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DEVONIAN FRASNIAN STRATIGRAPHY, ROCKY MOUNTAIN FRONT RANGES CROWSNEST PASS TO JASPER, ALBERTA

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ABSTRACT

Frasnian sedimentary rocks are exposed along the dolomitized Front Ranges of the Rocky Mountains of Alberta. Approximately 400 m. of variably dolomitized bank or reef carbonates and shale are equivalent to the Frasnian hydrocarbon reservoirs of the Alberta subsurface. A combination of surface sections and use of a helicopter as a stratigraphic tool reveals bank-to-basin relationtionships which have been obscured in part by the existing formation nomenclature.

The stratigraphy of these rocks can be understood in terms of a simplified carbonate model consisting of four distinctive rock suites:

1) inner detrital clastics with associated carbonates and evaporites,

2) shelf carbonates which include stomatoporoid-coral dominated banks and reefs,

3) slope and basin carbonates, a deeper water facies of the shelf carbonates, and

4) basin-fill including both bank-derived carbonate debris and siliciclastics derived from outside the basin.

Several large carbonate complexes with intervening basins are exposed along the Front Ranges. The margins of some complexes are characterized by bank-to-basin facies change, others by reciprocal sedimentation, or combinations of these two styles. The bank margins occur at increasingly higher statigraphic levels toward the northwest in response to prograding basin-fill.

Paleontological and biostratigraphic studies of the outcropping Frasnian succession have not kept pace with recent advances in stratigraphy. The majority of currently available works rely on brachiopods and corals which are most abundant in sediments proximal to the carbonate complexes. This has resulted in zonal schemes which are applicable to the basinal succession. Although conodonts are currently the most widely accepted of Frasnian index fossils, they have been only slightly studied within the project area.

The stratigraphic nomenclature within these rocks is defined by four basin-fill units, each of which is as much as 150 m. thick, onlaps the carbonate bank margins and presumably correlates with an unconformity upon the bank. The presently accepted formations are retained as facies units which occur within five depositional sequences, or cycles, which are assigned names derived from the Alberta subsurface. In ascending order, these are the Beaverhill Cycle; Leduc, Lower Cycle; Leduc, Upper Cycle; Nisku Cycle; and the Calmar-Blue Ridge Cycle.

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Note 2: Outcrop sections are available on computer disk.

INTRODUCTION

LOCATION

Frasnian sedimentary rocks are exposed within an elongate north-northwest trending rectangle, approximately 550 km long and a few tens of km wide in the southwestern part of the province of Alberta, Canada (Figs. 1, 2).

The Crowsnest Pass localities at the southern end of the area are separated from the remainder of the Devonian outcrops by more than 100 km with no Frasnian exposures. The more northerly outcrops occur mostly in the Front Ranges and a few Paleozoic inliers within the Foothills of the Rocky Mountains.

The study area extends from 49°,15'N, 114°30'W to 53°30'N, 119°W, (T. 5, R. 5 W5M to T. 52, R. 7 W6M). Because of limitations placed on sampling and helicopter access within Canada's National Parks, most of the documentation for this study is from east of Banff and Jasper Parks.

SCOPE OF THE STUDY

The major intent of the present account is to describe the stratigraphy of Frasnian rocks within the project area and relate these rocks to their subsurface equivalents. Preparation of the account has entailed interpreting more than 130 published, and 103 original surface sections, tracing beds between sections, a literature review including available paleontological information, preparation of a base map identifying surface control and correlation to the subsurface.

The study does not include an interpretation of the stratigraphy of the Main Ranges Devonian, detailed petrographic, geochemical or diagenetic analysis or interpretation. It is both an outgrowth and a composite of Workum (1983), Workum and Hedinger (1987) and various papers by the two authors included in CSPG Memoir 13 (1988).

ACCESSIBILITY

Highways, forestry roads and a variety of trails which are shown on available maps provide access to some of the surface sections. The majority of sections, however, are most easily and quickly reached by helicopter. This form of transportation may be obtained from several contractors located at a number of different bases in southwestern Alberta. Helicopters are especially useful in this sort of stratigraphic field work because they provide the ability to "fly out" or trace beds between sections, as well as locate the best exposures and provide access to them.

PREVIOUS WORK

Criteria for the selection of references on Devonian outcrops described in this section are quite subjective. Because of the large size of the area, and the number of workers who have published on various aspects of the Alberta Front Ranges, during a period of more than 100 years, only the works which treat particular areas in significant detail, or which attempt to interpret regional correlation are described. This is not a comprehensive compendium of all literature on the topic, but a general historical overview of some of the more important previous work.

There is some overlap between this description and the section on Evolution of Existing Stratigraphic Nomenclature. The major paleontological papers are described in Chapter IV. The order of the following references is chronological except, where several "significant" papers are by the same author, they are grouped with the first reference by that author.

McConnell (1887), while mapping in the vicinity of the Bow River, recognized two major Devonian units which he referred to as the "Intermediate Limestone", approximately 1 500 feet[1] thick; and the overlying resistant "Lower Banff Limestone", 600 to 800 feet thick. McConnell described and illustrated these two units as recognizable on several different thrust sheets in the Bow Valley area. These two fundamental Devonian units are recognizable throughout the study area.

Shimer (1926) working with faunas in the vicinity of Banff, Alberta, referred the 2 500 foot thick Devonian section beneath the Exshaw shale to the Minnewanka formation, recognizing an upper and a lower part. Although for regional mapping purposes it is useful to retain a unit for this interval, the name "Minnewanka" has fallen out of use and is considered obsolete.

Raymond (1930) reported on the geology of the Jasper Park area. This pioneering work was the result of the Harvard Summer School of Field Geology having studied "a section across the Rocky Mountains along the line of the Canadian National railway". Seven Devonian units were recognized by Raymond at Roche Miette. The Flume formation was defined as the lower 400 feet of "hard grey limestone and dolomite with fossils in the upper

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[1]In this historical overview, capitalization of such words as "formation" and units of thickness are consistent with their use in the reference cited.

part". The overlying 600 feet of "black fissile shale" was assigned to the Perdrix formation. The next two overlying units were combined into the Boule formation which was reported to consist of 400 feet of shaly fossiliferous limestone overlain by 1 200 feet of massive limestone. Beds of the "lower Boule" have been subsequently included in the Mount Hawk and Alexo formations; the "upper Boule" has become the Palliser Formation, and the term "Boule" is considered obsolete. The three overlying units attributed to the Devonian by Raymond consist of shale above the Palliser formation and older Devonian beds which have been repeated by thrust faults.

Beach (1943) mapped in the Moose Mountain and Morley areas to the southwest of Calgary, Alberta. Having "examined Devonian sections at widely separated localities ... in the eastern Rockies", Beach (ibid. p. 10 to 17) interpreted earlier work, named and defined the Fairholme and the overlying Palliser formations. Beach's Fairholme formation is the same as Shimer's Minnewanka formation (lower part), the Palliser being the "upper part". These two major units are the same as those previously recognized by McConnell (1887). Lithologies of the Fairholme formation and two measured sections were described (Beach, 1943).

deWit and McLaren (1950) described and interpreted a number of Devonian sections in the Rocky Mountains between Crowsnest Pass and Jasper, Alberta. This paper was the first significant published attempt to understand regional Devonian stratigraphic relationships in the Alberta Rockies. It was based on 19 separate localities, 9 of which are described in the text. The Fairholme formation of Beach (1943) was redefined to exclude the upper "silty strata" which were named the Alexo formation. The redefined Fairholme was described as composed of a Lower Member, less than 1 000 feet thick, characterized by light grey to black stromatoporoid-rich dolomite; and an Upper Member comprising a maximum thickness of 850 feet of more thinly bedded dolomite characterized by common "Disphyllum-type" corals. The term "Fairholme formation" was retained for the predominantly carbonate facies.

deWit and McLaren (ibid. p. 4, 5) accepted Raymond's (1930) Flume and Perdrix formations in the Jasper area, and introduced the name Mount Hawk formation for the overlying limestone, calcareous shale and siltstone which they correlated with the "upper member of the Fairholme formation". The paper described lithologies and faunas of the Upper Devonian, as well as economic aspects, reefs, and the difficulties in establishing surface to sub-surface correlations. The contrast between the massive carbonate sections to the south and the more recessive formations of the Jasper area was noted, but the nature of the stratigraphic relationships between them was not interpreted.

Fox (1951, reprinted with revisions in 1954) published on the same area as deWit and McLaren (1950). Whereas the latter work was primarily a stratigraphic study, Fox was more interested in "practical cartographic units" which were recognizable throughout the area. Previous geological work was described and interpreted. The terms

Fairholme and Palliser were used as originally defined by Beach (1943). In the basinal Jasper area, the Flume and Perdrix were used consistently with deWit and McLaren (ibid.), but rocks of the Alexo and Mount Hawk formations were combined within the Cheviot formation which consists of "thin-bedded, silty and argillaceous, fossiliferous limestone and dolomites lying directly above the Perdrix shale," and below the Palliser formation (Fox, 1951, p. 118). Fox recognized that within the Cheviot, the "upper faunal zone" was distinctly different from the "lower faunal zone". This faunal change coincides with the Frasnian - Famennian boundary as presently understood. In basinal areas where stratigraphic criteria for subdividing the upper part of the Fairholme Group are obscure, the term "Cheviot" is still useful; however, the name has not been generally accepted and at present is considered obsolete.

Fox's paper was based on 24 surface sections and observations from a number of other localities. It contains useful lithological and faunal information, and refers to several "reef" localities. Two diagrammatic cross sections (Fox, ibid. Figs. 3, 4) suggest that the change from dolomites of the Fairholme formation to the basinal formations is effected entirely by lateral facies change.

D.J. McLaren of the Geological Survey of Canada made significant contributions to understanding the Devonian stratigraphy of the Alberta Rocky Mountains. The most important of these works were McLaren (1953 and 1956); several papers co-authored with Belyea (1957a, 1957b); and with Mountjoy (1962). McLaren (1962) presents a zonation of the Upper Devonian based on rhynchonellid brachiopods.

McLaren's (1956) paper on Devonian formations in the Alberta Rocky Mountains between Bow and Athabasca Rivers remains the single most useful regional study on this topic. In this paper the Fairholme formation was raised to group status, and was applied to both the "carbonate" and the "clastic" sequences of the Frasnian portion of the Devonian. The Cairn and Southesk formations were defined as the lower and upper units of the Fairholme "carbonate" sequence. The Flume, Perdrix and Mount Hawk formations, from base to top, became the three components of the Fairholme "clastic" sequence. McLaren (ibid. p. 9 to 11) noted the lithological similarity between the various carbonate "developments", the difference between the "clastic" sequences in different areas, and the difficulties in applying formational nomenclature in transitional areas. The paper is illustrated with four regional stratigraphic cross-sections which correlate 26 surface sections. Nine of these are described in the appendix.

H.R. Belyea, a contemporary of McLaren with the Geological Survey of Canada, published many papers on the Alberta Devonian. Her work was mostly oriented towards the subsurface, but several papers, especially Belyea and McLaren (1956, 1957a and b), and Belyea (1958) primarily described surface exposures. Their 1956 paper described the Devonian of the Bow Valley area and attempted correlations to the subsurface. An outcrop section in the Canmore area (ibid. p. 78 to 83) was designated the type section for the Peechee, Grotto and Arcs members of the Southesk formation by Belyea and McLaren (1957a, p. 171, 172). Belyea's (1958) study consists of a similar analysis of outcrops with surface to subsurface correlations in the vicinity of the North Saskatchewan River. Belyea and McLaren (1957b) was a reply to Taylor (1957). Although some of Belyea's surface to subsurface correlations are probably correct, others are based only on a combination of superposition and lithological similarity which are demonstrably questionable criteria for correlation within the Devonian of this area.

Taylor (1957 and 1958), a geologist with Shell Oil Company, published on the Devonian of the area between Canmore and Jasper. Although his data base was similar to that of Belyea and McLaren (1956, 1957a and b), many of his conclusions were different. These differences outline many of the problems that still exist in Devonian bank-to-basin correlation. Some of Taylor's major observations are described under Bank-to-Basin Transitions.

The Flume formation of earlier workers was subdivided into a lower unit, (Flume formation revised) which correlates with the subsurface Beaverhill Lake Group, and an upper unit which Taylor (1957, p. 190) named the Maligne formation, and which he correlated with the Cooking Lake formation. Taylor correctly demonstrated that the boundary between the Cairn and Southesk formations is a facies contact that locally may range through several hundred feet of section. The subsurface Nisku formation was carried into the surface but was miscorrelated with a younger carbonate cycle (the Simla Member) in the Jasper area.

The major problem with Taylor's two papers is that he assumed that all differences between adjoining sections were exclusively the result of lateral facies changes. His lack of recognition of bank-to-basin reciprocal sedimentation[1] caused him to miscorrelate from the carbonate banks into both the Cline Channel and Jasper Basin.

Hargreaves (1959), traced the outcrop equivalents of the Nisku formation from the Bow to the Smoky River. His paper includes a Nisku lithofacies map, summarizes 37 stratigraphic sections, and contains many valuable data on Upper Devonian lithologies, faunas and correlation. Although his Nisku designation is valid southeast of the northern end of the Southesk Cairn Carbonate Complex (approximately Twp. 44), he miscorrelated the Nisku with younger beds of the Alexo Formation farther north and into the Jasper Basin.

McLaren and Mountjoy (1962) redefined the equivalents of the Alexo Formation in the region of Jasper, Alberta. The Alexo in this area was found to consist of two units, a lower interval of uppermost Frasnian age defined as

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[1]Described under Bank-to-Basin Transitions.

the Simla and Ronde Members of the Southesk Formation; and an upper unit of Famennian age, the Sassenach Formation. This differentiation was substantiated by both faunal and stratigraphic criteria. The subdivision of the Alexo is especially relevant in the Jasper Basin which was only partially infilled by the Frasnian Perdrix and Mount Hawk sediments, but was finally filled by the lower Famennian Sassenach Formation.

Price (1964 and 1965) produced the only significant work on the Devonian of the Flathead-Crowsnest Pass area of southern Alberta. The 1964 reference is a guidebook paper specifically on the Devonian, whereas the 1965 report is a Geological Survey of Canada Memoir. The Devonian outcrops of this area are more than 100 km from the nearest Devonian outcrops in the Front Ranges to the north; because of this lack of continuity, Price (1965) subdivided the lower part of the Fairholme Group into the basal Hollebeke Formation and the overlying Borsato Formation. Higher in the section he used the northern terminology of the Southesk Formation and its members, the Mount Hawk and "Sassenach" or Alexo Formations. Price (ibid.) suggests that the Hollebeke may correlate with the Flume or Beaverhill Lake Formation, and the Borsato with a portion of the Cairn Formation.

Mountjoy (1965) provided the most comprehensive study of the Miette reef complex and associated strata in the Jasper area. The report contains 15 measured surface sections and cross-sections.

Dooge (1966) described the stratigraphy of an Upper Devonian carbonate-shale transition between the North and South Ram Rivers, Alberta. The paper includes 17 stratigraphic sections, useful lithological and stratigraphic observations which led to the development of "the carbonate model" which is similar to that proposed by Wilson, (1975, p. 25 to 27, 350 to 360). Also included in the Dooge 1966 reference (p. 11 to 13, appendices 1 and 2) are the Upper Devonian faunal zones of southern Alberta, as defined by G.O. Raasch.

Woodhead and Wright-Broughton (1967) produced a map showing surface distribution of the Devonian in part of the Rocky Mountains with a palinspastic reconstruction in the disturbed belt. The map differentiates between "reef facies" and "off-reef facies" and incorporates both surface and subsurface control. It remains the most comprehensive published map of its kind, and was used to produce Map Figure 2 of the present report.

MacKenzie (1969) described the stratigraphy of the Southesk Cairn Carbonate Complex and associated strata, mostly dealing with lithology and stratigraphy of the northern and western margins and the interior of the complex. The report contains six stratigraphic sections and incorporates data from many other localities.

Noble (1970) and Cook (1972) added to the understanding of the Frasnian by studying the largely undolomitized Miette reef. Noble measured 28 stratigraphic sections and focused on lithologies and faunas within the Cairn Formation. Cook investigated the Flume platform beneath the Miette Carbonate Complex, its relationship to the underlying unconformity and its control on localization of the overlying carbonate bank. This work was based on 26 outcrop sections.

Because so much of the surface Devonian was profoundly altered during diagenesis, especially by dolomitization, these two papers give a unique insight into the original lithology of the Frasnian carbonate rocks.

Cook et al. (1972) described carbonate debris flows in front of three Devonian bank margins in the general Jasper area. The lithologies are described and methods of sediment transportation are discussed.

Mountjoy and MacKenzie (1974) described the southeast margin of the Ancient Wall Carbonate Complex carried on the Colin Thrust and located north of Jasper. The paper covers stratigraphy, lithologies and evolution of the complex which, like the Miette Complex, is largely undolomitized. Nine measured sections are provided. The authors proposed significant differential subsidence during the different depositional stages of the complex (Fig. 6). Beds that had previously been assigned to the Simla Member were reassigned to the Grotto and Arcs Members and the term Simla Member was abandoned (ibid. footnote [1], p. 5).

Coppold (1976), a student of Mountjoy, described the southern margin of Ancient Wall Carbonate Complex, where it is carried on the Chetamon Thrust. He followed Mountjoy's formation differentiation and emphasized the stratigraphy, lithology and diagenesis of the complex.

Mountjoy (1980) raised some interesting questions about the development of Upper Devonian carbonate buildups in western Canada. This paper addressed the correlation problems within the Southesk Formation between Miette and Ancient Wall Complexes, considered both outcrop and subsurface information, and concluded that there are many geological problems within the Devonian of Alberta which are still to be investigated.

Moore (1988) presented a regional synthesis of the Devonian of the western interior of Canada. He subdivided the Devonian into a number of discontinuity-bounded stratigraphic sequences each of which approximates a Stage, i.e. 5 to 15 m.y. The Frasnian of the present study is part of Moore's Beaverhill-Saskatchewan sequence. According to Moore, this sequence constitutes the Beaverhill Group, which consists of the Watt Mountain and Beaverhill Lake Formations; and the overlying Saskatchewan Group which extends upward to the base of the Famennian Palliser sequence.

Morrow and Geldsetzer (1988) provide a regional synthesis of the Devonian of the eastern Canadian Cordillera, from the U.S. border to the Arctic Ocean. The paper is a companion article to Moore (1988), and the two papers have considerable areal overlap. The Devonian was subdivided into a number of "assemblages" which approximate, or are subdivisions of, Moore's (1988) "sequences".

Within the area of the Alberta Rocky Mountains, Morrow and Geldsetzer (ibid.) recognized a Fairholme Assemblage, overlain in turn by the Graminia-Kakisa and the Palliser Assemblages. These Assemblages are readily recognizable and comparable to the depositional cycles defined in the present report.

GEOGRAPHY

The topography of the project area is dominated by a number of elongate ridges formed by thrust fault repetitions of resistant Paleozoic carbonate rocks, especially the Cambrian, Devonian and Mississippian, which stand in topographic relief above more recessive Paleozoic shales and Mesozoic clastic rocks. The northerly trend of these ridges in the southern part of the area turns toward approximately N.30°W. south of the Highwood River at about Twp. 15 (50°15'N. Lat.). Valley floors are generally about 1 500 m above sea level, whereas ridges are mostly in the 2 500 to 3 000 m range. Valleys are typically forested with coniferous and subsidiary deciduous trees. The elevation of tree line is quite variable depending on slope orientation, steepness and bedrock substrate, but generally occurs between 2 000 and 2 300 m. Slopes range from gentle to vertical and are mostly controlled by resistance to erosion of bedrock, structure and glaciation.

ACKNOWLEDGEMENTS

Many geologists have contributed to understanding the Devonain of the area by their publications, and they are referred to under the heading Previous Work. Amoco Canada Petroleum Company Ltd. supported some of the field investigations and released the outcrop sections which are part of the basis of this study. Parts of the project have benefited from critical reading by H.H. Geldsetzer, T.R. Marchant, I.D. Muir, G.E. Tebbutt and P.K. Wong. The study was partly funded by the Geological Survey of Canada.

CONCEPTS

CORRELATION

Correlation is defined as "the demonstration of correspondence between two geologic units in both some defined property and relative stratigraphic position," (North American Commission on Stratigraphic Nomenclature, 1983, p. 851). This definition implies that correlation may be based on different criteria, that, for example, a basal transgressive sandstone can be said to correlate throughout its areal extent.

The term "correlation" in the present study is synonymous with stratigraphic correlation, i.e. a stratigraphic unit correlates if stratigraphic continuity or equivalency can be demonstrated. This sort of correlation is not based on lithological or faunal similarity, or on abstract concepts of time, but on lateral continuity of bedding or bedding-related features, as well as stratigraphic position. Correlation within the Frasnian in this study is primarily established by recognizing the basic transgressive-regressive (T-R) cycles which controlled sedimentation.

Whether between outcrops or boreholes, stratigraphic correlations are generally illustrated, if not defined, by stratigraphic cross-sections. In constructing a cross-section, a datum is generally chosen, and columnar sections are plotted using true stratigraphic thickness for the vertical, and distance for the lateral component of the section. Both the selection of a suitable datum and use of true thickness can obscure stratigraphic correlation.

Stratigraphic relationships can best be illustrated on a cross-section of marine sedimentary rocks if a datum is chosen which approximates, or is parallel to, sea level; however, the stratigraphic relationships are only correct in close proximity to the datum. This is caused by three main variables; tectonics (i.e. differential subsidence), differential sedimentation and differential compaction.

The Frasnian within the study area is an unconformity-bounded depositional sequence comprising approximately 400 m of mostly marine sedimentary rocks. This fact suggests at least 400 m of subsidence and/or eustatic rise in sea level during the Frasnian. The thickness of some of the depositional cycles suggests that structure, in the form of differential subsidence, played a role in at least a portion of the observed transgression.

Excellent continuous outcrops give no hint of syndepositional faulting or recognizable folding during the Frasnian. However, the uppermost Frasnian (Calmar-Blue Ridge) depositional cycle, for example, thickens from a few metres to approximately 80 m from south to north. This northward thickening is accompanied by a facies change from restricted inner detrital to open marine sediments, which is at least partly attributable to a more rapid rate of subsidence in the north. Thus tectonics affected at least a portion of the Frasnian transgression. The unconformities above and below the Calmar-Blue Ridge Cycle on the carbonate buildups were each at, or parallel to sea level at the time they were formed, yet they are inclined relative to each other. If either of these unconformities is chosen as datum in a cross-section which uses true thickness for the vertical component, the other unconformity will be inclined, whereas it was not inclined during its development.

Differential sedimentation also obscures correlation on cross-sections. There is a tendency to correlate laterally, to assume that beds at the same elevation above or below a datum correlate. Examples of this sort of correlation are common in older work and exemplified in Taylor (1957, fig. 2). It is difficult to visualize that 150 m of bank carbonate may correlate with a few metres of basinal mudstone, or that an unconformity on a carbonate bank may correlate with more than 150 m of basin-fill, but these are in fact the kinds of relationships that characterize the transitions from carbonate banks into basinal settings.

Differential compaction refers to the observation that some sediment compacts more than other. Shale, because of dewatering; and lime mud, because of pressure solution and development of stylolites, have generally compacted more than dolomitized lime sand and gravel. This differential compaction can obscure correlation because it can induce post-depositional slopes that partly mask the successive geographies that evolved during the Frasnian.

CYCLES OF CYCLES OF CYCLES ...

One of the most striking aspects of the Paleozoic strata of the Front Ranges of the Rocky Mountains is that they are made up of distinctly bedded sedimentary rocks. A hierarchy of at least five different classes of cycles is recognizable.

(1) The three major Paleozoic cycles recognized are the Middle and Upper Cambrian, the Upper Devonian, and the Mississippian. Each of these represents 500 to 1 000 m of section, deposition during 15 to perhaps 50 m.y. and corresponds to a Period, a sequence of Sloss et al. (1949), or a "first order cycle" of Vail et al. (1977).

