INFORMATION TO USERS

This manuscript has been reproduced from the microfilm master. UMI films the text directly from the original or copy submitted. Thus, some thesis and dissertation copies are in typewriter face, while others may be from any type of computer printer.

The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleedthrough, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send UMI a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.

Oversize materials (e.g., maps, drawings, charts) are reproduced by sectioning the original, beginning at the upper left-hand corner and continuing from left to right in equal sections with small overlaps.

ProQuest Information and Learning
300 North Zeeb Road, Ann Arbor, MI 48106-1346 USA
800-521-0600

UMI[®]

NOTE TO USERS

This reproduction is the best copy available.

UMI[®]

**REGIONAL SUBSURFACE CORRELATIONS OF ALBIAN
SEQUENCES NORTH OF THE PEACE RIVER IN NORTHEASTERN BRITISH
COLUMBIA: NORTHWARD EXTENT OF FALHER AND NOTIKEWIN
SANDS ALONG THE EASTERN FLANK OF THE FOREDEEP**

Andrew C. Webb

B.Sc. H.

Copyright © 2003,
Andrew C. Webb

National Library
of Canada

Acquisitions and
Bibliographic Services

395 Wellington Street
Ottawa ON K1A 0N4
Canada

Bibliothèque nationale
du Canada

Acquisitions et
services bibliographiques

395, rue Wellington
Ottawa ON K1A 0N4
Canada

Your file Votre référence

Our file Notre référence

The author has granted a non-exclusive licence allowing the National Library of Canada to reproduce, loan, distribute or sell copies of this thesis in microform, paper or electronic formats.

The author retains ownership of the copyright in this thesis. Neither the thesis nor substantial extracts from it may be printed or otherwise reproduced without the author's permission.

L'auteur a accordé une licence non exclusive permettant à la Bibliothèque nationale du Canada de reproduire, prêter, distribuer ou vendre des copies de cette thèse sous la forme de microfiche/film, de reproduction sur papier ou sur format électronique.

L'auteur conserve la propriété du droit d'auteur qui protège cette thèse. Ni la thèse ni des extraits substantiels de celle-ci ne doivent être imprimés ou autrement reproduits sans son autorisation.

0-612-79823-2

The undersigned hereby recommend to
the Faculty of Graduate Studies and Research
acceptance of the thesis

**REGIONAL SUBSURFACE CORRELATIONS OF ALBIAN
SEQUENCES NORTH OF THE PEACE RIVER IN NORTHEASTERN BRITISH
COLUMBIA: NORTHWARD EXTENT OF FALHER AND NOTIKEWIN
SANDS ALONG THE EASTERN FLANK OF THE FOREDEEP**

Submitted by
Andrew Webb, B.Sc.H.
in partial fulfillment of the requirements
for the degree of Masters of Science

Chair, Department of Earth Sciences

Thesis Supervisor

Co-Supervisor

January 2003
Carleton University

Abstract

The highly explored Peace River Region and Elmworth Deep Gas Basin has yielded a large database of geophysical wireline well logs and cores. Recent exploration and research within the Trutch, Fort Nelson and the Liard Basin regions are providing a growing database of geological information, allowing for reliable correlation between these two regions, filling the gap between 55.5° N and 58° N. In northeastern British Columbia and northwestern Alberta, four major phases of marine inundation can be regionally traced outlining their resulting geometries in relation to the western foredeep. These are in ascending order, the Moosebar/Clearwater Sea, Hulcross/Harmon Sea, Joli Fou Seaway, and Mowry Sea. Within the western foredeep, Albian sedimentation to the northwest is preserved as distinct marine shales and siltstones of the Buckinghorse Formation. To the south this shale package is interrupted by distinct stacked coarsening upward cycles. Along the eastern margin of the foredeep, regional wireline cross-sections show a northward extension of the Notikewin Member, and the preservation of an attached lowstand facies including evidence for incised valley fill, yet within the western foredeep shale deposition continued, prior to the transgression of the Hulcross/Harmon Sea. The northward extent of the sands may be a result of proximity to the eastern flank of the foredeep, transport of sand north during storms over an overall shallow shelf setting, and strong basin wide currents allowing for the northward transport of these coarser deposits. In the southeast, as a result of an unconformity between the Paddy and Cadotte Members, Joli Fou sedimentation is not well preserved. In the north and west, however, a conformable suite of mudstones is thinning in easterly direction. An organic-rich, marginal marine shale that is topping the Paddy transgressive valley fill succession

appears to extend northward along the shallow margin of the foredeep. The equivalent Viking marker bed in the foredeep can only be detected by a subtle resistivity change.

Acknowledgements

First I would like to thank Dr. Claudia Schröder-Adams, my supervisor, for her continued support, patience, encouragement and the opportunity to learn and to further develop my skills as a young geologist, for which I am grateful. Great thanks to Dr. Per Kent Pedersen, co-supervisor, for all his time, help and suggestions, in particular regarding sequence stratigraphy. I would also like to thank David Jowett for his valuable discussions and suggestions.

Digital well logs were gratefully donated by iDc, Calgary, and I thank them for their continued support. Financial support was provided by Petro-Canada, along with a NSERC Research grant to Schröder-Adams.

I would like to thank my family and friends, especially my parents for support and encouragement, I give my sincere thanks to everyone concerned.

Table of Contents

Title Page	i
Acceptance form	ii
Abstract	iii
Acknowledgements	v
Table of Contents	vi
List of Figures	vii
1.0 Introduction	1
2.0 Area of Study and Previous Work	4
3.0 Geologic Setting	4
3.1 Peace River Arch	8
3.2 Lithostratigraphy	8
3.3 Wilrich Member/Moosebar Formation	10
3.4 Falher Member/Lower Gates Formation	10
3.5 Notikewin Member/Upper Gates Formation	13
3.6 Harmon Member/Hulcross Formation	13
3.7 Cadotte and Paddy members/Boulder Creek Formation	15
3.8 Hasler, Goodrich and Cruiser formations	15
4.0 Purpose of Study	16
5.0 Methods and Database	16
6.0 Major Albian Sea-level cycles and Sequence Stratigraphic Approach	20
6.1 Sequence 1 – Moosebar/Clearwater Sea	21

6.2 Structure map base of sequence 1 (Top of Gething/Bluesky)	47
6.3 Isopach map of sequence 1 (Spirit River Formation)	47
6.4 Sequence 2 – Hulcross/Harmon Sea	47
6.5 Structure map base of sequence 2 (Top of Notikewin Member)	56
6.6 Sequence 3 – Joli Fou Seaway	56
6.7 Isopach map of sequence 2 and 3 (Peace River Formation)	59
6.8 Sequence 4 – Mowry Sea	60
6.9 Structure map base of sequence 4 (Top of Paddy Member)	62
7.0 Discussion	62
8.0 Conclusions	80
References	83
Appendix A Outcrop and Core Descriptions	94
Appendix B Regional Cross-Sections	99

List of Figures

Fig. 1a	Map of study area.	2
Fig. 1b	Detailed map of study area.	3
Fig. 2	Sea level cycles.	5
Fig. 3	Regional stratigraphy.	6
Fig. 4	Legend for geologic descriptions.	11
Fig 5	Outcrop of Moosebar Formation, Dinosaur Lake.	12

Fig. 6	Reference coal core BSD-76-2.	14
Fig. 7a	Map of core locations.	18
Fig. 7b	Map of outcrop localities.	19
Fig. 8a.	North to south regional cross-section N-N'.	22
Fig. 8b	Southwest to northeast regional cross-section G-G'.	23
Fig. 8c	South to north regional cross-section F-F'.	24
Fig. 8d	South to north regional cross-section C-C'.	25
Fig. 8e	South to north regional cross-section D-D'.	26
Fig. 9	Coarsening up cycles with the Falher Member (10-01-070-11W6).	28
Fig. 10a	Southeast to northwest regional cross-section K-K'.	30
Fig. 10b	West to east regional cross-section I-I'.	31
Fig. 10c	West to east regional cross-section J-J'.	32
Fig. 10d	West to east regional cross-section A-A'.	33
Fig. 11	Gradational contact between Moosebar and Gates Formation.	34
Fig. 12a	East to west regional cross-section E-E'.	36
Fig. 12b	South to north regional cross-section Z-Z'.	37
Fig. 13a	Isopach map of the Notikewin Member, highstand.	39
Fig. 13b	Isopach map of the Notikewin Member, lowstand.	40
Fig. 14a	West to east regional cross-section R-R'.	41
Fig. 14b	West to east regional cross-section Q-Q'.	42
Fig. 14c	West to east regional cross-section P-P'.	43
Fig. 15	Southeast to northwest cross-section AA-AA'.	44
Fig. 16a	Distribution of wells (first appearance) with sharp base.	45

Fig. 16b	Southwest to northeast cross-section BB-BB'.	46
Fig. 17	Structure map, base of sequence 1.	48
Fig. 18	Isopach map sequence 1.	49
Fig. 19a	Outcrop example of the Hulcross Formation.	51
Fig. 19b	Outcrop example of the Hulcross Formation.	52
Fig. 20a	Core description C-40-F-93-P2-0.	54
Fig. 20b	Core description 12-23-079-15W6	55
Fig. 21	Structure map, base of sequence 2.	57
Fig. 22	Outcrop description, "Viking" grit beds.	58
Fig. 23	Isopach map, Peace River Formation.	61
Fig. 24	Structure map base of sequence 4.	63
Fig. 25	Contrasting individual wells from North and South.	65
Fig. 26	Reference coal core BWD 76-4.	67
Fig. 27	Example log C-047-G-094-H-02 illustrating sharp base.	70
Fig. 28a	Paleogeographic maps, Notikewin highstand.	72
Fig. 28b	Paleogeographic maps, Notikewin lowstand.	73
Fig. 29	Description of core C-61-J-094-H-3.	75

1.0 Introduction

Exploration within the Western Canada Sedimentary Basin (WCSB) has yielded a wealth of geophysical, structural and lithological data. Production and increased demand for energy has pushed forward the need to seek more oil and gas reserves. Northeastern British Columbia is a region with a recently rapid growing database of geophysical wireline well logs, but with limited published regional subsurface geology. Future exploration will require a better understanding and knowledge of regional trends within this area.

This study is a regional analysis of the Fort St. John Group of northwestern Alberta and northeastern British Columbia, focusing on the region between the Peace River and the Trutch map sheet. The Albian Fort St. John Group has been studied extensively in the Peace River region and recently in the Liard Basin due to increased hydrocarbon exploration. Many studies have focused on areas mainly to the south and east of the Peace River region, including the Elmworth Gas Field (Masters, 1984). Due to increased exploration near the gas field, there is a continually growing database of geophysical wire line well logs and access to an increased amount of drill core. In addition, the NATMAP Foreland Basin Project of the Geological Survey of Canada produced new maps and geological results of selected areas in northeastern British Columbia and the Liard Basin (e.g. Cecile et al., 2000). These new data aid subsurface correlations between both areas, increasing our understanding of depositional environments in regard to sea-level change and basin topography, filling the gap between 55.5° N and 58° N (Fig. 1a and b).

Figure 1a: Locality map showing the study area situated in northeastern British Columbia and northwestern Alberta, with the location of the Peace River Arch denoted by the double ended arrow.

Figure 1b: Detailed map illustrating the locations of regional cross-sections.

2.0 Area of Study and Previous Work

The study area is situated in the Peace River region of northwestern Alberta and northeastern British Columbia. This area is outlined on the eastern side of British Columbia by map areas 93-I to the south and 94-H to the north, and in Alberta includes townships 60 to 100 and ranges 8 to 13 west of the sixth meridian (Fig. 1b). Previous studies have mainly concentrated on pool-sized analysis, especially areas associated with the Elmworth Deep Basin Gas Field, e.g. (Arnott, 1993; Masters, 1984). Other studies have focused on the areas to the south of the Peace River region and southeast into Alberta (Leckie and Walker, 1982; Cant, 1984; Leckie, 1985; Leckie, 1986; Carmichael, 1988; MacDonald et al., 1988; Rahmani and Smith, 1988; Bloch, 1990; Leckie et al., 1990; Stelck and Leckie, 1990; Jervey, 1992; Casas and Walker, 1997; Rouble and Walker, 1997; Chen and Bergman, 1999; Hobbs and MacEachern, 2002). In areas north of the Peace River, limited studies include Foscolos and Sott (1975), Stott (1982) and Dixon (1999). This study examines outcrop exposures along the Peace River and Dinosaur Lake near the town of Hudson's Hope and exposures along the Moberly Lake road (Fig. 2). Subsurface analysis including regional wireline profiles has been conducted throughout the study area, with particular interest in the regions toward the north of the Peace River and Fort St. John regions, toward Trutch (Fig. 3).

