graham's correlation through M-59 showed it to be precisely the lower black shale part of the type Blackie. This tongue of the Blackie Formation in the southern Eagle Plain occurs in two subsurface sections, at B-34 and I-13. At I-13, which is a good reference section where it lies typically between the Hart River and Ettrain Formations, it is 254 m thick and consists of a heterogeneous lithology of calcareous silty shale, poorly sorted calcareous glauconitic quartz/chert sandstone, silty and sandy glauconitic limestone and calcareous siltstone. The thicker (524 m) section at B-34 is overlain by transitional Ettrain (see below). It consists of shale with two distinct intervals of limestone and one bed of very coarse-grained sandstone (see Appendix II).

More than 100 km to the west, at M-55 and O-18 near the Alaska border, a sequence of very calcareous siltstone, black silty calcareous shale and very calcareous sandstone and silty sandy limestone, lying between the Ford Lake Shale and Ettrain Formation, is assigned to the Blackie Formation. This may include equivalents of the Hart River Formation.

The Blackie Formation at B-34 was given an early Late Carboniferous age, "probably Middle Namurian" by M.S. Barss (in Norford et al., 1971, p. 8). The upper siltstone and shale division of the Blackie at M-59 has been dated Permian (M.S. Barss in Norford et al., 1971, p. 9) which means that the type Blackie may include basinal equivalents of the Jungle Creek, as well as of Ettrain Formations.

Ettrain Formation

The Ettrain Formation was named by Bamber and Waterhouse (1971, p. 53) and described (*ibid.*) as "a light grey- and brownish grey-weathering sequence of skeletal, skeletal-micritic and micritic limestone with dark grey chert beds and minor intervals of dolomite", lying between the Hart River and Jungle Creek Formations. At its type section, at approximately 65°23-24'N latitude, 140°40'W longitude, the Ettrain Formation was reported (*ibid.*) to be 549 m thick. Somewhat similar lithology was observed 50-60 km NNE of the type area, in the nearest borehole sections at M-55 and O-18, where it consists of buff, grey, brown and dark brown-grey, medium- to coarse-grained skeletal, argillaceous limestone with some dolomite and silica replacement, black, calcareous, pyritic shale and grey, brown and smoky chert. There the Ettrain overlies the Blackie Formation and is 231 m (at M-55) and 148 m (at O-18) thick.

Eastern equivalents of the Ettrain are present in the southern Eagle Plain: at I-13 the Ettrain (62 m thick) is in a shoreward facies of fine- to very coarse-grained, glauconitic, calcareous, pyritic sandstone, silty calcareous shale and very sandy and silty, very glauconitic, pyritic, fossiliferous limestone; at B-34, 115 m of interbedded silty and sandy argillaceous, glauconitic, fossiliferous, bioclastic limestone and calcareous shale is considered to be Ettrain Formation in transition to the Blackie Formation; at N-58, drilling was completed 257 m into an Ettrain section of cherty, skeletal, medium- and coarse-grained, partly glauconitic limestone, sandy limestone and very calcareous sandstone.

The age of the Ettrain Formation, according to Bamber and Waterhouse (1971, p. 59), ranges throughout most of Late Carboniferous in the type area, with both the base and the top varying in age toward the east and northeast.

Jungle Creek Formation

The name Jungle Creek Formation was proposed by Bamber and Waterhouse (1971, p. 60) for a "sequence of variable lithology, including skeletal, partly conglomeratic limestone; micritic-skeletal and spicular limestone; calcareous sandstone; chert pebble conglomerate; calcareous shale; siliceous mudstone; and siltstone", overlying the Ettrain Formation. At the type section, at 64°58'N,140°54'W, it is overlain by the Tahkandit Formation. The Jungle Creek Formation is about 425 m thick at the type locality and was stated (*ibid.*) to have approximately the same distribution as the Ettrain Formation in the Ogilvie Mountains and east to southern Eagle Plain. North of 67° latitude, Permian rocks outcropping along the lower Porcupine River, which had been reported earlier by Norford (1964) and Nassichuk (1971), were considered by Bamber and Waterhouse (*ibid.*, p. 61) to be equivalent to the Jungle Creek. Later, Graham (1973) documented the presence of the Jungle Creek Formation in the subsurface of Eagle Plain and in outcrops in the West Ogilvie Mountains.

By definition, the Jungle Creek Formation includes a wide range of lithologies. For this reason, all nine borehole sections of rock sequences in the appropriate interval above Upper Carboniferous beds, though ranging in lithology from conglomerate and limestone to black shale, are herein assigned to the one Jungle Creek Formation, with this exception that, as discussed under "Blackie Formation" (p. 48), the basinal shale and siltstone facies of the Jungle Creek is assigned to the Blackie Formation.

Data from both borehole and reported outcrop sections are included on lithofacies map, Figure 22. In southern Eagle Plain, the Jungle Creek Formation overlies the Ettrain or the Blackie Formation and is overlain by Mesozoic beds except where the Jungle Creek outcrops at D-77. A north to south change in lithology from mainly conglomerate and sandstone to sandstone and shale is evident. The Jungle Creek conglomerate is composed predominantly of chert, colour generally ranging from pale to dark grey, pale buff to brown and milky white to smoky, with some orange noted at M-59 and traces of grey-green at N-58; fragments of carbonates and quartz were observed at B-34. Sandstone is extremely poorly sorted with grain size from very coarse to silt and is made up of chert, quartz, feldspar and locally kaolin. Shale in all sections is silty, and at B-34, E-53 and D-63, is partly glauconitic. Permian spores at B-34 were studied by M.S. Barss (in Norford et al., 1971, p. 7). Macrofossils from core at M-59 (J.B. Waterhouse see Appendix I, 716-928-2011-JBW-1970) confirm the presence there both of Jungle Creek beds and of the inclusion within them of an upper 60 m of calcareous siltstone above a 2 m zone of chert pebbles and granules in highly glauconitic, pyritic, sandy and argillaceous matrix. The latter lithology might otherwise have suggested a basal Mesozoic pebble bed.

In two boreholes near the Alaska border, the Ettrain Formation is overlain: (at M-55) by 240 m of brown-grey to black, calcareous, siliceous shale and argillaceous limestone, in turn overlain by 480 m of sandy skeletal limestone, calcareous orthoquartzite and calcareous siliceous shale; (at O-18) by 264 m of black calcareous shale with rare limestone. Assigning these two sections to the Jungle Creek Formation conflicts with the Bamber and Waterhouse (1971, p. 104) facies distribution map which showed a mainly sandstone-conglomerate facies for that area, but agrees with Graham's (1973, p. 170, Fig. 5, p. 174) documentation of Jungle Creek "shale, siltstone, limestone" facies in the West Ogilvie Mountains.

In the lower Porcupine River area, a sequence of coarse and fine clastic rocks and limestone, overlying Devonian and older strata, has been reported (Norford, 1964; Nassichuk, 1971) from two outcrop locations and has been drilled at F-72. Norford (1964, p. 119-120, Section 24) assigned a Permian age to 158 m of chert-pebble conglomerate and sandstone overlying the Road River Formation, about 10 km NW of F-72. Nassichuk (1971, p. 103-104) measured and collected fossils from Lower Permian "dark grey siltstones, silty shales and silty carbonate rocks", about 12 km SE of F-72 and described (*ibid.*, p. 104) the section as "similar to the upper part of the Permian succession on Peel River, near the mouth of Hart River", adding, "According to E.W. Bamber (pers. comm.) the Porcupine River section also resembles a sequence of rocks in the Ogilvie Mountains designated 'Middle Recessive Unit' ". Both of these Porcupine River sections were considered (Bamber and Waterhouse, 1971, p. 61) to be equivalent to the Jungle Creek. Between them, at F-72, the Devonian "Imperial" is overlain (Well History Report, 1974) by 291 m of siltstone, shale, sandstone, orthoquartzite and some limestone; the only drill cuttings available indicate a basal 8 m of buff micro- to very fine-grained bioclastic limestone. An Early Carboniferous to Permian age was given (see Appendix I, RRNA-059-1973) to this interval on the basis of the presence of Carboniferous and Permian palynomorphs.

The Jungle Creek Formation is underlain by the sub-Permian unconformity and almost everywhere within the study area it is overlain by either the sub-Mesozoic or present day erosion surfaces. In the type area the Jungle Creek is overlain conformably and time-transgressively (Bamber and Waterhouse, 1971, p. 66) by Middle Permian beds (Takhandit Formation) and its age was reported as roughly spanning the Early Permian.

Unnamed shale and sandstone unit

In the area of the northern Richardson Mountains, Devonian or earlier rocks are overlain by upper Paleozoic rocks which are apparently younger than the Jungle Creek equivalents (described above) in the lower Porcupine River area.