(2) The Upper Devonian may be further subdivided into two distinct cycles each of which is 200 to 450 m thick, and represents 5 to 10 m.y. Each of these is a group or a formation, the Fairholme and the Palliser which approximates a stage, the Frasnian and the Famennian, or a sequence (Moore, 1988). Each represents several biozones as defined by brachiopods, or by conodonts, and may correspond to a "second order cycle" of Vail et al. (ibid.).

(3) The Frasnian may be further subdivided into several cycles each of which is generally 30 to 100 m thick, represents less than 2 m.y., and equates with a formation or member. These correspond closely to the "T-R cycles" of Johnson et al. (1985) and perhaps the Vail "third order cycles". Each cycle may comprise a portion of one to perhaps a few biozones. The recognition and definition of this type of cycle is the major focus of the present study.

(4) The margins of several carbonate banks, or reefs, are characterized by lateral interfingering between bank and basin sediment. Where patch reefs are in close proximity to each other, individual tongues of carbonate extend laterally from reef to reef, suggesting that the tongues are not randomly shed off the reefs, but that they are controlled by episodic relative rises of sea level. These individual cycles are a fraction of a metre to perhaps 10 m thick, are mostly recognizable at the margins of banks, or reefs, and not obvious in bank interior or distal basin settings.

These cycles are beyond the resolution powers of seismic stratigraphy, and thus are not a major focus of Vail et al., (ibid.). These could be considered as "fourth order cycles". They represent a duration of thousands to perhaps a few tens of thousands of years. They are probably the thinnest cycles, which are unquestionably attributable to such extrinsic factors as tectonics and eustacy. Topographically high portions of the carbonate buildups may have been periodically exposed during the regressive phases of these cycles.

(5) The thinnest cycles observed are in the order of individual beds, which range from a few cm to a little more than 1 m thick and were probably deposited over hundreds to perhaps a few thousands of years. They are probably the same as "punctuated aggradational cycles" as summarized by Goodwin and Anderson (1985). These "fifth order cycles" are not obvious at bank margins, but are present both in bank interior and in basinal settings. Within the carbonate banks, they are common within the Peechee and Arcs Members, where they appear to represent thin upward shallowing cycles. The basinal Mount Hawk and Perdrix Formations are characterized by rhythmic alternations of limestone and argillaceous limestone or shale, (deWit and McLaren, 1950, p. 7), from a few cm to a few tens of cm thick. These cycles appear to represent fluctuations in the rate of carbonate sedimentation against a steady background rate of non-carbonate sediment settling out of suspension. Wong and Oldershaw (1980, p. 411) suggest that this sort of cyclicity within the Swan Hills Kaybob reef in the Alberta subsurface may be caused by variations in the rate of carbonate production" under conditions of steady subsidence and stable sea level". They also comment on the inability to correlate individual cycles within the reef, and the absence of expression of the cycles in the "peripheral reef buildup".

Whether these "fifth order cycles" are auto- or allocyclic cannot be definitively resolved at present. The relationship, if any, between the cycles on the bank and in the basin is an interesting speculation which is not considered in the present study.

The depositional patterns, and hence the stratigraphy, of the Frasnian within the study area are most easily understood in terms of recognizing the relationships between superimposed "third" and "fourth order" cycles.

THE CARBONATE MODEL

If an individual depositional cycle is traced from bank interior to basin, it is observed to change facies through several different lithologies. Recognition of this fact has led previous workers (e.g. Dooge, 1966, modified 1972; and Wilson, 1975) to develop carbonate models composed of facies belts which occur in a fairly predictable pattern. Dooge and Wilson recognized approximately 10 lithofacies that constitute the carbonate model.

Each of these similar models can be used to interpret the Frasnian of the project area, but they both have limitations when used for purposes of stratigraphic analyses. Diagenesis, especially dolomitization, has commonly obscured the original nature of the carbonate sediment. Furthermore, these models do not differentiate between basinal facies and basin-fill. For these reasons, a lithologically simplified model is used for purposes of stratigraphic analysis. This stratigraphic carbonate model recognizes four distinctive rock suites which are herein referred to as inner detrital, shelf carbonate, slope and basin, and basin-fill (Fig. 3). Figure 4 illustrates the stratigraphic relationships that may occur between two superimposed depositional sequences. The model is outlined and compared to the Dooge and Wilson classifications in Table 1. Representative lithologies are illustrated on Plates 1 and 2.

The inner detrital facies is composed of mixtures and interbeds of dolomite, clay, fine siliciclastics and solution collapse breccia which suggests that evaporites were probably originally present as well. These rocks are generally light-coloured and barren or include traces of algae, gastropods and ostracodes. The depositional environment of this facies alternated from supratidal to subtidal, and waters ranged from restricted hypersaline to brackish. In the study area, this facies only occurs within the upper depositional cycle. The lithology of this facies suggests that it bordered a land area which was the source of the siliciclastics and clay.

The shelf carbonate facies consists of a broad range of lithologies deposited as part of a carbonate buildup. Typically this facies is composed of bedded lime sand, mud and gravel and their dolomitized equivalents, but it also includes "reefs". The rocks are light or dark coloured, and the most typical fossils are stromatoporoids and corals. Inner shelves or lagoons are characterized by fine grained carbonates and the presence of Amphipora, outer shelves are typically dominated by larger and more robust stromatoporoids, and colonial corals which increase in abundance and diversity toward the top of the Frasnian. This facies was produced mostly in subtidal environments above wave base. Salinities ranged from slightly elevated above the dysaerobic inner shelves to normal on the well aereated outer shelves.

The slope and basin facies occurs on the flanks of, and between, the carbonate buildups. Slopes are of variable steepness ranging from a few m/km to more than 20°. Gently sloping ramps may consist of a full range of carbonate lithologies from shallow water sands to deep water carbonate muds. Steeper slopes comprise carbonate sands and gravels, and debris flows which can contain clasts in excess of 10 m in diameter. Bank-derived carbonate debris can be recognized several km basinward of its site of origin. At greater distances from carbonate buildups, the basin facies consists of bank-derived carbonate mud which settled out of suspension, wind blown dust, organic debris and planktonic fossils. The most common fossils found in the slope facies are corals, brachiopods and crinoids; tentaculitids characterize the basins. Upper slopes appear to have been approximately at fair weather wave base, lower slopes were dysaerobic to anaerobic/euxinic. Normal marine salinities prevailed. Not every shelf carbonate has an equivalent slope and basin facies. The distribution of this facies appears to have been locally controlled by a combination of slope angle and current direction.

	LITHOLOGY	DOMINANT FOSSILS	ENVIRONMENT	DOOGE 1966 ENVIRON-MENTAL FACIES	WILSON 1975 FACIES NUMBER
1. Inner detrital	Mixture of clay, siliciclastics, dolomite, evaporites, light colour.	Algae, gastropods, ostracodes or barren.	Restricted, intra- and supratidal, hypersaline to brackish.	7-10	8-9
2. Shelf carbonate	Bedded clean carbonate sand to mud, and "reefs".	Stromatoporoids corals.	Bank, shelf, reef, sub-tidal, semi-restricted to normal marine above wave base.	4-6	5-7
3. Slope and basin	Carbonate debris flows, mud, small bioherms.	Corals, brachiopods, crinoids, Receptaculites, tentaculitids.	Aerobic to anaerobic, at or below wave base, normal marine and restricted.	1-3	3-5
4. Basin-fill	Shale, detrital carbonate, lime mudstone.	Brachiopods, bryozoans, crinoids, fish, cephalopods, tentaculitids.	Dysaerobic to anaerobic, open marine to restricted.	not recognized	1-3

TABLE 1 The Carbonate Model

The basin-fill facies consists of two distinctly different lithologies. Carbonate debris was produced on the banks and transported off and downward into the adjoining basin. The basin-fill also includes clay and fine siliciclastics which were derived from outside the basin, and prograded in from the basin margin. More petrographic and geochemical work is required to document the nature of the basin-fill rocks. This is beyond the scope of this study. The basin-fill may include mixtures of these two sediment types. Brachiopods, crinoids, fish, bryozoans, cephalopods and conodonts are the characteristic fauna, especially of the terrigenous basin-fill. These organisms may have flourished in cooler marine waters which transported the extra-basinally sourced sediment into the basin from the north. The basin-fill is defined partly by lithological criteria, but mostly by the stratigraphic criterion that it onlaps the bank margin, and correlates with an unconformity on the bank. In general, the basin-fill units are the result of reciprocal sedimentation in that they were deposited during episodes of sea-level still-stand or regression. Salinities appear to have been mostly normal marine. Prolific brachiopod faunas occur locally in limy grey basin-fill shales and carbonates suggesting ideal conditions for these animals, however, some thick wedges of carbonate basin-fill appear to be barren. The environment appears to have evolved from normal to restricted marine both laterally and vertically within the individual basin-fill units.

Several workers (e.g. Weissenberger, 1988, p. 457; Weissenberger and McIlreath, 1988, p. 539; McLean and Sorauf, 1988, p. 385) attribute the argillaceous basin-fill to rising sea-level/transgression. Two significant lines of evidence argue against this interpretation; the argillaceous basin-fill onlaps but does not cover the tops of any of the large carbonate complexes. Also, as convincingly demonstrated by Stoakes (1980), Devonian sea-level rises resulted in carbonate sedimentation, whereas the extra-basinally sourced terrigenous sediment was only able to prograde into the basin during periods of sea-level still-stand or regression. The terrigenous sediments were presumably being produced during periods of sea-level rise, but were deposited in closer proximity to their extra-basinal source.

Although there is some degree of predictability in this sort of stratigraphic model, each bank margin is characterized by its own unique style. There is, however, a general tendency for the thicker basin-fill units to be younger from southeast to northwest, reflecting a gradual northwest progradation towards the Jasper Basin. This is shown diagrammatically on Figures 12 and 13.

TIME AND SEDIMENTATION

Aspects of time and rates of carbonate sedimentation have been discussed or summarized by Wilson (1975, p. 14 to 17), Mountjoy (1980, p. 332 to 340) and Sandberg et al. (1988, p. 183 to 201). Wilson (ibid. p. 15) concluded that modern rates of shallow water carbonate sedimentation range from 0.5 to 3+ m/1 000 years, with an average of 1 m/1 000 years. He commented that these known rates of modern carbonate sedimentation appear to be much more rapid than those of ancient rocks, which have average rates of 0.04 m/1 000 year, and concluded that carbonate sedimentation is characterized by fast but intermittent deposition. A similar conclusion was reached by Mountjoy (ibid.) in reference to the Upper Devonian of Western Canada.

Sandberg et al. (ibid. summarized in Table 1, p. 185) suggest that the Upper Devonian represents approximately 15 m.y., which comprises 5.2 m.y for the Frasnian and 9.8 m.y. for the Famennian. Combining the Wilson and Sandberg et al. numbers, and assuming continuous carbonate sedimentation, the 400 m Frasnian of the project area should have been deposited in less than 0.5 m.y., or conversely, the Frasnian of the area should be 5 000 m thick. The Frasnian of the project area could thus represent sedimentation during as little as 10% of Frasnian time.

Given the four Frasnian brachiopod zones of McLaren (1954, 1962), the eight conodont zones referred to by Sandberg et al. (1988, p. 183), or the twelve zones of the Raasch (in Dooge, 1966) zonal scheme, each Frasnian zone is seen to have a duration of approximately 0.5 to 1 m.y.

BANK-TO-BASIN TRANSITIONS

The 350 to 450 m thick Frasnian outcrop belt of the Rocky Mountain Front Ranges consist of some areas dominated by carbonate rocks, and intervening areas composed of alternations of carbonates and variably carbonate-rich shale. Since the 1950's, the thick carbonate masses which are characterized by stromatoporoids and corals have been recognized as reefs, reef complexes or banks; and areas of shaly rocks characterized by brachiopod faunas were correctly identified as off-reef areas, or basins.

The lateral changes from bank-to-basin are generally considered to be "facies changes", but when individual bank margins are examined, it is obvious that there are three fundamentally different types of margins which were formed by different processes; in this study these processes are referred to as lateral facies change, reciprocal sedimentation, and intertonguing. These three processes are not mutually exclusive, and an individual depositional cycle is not always characterized by a particular style of margin. The three types of transitions are described in the following section.

(1) Lateral facies change from bank-to-basin is defined as a lateral lithological change observable within a bed or a set of beds as it is traced laterally. The pattern of lateral facies changes is quite predictable and follows the sort of models proposed by Dooge (1966, p. 48 to 50, and Appendix 7) and Wilson (1975, p. 26, 351). The width of individual facies tracts can be quite variable and depends primarily on steepness of depositional slope and current direction. Lateral facies changes occur during periods of transgression and are commonly obscured by subsequent diagenesis, especially dolomitization.

(2) Reciprocal sedimentation characterizes bank-to-basin relationships at some margins, where bank carbonates terminate at the bank edge, and the laterally equivalent beds onlap, and are younger than the beds of the bank margin. These younger, basinally restricted beds are herein referred to as

"basin-fill". Within the study area, this basin-fill is mostly composed of bank-derived detrital carbonate, or extrabasinally derived clay and silt, or mixtures of these two fundamentally different types of sediment intermixed with variable amounts of organic matter. The bank carbonate was deposited during periods of rising sea level, or transgression, the reciprocal basin-fill was deposited during periods of sea-level still-stand, or regression.

(3) Intertonguing, or interfingering, is another style of bank-to-basin transition. An intertonguing margin within a depositional cycle is characterized by beds of the carbonate bank which become thinner as they extend laterally into the more basinal areas. The tongues of bank carbonates are separated from each other by tongues of basinal rocks which become thinner as they are traced laterally into the banks. The distal ends of the individual tongues may pinch out, through onlap or downlap; or may change facies laterally and become unrecognizable into the adjoining bank or basin.

Interfingering margins incorporate aspects of small scale lateral facies change and reciprocal sedimentation. Each basinward-extending tongue of the carbonate bank was produced during a relative rise in sea level, the bankward-extending tongues of basinal rock were deposited during intervening periods of sea-level still-stand; thus they are the result of fourth order cycles.

The conventional symbol used to illustrate lateral facies change on a geological cross-section is a zig-zag line. It is unfortunate that this one symbol is used to denote lateral facies change, reciprocal sedimentation and interfingering. In this report the zig-zag line refers to lateral facies change and/or intertonguing, whereas contacts resulting from reciprocal sedimentation are shown by a solid straight or curved line.

STRATIGRAPHY

The Rocky Mountain Front Ranges of Alberta have long been recognized as comprising some of the best Devonian outcrops in the world. Early stratigraphic studies in the area were in part a result of regional mapping projects and were partly motivated by scientific curiosity. The discovery of oil in 1947 at Leduc, Alberta, in Devonian carbonates provided the economic incentive for renewed interest in the surface Devonian. This led to the stratigraphic studies of the 1950's. Aside from many subsequent papers of a more local nature, little has been added to the understanding of surface Devonian stratigraphy of this area since the 1950's, although Bassett and Stout (1967), Moore (1988), and Morrow and Geldsetzer (1988) considered the Devonian stratigraphy of western Canada from a much larger perspective. The constantly increasing data base provided by the oil industry, especially in the Alberta Basin, and more recent understanding of the nature of the Devonian, and carbonate stratigraphy and sedimentation in general, provide a basis for re-examining the presently accepted surface Devonian stratigraphic models. The authors of the present study have benefitted tremendously by not just having observed the surface sections available to our predecessors, but also having worked the Alberta subsurface and used the helicopter as a stratigraphic tool to trace beds between the various surface sections.

"The formation is the fundamental unit in lithostratigraphic classification." This definition, from the Stratigraphic Code of the North American Commission on Stratigraphic Nomenclature (1983, p. 858), implies that the stratigraphy of an area should be able to be expressed in terms of formations.

In practice, however, the formation and member names of the Frasnian of the Alberta Rocky Mountains have been defined on the basis of recognizable lithofacies rather than absolute stratigraphic position. It is possible to understand this stratigraphy without reference to formations, however, the formations are the building blocks from which the stratigraphy may be assembled, and a complete understanding of the stratigraphy should relate it to the formations. A brief description of the surface Devonian lithostratigraphic nomenclature follows. It is taken in part from original definitions, their subsequent modifications, a lexicon published by the Alberta Society of Petroleum Geologists (1960), and the authors' experience. Type sections are located on map Figure 5. Documentation for some of the conclusions in the following discussion is presented in Chapter V. The current surface Devonian formation nomenclature is still evolving after 60 years.

FAIRHOLME GROUP

The Fairholme formation[2] was originally named by Beach (1943, p. 11-15) from exposures at the southern end of the Fairholme Range. In the type area, according to Beach, the Fairholme is 330 to 445 m thick and consists of a lower unit of dark coloured dolomitic limestone, a middle unit of bedded light grey dolomite and an upper unit with thin beds of cream-coloured quartzite. It is underlain by Cambrian beds and overlain by the Palliser formation. The Fairholme formation was redefined by deWit and McLaren (1950) who excluded the upper "silty strata" which were named the Alexo formation. The Fairholme was raised to group status by McLaren (1956) and was extended to include both the carbonate buildups and their more argillaceous basinal equivalents. Although the Alexo was excluded from the Fairholme Group, to the north of the Southesk Cairn Carbonate Complex the Frasnian portion of the Alexo (i.e. the upper Mount Hawk, Ronde and Simla) were included.

The two distinct facies realms of the Fairholme Group were referred to as "carbonate" and "clastic" by McLaren (1956). Separate formational nomenclature was assigned to each of these domains as shown on the following diagram, modified from Belyea and McLaren (1957a, p. 168).

"Clastic" facies	"Carbonate" facies	
Mount Hawk Formation	Southesk Formation	Arcs Member Grotto Member Peechee Member
Perdrix Formation	Cairn Formation	
Flume Formation		

The type area for the "carbonate" formations was selected at Mount Dalhousie near the Brazeau River (T. 42, R. 21, W5), whereas the "clastic" formations were defined at Roche Miette (T. 48, R. 27, W5M).

Formations of the Carbonate Facies

Cairn Formation - The lower unit of the Fairholme Group within the carbonate complexes was named the Cairn formation by McLaren (1956, p. 17). The unit is between 120 and 250 m thick and typically composed of dark grey dolomite dominated by a stromatoporoid fauna. The Cairn overlies various lower Paleozoic units, or, where present, a basal detrital unit of probable Middle Devonian age referred to as the Yahatinda Formation (Aitken, 1966, p. 15-24). It is overlain by the Southesk or the Perdrix Formation. The upper contact is a diagenetically

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[2]Capitaliztion in this chapter follows original usage.

affected lithofacies boundary which locally approximates a stratigraphic boundary, but regionally ranges through more than 100 m of section. Some workers, e.g. Mountjoy (1965, 1980), Noble (1970) and Cook (1972), differentiate a lower unit within the Cairn which is variably referred to as "lower cherty Cairn", or Flume Member of the Cairn Formation; this unit approximately correlates with the upper Beaverhill Lake of the subsurface. The remainder of the Cairn correlates with the Cooking Lake and lower portion of the Leduc Formation of the subsurface.

Southesk Formation - The Southesk Formation within the carbonate complexes overlies the Cairn Formation. The formation was proposed by McLaren (1956 p. 19). In the type area the Southesk is approximately 160 m thick. The upper boundary is the base of the "Alexo Formation" south of the Southesk Cairn Carbonate Complex, and the top of the Frasnian portion of the Alexo (top of the Ronde or Simla) to the north.

The Southesk Formation consists of a number of carbonate lithologies, the most common being evenly bedded light grey crystalline dolomite, light grey "reefal" dolomite, and dark grey biostromal beds dominated by disphyllid and thamnoporid corals. Dolomitization is pervasive south of approximately Township 43 within the interior of the Southesk Cairn Complex and decreases to the north. Although these dominant lithologies may occur throughout the Southesk, it is common for upper and lower light grey dolomites to be separated by an intervening dark grey coral bearing unit. In this case, the upper light grey unit is referred to as the Arcs Member, the middle unit as the Grotto Member and the lower light grey unit as the Peechee Member of the Southesk Formation. The type section for the three members of the Southesk Formation is at Canmore, Alberta, where they were defined by Belyea and McLaren (1956, p. 78-86; and 1957a, p. 171-172); the type sections are summarized below (ibid. 1957a, p. 171-172).

The Peechee Member consists of 61 m of "light grey, porous, coarse grained dolomite, massive to vaguely thick-bedded ... almost entirely lacking in organic traces of any sort." The lower contact at this locality is a stylolite within a series of light and dark grey dolomite interbeds.

The Grotto Member consists of 49 m of "dark grey and black, slightly argillaceous dolomite, containing corals and Amphipora ... Toward the base beds resembling the Peechee Member are interbedded with the dark coloured dolomites typical of the Grotto. The junction with the overlying Arcs Member is sharp and clearly defined."

The type Arcs Member comprises 74 m of " ... grey, medium and coarse grained dolomite. It is medium and thick-bedded with some massive units" and "is almost devoid of organic remains."

Southeast of approximately the Brazeau River (Township 42), the Southesk Formation is overlain by a restricted, mostly unfossiliferous, facies of the "Alexo Formation"; to the north of this area the Ronde or Simla Member overlie the Arcs Member and are included within the Southesk Formation.

Formations of the "Clastic" Facies

The formation nomenclature in the basinal "clastic" domain was developed near the Athabasca River north of Jasper.

Flume Formation - The Flume Formation was defined by Raymond (1930, p. 294, 295) as the lowest unit of the Devonian with "outcrops on Roche Miette regarded as typical". The unit was described as 400 feet of hard grey limestone with stromatoporoids and brachiopods.

Taylor (1957, p. 190, 191) revised the Flume Formation by restricting it to the lower part of Raymond's Flume, and erecting the Maligne Formation for the upper, more argillaceous beds. Taylor correlated the revised Flume with the Beaverhill Lake, and the Maligne with the Cooking Lake of the subsurface.

Perdrix Formation - The Perdrix Formation was also named by Raymond (1930, p. 294, 295) for 600 feet of black fissile shale with Tentaculites and Styliolina, which overlies the Flume (or Maligne of Taylor, 1957). The "typical section" is also on Roche Miette. The Perdrix was redefined by McLaren (1956, p. 14) who restricted it to 115 m of black shales to make it regionally stratigraphically consistent. As the Perdrix is followed toward adjoining carbonate complexes, its carbonate content increases markedly.

Mount Hawk Formation - The Mount Hawk Formation was erected by deWit and McLaren (1950, p. 5) for 155 m of grey, in part silty and argillaceous limestone and shale overlying the type section of the Perdrix Formation on Roche Miette. The Mount Hawk was subsequently redefined by McLaren (1956, p. 15-17), to include 48 m of grey shale that had previously been included within the Perdrix. Mountjoy (1965, p. 27, 28) excluded the "upper grey limestone" of McLaren (ibid.) from the type Mount Hawk, but did not formally redefine the type section. Regionally, the top of the Mount Hawk Formation occurs at different stratigraphic levels; at the top of the Frasnian, or the base of the Southesk Formation in areas where significant thicknesses of upper Frasnian carbonates are present above the Mount Hawk.

ALEXO FORMATION AND ITS EQUIVALENTS

The Alexo Formation was defined by deWit and McLaren (1950, p. 6, 38-42) for 68 m of unfossiliferous dolomite, siltstone and shale above the Mount Hawk Formation, with the type locality at the North Saskatchewan

River Gap in the Brazeau Range. The type section is within the Rocky Mountain Foothills, to the east of the Front Ranges.

The Alexo interval in the Jasper region is fossiliferous and consists of a lower unit of Frasnian age, and an upper unit of Famennian age (McLaren and Mountjoy, 1962). The Frasnian portion of the Alexo has been variously assigned to the Mount Hawk Formation, or to the Arcs, Ronde or Simla Members of the Southesk Formation. The Famennian portion of the Alexo was named the Sassenach Formation. The following descriptions are mostly from McLaren and Mountjoy (1962, p. 1-14).

The Ronde Member is defined from its type section on Roche Miette, where it consists of about 30 m of "fine-grained and silty carbonates" which overlie the "Arcs Member" (Mountjoy, 1965, p. 52) and is overlain in turn by the Sassenach Formation.