3.0 Geologic Setting

The study area is located within the WCSB, a foreland basin, stretching from the eastern edge of the Rocky Mountains to the westernmost portion of Ontario. Changes in relative sea-level, either tectonically or eustatically derived, have greatly influenced the

Figure 2: Sea-level cycles of the Western Interior Sea, S1 to S4 represent the four phases of marine inundation studied. Absolute time after Obradovich (1993) and global transgressive-regressive cycles after Kauffman (1977)

Peace River Foothills	Peace River Plains	Sikanni Chief River	Muskwa/Tetsa rivers	Liard River
Dunvegan Formation	Dunvegan Formation	Dunvegan Formation	Dunvegan Formation	Dunvegan Formation
Fort St. John Group	Fort St. John Group	Fort St. John Group	Fort St. John Group	Fort St. John Group
Goodrich Fm	Paddy Mb	Sikanni Formation	Sikanni Formation	Sikanni Formation
"Viking" marker bed	Cadotte Mb	Bougie mb		Tussock Mb
Boulder Creek Fm	Peace River Fm	"Viking" marker bed		Scatter Fm
Gates Fm	Notikewin Mb			Bulwell Mb
	Falher Mb			
	Bluesky Fm	Bluesky Fm		
Gething Formation	Gething Formation	Gething Formation		Chinkeh Fm
Cadomin Fm	Cadomin Fm			

Figure 3: Regional stratigraphic framework modified from Stott (1982), Stelck and Koke (1987) and Leckie and Potocki (1998), Pedersen and Schröder-Adams (2001), Schröder-Adams and Pedersen (in press).

paleogeography and sediment deposition within the WCSB. In addition, factors such as plutonism, volcanism, and lithospheric loading in the thrust belt caused by subduction, have influenced basin subsidence and sedimentation (Leckie and Smith, 1992). These factors, together with climate change, have also influenced sediment flux into the basin with time. Associated with the developing Cordillera is the formation of a foredeep and forebulge (Beaumont, 1981). Thick packages of marine and alluvial sediments are preserved within the Cretaceous foredeep on the eastern flanks of the Cordillera (Stott et al., 1993). As the foredeep began to increasingly subside, the development of an associated forebulge began further east.

The Canadian Cordilleran fold and thrust belt has been divided into the Foothills and the Rocky Mountains. Closely spaced easterly verging imbricate thrust slices of the Mesozoic-Cenozoic clastic foreland succession form the Foothills in the southern portion of the Canadian Cordillera. In the Peace River region in the northern Foothills, the Inner Foothills form a topographic high fold terrain with surface exposures of box-style, kink-folded Mesozoic sedimentary rocks inferred to be underlain by “blind” thrust sheets of Paleozoic and Mesozoic strata (Fermor and Moffat, 1992).

The Cretaceous strata within the WCSB were deposited in a series of ten major transgressive-regressive marine cycles, five of which covers the lower Cretaceous strata (Caldwell, 1984; Stritch and Schröder-Adams, 1999). At time of maximum transgression, the Cretaceous Western Interior Seaway extended from the northern Boreal Sea south to the Tethyan Sea. The fifth transgressive-regressive Kiowa-Skull Creek Cycle and the basal transgressive phase of the Greenhorn Cycle corresponds to the Albian stage (Kauffman, 1977; Obradovich, 1993) (Fig. 2). In Canada well-preserved records of

higher frequency cycles subdivide the Kiowa-Skull Creek Cycle into the Moosebar/Clearwater Sea, Hulcross/Harmon Sea and Joli Fou Seaway, whereas the Mowry Sea forms the beginning of the Greenhorn Cycle (Williams and Stelck, 1975; Stott, 1984). The deposition of the various strata within the early to early Late Albian Fort St. John Group were placed during a period of overall global eustatic sea-level rise, punctuated by several relative sea-level falls (Kauffman, 1977; Obradovich, 1993) (Fig. 2).

3.1 Peace River Arch

Located in northeastern British Columbia and northwestern Alberta, the Peace River Arch is a significant northeast-trending Precambrian basement feature (Leckie et al., 1990) (Fig. 1a), and has undergone several periods of uplift and subsidence during Phanerozoic time (Chen and Bergman, 1999). The initial uplift occurred between the latest Proterozoic and the earliest Cambrian (Cant, 1988; McMechan, 1990; Chen and Bergman, 1999). It became an area of topographic relief from Late Cambrian to Late Devonian, indicated by the presence of preserved Ordovician and Silurian sediments to the north, northwest and to a lesser extent to the southwest of the Peace River Arch (Cant, 1988; O'Connell et al., 1990). During the Mississippian, the arch began to subside and continued until the Early Cretaceous, where the arch was a topographic low (Cant, 1988; Leckie et al., 1990)

3.2 Lithostratigraphy

The Peace River district was first explored by Sir Alexander Mackenzie along with other notable explorers as early as 1792 (Stott, 1968). However detailed geological

reports of the region did not start to appear until the end of the nineteenth century. The observation of noticeable coal within the lower Cretaceous rocks likely increased the interest in exploring and mapping this region. Over one hundred years have passed since the first subdivision and nomenclature was placed on what is presently the Fort St. John Group. In 1881 George M. Dawson initially named everything overlying the present day Notikewin Member the Fort St. John Shales (Stott, 1968). As exploration continued and more data were collected, more subdivisions were made and the term Fort St. John Group was given by Wickenden and Shaw (1943). The Fort St. John Group at that time contained the Moosebar, Commotion, Hasler, Goodrich and Cruiser formations. As subsurface data became more readily available during the 1950's to the present, the nomenclature changed, with Stott (1982) suggesting the removal of the name Commotion Formation, and giving the Gates, Hulcross and Boulder Creek members formation status. The nomenclature has changed little if at all since Stott (1982); figure 3 illustrates the current stratigraphic nomenclature for northeastern British Columbia, from the Peace River Foothills north to the Liard River region.

In the subsurface of the Peace River Plains, the Fort St. John Group (Albian to lower Cenomanian) consists of the Spirit River Formation overlain by the Peace River Formation (Fig. 3). The Spirit River Formation has been further subdivided into the Wilrich, Falher and Notikewin members, while the Harmon, Cadotte and Paddy members form the Peace River Formation. Where these strata outcrop in northeastern British Columbia the nomenclature differs with the Fort St. John Group consisting of the Moosebar, Gates, Hulcross, Boulder Creek, Hasler, Goodrich and Cruiser formations (Fig. 3). Toward the north, the interval from the Moosebar to the Hasler formations is

comprised within the Buckinghorse Formation (Stott, 1982; Schröder-Adams and Pedersen, in press). The Goodrich and Cruiser formations correlate with the Sikanni and Sully formations respectively (Fig. 3, Stelck, 1975; Stott, 1982; Stelck and Hedinger, 1983). The Fort St. John Group is equivalent to the Upper Mannville Group in eastern and southern Alberta and western portions of Saskatchewan (e.g. Jackson, 1984; Cant, 1988; Cant, 1995; Cant, 1996; Cant and Abrahamson, 1996; Cant, 1998).

3.3 Wilrich Member/Moosebar Formation

The Wilrich Member has been described as predominately marine shale, the result of the transgression of the Boreal Moosebar/Clearwater sea, which flooded much of Alberta and extended as far south as Montana (Smith et al., 1984). The Wilrich Member is the subsurface equivalent to the Moosebar Formation, with outcrops in northeastern British Columbia. As described by Stott (1982), the Moosebar Formation is a dark grey marine shale and siltstone with sideritic concretions, with glauconitic sandstone and pebbles at the base. The type section of 289 m (Stott, 1982) of the Moosebar Formation at Moosebar Creek is no longer accessible due to flooding by the Peace River Canyon Dam and creation of Dinosaur Lake. Therefore exposures of the Moosebar Formation were measured in this study along Dinosaur Lake (Fig. 5).

3.4 Falher Member/Lower Gates Formation

Based on a common occurrence of sandier-upward gamma-ray profiles, the Falher Member has been further subdivided into five successions lettered A through E. Recent studies (Casas and Walker, 1997) suggest that some of these units may be further

Legend

Parallel lamination:
Hummocky cross-stratification
Planar cross-bedding
Trough cross-bedding
Ripples symmetrical
Ripples asymmetrical
Lenticular bedding
Lenticular bedding with mud drapes
Bioturbation	<div>slight </div> <div>intensive </div>
Pebbles
Clay clast
Concretion
Coal fragment

shale
siltstone
sandstone
conglomerate	

Trace Fossils

Terebellina		Escape structure
Skolithos		Planolites
Zoophycos		Chondrites
Helminthopsis

Figure 4: Legend

subdivided due to two or more high resolution sequences. In the Peace River region, the Falher Member is composed of nonmarine, coastal and shallow marine mudstones, sandstones and conglomerates (Casas and Walker, 1997). Here, a long coal core (Fig. 6) illustrates the varying depositional environments.

3.5 Notikewin Member/Upper Gates Formation

The Notikewin Member of the Spirit River Group is similar in composition to that of the stratigraphically older Falher Member, and in the south, composed of nonmarine, coastal and shallow marine mudstones, sandstones and conglomerates. Lithologically, Leckie (1985) defines the top of the Notikewin Member as “consistently occurring above the last carbonaceous unit within the member, 5 to 30 m below two bentonite beds in the overlying Harmon/Hulcross Formation”, and the base defined by the “top of the highest Falher coal, carbonaceous shale, or coarse-grained sandstone-conglomerate.” In regions south of the Peace River Leckie (1985) recognized four general facies within the Notikewin Member: 1) a transgressive facies, 2) a regressive facies, 3) a tidal-flat facies and 4) an alluvial-plain facies.

3.6 Harmon Member/Hulcross Formation

The subsurface Harmon Member and equivalent Hulcross Formation is Middle Albian in age, and is stratigraphically the oldest member of the Peace River Formation. In a previous study, just south of this study area, Leckie (1990) described the Harmon Member as predominately marine shale with lesser amounts of finely interbedded, very

Figure 6: Reference coal core BSD-76-2

fine-grained sandstone and sharp based; internally graded and parallel to wavy laminated siltstone.

3.7 Cadotte and Paddy members/Boulder Creek Formation

South of the Peace River, Stott (1984) describes the Boulder Creek Formation as shoreline facies associated with fluvial sediments. In the Monkman area of northeastern British Columbia Stelck and Leckie (1990) described the Boulder Creek Formation as consisting of 23 metres of marine shoreface to foreshore sandstone and conglomerate overlain by 112 m of non-marine, alluvial plain sandstone, siltstone, and shale.

3.8 Hasler, Goodrich and Cruiser formations

In the foothills of northeastern British Columbia the Fort St. John Group extends upward into the early Cenomanian. These additional lithofacies include the Hasler, Goodrich and Cruiser formations. All three formations are equivalent to the Shaftesbury Formation of the Alberta plains. Exposed along the road cuts along the Moberly Lake road, the Hasler Formation consists predominately of shales, siltstones and minor sandstones (Stott, 1968; 1982). The Goodrich Formation overlies the Hasler Formation and consists of fine-grained sandstones with recessive intervals of mudstone. Shales of the Cruiser Formation overlie the Goodrich Formation, and as described by Stott (1968), are silty and weather into blocky fragments.

4.0 Purpose of Study

The Fort St. John Group in the southern study area, south of the Peace River, during times of relative sea-level fall was an area of predominately coastal deposition (Stott, 1982). Most published paleogeographic maps limit their interpretation to just north of the Peace River (e.g. Smith et al., 1984). In the northern region, distal to shelf sediments, these stratigraphic units become indistinct where they are comprised within the marine mudstones of the Buckinghorse Formation (Stott, 1982). A recent investigation of these distal mudstones along the Sikanni Chief River, however, has shown that the strata can be subdivided based on micropaleontological content (Schroder-Adams and Pedersen, in press). This project was initiated to 1) determine the stratigraphic relationship between proximal and distal strata in northeastern British Columbia and their orientation in respect to the foredeep; 2) identify widely recognizable surfaces and their log expression; 3) establish the northern extent of sandstone progradation; and 4) interpret regional paleoenvironments in regard to Albian sea-level history.