At K-35, the Road River Formation is overlain by 91 m of shale and sandstone, the top of which marks the sub-Mesozoic unconformity. This section is made up of a lower 78 m of brown, dark brown and black silty and sandy shale with interbedded fine grained quartzitic sandstone and orthoquartzite and an upper 13 m of pale buff, fine- and very fine-grained quartzose kaolinitic sandstone. About 20 and 32 km west of K-35 (see map, Fig. 22) there are two outcrop sections (116M-7 and 116P-9), of similar strata which were referred to as "Permian Rocks (unnamed)" by Bamber and Waterhouse (1971, p. 86-88). These rocks in the general area of the northern Richardsons were subdivided (*ibid.*) into a lower Carbonate unit, a middle Shale unit of silty shale, siltstone and sandstone, and an upper Sandstone unit of fine-grained quartzose sandstone. The Shale and Sandstone units were assigned to the Lower and Middle Permian. For the purpose of this report, the probably equivalent beds at K-35 are referred to as "Unnamed shale and sandstone unit".

Two more outcrop sections (see map, Fig. 22) of possibly equivalent rocks were reported by Jeletzky (1967): 23 km west of K-35, 24 m of fine grained quartzose sandstone of Permian age 14 km north of K-35, 21 m of "Breccia---conglobreccia---conglomerate" designated "Permian and ?Upper Carboniferous".

CHAPTER III

STRUCTURAL GEOLOGY

Introduction

The physiographic expression of the structures underlying the Peel River map-area is dominated by two broad areas of plains and plateaux, bissected by the narrow north-south belt of the Richardson Mountains and bordered along their entire southern edge by mountains from the Ogilvies to the Mackenzies. Structurally, the Richardson Mountains are an anticlinorial feature separating a western intermontane basin from an eastern synclinal basin at the craton edge. These main features are evident in the structure contours from the Precambrian surface (Fig. 3) to the sub-Mesozoic surface (Fig. 23).

Tectonic setting

The Peel River map-area is at the junction between two major geosynclinal belts, the Franklinian Geosyncline (Schuchert, 1923; Martin, 1959, 1961) and the Cordilleran Geosyncline. In fact, earlier workers interpreted the Richardson Mountains as a connecting link between these two geosynclinal belts, a hypothesis which was rejected by Jeletzky (1962), who suggested instead that the entire inter-geosyncline area was "best classified either as stable or labile shelves or as intracratonic troughs or basins". Jeletzky on the basis of substantial evidence, concluded that the "northern Yukon, adjacent parts of Northwest Territories and those of northeastern and east-central Alaska --- maintained essentially the present day geographical relationships to each other at least since early Paleozoic time".

Tectonic elements of this postulated ancient continental landmass, pertinent to this report (see map, Fig. 1) are as follows:

Aklavik Arch (ancestral) - Jeletzky, 1961, p. 577; 1962, p. 66 (Dave Lord Ridge, Martin, 1959; Dave Lord High, Jackson, Lenz and Pedder, 1978). ?Proterozoic to Mesozoic.

Blackstone Trough - Lenz, 1972, p. 331. Cambrian to Early Devonian.

Canada Basin - deep part of Arctic Ocean bordering Alaska and Canada.

Mackenzie Arch - Gabrielse, 1970, p. 375-400; Aitken et al., 1973, p. 37-38. Proterozoic to Cambrian.

Mackenzie Platform - Lenz, 1972, p. 328-329. Cambrian to Middle Devonian.

Misty Creek Embayment - Cecile, 1978, p. 376. Early Paleozoic.

Porcupine Platform - proposed for the eastern part of the Yukon Stable Block (Jeletzky, 1962, p. 62) between the ancestral Aklavik Arch and the Richardson Trough. Cambrian to Middle Devonian.

Richardson Trough - ancestral to Porcupine Plain-Richardson Mountain Trough, Jeletzky, 1971, p. 1; 1972, p. 212, Figure 1 (previously Richardson Mountains Trough, Jeletzky, 1963). Cambrian to Middle Devonian.

Richardson Aulacogen

The most striking structural feature of the Peel River area is the roughly north-south trending alignment of the Richardson Trough, perpendicular to two major orogenic belts. According to Jeletzky (1975, p. 2), throughout Jurassic and Early Cretaceous time the Porcupine Plain-Richardson Mountain Trough was "a major north-northeast-trending, fault-controlled, marine intracratonic trough fragmenting the western shelf of the Canadian Shield", a trough which Jeletzky (*ibid.*) suggested was an aulacogen "under the original definition[1] of the term (Shatsky, 1964, p. 551-552) as it appears to merge into the northern part of the Mesozoic orogenic belt of the Canadian Cordillera to the south and southwest". Jeletzky (*ibid.*) considered "the Porcupine Plain-Richardson Mountain aulacogen appears to end abruptly or gradually in the north beneath the Beaufort Sea". Evidence from the present study supports Jeletzky's postulated aulacogen by indicating that the Richardson Mountains belt was the site of an earlier structurally controlled trough, referred to herein as the Richardson Aulacogen.

During early Paleozoic time the Richardson Trough was the site of accumulation of thick basinal limestone and graptolitic shales (Road River Formation) in a narrow belt between shelf carbonate build-up (Ronning Group) both to the east and to the west. To the south of, and with similar northerly alignment as, the Richardson Trough, lies the lower Paleozoic Misty Creek Embayment (Cecile, 1978, p. 376; Cecile, in press - see Figs. 7, 8 this report), a discrete basin from the Richardson Trough, separated from it by Ronning Group carbonate platform, and filled with basinal limestones and graptolitic shales of Road River Formation (Cecile, *ibid.*). Results from the present study, indicating that the Richardson Trough was fault-controlled, are in agreement with previous observations. Norris and Hopkins (1977, p. 11), reporting on the geology of the Bonnet Plume Basin in the south of the present study area, suggested, "The mosaic of both the intertonguing and laterally contiguous Road River Formation and unnamed carbonate banks suggests that a structurally controlled, variably shallow and deep seaway persisted intermittently in the position of the Bonnet Plume Basin during the early Paleozoic"; Cecile (1978, p. 376) stated, "A combination of several factors suggests that the Misty Creek Embayment was produced and controlled by extension faults". Northward, the Richardson Trough appears to have extended to an early Paleozoic geosynclinal belt (Churkin, 1969). During the late Paleozoic, thick wedges of clastic debris deposited over the Porcupine Plain-Richardson Mountains area, attest to a northern source - the documented Late Devonian uplift and granitic intrusions of several authors, summarized by Churkin, 1969. The evidence, therefore, suggests that the Richardson Trough during

[1]Translated (Burke and Wilson, 1976), "Aulacogens are rifts that extend from belts of folded mountains into continental platforms".

Paleozoic time was an aulacogen extending into the continental platform from a northern orogenic belt.

According to Burke and Dewey (1973), aulacogens are the failed arms of plume-generated triple junctions or rrr junctions. These authors stated that study in Africa of the continental rupture process prior to ocean opening (*ibid.*, p. 406) "has demonstrated the existence of an evolutionary sequence from uplift through rifting and uplift-generated triple-junction formation, to continental break up". From a global study of heat plume-generated junctions, the first of eight conclusions drawn by Burke and Dewey (*ibid.*, p. 429) was, "Plumes under continental lithosphere - especially where that lithosphere is at rest over the underlying asthenosphere - typically cause uplifts that rupture along three rifts meeting at rrr junctions. Commonly, two of these rifts become a plate boundary (either a ridge or a ridge transform) while the third does not spread and becomes a failed arm".

If the Richardson Trough is a Paleozoic aulacogen, or failed arm, as the present evidence suggests, then its genesis might lie in a heat plume-generated triple junction, leading to continental rupture and accretion of new oceanic crust in the two arms that succeeded in spreading. Would this be related to the origin of the Canada Basin? - or to continental separation along the Cordillera? Both are conceivable: for the Canada Basin - Churkin (1969, 1970), reviewing the geological and geophysical data available and rejecting the then prevailing continental subsidence theory for the origin of the deep Canada Basin, concluded (*ibid.*, 1969, p. 555) that the Canada Basin "is, I believe, a true and probably very ancient ocean basin floored by oceanic crust and rimmed by an early Paleozoic geosynclinal belt", and that "the movement of the floor of the Arctic Ocean against the continental crust of North America (sea-floor spreading) would provide a mechanism to account for the long history of orogenic activity along the basin margin"; for the Cordillera - opening of the Proto-Pacific seems to have been a Proterozoic event (Monger, Souther and Gabrielse, 1972; Stewart, 1972, p. 1345; Burke and Dewey, 1973, p. 423). It is beyond the scope of this subsurface study to speculate further on the early history of the Richardson Aulacogen. Road River deposits in the Richardson Mountains area are underlain (Norris, in press) by thick clastic sequences of Cambrian and earlier age, indicating that aulacogen genesis may be associated with Proterozoic events postulated by several authors (e.g. Aitken and Long, 1978; Stewart, 1972; Young et al., 1979).