The Simla Member is a 60 m thick "limestone unit and an underlying soft-weathering silty mudstone interval" (McLaren and Mountjoy, 1962, p. 7) which comprises the upper part of the Southesk Formation in the Ancient Wall Carbonate Complex. It overlies the "lower member of the Southesk" and is overlain by the Sassenach Formation. McLaren and Mountjoy (1962, p. 4) state that "The Ronde Member, as defined in this paper, occupies the same stratigraphic position as the Simla Member in the Ancient Wall area", and (ibid. p. 7) "that the Ronde and Simla Members are correlative." Fossils from the Simla (ibid., p. 8) indicate "a highest Frasnian age for the member". The Simla Member of the Ancient Wall Carbonate Complex is a synonym for the Ronde Member of both the Miette Carbonate Complex (Mountjoy 1965, p. 21, 22 and Fig. 6), and the northern margin of the Southesk Cairn Complex (MacKenzie, 1969, p. 12, 13, Fig. 6). The name Simla Member was subsequently abandoned (Mountjoy and MacKenzie, 1974, p. 4) and these beds were assigned to the Grotto and Arcs Members of the Southesk Formation. Geldsetzer (1982, p. 61-62) has reintroduced the Simla as a formation in and to the northwest of the Ancient Wall Carbonate Complex because faunal and lithological criteria indicate that the Simla at Ancient Wall is younger than both the Grotto and Arcs Members. Mountjoy (1987, p. 5, 6) concurred with this interpretation.

The Sassenach Formation ranges in thickness from a few metres to more than 180 m within the Jasper Basin. The lithology is quite variable, comprising silty and sandy limestone, fine grained quartz sandstone to siltstone and black or grey shale. It contains a prolific lower Famennian brachiopod fauna which differs significantly from that of the underlying beds. Corals and stromatoporoids are characteristically absent. In areas where the Sassenach overlies Frasnian carbonate buildups, the basal contact is normally an obvious unconformity, commonly with siliciclastics at the base of the unit. In this setting, the upper part of the Sassenach usually evidences repeated subaerial exposure surfaces and the top is generally disconformable below the Palliser Formation. Within the basins this contact becomes more subtle; oncolites may characterize the lowest Sassenach beds as may debris flows, siliciclastics and black shale. In this setting the top of the Sassenach is picked at the base of the massive Palliser Formation and the contact between them is probably gradational.

There are several problems associated with the Alexo and its equivalents. The Alexo Formation south of the headwaters of the Cairn River in Township 43 comprises a mostly unfossiliferous mixture of dolomite, quartz silt and clay deposited in inter- to supratidal environments with evidence of repeated subaerial exposure within the upper part. It is thus not possible to differentiate the Frasnian from the Famennian portions of the Alexo south of Township 43. This situation could possibly be resolved by detailed paleontology-palynology.

There is an unconformity at the base of the Alexo Formation within all of the Frasnian carbonate complexes in the study area. This unconformity is not apparent within the type section of the Alexo or within other basinal areas, where, in its place, as much as several tens of metres of extra stratigraphic section are present. The base of the Alexo is therefore not defined with stratigraphic consistency.

According to Mountjoy (1965, p. 21, 51, 52 and fig. 6), the Ronde Member in its type section overlies the Arcs and Grotto Members of the Southesk Formation. The units that Mountjoy refers to as Arcs and Grotto beneath the type Ronde appear to correlate with part of the Ronde Member of the Miette Complex (Mountjoy, 1965), and the Ronde Member of the Southesk Cairn Complex (MacKenzie, 1969). The term "Ronde" thus seems to have been used stratigraphically inconsistently in the Jasper area. In addition, the boundary between the Sassenach Formation and the Ronde Member in some sections "is very difficult to distinguish because of similar lithologies" (McLaren and Mountjoy, 1962, p. 9).

The name "Ronde Member" has been applied to unfossiliferous inner detrital, or "peritidal" rocks south of Jasper Basin (e.g. Morrow and Geldsetzer, 1988, Fig. 21). There are no criteria for subdividing the Alexo Formation in this area, and the unit referred to as "Ronde" includes equivalents of both the Ronde Member and the Sassenach Formation. The term "Alexo Formation" is used in the present study within areas where the differentiation of Ronde and Sassenach (i.e. the Frasnian - Famennian boundary) cannot be demonstrated with certainty.

If the Ronde is to be retained as a useful unit, it should be applied to the open marine or basinal facies of the uppermost Frasnian depositional cycle, retaining the Simla for the carbonate shelf facies. As used in this sense, the Ronde is the uppermost part of the Mount Hawk Formation.

SUBSURFACE FORMATION NOMENCLATURE

Discovery of oil in the Upper Devonian of the Edmonton area led to the development of a subsurface formational nomenclature (Imperial Oil Limited, Geological Staff, 1950). Dual terminology was proposed for "on-reef" and "off-reef" areas. Although the status of the original units has been raised (e.g. the original formations have become groups), the terminology has proven to be effective and remains in use throughout much of the Alberta subsurface. As an addition to these original units, the Blue Ridge Member of the Graminia Formation was subsequently added by Choquette (1955) for a clean carbonate facies below the silty argillaceous beds within the upper part of the Graminia Formation. The Nisku Formation has been subdivided in the West Pembina subsurface area (Chevron Standard Limited, Exploration Staff, 1979) following the discovery of a reefal tract within the Nisku. These subdivisions of the Nisku Formation do not appear to be recognizable in the outcrop belt.

The typical subsurface nomenclature is illustrated on Figure 6.

Attempts have been made in the past to intermingle surface and subsurface Devonian stratigraphic nomenclature. The contrasting conclusions of Belyea and McLaren (1957a, b) on the one hand and Taylor (1957, 1958) on the other are examples of this. The former papers extended part of the surface nomenclature into the subsurface whereas Taylor extended certain subsurface terms into the mountains. In a prefatory note to the Belyea and McLaren (1957a) paper, the Geologic Names and Correlations Committee of the Alberta Society of Petroleum Geologists (1957, p. 165) noted that the papers are "complementary as to evidence, and contradictory as to interpretation and consequently nomenclature."

The subsequent addition of a great deal of subsurface control and use of a helicopter as a stratigraphic tool suggest that each of the protagonists in this debate were correct in some aspects and incorrect in others. Taylor (1957, p. 187, and Figure 2) correctly recognized that the contact between the Cairn and Southesk Formations is a facies boundary. Belyea and McLaren (1957b, p. 274) correctly recognized that Taylor had miscorrelated the Nisku Formation into the Jasper Basin. The geological community showed wisdom in the 1950's in not mingling surface and subsurface Devonian nomenclature, but, with more available information, it appears to be justified at the present time.

THE STRATIGRAPHIC DILEMMA

The formation nomenclature which is applied to the Upper Devonian of the Alberta Rocky Mountain outcrop belt has evolved over more than 60 years. Although this nomenclature may offer a general understanding of lithology and relative stratigraphic position, it does not adequately reflect the demonstrable stratigraphy. The following are three obvious possible solutions to this dilemma.

(1) Redefine the existing formations so they are stratigraphically, rather than lithologically, consistent. This solution would violate the nature of what a formation is, i.e., "a body of rock identified by lithic characteristics", (North American Commission on Stratigraphic Nomenclature, 1983, p. 855, 858). Furthermore it would lead to such complex and cumbersome expressions as "Grotto facies of the Peechee Member", or "Peechee facies of the Cairn lithostratigraphic unit", or "Simla Member (Arcs of Mountjoy and MacKenzie, 1974)".

(2) Erect a new nomenclature based not upon lithology, but upon stratigraphic continuity. This solution would further complicate an already complex nomenclature and does not appear to be necessary.

(3) Utilize the present surface nomenclature recognizing that the names are more descriptive of lithologies than of stratigraphic position. Superimpose another system of stratigraphically defined depositional sequences, or cycles, that are recognizable throughout the area and that may have basin-wide distribution. These cycles are direct analogs to the "T-R' (transgressive-regressive) cycles of Johnson et al. (1985), and to allostratigraphic units (North American Commission on Stratigraphic Nomenclature, 1983, p. 865-867). They are probably analogous to the "third order cycles" of Vail et al. (1977), though they may be of somewhat shorter duration and thickness. By combining standard surface formation nomenclature with subsurface names, a system is proposed which integrates the existing nomenclature into widespread transgressive-regressive depositional cycles.

DEPOSITIONAL CYCLES

Five depositional cycles are recognized and proposed within the Frasnian of the study area. Although they have many of the attributes of sequences e.g. Sloss et al. (1949), and Moore (1988), they are certainly subdivisions of these thicker sequences and hence are termed cycles rather than sequences. These cycles have been assigned names from the subsurface of central Alberta. They are an expansion and revision of the four "sequences" described by Workum (1983), with the addition of the Beaverhill Cycle. These cycles have certain characteristics:

(1) Each of the cycles fits the definition of a depositional sequence of Vail et al. (1977), as "a stratigraphic unit composed of a relatively conformable succession of genetically related strata and bounded at its top and base by unconformities or their correlative conformities."

(2) Each cycle is defined within a carbonate buildup and is recognized at the buildup margin by observing the onlap of thick intervals of basin-fill sediment with no lateral facies equivalents on the buildup.

(3) Each cycle may, but does not necessarily, have an equivalent basinal facies and a reciprocal basin-fill interval.

(4) Not all of these cycles are present everywhere within the area. An individual cycle may be missing either because of onlap or non-deposition.

(5) The cycles cannot be defined by distinctive lithologies or thicknesses. They are recognizable throughout their full range of lithofacies. Typically each cycle is 30 to 100 m thick and was probably deposited during less than 1 m.y., as discussed under the heading **Time and Sedimentation.** On the carbonate buildups, the base of each is an unconformity which may be overlain by an argillaceous-silty unit, and/or

by an upward-shoaling carbonate unit. The basinal cycles may, but do not necessarily, consist of a deep-water facies of the bank carbonate unit overlain by a basin-fill unit.

(6) The rocks of the carbonate banks were produced and deposited essentially in situ. The basins were filled with basinal facies of the bank carbonates interbedded with two fundamentally different types of basin-fill sediment; bank-derived carbonate sediment ranging in size from mud to large boulders, and extra-basinally derived non-carbonate sediment which prograded laterally into the basin during periods of sea level stillstand or regression. The basinal rocks also include wind-blown dust, plankton and other organic debris.

Generalizations made in this section are illustrated on Figures 7 - 9 and discussed as individual localities in Chapter V.

Beaverhill Cycle

The Beaverhill Cycle is the oldest Devonian cycle exposed in the Front Ranges. It is named from the Beaverhill Lake Formation with the type section defined as the interval 4325-5047 feet in the well Anglo Canadian Beaverhill Lake No. 2, located at 11-11-50-17W4M, ESE of Edmonton, Alberta. The Beaverhill Cycle is used in the same sense as the Beaverhill Lake Group of Leavitt and Fischbuch (1968), and the Beaverhill Group of Moore (1988). The unit in the type area consists of 220 m of interbedded limestone and argillaceous limestone. The unit thins toward the west mostly because of onlap onto the West Alberta Ridge and in the Front Ranges constitutes approximately the Flume, or the lower part of the Cairn Formation. The unit is generally 30 to 60 m thick in the Front Ranges south of Mount MacKenzie (Township 45) and thickens gradually to the northwest to more than 100 m, mostly because of the addition of extra section at the base through onlap.

The basal Devonian unit in the Miette Carbonate Complex has been named the Utopia Member by Noble (1970, p. 497, 533). It is missing to the south of Miette because of onlap onto the West Alberta Ridge. A unit similar to the Utopia Member forms the top of the "Lower Flume" at the base of the Ancient Wall Complex (Geldsetzer, 1988, p. 433-439), where it overlies an additional 45 m of Beaverhill Cycle sediments. An unconformity at the top of the Utopia Member may represent a third or fourth order sequence boundary.

The base of the Beaverhill Cycle is an unconformity with Devonian carbonate rocks overlying Lower Paleozoics. Basal Devonian clastic rocks, such as the Yahatinda Formation (Aitken, 1966), are locally present below the lowest Devonian carbonates, but are excluded from the Beaverhill Cycle because their precise age and stratigraphic position are unknown, and they are probably older than the cycle. Aitken (ibid. p. 24) suggested a Middle Devonian age for the Yahatinda; Morrow and Geldsetzer (1988, p. 106) suggest that the unit is Givetian (upper Middle Devonian) associated with a regression at the base of the subsurface Watt Mountain Formation. The top of the Beaverhill Cycle cannot usually be precisely determined within the carbonate complexes; it approximates the top of the Flume Member, or lower cherty Cairn. For this reason Workum (1983) included

TABLE 2: Origin of subsurface names used for depositional cycles.

NAME	WELL NAME	LOCATION	INTERVAL (feet)	AUTHOR
Wabamun	Anglo Canadian Wabamun Lk 1	5-10-51-4W5	5735-6297	Imperial Oil (1950)
Blue Ridge	Canadian Gulf Blue Ridge	5-14-58-5W5	5992-6162	Choquette (1955)
Calmar	British American Pyrcz No. 1	25-50-26-4W4	4865-4909	Imperial Oil (1950)
Nisku	British American Pyrcz No. 1	25-50-26-4W4	4909-5065	Imperial Oil (1950)
Leduc	British American Pyrcz No. 1	25-50-26-4W4	5327-5930	Imperial Oil (1950)
Beaverhill	Anglo Canadian Beaverhill Lk 2	11-11-50-17W4	4325-5047	Imperial Oil (1950)

For this reason Workum (1983) included the Beaverhill Cycle with the overlying beds in "sequence A". In basinal areas the top of the cycle corresponds to the top of the continuous Flume carbonate platform, or Flume Formation (revised) of Taylor (1957, p. 187, 191-192). In the Front Ranges south of Mount MacKenzie, the Beaverhill Cycle probably only includes beds equivalent to the Mildred and Moberly Members of the Waterways Formation (upper part of the complete Beaverhill Lake Group of Leavitt and Fischbuch, 1968).

The Beaverhill Cycle within the study area contains the Allanaria allani fauna as well as the lower and perhaps part of the middle asymmetricus condont zone. The older Ladogoides pax and L. kakwaensis faunas as well as the lowermost asymmetricus condont fauna are present north of Miette Complex and onlap the western flank of the West Alberta Ridge, but are absent to the south (Raasch in Dooge, 1966, App. 1; Noble, 1970, p. 498; and Braun et al. 1988). This cycle approximates T-R cycle IIB of Johnson et al. (1985).

In spite of the fact that the top of the cycle cannot usually be exactly identified within the outcropping carbonate complexes, it is a distinctive unit both lithologically and faunally.

Leduc, Lower Cycle

The two Leduc cycles are named after the Leduc Formation, the type section of which is the interval 5327-5930 feet in B.A. Pyrcz No. 1, located in 12-25-50-26W4M, a short distance south of Edmonton, Alberta. The Cooking

Lake Formation, which forms a widespread platform beneath the Leduc in central Alberta is not usually recognizable as a discrete cycle in the mountains, and its equivalents are included within the Leduc, Lower Cycle. A similar practise is followed in the Alberta subsurface in wells within which the Cooking Lake is not a recognizable unit. Throughout much of the Alberta subsurface, it is not possible to differentiate the upper from the lower cycle of the Leduc. The subsurface Leduc Formation comprises as much as 300 m of bank and reef carbonate rocks. The greater thickness of the subsurface equivalents is mostly attributable to differential subsidence between the two areas. The two Leduc cycles correspond to T-R cycle IIc of Johnson et al. (1985).

The Leduc, Lower Cycle in the Front Ranges comprises as much as 150 m of bank or reefal carbonate rocks that have been included in the Cairn Formation or Peechee Member and their basinal facies and reciprocal basin-fill which comprise the Maligne and part of the Perdrix Formation.

The nature of the bank margin of this cycle can be quite variable. In some areas, (e.g. Wapiabi Gap, Job) the entire margin is steep and not affected by significant back-stepping. In other areas, however (e.g. Cripple Creek-North Ram), the lower portion of the cycle backsteps gently over a distance of several km before encountering the steeper margin within the upper part of the cycle.

Recognition of this sedimentary package as a distinct cycle is based mostly on observing a thick basin-fill unit which onlaps the bank margins to the south of the Southesk Cairn Carbonate Complex. This basin-fill unit consists of bank-derived dark grey to black variably argillaceous and organic-rich lime mudstone, grading basinward into carbonate-rich shale, and their dolomitized equivalents. Farther to the north, the differentiation of the two Leduc cycles is not obvious. This is probably because the Leduc, Lower Cycle basin-fill unit is not as thick, therefore the Leduc, Upper Cycle does not tend to prograde basinward over the underlying bank margin. More detailed studies might document that the Leduc, Lower Cycle consists of more than one third order cycle.

Leduc, Upper Cycle

The Leduc, Upper Cycle, consists of a few tens to a hundred metres of carbonate rock and as much as 150 m of reciprocal basin-filling shale. It is analogous to, and probably correlates with at least part of the Grosmont Formation of the subsurface, as well as the upper part of the Leduc Formation and the type Peechee Member of the Southesk Formation. When traced from bank to basin, this unit either terminates at the bank margin, or passes laterally from shallow-water carbonates, through a Grotto facies, to either become the upper part of the Perdrix Formation or to be absent because of non-deposition.

The reciprocal basin-filling shale of the Leduc, Upper Cycle, was originally included in the upper Perdrix (deWit and McLaren, 1950, p. 4, 5, 23, 43), but was reassigned to the Mount Hawk Formation, (McLaren, 1956, p. 14-16). This shale basin-fill equates with the subsurface type Ireton shale which, within the 262 foot thick type section in B.A. Pyrcz No. 1, overlies a partial Leduc carbonate buildup. The type Ireton is clearly post-Leduc basin-fill. The basin-fill unit has been informally referred to as the "Cripple Tongue" by Dooge (1966, p. 22) in the vicinity of the Cline Channel. The unit is typically composed of grey shale which was derived from outside the Alberta Basin and prograded into the basin in the manner described by Oliver and Cowper (1963) and by Stoakes (1980). It typically becomes more carbonate-rich in proximity to carbonate buildups. It is absent within the interiors of all of the large carbonate banks, and thickens by onlap to more than 150 m in the basins.

The top of the Leduc, Upper Cycle is a disconformity on the carbonate banks where it may correspond to the Grotto-Peechee contact. In basinal areas the top of the cycle is the base of a carbonate unit above the lower shale of the Mount Hawk Formation. The two combined Leduc cycles constitute T-R cycle IIc of Johnson et al. (1985).

The problems in using paleontology to date the rocks of the carbonate complexes are discussed within Chapters IV and V. The Leduc Cycles range from DFR 5-11 in the Raasch zonal scheme (in Dooge, 1966, Appendix 1) and are the insculpta and lower albertensis zones of McLaren (1954, 1962).

Weissenberger (1988, Figure 2 and p. 458-460) suggests that the Leduc, Lower Cycle is upper or possibly middle asymmetricus to A. triangularis Zone, whereas the Leduc, Upper Cycle is within the A. triangularis to lower gigas conodont Zone.

Nisku Cycle

The Nisku Cycle is named from the Nisku Formation, the type section of which is the interval 4909-5065 feet in B.A. Pyrcz No. 1, located in 12-25-50-26W4M, SE of Edmonton. The cycle consists of the type Grotto and Arcs Members of the Southesk Formation, and a portion of the Mount Hawk Formation. On the carbonate banks the Nisku Cycle is usually 45 to 60 m thick, was initiated by a transgression which resulted in the locally developed dark, coral-bearing facies of the Grotto Member, and terminated by a basinwide regression which produced a widespread exposure surface at the top of the Arcs Member. This exposure surface underlies the argillaceous and silty equivalent of the Calmar Formation, which on the carbonate banks, appears to be of supratidal origin. The bank carbonates of the Nisku Cycle change facies basinward to grey lime mudstone, where they may be overlain by tens of meters of extra carbonate and argillaceous or silty basin-filling rocks. The Nisku Cycle contains part of McLaren's (1954, 1962) albertensis zone, and the upper gigas conodont zone (Johnson et. al. 1985; Weissenberger 1988). The well-developed coral fauna has been described by McLean and Sorauf (1988). The Nisku Cycle is the lower part of T-R cycle IId of Johnson et al. (1985).

Calmar-Blue Ridge Cycle

The Calmar-Blue Ridge Cycle is named after the Calmar Formation and the Blue Ridge Member of the Graminia Formation from the Alberta subsurface. In the subsurface, on carbonate banks the cycle consists of the Calmar shale and the overlying Blue Ridge Member carbonates. The top of the cycle is an unconformity at the top of the Blue Ridge, at the base of the Upper Graminia siltstone. In subsurface basinal areas, the Calmar is commonly unrecognizable and its underlying unconformity is lost within the Winterburn Group.

Within the project area, the cycle includes the lower part of the "Alexo Formation". It also includes the following units: The Ronde Member of Mountjoy (1965) and MacKenzie (1969) as used in the Miette and Southesk Cairn Carbonate Complexes; the Simla Member of McLaren and Mountjoy (1962) as used at Ancient Wall; the Arcs and Grotto of Mountjoy and MacKenzie (1974) at Ancient Wall, the type Ronde and underlying "Arcs" and "Grotto" at Roche Miette (Mountjoy, 1965); and, in Jasper Basin, the upper part of the Mount Hawk Formation and the lower, basin-fill portion of the Sassenach Formation (see Figures 12 and 13).

This is the only cycle within which the relative ages of the bank carbonate and the younger reciprocal basin-fill can be demonstrated paleontologically (McLaren and Mountjoy, 1962, p. 7-14; and McLaren, 1982, p. 477-484). This cycle is the upper part of McLaren's (1954, 1962) albertensis zone, overlain by the lower Famennian walcotti zone. It includes the Raasch (in Dooge, 1966, Appendix I) V. scopulorum fauna (DFR-12), and the P. rhenana and P. triangularis conodont zones (Orchard, 1988). This cycle is within the upper part of T-R cycle IId of Johnson et al. (1985, p. 578), and Sandberg et al. (1988, p. 199).

Wabamun Cycle

This depositional sequence is named after the subsurface Wabamun Group. The Wabamun Cycle is used in the same sense as the Palliser sequence of Moore (1988, p. 79) except within the Jasper Basin, where the lower basin-filling part of the Sassenach Formation is included in the underlying Calmar-Blue Ridge Cycle.

On the carbonate buildups, the base of the Wabamun Cycle coincides with the Frasnian-Famennian boundary and is within the crepida conodont zone of early, but not earliest Famennian age (Geldsetzer, per. comm.). The base of the cycle approximates the base of an argillaceous and fine siliciclastic unit immediately below the Palliser Formation, within the Graminia and "Alexo" Formations. In the Jasper Basin, the base of the cycle occurs within the upper part of the Sassenach Formation.

The Wabamun Cycle is of early and middle Famennian age and is not discussed at greater lengths in the present study.

SEA LEVEL

Each depositional cycle formed in response to a relative rise of sea level, controlled by a combination of eustacy and subsidence. It is difficult to differentiate these two factors, or to accurately measure the height of the individual rises and falls of sea level, however the rocks of each cycle, both on the carbonate buildups and in the basins, offer clues to minimum relative changes in sea level for both the transgressions and the regressions.

On the buildups, the minimum height of each relative rise in sea level is equal to the thickness of each depositional cycle. The lithology of the carbonate rocks in the upper part of each depositional cycle gives evidence as to whether the cycle built up to sea level or not. Upward-shoaling cycles culminating in intertidal carbonates built up to sea level, whereas cycles that culminate in subtidal normal marine sediments did not.