5.0 Methods and Database

The study area is located between the Peace River region and the Trutch region of northwestern Alberta and northeastern British Columbia (Fig. 1a). This area is outlined in British Columbia by map areas 93-I to the south and 94-H to the north, and in Alberta includes townships 60 to 100 and ranges 8 to 13 west of the sixth meridian (Fig. 1b). Albian strata, which outcrop within the Trutch region in the Sikanni Chief River, reflect an overall distal marine setting (Schröder-Adams and Pedersen, in press). This study

targets the transitional zone between the Peace River region with several distinct lowstand sandstones and the distal northern Buckinghorse Formation and relies mainly on well logs since only few cores are available.

Regional stratigraphic correlations, from a grid of over 30 well log profiles, are based on a total of 3500 wells and were constructed using the iDc Canadian petroleum database. Outcrops were studied in the Hudson Hope area along Dinosaur Lake, Peace River and along the road connecting Moberly Lake and Hudson Hope (Figs. 7a and b) in order to understand the lithological character and nature of boundaries within Albian strata. Several of these localities have been reported on previously (e.g. Stelck and Leckie, 1990; Koke and Stelck, 1985; Leckie, 1986). Albian successions and their foraminiferal assemblages along the Sikanni Chief River on the Trutch map sheet have been documented by Stelck (1975), Stott (1982), Stelck and Hedinger (1983) and Schröder-Adams and Pedersen (in press). A hand held spectrometer was used to generate gamma-ray curves of outcrops to compare general log trends with subsurface well log curves. Three long coal cores were studied from an area located approximately 160 km southeast of Hudson Hope, (Figs. 7a and b). These cores cover various stratigraphic intervals including the Wilrich, Falher and Harmon strata within the Fort St. John Group. In the northern part of the study area only three cores were available (Fig. 7a), covering short sections of Albian sandstones.

Correlations between wells were based on transgressive surfaces, which are numbered from TS1 to TS11. These surfaces can be correlated regionally. On gamma-ray curves, these surfaces appear as a distinct increase in gamma radiation, and on resistivity curves as a decrease in electrical resistance values. When available, acoustic logs were

Figure 7a: Map of core locations. Filled circles represent location of observed core and filled squares are well localities in figure 25.

Figure 7b: Map illustrating outcrop localities, Peace River, Dinosaur Lake and Moberly Lake Road.

also used. Several of the transgressive surfaces mentioned above are correlative with tops of some lithostratigraphic units. Structure and isopach maps were created based on these key transgressive surfaces and corresponding lithostratigraphic boundaries.

6.0 Major Albian sea-level cycles and sequence stratigraphic approach

Interpretation of subsurface strata without core control and knowledge of lithology, geochemical signature and faunal content has to rely on identification of regionally extensive log markers. Important surfaces such as pebble lags, glauconite concentrations or hardgrounds cannot be recognized without core control. During my log correlations it became clear that certain transgressive surfaces within the Albian strata are widely recognizable. These surfaces mark the initiation of four major phases of marine inundation of Western Canada; they are in ascending order the Moosebar/Clearwater Sea, Hulcross/Harmon Sea, Joli Fou Seaway and Mowry Sea. Consequently, I subdivide the Albian sedimentary package into four main sequences (S1 to S4), which are bounded by transgressive surfaces of the four main phases of marine transgression. The transgressive surface is used following Embry (1995), suggesting that this surface was a more practical surface to bound sequences where boundary recognition is difficult. Within the four sequences, a total of eleven transgressive surfaces (TS1-TS11) were identified, where TS1, TS9, TS10 and TS11 are regionally recognizable and mark the basal boundary for each of the main sequences. The remaining surfaces, (TS2-TS8) are laterally less extensive transgressive surfaces, although, where recognizable, they provide indications of broader stratal patterns (Figs. 8a to 8e).

In the Peace River region, sea-level lowstands, separating the four major phases of inundation, are characterized by complex facies changes of nearshore, shoreface, estuarine and coastal-plain deposits. These strata are composed of numerous stacked upward coarsening cycles allowing for detailed correlations in that region. To the north, seaward from the coastal environment, and particularly in the western foredeep, these cycles become indistinct as offshore sedimentation prevailed. Nevertheless, the four main phases of marine inundations, all contained within the Buckinghorse Formation, can be recognized on logs as distinct transgressive surfaces. In the southern part of the study area, where shallow conditions prevailed, these surfaces might reflect transgressive surfaces of erosion, whereas in deeper water these become conformable. These transgressive surfaces are overlain by highly radioactive units, which represent condensed sections and maximum flooding surfaces (MFS). All four major phases of marine inundation are recognized by distinct foraminiferal assemblages observed in an extensive exposure of the distal Buckinghorse Formation along the Sikanni Chief River in the Trutch area (Schröder-Adams and Pedersen, in press).

6.1 Sequence 1 – Moosebar/Clearwater Sea

Sequence 1 is bound at the base by TS1 and at the top TS9. The basal transgressive surface of the Moosebar/Clearwater Sea is a distinctive regional gamma-ray and resistivity log marker, separating coastal plain and shoreface deposits of the Gething and Bluesky formations from marine mudstones of the Moosebar/Wilrich Member/Buckinghorse (Figs. 8 and 9). The top of sequence 1 is the major transgressive surface of the Hulcross/Harmon Sea capping the top of the Notikewin Member, a

Figure 8a: North to south regional cross-section N-N', illustrating the northward shale-out of the Falher Member. The sharp-based Notikewin lowstand deposits in northern most part of the section. The zoomed section illustrates the rela

of the Falher Member. The surfaces TS1-TS11 represent transgressive surfaces used for correlation, see text for further description. S1 to S4 mark four transgressive surfaces. This section illustrates the relationship between Joli Fou and Harmon/Hulcross deposits. Note a maximum flooding surface (MFS) above TS11.

ssive surfaces used for correlation, see text for further description. S1 to S4 mark four transgressive-regressive sequences. Note on/Hulcross deposits. Note a maximum flooding surface (MFS) above TS11.

G
Southwest

Intersects D-D'

GR	A-089-B-093-P-12	GR	07-02-077-24-W6	GR	14-35-078-23W6	GR	RES	10-04-083-21W6	GR	RES	10-10-083-21W6	GR	RES	06-26-083-21W6	GR	RES	12-35-083-21W6	GR	RES	06-30-084-20W6	GR	RES	06-34-084-20W6	GR	RES	04-02-088-20W6
----	------------------	----	-----------------	----	----------------	----	-----	----------------	----	-----	----------------	----	-----	----------------	----	-----	----------------	----	-----	----------------	----	-----	----------------	----	-----	----------------

06-30-084-20W6
GR
06-34-084-20W6
GR
04-02-086-20W6
GR RES
07-14-086-20W6
GR
07-30-086-19W6
GR
07-10-087-19W6
GR RES
14-23-087-19W6
GR
06-13-088-19W6
GR RES
C-054-K-094-A-10
GR RES
C-009-B-094-A-15
GR RES
D-079-B-094-A-15
GR RES
D-097-B-094-A-15
GR RES

Figure 8b: Southwest
Note the persistent r
the northeast, along
foredeep. FSMB=Fis
MFS=Maximum flood
boundary.

G'
Northeast

B-070-C-004-H-08
GR RES

B-008-F-004-H-08
GR

D-003-K-004-H-08
GR

A-021-K-004-H-08
GR RES

50 m

FSMB

MFS

TS11

TS9

SB

Attached Lowstand

TS8

TS7

Datum

TS1

Shafesbury Formation

Peace River Formation

Notikewin Mbr.

Wilrich Falher Eq.

Figure 8b: Southwest to northeast cross-section G-G'. Note the persistent nature of the Notikewin Member to the northeast, along the eastern margin of the foredeep. FSMB=Fish Scales Marker Bed, MFS=Maximum flooding surface, SB=sequence boundary.

F South

Intersects J-J'

Intersects A-A' Intersects E-E'

10-18-083-16W6

14-07-084-16W6

15-30-084-16W6

11-02-085-17W6

08-13-085-17W6

10-23-085-17W6

06-04-086-17W6

09-19-088-16W6

D-074-I-094-A-10

B-084-A-094-A-15

RES

GR RES

GR RES

GR RES

GR RES

GR RES

GR RES

GR RES

GR RES

GR

50 m

FSMB

MFS

sects E-E'

F'
North

58°

	15	16
	15	16
7	9	
94G	2	1
	15	16
10	9	
94B	7	8
	2	1
	15	16
10	9	
7	9	

Figure 8c: S

F'
North

D-007-I-084-A-15

GR RES

D-034-I-084-A-15

GR RES

C-083-I-084-A-15

GR RES

Figure 8c: South to north cross-section F-F'

Shafesbury Formation	
Paddy Mbr.	
Cadotte Mbr.	
Harmon Mbr.	
Notikewin Mbr.	
Falher Mbr.	
Wilrich Member

GR 06-10-079-19W6
RES

GR 16-21-079-19W6

GR 03-15-080-19W6

GR 01-02-081-19W6

Intersects I-I'

GR 06-26-081-19W6

GR 06-02-082-19W6
RES

GR 10-10-083-19W6
RES

Intersects J-J'

GR 02/01-15-084-19W6

GR 14-02-085-19W6
RES

06-11-085-19W6

GR 02-35-086-19W6
RES

Intersect

GR 14-01-086-19W6

TS10

08-11-085-19W6

GR RES

02-35-086-19W6

Intersects A-A'

GR RES

14-01-086-19W6

GR RES

08-01-087-19W6

GR RES

06-24-087-19W6

GR RES

06-13-088-19W6

GR RES

11-26-088-19W6

GR

D-040-K-084-A-10

GR RES

C-058-K-084-A-10

GR RES

B-045-C-084-A-15

C-058-K-094-A-10
GR RES

B-045-C-094-A-15
GR RES

A-072-F-094-A-15
GR RES

C'
North

Figure 8d: North to south cross-section C-C'

D
South

B-079-C-003-P-08

C-016-E-003-P-11

B-054-E-003-P-11

18-27-077-22W6

Intersects G-G'

14-35-079-23W6

12-29-080-22W6

07-02-082-22W6

12-20-080-22W6

07-02-082-22W0

10-20-083-21W6

07-08-084-21W6

Intersects J-J

10-32-084-21W6

06-08-085-21W6

07-20-085-21W6

Intersects A-A'

10-05-086-21W6

10-16-080-21W6

07-20-085-21W6

Intersects A-A'

10-05-086-21W6

10-16-088-21W6

10-09-087-21W6

10-21-087-21W6

07-26-087-21W6

Intersects E-E'

09-04-088-21W6

B-084-K-004-A-11

C-014-F-004-A-14

B-014-F-004-A-14

D-055-F-004-A-14

B-073-F-004-A-14

C-009-G-004-A-14

TS10

B-044-F-004-A-14

D-055-F-004-A-14

B-073-F-004-A-14

C-000-G-004-A-14

D-039-J-004-A-14

C-083-K-004-A-14

D' North

Figure 8e: South to north cross-section D-D'.

remarkable persistent sandstone unit. Facies changes within sequence 1 are particularly variable in the south including numerous transgressive/regressive cycles (Fig. 9).

Within sequence 1, seven regionally less extensive transgressive surfaces were mapped, each topping a distinct coarsening upward cycle (Fig. 8). Cyclicity within the lower portion of the sequence (TS1 to TS4) is most expressed in the south in map area 93-P (Fig. 8a). Surfaces TS2 to TS5 downlap to the north and northwest onto transgressive surface TS1 (Figs. 8 and 10).

In outcrop on Dinosaur Lake (Fig. 4) the lower portion of sequence 1 contains several coarsening-up successions of marine mudstone interbedded with an upward increasing proportion of sandstone interbeds. The section shows a gradational contact between the upper Moosebar and Gates formations (Fig. 11), similar to the contact between the Wilrich and Falher members as seen on well logs.

Transgressive surfaces TS5 to TS8, representing Falher cycles, are most easily recognized in townships 75 to 82. South of township 65 in British Columbia nonmarine conditions prevail (Stott, 1968; Leckie and Walker, 1982; Cant, 1984). To the north, along range 14W6 shale-out of the sandstones underlying the surfaces TS5 and TS6 occurs approximately in township 87 (Fig. 8a). Within younger cycles, sandstones, which underlie TS7 and TS8 reach farther north to township 94. The sandstones shale-out in a westerly direction along township 88 at approximately range 24 west of the sixth meridian (Figs. 10a and 12a).