Speculation on the tectonic history of the Peel River area is of more than academic interest. Burke and Dewey (1973) cite many examples of aulacogens with "economically important sulphide deposits" and "major fluid hydrocarbon accumulations". The economic prospects in the general area of the postulated Richardson Aulacogen are discussed in Chapter V.

CHAPTER IV

HISTORICAL GEOLOGY

Introduction

The writer's brief version of the Peel River story is based mainly on interpretation of subsurface geological data, supplemented by published views of surface workers. The historical record falls into five phases: earliest record; Cambrian-hypersaline basin; lower Paleozoic-shelf carbonates; Givetian interlude; upper Paleozoic-clastic sediments.

Earliest record

The known subsurface record of sedimentation within the map-area begins with rocks correlative with Helikian formations to the southwest, formations which subsequently were eroded or completely truncated over the Mackenzie Arch. Helikian sediments in the Canadian Cordillera have been regarded (Gabrielse, 1967, 1972) as representing a continental terrace wedge and the Helikian formations in the northern Yukon have been interpreted (Aitken et al., 1973, p. 34) "as constituting the shallow-water part of a continental terrace wedge assemblage". During the Proterozoic eon rifting and continental separation have been postulated to have taken place: Monger et al. (1972) considered it to be a mid-Proterozoic event, preceding development of the Helikian terrace wedge; Stewart (1972, p. 1345), on the other hand, suggested that a change in the tectonic framework, which occurred after the deposition of the Helikian sediments, marked the beginning of the Cordilleran geosyncline; recently Young et al. (1970), summarizing evidence from the well-studied Proterozoic of the northwest, have suggested that continental fragmentation may not have occurred until Phanerozoic time.

The Helikian rocks of the study area and the subsequent rise of the Mackenzie Arch, therefore, appear to be related in some way to the genesis of a major continental separation. It is from this point that we may take up the geological history of the Peel River area.

Cambrian - hypersaline basin

By Early Cambrian time, the Precambrian land surface northeast of the Mackenzie Arch had been sculptured into depressions in the less resistant Argillite unit between ridges of the more resistant outcropping Orthoquartzite and Dolomite units. The initial sediments of the Phanerozoic were deposited into such paleotopographic depressions, as discontinuous and diachronous spreads of quartzose sands, derived either very locally from the orthoquartzites exposed over the Mackenzie Arch, or transported from older Precambrian rocks in the east.

Deposition of Mount Cap sediments which followed, may have begun as a localized accumulation of glauconitic and oolitic dolomites and some green-grey shale in channel or trough-like depressions in the Precambrian surface, as suggested by the unique occurrence of these lowest Mount Cap beds at D-40, until more extensive flooding of a broad shallow basin northeast of the Arch allowed deposition through Mid-Cambrian time of shallow marine silts, shales and sands with glauconite and eastward some carbonates. Westerly and southwesterly depositional thinning of both Mount Cap and subsequent Saline River sediments attest either to a western shoreline, or more likely, as suggested by Cecile (in prep.), a Middle Cambrian carbonate barrier on the Mackenzie Arch separating the hypersaline basin from the Selwyn Basin to the southwest. In the Richardson Trough a thick succession of limestones and clastics had been building up throughout the Cambrian (Hume, 1954; Martin, 1959; Norris et al., 1963), suggesting that the Aulacogen had its origins during or before Early Cambrian time. Whether the Richardson Aulacogen was related to the opening of the "Proto-Pacific", or the opening of the Canada Basin, or to both, or to neither, remains obscure, but a clue for future research is suggested by the proximity and alignment to the Aulacogen of a possible northern extension of the Mackenzie Arch and also by the activity of the Aklavik Arch to the northwest at least as early as mid-Cambrian time (Jeletzky, 1963, p. 66).

Some positive movement of the Mackenzie Arch and probably also of its northern extension, took place at the end of Mount Cap deposition, causing local truncation of Mount Cap beds along the northeastern flank of the Arch and accompanied by a depositional change extending northeastward into the consequently more restricted marine basin, in which increasingly hypersaline conditions gave rise to precipitation of salt during the Late Cambrian. At this time, the last islands of Precambrian outcrop, for example, at L-26, were finally buried and, as the basin filled, there began a slow subsidence of the entire shelf area with resulting open marine circulation and a depositional transition through varicoloured shale (Upper clastic member of Saline River Formation) to argillaceous dolomite and progressively decreasing amounts of grey shale (basal Franklin Mountain Formation) in later Cambrian time. To the west, depositional change in the Richardson Trough was from coarser Lower and Middle Cambrian clastics to black shale and carbonate of the Road River Formation.

Lower Paleozoic - shelf carbonates

During the lapse of time from Late Cambrian to Middle Devonian, overall tectonic stability of the northwestern cratonic shelf was essentially undisturbed. Relatively minor periodic movements and adjustments gave rise to various correspondingly minor depositional changes, both locally and regionally within the thick successions of shelf carbonates and of basinal shales that accumulated over the Mackenzie and Porcupine Platforms and in the intervening Richardson Trough rift. The regional changes are reflected in today's lithoboundaries between the carbonates of the Franklin Mountain, Mount Kindle, Peel, Tatsieta, Arnica, Landry and Hume Formations and between their homotaxial shale unit equivalents within the Road River Formation.

Late Cambrian to Late Ordovician

The barrier which formed the western margin of the Cambrian evaporite basin appears not to have been buried by the earliest carbonate deposits. During the initial deposition of Franklin Mountain shaly dolomites, Precambrian orthoquartzite probably continued to outcrop along the line of the Mackenzie Arch and its northern extension and some quartzose sand and silt derived from it were locally reworked into the basal beds of the cleaner crystalline dolomites which had begun to build up over most of the Peel River area.

The Mackenzie and Porcupine Platforms were separated by the Richardson Trough, in which dark graptolitic shales and carbonates of the Road River Formation had been accumulating since probably as early as Middle Cambrian time. Basinal facies homotaxial with Franklin Mountain dolomites appear to have been less extensive, implying that the rift was narrower, than at any subsequent time.

During the Early Ordovician the formation of chert was common throughout the eastern part of the study-area and it seems that the conditions favouring its development had moved westward toward the Richardson Trough by Middle Ordovician time. During Late Ordovician time, chert deposition was common to most or all of the Porcupine area where it became interbedded with limestone.

During Middle Ordovician time much of the Mackenzie Platform was exposed to erosion, and in the Late Ordovician or Early Silurian the Porcupine Platform was raised above sea level, while the Richardson Trough continued to be a submarine basin.

Late Ordovician to Late Silurian

Renewed transgression of marine waters during the Late Ordovician terminated the erosional break over the eastern part of the area and resulted in a depositional change east of the Richardson Trough from the pure, very pale dolomite of the Franklin Mountain Formation to the generally brown, very finely to medium crystalline dolomite of the Mount Kindle Formation. A limestone "fringe" flanked the eastern margin of the Trough.

While the eastern shoreline was apparently stable, the western shore retreated slowly through Early and Middle Silurian time, so that the erosional interval in the extreme west of the area came to represent missing sediments, absent partly by erosion and partly by non-deposition, of age range of pre-Late Ordovician to possibly Late Silurian. The deposition of Road River basinal facies, homotaxial with the Mount Kindle Formation, reached greatest areal extent by Late Silurian time. Much dark brown and black chert was interbedded with the basinal shales and carbonates. The Porcupine Platform was correspondingly most restricted at this time and Mount Kindle equivalent carbonates of that area were mostly transitional facies to Road River.

The Mount Kindle to Peel Formation boundary within the study-area ranged from a gradational deposition change in the extreme west to at least a depositional break over the eastern part of the Mackenzie Platform.

Late Silurian to Early Devonian

The second regional change in lower Paleozoic carbonate deposition took place during the Late Silurian: over the Mackenzie Platform from generally brown medium crystalline dolomite of Mount Kindle Formation to generally very pale microsucrosic dolomite of Peel Formation; and over the Porcupine Platform from a carbonate-shale transitional facies to very pale and also darker microcrystalline dolomite. Along the eastern margin of the Richardson Trough, the Mount Kindle limestone "fringe" continued as a feature also of Peel deposition, along with a belt of Peel transitional facies to the Road River graptolitic shales within the Richardson Trough.

Toward the end of Peel deposition, faulting and possibly minor crustal warping heralded a regional uplift which subsequently, during Early Devonian time, raised the entire shelf area above sea level including probably all but a northern part of the Richardson Trough. Topographic relief on the Peel surface included a broad depression and at least one fault escarpment (Tree Fault), and on the west side of the Trough Lower Silurian strata were exposed by erosion.

Early to Middle Devonian

Re-submergence followed slowly, accompanied by deposition of shallow marine pale buff aphanitic limestone and pale green shale of the Tatsieta Formation, initially restricted to depressions in the sculptured Peel surface and progressively covering most of the shelf area. In the Richardson Trough a renewed sequence of Road River black calcareous shale deposits began with limestone breccia in the southern part, probably derived from the rift slopes. To the southeast of Mackenzie Platform, there may have been at this time a very shallow marine connection with, or alternatively a very narrow land separation from, an evaporite basin in which the earliest sediments of the Fort Norman Formation had begun to settle.