Whereas the minimum relative rise in sea level can be determined in some cycles, an estimate of the height of relative sea level fall during the regressions is difficult to determine within the buildups of the Front Ranges. The thickness of the vadose zone and the nature of karst features below the tops of the depositional cycles can be used to suggest the amount of lowering of sea level during the regressions. Karst features are present within the upper parts of the Leduc Lower and Upper Cycles, at several localities. The problem is that relatively recent solution by ground water is often superimposed upon Devonian karst features, and it can be difficult to differentiate the two karst episodes. In general the Devonian karst features are elongate parallel to bedding, and are either open vugs in weathered outcrops or contain carbonate cement or yellow clay; whereas solution features produced in the late Tertiary and Recent cycle of erosion tend to be sub-horizontal, and are either open or contain debris derived from overlying units.

In the deep Alberta Basin to the east of the Front Ranges, the upper parts of the two Leduc cycles contain abundant high angle solution cavities interpreted as having developed in response to downward percolation of water in the paleo-vadose zone. The thickness of these intervals provides a minimum value for drop in sea level during regression. This line of evidence does not support relative drops of sea level of more than a few metres.

The basinal areas also provide data on relative sea level changes. The stratigraphic geometries of basin-fill units argue against sea-level drops of more than a few metres. The tops of foresetting beds of bank-derived carbonate basin-fill are almost always at the level of the top of the bank from which they were derived.

The recognition of shallow-water sediments within basin-fill units would argue for significant drops of sea level. Such sediments are not recognized within the basin-fill units of the Devonian in the Front Ranges.

Another line of evidence that can be used in support of significant drops in sea-level during the regressive phase of the cycles is the recognition of basinward displacement of facies tracts. The presence of shelf limestone in the lower part of the Calmar-Blue Ridge Cycle immediately above open marine basin-fill of the Nisku Cycle north of Mount MacKenzie and at Roche Miette, for example, suggests a sea-level drop of more than a few metres during the regression at the top of the Nisku Cycle (see Figures 63, 66, 67 and 73).

In summary, a variety of lithological and stratigraphic observations suggest that individual relative rises of sea level in the third order depositional cycles were approximately 30 to 100 m each. The regressions resulted in relative drops of sea level sufficient to expose the carbonate buildups, but probably were measured in metres or at the most, less than several tens of metres.

PALEONTOLOGY AND BIOSTRATIGRAPHY

Biostratigraphic studies of the outcropping Frasnian succession within the project area have followed a similar history to that of their stratigraphic counterparts. Interest peaked about three decades ago, and has only been revived in the past few years. This chapter reviews the state of current knowledge of biostratigraphically useful taxa and the development and current status of zonal schemes. Integration of the biostratigraphic data into the proposed sequence stratigraphy follows in the next chapter.

PALEONTOLOGY

Fossils are the building blocks of any biostratigraphic zonal scheme. Frasnian carbonates and clastics outcropping within the Front Ranges contain a variety of fossil groups that have proven useful for biostratigraphic purposes. The most important ones are conodonts, brachiopods, corals, stromatoporoids, ammonoids, ostracodes and foraminifers. Since we are, at least in part, dealing with a carbonate-rich environment, diagenesis plays an important role in fossil preservation. Dolomitization often hinders the identification, and hence the usefulness, of most fossils by destroying their delicate internal structures.

Macrofossils

Brachiopods - Brachiopods reached their greatest diversity during Devonian time (Williams and Hurst, 1977) and are among the most common constituents of many Frasnian assemblages. They occur most often in basinal (shaly) and near-reef sediments and are only rarely found within carbonate buildups. Zonations that rely heavily on brachiopods are more useful in dating stages of basin infill (e.g. Perdrix, Mount Hawk) than in relating the timing of reef growth to basin infill.

Much taxonomic work remains to be done on the brachiopod faunas of the study area. The sole monographic study is McLaren's (1962) work on the order Rhynchonellida. Photographs of other biostratigraphically useful brachiopod species were provided by McLaren (1954, 1958), McLaren, Norris and MacGregor (1962), Maurin and Raasch (1972) and Warren and Stelck (1956).

Brachiopods form the framework of the major zonal schemes proposed by McLaren (1954, 1962), Raasch (in Dooge, 1966; Maurin and Raasch, 1972) and Warren and Stelck (1950, 1956). The relatively recent practise of calibrating brachiopod zones against conodont zones (see discussion in Johnson, 1979) has not been attempted within the project area.

Corals - Corals are an important faunal element in near-reefal environments, as well as in those portions of the buildups that are not dominated by stromatoporoids. They are common in open marine shelf carbonates of the Southesk Formation (Nisku and Calmar-Blue Ridge Cycles) and in carbonate-rich portions of the Mount Hawk Formation. They occur locally within the upper portions of the Cairn Formation (Leduc, Lower Cycle). According to McLean and Sorauf (1988) corals reached their greatest diversity in latest Frasnian time, just prior to the faunal crisis associated with the Frasnian-Famennian boundary event (Sorauf and Pedder, 1986).

Warren and Stelck (1956) and McLaren (in McLaren, Norris and MacGregor, 1962) illustrated a few biostratigraphically significant coral species from the Alberta Front Ranges. Jull (1977) described the spatial distribution of different coral groups along the southern margin of the Ancient Wall Carbonate Complex, but did not publish any taxonomic studies. Recently several important monographs have been produced by McLean (1982, 1986) and McLean and Pedder (1984, 1987).

Although corals have not been widely used as Frasnian index fossils, they were included within the assemblage zones proposed by Warren and Stelck (1950, 1956) and Raasch (in Dooge, 1966).

Stromatoporoids - Stromatoporoids were the major reef-building organisms during the Beaverhill and Lower Leduc Cycles, and were again prominent in shelf carbonates of the Calmar-Blue Ridge Cycle. They are mostly restricted in occurrence to carbonate buildups. Although much has been written about the ecological distribution and succession of stromatoporoids in reefs (i.e. Cook, 1972; Kobluk, 1974, 1975, 1978; Noble, 1970), the only taxonomic studies are those of Stearn (1961, 1976).

Ammonoids - House and Pedder (1963) described the ammonoids of the Devonian of Western Canada. Goniatites are exceedingly rare within the Frasnian succession of the Front Ranges, and are restricted in occurrence to basinal sediments. The Flume Formation has yielded several specimens, while shales of the Perdrix and Mount Hawk Formations have produced a few specimens of Manticoceras. Ammonoids are widely used as a zonal tool in western Europe, but their scarcity limits their use in the study area.

Microfossils

Conodonts - Since the early sixties, conodonts have become the single most important taxon used to zone the Devonian. The "standard" reference section was established in West Germany by Ziegler (summary in Ziegler, 1979). Like many other organisms, conodonts are facies controlled, such that the deeper water (Palmatolepis) biofacies and the shallow water (Polygnathus-Icriodus) biofacies co-exist with only limited mixing of the two. Despite this handicap, conodonts have become the taxon of choice for biostratigraphic calibration.

Conodont studies of the Frasnian interval in the Alberta Front Ranges are rare, with only a single paper adequately documenting most of the succession (Klapper and Lane, 1988). Studies of a more limited nature (i.e. from smaller portions of the succession at select localities) have been carried out by Pollock (1968), Orchard (1988) Uyeno (in Braun, Norris and Uyeno, 1988), and Weissenberger (1988).

Ostracodes - Braun (1968, 1979) utilized ostracodes to zone the Middle and Upper Devonian strata of the Northwest Territories and northeastern Alberta, but did not extend these studies to include the project area.

Foraminifers - Toomey et al. (1970) described some Frasnian foraminifers from the Ancient Wall Carbonate Complex. Marchant (1987) outlined the basis for a foraminiferal zonation of the Frasnian, but has yet to publish his findings.

BIOSTRATIGRAPHY

Since 1950, numerous workers have proposed biostratigraphic zonal schemes for the Frasnian of Alberta. Major studies include those of Braun (1978), Clark and Ethington (1965), Crickmay (1950, 1953, 1957, 1966), House and Pedder (1963), Klapper and Lane (1988), Maurin and Raasch (1972), McLaren (1954, 1962), Mound (1968), Norris and Uyeno (1981, 1983), Pollock (1968), Raasch (in Dooge, 1966), Stearn (1975), Uyeno (1974) and Warren and Stelck (1950, 1956). The following review and discussion is concerned with those schemes relevant to the Frasnian succession of the Alberta Rocky Mountains. The studies are divided into two broad categories:

(1) "Integrated" Zonal Schemes
These are defined as those zonations based on detailed studies of a large number of collections from the entire Frasnian stratigraphic interval thoughout the study area. They may be based on a single taxon (McLaren, 1954, 1962), or on several taxa (Raasch in Dooge, 1966; Warren and Stelck, 1950, 1956).

(2) "Other" Zonal Schemes
These are defined as zonations that do not meet the criteria set out above. They include schemes based on a single locality or a limited area (i.e. Klapper and Lane, 1988; Stearn, 1975) those encompassing only part of the stratigraphic succession (i.e. Orchard, 1988; Pollock, 1968) and those based on uncommon (rare) taxa (House and Pedder, 1963).

Figure 9 shows the distribution of the most common macrofossil groups within the Frasnian of the Alberta Front Ranges. It demonstrates that there was relatively little mixing between those faunas inhabiting basinal (shaly) environments and those dwelling within or in close proximity to carbonate buildups. This distribution pattern has important ramifications for the interpretation of the faunal succession in any give area, i.e. the absence of a particular assemblage or zone may simply be related to the absence of a particular lithofacies. Early workers such as Warren and Stelck (1956) were acutely aware of the fact that many of their faunas were restricted in occurrence to basinal (argillaceous) or, at best, near-reefal environments and that the occurrence of at least some faunas was probably paleoenvironmentally controlled. They stated (op. cit., p. 11):

"One of the major factors influencing the correlations of Devonian fossil faunas in the western basin is the various ecological conditions under which the faunas lived. Reefal and non-reefal facies must be considered; shale and limestone facies present problems as well as strongly argillaceous shales as opposed to limy shales ... It is evident ... that climate had little effect on the faunas and we must look rather to local sedimentary conditions to get an understanding of the reasons for lateral changes in faunas which were presumably contemporaneous."

Raasch (in Maurin and Raasch, 1972) concluded that his Leiorhynchus albertense (=Calvinaria albertensis) Zone (DFR-9) probably had a much broader vertical range than originally indicated because the form appeared to be facies dependant.

"Integrated" Zonal Schemes

Only three "Integrated" zonations have been proposed for the Frasnian succession of the Alberta Rocky Mountains: those of Warren and Stelck (1950, 1956), McLaren (1954, 1962) and Raasch (in Dooge, 1966). All are "first generation" attempts at developing a working macrofossil zonation of the stratigraphic succession. Brachiopods form the framework of each zonation, and most of the faunal zones are named after brachiopod species. Other taxa used include corals, pelecypods, gastropods, ammonoids and tentaculitids. Figure 10 illustrates how the schemes correlate with one another.

McLaren, Norris and MacGregor (1962) published an illustrated guide to Devonian index fossils of Canada. Characteristic species from the Frasnian formations of the study area were illustrated, but no zonal scheme was presented.

Warren and Stelck (1950, 1956) subdivided the stratigraphic succession of the "mountains of western Alberta" into six faunal zones:

Spirifer strigosus fauna
Tenticospirifer cyrtiniformis fauna
Macgeea proteus fauna
Buchiola retrostriata fauna
Eleutherokomma leducensis fauna
Allanaria allani fauna

All of these zones were based on " ... accurately located specimens that the writers are satisfied occur together and occur in place throughout a restricted stratigraphic interval" (Warren and Stelck, 1956, p. 5). The main index fossils were brachiopods, although some corals, ammonoids and gastropods were also utilized. The faunas were illustrated with photographic plates.

The authors were well aware of the fact that their faunal distributions were partially governed by lithofacies. Thus the Tenticospirifer cyrtiniformis fauna was found " ... at the top of the Mount Hawk Formation in the mountains in marginal reef facies. It has not been collected elsewhere as a distinct fauna ... " (Warren and Stelck, op. cit., p. 12). This fauna is shown on Figure 10 as being partially correlative with both the underlying Macgeea proteus fauna and the overlying Spirifer strigosus fauna.

To date, Warren and Stelck's (1956) pioneering zonation remains as the sole well documented "integrated" zonal scheme in existence. Raasch's (Dooge, 1966; Appendix I) scheme possessed twice as many zones, but lacked illustrations of the fauna.

McLaren (1954, 1962) proposed a zonation of the Frasnian based on the brachiopod order Rhynchonellida. The original scheme was presented in 1954, while a slightly modified version, accompanied by detailed taxonomic documentation appeared in 1962. In both papers, McLaren subdivided the Frasnian into four zones:

Calvinaria albertensis Zone
Calvinaria variabilis insculpta Zone
Calvinaria variabilis athabascensis Zone
"Ladogioides" Zone.

The two versions are superficially similar, but the latter carries some important reinterpretations of the late Frasnian Calvinaria albertensis Zone. In his earlier work (McLaren, 1954, p. 171) noted that while the Mount Hawk was abundantly fossiliferous, "The corals are most common in the upper beds of the formation, that is, in or near the reefs ... whereas the lower, more argillaceous beds are typified by a predominantly brachiopod fauna, although many of the brachiopod species are known from above the coral-rich horizon."
Thus he showed (op. cit. Fig. 1) his "Nudirostra albertensis" Zone ranging from the top of the Perdrix to the base of the Famennian.

In the later work, McLaren (1962, p. 4, 5 and Fig. 1) restricted the vertical range of the Calvinaria albertensis Zone to the lower and middle Mount Hawk, stating that: "The highest beds of the Mount Hawk formation are commonly massive carbonates ... assigned to the Arcs member. They contain a highly characteristic late Frasnian fauna which includes: Pachyphyllum cinctum (Smith), Thamnophyllum tructense (McLaren) and many other corals, Theodossia keenei (Crickmay) and ... species of Hypothyrindina, Athyris and Cranaena. This fauna is wide-spread in the upper Mackenzie River region ... in the Kakisa formation ... The assemblage everywhere overlies beds containing an abundant fauna typified by Calvinaria albertensis albertensis ..."

In sections where the "Arcs member" was missing (i.e. the Deception Creek-Cardinal River headwaters area, see McLaren, 1956, p. 26 and Cross-Section I-I'), beds carrying Calvinaria albertensis were found to be directly overlain by clastics carrying an early Famennian fauna. In such areas, McLaren (1962, p. 5) inferred that the "Arcs" - and hence the latest Frasnian - was missing by erosion.

An alternative hypothesis is that the latest Frasnian "Theodossia" fauna was environmentally restricted to near reefal areas and that it was laterally replaced in basinal areas by the Calvinaria albertensis fauna. This interpretation is favoured by the authors and illustrated in Figure 10.

Other drawbacks to the McLaren scheme are its reliance solely on rhynchonellid brachiopods, which, though more tolerant of environments than other taxa, are still generally restricted in occurrence to basinal sediments. The zones themselves are also comparatively long ranging, e.g. the Calvinaria variabilis insculpta Zone ranges through both the Leduc Cycles, whereas the Calvinaria albertensis Zone ranges through at least the late Upper Leduc, Nisku and Calmar - Blue Ridge Cycles.

Taxonomically, McLaren's zonal scheme is the most thoroughly documented of the three "integrated" schemes. It is useful for grossly subdividing the basinal (Flume-Perdrix-Mount Hawk) succession, but cannot be used to date stages of reef growth. It also lacks the sensitivity required for the identification of individual pulses of basin fill within the Perdrix-Mount Hawk interval.

Raasch (in Dooge, 1966) outlined a twelve-fold zonation of the Frasnian of the central and northern Front Ranges. This information was summarized in Appendix 1 of Dooge's stratigraphic and sedimentologic study of the Cripple/North Ram Margin of the Fairholme Carbonate Complex. The zonation was based on fossil suites garnered from forty stratigraphic sections measured by Shell Oil geologists between North Saskatchewan River and Cecilia Lake (Raasch in Maurin and Raasch, 1972, p. 61). Each zone is identified with the prefix "DFR" and a number.

The zones are:

DFR 12	Vandergrachtella (Theodossia) scopulorum Zone
DRF 11	Cyrtospirifer whitneyi Zone
DFR 10	Cyrtospirifer placitus Zone
DFR 9	Leiorhynchus (=Calvinaria) albertense Zone
DFR 8	Leiorhynchus carya Zone
DFR 7	Receptaculites Zone
DFR 6	Leiorhynchus (=Calvinaria) insculptum Zone
DFR 5	Leiorhynchus (=Calvinaria) athabaskense Zone
DFR 4	Allanaria allani Zone
DFR 3	Ladogioides kakwaensis Zone

DFR 2 Ladogioides pax Zone
DFR 1 (not present in Alberta)

As is the case with the two previously mentioned "integrated" zonations, the framework is based on brachiopods, with the exception of DFR 7, which is simply termed the Receptaculites Zone. Despite being named after a facies-restricted taxon, the zone carries eight diagnostic brachiopod species and was subsequently (Raasch in Maurin and Raasch, 1972) renamed the Monelasmina besti zone.

According to Raasch (discussion in Maurin and Raasch, 1972), Zone DFR 1 is not recognized in western Canada while Zone DFR 2 is present only in the subsurface. Recent redefinition of the Givetian-Frasnian boundary (Ziegler and Klapper, 1985; discussed in Braun et. al., 1988, p. 99) suggests that the DFR 2 Zone is now considered latest Middle Devonian in age. Zone DFR 3 occurs in the Flume north of the Ancient Wall Carbonate Complex and in the Main Ranges west of Cline Channel (Mountjoy, 1978). Whereas McLaren (1962) considered the ranges of Ladogioides pax McLaren and L. kakwaensis (McLaren) to be essentially concurrent, Raasch separated them into two zones.

Raasch (in Dooge, 1966) recognized four zones in the Maligne-Perdrix interval whereas both Warren and Stelck (1956) and McLaren (1954, 1962) each only recognized two. The number of faunas in the Mount Hawk was also expanded (i.e. McLaren recognized two and Raasch four).

The only obvious discrepancy within Raasch's (ibid, Appendices I, II) scheme is the placing of the Grotto and Arcs (Nisku Cycle) into the latest Frasnian DFR 12 Zone, and the Calmar-Blue Ridge Cycle into the basal Famennian DFA-1A Zone. In Jasper Basin, the DFR 12 fauna clearly lies above the Grotto-Arcs stratigraphic interval (McLaren and Mountjoy, 1962; p. 10; Hedinger and Workum, 1988c; p. 468), within strata equivalent to the Simla Member (Calmar-Blue Ridge Cycle).

Raasch later (in Maurin and Raasch, 1972) attempted to expand and modify his twelve-fold zonation to embrace Devonian strata from northeastern British Columbia, the Northwest Territories and the Alberta subsurface. He also provided some insights into paleo-environmental conditions that may have influenced the apparent vertical ranges of some of his key brachiopod species. Raasch indicated that the DFR 9 ("Leiorhynchus albertense") fauna may be a deeper water equivalent of the "younger" DFR 10 and possibly DFR 11 Zones.

"Other" Zonal Schemes

Zonations included in this category are not necessarily inferior to "integrated" schemes, but simply do not have the scope of the latter. They are discussed in order of biostratigraphic importance.

Conodonts - Since the pioneering work of Ziegler (summary in Ziegler, 1979), conodonts have become the prime tool used to zone the Devonian System worldwide. Few detailed taxonomic studies of this important phyllum have been conducted in the project area. Initial works include a preliminary survey by Clark and Ethington (1965) and a more important partial zonation of the Flume and "Maligne" Formations by Pollock (1968). Orchard (1988) described and illustrated some latest Frasnian conodonts from the Jasper Basin. Zonal schemes (based on the West German standard of Ziegler) have appeared in Morrow and Geldsetzer (1988, Fig. 15) and Weissenberger (1988), but these papers lack both taxonomy and illustrations.

Klapper and Lane (1988) pubished a preliminary study of the rich Frasnian conodont faunas recovered from two sections along the margins of the Jasper Basin (Section 9-47-24, in the Nikanassin Range and Section 6-49-2W6, at the south margin of the Ancient Wall Carbonate Complex at Mount Haultain). They recognized six zones within the Perdrix Formation, two within the Mount Hawk Formation and one within the "Ronde" (Simla) interval (Fig. 10). These faunas were correlated with Klapper's (1988) Frasnian zonal scheme from the Montagnes Noire region of France. All of the biostratigraphically important elements were illustrated and the authors' "species concepts" presented in synonomy form. Klapper and Lane (op. cit.) cautioned that:

"The Frasnian standard zones (summary in Ziegler, 1979), especially from the base of the Ancyrognathus triangularis Zone upward are not readily applicable to the Alberta sequence because of past inconsistency in the taxonomic concepts of such species as Ancyrognathus triangularis and Palmatolepis gigas, among others. Furthermore, above the level of Zone 5a, the Alberta sequence is in a Polygnathus biofacies (as this term is used by Klapper and Lane, 1985) which makes correlation with the Palmatolepis biofacies of the standard zonation unresolvable at present".

Ammonoids - House and Pedder (1963) presented a three-fold ammonoid zonation for the Frasnian of western Canada (Fig. 10). The major limitations of this scheme are its relative lack of sensitivity and the poor recovery of ammonoids from the basinal (Flume-Perdrix-Mount Hawk) succession of the project area.

Stromatoporoids - Stearn (1976) proposed a zonation of the Frasnian on the basis of the rich stromatoporoid faunas recovered from the undolomitized southern margin of the Ancient Wall Carbonate Complex at Mount Haultain (Fig. 11). This scheme is unique among the six discussed as it dates reefal rather than basinal sediments. The zonation cannot be expanded into the Southesk Cairn and Fairholme Carbonate Complexes because widespread dolomitization has destroyed the diagnostic micro-structures of the stromatoporoids within these carbonate buildups.

Stearn's zonal scheme is shown separately (Fig. 11) because only two of the zones (1 and 5) can be related with some degree of certainty to other schemes. This correlation is based solely on stratigraphic criteria. Zone 1 occurs within the "White Limestone Unit" of the Lower Flume of Mountjoy and MacKenzie (1974). This is equivalent to the Utopia Member of the Flume in the Miette Carbonate Complex (Noble, 1970). The unit is absent south of the Miette Complex due to onlap of the West Alberta Ridge. Zone 5 occurs within the "Arcs Member" of Mountjoy and MacKenzie (op. cit.), which is equivalent to the Simla Member (Calmar-Blue Ridge Cycle). The zone cannot be identified south of the northern margin of the Southesk Cairn Carbonate Complex because of the change from normal marine to restricted inner detrital environments of the "Alexo Formation" and the attendant loss of stromatoporoids.

Corals - Corals have not been used to zone the Frasnian succession as they are generally considered to be too facies restricted. Certain species have appeared in assemblage zones (i.e. Warren and Stelck, 1956; Raasch, in Dooge, 1966) or have been cited as being diagnostic of certain portions of the succession (i.e. latest Frasnian "Kakisa equivalent" forms in McLaren, 1962). One of the drawbacks of the recent monographic studies by McLean (1982, 1986) and McLean and Pedder (1984, 1987) is the lack of vertical range charts for the various coral species. This has been partially remedied in McLean and Sorauf (1988), where some species are listed as occurring within restricted stratigraphic intervals, i.e. the latest Frasnian species associated with the Simla (Ronde) - Kakisa interval (Calmar - Blue Ridge Cycle).

LOCALITIES

INTRODUCTION

The Devonian of the study area is discontinuously exposed in a belt 550 km long; the outcrops transect several different carbonate complexes and intervening basinal areas. The margins of the various carbonate complexes are defined by different criteria in different areas, although in general it is the Leduc Cycles which usually define the bank margins. Some margins (e.g. south margin Ancient Wall Complex) are obvious and affect all of the depositional cycles within the Frasnian; however, other margins are more subtle and only affect one, or a few cycles. In some localities the bank margins of several cycles are stacked above each other, in other places they backstep or prograde relative to each other. The farthest basinward incursion of bank carbonates may be many kilometres from the farthest incursion of basin-fill into the bank. The width of the various bank margins also shows great variation ranging from less than one, to several kilometers. For these reasons the definition of the bank margins is somewhat arbitrary.