In the Peace River area the Notikewin Member is bound by transgressive surfaces TS8 and TS9, of which TS9 forms the boundary between sequences 1 and 2. In the region south of township 87 two coarsening-up successions are visible within the Notikewin

Figure 9: Coarsening up cycles within the Falher Member in 10-01-070-11W6. TS1-TS11 represent transgressive surfaces used for regional correlation, with the four sequences marked S1 to S4 (Lithostratigraphy modified from Smith et al., 1984).

K Southeast

Shaftesbury	
Paddy Mbr.	TS11
Cadotte Mbr.	TS10
Harmon Mbr.	TS9
Notikewin Member	TS8
Falher Member	TS7
	TS6
Wirlich Member	TS5
	TS4
	TS3
	TS1

D-013-H-093-P-10

06-01-077-19W6

07-22-077-17W6

03-29-078-19W6

07-07-080-19W6

GR

RES

GR

GR RES

GR

GR

03-29-078-19W6

GR

07-07-080-19W6

GR

11-22-081-20W6

GR RES

07-19-082-20W6

GR RES

11-26-082-21W6

GR RES

09-33-082-21W6

GR RES

11-26-082-21W6

09-33-082-21W6

10-15-083-21W6

04-34-083-21W6

10-22-084-21W6

10-32-084-21W6

GR RES

GR RES

RES

GR RES

GR RES

GR RES

Intersects

10-16-088-22W6

11-35-087-22W6

02-07-087-21W6

07-25-086-21W6

11-31-084-21W6

10-32-084-21W6

10-22-084-21W6

RES

GR

RES

GR

GR

RES

GR

RES

GR

RES

50 m

Mowry Deposits

Joli Fou Deposits

Hulcross/Harmon Deposits

? Falher lowstand

Moosebar/Clearwater
Deposits

Datum

Figure 10a: Regional southeast to northwest cross-section K-K', note the shale-out of the Falher, Notikewin and Cadotte/Paddy members toward the northwest, as the strata approach the foredeep. Note also the sharp base of the Notikewin lowstand deposit in 11-31-084-21W6 and northwestward change to an apparent conformable basal boundary. A possible Falher lowstand deposit visible in the northwestern portion of the cross-section.

West

06-18-081-24W6

GR RES

11-34-081-24W6

GR RES

10-19-081-23W6

GR RES

07-02-082-22W6

GR RES

02/06-21-081-21W6

GR RES

11-22-081-20W6

GR RES

11-22-081-20W6

GR RES

14-04-081-19W6

GR RES

Intersects C-C'

06-26-081-19W6

GR RES

11-17-081-18W6

GR RES

06-25-081-18W6

GR RES

Intersects F-F'

15-29-081-17W6

GR

06-21-081-17W6

GR

RES

Intersects F-F'

15-29-081-17W6

GR

06-21-081-17W6

GR

12-25-081-17W6

GR RES

10-29-081-16W6

GR RES

07-27-081-16W6

GR RES

10-26-081-16W6

GR RES

14-19-081-15W6

GR RES

15-17-081-15W6

GR

Intersects N-N'

14-19-081-15W6

15-17-081-15W6

10-11-081-15W6

08-17-081-14W6

08-15-081-14W6

07-24-081-14W6

East

GR RES

GR

GR RES

GR RES

GR RES

GR RES

FSMB

50 m

S4

TS11

? S3

S2

TS9

TS8

TS7

TS6

TS5

TS4

TS3

TS2

TS1

Cadotte

Mbr.

Harmon

Mbr.

Notikewin

Mbr.

Falher Member

Wilrich

Member

58°

4	5
6	7
94G	8
2	1
10	11
12	13
14	15
16	17
18	19
20	21
22	23
24	25

Figure

Intersects N-N'

08-17-081-14W6

06-15-081-14W6

07-24-081-14W6

East

GR RES

GR RES

GR RES

FSMB

50 m

TS11

? S3

S2

TS9

TS8

TS7

TS6

TS5

TS4

TS3

TS2

TS1

Cadotte

Mbr.

Harmon

Mbr.

Notikewin

Mbr.

Falher Member

Wilrich

Member

Figure 10b: West to east cross-section I-I'.

J
West

04-31-084-24W6
RES

06-29-084-23W6
GR RES

11-26-084-23W6
GR RES

16-26-084-23W6
GR RES

08-29-084-22W6
GR RES

07-26-084-23W6
GR RES

10-32-084-21W6
GR RES

11-27-084-21W6
GR RES

Intersects D'D'

Willich Mbr.	Falher Mbr.	Notikewin Mbr.	Peace River Formation
--------------	-------------	----------------	-----------------------

Intersects D'D'

Intersects C-C'

10-32-084-21W6

11-27-084-21W6

08-20-084-20W6

02/01-15-084-19W6

14-25-084-19W6

12-30-084-18W6

04-29-084-18W6

14-21-084-18W6

13-25-084-18W6

14-19-084-17W6

GR RES

GR RES

GR RES

GR RES

GR RES

GR RES

GR RES

GR RES

GR RES

Intersects F-F'

Figure 10c: West to east c

Figure 10c: West to east cross-section.

Intersects C-C'

Intersects F-F'

14-01-086-19W6

16-04-086-18W6

08-08-086-17W6

08-04-086-17W6

11-31-085-16W6

10-05-086-16W6

07-04-086-16W6

07-02-086-16W6

GR RES

GR RES

GR RES

GR RES

GR RES

GR RES

GR RES

GR

Figure 10d: West to east cross-section A-A'

Figure 11: Outcrop described along Dinosaur Lake. Notice a gradational contact between Moosebar and Gates formations. Wireline logs suggest a similar contact. The photograph illustrates outcrop of the Moosebar and Gates formations along the south side of Dinosaur Lake. Note the gradational contact between the two formations expressed as interbedded mudstone and sandstone.

E
West

Intersects Z-Z'

A-087-G-094-B-09

D-057-H-094-B-09

10-08-088-25W6

06-10-088-25W6

Intersects K-K'

06-10-088-25W6

16-08-088-23W6

10-16-088-22W6

04-08-088-21W6

09-04-088-21W6

06-16-088-20W6

08-22-088-20W6

06-18-088-19W6

RES

GR

RES

RES

RES

GR

GR

GR

GR

GR

08-22-088-20W6

GR

06-18-088-19W6

GR

10-04-088-19W6

GR

RES

06-13-088-19W6

GR

RES

10-06-088-18W6

GR

RES

10-14-088-18W6

GR

R

10-06-088-18W6

RES

GR

10-14-088-18W6

RES

GR

06-18-088-16W6

RES

Intersects F-F'

09-19-088-16W6

GR

RES

06-07-088-14W6

GR

RES

Intersects

GR

Intersects N-N'

16-17-088-14W6

10-12-088-14W6

E'
East

RES

GR

RES

GR

50 m

MFS

Shaftesbury Formation

Peace River Fm.

Spirit River Formation

TS11

TS9

TS8

TS7

TS6

TS5

TS4

TS3

TS1

Datum

122° British Columbia 120° Alberta

Figure 12a: West to east cross-section E-E' through township 88. Increased thickness within the western foredeep is clearly contrasted with a distinct thinning to the east. Marine sedimentation of the Joli Fou Seaway S3 is well preserved to the west, yet eastward cannot be distinguished on wireline logs from sequence 2.

Z
South

B-015-G-094-B-01

GR

A-081-B-094-B-08

GR RES

C-014-H-094-B-08

GR RES

B-033-H-094-B-08

GR RES

Intersects A-A'

A-041-I-094-B-08-08

GR RES

D-013-A-094-B-09

GR

D-086-A-094-B-09

GR RES

D-013-A-094-B-09

GR

D-086-A-094-B-09

GR RES

Intersects E-E'

A-087-G-094-B-09

GR RES

B-013-B-094-B-16-2

GR RES

D-019-H-094-B-16

GR RES

B-087-H-094-B-16

GR RES

D-034-I-094-B-16

GR RES

TS7

Datum

Z'
North

RES

Figure 12b: South to north cross-section within the western foredeep Z-Z'. Log signatures indicate that no Notikewin sandstones are present within this westerly located cross-section. Note the northward thinning of sequence 1 to 3, contrasted with a northward thickening of sequence 4, suggesting a change in sediment source from the south to the north at the start of sequence 4.

Buckingham Formation

TS11

TS10

TS9

S4

MFS

S3

S2

S1

Member (fig. 8a), whereas north of township 87, it appears as one coarsening-up succession, (Figs. 8 and 10a). On an easterly-located north-south cross-section (Fig. 8a), this single Notikewin cycle can be distinguished north to township 99 (94-H-9), at which point the sandstone shales-out. In contrast, on a westerly located north to south cross-section (Fig 12b) within the western foredeep, sandstones of Notikewin Member are not present north of township 83. The Notikewin Member has an average thickness of 60 m throughout most of the study area (Fig. 13a). It should be noted that the lower boundary becomes more difficult to pick towards the north where sandstones of the underlying Falher Member shale-out and obscure TS8. In map area 94-H and the northern portion of 94-A, however, the Notikewin sandy facies thickens locally to 75 m (Figs. 13b, 14 and 15). Within this area the sandstone unit is sharp-based opposed to gradational as seen elsewhere (Figs. 14a and 15). Mapping of wells with sharp-based sandstone indicate a position along a southwest to northeast trend (Fig. 16).

Westward, Notikewin sandstones pinch-out toward the foredeep, at approximately range 22W6 along a west-east oriented cross-section through township 88 (Fig. 12a). Transgressive surface TS9, overlying the Notikewin Member in the proximal area to the south, becomes much less distinguishable west of range 23 where the surface becomes conformable, and deep water sedimentation is less affected by transgression. Eastward into western and central Alberta, Notikewin sandstones shale-out into the equivalent Loon River Formation at range 14W5 (Hayes et al., 1994, figure 19.16).

Figure 13a: Isopach map of the Notikewin Member, highstand.

Figure 13b: Isopach map of the Notikewin Member composite lowstand.

R
West

B-041-H-094-H-04

A-043-E-094-H-03

B-084-F-094-H-03

D-047-F-094-H-03

B-066-G-094-H-03

D-054-G-094-H-03

D-037-H-094-H-03

Buckinghorse Formation

D-054-G-094-H-03

GR

D-037-H-094-H-03

GR

RES

D-044-H-094-H-03

GR

RES

D-051-H-094-H-03

GR

RES

D-055-E-094-H-02

GR

RES

D-042-E-094-H-02

GR

RES

Intersects AA-AA'

D-067-F-094-H-02

GR

RES

B-064-F-094-H-02

GR

RES

Intersects AA-AA'

D-067-F-094-H-02

B-064-F-094-H-02

C-050-G-094-H-02

C-047-G-094-H-02

D-024-H-094-H-02

B-039-E-094-H-01

D-036-E-094-H-01

D-042-E-094-H-01

GR RES

GR RES

GR RES

GR RES

GR RES

GR RES

GR RES

GR

Attached Lowstand

Highstand

Intersects N-N'

R'
East

D-036-E-094-H-01

D-042-E-094-H-01

A-045-F-094-H-01

D-039-G-094-H-01

A-031-G-094-H-01

A-047-H-094-H-01

GR RES

GR RES

GR RES

RES

GR RES

GR RES

50 m

MFS

TS11

S3?
S2?

TS9

TS8

TS7

S1

TS4

TS3

TS1

Datum

Highstand

Getling/ Bluesky	Wilrich Mbr.	Falher Mbr.	Notikewin Mbr.	Peace River Fm.
---------------------	-----------------	-------------	-------------------	-----------------------

Figure 14a: West to east cross-section R-R'. The contact between the Falher and underlying Wilrich Member becomes less distinct toward the west (foredeep) as the Falher cycles shale-out into the Buckinghorse Formation. Note the sharp-based log signatures within the Notikewin Member dividing highstand sandstones from attached Notikewin composite lowstand deposits. Note the eastward thinning of the Peace River Formation.