Deeper marine environment followed, with brown sucrosic dolomites of the Arnica Formation deposited over both Mackenzie and Porcupine Platforms and, to the southeast, interfingering with Fort Norman evaporites. A limestone "fringe" (Landry Formation) developed on the western side of both platforms. The depositional boundaries between Landry brown pelletal limestone and Arnica dolomite and between Arnica and Fort Norman sediments, underwent a pulsating but overall easterly migration, so that by Middle Devonian time, limestone (Landry) deposition dominated the platform areas.

A laterally uniform series of argillaceous bioclastic limestones and grey shales of the Hume Formation were deposited over the Mackenzie platform during Eifelian time, while brown pelletal limestone banks continued to build over the Porcupine Platform.

Road River black shale and limestone equivalents of the Arnica-Landry and Hume carbonates are to be found in a much condensed sequence in the Richardson Trough, indicating a diminishing detrital supply during Early and Middle Devonian time.

Givetian interlude

The Givetian Stage was the lull before the tectonic storm of the later Paleozoic. The northwestern shelf area of continental North America was at rest and the sedimentary processes across the study-area slowed and finally came almost to a standstill straddling the boundary of Middle to Late Devonian time.

The change in depositional pattern began as black limy mud settled thinly over the Mackenzie Platform, the bituminous black shale with fibrous calcite of the Bluefish Member. The change initially took the form of an offshore reef complex (Ramparts Formation) on the Mackenzie Platform and of limestone banks and reef development (upper part of Ogilvie Formation) over the Porcupine Platform. Detrital material, carried in from the east, consisted of some quartzose silts and fine sand which became an integral part of the Ramparts reef complex, and green-grey micaceous clay which settled as off-reef calcareous shales (Hare Indian Formation).

Finally, over a tectonically undifferentiated shelf area, marine life diminished and carbonate build-up terminated. Reef-top debris tumbled down the seaward side into the muds that began to settle as a regional black veneer. It was with the black bituminous pyritic shale of the Canol Formation that the Frasnian Stage opened in the study-area and, as if to herald the forthcoming tectonic display, some coarse silt was deposited locally in the black sea, in the area, in fact which was subsequently to become a major distribution centre for orogenic sediments throughout most of late Paleozoic time.

Upper Paleozoic clastic sediments

Late Devonian to earliest Carboniferous

Following the Canol opening of the Late Devonian the thin black basinal sedimentary veneer began to be covered by the first of the detrital sediments which were to grow to immensely thick wedges of coarse and fine clastics. Within the study-area, the deposits were initially marine, mostly transported from the north, but with a minor wedge developing also from the southeast. The sedimentary load consisted at first mostly of clay, silt and some fine sand and became in time progressively coarser grained. Probably a deltaic system, through which the marine-deposited clastics had been carried, moved southwestward as the shelf area filled and by Famennian time, marine turbidite and deltaic deposits covered much of the north-central part of Peel River area, while the marine clastic wedge continued to grow and spread to the southwest.

The major part of the earlier deposits ("Imperial") of the Late Devonian may have been derived from the north. Their distribution straddling the north-south trending Richardson Trough suggests that, at least initially, drainage followed the old aulacogen rift valley. The later coarser grained clastics of the Tuttle Formation were distributed over much the same area and came from the northeast.

Early Carboniferous to Permian

The overall pattern of coarse, chert-rich erosional debris, brought from a northeastern source to the continental margin, continued throughout the remainder of the late Paleozoic. However, a significant depositional change took place during Early Carboniferous time. Coarse clastic sediments, which were carried to the sea in three main pulses between late Early Carboniferous and Early Permian time, were deposited as marine wedges which, in contrast to the preceding totally clastic wedge system of the Imperial-Tuttle, now consisted of shoreward conglomerate and sandstone facies, grading into a seaward facies of skeletal and cherty limestone and calcareous shale (Hart River, Ettrain and Jungle Creek Formations), before "shaling out" into dark grey to black basinal shales (Ford Lake Shale and Blackie Formation). In contrast, therefore, to the dumping of great quantities of sediments, which had caused the shoreline to prograde during Late Devonian and earliest Carboniferous time across the marine terrace presumably as far as the edge of the continental slope, the deposition of clastic sediments from Early Carboniferous to Permian time took the form of conglomeratic material held behind a shelf-edge carbonate build-up, with finer clastic material carried to the continental slope beyond the shoals. These two distinct depositional patterns are very similar to two models, proposed by Dietz and Holden (1966, p. 570-573), for a sedimentary continental slope to be maintained. The change from the one pattern to the other was also the change from advancing to retreating shoreline (see p. 44). At the same time, a distinct vertical change from dark grey shale to black siliceous basinal shale deposition (by which the Imperial-Ford Lake boundary is recognized beyond the basinward limit of Tuttle beds) indicates that a flexing of the continental margin, presumably under the accumulating sedimentary load, accompanied the change in depositional pattern. A similar conclusion has been reached by Bamber et al. (1980) who postulate a northeastward marine transgression and a deepening upward succession in the northern Yukon Territory beginning in approximately Middle Viséan time and continuing throughout the Early Carboniferous.

A latest Carboniferous or Early Permian uplift of the shelf area resulted in the erosion of Ettrain beds prior to renewed marine flooding and burial beneath the Jungle Creek wedge. During this time the Aklavik Arch was active, causing older Paleozoic carbonates and shales to be eroded from its crest, as far down as Cambrian or Proterozoic strata. The truncated beds were then covered by largely clastic deposits of Early and/or Middle Permian age and these, in turn, along with Paleozoic and older beds throughout the study-area, were exposed at the sub-Mesozoic erosion surface.

CHAPTER V

ECONOMIC GEOLOGY

Oil and gas

Hydrocarbon potential within the study-area is indicated by a combination of factors: an abundance of source rocks; widespread porosity in carbonates and sandstones; various mechanisms of entrapment; and numerous hydrocarbon occurrences (shown on Economic geology map, Fig. 35).

Source rocks

Thousands of metres of black shales of the Road River Formation lie in the Richardson Mountains belt. To the east and west these basinal shales are found in transition to shelf carbonates and their distribution extends around the periphery of the Porcupine Platform.

The black bituminous Bluefish shale covers the Devonian shelf carbonates on the Mackenzie Platform, forming the basal unit of the Horn River Group. This group also includes the Ramparts reef complex with its bituminous Carcajou member and it is topped by black bituminous "Canol" shales. A condensed Horn River ("Canol") black shale sequence covers the Devonian shelf carbonate and reef over the Porcupine Platform.

Upper Paleozoic black shales occur as thick basinal deposits (Ford Lake Shale and Blackie Formation) in the southwestern part of the study-area and they are found interbedded with sandstone in the Tuttle Formation and intertongued with coarse clastics in the Tuttle, Hart River, Ettrain and Jungle Creek Formations.

Reservoir rocks

Porous quartzose sandstones occur as discontinuous basal beds of the Cambrian succession and as shoreline facies of the Cambrian evaporites.

Intercrystalline porosity is a regional feature of the platform carbonates, notably in the Franklin Mountain, Mount Kindle and Arnica dolomites and in the Ramparts Reef member. The Siltstone lentil and Sandy member of the Ramparts also have good intergranular porosity.

Upper Paleozoic sandstones, although in great abundance in the Peel River area, generally have poor porosity: Imperial sandstones are mostly argillaceous or silty; Tuttle sandstones are commonly kaolinitic; later Paleozoic coarse clastics are variably calcareous, siliceous and/or kaolinitic. However, some areas of good porosity exist and these are discussed under the following heading.

Hydrocarbon potential

Cambrian clastics

Lower Cambrian Mount Clark sandstone has tested gas to surface at 4.4 mm cf/d at K-24 near Tedji Lake, a little east of the study-area. There appear to be excellent chances of repeating the discovery in the Colville Hills, according to Matthew (1977), who has postulated also the probability of structural-stratigraphic traps in the Mount Clark Formation occurring within a belt of aligned arches and troughs extending southward to Bulmer Lake. In the Ontaratue River area, Mount Clark, or equivalent basal Cambrian sandstones, may be present at H-34o[1] and K-04, but these are highly silicified.

Of economic interest, however, within the Cambrian clastics of the study-area, are the red beds at H-34o, interpreted to be shoreline equivalents of the Saline River salt. Matthews (1977) drew attention to these beds because of their location on the flanks of a western land barrier (Mackenzie Arch and its northward extension), indicating the possiblity of alluvial fans and sand dunes, which if sealed, would be excellent reservoirs. The overlying beds are in fact, the basal non-porous argillaceous dolomites of the Franklin Mountain Formation.