In general, the bank margins and thick intervals of basin-fill occur at increasingly higher stratigraphic levels as the outcrop belt is followed from southeast to northwest. This is shown schematically (Figs. 12, 13) and is primarily caused by the prograding nature of the basin-fill. The localities are described under the following headings:

Flathead-Crowsnest Pass Area
Fairholme Carbonate Complex
Cline Channel
Southesk Cairn Carbonate Complex
Jasper Basin
Miette Carbonate Complex
Ancient Wall Carbonate Complex

The Flathead-Crowsnest Pass area is defined by its geographic isolation from other Devonian outcrop areas farther to the north. The other areas are discrete carbonate complexes or intervening "basins". Each of these areas is characterized by a particular range of lithologies and a particular style, or styles, of bank-to-basin stratigraphic relationships.

The localities are illustrated by photographs which are annotated with symbols explained in Figure Annotations (Appendix 1).

FLATHEAD-CROWSNEST PASS AREA

The Devonian is continuously exposed on the east flank of the Flathead Range of southwestern Alberta between 49°20'N and 49°40'N, 114°35' to 40'W; (T. 5 to 9, R. 5 W5M). This locality is immediately west of the western margin of the Southern Alberta Carbonate Complex. These rocks have been described by Price, (1964 and 1965), and Workum (1988a) and are illustrated by Figures 14 to 18 in the present report.

Price (1965, p. 28-38) adapted some of the stratigraphic nomenclature of the upper Fairholme Group from farther north, and erected two new formations, the Hollebeke and Borsato, for locally developed lithofacies within the lower portion of the Fairholme.

The Hollebeke Formation was applied to the lower light and medium grey weathering carbonates at the base of the Fairholme Group. This formation was informally further subdivided into a lower recessive argillaceous, silty and in part dolomitic member, and an upper resistant limestone member. Price (ibid. p. 29) reported that thicknesses range from 99 to 121 m for the Hollebeke of the Flathead Range, and that the lower member thickens to the west (Price, 1964, p. 434). Relative to over- and underlying units, the Hollebeke is structurally incompetent and usually tectonically overthickened by a combination of folds and thrust faults; the thicknesses reported by Price are probably excessive. Price correlated the Hollebeke with the Flume, Cairn and Waterways Formations based on stratigraphic position and paleontology.

The Borsato Formation comprises 20 to 50 m of dark grey organic-rich dolomite with a stromatoporoid-coral fauna which overlies the Hollebeke and is in turn gradationally overlain by the Mount Hawk, or by the Peechee Member of the Southesk Formation (Price, 1965, p. 34). The Borsato probably correlates with part of the Cairn or Perdrix Formations, although Price (ibid.) reported a Mount Hawk fauna in the upper part of the formation.

The Mount Hawk Formation overlies the Borsato throughout most of the Flathead-Crowsnest Pass area. It consists of 120 to 150 m of dark grey slightly argillaceous fine-grained limestone with silty interbeds in the upper part. These sediments are mostly carbonates derived from the Southern Alberta Shelf with a minor admixture of clay and siliciclastics which were presumably derived from outside the Alberta Basin. The typical Ireton shale lithofacies was probably unable to prograde into this area because of the presence of the intervening Southern Alberta Carbonate Shelf (Fig. 1). The Mount Hawk Formation was shown by Price (ibid.) to be overlain in turn by the Grotto and Arcs Members.

Two laterally linked and three isolated masses of light grey dolomite are present above the Borsato Formation on the east side of the Flathead Range. They range from approximately 100 to 330 m thick and are a few hundred metres to perhaps one km wide. These have been described by Price (1964, 1965) and Workum

(1988a). Price interpreted these masses to be westward protuberances of the Southern Alberta Shelf margin reef complex, whereas Workum suggested they were isolated pinnacle reefs located to the west of, and downslope from, a major carbonate complex. They have been referred to the Peechee Member of the Southesk Formation. Price (1964, Figs. 3 and 5) showed that the three South Lost Creek reefs are approximately 120 m thick, and interfinger with, and are overlain by the Mount Hawk Formation. The South Goat and South Lynx Creek Peechee reefs were illustrated (ibid. Figs. 4, 6 to 8) as approximately 330 m thick and as also including facies of the Grotto and Arcs Members.

Price (1964, Fig. 4 and p. 448) noted that the basinal sections are as much as 40% thinner than the "reef front facies" and attributed this primarily to differential compaction between the two lithologies. The three more northerly reefs have all been tectonically overthickened by thrust faults, which are manifested primarily as bedding plane slip in the off-reef sections, but which have been deflected upward by the flanking dips of the reefs and have structurally overthickened them.

The differentiation of reef and off-reef environments in this area was attributed to differential subsidence by Price (1964, p. 446-447). The features attributed to variations in rate of subsidence can also be explained in terms of topography, i.e. that the western margin of the Southern Alberta Carbonate Shelf was controlled by the location of the underlying West Alberta Ridge.

The depositional cycles defined farther to the north are for the most part readily recognizable in the Flathead-Crowsnest Pass Area.

Formations, Members (Price, 1964, 1965)	**Depositional Cycles**
Alexo, "Sassenach"	Calmar-Blue Ridge
Grotto-Arcs, upper "Peechee"	Nisku
Mount Hawk, Peechee, Borsato	Leduc Cycles (2)
Hollebeke	Beaverhill

The differentiation of the two Leduc cycles is difficult in this area, partly because of structural complications and partly because of discontinuous outcrop. The upper Peechee at South Lost Creek and a tongue of the Peechee which extends basinward north of the Lynx Creek reef (Figs. 15, 17) are probably the Leduc, Upper Cycle based on both stratigraphic position and geometric style.

Whereas the type section of the Mount Hawk Formation only includes beds younger than the carbonates of the Leduc, Upper Cycle it includes beds which interfinger with the Leduc Cycles in the Flathead Range. This usage is stratigraphically inconsistent, although lithologically justifiable.

The bases of the isolated masses of light grey dolomite, (reefs) referred to as the Peechee Member, Southesk Formation are at approximately the same stratigraphic level. The well exposed Peechee margins at South Lost, Goat and Lynx Creek demonstrate interfingering, lateral facies change and reciprocal sedimentation between the Peechee carbonate buildups and the surrounding Mount Hawk Formation. At South Lost Creek approximately 120 m of light grey Peechee dolomite interfinger with 75 m of Mount Hawk section. In this area, if some allowance is made for differential compaction, water depth above the off-reef sediments surrounding the pinnacles was probably more than 30 m deeper than above the tops of the pinnacles. This depth differential was compensated for by extra upper Mount Hawk section which filled in the deeper water areas around the reefs and allowed the overlying Nisku Cycle to be little affected by the presence of the underlying reefs. At South Goat and South Lynx Creek, however, there was enough water depth differential at the top of the Leduc, Upper Cycle, that the Nisku Cycle is draped over and changes facies over the reefs of the underlying Leduc cycles. This probably caused Price to include the Nisku Cycle at these localities within the Peechee Member.

The contact between the Mount Hawk Formation and the Grotto Member is sharp and coincides with an upward change from fine grained argillaceous and silty carbonates to dark, more coarsely crystalline dolomitized skeletal calcarenite (Price, 1964, p. 442). The Grotto grades upward into the overlying light grey coarse crystalline dolomite of the Arcs Member. The Grotto and Arcs Members together are 60 to 75 m thick and constitute the Nisku Depositional Cycle.

The uppermost depositional cycle was referred to as the "Sassenach Formation" by Price (1964, p. 443) and as the Alexo Formation (Price 1965, p. 38). This unit is 5 to 10 m thick where it overlies the Peechee reefs of the Flathead Range, and thickens to slightly more than 30 m above the off-reef areas. It consists of yellow-weathering mudstone, silty dolomite, and sedimentary breccia. Mudcracks are common. Stratigraphic relationships and lithology suggest that this unit is a thin equivalent of the subsurface Calmar-Graminia Formations (Workum, 1988a, p. 545), rather than of the lower Famennian Sassenach Formation. It constitutes the Calmar-Blue Ridge Depositional Cycle in this area.

Biostratigraphy

The Frasnian faunas of the Flathead area are poorly known. Price (1964, 1965) obtained a small fauna from the Upper Member of the Hollebeke Formation which included Atrypa multicostellata Kottlowski, Atrypa sp. Spinatrypa sp., Eleutherokomma reidfordi Crickmay and allied forms, Eostrophalosia sp. H, ?Eosyringothyris sp., Athyris sp., Productella sp. O, Smithiphyllum imperfectum (Smith) and Thamnopora. McLaren (in Price, op. cit) "reported that there is only the most tentative suggestion that the fauna is of Flume age ...", suggesting that the Hollebeke is part of the Beaverhill Cycle.

Price (ibid.) also obtained two separate faunas from the Mount Hawk Formation. The "lower" fauna contained: Calvinaria albertensis (Warren), Atrypa sp. cf. varicostata Stainbrook, Warrenella nevadensis (Walcott), Atrypa sp. cf. devoniana Webster, Cyrtina sp., Leptostrophia sp., Spinatrypa sp. C and Thamnophyllum sp. cf. tructense McLaren; whereas the "upper" assemblage contained: Grunewaldtia americana Stainbrook, Devonoproductus vulgaris Stainbrook, Schizophoria cf. amanaensis Stainbrook, Nervostrophia sp., Gypidula sp. cf. munda Calvin, Mictophyllum sp. cf. modicum Smith, Spinatrypa sp. C, Atrypa sp. M. Thamnophyllum sp. and Tabulophyllum sp. Both suites contain elements of the Calvinaria albertensis fauna. The age of the Mount Hawk of the Flathead area relative to the Mount Hawk of Cline Channel and the Jasper Basin is beyond the resolution of the present zonal schemes, however it appears that the Calvinaria albertensis fauna occurs stratigraphically lower in the Flathead Range than anywhere else in the project area.

FAIRHOLME CARBONATE COMPLEX

The Fairholme Carbonate Complex is the largest and southernmost of the Frasnian platform reefs exposed along the Front Ranges of the Alberta Rocky Mountains (Fig. 1). Prior to thrusting it may have covered more than 20 000 km^2. The areal extent of the complex is defined by the limits of Leduc carbonate cycles. The northwestern flank is the most easily defined, as it abuts basinal clastics of the Cline Channel. Three well defined margins are present at Cripple/North Ram in the First Range, Hummingbird in the Third Range and Whiterabbit in the Fourth Range. From here, the Complex extends some 200 km to the southeast along the mountain front to the Little Elbow River, where Frasnian strata cease to outcrop. It has been assumed that the Fairholme Complex extends southward beneath the thrust belt to the Fernie area of southeastern British Columbia because the succession is still a carbonate buildup where last encountered in outcrop.

The western flank of the Fairholme Complex is not well defined, but approximately coincides with the continental divide south of the Bow River Valley and in the vicinity of Cline Channel. The eastern flank is defined by the eastern limit of outcrop augmented by subsurface control. Three small basinal reentrants are present along the McConnell Thrust Sheet north of the Bow River. These are the Burnt Timber, Red Deer and Scalp Creek Embayments.

Internal Stratigraphy

Internal stratigraphy and sedimentology are discussed in terms of the five major depositional cycles outlined in Figures 7 and 8. For convenience, the Fairholme Carbonate Complex is geographically sub-divided into three areas: the Kananaskis, the Bow Corridor, and the area between Bow Corridor and Cline Channel.

Kananaskis Area - The Kananaskis area is defined as that portion of the Fairholme Complex outcropping between the Little Elbow River to the south and the Bow River Valley to the north. Other than the Fairholme reef distribution map of Woodhead and Wright-Broughton (1967) only Usher (1959) and Workum and Hedinger (1988a) have outlined the Frasnian succession of this area.

The Flume Member (cherty dolomite of Mountjoy, 1965) represents the basal Frasnian transgression of the West Alberta Ridge. It is usually difficult to separate lithologically from the overlying organic dolomites of the remainder of the Cairn Formation (Leduc, Lower Cycle).

In the Kananaskis area, the Flume ranges in thickness from 35 to 45 m. Sections examined along the Fisher Range (Cross-section A-A′) show considerable lithological variation from that of the Flume present farther to the north. The basal 5 to 10 m are characterized by recessive, grey weathering, platy and barren lime mudstone that gives way upsection to the more characteristic stromatoporoid-rich dolomite. Intercalated with these units are two distinctive intervals of very recessive weathering, ochre colored argillaceous dolomite and dolomitized nodular lime mudstone. These beds carry a distinctive macrofauna of thin-shelled brachiopods (including Atrypa) and crinoid debris. The shale beds make useful local marker horizons, but are not present north of Wasootch Creek (Cross-section A-A′). They were probably derived from erosion of local topographic "highs" on the Cambrian erosion surface. The ?top of the Beaverhill Cycle at some locations (e.g. Sections 26-21-8 Fisher Peak East, 26-22-8 Bryant Lake) is marked by an interval of golf-ball sized oncolites. This horizon also occurs at approximately the same stratigraphic level farther to the north in the Burnt Timber and Scalp Creek Embayments.

Although biostromal stromatoporoid banks are an important constituent of the Cairn in some areas of the Kananaskis (e.g. Cross-section A-A′, Sections 13-21-8 Mt. Romulus; 36-23-9 Mt. Lorette) the Leduc, Lower Cycle of this region is normally dominated by more open marine (?deeper water) dolomitized lime mudstone in which the dominant reef-builders were branching rugose corals. Coralline patch reefs are common in the upper portion of the Cairn in the Fisher and Kananaskis Ranges (Workum and Hedinger, 1988a, Figs. 2 to 6). They form massive, pale grey weathering, mound-like features that stand out in marked contrast to the dark brown-grey weathering Cairn dolomite (Fig. 20). Dolomitization precludes the identification of the coral fauna beyond the genus level. Coral biostromes also occur throughout the upper 35 m of the Cairn at Mount Buller (Section 27-22-10). Here these sediments could be mistaken for the younger Grotto Member of the Southesk Formation were it it not for their lower stratigraphic position.

At Fortress Mountain (Section 31-21-9), the upper 50 m of the Lower Leduc consist of dolomitized nodular and argillaceous lime mudstone that carries a fauna of brachiopods and crinoids. This assemblage is usually associated with open marine conditions, suggesting that this portion of the Cairn was either an open marine bank or a deep lagoonal setting analogous to that of the Owen Creek bioherm (Workum and Hedinger, 1988c).

The Cairn ranges in thickness from 150 to 230 m in the Fisher Range, with the latter values almost certainly caused by intra-Cairn thrust repetitions. Calcitization associated with this faulting has produced resistant, pale grey masses of coarsely crystalline calcite which superficially resemble biologically produced reefs (Workum and Hedinger, 1988a).

Thick to massive-bedded, resistant, pale grey weathering dolomites of the Peechee Member, Southesk Formation are characteristic of the Leduc, Upper Cycle in the Kananaskis area. Dolomitization has obscured most of the primary sedimentary textures. By analogy with other areas, the original sediments were most probably carbonate sand and mud. At several locations within Fisher Range (Cross-section A-A′, Sections 13-21-8 Mt. Romulus; 15-22-8 Canyon Creek) the Peechee contains identifiable colonial rugose corals, and at Fisher Peak itself (Section 26-21-8) most of the Peechee consists of colonial rugosan biostrome.

Sediments of the Nisku Cycle consist of a lower, dark brown, bituminous dolomite (Grotto Member) and an upper, pale grey weathering, well-bedded dolomite (Arcs Member). These units do not differ markedly from their counterparts in the Bow Corridor area (see below).

The topographic expression of the Calmar-Blue Ridge Cycle in the Kananaskis is a 40 to 50 m thick covered interval separating the massive, resistant carbonates of the Southesk and Palliser Formations. The interval consists of interbedded, variably silty and sandy dolomite and minor limestone assigned to the "Alexo Formation". In the western Front Ranges (Cross-section B-B′), the succession is considerably thicker and readily divisible into three mappable units.

Bow Corridor - Beach (1943) originally named the Fairholme formation for Upper Devonian sediments exposed along the Fairholme Range in the Bow River Valley (Fig. 22). Since that time, most sedimentological studies of the carbonates of the Fairholme Complex have come from several readily accessible outcrops on either side of the Bow River valley between the First Range and Banff, Alberta. Table 3 summarizes the main localities and the studies relating to each of them.

TABLE 3: Selected Bibliography for Bow Corridor Outcrops

Locality	General Location	Comments
1	Rundle Range above Canmore (Grassi Lakes/Whiteman Gap and vicinity).	deWit & McLaren (1950), McLaren (1956), Belyea & McLaren (1956, 1957a), Desbordes & Maurin (1974),Burrowes (1979), Hunter, Bloy & Leggett (1986).
2	Lac des Arcs	Belyea & McLaren (1956), Taylor (1957), Jin (1987).
3	Loder Lime	Belyea & McLaren (1956), Taylor (1957), Jin (1987), Beach (1943).
4	Sawback Range	Beales & Brown (1963).

TABLE 4: Upper Leduc Diastemic Shale Beds, Bow Corridor

Locality	Lat & Long	Comments
Spray Lakes Road	51°04'30"N 115°11'15"W	Located low in the Peechee along the Spray Lakes Road directly above the valley in which the Grassi Lakes outcrops occur. Apparently not present within the type Peechee which outcrops in a gully within a kilometre of this section.
Lac des Arcs	51°02'45"N 115°11'15"W	Exposed in a road cut on the southeast side of the Trans-Canada highway. Discontinuous bed ranging in thickness from 0 to 50 cm. Basal contact with Peechee rusty weathering. Occurs high in Peechee.
Loder Lime	57°04'45"N 115°05'45"W	Occupies metre thick covered interval in basal third of Peechee exposed on skyline ridge above the Loder lime Plant (Section 36-24-10).

In Bow Corridor, the Flume Member (Beaverhill Cycle) is difficult to distinguish from the overlying upper Cairn (Leduc, Lower Cycle) because the lithologies are similar. The presence of abundant chert has often been used to distinguish the former from the latter.

The Leduc, Lower Cycle is represented by thick to massive-bedded, resistant, dark brown-grey weathering organic dolomites of the upper Cairn. Detailed sedimentologic studies have been carried out by Desbordes and Maurin (1974), Burrowes (1979), Hunter et al. (1985), Jin (1987) and Bloy et al. (1988). The Cairn in this area carries particularly well developed stromatoporoid banks composed of globular and bulbous forms enclosed in a dolomitized mudstone matrix. The exposures at Grassi Lakes (Table 3, locality 1) can leave the impression that most of the Cairn is typified by this lithology. A persistent horizon of pale grey weathering, low relief bioherms is well developed in the lower third of the Cairn in the Rundle Range near Canmore and has been documented by Desbordes and Maurin (1974), Hunter et al. (1985) and Bloy et al. (1988).

The Leduc, Upper Cycle is represented by the Peechee Member of the Southesk Formation. Its type section is located at the southeast end of Mount Rundle (Belyea and McLaren, 1957a), just above the Spray Lakes road. Here the Peechee is 61.3 m thick and consists of resistant, thick to massive bedded, pale grey weathering, coarsely crystalline dolomite. As is the case in other areas, intense dolomitization has obliterated most of the primary sedimentary fabrics.

At several different localities in the Bow Corridor, diastemic shale beds occur at different stratigraphic levels within the Upper Leduc (Table 4). These are characterized by thin, discontinuous beds of pale greenish-grey dolomitic mudstone or shale sandwiched between the massive Peechee dolomites. The shales range in thickness from a few centimetres to over one m. Where examined (Fig. 21), they invariably have sharp lower and upper contacts and do not appear to intertongue with the carbonates. The origin and significance of these thin clastic units may be analogous to the more widely known green shale breaks within the Swan Hills reef complexes of the central Alberta subsurface (Fischbuch, 1968; Havard and Oldershaw, 1976; Wendte and Stoakes, 1982).

The Nisku Cycle is represented by the Grotto and Arcs Members of the Southesk Formation, the type sections of which are also located at the southeast end of Mount Rundle (Belyea and McLaren, 1957a). Here, the Grotto is 48.8 m thick and consists of bituminous, dark brownish-grey weathering dolomite with a few interbeds of Amphipora mudstone to wackestone. This lithology is not typical of the "coral bed" facies which is developed farther to the north (McLaren, 1956) and may represent a more ?restricted facies of the Grotto. The Arcs is 74.3 m thick and consists of resistant, light grey weathering, well-bedded dolomite of similar appearance and origin to the Peechee Member.

Within the eastern Front Ranges, sediments of the latest Frasnian Calmar-Blue Ridge Cycle consist of variegated mudstone, siltstone and silty to sandy carbonate of the "Alexo Formation". The unit is generally 50 to 60 m thick and, as in the Kananaskis area farther to the south, usually forms a recessive saddle between the massive carbonates of the Southesk and Palliser Formations (Figs. 22, 29). A good representative section is present above the Loder Lime plant (Section 36-24-10; Fig. 22) where basal beds equivalent to the Calmar Formation are unusually well exposed.

In the western Front Ranges, Usher (1959) first noted that the "Alexo" interval was 50 to 100% thicker and could be readily subdivided into lower and upper arenaceous units separated by a thick, light grey weathering dolomite unit. Beales and Brown (1963) described such a section along the Sawback Range west of Banff townsite. Here the "Alexo" is approximately 125 m thick. The middle dolomite unit is 60 m thick and contains poorly preserved remains of ?branching corals and crinoids. Their section ties in well with the Mount Black Prince outcrops (Section 30-20-9 and Cross-section B-B′) in the western portion of the Kananaskis area. Here the "middle carbonate" is of approximately the same thickness and carries Megalodon coquinas and common interbeds of coarse skeletal debris.

This expanded "Alexo" of the western Front Ranges is analogous to the Simla/Sassenach succession that comprises the Calmar-Blue Ridge Cycle northwest of Cline Channel. The basal arenaceous unit is equivalent to the Calmar Formation, the "middle carbonate" is equivalent to the Simla and the upper arenaceous unit is equivalent to the Sassenach Formation. The thickened Calmar-Blue Ridge Cycle present in the western Front Ranges of the Kananaskis-Bow Corridor area suggests that it was originally located on the western flank of the West Alberta Ridge, whereas the eastern Front Ranges, with their thinner, condensed "Alexo" straddled the crest of the West Alberta Ridge.

Bow Corridor to Cline Channel - The bulk of the Fairholme Complex north of the Bow Corridor is situated within the confines of Banff National Park, and has received little study, save for the outcrops along the McConnell Thrust Sheet, the crest of which forms much of the eastern boundary of the park. Geological descriptions within this area are limited to the northern margins of the Fairholme Complex in the vicinity of Cline Channel, and to the basinal embayments present along the McConnell Thrust Sheet.

Reefoid Frasnian sediments cease to outcrop southward in the vicinity of the Little Elbow River (Fig. 2). When next observed, exposures along the Flathead Range near Fernie, British Columbia (Price, 1964; Workum, 1988a) are limited to a pinnacle reef tract within a basinal setting. The actual location of the southeastern margin of the Fairholme Complex is not known, although the lack of outcrops southeast of the Little Elbow River may indicate that a relatively incompetent Fairholme section is present beneath the outcrop belt.

Southwestern Flank

In the western Front Ranges, Usher (1959), Woodhead and Wright-Broughton (1967) and Price and Mountjoy (1972a, 1972b) mapped a Southesk bank margin in the vicinity of Fatigue Mountain (NTS 82O/4 at 51°02′10″N; 115°41′W). Here the Southesk (?Leduc, Upper Cycle and ?Nisku) is replaced basinward by dark, argillaceous lime mudstone and shale probably equivalent in age to the Mount Hawk Formation.

To the southwest, the Fairholme Carbonate Complex bordered the open ocean of the Cordilleran Geosyncline ("Sassenach Depression" of Geldsetzer et al. 1987) (Fig. 1). The actual margin of the complex has never been accurately mapped and the bank-to-basin transition zone may be gradational.

South and west of the Bow Corridor and within the Kananaskis area, the margin approximately coincides with the continental divide (Usher, 1959; Woodhead and Wright-Broughton 1967; McMechan, 1989). Immediately west of the divide near the headwaters of the Palliser River a thick interval of basinal, black, argillaceous, limestone and calcareous shale presumably equivalent to the entire Frasnian succession is present. This is overlain by approximately 125 m of brownish weathering variably argillaceous silty and sandy carbonate equivalent to the Sassenach Formation. The Frasnian section in the next thrust sheet to the east (McMechan, 1989) is wholly reefal.