West
Q

A-032-A-094-H-05

B-030-D-094-H-06

D-017-C-094-H-06

C-014-C-094-H-06

C-012-C-094-H-06

D-013-B-094-H-06

D-031-B-094-H-06

D-033-A-094-H-06

B-030-D-094-H-07

A-047-D-094-H-07

D-033-A-094-H-06

B-030-D-094-H-07

A-047-D-094-H-07

D-015-D-094-H-07

D-010-C-094-H-07

D-029-C-094-H-07

D-015-C-094-H-07

D-001-C-094-H-07

D-003-B-094-H-07

B-010-A-094-H-07

A-009-A-094-H-07

D-003-B-094-H-07

B-010-A-094-H-07

A-009-A-094-H-07

B-026-A-094-H-07

A-021-A-094-H-07

A-027-D-094-H-08

A-005-D-094-H-08

A-012-D-094-H-08

B-026-C-094-H-08

B-006-B-094-H-08

50 m

SB

Datum

Figure 14b: West to east cross-section Q-Q'. No
ward shale of the Notikewin Member, no underly
sandstones are visible. Within the western foree
within sequence 2 and 3 are preserved.

D-015-A-094-H-08

Q'
EAST

Figure 14b: West to east cross-section Q-Q'. Note the westward shale of the Notikewin Member, no underlying Falher sandstones are visible. Within the western foredeep, strata within sequence 2 and 3 are preserved.

Buckinghorse Formation

p
West

S1 — S2 — S3 — S4

Well	Depth	Interval
D-072-H-094-G-08	RES	GR
C-078-E-094-H-05	GR	RES
D-077-E-094-H-05	RES	GR
C-072-E-194-H-05	GR	GR
D-071-E-094-H-05	GR	GR
B-066-F-094-H-05	GR	RES
B-068-G-094-H-05	RES	GR
B-065-G-094-H-05	GR	GR
A-066-H-094-H-05	GR	RES
B-054-H-094-H-05	RES	GR
B-042-H-094-H-05	GR	GR

MFS

TS11

TS10

TS9

D-019-G-094-H-07

GR

D-017-G-094-H-07

RES

A-021-G-094-H-07

GR

D-037-H-094-H-07

GR

D-013-H-094-H-07

GR

D-031-H-094-H-07

RES

B-026-E-094-H-08

GR

B-034-E-094-H-08

GR

B-002-E-094-H-08

RES

B-008-F-094-H-08

GR

A-004-F-094-H-08

GR

C-092-B-094-H-08

GR

D-028-H-094-H-08

GR

50 m

TS10

Datum

MFS

FSMB

TS

TS9

Figure 14c: West to east cross-section P-P'.

Southeast

GR B-036-B-094-H-02

GR D-061-C-094-H-02

GR D-082-C-094-H-02

GR D-093-C-094-H-02

GR B-024-F-094-H-02

GR D-067-F-094-H-02

GR D-079-F-094-H-02

Intersects R-R'

TS10

Attached Lowstand

Submarine erosion surface

Intersects R-R'

D-067-F-094-H-02

GR

D-079-F-094-H-02

GR

D-072-E-094-H-02

GR

B-003-L-094-H-02

GR

B-013-L-094-H-02

GR

D-024-L-094-H-02

GR

A-041-L-094-H-03

GR

GR D-024-L-094-H-02

GR A-041-I-094-H-03

GR D-073-I-094-H-03

GR D-031-B-094-H-06

GR B-070-A-094-H-06

GR D-095-B-094-H-06

GR D-017-G-094-H-06

D-095-B-094-H-06
GR
D-017-G-094-H-06
GR
A-045-F-094-H-06
GR

AA'
Northwest

Buckingham Formation

Figure 15: Southeast to northwest cross-section AA-AA'. Note the slight thickening and the sharp-based gamma-ray signature at the base of the Notikewin Member in wells northwest of well D-061-C-094-H-02 associated with an attached lowstand deposit. Also note the northwestward shale-out of the Notikewin attached composite lowstand deposit.

Figure 16a: Distribution of wells according to the first appearance of sharp-based gamma-ray signatures, forming a southeast to northwest trend.

Buckinghamshire Formation

GR D-099-A-094-H-03

GR D-037-H-094-H-03

GR B-046-H-094-H-03

GR D-044-H-094-H-03

GR D-053-H-094-H-03

GR D-051-H-094-H-03

GR D-098-E-094-H-02

GR D-005-L-094-H-02

GR D-002-L-094-H-02

GR D-005-L-094-H-02

GR D-002-L-094-H-02

GR D-046-K-094-H-02

GR D-062-K-094-H-02

GR D-090-J-094-H-02

GR B-096-J-094-H-02

GR D-095-J-094-H-02

GR D-003-B-094-H-07

GR D-021-B-094-H-07

GR D-003-B-094-H-07

GR D-021-B-094-H-07

GR B-044-S-094-H-07

GR A-053-A-094-H-07

GR A-061-A-094-H-07

GR A-007-E-094-H-08

GR A-025-E-094-H-08

GR D-003-K-094-H-08

GR A-021-K-094-H-08

Figure 16b: Southwest to northeast BB-BB', parallel with Notikewin shoreface.

Figure 16b: Southwest to northeast cross-section BB-BB', parallel with Notikewin highstand shoreface.

6.2 Structure map base of the sequence 1 (Top of Gething/Bluesky)

A structural map of the base of the Wilrich Member (Fig. 17) illustrates a significant structural southward dip of the underlying strata south of the Peace River. The structural high coincides with exposure along the Peace River, including observed outcrop of the equivalent Moosebar Formation. North of the Peace River, contours show a slight northward dip.

6.3 Isopach map of sequence 1 (Spirit River Formation)

An isopach map (Fig. 18) of the entire Spirit River Formation Sequence 1, (base of the Wilrich Member to top of the Notikewin Member) show a slight northwestward thinning of these strata. Starting in the south, township 69, the strata thin from approximately 380 m to 220 m near township 96 where the Notikewin Member shale-out occurs.

6.4 Sequence 2 – Hulcross/Harmon Sea

Sequence 2 is bounded by major transgressive surfaces TS9 and TS10. TS9 represents the transgression of the Hulcross/Harmon Sea, which is widely recognizable (Fig. 8). TS10 is the surface associated with the transgression of the Joli Jou Seaway. The basal portion of sequence 2 consists predominately of marine shales and siltstones deposited during a period of overall sea-level rise of the Boreal Hulcross/Harmon Sea. Outcrops of the Hulcross Formation along Starfish Creek on Dinosaur Lake contain several bentonite layers (Fig. 19). These are likely correlatable with bentonites observed in the Hulcross-correlative strata of the Buckinghorse Formation exposed along the

Figure 17: Structure map of the base of sequence one, (Top of Gething/Bluesky)

Figure 18: Isopach map of sequence 1 (Spirit River Formation).

Figure 19a: Outcrop description of the Hulcross Formation, Dinosaur Lake, illustrating offshore marine conditions. Note the frequent bentonite beds in the lower portion of the formation. Refer to Figure 8 for legend. Photograph of the outcrop illustrates the shale and siltstone composition of the Hulcross Formation, overlain by the massive sand of the Boulder Creek Formation.

Figure 19b: Upper portion of measured section, Hulcross formation, Dinosaur Lake.

Sikanni Chief River (Schröder-Adams and Pedersen, in press), and with bentonites within the lower Harmon in the study area (Fig.9), seen as gamma-ray spikes.

The Harmon/Hulcross Sea retreated as the result of the progradation of the Boulder Creek/Cadotte clastic wedge in the Peace River region. The Cadotte Member overlies the Harmon Member as a coarsening-up unit easily recognized in core (Fig.20) and wireline log particularly south of township 84 (Fig. 8a) and forms the upper portion of sequence 2. North of township 84 (Fig. 8a), the Cadotte sandstone shales-out into the Buckinghorse Formation, and the coarsening-up signature becomes less distinct.

The Boulder Creek Formation, in outcrop at Dinosaur Lake, has a gradational contact with the underlying Hulcross Formation (Fig. 19). South of Chetwynd, Gibson (1992) subdivides the Boulder Creek Formation into the Cadotte Member and the overlying Walton Creek member. His Cadotte Member forms the equivalent to the Cadotte Member of the Peace River Formation in the subsurface, whereas the Walton Creek Member is equivalent to the lower Hasler Formation, where preserved, and the lower Paddy Member. Walton Creek/Paddy/lower Hasler strata are part of sequence 3.

In the south and central region, uniformly high gamma-ray and low resistivity signatures distinguish the Harmon Member from the underlying Notikewin and overlying Cadotte members. The Harmon Member thins toward the east, with the thickest strata toward the west and northwest. The blocky gamma expression of the Cadotte Member is traceable north to township 87. Along the margin of the foredeep at 14W6 north of township 87 (Fig. 8a) the Cadotte marker disappears and uniformly high gamma ray and low resistivity readings obscure the boundary between Harmon/Hulcross Sea strata and the overlying shaly Joli Fou strata. Westwards in the foredeep, however, the top of the

Core C-40-F-93-P2

Figure 20a: Core and accompanying wireline well logs from well C-40-F-93-P2-0 illustrating the contact between the Harmon and Cadotte members and the change from offshore marine conditions to shallow shoreface environments.

12-23-079-15W6

Core interval 878-890 m.

Figure 20b: Core from well 12-23-079-15W6 illustrating the the fine to medium grained nature of the Cadotte Member in the region township 79 range 15 west 6.

Harmon cycle can be determined by a renewed decrease in resistivity that I regard as the transgressive surface of the Joli Fou Seaway (Fig. 12a).

6.5 Structure map base of sequence 2 (Top of Notikewin Member)

A structural map of the base of sequence 2 (Fig. 21) reveals similar patterns as observed in the structural map of the base of sequence 1. South of the Peace River contours show a significant dip to the south, dipping -900 m below MSL. The structural high of the base of sequence 2 (top of the Notikewin Member) coincides with outcrops of the equivalent Gates Formation. North of the Peace River, relief is minimal, displaying only a minor dip to the north.

6.6 Sequence 3 – Joli Fou Seaway

Sequence 3 is bounded by transgressive surfaces TS10 and TS11 and contains sediments deposited in the Joli Fou Seaway. These are well preserved in Alberta as the Joli Fou Formation (Stritch and Schröder-Adams, 1999). In outcrop south of Hudson Hope equivalent strata form the lower Hasler Formation below the “Viking grit beds” (Fig. 22)(Koke and Stelck, 1985). In the 93-P area, surface TS10 represents an unconformity between the Cadotte and Paddy members, related to a sea-level fall and following sea-level rise, which can be traced north along range 14W6 to township 80 (Fig. 8a). In the 93-P area, the Paddy Member is distinguished by a gamma-ray signature that is slightly higher and more erratic compared to the blocky signature of the Cadotte Member. North of township 80 the typical erratic Paddy estuarine signature is no longer present, but the Cadotte blocky log character persists up to township 82. Where the Paddy

Figure 21: Structure map of the base of sequence 2, (Top of Notikewin Member).

Figure 22: Outcrop locality along the Moberly Lake Road containing the "Viking" marker bed Hasler Formation. Overlain by the upper Hasler Formation, Mowry deposits.

Member unconformably overlies the Cadotte Member, Joli Fou deposition is partly represented in the lower Paddy estuarine fill (Stelck et al., 2000). Within the region between township 84 and township 87, the Cadotte Member shales-out, and consequently the distinction between sequence 2 and 3 and with that, the basal transgressive surface of the Joli Fou sequence, cannot be easily recognized (Fig. 8a).

Within the foredeep (Fig. 12) the basal and top boundary of the Joli Fou sequence is recognized by a decrease in resistivity representing the transgressive surfaces of the Joli Fou cycle and Mowry cycle respectively, whereas the gamma response at both boundaries remains indistinct. In the Sikanni Chief River area, a thick Joli Fou equivalent succession was identified in outcrop based on the presence of the indicative *Haplophragmoides gigas* Zone within the Buckinghorse Formation. There it is marked by the Viking marker interval (Schröder-Adams and Pedersen, in press).

6.7 Isopach map of sequence 2 and 3 (Peace River Formation)

The unconformity between the Cadotte and Paddy members (boundary between sequence 2 and 3) is present in the southeastern portion of the study area and therefore strata within sequence 3 are not preserved there. In the region along the northeastern margin of the foredeep (Fig. 8a), strata within sequence 3 are preserved; however, due to the shale upon shale contact between Hulcross/Harmon deposits (sequence 2) and Joli Fou deposits (sequence 3) the boundary between these two sequences is often difficult to determine. As a result, isopach maps of the individual sequences 2 and 3 were not made. To best illustrate strata between the top of sequence 1 and the base of sequence 4 an isopach map of the combined sequences 2 and 3 (Peace River Formation) was

constructed, which clearly illustrates the eastward thinning of the Peace River Formation (Fig. 23).