Cambrian to Devonian carbonates

A major prospective area of hydrocarbon accumulation is the carbonate-shale transition belt. Five out of the six boreholes which have penetrated these strata along the eastern side of the Richardson Mountains, have recorded positive signs (see Economic geology map, Fig. 35), ranging from tested gas to surface to free bitumen and bitumen-streaked rocks. In the most recently drilled well, H-71, located where porosity is stratigraphically closed by shale on the up-dip (western) side, Mount Kindle dolomite tested some gas to surface (less than 100 Mcf/d) and Landry limestone kicked gas while being drilled. The only well drilled close to the Richardson shale belt on the western side, at N-05, tested gas to surface in the Arnica and upper Ogilvie Formations. At D-77, also in a transition belt in southern Eagle Plain, drill stem tests on Franklin Mountain dolomite and Road River-Peel transition beds recovered gassy water, and rock samples from Franklin Mountain and Arnica Formations contain bitumen.

Of the lower Paleozoic shelf dolomites which are prospects for oil and gas (see map, Fig. 35), porous sucrosic dolomites of the Arnica Formation have shown greatest promise. Over the Mackenzie Platform, Arnica dolomites are commonly in part dark brown, often oil-stained or with oily odour. In the H-47m well, the Arnica tested some gas to surface (less than 100 Mcf/d) and in the Arctic Red River area three wells on test recovered gas-cut mud or water. It is of interest that two of the latter three shows (at H-34o and K-15t) were from Arnica tongue dolomite. These occurrences strengthen the possibility of stratigraphic traps in Arnica tongues or lentils, encased in tight Landry limestones, in an area where the general west dip of the strata may otherwise have allowed escape of hydrocarbons through permeable strata with no up-dip closure. Franklin Mountain dolomite and Landry limestone tested gas to surface at N-53 and N-49, respectively, wells which were drilled on structural high in the Porcupine River area, which is virtually untested.

---

[1]Borehole section reference number (see Introduction-Borehole reference, and Appendix III). H-34o = Atlantic Ontaratue H-34, located in H-34-66-30-132-00 according to Y.T. and N.W.T. Land Survey System.

At the top of the Paleozoic carbonates are two Middle Devonian reef developments. The well known Ramparts reef, extending into the study-area northwest of Norman Wells, has tested gas to surface at L-24 and O-62 and the Ramparts Siltstone lentil at G-26 and Sandy member at A-37g are oil-stained. A relatively unknown reef, equivalent to the upper part of the Ogilvie Formation, extending for some 150 km below Eagle Plain, has been penetrated by only four boreholes. At these locations, N-49, O-22, D-61 and D-77, reef limestone appears to be tight, but at O-22 it tested some gas to surface.

Upper Paleozoic clastics

Sandstone bodies within the composite Imperial-Tuttle clastic wedge system, although generally possessing poor porosity and permeability due to either argillaceous matrix or kaolinite pore-filling or quartz overgrowths, are more favourable reservoir rocks southward, where Tuttle sandstones are better sorted, more quartzose and less kaolinitic. It is, in fact, only in the southern part of its distribution that the Tuttle has tested gas to surface and recovered gassy water (see map, Fig. 35). Lutchman (1977, p. M-9/10) has recommended the Tuttle wedge as an area of economic interest, particularly with reference to those sandstone bodies in "delta front facies", for which three categories of traps were interpreted. To the west of the Richardsons one show of gas is recorded from Tuttle beds, at C-24.

Carboniferous and Permian clastics below Eagle Plains have yielded up to 5 and 6 MMcf/d of gas and significant amounts of oil. The major occurrences have been in the Chance sandstone and basinal sandstones of the Hart River Formation and in conglomeratic sandstone of the Jungle Creek Formation. Ettrain Formation sandstone tested some gas to surface at one location and a sandstone tongue within Ford Lake Shale at D-61 was tested with recovery of gas-cut water. Many of the above Carboniferous and Permian prospective units are truncated at the sub-Mesozoic erosional surface (see Subcrop Map, Fig. 23), by way of which hydrocarbons may have migrated into overlying basal Mesozoic sandstones.

Mineral deposits other than hydrocarbon

Occurrences of barite (at K-15t and N-05) and of fluorite (at K-15t) at the base of the Horn River Group (see p. 35) are reported (R.J. Kirker, pers. comm.). Heavy mineralization at this same horizon near the Alaskan border, is considered to be an indicator of possible metalliferous deposits in the western half of the study-area, particularly in view of the fact that the Bituminous member at the base of the Horn River at Pine Point (Great Slave Lake) has been found (Macqueen et al., 1975) to contain high values of zinc, lead and uranium oxide.

Summary

Aulacogens around the world are economically productive, according to Burke and Dewey (1972, p. 428-429). The Richardson Aulacogen appears to conform to this rule. Evidence from the subsurface of the Peel River area focuses economic interest primarily in the general area of the Richardson Mountains. Future exploratory drilling in a narrow belt on the eastern side and in a probably wider belt on the western side of the Richardsons would have multiple chances of sub-Mesozoic discovery - for hydrocarbons in any of the Cambrian to Devonian carbonate-shale transitions and in many of the numerous upper Paleozoic sandstones and for Middle Devonian metalliferous deposits. Also of economic interest should be full evaluation of the Cambrian to Devonian shelf carbonates, particularly over the Porcupine Platform with its combination of carbonate-shale transitions and anticlinal structures. Further evaluation should also be made of the Middle Devonian reef to the west of the Richardsons.

REFERENCES

Aitken, J.D. and Cook, D.G.
1969: Geology Lac Belot, District of Mackenzie; Geological Survey of Canada, Map 6-1969.

1974: Carcajou Canyon map-area, District of Mackenzie, Northwest Territories; Geological Survey of Canada, Paper 74-13.

in press: Geology of parts of Mount Eduni (106 A) and Bonnet Plume Lake (106 B) map-area, District of Mackenzie, Northwest Territories; Geological Survey of Canada, Open File 221.

Aitken, J.D., Cook, D.G. and Yorath, C.J.
in press: Upper Ramparts River (106 G) and Sans Sault Rapids (106 H) map-areas, District of Mackenzie, Northwest Territories; Geological Survey of Canada, Memoir 388, Open File 272.

Aitken, J.D. and Long, D.G.F.
1978: Mackenzie Tectonic arc - Reflection of early basin configuration?; Geology, v. 6, p. 626-629.

Aitken, J.D., Long, D.G.F. and Semikhatov, M.A.
1978: Progress in Helikian stratigraphy, Mackenzie Mountains; in Current Research, Part A; Geological Survey of Canada, Paper 78-1A, p. 481-484.

Aitken, J.D., Macqueen, R.W. and Usher, J.L.
1973: Reconnaissance studies of Proterozoic and Cambrian stratigraphy, Lower Mackenzie River area (Operation Norman), District of Mackenzie; Geological Survey of Canada, Paper 73-9.

American Commission on Stratigraphic Nomenclature
1961: Code of Stratigraphic Nomenclature, American Association of Petroleum Geologists, Bulletin, v. 45, p. 645-665.

Bamber, E.W. Macqueen, R.W. and Richards, B.C.
1980: Facies relationships at the Mississippian carbonate platform margin, Western Canada; Geological Survey of Canada, Open File No. 674.

Bamber, E.W. and Waterhouse, J.B.
1971: Carboniferous and Permian stratigraphy and paleontology, northern Yukon Territory, Canada; in Bulletin of Canadian Petroleum Geology, v. 19, p. 29-250.

Bassett, H.G.
1961: Devonian stratigraphy, central Mackenzie River region, Northwest Territories, Canada; in Geology of the Arctic, v. 1, G.O. Raasch, ed.; Alberta Society of Petroleum Geologists and University of Toronto Press, p. 481-495.

Bassett, H.G. and Stout, J.G.
1967: Devonian of Western Canada; in International Symposium on the Devonian System, Calgary, 1967; Alberta Society of Petroleum Geologists, v. 1, p. 717-752.

Bell, J.S.
1973: Late Paleozoic Orogeny in Northern Yukon; in Proceedings of the Symposium on the Geology of the Canadian Arctic, p. 25-38.

Belyea, H.R. and Norris, A.W.
1962: Middle Devonian and older Paleozoic formations of southern District of Mackenzie and adjacent areas; Geological Survey of Canada, Paper 62-15.

Blusson, S.L.
1974: Preliminary drafts of six geological maps with legends of part of Nadaleen River map-area, Yukon Territory (NTS 106C/6, 7, 10, 11, 13, 14, 15); Geological Survey of Canada, Open File Report, No. 206.

Brabb, E.E.
1967: Stratigraphy of the Cambrian and Ordovician rocks of east-central Alaska; United States Geological Survey, Professional Paper 559-A.

1969: Six new Paleozoic and Mesozoic formations in east-central Alaska; United States Geological Survey, Bulletin 1274-I.

Brabb, E.E. and Churkin, M., Jr.
1967: Stratigraphic evidence for the Late Devonian age of the Nation River Formation, east-central Alaska, in Geological Survey Research 1967; United States Geological Survey, Professional Paper 575-D, p. D4-D15.