North of Bow Corridor, the southwestern flank is poorly defined, although Mountjoy (1978, 1980) stated that it roughly coincided with the continental divide.

Northeastern Flank

The northeastern flank of the outcropping portion of the Fairholme Carbonate Complex is defined by the McConnell Thrust. From the Bow Corridor to the Cline Channel, the Complex is pierced by three small basinal re-entrants (Figs. 1, 2; Cross-sections C-C′; D-D′) termed the Burnt Timber, Red Deer and Scalp Creek Embayments. All three are only present along the First Range.

<u>Burnt Timber Embayment</u> - The most southerly of the basinal reentrants along the northeastern flank of the Fairholme Carbonate Complex is the Burnt Timber Embayment, which outcrops at the headwaters of North Burnt Timber Creek (NTS 82O/6 Lake Minnewanka). The southern margin is situated at 51°26′N; 115°26′W, whereas the northern margin is located at 51°29′N; 115°29′W (Fig. 23).

Edgar (1960) first recognized the presence of basinal sediments within the Burnt Timber Embayment and described the isolated Leduc, Lower Cycle pinnacle reef within it. Dooge (1966, Figs. 51, 56) described the southern margin of what he termed the "Clearwater Embayment" and illustrated the prominent Leduc, Lower Cycle reef toe. Subsequently published geological maps (Woodhead and Wright-Broughton, 1967; Price and Ollerenshaw, 1971a) incorrectly showed carbonates of the Fairholme Complex stretching unbroken from Bow Corridor to Cline Channel. Both Mountjoy (1978, 1980) and Workum (1978) noted the presence of the Burnt Timber Embayment on regional reef distribution maps. Brief outlines of the stratigraphy and sedimentology have been published by Workum and Tebbutt (1984), Tebbutt and Weissenberger (1987) and Workum and Hedinger (1988b).

The Flume Formation (Beaverhill Cycle) is 35 to 45 m thick adjacent to, and within, the Burnt Timber Embayment. Whereas the basal few metres show evidence of deposition under very shallow marine conditions (interbedded dense lime mudstone and flat pebble conglomerate), the bulk of the succession consists of dark grey, recessively weathering, variably argillaceous lime mudstone and nodular lime mudstone with common brachiopods. Thin globular stromatoporoid biostromes are present, but constitute only a minor lithofacies. Unlike Beaverhill Cycle sediments found within other basinal areas (i.e. Cline Channel, Jasper Basin), the Flume within the Burnt Timber Embayment is in a basinal, lithofacies composed of interbedded open marine shale and limestone.

The Leduc, Lower Cycle is equivalent to the Upper Member of the Cairn Formation. Along both margins of the Embayment these dolomites are in a light grey weathering, Peechee-like lithology (Figs. 24, 28). Bank-to-basin relationships are particularly well exposed at the southern margin of the Burnt Timber Embayment, in the vicinity of Mount Oliver. Here the Cycle is represented by a massive reef flank and toe stretching some 500 m into the Embayment (Cross-Section C-C'; Fig. 24). The upper surface of the toe dips basinward at an angle of 20°, and is commonly encrusted with colonies of <u>Receptaculites</u> (Pratt and Weissenberger, 1988; Workum and Hedinger, 1988b, Fig. 10). Fragments of these organisms can be found within bank-derived debris flows 4.5 km northwest of the bank margin (Cross-section C-C'; Section 10-29-11). The toe itself is composed of allochthonous carbonate debris ranging from calcarenites to larger blocks and boulders (Fig. 25). Debris sheets derived from the upper portion of the toe (Fig. 24) interfinger with dark, bituminous dolomitized mudstone of the Perdrix Formation, indicating that some of the basin-fill was in part coeval with the upper portion of the bank.

Stratigraphic relationships at the northern margin (Figs. 27, 28) are similar. Here the Lower Leduc is composed of thick sheets of dolomitized, bank-derived, bioclastic sand and gravel interbedded with intervals of in situ stromatoporoid boundstone. These beds dip basinward at angles of up to 20°.

Basinal sediments consist of up to 150 m of dark grey to black, recessive weathering, platy to thin-bedded, cherty, bituminous lime mudstone, argillaceous lime mudstone and minor calcareous shale of the Perdrix Formation.

Debris flows derived from the adjacent bank margin (Workum and Hedinger, 1988b, Fig. 10) punctuate this otherwise monotonous succession. The beds carry a sparse fauna of tentaculitids and brachiopods. These sediments are dolomitized proximal to the margins of the Embayment.

The bulk of the Leduc, Lower Cycle reciprocal basin fill was locally derived and deposited after the banks had ceased vertical growth. This is well documented at the northern margin (Fig. 28), where the Perdrix onlaps and interfingers with the bank margin.

An isolated pinnacle reef occurs within the Burnt Timber Embayment about two km northwest of the southern margin (51°27'N; 115°27'W; see also Workum and Hedinger, 1988b, Fig. 5). The feature is approximately 150 m thick and is entirely encased in basinal clastics of the Perdrix. It is composed of massive, resistant weathering, nearly featureless light grey dolomite (Fig. 26).

Light grey, well bedded dolomites of the Upper Leduc and Nisku Cycles prograde over the entire Burnt Timber Embayment (Cross-section C-C'). Gross subdivision of these cycles can best be observed at the northern margin (Fig. 28), where the succession is some 110 m thick. As no typical dark brown Grotto facies dolomites are developed near the northern margin, it is difficult to define the Leduc/Nisku contact with certainty.

The Calmar-Blue Ridge Cycle is represented by 45 m of recessively weathering, interbedded quartz siltstone, silty lime mudstone and solution breccia of the "Alexo Formation".

<u>Red Deer Embayment</u> - McLaren (1956, p. 15) and Taylor (1957a) both noted the presence of basinal sediments (Perdrix and basal Mount Hawk) within the Fairholme Carbonate Complex at Red Deer Gap in the Front Range (NTS 82O/11 @ 51°41'N; 115°25'W). McLaren (ibid.) reported " ... an interesting development of about 190 feet (58 m) of black shale and argillaceous dolomite at the top of the Cairn formation ... As this is an isolated occurrence, this facies is merely distinguished as a separate member of the Cairn formation, rather than Perdrix, of which, however, it is an undoubted equivalent, both lithologically and faunally." On his Figure 2, he showed a further development of argillaceous (open marine) dolomite within the basal Peechee (Leduc, Upper Cycle). McLaren (ibid.) indicated that these basinal sediments carried brachiopod faunas diagnostic of Perdrix and basal Mount Hawk age. These basinal sediments were not recorded on the subsequently published geological map of the area (Ollerenshaw, 1966).

Based on these limited data and Section 30-31-10 it is apparent that a basinal reentrant of unknown lateral extent exists in the Red Deer River area. The lower (Perdrix) portion appears to be lithologically and faunally similar to the basinal sediments infilling the Burnt Timber and Scalp Creek Embayments, whereas the argillaceous dolomites that appear to be developed within the basal Peechee interval imply that a portion of the Upper Leduc is also in a more open marine facies. Unlike the Burnt Timber and Scalp Creek Embayments there is no obvious Peechee lithology rimming the flanks of the Red Deer Embayment.

Scalp Creek Embayment - The Scalp Creek Embayment (Figs. 29 to 31; Cross-section D-D') is the most northerly of the basinal reentrants recognized along the northeastern flank of the Fairholme Carbonate Complex. The feature is 14 km wide and is well exposed along the McConnell Thrust Sheet between Willson Creek and the Clearwater River. The southern margin is located at 51°49'N; 115°29'W (NTS 82O/14) whereas the northern margin is situated at 51°53'N; 115°36'W (NTS 82O/13). This feature was first identified on a reef distribution map published by Workum (1978). Earlier geological maps prepared by Woodhead and Wright-Broughton (1967), Ollerenshaw (1969) and Price and Ollerenshaw (1971b) show this area as being underlain by carbonate sediments of the Fairholme Group.

The Flume Member (Beaverhill Cycle) is 46 to 53 m thick and is readily divisible into two units. The lower consists of very recessive, poorly exposed, thin-bedded dark weathering lime mudstone, whereas the upper consists of resistant weathering, medium to thick bedded limestone. At two of three measured sections (Cross-section D-D'; Sections 10-33-11; 36-33-12) the contact between the two is marked by a thin horizon of sedimentary breccia. Globular stromatoporoid biostromes are well developed within the upper Flume underlying the adjacent carbonate bank whereas the same interval within the Embayment is characterized by interbedded lime mudstone and Amphipora wackestone/packstone. The top of the Flume within the Embayment is marked by a bed containing large algal oncolites.

Thick to massive bedded, resistant weathering, dark organic dolomite of the Cairn Formation (Upper Member) characterizes the Leduc, Lower Cycle on the adjacent carbonate banks. Near the margins of Scalp Creek Embayment, these units undergo facies change into light grey, resistant Peechee-like dolomite.

At the northern margin (Fig. 30), light colored Peechee reef toes can be clearly seen to interfinger with dark, recessive, dolomitized basinal mudstone. At the southern margin the bank-to-basin transition is obscured by talus, but the entire Lower Leduc interval is in light grey Peechee-like facies.

Basinal sediments within the Scalp Creek Embayment are confined to the Lower Leduc and consist of approximately 230 m of dark recessive weathering, thin-bedded and nodular lime mudstone, argillaceous lime mudstone and black, calcareous shale (Figs. 29, 30; Cross-Section D-D', Section 36-33-12). Nodules and stringers of black chert are common in some intervals. The fauna consists of rare solitary rugose corals, brachiopods and crinoids. Tentaculitids are abundant in the basal 20 m. This basinal sediment is dolomitized in the vicinity of the bank margins. The contact between the Leduc, Lower Cycle basin fill and the Leduc, Upper Cycle is readily picked at the upward change from argillaceous lime mudstone to dolomitized coral-rich biostromes.

All of the basinal sediments were probably locally derived (Workum and Hedinger, 1988b) from the adjacent carbonate banks and are presumably equivalent in age to the Perdrix Formation.

The Leduc, Upper Cycle consists of approximately 60 m of resistant weathering biostromal dolomite that was deposited over both the carbonate bank and the basinal sediments infilling the Embayment (Cross-section D-D'; Fig. 29). The unit consists of interbedded light grey weathering, coarsely crystalline dolomite and dark brown (Grotto-like) organic dolomite that carries branching rugose corals and Euryamphipora. The darker interbeds are only developed over Lower Leduc basinal carbonates.

The Nisku Cycle at Scalp Creek is approximately 60 m thick and consists of a lower, dark brown coral-rich (disphyllid-thamnoporoid) dolomite (Grotto Member) overlain by massive, light grey weathering dolomite (Arcs Member). In some areas the Arcs contains recognizable corals, crinoid debris and skeletal sands.

The Calmar-Blue Ridge Cycle ("Alexo Formation") disconformably overlies the Nisku Cycle and forms a recessive, commonly talus and grass covered slope beneath the overlying Palliser Formation (Figs. 29, 31). This unit was mapped as the Mount Hawk Formation within the Scalp Creek Map Area (NTS 820/13) by Price and Ollerenshaw (1971b, 1971c).

The basal 15 m consist of interbedded medium green and red mudstone and fine siltstone equivalent to the Calmar Formation. These are gradationally overlain by slightly more resistant light grey silty dolomite and solution breccia.

Northwestern Flank

At the northwestern margin of the Fairholme Carbonate Complex, Leduc age carbonates are abruptly juxtaposed with basinal clastics infilling Cline Channel. The nature and style of the bank-to-basin transition zone can be studied along three different thrust sheets in the Front Ranges southeast of Lake Abraham (Figs. 1, 2). These are:

Margin Name	Thrust Sheet	Location
Cripple/North Ram	McConnell Thrust (First Ram Range)	NTS 83C/1 52°09'30"N; 116°05'W (Cripple) 52°11'N; 116°08'30"W (North Ram)
Hummingbird	Bare Thrust (Third Ram Range)	NTS 83C/1 52°04'N; 116°12'30"W
Whiterabbit	Sulphur Mtn Thrust (Whiterabbit Range)	NTS 83C/1; 82N/16 52°00'15"N; 116°16'30"W

Geological maps of the Whiterabbit Creek sheet (83C/1) (Mountjoy, Price and Aitken, 1974a, 1974b) did not identify either the Cripple/North Ram or the Hummingbird margins.

Detailed stratigraphic-sedimentologic descriptions of the Leduc and Nisku Cycles at each of the three margins follow. The sedimentology of the oldest (Beaverhill) and the youngest (Calmar-Blue Ridge) Cycles are summarized separately as little variation occurs in these units along the three margins.

Platform carbonates of the Beaverhill Cycle underlie both the Fairholme Complex and the adjacent Cline Channel. Within the carbonate bank they are represented by the Flume Member of the Cairn Formation, whereas in Cline Channel the same beds are termed Flume Formation (Figs. 48 to 50).

The Flume underlying the northern portion of the Fairholme Complex averages 35 m in thickness (Dooge, 1966, 1978; Harrison and Jackson, 1978) and consists of dolomitized reefoid carbonates that can be subdivided into three distinct microfacies. The lower portion of the Flume is characterized by cyclic alternations of dolomitized (1) dark, Amphipora-rich lime mudstone and (2) light grey, barren to finely laminated lime mudstone indicative of shoaling upward (subtidal to ?supratidal) conditions. In the upper Flume, microfacies (1) dolomites are interbedded with microfacies (3) globular stromatoporoid biostromes. Stringers and nodules of dark grey to black chert occur throughout and the stromatoporoids are commonly partially silicified. The top of the Beaverhill Cycle within the carbonate domain has been considered to be synonymous with the "top of the chert" (Dooge, 1966, 1978; Mountjoy, 1980). While the stratigraphic consistency of this definition is open to question, it is a useful field mapping criterion.

The Calmar-Blue Ridge Cycle is represented by 45 to 50 m of interbedded, recessively weathering variegated mudstone, siltstone, variably silty carbonate and minor solution breccia assigned to the "Alexo Formation". The Calmar is readily identifiable as a recessive interval consisting of interbedded light grey-green argillaceous mudstone and very fine quartzose siltstone. Mud cracks and ripple marks indicative of shallow marine to supratidal conditions are occasionally preserved (Plate 1a). It disconformably overlies carbonates of the Nisku Cycle and is conformably and gradationally overlain by light grey weathering intertidal to supratidal carbonates.

The entire Calmar-Blue Ridge Cycle in the vicinity of Cline Channel was deposited under restricted marine, peritidal conditions, and has not, as yet, yielded any diagnostic fossils.

Cripple/North Ram Margin - The Cripple/North Ram margin of the Fairholme Carbonate Complex is exposed along the McConnell Thrust Sheet in the vicinity of Cripple Creek and the North Ram River. This bank-to-basin transition has been previously termed the "Cripple Creek" margin, as past workers were most interested in the backstepping "Middle Leduc" margin exposed in the valley of Cripple Creek. In reality, three distinct Leduc edges are inferred to be present along the First Range (Fig. 48), with the upper two being exceptionally well exposed. The term Cripple/North Ram margin is proposed to better geographically designate the known Leduc margins within the First Range.

With the possible exception of the southeastern margins of the Miette and Ancient Wall Carbonate Complexs, the Cripple/North Ram margin is the most thoroughly studied Leduc reef margin within the project area. Published studies include: McLaren (1956); Belyea (1958); Dooge (1966, 1972, 1978); Workum (1978, 1983); Eliuk, Dooge and Andrews (1987); Workum and Hedinger (1987); Eliuk (1988), Weissenberger (1988) and Wong et al. (1989).

Bedrock geological mapping (Mountjoy, Price and Aitken, 1974a, 1974b) did not locate either the Cripple or the North Ram Leduc margins. The Peechee Member was shown to extend 18 to 20 km northwest of its known limit, whereas the Mount Hawk was shown to underlie the Peechee, when in fact the reverse is true.

The northwestern margin of the Fairholme Carbonate Complex exposed along the McConnell Thrust Sheet suggests that the Leduc, Lower Cycle may consist of two third order cycles. A modified terminological scheme for this area is shown in Table 5. These cycles may occur within the Leduc, Lower Cycle elsewhere, but simply lack stratigraphic expression.

The Leduc, Lower Cycle "A" constitutes the initial backstep of the carbonate platform in response to the transgression at the start of Leduc time. It forms the Cairn or "Leduc" platform (Workum, 1978) of dark brown, organic dolomite present at both Cripple Creek (Cross-section E-E'; Figs. 34 to 36) and North Ram River.

Faunas and lithofacies are similar to those found in the upper part of the Flume (Dooge, 1966, 1978). The upper surface of this platform occasionally shows evidence of a transgressive or deepening event during late Lower

TABLE 5

Leduc Cycle Terminology, Cripple/North Ram Margin
Fairholme Carbonate Complex

Workum & Hedinger Depositional Cycle	Geographic Location of Bank Marginor Ramp	Published References
LEDUC, Upper Cycle	North Ram River Gap 52°11'N 116°08'30"W	Dooge (1966, 1972, 1978; = Ram Member) McLaren (1956) Workum & Hedinger (1987)
"B" LEDUC, Lower Cycle	Cripple Creek 52°09'30"N 116°05'W	McLaren (1956) Belyea, (1958) Dooge (1966, 1972, 1978) Workum (1978b) Eliuk et al. (1987) Workum & Hediner (1987) Andrews (1988) Eliuk (1988) Weissenberger (1988) Wong et al. (1989)
"A"	unknown	none

Leduc "A" time. At both Cripple Creek North (Section 8-37-15) and North Ram Gap (Section 13-37-16) the globular stromatoporoid bank is abruptly overlain by stromatactis-rich carbonate muds, followed by basinal clastics of the Perdrix.

The Lower Leduc "A" platform thins perceptibly to the northwest into Cline Channel (Cross-section E-E'). Thinning may have been accomplished by lateral facies change into the Perdrix, or the entire Lower Leduc "A" Cycle might simply represent a low angle ramp.

In the vicinity of Kiska Creek (Cross-section E-E') a small, low relief ?bioherm composed of light grey, Peechee facies dolomite is present. The reef may be rooted on the Flume platform or on a distal toe of the Lower Leduc "A". Pratt and Weissenberger (1988, p. 511) noted the occurrence of a small Receptaculites mound in the general vicinity of this feature.

The "Cripple Creek Margin" of the Fairholme Carbonate Complex is exposed where Cripple Creek intersects the First Ram Range (Fig. 2). Stratigraphically, this margin occurs within the upper portion of the Leduc, Lower Cycle and is provisionally termed the Lower Leduc "B". The reef margin (Figs. 35, 36) is in light grey Peechee facies. The juxtaposition of dark and light lithofacies within the upper Cairn stratigraphic interval has, in the past, led to confusion in resolving the actual stratigraphic position of this margin (e.g. Dooge (1966) assigned this margin to the Southesk Formation).

Although the reef-to-basin transition at Cripple Creek can be diagnosed as a simple "back-stepping" margin (Eliuk, 1988), the attendant facies changes are more complex (Fig. 35) and have been discussed at length by Belyea (1958), Dooge (1966, 1972, 1978), Workum (1978), Eliuk, Dooge and Andrews (1987); Workum and Hedinger (1987), Eliuk (1988), Weissenberger (1988) and Wong et al. (1989). The margin has come to be considered the archetypical example of a leeward Leduc reef margin because of its transitional nature and the debris apron developed in front of the reef margin itself (Fig. 35). The obvious forsetting beds in this talus apron (Fig. 35) lack correlative topsets, suggesting that the top of the Lower Leduc "B" is marked by an hiatus or disconformity on the bank itself. Basinal sediments interfingering with this margin are represented by bank-derived carbonate debris and lime mudstone and shale of the Perdrix Formation.

The Leduc, Upper Cycle oversteps the Lower Leduc "B" bank margin and progrades basinward from Cripple Creek to the North Ram River, where it foresets into the upper portion of the Perdrix Formation (Figs. 37, 38, Cross-section E-E'). These relationships are well exposed immediately northwest of North Ram Gap. This biostromal Upper Leduc unit has informally been termed the "Ram Member" of the Southesk Formation by Dooge (1966).

Facies changes associated with the Upper Leduc bank-to-basin transition are complex and begin at South Ram River (Cross-section E-E'; Fig. 33) where dark brown, coral-rich Grotto facies occurs within the upper part of the Upper Leduc interval. At Cripple Creek SE (Figs. 34, 35) the entire Cycle is in Grotto lithofacies. From here, the Upper Leduc progrades basinward over the Lower Leduc "B" bank margin and the adjacent basin fill. In less than one km it changes facies from dark brown, coral-rich dolomite to pale grey weathering, massive and resistant coral-rich limestone (Figs. 36, 37). This Upper Leduc coral biostrome progrades some six km basinward and reaches a maximum thickness of 60 m two km southeast of North Ram Gap where it is easily recognizable by it's massive and resistant weathering habit (Fig. 37). Weissenberger (1988, Fig. 3) incorrectly interpreted this unit as "fore-reef" dolomite.

Immediately southeast of North Ram Gap, the Upper Leduc biostrome becomes distinctly bedded and loses it's resistant weathering aspect (Fig. 37). This is coupled with a gradual change in lithology from coral biostrome to detrital carbonate debris and calcarenite. Taken together, this evidence suggests that the Leduc, Upper Cycle bank margin is being approached. At North Ram Gap, the detrital carbonate beds are interbedded with black lime mudstone and calcareous shale of the Perdrix Formation. Slightly farther to the northwest, the entire Upper Leduc foresets into the upper portion of the Perdrix Formation (Fig. 38). This relationship demonstrates that the Upper Leduc is coeval with the uppermost Perdrix, whereas Weissenberger (1988, Figs. 3, 4) contended that the Upper Leduc actually changed facies into the Mount Hawk Formation. The margin is probably localized by a change in slope within the underlying Lower Leduc "A" ramp and the thickness of the Perdrix basin-fill. The "Basinal Rusty Marker" makes its first appearance at the top of the Perdrix Formation immediately northwest of the distal edge of the Upper Leduc (Cross-Section E-E'; Fig. 43).

Upon the termination of Upper Leduc reef growth, the Cline Channel was infilled with pale green-grey calcareous shale of the lower Mount Hawk Formation. This unit represents the reciprocal basin-fill of the Upper Leduc and throughout Cline Channel is younger than the Leduc carbonates themselves. There are no known localities where Mount Hawk clastics are interbedded with or change facies into either the underlying carbonates of the Leduc or the overlying carbonates of the Nisku. Weissenberger (1988, Fig. 3) incorrectly interpreted both of these contacts as being facies changes. In the final stage of Mount Hawk deposition, shales penetrated some 20 to 30 km into the northwestern margin of the Fairholme Carbonate Complex. This thin clastic wedge was informally termed the "Cripple Tongue" by Dooge (1966).

Within the First Range, carbonates of the Nisku Cycle are 50 to 55 m thick and consist of a lower, dark brown weathering, coralliferous dolomite (Grotto Member) and an upper, well bedded, light grey dolomite (Arcs Member). These units are lateral facies equivalents of one another, with the Arcs being thicker over areas of Leduc carbonate buildup and the Grotto predominating in deeper water areas (Cross-section E-E'; Fig. 48). The facies change from Arcs to Grotto is particularly well exposed immediately basinward of the Cripple margin where its significance was first noted by Belyea (1958).

The Grotto Member is noted for its rich fauna of disphyllids, Thamnopora, and Syringopora. Dolomitization is so severe that the corals can only be identified to genus level. This coral-rich microfacies is well developed over the Leduc banks and extends for some distance into Cline Channel. In the heart of the channel, however, the Grotto changes facies to barren, dark brown, bituminous dolomitized lime mudstone.

Hummingbird Margin - The Hummingbird margin of the Fairholme Carbonate Complex outcrops along the Bare Thurst in the Third Ram Range. The Leduc, Upper Cycle margin coincides with the valley of North Hummingbird Creek, whereas the location of the Leduc, Lower Cycle margin is not known. It's "zero-edge" presumably occurs a short distance northwest of where the North Ram River cuts through the Third Range (Cross-Section F-F').