6.8 Sequence 4 – Mowry Sea

Sequence 4 encompasses deposition within the Mowry Sea. The basal boundary and transgressive surface F11 overlies: a) the Viking marker bed within the Hasler Formation along the Moberly Lake road (Figs. 7b and 22) (Stelck and Koke, 1987; Leckie and Stelck, 1990; Stelck et al., 2000); b) the Walton Creek Member of the Boulder Creek Formation south of Chetwynd (Gibson, 1992) and c) the newly identified Viking marker interval in the most northwestern portion of the study area, within the Buckinghorse Formation (Schröder-Adams and Pedersen, in press). Where the incoming Mowry Sea encountered estuaries, partly filled by the previous transgression, the basal transgressive surface is found within the Paddy Member (Peace River town area) (Leckie et al., 1990; Leckie and Singh, 1991). Elsewhere a distinct sharp increase in gamma radiation and slight decrease in resistivity marks this surface. The sharp gamma increase above the Paddy must therefore represent a slightly younger transgressive phase compared to the surface in the west. Leckie and Singh (1991) describe this unit as “a shallow-water condensed section characterized by marine organic-rich radioactive shale”.

The upper boundary of my sequence is not discussed here, but represents the Fish Scales Marker, associated with a fall in relative sea-level at the Albian/Cenomanian boundary (Leckie et al., 2000). Cross-section profiles, which pass through the Peace River valley do not contain complete correlations of Mowry Sea strata (sequence 4) due to erosion. Mowry Sea strata in the Trutch area reach a thickness of over 500 m, where a

Figure 23: Isopach map of combined sequences 2 and 3 (Peace River Formation)

series of four stacked shoreface sandstones, bounded by sequence boundaries of higher order forming the Sikanni Formation add to the thickness of sequence 4. Equivalent deposits of the Shaftesbury Formation in the southern part of the study area are only approximately 200 m thick. The upper interval of the Buckinghorse Formation from the basal Mowry transgressive surface to the Sikanni Formation (lower part of Sequence 4) also thins in an easterly direction toward the eastern flanks of the foredeep (Fig. 14).

6.9 Structure map base of sequence 4 (Top of Paddy Member)

A structural map of the base of sequence 4 (top of Paddy Member) (Fig. 24) shows a gradual southward dip from 0 m (township 80) to 800 m below MSL (township 65). North of the Peace River the structural dip is minimal. Due to only a limited number of wells where the upper well casing allows stratigraphic coverage and upper boundary determination in regions where the Sikanni Formation is preserved, an isopach map of sequence 4 was not constructed.

7.0 Discussion

Sequence 1 in the south is a thick unit (Fig. 25), related to the northward progradation of the Falher and Notikewin clastic wedges. Cores observed from the 93-I map area contain evidence of lower shoreface to upper shoreface, back barrier, estuary and lagoonal deposits within the Falher Member (Fig. 26). Oscillating relative sea-level during this period resulted in variable depositional environments along the southwestern margin of the early Albian Moosebar Sea (Jackson, 1984; Smith et al., 1984). In the Peace River region along the Alberta and British Columbia border and in the Elsworth

Figure 24: Structure map base of sequence 4 (Top of Paddy Member).

Figure 25: Two wireline well logs (see Fig. 7a for location) contrasting strata proximal to sediment source in the south with distal strata in the north. The northern well clearly shows preservation of Joli Fou sediments (S3). This is contrast with the southern well, where sedimentation during sequence 3 is not preserved, and an unconformity lies between the Cadotte and Paddy members.

Figure 26: Reference coal core BWD 76-4 which contains strata from the Wilrich and Falher Members, refer to Figure 7a for core location. This core illustrates the varying environments preserved in the Falher Member to the south, proximal to sediment source.

area, each Falher cycle involved at least one fall and rise in relative sea-level (Arnott, 1993; Cant, 1995; Rouble and Walker, 1997; Armitage and et al., 2002). These cycles are expressed seaward as stacked coarsening-up cycles, where younger Falher sandstones prograded farther north than the underlying older units before they shale-out (Fig. 8). The vertical stacking of cyclical strata, which make up the Falher and Notikewin clastic wedges (e.g. well 13-01-077-15W6, Fig. 8a) has been related to the sporadically subsiding Peace River Arch (Cant, 1996). With each given episode of sporadic subsidence of the arch, and the deposition of each Falher cycle, the basin filled and allowed the younger overlying sediments to prograde further north.

The stacking of the coarsening-up cycles within the upper Falher and Notikewin members occurred during the tail end of a highstand systems tract (Cant, 1996). However, in the areas of 94-H and the northern portion of 94-A, wireline logs suggest the presence of a lowstand deposit, indicated by the presence of a sharp-based unit characterized by lower gamma-ray and higher resistivity readings (Figs. 8 and 27). Gradationally-based coarsening-up signatures in the Notikewin Member are common throughout most of the southern study region. From map area 94-A-14 northeastward to 94-H-8, sharp-based sandstones are present, suggesting a northward lateral transition from a gradational-based highstand to an erosive-based lowstand deposit (Figs. 14a and 15).

The first indication of a relative sea-level fall marks the boundary between a highstand systems tract (HST) and the lowstand systems tract (LST) (Posamentier and Allen, 1999). These sharp-based sandstones reflect a fall in relative sea-level and thereby lowering of wave base, leading to the formation of a submarine erosion surface as waves

Figure 27: Example of a wireline well log from well C-047-G-094-H-02-0 illustrating the sharp-based signature of the Notikewin Member.

C-047-G-094-H-02-0

reworked previously deposited fine-grained deposits prior to deposition of the overlying shoreface deposits (Plint, 1988). North and westward, the unconformity becomes a conformity (Figs. 8a and 10a), reflecting greater water depths less affected by the sea-level fall. The northeast-southwest trend of wells with sharp-based lowstand deposits (Fig. 16), thus likely reflects the orientation of the highstand shoreline (Fig. 28a). Isopachs of the sandy lowstand deposits show a similar orientation (Fig. 13b).

The one available core C-61-J-94-H-3 located within the lowstand deposit consists of a coarsening up shaly siltstone to fine-grained sandstone with shale interbeds and 5-10 cm planar cross-bedding and minor bioturbation (Fig. 29). Abundant vertical burrows were observed in the finer-grained deposits and a surface demarcated by a *Glossifungites* ichnofacies was observed near the top of the sandstone, coinciding with the transgressive surface TS9. Rip-up clasts and frequent cross bedding indicate traction currents and possible deposition within a tidally influenced incised estuarine/lagoonal environment (Fig. 29). The log expression of this core is not representative of all wells within this lowstand environment, so that neighbouring shoreface facies may be present. In addition, this stratigraphic interval might represent a composite of several lowstands. The observed estuary fill, however, suggests that landward there was subaerial exposure (Fig. 28b), which might have resulted in considerable erosion of the upper Notikewin strata. Landward, marine shales associated with transgression of the Hulcross Sea overlie Notikewin sediments. Without additional core, no significant evidence of incised valleys can be positively identified landward of the sharp-based lowstand deposits on wireline logs. However, if they were present, erosion associated with subaerial exposure and

Figure 28a: Paleogeographic map illustrating the distribution of sediment along the eastern flank of the foredeep during Notikewin highstand. Arrow indicates possible northeast direction of paleoceanographic circulation.

Figure 28b: Paleogeographic maps illustrating the distribution of sediment along the eastern flank of the foredeep during Notikewin lowstand prior to the inundation of the Hulcross/Harmon Sea. Arrow indicates possible northeast direction of paleoceanographic circulation.

Figure 29: Description of core C-61-J-94-H-3 located within the Notikewin attached composite lowstand deposit. Note the *Glossifungites* ichnofacies, demarcating transgressive surface TS9. Rip-up clasts and frequent cross bedding indicate traction currents and possible deposition within a tidally influenced incised estuarine/lagoonal environment. This core illustrates a localized feature and as indicated by log signatures is not a representation of all wells within the lowstand deposit.

subsequent transgression may have reworked and removed additional lowstand deposits, evidence of incision, and possibly also parts of the Notikewin highstand sediments.

Regional north-south correlations by Dixon (1999, his Fig. 39) show the presence of an unconformity between two coarsening-up cycles in the Notikewin Member, south of well Hun d-13-C. Northward of Hun d-13-C this unconformity becomes the top of the Notikewin and major transgressive surface of the Hulcross/Harmon Sea. The disappearance of the top cycle can either be interpreted as being the result of complete erosion or a more southern pinch-out of the upper sandstone compared to the lower one. North of Beatton d-14-L, Dixon's (1999) correlation with the base of the here described sharp-based attached lowstand sandstone, supports my interpretation of a sequence boundary dividing highstand and lowstand deposits (Figs. 14a and 15). Jackson (1984) mapped this lowstand deposit as Notikewin-equivalent turbidite deposits. As demonstrated here, sedimentological observations, stratigraphic architecture and the lack of significant paleo-relief suggests these sharp-based sandstones were deposited as attached lowstand shoreface deposits. Cant (1996) likewise referred to Jackson's observation as a major lowstand body.

Numerous studies have described similar sandy lowstand deposits encased in mudstones and shales, detached and isolated from underlying sandy highstand facies (e.g. Snedden and Bergman, 1999). These detached lowstand facies commonly occur with the onset of rapid sea-level fall or forced regression (e.g. Plint, 1988; Posamentier et al., 1992; Posamentier and Allen, 1999; Hunt and Gawthrope, 2000). Recent studies (Pattison, 1994; Ainsworth and Pattison, 1995; Ainsworth et al., 2000) show that interactions between subsidence, eustasy and sediment supply can significantly affect

whether a forced regressive shoreface will be attached or detached. North of township 82, correlations of the combined Notikewin highstand/lowstand sandstones are uninterrupted until the unit shales-out into northern offshore Buckingham Formation at township 99 (Fig. 8). North of township 99 no sharp-based sandstones, time-equivalent to the Notikewin lowstand deposit were observed (Schröder-Adams and Pedersen, in press). With no evidence indicating a detached system, yet given the observation of sharp-based log signatures, I suggest that the northern sandy facies of the Notikewin Member is likely an attached lowstand system (Figs. 13b, 14a and 15). Similar attached lowstand systems have been described by Ainsworth and Pattison, (1994) and Pattison (1995), in contrast to the more commonly described detached lowstand systems tract (e.g. Snedden and Bergman, 1999).

Previously published studies have limited their paleoenvironmental interpretations and facies distribution of the Notikewin Member in northeastern British Columbia to south of the Peace River, and interpret sandstone occurrences in the region north of township 80 to be offshore bars within a distal marine setting e.g. (Smith et al., 1984) or turbidite deposits (Jackson, 1984). I propose that during Notikewin highstand time, a shallow marine environment persisted north of the Peace River to township 98. Distal offshore marine shale facies were further north, particularly in the region along the British Columbia/Alberta border, and northwest to 94-H-7 (Figs. 13a and 28a). However, a relative fall in sea-level prior to the inundation of the Harmon/Hulcross sea resulted in sediment being transported even farther north, deposited as composite lowstand sands as far north as township 99 and northwest to map sheet 94-H-6 (Figs. 13b and 28b). During the lowstand period, the coastal plain likely moved northward. However, any evidence of

its presence was likely eroded during the transgression of the Harmon/Hulcross Sea. The highstand deposits were likely subaerially exposed during this period of lowstand. Within the foredeep, however, during this lowstand period, offshore marine conditions prevailed west of range 25, preserved as mudstones of the Buckinghorse Formation.

The second major phase of transgression during the Albian was the incursion of the Hulcross Sea from the north. This transgressive surface is most distinct in regions proximal to the Notikewin shorelines. In the northern and western distal setting, however, the transgressive event is less distinct, where distal Hulcross/Harmon sediments overlie the distal Moosebar sediments (Fig. 14). Correlations by Dixon (1999) show a variable thickness of the Harmon strata in the subsurface, due to downcutting of the unconformity between the Cadotte and Paddy members, partially eroding the Harmon Member.