Braun, W.K.
1966: Stratigraphy and microfauna of Middle and Upper Devonian formations, Norman Wells area, Northwest Territories, Canada; Neues Jahrbuch Fur Geologie und Palaontologie, Abstract, v. 125, p. 247-264.

Brideaux, W.W., Clowser, D.R., Copeland, M.J., Jeletzky, J.A., Norford, B.S., Norris, A.W., Pedder, A.E.H., Sweet, A.R., Thorsteinsson, R., Uyeno, T.T. and Wall, J.
1976: Biostratigraphic determinations from the subsurface of the Districts of Franklin and Mackenzie and the Yukon Territory; Geological Survey of Canada, Paper 75-10.

Burke, K. and Dewey, J.F.
1973: Plume generated triple junctions: key indicators in applying plate tectonics to old rocks; Journal of Geology, v. 81, p. 406-433.

Burke, D.C. and Wilson, J. Tuzo
1976: Hot spots on the Earth's surface; Scientific American, v. 235, p. 46-57.

Cairnes, D.D.
1914: The Yukon-Alaska international boundary between Porcupine and Yukon Rivers; Geological Survey of Canada, Memoir 67.

Caldwell, W.G.E.
1964: The nomenclature of the Devonian formations in the lower Mackenzie River valley; Bulletin of Canadian Petroleum Geology, v. 12, p. 611-622.

Canada Department of Northern Affairs and National Resources
1965: Schedule of Wells, 1962-1964, Northwest Territories and Yukon Territory, published annually.

1967: Schedule of Wells, 1966, Northwest Territories and Yukon Territory, published annually.

Cecile, M.P.
1978: Report on Road River stratigraphy and the Misty Creek Embayment, Bonnet Plume (106 B) and surrounding map-areas, Northwest Territories; in Current Research, Part A, Geological Survey of Canada, Paper 78-1A, p. 371-377.

in press: The Lower Paleozoic Misty Creek Embayment, Selwyn Basin, Yukon and Northwest Territories; Geological Survey of Canada, Bulletin 335.

Cecile, M.P. and Norford, B.S.
1979: Basin to Platform transition, Paleozoic strata of Ware and Trutch map-areas, northeastern British Columbia; in Current Research, Part A; Geological Survey of Canada, Paper 79-1A, p. 219-226.

Chi, B.I. and Hills, L.V.
1973: Stratigraphic and paleoenvironmental significance of Upper Devonian megaspores, type section of the Imperial Formation, Northwest Territories, Canada; in Proceedings of the Symposium on the Geology of the Canadian Arctic, p. 241-257.

Christie, R.L.
1979: Phosphorite in sedimentary basins of Western Canada; in Current Research, Part B, Geological Survey of Canada, Paper 79-1B, p. 253-258.

Churkin, M., Jr.
1969: Paleozoic tectonic history of the Arctic basin north of Alaska; in Science, v. 165, p. 549-555.

1970: Canada basin-speculations on origin; in Oil and Gas Journal, v. 68, p. 186-196.

Churkin, M. and Brabb, E.E.
1965: Ordovician, Silurian and Devonian biostratigraphy of east-central Alaska; American Association of Petroleum Geologists, Bulletin, v. 49, n. 2, p. 172-185.

Cook, D.G. and Aitken, J.D.
1969: Geology Fort Good Hope, District of Mackenzie; Geological Survey of Canada, Map 4-1969.

1974: Geology of Norman Wells (96E) and Mahony Lake (96F) map-areas, District of Mackenzie, N.W.T.; Geological Survey of Canada, Open File 304.

1975: Ontaratue River (106 J), Travaillant Lake (106 O) and Canot Lake (106 P) map-areas, District of Mackenzie, Northwest Territories; Geological Survey of Canada, Paper 74-17.

1978: Twitya Uplift: A pre-Delorme phase of the Mackenzie Arch, Current Research, Part A; Geological Survey of Canada, Paper 78-1A, p. 383-388.

Dietz, R.S. and Holden, J.C.
1966: Miogeoclines (miogeosynclines) in space and time; Journal of Geology, v. 74, Part 1, p. 566-583.

Douglas, R.J.W. (ed.)
1970: Geology and economic minerals of Canada; Geological Survey of Canada, Economic Geology Report No. 1.

Douglas, R.J.W. and Norris, A.W.
1960: Horn River map-area, Northwest Territories; Geological Survey of Canada, Paper 59-11.

1963: Dahadinni and Wrigley map-areas, District of Mackenzie, Northwest Territories; Geological Survey of Canada, Paper 62-33.

Gabrielse, H.
1967: Tectonic Evolution of the northern Canadian Cordillera; Canadian Journal of Earth Sciences, v. 4, p. 271-298.

1970: Geology of western Canada; in Douglas, R.J.W. (ed.), Geology and economic minerals of Canada; Geological Survey of Canada, Economic Geology Report No. 1.

1972: Younger Precambrian of the Canadian Cordillera; American Journal of Science, v. 272, p. 521-536.

1975: Geology of Fort Grahame E½ map-area, British Columbia; Geological Survey of Canada, Paper 75-33.

Gabrielse, H., Blusson, S.L. and Roddick, J.A.
1973: Geology of Flat River, Glacier Lake and Wrigley Lake map-areas, District of Mackenzie and Yukon Territory; Geological Survey of Canada, Memoir 366.

Gilbert, D.L.F.
1973: Anderson, Horton, Northern Great Bear and Mackenzie Plains, Northwest Territories; in The future petroleum provinces of Canada, R.G. McCrossan (ed.); Canadian Society of Petroleum Geologists, Memoir 1, p. 213-244.

Glaister, R.P. and Hopkins, J.
1974: Turbidity-current and debris-flow deposits; in Shawa, M.S. (ed.), Use of sedimentary structures for recognition of clastic environments; Canadian Society of Petroleum Geologists, p. 23-28.

Gordey, S.P.
1978: Stratigraphy and structure of the Summit Lake area, Yukon and Northwest Territories; in Current Research, Part A; Geological Survey of Canada, Paper 78-1A, p. 43-48.

1979: Stratigraphy of the southeastern Selwyn Basin in the Summit Lake area, Yukon and Northwest Territories; in Current Research, Part A; Geological Survey of Canada, Paper 79-1A, p. 13-16.

Graham, A.D.
1973: Carboniferous and Permian stratigraphy, southern Eagle Plain, Yukon Territory, Canada; in Symposium on geology of the Canadian Arctic, J.D. Aitken and D.J. Glass (eds.); Geological Association of Canada and Canadian Society of Petroleum Geologists, p. 159-180.

Gray, F.F. and Kassube, J.B.
1963: Geology and stratigraphy of Clark Lake gas field, British Columbia; American Association of Petroleum Geologists, Bulletin, v. 47, p. 467-483.

Green, L.H.
1972: Geology of Nash Creek, Larsen Creek and Dawson map-areas, Yukon Territory; Geological Survey of Canada, Memoir 364.

Griffin, D.L.
1965: The Devonian Slave Point, Beaverhill Lake and Muskwa Formations of Northeastern British Columbia and adjacent areas, British Columbia, Department of Mines and Petroleum Resources, Bulletin No. 50.

Hills, L.V. and Braman, D.R.
1978: Sedimentary structures of the Imperial Formation, Northwest Canada, in Display Summaries, Ashton F. Embry (compiler), Canadian Society of Petroleum Geologists, reprinted 1979, p. 35-37.

Hofmann, H.J. and Aitken, J.S.
1979: Precambrian biota from the Little Dal Group, Mackenzie Mountains, Northwestern Canada; in Canadian Journal of Earth Sciences, v. 16, p. 150-166.

Hume, G.S.
1923: Geology of the Norman Wells oil fields and a reconnaissance of a part of Liard River; Geological Survey of Canada, Summary Report 1922, Part B, p. 47-64.

1954: Lower Mackenzie River area, Northwest Territories and Yukon; Geological Survey of Canada, Memoir 273.

Hume, G.S. and Link, T.A.
1945: Canol investigations in the Mackenzie River area, Northwest Territories and Yukon; Geological Survey of Canada, Paper 45-16.

Jackson, D.E. and Lenz, A.C.
1962: Zonation of Ordovician and Silurian graptolites of northern Yukon, Canada; in American Association of Petroleum Geologists, Bulletin, v. 46, p. 30-45.

Jackson, D.E., Lenz, A.C. and Pedder, A.E.H.
1978: Late Silurian and Early Devonian graptolite, brachiopod and coral faunas from northwestern and Arctic Canada; Geological Association of Canada, Special Paper No. 17.

Jeletzky, J.A.
1961: Eastern slope, Richardson Mountains: Cretaceous and Tertiary structural history and regional significance; in Geology of the Arctic, v. 1, G.O. Raasch, ed.; Alberta Society of Petroleum Geologists and University of Toronto Press, p. 532-583.