Few detailed studies have been published on this margin, and none at all on the bank or basinal successions outside of the valley of North Hummingbird Creek. Preliminary descriptions were provided by McLaren (1956), Taylor (1957), Hargreaves (1959) and Wilson (1968).

Slightly more detailed studies were given by Harrison and Jackson (1978), Jackson and Harrison (1982), Workum and Hedinger (1987) and Hedinger and Workum (1988a).

Bedrock mapping of the Frasnian in the Third Ram Range (Mountjoy, Price and Aitken 1974a, 1974b) demonstrates many of the same problems encountered in the First Range. The location of the Hummingbird margin is not indicated and the Peechee (Leduc, Upper Cycle) is shown to extend 18 to 20 km basinward of its known limit. In contrast, shales of the Perdrix Formation are shown to extend 2 to 3 km southeast of their known limit, and the Mount Hawk is again placed beneath the Peechee.

In contrast to the Cripple/North Ram margin, only one third order cycle can be recognized within the Lower Leduc. It comprises that portion of the Cairn Formation above the Flume Member. At North Hummingbird Creek, the Cairn consists of about 135 m of dark brown-grey weathering, finely to medium crystalline, thick to massive bedded dolomite. The dominant sediment types were originally carbonate mud and sand with varying admixtures of coarse skeletal debris. Like the underlying lower portion of the Flume Member, the Cairn at Hummingbird shows a pronounced cyclicity. Harrison and Jackson (1978, p. 41) recognized four dominant microfacies:

(1) dark, barren mudstone
(2) lighter grey, coarsely crystalline calcarenite
(3) Amphipora-rich mudstone
(4) light grey, laminated to mottled? fenestral mudstone

These sediments are indicative of subtidal to supratidal environments in a back reef to lagoonal setting. The Lower Leduc platform (?ramp) drops off gently into Cline Channel and is still some 30 m thick at the North Ram River (Section 25-36-17), eight km northwest of North Hummingbird Creek. The basinward limit of the Lower Leduc has not been located.

The North Branch of Hummingbird Creek cuts through the Leduc, Upper Cycle bank margin. The bank-to-basin transition is covered by the creek valley so that crucial relationships between bank and basinal sediments are not known. The Upper Leduc consists of 65 m of massive, crudely bedded, light grey weathering dolomite (Fig. 39). It is well exposed on the southeast side of North Hummingbird Creek. Dolomitization has obliterated primary textures, but the sediments most probably consisted of interbedded lime mudstone, sand and bioclastic gravel. There is no evidence to suggest that stromatoporoid biostromes were present at the bank margin.

Whereas at the bank margin the Upper Leduc is in Peechee facies, this is not the case within the carbonate complex. At both Canary Creek (Section 18-35-15) and Hummingbird Main Branch (Section 25-35-16) the interval contains interbeds of dark brown Grotto facies dolomite with abundant disphyllid corals, Thamnopora and Syringopora (Cross-section F-F').

On the northwestern (basinal) side of the North Hummingbird Creek valley (Fig. 40), the Peechee has been laterally replaced by an equal thickness of dark grey, recessively weathering argillaceous lime mudstone and shale of the Perdrix. While stratigraphic relationships between the bank and the basin are not known, it is obvious that little coarse detritus was shed from the former because it is not present within the Perdrix on the north side of the valley.

Some 40 m of Mount Hawk shale and siliceous, biolastic limestone overlie both the bank carbonates and the basinal shale of the Perdrix. The "Basinal Rusty Marker" first makes its appearance some 2.5 km northwest of the margin.

At Hummingbird, the Nisku Cycle is 60 m thick and consists of approxmiately equal proportions of Grotto and Arcs facies dolomites (Figs. 39, 40).

Whiterabbit Margin - The Whiterabbit margin outcrops along the Sulphur Mountain Thrust. Exposures occur along a series of steep east-facing cirque walls at or above 2 400 m. The authors have only examined this bank-to-basin transition from the air and the present interpretation is based on a series of sequential photographs augmented by aerial observations. The only measured section is a wholly basinal one located seven km northwest (Section 25-35-17).

McLaren (1956) first noted the presence of a Fairholme reef margin near "Twin Falls Creek" in the Whiterabbit Range. Mountjoy, Price and Aitken (1974a) correctly located the Whiterabbit margin, but included the carbonates of the Nisku Cycle within the Mount Hawk Formation. Hedinger and Workum (1988a) provided outcrop photographs of the margin and gave a brief account of major facies relationships.

The Leduc, Lower Cycle corresponds to the entire Cairn stratigraphic interval minus the Flume Member. The unit consists of massive, resistant, dark brown weathering dolomite. Near the reef margin (Figs. 41, 50) this dark lithology gives way to massive, light grey Peechee facies carbonate. The nature of the facies change between the normal Cairn and the light grey margin is obscured by a steep talus slope, as is the contact between this margin and the lower Perdrix shales. The Lower Leduc margin at Whiterabbit is markedly different from both the Cripple/North Ram and Hummingbird margins in that it occurs in close proximity to the overlying Upper Leduc margin.

Within the carbonate complex, the Upper Leduc is also in dark brown Cairn lithofacies, even though it occurs at the Peechee stratigraphic level. The characteristic Peechee dolomite is only developed in relatively close proximity to the reef margin itself (Figs. 41, 50). As the margin is approached, the Upper Leduc appears to change facies laterally and vertically into light grey Peechee dolomite over the space of approximately one km.

The basal portion of the Upper Leduc toe interfingers with and is overlapped by shale of the Perdrix Formation. The nature of the outcrop is such that it is not possible to observe the stratigraphic relationship between the upper portion of the toe and the Perdrix. The Mount Hawk section also appears to thicken rapidly immediately basinward of the bank margin - a phenomenon that does not occur as quickly at either of the more easterly margins.

Over the studied portion of the Whiterabbit margin, the entire Nisku Cycle consists of Grotto facies dolomite, which was mapped as Mount Hawk Formation by Mountjoy, Price and Aitken (1974b). At Section 25-35-17, the Nisku is 66 m thick and consists of dark brown to black, microcrystalline, thick-bedded, resistant dolomite, with interbeds rich in disphyllids, Thamnopora, solitary corals and Atrypa.

Biostratigraphy

Carbonate strata within the Fairholme Complex are generally too completely dolomitized to yield identifiable material despite the widespread occurence of stromatoporoids within the Beaverhill and Lower Leduc Cycles, and the diverse rugose coral faunas found in both the Leduc Cycles of the Kananaskis area. In a few places within the latter area, McLean and Sorauf (1988) have recognized Pachyphyllum anfractum McLean, Smithiphyllum belanskii McLean and Pedder and Disphyllum in limy interbeds of the Leduc, Upper Cycle. The three basinal reentrants present along the McConnell Thrust Sheet (Burnt Timber, Red Deer and Scalp Creek) are filled with open marine carbonates and calcareous shales of the Flume and Perdrix Formations. In Burnt Timber Embayment, the Flume has yielded Atrypa sp., Eleutherokomma sp. and Smithiphyllum crassatum McLean and Pedder. At Red Deer Gap, McLaren (1956) reported the presence of Calvinaria variabilis insculpta (McLaren) from Perdrix-like lime mudstone high in the Leduc, Lower Cycle, and Calvinaria albertensis (Warren) from similar lithologies in the basal portion of the Leduc, Upper Cycle. Most of the remaining biostratigraphic information comes from the northwestern flank of the Complex where it borders Cline Channel. It is discussed under that heading.

CLINE CHANNEL

The Cline Channel is a linear trough that separates the Fairholme Carbonate Complex from the Southesk Cairn Carbonate Complex (Fig. 42). In the Front Ranges the feature is 30 to 50 km wide and trends at right angles to the West Alberta Ridge. It influenced sedimentation throughout Frasnian time, but the effect was most pronounced during the Leduc Cycles when the trough linked the open ocean to the west with the Ireton Shale Basin to the east and was infilled with basinal clastics of the Perdrix and lower Mount Hawk Formations. The origins and tectonic significance of this feature are not understood.

Beaverhill Cycle

Within Cline Channel the Beaverhill Cycle is represented by dark, well bedded, resistant weathering carbonates of the Flume Formation. The unit is somewhat thinner and less fossiliferous than the Flume Member underlying the adjacent carbonate complexes. It consists of interbedded lime mudstone and Amphipora-rich mudstone. Subspherical and globular stromatoporoids are also present, though not in the numbers found in the adjacent banks.

The subtle thickness and facies variations between the Flume platform of the Fairholme and Southesk Cairn Complexes and the Flume Formation within Cline Channel indicate that the factors which localized Cline Channel were already active in earliest Frasnian time.

Leduc (Lower and Upper Cycles)

During Leduc time (Lower and Upper Cycles) the Cline Channel received two different types of clastic basin fill. The Perdrix Formation (Duvernay equivalent) consists of dark grey to black organic-rich, recessively weathering, platy lime mudstone and calcareous shale deposited under starved basin conditions during the time of Leduc reef growth. The sediments were derived, for the most part, from the carbonate buildups themselves. Like the subsurface Duvernay Formation, the Perdrix is more highly radioactive than the shales of the overlying Mount Hawk Formation (Ireton equivalent). The Perdrix reaches a maximum thickness of between 125 to 150 m in the heart of Cline Channel. (Figs. 43, 45, 48 to 50). It carries a depauperate macrofauna of brachiopods, small pelecypods and tentaculitids and lies within McLaren's (1962) Calvinaria variabilis insculpta Zone.

Within Cline Channel, the Perdrix Formation is commonly capped by five to 20 m of hard, siliceous bright orange to rusty-brown weathering, pyritic, phosphatic lime mudstone. This unit is easily mappable (Fig. 43) and makes an excellent local marker horizon. It was informally termed the "Basinal Rusty Marker" by Workum and Hedinger (1987), but has received only passing mention in the literature (Krause, 1984; Eliuk, 1988). The "Basinal Rusty Marker" carries a prolific macrofauna of bryozoans, brachiopods, sponges, nautiloids, ostracoderm plates and rare corals. The unit represents a period of starved basin deposition during late Perdrix time and is coeval with a portion of Leduc, Upper Cycle sedimentation.

The Mount Hawk Formation (Ireton equivalent) consists of up to 150 m of pale grey-green, recessively weathering calcareous mudstone and shale. The clastics demonstrably post-date Leduc reef growth and fall within McLaren's (ibid.) Calvinaria albertensis Zone. These clay-rich sediments were extrabasinally sourced in the manner suggested by Oliver and Cowper (1963) and Stoakes, (1981). They infilled the remaining basinal portions of Cline Channel and onlapped the flanks of the adjoining Fairholme and Southesk Cairn Carbonate Complexes (Figs. 33 to 37, 39 to 41, 48 to 50). In the latter areas, the Mount Hawk has been informally termed the "Cripple Tongue" (Dooge, 1966, 1972, 1978; Harrison and Jackson, 1978) or the "Cripple Member" (Weissenberger and McIlreath, 1988). Unlike the remainder of the Mount Hawk in Cline Channel, which is only sparsely fossiliferous, the "Cripple Tongue" carries a rich macrofauna of brachiopods, bryozoans, solitary and colonial rugose corals, tabulate corals, gastropods, crinoids and sponges.

A number of isolated carbonate bodies (mud mounds) are present within the "Cripple Tongue" between the Bighorn Centre Margin of the Southesk Cairn Carbonate Complex and Lake Abraham (Figs. 46, 49). To date five of these features have been identified and are listed below:

Name	NTS Sheet	Location	References
Bighorn Centre	83C/7	52°23'30"N 116°39'15"W	This paper
Bighorn River	83C/7	52°20'45"N 116°35'15"W	Hedinger (1988)
Littlehorn	83C/7	52°18'N 116°31'W	Krause (1984) Workum & Hedinger (1987) Workum (1988b)
Allstones	83C/8	52°16'50"N 116°28'40"W	Workum & Hedinger (1987) Hedinger (1988)
Windy Point	83C/1	52°15'N 116°25'W	This paper

The mounds are usually lens-shaped, a few hundreds of metres wide and from 10 to 30 m thick. They are composed of massive, resistant, crudely-bedded lime mudstone or coalesced nodular lime mudstone which is sparsely fossiliferous (brachiopods, colonial rugose corals, bryozoans and crinoids) and quite cherty. The Allstones feature (Hedinger, 1988) is a coralline patch reef. Some of the mounds had positive topographic relief on the sea floor, and the Littlehorn mound (Figs. 46, 49) probably served as a locus for the growth of a bioherm in the overlying Nisku Cycle. The controlling mechanisms for both the localization and growth of these features are poorly understood.

Similar small carbonate bodies have been observed within the "Cripple Tongue" near the reef-to-basin transition zone of the Bighorn Centre Leduc margin. These may be related to the larger lensoid bodies present farther to the southeast but have yet to be studied.

The age of the Mount Hawk Formation infilling Cline Channel relative to the Mount Hawk of Jasper Basin can best be determined by stratigraphic position. In Cline Channel, the Mount Hawk is underlain by the Perdrix Formation and overlain by sediments of the Nisku and Calmar-Blue Ridge Cycles whereas in the heart of Jasper Basin, it is underlain by the Perdrix Formation and overlain by the Sassenach Formation. Assuming that the top of the Perdrix Formation is coeval in both areas, the Mount Hawk of Cline Channel is equivalent to the lower part of the Mount Hawk of Jasper Basin. This age determination is presently more accurate than one that can be derived using fossils, (see Biostratigraphy for discussion).

Andrews (1988) lumped all outcropping basinal clastics into the Ireton Formation (Mount Hawk equivalent) regardless of whether the sediments actually belonged to the Perdrix or the Mount Hawk Formations. This practice contradicted his own stratigraphic framework (ibid., Fig. 1) and his reasoning behind this nomenclatural change was not explained.

Correlations across Cline Channel are useful in showing relationships of the various reefal phases to the basinal clastics as well as highlighting depositional patterns within the clastic package itself. Such correlations are best drawn at right angles to the trend of the channel, and, if possible, along the same thrust sheet (Figs. 48 to 50); see also Workum and Hedinger, 1987, Fig. 18). This process yields a truer representation of depositional geometries than correlating from one thrust sheet to another.

In the past, such reconstructions had been hampered by the lack of identified Leduc reef margins on the southeastern flank of the Southesk Cairn Carbonate Complex. The commonest rendering of a Cline Channel cross-section (i.e. McLaren, 1956, Fig. 2; Workum and Hedinger, 1987, Fig. 14; Weissenberger, 1988, Fig. 3) linked the Cripple/North Ram margin of the Fairholme Complex with the Wapiabi Gap margin of the Southesk Cairn Complex (Fig. 47). This line of section introduces two false impressions into the sedimentologic model because:

(1) the reef margins are not located on the same thrust sheet i.e. the Cripple/North Ram margin is located on the McConnell Thrust whereas the Wapiabi Gap margin is located on the Bighorn Thrust (Fig. 2), and

(2) the reef margins do not occur in the same paleogeographic settings. The Cripple/North Ram margin is situated on the West Alberta Ridge and faces out into Cline Channel proper. The Wapiabi Gap margin is situated on the southeastern margin of the Southesk Cairn Carbonate Complex and faces into the Ireton Basin.

At Wapiabi Gap there is an anomalously thick (150 m) accumulation of Mount Hawk shale with only a thin sliver of Perdrix underneath, whereas just a short distance basinward of the Cripple/North Ram margin the Perdrix and Mount Hawk are of nearly equal thickness. Cross-sections drawn between these two margins (Fig. 47) show a peculiar "asymetrical" style of basin-fill during Mount Hawk time.

Workers relying solely on this reconstruction have come to some erroneous conclusions on the style of sedimentation and basin fill within Cline Channel. Eliuk (1988, p. 427) stated that "... northwest of North Ram River, gentle (Ireton) clinoforms filled Cline Channel subbasin asymetrically from south to north ..." Weissenberger (1989 p. 101), using a similar line of section, concluded that the "Filling of the Cline Channel was asymetric. Perdrix Formation shale was preferentially deposited on the south side of Cline Channel ... The Mount Hawk Formation was deposited as sigmoidal lobes, with depositional surfaces dipping to the northeast ..."

Both of these studies did not include data from the Leduc reef-to-basin transitions located northwest of Cline Channel. The Bighorn margins are leeward margins in the sense of Cripple/North Ram. Far from being absent, the Perdrix present here is 100 to 125 m thick (Cross-section H-H'). Figure 49 is a schematic cross section along the Bare Thrust from the Hummingbird margin of the Fairholme Complex to the Bighorn Centre margin of the Southesk Cairn Complex. It clearly demonstrates that the Perdrix Formation extends across Cline Channel as a unit of uniform thickness.

Data derived from the three Bighorn margins also indicates that the Mount Hawk shales at Wapiabi Gap are of an anomalous thickness when compared to other southeastern margins of the Southesk Cairn Carbonate Complex. This has led the authors to conclude that the Wapiabi Gap Margin does not face into Cline Channel, but rather forms a protuberance or headland on the southeastern flank of the Southesk Cairn Complex and faces into the Ireton Basin. In such a setting, current action may have prevented the Perdrix from accumulating.

Nisku Cycle

Within Cline Channel, the Nisku Cycle consists predominantly of dark brown, barren, dolomitized mudstone of the Grotto Member, overlain by a thin veneer of light grey Arcs Member dolomite. The entire interval is 50 to 66% thicker than it is over the adjacent Leduc carbonate complexes and extends in pancake-like fashion over the basinal clastics of the Mount Hawk Formation. Although the contact between the Mount Hawk and the overlying Grotto occurs over a few metres, intertonguing relationships between the two units have never been observed.

Reefal developments within the Nisku Cycle occur as either biostromes or bioherms. Both are dominated by colonial rugose corals. Biostromes were first described by McLaren (1956) in the vicinity of Mount Stelfox (Fig. 45). They consist of densely intergrown thickets of disphyllid and thamnoporid corals in a mudstone matrix. Dolomitization and subsequent leaching of the corallites has often produced excellent leached fossil porosity.

Two bioherms have also been recognized within the Nisku of Cline Channel. The Kiska reef (NTS 83C/1 at 52°14'15"N; 116°16'W; Fig. 44) occurs about ten km basinward of the Cripple/North Ram margin of the Fairholme Carbonate Complex (Fig. 48) and has been described by Krause (1984), Workum and Hedinger (1987) and Workum (1988b). It is about 25 m thick and somewhat less than 500 m wide. The reef itself consists of light grey weathering, coral (disphyllid) rich dolomite. The flanks are partially talus-covered, but appear to be steep. The reef is encased by recessively weathering, dark brown, barren dolomitized mudstone of the Grotto. Littlehorn reef (Krause, 1984; Workum and Hedinger, 1987; Workum, 1988b) outcrops about ten km basinward of the Bighorn Centre margin of the Southesk Cairn Carbonate Complex (NTS 83C/7 at 52°18'N; 116°31'W) and appears to be rooted on a mud mound in the uppermost Mount Hawk Formation (Figs. 46, 49; Cross-Section

H-H'). The reef is about 30 m thick and has similar lateral dimensions to Kiska. It is composed of disphyllid coral wackestone-packstone. Flanking beds are again steep, and some debris flows carrying coral fragments are present.

Unlike the underlying Leduc carbonates, which change abruptly into clastics at the margins of Cline Channel, Nisku carbonates were deposited over the entire area. At the conclusion of the Nisku Cycle, very little space remained over this shelf for reciprocal sedimentation. In most places Nisku carbonates (either Grotto or Arcs facies) are disconformably overlain by variegated shale and siltstone of the basal Calmar-Blue Ridge Cycle.

At Littlehorn Creek (Section 34-38-18; Cross-section H-H'; Fig. 46) dark brown dolomitized mudstone of the Grotto is overlain by 25 m of slightly silty, dark, thin-bedded argillaceous dolomite with fish remains and rare brachiopods. This facies bears little resemblance to either the underlying Grotto or the overlying "Alexo Formation", and may represent a local depression infilled with Nisku Cycle reciprocal basin-fill sediments. A similar, though thicker section is developed at Wapiabi Gap Southeast (Section 33-40-17) and at the Gap (Section 36-39-14).

Biostratigraphy

Beaverhill Cycle - The Flume Member (Cairn Formation) underlying the adjacent Fairholme and Southesk Carbonate Complexes contains both stromatoporoids and Amphipora, but little else in the way of diagnostic fauna. Within Cline Channel, the somewhat more open marine platform carbonates of the Flume Formation carry a brachiopod fauna characteristic of the same interval in Jasper Basin. McLaren (1956) reported Eleutherokomma jasperensis (Warren), E. leducensis Crickmay, Allanaria minutilla Crickmay and Atrypa multicostellata Kottlowski from this interval. Pollock (1968) obtained good conodont recoveries from dark limestones that underlie the lower Mount Hawk shale near the base of the section at the North Saskatchewan Gap in the Brazeau Range (Section 36-39-41).

Leduc Cycles - Clastics of the Perdrix and Mount Hawk Formations represent basinal beds of the Leduc Cycles in Cline Channel (Figs. 42, 48 to 50). According to McLaren (1962), the oldest beds of the Perdrix Formation within Cline Channel fall within the Calvinaria variabilis athabascensis Zone, whereas the bulk of the formation lies within the overlying Calvinaria variabilis insculpta Zone. This fauna is characterized by a limited number of brachiopod species including: Calvinaria variabilis insculpta (McLaren) Leiorhynchus carya Crickmay and Warrenella nevadensis (Walcott). Tentaculitids are the only other common faunal element. The rich megafauna present within the uppermost few metres of the Perdrix (i.e. within the "basinal rusty marker") has yet to be described.

The Perdrix is part of the Leduc Cycles based on intertonguing relationships present at the Cripple/North Ram Margin of the Fairholme Carbonate Complex (Figs. 37, 38, 48), and the Bighorn and Job Lake Margins of the Southesk Cairn Carbonate Complex (Figs. 51, 52). Near the Wapiabi Gap Margin of the Southesk Cairn Complex (Fig. 5, 6), reefoid carbonates of the Leduc, Lower Cycle are interbedded with, and override a portion of the Perdrix. Limitations of McLaren's zonation are evident at the Cripple/North Ram Margin, where two distinct Leduc margins can be identified on the basis of stratigraphic relationships (Fig. 48). This same interval is spanned by one brachiopod zone.

In most areas, the lower carbonate beds of the Leduc, Upper Cycle consist of dolomitized lime sand and lime mudstone devoid of diagnostic fossils. However, at the Cripple/North Ram margin of the Fairholme Complex, this unit changes facies basinward to a coralline limestone biostrome which extends some six km basinward of the Leduc, Lower Cycle "B" margin (Figs. 36, 37, 48; Cross Section E-E'). This unit, equivalent to Dooge's (1966) "Ram Member", carries an abundant, well preserved coral fauna. McLean and Sorauf (1988) listed Smithiphyllum grandivesiculosum (Soshkina), Hexagonaria sp. cf. H. inequalis (Hall and Whitfield), Peneckiella densa (Smith), Hunanophrentis praecendens (Stainbrook), Tabulophyllum, Peneckiella and Thamnopora from here. This faunule has yet to be placed within a zonal scheme but is equivalent in age to the uppermost Perdrix.