Sequence 3 was deposited during the transgression of the Joli Fou Seaway. The extent and western margin of this narrow seaway in the Peace River region is not well documented as this marine phase has previously been lumped into the Shaftesbury marine cycle, encompassing both the Joli Fou and Mowry cycles (Leckie et al., 1990a; Leckie and Singh, 1991). Foraminiferal studies by Stelck and Leckie (1990) of the Paddy Member underlying the Shaftesbury Formation in the Goodfare area of western Alberta found a transitional change within the member from a *Haplophragmoides gigas* to a *Miliammina manitobensis* faunal composition. This indicates that both transgressions have contributed to the sedimentary valley fill. Along the Peace River close to Hudson Hope, Boulder Creek/Cadotte strata outcrop at the surface, and therefore no Joli Fou and younger sediments are preserved here.

I distinguish the bounding surfaces of the Joli Fou cycle based on a distinct decrease in resistivity. These picks tend to be more reliable in the western foredeep within overall fine-grained sediments (Fig. 12b). Towards the eastern margin of the foredeep (Fig. 8a), where more quartz is present, these surfaces become obscured (Rider, 1996). Where distinct, an eastward thinning of the Joli Fou sequence can be observed. Along the eastern margin of the foredeep in northerly direction Joli Fou strata cannot be distinguished from underlying Harmon strata. Yet, a radioactive condensed section distinctly marks the base of overlying Mowry strata, which also marks the top of the Joli Fou sequence. In contrast, that marker disappears in deeper settings of the foredeep to the west (Figs. 10, 12a, 14, 15). In the area of Peace River town this gamma ray kick, overlying the Paddy transgressive valley fill, is interpreted as being the result of a restricted, organic rich, marginal marine shale, related to the Mowry Sea transgression (Leckie and Singh, 1991). It appears here that this shale indicating marginal marine conditions persists northwards to quite an extent, but only along the eastern margin of the foredeep, whereas in the foredeep itself the lowering of sea level separating the Joli Fou from the Mowry marine incursion is expressed as increased flux of quartz components. Although it is interesting to note that associated with the Viking marker bed within the Buckinghorse Formation along the Sikanni Chief River and therefore in the western foredeep, a black shale was recognized bearing a foraminiferal assemblage of lower abundance and lower diversity compared to underlying and overlying strata (Schröder-Adams and Pedersen, in press). This black shale might indicate that restricted shallow marine conditions even existed at this western location. As sea level continued to rise during early Mowry Sea time maximum flooding finally drowned the shallow marine

setting along the eastern margin of the foredeep. Maximum flooding, expressed by a resistivity decrease and gamma ray increase, is correlatable from east to west likely reflecting a condensed interval (Fig. 12a).

The top boundary of sequence 4 is the Fish Scales Marker Bed, representing a basinwide lowstand event, terminating the Mowry Sea phase (Leckie et al., 2000). Correlations of sequence 4 throughout the study area, however, are partly hindered by erosion of Mowry Sea strata in the Peace River valley. In the northern region, increased accommodation space in the western foredeep and a new sediment source in the northwest resulted in deposition of thick Mowry successions, which thin in an easterly direction. The Bougie and Sikanni deltas became a northern source of abundant clastic input (Pedersen and Schröder-Adams, 2001; Jowett and Schröder-Adams, 2002) and added thick upper offshore to lower shoreface sediments in the Trutch region (Schröder-Adams and Pedersen, in press).

8.0 Conclusions

Strata deposited during the Albian stage in northeastern British Columbia can be regionally correlated showing a transition from proximal nearshore settings in the south to distal offshore settings in the north and western foredeep. Four major phases of marine transgression are preserved within the various strata of the Albian Fort St. John Group, which are in ascending order the Moosebar/Clearwater Sea, Hulcross/Harmon Sea, Joli Fou Seaway, and Mowry Sea. Each of the marine sequences can be traced regionally. Log signatures within the western foredeep north of the Peace River indicate a dominantly marine shale and mudstone lithology throughout the Albian, whereas

sandstones persist in northern direction along the eastern margin of the foredeep. Transgressive surfaces recognized on logs become increasingly indistinct in the western foredeep, where the previous lowstands and subsequent transgression are recognized mainly by subtle resistivity changes. Regional wireline cross-sections show a northward extension of the Falher and Notikewin members, and the presence of an attached Notikewin lowstand deposit at 94-H and the northern portion of 94-A, with evidence of incision. The latter indicates a fall in relative sea-level prior to the transgression of the Hulcross/Harmon Sea exposing the area south of this lowstand to subaerial erosion. The northward progradation of the Notikewin and Falher clastic wedges is likely related to a combined effect: 1) less accommodation space; 2) counterclockwise circulation, resulting in east and northward transport of Falher and Notikewin delta front deposits; and 3) possible focus of ocean currents along the eastern side of the foredeep. Another mechanism for the northward transport of the Falher and Notikewin sands might be the lateral redistribution of sands across the shelf from a point source. Due to the shallow nature of the shelf, wave orbitals were able to lift sediment back into suspension (Rice, 1984), where currents could transport them a significant distance from where the sediments were initially deposited by the prograding Falher and Notikewin deltas.

Up section, shallower marine conditions bordering the western foredeep seem to persist northwards throughout deposition of middle to upper Albian sequences. A high gamma-ray marker resulting from radioactive marginal marine shale on top of the Paddy Member is remarkably persistent in its expression along the eastern foredeep margin in northerly direction. Core with micropaleontological analysis would be needed to resolve the northern nature of this shale. During late Albian time the sediment source switched to

a northwestern location filling western accommodation space and depositing four stacked shoreface units of the Sikanni Formation in the northwest.

References

- Ainsworth, R.B., H. Bosscher, and Newall, M.J. 2000. Forward stratigraphic modelling of forced regressions: evidence for the genesis of attached and detached lowstand systems. In: *Sedimentary Response to Forced Regressions*. D. Hunt, and R.L. Gawthrope (eds.). Geological Society of London Special Publication, p. 163-176.
- Ainsworth, R.B., and Pattison, S.A.J. 1994. Where have all the lowstands gone? Evidence for attached lowstand systems tracts in the Western Interior of North America. *Geology*, v. 22, p. 415-418.
- Armitage, I., Pemberton, S.G., and Moslow, T.F. 2002. Facies Architecture and High-resolution Sequence Stratigraphy of the Falher "C" Member, Spirit River Formation, Deep Basin, Westcentral Alberta, Canada. *Canadian Society of Petroleum Geologists Abstracts*, p. 1-16.
- Arnott, R.W.C. 1993. Sedimentological and sequence stratigraphic model of the Falher "D" Pool, Lower Cretaceous, northwestern Alberta. *Bulletin of Canadian Petroleum Geology*, v. 41, p. 453-463.
- Beaumont, C. 1981. Foreland basins. *Geophysical Journal of the Royal Astronomical Society*, v. 41, p. 453-463
- Bloch, J. 1990. Stable isotopic composition of authigenic carbonates from the Albian Harmon Member (Peace River Formation) evidence of early diagenetic processes. *Bulletin of Canadian Petroleum Geology*, v. 38, p. 39-52.

- Caldwell, W.G. E. 1984. Early Cretaceous transgressions and regressions in the southern Interior Plains. In: *The Mesozoic of Middle North America*. D.F. Stott, and D.J. Glass, (eds.). Canadian Society of Petroleum Geologists, p. 173-203.
- Cant, D.J. 1984. Development of shoreline-shelf sand bodies in a Cretaceous epeiric sea deposits. *Journal of Sedimentary Petrology*, v. 54, p. 541-556.
- Cant, D.J. 1988. Regional structure and development of the Peace River Arch, Alberta: a Paleozoic failed rift system? *Bulletin of Canadian Petroleum Geology*, v. 36, p. 284-295.
- Cant, D.J. 1995. Sequence stratigraphic analysis of individual depositional successions. Effects of marine/nonmarine sediment partitioning and longitudinal sediment transport, Mannville Group, Alberta Foreland Basin. *American Association of Petroleum Geologists*, v. 79, p. 749-762.
- Cant, D.J. 1996. Sedimentological and sequence stratigraphic organization of a foreland clastic wedge, Mannville Group, Western Canada Basin. *Journal of Sedimentary Research*, v. 66, p. 1137-1147.
- Cant, D.J. 1998. Subsurface Facies Analysis. In: *Facies Models Response to Sea Level Changes*. R.G. Walker, and N.P. James, (eds.). Geological Association of Canada, p. 27-45.
- Cant, D.J., and Abrahamson, B. 1996. Regional distribution and internal stratigraphy of the Lower Mannville. *Bulletin of Canadian Petroleum Geology*, v. 44, p. 508-529.
- Carmichael, S.M.M. 1988. Linear estuarine conglomerate bodies formed during a mid-Albian marine transgression; "Upper Gates" Formation, Rocky Mountain Foothills of northeastern British Columbia. In: *Sequence, Stratigraphy,*

- Sedimentology. Surface and Subsurface. D.P. James, and D.A. Leckie, (eds.). Canadian Society of Petroleum Geologists Memoir 15, p. 49-62.
- Casas, J.E., and Walker, R.G. 1997. Sedimentology and depositional history of Units C and D of the Falher Member, Spirit River Formation, west-central Alberta. Bulletin of Canadian Petroleum Geology, v. 45, p. 218-238.
- Cecile, M.P., Khudoley, A.K., and Currie, L.D. 2000. Composite Geological Map of Marion Lake (94G/3), Mount Withrow (94G/6) and Minaker River (94G/11) northeastern British Columbia. Geological Survey of Canada Open File 3879, scale 1:50 000
- Chen, D., and Bergman, K. 1999. Stratal reorientation, depositional processes, and sequence evolution of the Cretaceous in the Peace River Arch region of the Western Canada Sedimentary Basin. Bulletin of Canadian Petroleum Geology, v. 47, p. 594-620.
- Dixon, J. 1999. Mesozoic-Cenozoic Stratigraphy of the Northern Interior Plains and Plateaux, Northwest Territories. Geological Survey of Canada, v. Bulletin 536. pp. 56.
- Embry, A.F. 1995. Sequence boundaries and sequence hierarchies: problems and proposals. In: Sequence Stratigraphy on the Northwest European Margin, R.J. Steel, V.L. Felt, E.P. Johannessen, and C. Mathieu (eds.). Norwegian Petroleum Society Conference Special Publication No. 5, p. 1-11.
- Fermor, P.R., and Moffat, I.W. 1992. Tectonics and structure of western Canada foreland basin. In: Foreland Basins and Foldbelts. R.W. Macqueen and D.A. Leckie, (eds.). American Association of Petroleum Geologists Memoir 55, p. 81-105

- Foscolos, A.E., and Sott, D.F. 1975. Degree of diagenesis, stratigraphic correlations and potential sediment sources of Lower Cretaceous shale of northeastern British Columbia. Geological Survey of Canada v. Bulletin 250. pp. 46.
- Gibson, D.W. 1992. Stratigraphy and sedimentology of the Lower Cretaceous Hulcross and Boulder Creek Formations, Northeastern British Columbia. Geological Survey of Canada, v. Bulletin 440. pp. 111.
- Hayes, B.J.R., Christopher, J.E., Rosenthal L., Los, G., and McKercher, B. 1994. Cretaceous Mannville Group of the Western Canada Sedimentary Basin. In: Geological Atlas of the Western Canada Sedimentary Basin. G. Mossop, and I. Shelsen, (eds.). Canadian Society of Petroleum Geologists, Alberta Research Council, Alberta Geological Survey, p. 317-334.
- Hobbs, T.W., and MacEachern, J.A. 2002. Along-strike variations in the Falher A and basal Notikewin Members, Fort St. John Group of West-Central Alberta and NE British Columbia: Integrated ichnological-sedimentological models in a sequence stratigraphic Framework. Canadian Society of Petroleum Geologists Core Conference 2002, Calgary Alberta.
- Hunt, D., and Gawthrope, R.L. 2000. Sedimentary Response to Forced Regressions. Geological Society of London Special Publication No. 172, pp. 383
- Jackson, P. 1984. Paleogeography of the Lower Cretaceous Mannville Group of Western Canada. In: Elmworth Case Study of a Deep Basin Gas Field. J. A. Masters, (ed.). Tulsa, American Association of Petroleum Geologists Memoir 38, p. 79-114.
- Jervey, M.T. 1992. Siliciclastic sequence development in foreland basins with examples from the Western Canada Foreland Basin. In: Foreland Basins and Foldbelts.