1962: Pre-Cretaceous Richardson Mountains Trough: Its place in the tectonic framework of Arctic Canada and its bearing on some geosynclinal concepts; Royal Society of Canada, Transactions, v. LVI, Series III, Section III, p. 55-84.

Jeletzky, J.A. (cont'd)
1967: Jurassic and (?)Triassic rocks of the eastern slope of Richardson Mountains, northwestern District of Mackenzie (106 M) and (107 B) (parts of); Geological Survey of Canada, Paper 66-50.

1971: Biochronology of Jurassic-Cretaceous transition beds in Canada; Geological Survey of Canada, Paper 71-16.

1972: Stratigraphy, facies and paleogeography of Mesozoic and Tertiary rocks of northern Yukon and northwest District of Mackenzie; in Report of Activities, Part A, Geological Survey of Canada, Paper 72-1A, p. 212-215.

1975: Jurassic and Lower Cretaceous paleogeography and depositional tectonics of Porcupine Plateau, adjacent areas of northern Yukon and those of Mackenzie District; Geological Survey of Canada, Paper 74-16.

Kindle, E.M. and Bosworth, T.O.
1921: Oil-bearing rocks of lower Mackenzie River valley; Geological Survey of Canada, Summary Report, 1920, Part B, p. 37-63.

Kunst, H.
1973: The Peel Plateau: in The future petroleum provinces of Canada, R.G. McCrossan ed.; Canadian Society of Petroleum Geologists, Memoir 1, p. 213-244.

Laudon, L.R.
1944: Imperial River area; Imperial Oil Ltd., Canol Project, unpublished report in Geological Survey of Canada Files.

Lenz, A.C.
1966: Upper Silurian and Lower Devonian paleontology and correlations, Royal Creek, Yukon Territory: preliminary report; Bulletin of Canadian Petroleum Geology, v. 14, p. 604-612.

1968: Upper Silurian and Lower Devonian biostratigraphy, Royal Creek, Yukon Territory, Canada; in International Symposium on the Devonian System, Proceedings, Calgary, D.H. Oswald, ed.; Alberta Society of Petroleum Geologists, v. 2, p. 587-599.

Lenz, A.C.
1972: Ordovician to Devonian history of northern Yukon and adjacent District of Mackenzie; Bulletin of Canadian Petroleum Geology, v. 20, p. 321-361.

Lenz, A.C. and Pedder, A.E.H.
1972: Lower and Middle Paleozoic sediments and paleontology of Royal Creek and Peel River, Yukon and Powell Creek, Northwest Territories; International Geological Congress XXIV, Field Excursion Guidebook, A14.

Lerand, M.
1973: Beaufort Sea: in The future petroleum provinces of Canada, R.G. McCrossan ed.; Canadian Society of Petroleum Geologists, Memoir 1, p. 315-386.

Lichtenbelt, J.H.
1961: Geology of the Lower Mackenzie River Basin, Northwest Territories (unpublished).

Loranger, D.M.
1974: Biostratigraphic zonation, Shell Aklavik A-37, Northwest Territories: Paleo Services Limited; in Well history report, Canada Department of Northern Affairs and National Resources Files.

Lutchman, M.
1977: Mississippian clastic wedge; in Lower Mackenzie energy corridor study, geological component, AGAT Consultants Ltd., p. M-1 to M-10.

McConnell, R.G.
1889: Report on an exploration in the Yukon and Mackenzie basins, Northwest Territories; Geological and Natural History Survey of Canada, Annual Report, v. IV, 1888-89, Part D, p. 120-134.

MacKenzie, W.S.
1970: Allochthonous reef-debris limestone turbidites, Powell Creek, Northwest Territories; Bulletin of Canadian Petroleum Geology, v. 18, p. 474-492.

1972: Fibrous calcite, a Middle Devonian geologic marker, with stratigraphic significance, District of Mackenzie, Northwest Territories; Canadian Journal of Earth Sciences, v. 9, p. 1431-1440.

1973: Upper Devonian echinoderm debris beds with graded texture, District of Mackenzie, Northwest Territories; Canadian Journal of Earth Sciences, v. 10, p. 519-528.

1974: Lower Paleozoic carbonates, C.D.R. Tenlen Lake A-73 well, Northwest Territories; in Report of Activities, Part B, Geological Survey of Canada, Paper 74-1B, p. 265-270.

MacKenzie, W.S., Pedder, A.E.H. and Uyeno, T.T.
1975: A Middle Devonian sandstone unit, Grandview Hills area, District of Mackenzie; in Report of Activities, Part A, Geological Survey of Canada, Paper 75-1A, p. 547-552.

Macqueen, R.W.
1969: Lower Paleozoic stratigraphy, Operation Norman, 1968; in Report of Activities, Part A, Geological Survey of Canada, Paper 69-1A, p. 238-241.

Macqueen, R.W.
1970: Lower Paleozoic stratigraphy and sedimentology; eastern Mackenzie Mountains, northern Franklin Mountains; in Report of Activities, Part A, Geological Survey of Canada, Paper 70-1A, p. 225-230.

1974: Lower and middle Paleozoic studies, northern Yukon Territory; in Report of Activities, Part A, Geological Survey of Canada, Paper 74-1A, p. 323-326.

Macqueen, R.W. and MacKenzie, W.S.
1973: Lower Paleozoic and Proterozoic stratigraphy, Mobil Colville Hills E-15 well and environs, Interior Platform, District of Mackenzie; in Report of Activities, Part B, Geological Survey of Canada, Paper 73-1B, p. 183-187.

Macqueen, R.W., Williams, G.K., Barefoot, R.R. and Foscolos, A.E.
1975: Devonian metalliferous shales, Pine Point region, District of Mackenzie; in Report of Activities, Part A, Geological Survey of Canada, Paper 75-1A, p. 553-556.

Martin, H.L.
1972: Upper Paleozoic stratigraphy of the Eagle Plain basin, Yukon Territory; Geological Survey of Canada, Paper 71-14.

1973: Eagle Plain basin, Yukon Territory; in The future petroleum provinces of Canada, R.G. McCrossan ed.; Canadian Society of Petroleum Geologists, Memoir 1, p. 275-306.

Martin, L.J.
1959: Stratigraphy and depositional tectonics of North Yukon-Lower Mackenzie area, Canada; American Association of Petroleum Geologists, Bulletin, v. 43, p. 2399-2455.

1961: Tectonic framework of northern Canada; in Geology of the Arctic, v. 1, G.O. Raasch, ed.; Alberta Society of Petroleum Geologists and University of Toronto Press, p. 442-457.

Matthews, D.D.
1977: Cambrian unit; in Lower Mackenzie energy corridor study, geological component, AGAT Consultants Ltd., p. C-1 to C-48.

Meijer-Drees, N.C.
1975: Geology of the lower Paleozoic formations in the subsurface of the Fort Simpson area, District of Mackenzie, Northwest Territories; Geological Survey of Canada, Paper 74-40.

in prep: Devonian evaporitic and carbonate rocks in the subsurface of the Great Slave and Great Bear Plains, Northwest Territories; Geological Survey of Canada.

Monger, J.W.H., Souther, J.G. and Gabrielse, H.
1972: Evolution of the Canadian Cordillera: a plate-tectonic model; American Journal of Science, v. 272, p. 577-602.

Nassichuk, W.W.
1971: Permian biostratigraphy, northern British Columbia and northern Yukon; in Report of Activities, Part A, Geological Survey of Canada, Paper 71-1A, p. 103-105.

Nauss, A.W.
1944a: The lower Mackenzie River area; Imperial Oil Ltd., Canol Project, unpublished report in Geological Survey of Canada files.

1944b: The upper Carcajou-Imperial River area; Imperial Oil Ltd., Canol Project, unpublished report in Geological Survey of Canada files.

Norford, B.S.
1964: Reconnaissance of the Ordovician and Silurian rocks of northern Yukon Territory; Geological Survey of Canada, Paper 63-39.

1979: Lower Devonian graptolites in the Road River Formation, northern British Columbia; in Current Research, Part A, Geological Survey of Canada, Paper 79-1A, p. 383-384.

Norford, B.S., Barss, M.S., Brideaux, W.W., Chamney, T.P., Fritz, W.H., Hopkins, W.S., Jr., Jeletzky, J.A., Pedder, A.E.H. and Uyeno, T.T.
1971: Biostratigraphic determinations of fossils from the subsurface of the Yukon Territory and the District of Mackenzie; Geological Survey of Canada, Paper 71-15.

Norford, B.S., Braun, W.K., Chamney, T.P., Fritz, W.H., McGregor, D.C., Norris, A.W., Pedder, A.E.H. and Uyeno, T.T.
1970: Biostratigraphic determinations of fossils from the subsurface of the Yukon Territory and the District of Mackenzie and Franklin; Geological Survey of Canada, Paper 70-15.

Norford, B.S., Brideaux, W.W., Chamney, T.P., Copeland, M.J., Frebold, H., Hopkins, W.S., Jr., Jeletzky, J.A., Johnson, B., McGregor, D.C., Norris, A.W., Pedder, A.E.H., Tozer, E.T. and Uyeno. T.T.
1973: Biostratigraphic determinations of fossils from the subsurface of the Yukon Territory and the Districts of Franklin, Keewatin and Mackenzie; Geological Survey of Canada, Paper 72-38.

Norford, B.S. and Macqueen, R.W.
1975: Lower Paleozoic Franklin Mountain and Mount Kindle Formations, District of Mackenzie: their type sections and regional development; Geological Survey of Canada, Paper 74-34.

Norris, A.W.
1967: Descriptions of Devonian sections in northern Yukon Territory and northwestern District of Mackenzie; Geological Survey of Canada, Paper 66-39.

1968a: Devonian of northern Yukon Territory and adjacent District of Mackenzie; in International symposium on the Devonian System, Calgary, 1967; D.H. Oswald, ed.; Alberta Society of Petroleum Geologists, v. 1, p. 753-780.

1968b: Reconnaissance Devonian stratigraphy of northern Yukon Territory and northwestern District of Mackenzie; Geological Survey of Canada, Paper 67-53.

Norris, D.K.
1975: Geological maps comprising Hart River, Y.T., Wind River, Y.T. and Snake River, Y.T. and N.W.T.; Geological Survey of Canada, Open File Report, No. 279.

1977: Geological maps of Yukon Territory and Northwest Territories: Blow River (117A), Davidson Mountains (117B), Demarcation Point (117C) and Herschel Island (117D); Geological Survey of Canada, Open File 499.

in press: Geological maps of Operation Porcupine area, northern Yukon Territory and northwestern District of Mackenzie; Geological Survey of Canada, Maps 1514A-1530A and structure sections.

Norris, D.K. and Hopkins, W.S., Jr.
1977: The geology of the Bonnet Plume Basin, Yukon Territory; Geological Survey of Canada, Paper 76-8.

Norris, D.K., Price, R.A. and Mountjoy, E.W.
1963: Geology northern Yukon Territory and northwestern District of Mackenzie; Geological Survey of Canada, Map 10-1963.

Pedder, A.E.H.
1975: Revised megafossil zonation of middle and lowest Upper Devonian strata, central Mackenzie Valley; in Report of Activities, Part A, Geological Survey of Canada, Paper 75-1A, p. 571-576.

Shatsky, N.S.
1964: O progibakh donetskogo typa (About the troughs of the Danetz type); N.S. Shatsky, Izbrannye Trudy, t. II "Nauka" Press, Akademiia Nauk SSSR, p. 544-553. (in Russian).

Schuchert, C.
1923: Sites and nature of the North American geosynclines; Geological Society of America, Bulletin, v. 34, p. 151-229.

Stewart, J.H.
1972: Initial deposits in the Cordilleran Geosyncline: evidence of a late Precambrian (<850 m.y.) continental separation; Geological Society of America, v. 83, p. 1345-1360.

Stewart, J.S.
1944: Petroleum possibilities of Mackenzie River valley, Northwest Territories; Canadian Institute of Mining and Metallurgy, v. XLVII, p. 152-171.

Tassonyi, E.J.
1969: Subsurface geology, lower Mackenzie River and Anderson River area, District of Mackenzie; Geological Survey of Canada, Paper 68-25.

Warren, P.S. and Stelck, C.R.
1949: The late Middle Devonian unconformity in northwestern Canada; Royal Society of Canada, Transactions, v. 43, 3rd. series, sec. 4, p. 139-148.

Whittaker, E.J.
1922: Mackenzie River district between Great Slave Lake and Simpson; Geological Survey of Canada, Summary Report, 1921, Part B, p. 45-55.

Williams, M.Y.
1922: Exploration east of the Mackenzie River between Simpson and Wrigley; Geological Survey of Canada, Summary Report, 1921, Part B, p. 56-66.

1923: Reconnaissance across northeastern British Columbia and the geology of the northern extension of Franklin Mountains, N.W.T.; Geological Survey of Canada, Summary Report, 1922, Part B, p. 65-87.

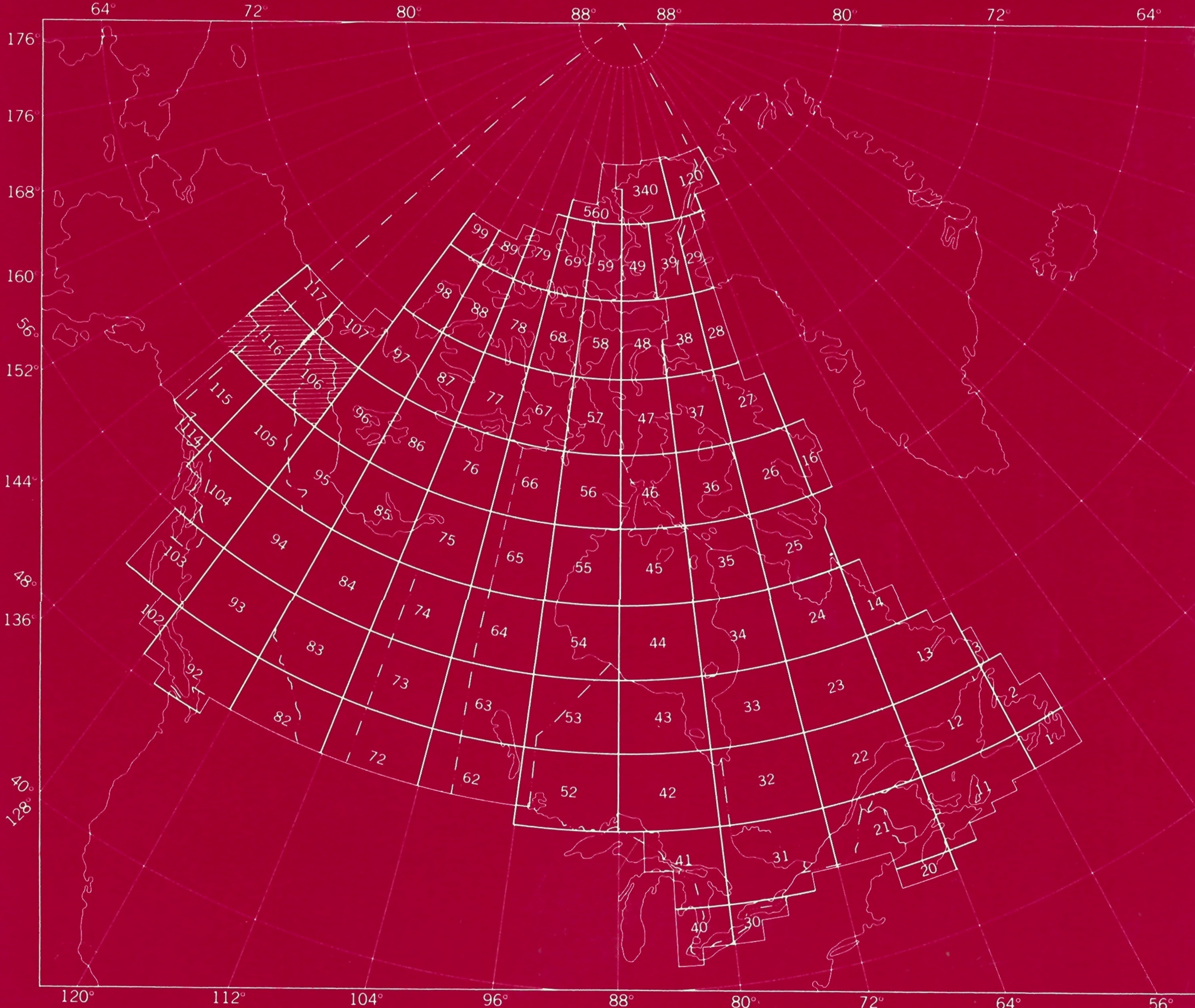
Yorath, C.J. and Balkwill, H.R.
1969: Geology Crossley Lakes, District of Mackenzie; Geological Survey of Canada, Map 8-1969.

Yorath, C.J. and Cook, D.G.
in press: The Cretaceous and Tertiary stratigraphy and paleontology, northern Interior Plains, District of Mackenzie; Geological Survey of Canada, Memoir 398.

Young, F.G.
1975: Stratigraphic and sedimentologic studies in northeastern Eagle Plain, Yukon Territory; in Report of Activities, Part B, Geological Survey of Canada, Paper 75-1B, p. 309-319.

Young, G.M., Jefferson, C.W., Delaney, G.D. and Yeo, G.M.
1979: Middle and late Proterozoic evolution of the northern Canadian Cordillera and Shield; Geology, v. 7, p. 125-128.

Ziegler, P.A.
1969: The development of sedimentary basins in western and Arctic Canada; Alberta Society of Petroleum Geologists.



Energy, Mines and Resources Canada

Énergie, Mines et Ressources Canada