- R.W. Macqueen, and D.A. Leckie (eds.). Tulsa, American Association of Petroleum Geologists Memoir 55, p. 9-14.
- Jowett, D.M.S., Schröder-Adams, C.J. 2002. Proximal and Distal Expression and Sequences of the Sikanni Formation in the Liard Basin. Canadian Society of Petroleum Geologists, Conference 2002, Calgary Alberta.
- Kauffman, E.G. 1977. Geological and biological overview, Western Interior Cretaceous Basin: *The Mountain Geologist*, v. 14, p. 75-99.
- Kauffman, E.G. 1984. Paleobiogeography and evolutionary response dynamic in the Cretaceous Western Interior Seaway of North America. In: *Jurassic-Cretaceous Biochronology and Paleogeography of North America* G.E.G. Westermann (ed.). Geological Association of Canada, p. 273-306.
- Koke, K.R., and Stelck, C.R. 1985. Foraminifera of a Joli Fou shale equivalent in the Lower Cretaceous (Albian) Hasler Formation, northeastern British Columbia. *Canadian Journal of Earth Sciences*, v. 22, p. 1299-1313.
- Leckie, D. 1985. The Lower Cretaceous Notikewin Member (Fort St. John Group), Northeastern British Columbia: A progradational barrier island system. *Bulletin of Canadian Petroleum Geology*, v. 33, p. 39-51.
- Leckie, D. 1986. Rates, controls, and sand-body geometries of transgressive-regressive cycles: Cretaceous Moosebar and Gates Formations, British Columbia. *American Association of Petroleum of Geologists Bulletin*, v. 70, p. 516-535.
- Leckie, D.A., and Potocki, D. 1998. Sedimentology and petrography of marine shelf sandstones of the Cretaceous Scatter and Garbutt formations, Liard Basin, northern Canada. *Bulletin of Canadian Petroleum Geology*, v. 46, p. 30-50.

- Leckie, D.A., Schröder-Adams, C.J. and Bloch, J. 2000. The effect of paleotopography on the late Albian and Cenomanian sea-level record of the Canadian Cretaceous interior seaway. Geological Association of America, Bulletin 112, p. 1179-1198.
- Leckie, D.A., and Singh, C. 1991. Estuarine deposits of the Albian Paddy Member (Peace River Formation) and lowermost Shaftesbury Formation, Alberta Canada. Journal of Sedimentary Petrology, v. 61, p. 825-849.
- Leckie, D.A., Singh, C., Goodarzi, F., and Wall, J. 1990a. Organic-rich, radioactive marine shale: A case study of a shallow-water condensed section, Cretaceous Shaftesbury Formation, Alberta, Canada. Journal of Sedimentary Research, v. 60, p. 101-117.
- Leckie, D.A., and Smith, D.G. 1992. Regional Setting, Evolution, and Depositional Cycles of the Western Canada Foreland Basin. In: Foreland Basins and Foldbelts. R.W. Macqueen, and D.A. Leckie, (eds.). Tulsa, Oklahoma, American Association of Petroleum Geologists Memoir 55, p. 9-14.
- Leckie, D.A., Staniland, M.R., and Hayes, B.J. 1990b. Regional maps of the Albian Peace River and lower Shaftesbury formations on the Peace River Arch, northwestern Alberta and northeastern British Columbia. Bulletin of Canadian Petroleum Geology, v. 38A, p. 176-189.
- Leckie, D.A., and Walker, R.G. 1982. Storm- and tide-dominated shorelines in Cretaceous Moosebar-Lower Gates interval-Outcrop equivalents of deep basin gas trap in Western Canada. American Association of Petroleum Geologists Bulletin, v. 66. p. 138-157.

- MacDonald, D.E., Langenberg, C.W., and Strobl, R.S. 1988. Cyclic Marine Sedimentation in the Lower Cretaceous Luscar Group and Spirit River Formation of the Alberta Foothills and Deep Basin. In: Sequences, Stratigraphy, Sedimentology: Surface and Subsurface. D.P. James, and D.A. Leckie (eds.). Canadian Society of Petroleum Geologists Memoir 15, p. 143-154.
- Masters, J.A. 1984. Elsworth Case Study of a Deep Basin Gas Field. Tulsa, American Association of Petroleum Geologists Memoir 38, pp. 316.
- McMechan, M.E. 1990. Upper Proterozoic to Middle Cambrian history of the Peace River Arch: evidence from the Rocky Mountains. Bulletin of Canadian Petroleum Geology, v. 38A, p. 36-44.
- Obradovich, J.D. 1993. A Cretaceous Time Scale. In: Evolution of the Western Interior Basin. W.G.E. Caldwell, and E.G. Kauffman (eds.). Geological Association of Canada Special Paper 39, p. 379-396.
- O'Connell, S., Dix, G.R., and Barclay, J.E. 1990. The origin, history, and regional structural development of the Peace River Arch, Western Canada. Bulletin of Canadian Petroleum Geology, v. 38A, p. 4-24.
- Pattison, S.A.J. 1995. Sequence stratigraphic significance of sharp-based lowstand shoreface deposits, Kenilworth Member, Book Cliffs, Utah. American Association of Petroleum Geologist Bulletin, v. 79, p. 444-462.
- Pedersen, P.K. 2001. Depositional environment and sequence architecture of the new Cretaceous gas bearing Bougie sandstone member, Northeastern British Columbia. Canadian Society of Petroleum Geologists, 2001 Conference Abstracts, p. 059-1.

- Plint, A.G., 1988. Sharp-based shoreface sequences and "offshore bars" in the Cardium Formation of Alberta: Their relationship to relative changes in sea level. In: *Sea-Level Changes: An Integrated Approach*. C.K. Wilgus, B.S. Hastings, C.G. Kendall, H.W. Posamentier, C.A. Ross, and J.C. Van Wagoner (eds.). Society of Economic Paleontologists and Mineralogists, p. 357-370.
- Posamentier, H.W., and Allen, G.P. 1999. Siliciclastic Sequence Stratigraphy - Concepts and Applications. *SEPM Concepts in Sedimentology and Paleontology* #7, v. 7, Society for Sedimentary Geology, 210 p.
- Posamentier, H. W., Allen, G. P., James, D. P., and Tesson, M., 1992. Forced Regression in a Sequence Stratigraphic Framework: Concepts, Examples, and Exploration Significance. *American Association of Petroleum Geologists Bulletin*, v. 76.
- Rahmani, R.H., and Smith, D.G. 1988. The Cadotte Member of northwestern Alberta; a high-energy barred shoreline. In: *Sequences, Stratigraphy, Sedimentology: Surface and Subsurface*. D.P. James, and D.A. Leckie, (eds.). Canadian Society of Petroleum Geologists Memoir 15, p. 431-437.
- Rice, D. 1984. Widespread, shallow-marine, storm-generated sandstone units in the Upper Cretaceous Mosby Sandstone, central Montana. In: *Siliciclastic Shelf Sediments*. R. W. Tillman and C. T. Siemers, (eds.). Society of Economic Paleontologists and Mineralogists, Special Publication 34, p 143-161.
- Rider, M. 1996. *The Geological Interpretation of Well Logs*. Second Edition Whittles Publishing pp. 280.
- Rouble, R., and Walker, R G. 1997. Sedimentology, high-resolution allostratigraphy, and key stratigraphic surfaces in Falher Members A and B, Spirit River Formation,

- west-central Alberta. In: Petroleum Geology of the Cretaceous Mannville Group, western Canada. S.G. Pemberton, and D.P. James (eds.). Canadian Society of Petroleum Geologists Memoir 18, p. 1-28.
- Schröder-Adams, C.J., and Pedersen, P.K., in press. Litho- and biofacies analysis of the Buckinghorse Formation: The Albian Western Interior Sea in Northeastern British Columbia (Canada). Canadian Society of Petroleum Geologists Bulletin.
- Smith, D.G., Zorn, C.E., and Sneider, R.M. 1984. The Paleogeography of the Lower Cretaceous of Western Alberta and Northeastern British Columbia in and Adjacent to the Deep Basin of the Elmworth Area In: Elmworth Case Study of a Deep Basin Gas Field. J.A. Masters, (ed.). Tulsa, Oklahoma, American Association of Petroleum Geologists Memoir 38, p. 79-114.
- Snedden, J. W. and Bergman, K. M. 1999. Isolated shallow marine sand bodies: deposits for all interpretations. In: Isolated Shallow Marine Sand Bodies: Sequence Stratigraphic Analysis and Sedimentologic Interpretation. Bergman K.M. and Snedden J.W. (eds.) SEPM Special Publication No. 64 pp. 1-11.
- Stelck, C.R. 1975. The upper Albian *Miliammina Manitobensis* zone in northeastern British Columbia In: The Cretaceous System in the Western Interior of North America. Caldwell, W.G.E. (ed.). Geological Association of Canada, Special Paper 13. p. 253-275
- Stelck, C.R., and Hedinger, A.S. 1983. Foraminifera of the lower part of the Sully Formation (upper Albian), northeastern British Columbia. Canadian Journal of Earth Sciences, v. 20, p. 1248-1259.

- Stelck, C.R., and Koke, K.R. 1987. Foraminiferal zonation of the Viking interval in the Hasler Shale (Albian), northeastern British Columbia. *Canadian Journal of Earth Sciences*, v. 24, p. 2254-2278.
- Stelck, C.R., and Leckie, D.A. 1990a. Biostratigraphy constraints and depositional environment of the Lower Cretaceous (Albian) Boulder Creek Formation, Monkman area, northeastern British Columbia. *Canadian Journal of Earth Sciences*, v. 27, p. 452-458.
- Stelck, C.R., and Leckie, D.A. 1990b. Biostratigraphy of the Albian Paddy Member (Lower Cretaceous Peace River Formation), Goodfare, Alberta: *Canadian Journal of Earth Sciences*, v. 27, p. 1159-1169.
- Stelck, C.R., and MacEachern, J.A., and Pemberton, S.G. 2000. A calcareous foraminiferal faunule from the upper Albian Viking Formation of the Giroux Lake and Kaybob North field, northwestern Alberta: implications for regional biostratigraphic correlation. *Canadian Journal of Earth Sciences*, v. 37, p. 1389-1410.
- Stott, D.F. 1968. The Lower Cretaceous Bullhead and Fort St. John Groups, Between Smoky and Peace Rivers, Rocky Mountain Foothills, Alberta and British Columbia. *Geological Survey of Canada Bulletin* v.152, pp. 279.
- Stott, D.F. 1982. Lower Cretaceous Fort St. John Group and Upper Cretaceous Dunvegan Formation of the foothills and plains of Alberta, British Columbia, District of MacKenzie and Yukon Territory. *Geological Survey of Canada*, v. Bulletin 328. pp. 124.

- Stott, D.F. 1984. Cretaceous Sequences of the Foothills of the Canadian Rocky Mountains. In: The Mesozoic of Middle North America. D.F. Stott, and D.J. Glass, (eds.). Canadian Society of Petroleum Geologists Memoir 9, p. 85-107.
- Stott, D.F. 1993. Evolution of Cretaceous Foredeeps: A Comparative Analysis Along the Length of the Canadian Rocky Mountains. In: Evolution of the Western Interior Basin. W.G.E. Caldwell, and E.G. Kauffman, (eds.). Geological Association of Canada, p. 131-150.
- Stott, D.F., Caldwell, W.G.E., Cant, D.J., Christopher, J.E., Dixon, J., Koster, E. H., McNeil, D. H., and Simpson, F. 1993. Cretaceous; Subchapter 4I, In: Sedimentary Cover of the Craton in Canada. D.F. Stott, and J.D. Aitken, (eds.). Geological Survey of Canada, p. 358-438.
- Stritch, R.A., and Schröder-Adams, C.J. 1999. Foraminiferal response to Albian relative sea-level changes in northwestern and central Alberta. Canadian Journal of Earth Sciences, v. 36, p. 1617-1643.
- Wickenden, R.T.D., and Shaw, G. 1943. Stratigraphy and structure in Mount Hulcross-Commotion Creek map-area, British Columbia. Geological Survey of Canada, Paper 43-13, p. 14.
- Williams, G.D., and Stelck, C.R. 1975. Speculations on the Cretaceous paleogeography of North America. In: The Cretaceous System in the Western Interior of North America. W.G.E Caldwell (ed.). Geological Association of Canada Special Paper, no. 13, p. 1-29.

Appendix A Outcrop and Core Descriptions

Outcrop locality PRC Peace River at 'The Gates'
 0573824E
 6217431N

Outcrop locality PRF Peace River
Canyon Dinosaur Lake
0559118E
6202468N

B-088-D-094-H-08-0

Appendix B Regional Cross-sections