The lower Mount Hawk shale is the reciprocal basin-fill of the Leduc, Upper Cycle. Throughout much of its thickness in Cline Channel it is represented by barren calcareous, silty mudstone. It is only in the uppermost 30 to 40 m that this situation changes. These beds, equivalent to the "Cripple Tongue" of Dooge (1966, 1972, 1978) and the "Cripple Member" of Weissenberger and McIlreath (1988) carry a prolific and largely undescribed megafauna. Based on faunal lists taken from McLaren (1954, 1956), Warren and Stelck (1956), Raasch (in Dooge, 1966; in Maurin and Raasch, 1972) and McLean and Sorauf (1988), the faunal assemblage includes: Atrypa hackberryensis Stainbrook, A. ciliipes Crickmay, A. sup. J, K, L and M of McLaren, Schizophoria sp. cf. iowaensis, Tenticospirier cyrtiniformis (Hall and Whitfield), Cyrtospirifer whitneyi Hall, Indospirifer cf. orestes (Hall and Whitfield), Devonoproductus walcotti (Fenton and Fenton), Schuchertella cf. parva Hall, Gypidula cf. cornuta Fenton and Fenton, Calvinaria albertensis (Warren), Nervostrophia, Douvillaria, Cranaena, Pugnoides, Hunanophrentis praecedens (Stainbrook), Disphyllum fasciculum (Meek), Smithiphyllum grandivesiculosum (Soshkina), Phillipsastrea woodmani (White), Macgeea proteus (Smith), Peneckiella densa (Smith), Tabulophyllum mcconnelli (Whiteaves), Hexagonaria bassleri bassleri (Webster and Fenton) and undescribed species of Phacellophyllum, Phillipsastrea, ?Mictophyllum, Thamnopora, Syringopora, Aulopora, Alveolites, Cladopora and Coenites. In addition, the unit contains fenestellid and ramose bryozoans, crinoids, echinoderms, gastropods, stromatoporoids, sponges, trilobites and ostracoderms.

According to McLaren (1962) the Mount Hawk Formation of Cline Channel falls within the Calvinaria albertensis Zone. In the author's experience, the nominal index fossil (Calvinaria albertensis (Warren)) occurs only rarely within the "Cripple Tongue" itself, apparently perferring somewhat ?deeper or ?muddier environments. The Macgeea proteus fauna of Warren and Stelck (1956) is well developed within the "Cripple Tongue" but not at all within that portion of the Mount Hawk underlying it. This probably reflects paleoenvironmental control of faunal distribution.

With the Jasper Basin, the Calvinaria albertensis Zone ranges from the top of the Perdrix Formation to the base of the Sassenach Formation. Here, the Mount Hawk facies also encompasses basinal equivalents of the Nisku and Calmar-Blue Ridge Cycles. Thus, even though the Mount Hawk of Cline Channel lies within the albertensis Zone, it is impossible to determine just where within it. At present the age of the Mount Hawk within Cline Channel relative to the Mount Hawk of Jaspér Basin can be determined more accurately by stratigraphic position than by biostratigraphy (Figs. 48 to 50; i.e. relative to the Jasper Basin, the Cline Channel clastics belong to the "lower" Mount Hawk).

Dooge (1966, 1972, 1978) presented two differing interpretations of the age of the "Cripple Tongue". In the 1966 study he stated that the "Cripple Tongue" carried the diagnostic Vandergrachtella (=Theodossia) fauna. Raasch (in Dooge, 1966, Appendix I) indicated that the "Cripple Tongue" fell within the Cyrtospirifer whitneyi Zone (DFR-11). Faunal components of the "Cripple Tongue" listed in Appendix I range in age from Zones DFR-9 to DFR-11. The stratigraphic equivalents of the DFR-12 Zone within Cline Channel occur within barren inner detrital beds of the "Alexo Formation".

Nisku Cycle - Within the Nisku Cycle, the Grotto Member is abundantly fossiliferous near the margins of Cline Channel, but less so towards its centre. The fauna is coral dominated and carries abundant Thamnopora, Syringopora' Aulopora, Alveolites and disphyllids. Pervasive dolomitization precludes the identification of most forms beyond the genus level.

Calmar-Blue Ridge Cycle - Peritidal carbonates within the "Alexo Formation" have thus far failed to yield any diagnostic faunas.

SOUTHESK CAIRN CARBONATE COMPLEX

The Southesk Cairn Carbonate Complex is exposed in the Rocky Mountain Front Ranges and in the Foothills Bighorn Range between Tps. 39 and 45, W5M and extends to the southwest into the Main Ranges. It is continuously exposed along several ranges for a maximum width of at least 65 km, and prior to thrusting may have extended more than 200 km in a NE-SW direction (Mountjoy, 1978, p. 6; 1980, p. 317; Weissenberger and McIlreath, 1988, p. 535). It may have covered an area of as much as 10 000 km^2. Sparse drilling control suggests that the northeastern end of the Complex may extend to the northwest in the subsurface as far as Tp. 52, R. 25, W5. This interpretation is shown on Figure 1. The buildup is surrounded by basinal sediments on all sides, however the bank-to-basin stratigraphic relationships are not consistent around the Complex.

Early geological studies of the Complex include deWit and McLaren (1950), Fox (1951), McLaren (1953, 1956), Taylor (1957), Belyea and McLaren (1957a) and Hargreaves (1959). The most comprehensive published reports are those of MacKenzie, (especially 1965, 1968 and 1969). Mountjoy (1980) discussed aspects of the Complex; Weissenberger and McIlreath (1988) provided a more recent summary.

The various exposed margins of the Complex can be conveniently grouped into those of the southeastern flank which faces the Cline Channel, the eastern flank which faces the Ireton Shale Basin of central Alberta and the western flank facing the Jasper Basin. Each of these sides is characterized by a particular style of bank-to-basin stratigraphic relationship.

Southeastern Flank

The southeastern flank of the Southesk Cairn Carbonate Complex borders the Cline Channel (Figs. 1, 2) where four margins are present in the Front Ranges northwest of Lake Abraham. Three of these margins are situated near the headwaters of the Bighorn River. These localities are referred to herein as Bighorn East in S. 35, Centre in S. 27 and West, which is not defined but also occurs within T. 39, R. 19 W5M. The Job Lake margin is located farther to the west in S. 34, T. 39, R20 W5 and S. 4, T. 40, R. 20 W5M. Positive correlation of these margins with the three northwestern margins of the Fairholme Carbonate Complex is hampered by structural complications such that the three Bighorn margins are equivalent to the two easternmost margins of the Fairholme Complex. Both the Whiterabbit (Fairholme Complex) and Job Lake (Southesk Cairn Complex) margins are exposed along the Sulphur Mountain Thrust Fig. 2).

As is the case at the northwestern flank of the Fairholme Complex, major facies changes only occur within the two Leduc cycles. Sediments of the Beaverhill Cycle (Flume Member) are of a similar thickness and lithology beneath both Carbonate Complexes, as are the lithofacies of the overlying Nisku Cycle (Grotto and Arcs Members, Southesk Formation). The Calmar-Blue Ridge Cycle consists of peritidal silty dolomite and barren, aphanitic lime mudstone, although the amount of solution collapse breccia has diminished northward. At Mount Dalhousie, sixteen km northwest of the Bighorn margins, skeletal sands and Amphipora-Stachyodes gravels occur in the upper half of this Cycle and represent a facies change to lagoonal and normal marine conditions (McLaren, 1956, p. 33; see also Section 1-43-21). Thus while sediments of the Calmar-Blue Ridge Cycle are still assigned to the "Alexo Formation" near the northwest flank of Cline Channel, they change facies to the more normal marine shelf carbonates of the Ronde or Simla Member (Southesk Formation) within the interior of the Complex.

Bighorn Margins - The Bighorn margins of the Southesk Cairn Carbonate Complex are exposed along three closely spaced thrust faults at the headwaters of the Bighorn River. The style of all three Leduc margins is so similar that they are discussed as one composite Bighorn margin.

The two easternmost margins (Bighorn East and Centre) were accurately located on the Woodhead and Wright-Broughton (1967) reef distribution map. Bighorn East was briefly discussed by Workum and Hedinger (1987, p. 31-32) and referred to by Weissenberger and McIlreath (1988, Fig. 2) as the Linda Creek margin. The other two margins (Centre and West) have not been described in print, although McLaren (1956, Fig. 1) inferred their general location.

Complete Leduc carbonate sections are well exposed at Bighorn East and Centre, but have not been studied in detail. The Leduc, Lower Cycle, within the interior of the Complex is represented by massive, dark brown weathering, organic dolomite of the Upper Cairn. At Bighorn East (Fig. 51) the Lower Leduc bank-to-basin transition is well exposed. Here, the bank margin consists of massive, pale grey weathering "Peechee" dolomite, which both interfingers with, and grades laterally into dark grey basinal clastics of the lower Perdrix Formation. In close proximity to the margin, the Perdrix consists mostly of reef-derived detritus.

The "Peechee" facies of the Leduc, Upper Cycle backsteps the Leduc, Lower Cycle bank margin at the Bighorn localities. This backstep is masked by a carbonate debris apron within the upper portion of the Perdrix Formation (Fig. 52). At Bighorn Centre (Cross-Section H-H'), the Upper Leduc bank consists of massive bedded, resistant, light grey weathering Peechee dolomite. At the bank-to-basin transition, the Lower Leduc bank extends some 1 000 to 1 500 m basinward of the overlying Upper Leduc bank margin. Approximately 110 m of interbedded dolomitized calcarenite, debris flows and minor dark, argillaceous mudstone of the upper Perdrix Formation represent the slope and basin facies of the Leduc, Upper Cycle. Some large, allochthonous blocks of lithified bank material are also present. This detrital carbonate facies of the Perdrix extends some two to three km basinward of the bank margin and overlies reciprocal basin-fill of the lower Perdrix. A similar carbonate debris apron is well developed within the same stratigraphic interval at Bighorn West.

The Perdrix at all three of the Bighorn margins consists partly of reciprocal basin-fill and partly of slope and basin facies of the bank carbonates. Basinward of the Lower Leduc margin at Bighorn East, and of the margins of both Leduc Cycles at Bighorn Centre and West, the Perdrix clearly interfingers with the bank. More typical basinal Perdrix clastics occur basinward of the distal portion of the carbonate debris apron.

Reciprocal basin-fill sediments of the Leduc, Upper Cycle at Bighorn Centre consist of 60 m of interbedded coalesced nodular lime mudstone and minor shale of the lower Mount Hawk Formation. These sediments thicken and become more argillaceous where the underlying Perdrix becomes thinner and changes facies basinward from the detrital carbonate apron to thin-bedded, open marine carbonate mudstone and shale.

Job Lake Margin - The Job Lake margin of the Southesk Cairn Carbonate Complex is located on both sides of the west branch of Job Creek. The margin was originally described by McLaren (1956, p. 9, Figs. 1, 4) and subsequently discussed by Workum and Hedinger (1987), Andrews (1988) and Weissenberger and McIlreath (1988).

At Job, the major bank margin occurs within the Leduc, Lower Cycle. The buildup-to-basin transition is well exposed on the northwest face of a ridge immediately south of Job Creek (Figs. 50, 54). The reef margin itself consists of massive "Peechee" facies that slopes into the adjacent basin at 15 to 20°. The flank is abruptly onlapped and overlain by dark grey to black, recessively weathering basin-fill clastics of the lower portion of the Perdrix Formation. Although some bank-derived bioclastic debris occurs along the top and at the foot, there is no recognizable interfingering or lateral facies change between the Lower Leduc bank margin and the Perdrix. This contrasts to the relationship between bank and basinal sediments at the Bighorn East margin.

The basin-fill clastics are clearly part of the Perdrix Formation based on lithology, fossil content and stratigraphic position. Both Andrews (1988, Fig. 1) and Weissenberger and McIlreath (1988, Fig. 3) referred this stratigraphic interval to the Perdrix in their respective tables of formations, but show the interval as Ireton, or Mount Hawk on illustrations of the Job Lake margin (Andrews, 1988, Figs. 10, 13 to 16; Weissenberger and McIlreath, 1988, Fig. 4).

As is the case farther to the east, the shelf dolomite facies of the Leduc, Upper Cycle backsteps relative to the Lower Leduc margin (Fig. 53). The Leduc, Upper Cycle progrades several kilometres basinward over the underlying Perdrix basin-fill. This is accompanied by lateral facies change from light grey bedded dolomite of the Peechee Member to dark grey, stromatactis-rich mudstone, which becomes the uppermost beds of the Perdrix Formation a short distance basinward of the Lower Leduc buildup margin (Fig. 54). The reciprocal basin-fill of the Leduc, Upper Cycle is the grey argillaceous, nodular lime mudstone of the lower Mount Hawk Formation. This is equivalent to the "Upper Ireton" or Mount Hawk of Andrews (1988, Figs. 10, 13 to 16) and to the "Cripple Member" of the Weissenberger and McIlreath (1988, Figs. 3, 4). Whereas Andrews (ibid.) correctly recognized the prograding nature of the Upper Leduc (his "overhang unit"), Weissenberger and McIlreath (ibid.) interpreted the latter as being part of the lower Mount Hawk basin-fill.

Eastern Flank

The east flank of the Southesk Cairn Carbonate Complex is only exposed at Wapiabi Gap in the Bighorn Range of the Rocky Mountain Foothills, (northwest quarter T. 40, R. 17 W5M). This locality has been described by Belyea (1954, 1958), Belyea and McLaren (1956), McLaren (1956), Dooge (1966), Workum and Hedinger (1987), Andrews (1988), Weissenberger (1988), Weissenberger and McIlreath (1988).

Whereas the southeastern margin faces the somewhat constricted Cline Channel, the eastern flank faces the open Ireton Shale Basin of central Alberta (Fig. 1). At Wapiabi Gap the Beaverhill Cycle is the platform for the major carbonate buildup which commenced low in the Leduc, Lower Cycle and continued to the top of the Leduc, Upper Cycle. The two Leduc Cycles consist of a wedge of bank marginal dolomite slightly less than 200 m thick which in close proximity to the margin, progrades out over Perdrix debris (Figs. 55 to 57). The Perdrix is absent one km basinward of the Wapiabi Gap margin however (Fig. 58) and it appears that the entire margin comprises backstepping dolomite of both of the Leduc Cycles, with a slope angle of 15 to 20°. The basin-fill in front of the bank margins consists of more than 150 m of lower Mount Hawk shale, which is the reciprocal basin-fill of the Leduc, Upper Cycle.

The stratigraphic relations between the bank carbonates and the spatially equivalent basinal shales at Wapiabi Gap are not exposed. The boundary was interpreted as a lateral facies change by McLaren (1956, Figs. 2 and 5), but as abrupt onlap by subsequent workers (Dooge, 1966; Workum, 1978, 1983; Workum and Hedinger, 1987; Weissenberger, 1988). By analogy with the margins of the Southesk Cairn Complex which flank the Cline Channel, it can only be attributed to onlap. The lack of Perdrix lithology immediately in front (south) of the Wapiabi Creek margin (for example in Section 33-40-17) is attributable to this area having been a windward-facing headland during the transgressive Leduc Cycles. The Perdrix facies was presumably being produced by the upward building Leduc, but was continuously being swept away from the headland and accumulated within the Cline Channel to the southwest. This locality is an excellent example of the ability of basin-fill of one depositional cycle to fill a "hole" left over from a previous cycle.

The Nisku Cycle exposed on the ridge south of Wapiabi Gap (Fig. 58) consists of approximately 100 m of dark, barren, siliceous, partially dolomitized detrital carbonates, presumably derived from the Nisku bank which was developed upon the Southesk Cairn Carbonate Complex, and deposited in water depths too great to support an in situ coral fauna. The Cycle also includes an interval of dark grey flaggy lime mudstone basin-fill at the top.

The Calmar-Blue Ridge Cycle consists of an overthickened Calmar equivalent of silty dilomite and a more normal marine Blue Ridge carbonate than occurs along the southeast flank of the Complex.

Western Flank

The western flank of the Southesk Cairn Carbonate Complex is exposed on several thrust sheets where it faces the Jasper Basin to the west (Figs. 1, 2). This area has been described by MacKenzie (1965, 1968 and 1969), and by Weissenberger and McIlreath (1988). Exposures on the south side of Mt. MacKenzie, in the vicinity of Toma Creek (S. 2, T. 44, R. 23 W5) are located outside of Jasper National Park, and are described below (Fig. 61). The three western margins which are within Jasper Park were described by MacKenzie (ibid.) but have not been visited by the present authors.

As with the other margins of the Complex, the Beaverhill Cycle forms the platform for the major carbonate buildup of the Leduc Cycles. This cycle is less than 50 m thick in the most easterly Front Range and thickens gradually the west. MacKenzie (1969, p. 7) recognized "a lower chert-free carbonate and an upper cherty-carbonate" which retains its identity as dolomitized stromatoporoid biostrome for several kilometres basinward from the overlying Leduc bank margin.

The two Leduc Cycles cannot be easily differentiated in the vicinity of the Toma Creek margin. In a general sense, within the Complex, the Cairn Formation represents the Leduc, Lower Cycle, whereas the Peechee Member is the Leduc, Upper Cycle. In close proximity to the bank margin however, the Peechee also occurs as a diagenetic lithofacies well down within the Leduc, Lower Cycle. This stratigraphic relationships between bank and basin are not well exposed at the Toma Creek locality, but appear to be primarily the result of lateral facies change. An accumulation more than 100 m thick of dark grey to black argillaceous fine grained carbonate debris is present basinward of the Complex. The carbonate constituent of this lithology was presumably derived from the northwestern extension of the Complex which is present in the subsurface to the east of the Front Ranges. This unit is transitional between the carbonate buildup from which it was derived, and the basinal Perdrix Formation. It was incorrectly assigned to the Mount Hawk Formation by Weissenberger and McIlreath (1988, Fig. 5). The basinal facies of the Leduc, Upper Cycle, was included in the Mount Hawk Formation by MacKenzie (1969), in close proximity to the Complex. Its more basinal equivalent, however, changes facies into the upper part of the Perdrix Formation. The light grey or green-grey Mount Hawk Shale reciprocal basin-fill of the Leduc, Upper Cycle conspicuously onlaps the southeastern flank of the Complex. Weissenberger and McIlreath (1988, Fig. 3 and p. 539) state that this unit "covers the entire carbonate complex". Although it is present where the Complex is carried on the Sulphur Mountain Thrust (Sawtooth Mountain Thrust of Mackenzie, 1969), it is absent farther to the northeast. It does appear as a recognizable basin-fill wedge to the northwest of Mount Cardinal (T. 45, R. 23 W5). Presumably this unit was unable to prograde over the more northeasterly portions of the Complex because it was impeded by the presence of the full carbonate buildup of the Leduc Cycles.

The Nisku Cycle comprises recognizable Grotto and Arcs facies which are not completely dolomitized in the vicinity of Thistle and Ruby Creek (T. 43, 44, R. 21, 22 W5). These lithologies were described by MacKenzie (1965, p. 470-474). The basinal facies of the Nisku bank carbonates are not obvious to the northwest of the Complex. Presumably significant amounts of carbonate debris from the Nisku Cycle were not being shed from the Complex into the Jasper Basin. The Nisku Cycle is represented to the west of the Complex by intervals of grey open marine lime mudstone to wackestone and by grey shale reciprocal basin-fill within the lower part of the Mount Hawk Formation.

The Calmar-Blue Ridge Cycle thickens to the northwest and changes facies from restricted inner-detrital rocks of the "Alexo Formation" to normal Frasnian bank margin limestone with common stromatoporoids, corals and megalodonts at Toma Creek. This unit was assigned to the Ronde Member of the Southesk Formation by MacKenzie (1969) following Mountjoy's (1965) usage within the Miette Complex. The argillaceous Calmar interval is only sporadically present at the north end of the Complex (eg. east side of Mount MacKenzie T. 44, 45, R. 23 W5), where carbonates of the Calmar-Blue Ridge Cycle may directly overlie dolomite of the Nisku Cycle, separated locally by a terra rosa horizon which marks the unconformity between the two cycles. Basinward from the western margin of the Complex, the carbonates of the Calmar-Blue Ridge Cycle thicken and change facies to open marine lime mudstone (Fig. 62). Although the stromatoporoids are limited to the bank margin, a diverse colonial coral fauna characterizes the foreslope beds of this cycle for several kilometres basinward from the margin. Coral-dominated patch reefs (Fig. 63) occur in this setting (Hedinger and Workum, 1988c). Farther basinward and at greater water depth, the coral component of the cycle is lost and the unit changes facies to thinner bottomset lime mudstone of the upper Mount Hawk Formation.

The reciprocal basin-fill of the Calmar-Blue Ridge Cycle is the lower part of the lower Famennian Sassenach Formation which becomes the thickest and most obvious basin-fill unit within Jasper Basin. This unit onlaps, but does not extend into the Complex.

In summary, the Southesk Cairn Complex is characterized by a large dolomitized stromatoporoid biostrome within the Beaverhill Cycle. The Leduc, Lower Cycle backsteps relative to the underlying Cycle. A thick halo of bank-derived carbonate debris was shed to the southeast and the west but not to the east into the Ireton Shale Basin. This basin-fill debris served as a substrate which allowed the Leduc, Upper Cycle to prograde, especially into the Cline Channel to the southeast. A thick wedge of Leduc, Upper Cycle shale to the east and southeast of the Complex allowed the carbonates of the Nisku Cycle to prograde basinward from the bank margin. This basin-fill unit was thinner to the west of the Complex. The carbonates of the Nisku Cycle become unrecognizable within the Jasper Basin because water depth was too great for active production of carbonate sediment. The Calmar-Blue Ridge Cycle thickens and changes facies from restricted inner detrital lithologies to normal marine limestone from southeast to northwest across the Complex.

JASPER BASIN

The Jasper Basin (Mountjoy, 1980, Fig. 7) is located north and west of the Southesk Cairn Carbonate Complex and both between and to the southwest of Miette and Ancient Wall Complexes, within Tps. 43-48 and west of Rge. 23W5M, (Fig. 1). The eastern margin of the basin was controlled by the above mentioned carbonate buildups coupled with westward prograding Frasnian basin-fill. This is not a tectonic basin, but rather an area that received little sediment during the Frasnian, and is characterized by a thick accumulation of lower Famennian basin-fill of the Sassenach Formation. The Jasper Basin lies to the west of the tract of carbonate buildups developed on the West Alberta Ridge. Although the eastern margin of the basin is somewhat nebulous, it does not appear to extend into the structurally undisturbed subsurface of western Alberta. Relative to the Laremide structural grain of the Rocky Mountains, the Jasper Basin represents a northeastward incursion of basinal conditions into the Frasnian Alberta Shelf.

Depositional Cycles

The Beaverhill Cycle is represented by dark grey partly dolomitized siliceous limestone of the Flume Formation (as revised by Taylor, 1957) throughout the Jasper Basin. Brachiopod limestone characterizes the interior of the basin. Toward the north and east margins however, stromatoporoids become more abundant as the Flume changes from open marine facies to coalesced stromatoporoid banks. The stromatoporoid facies had the potential to localize carbonate buildups within the overlying Leduc Cycles.

The Leduc Cycles within Jasper Basin comprise dark grey to black rocks gradational between limestone and shale, which have been referred to the Perdrix and Maligne Formations and to limestone of the lower part of the Mount Hawk Formation (Fox (1954), McLaren (1956), Taylor (1957), Mountjoy (1965), MacKenzie (1969)). The thickness and the carbonate content of these cycles increase markedly toward the buildups from which the carbonate fraction was derived. The typical basinal lithologies include dark grey shale and interbedded cycles, a few tens of cm thick, of dark grey lime mudstone and calcareous shale. The carbonate grains are mostly of sand size in close proximity to the carbonate buildups around the basin, but mud size grains predominate within the basin.

Two small carbonate buildups within the Leduc, Lower Cycle are exposed in the southeastern part of Jasper Basin, a few km basinward of the Southesk Cairn Complex. These are referred to as the Cardinal River and Deception Creek mounds(Figs. 64, 65), located at S. 22, T. 45, R. 24 W5, and S. 15, T. 45, R. 24 W5. They have been described by Fox (1951), MacKenzie (1965, 1968, and 1969) and Workum (1988c). The buildups are exposed over a distance of 0.5 to 2 km. Cardinal River mound is approximately 60 m thick. The Deception Creek buildup is somewhat thicker at about 100 m. Each of these is developed upon a dolomitized stromatoporoidal platform of the Beaverhill Cycle, and constitutes a dolomitized stromatoporoid buildup. The Cardinal River mound is onlapped by dark grey basinal rocks, whereas the Deception Creek mound interfingers laterally with the encasing beds. These small mounds are analogous to the satellite patch reefs that surround many of the larger Leduc carbonate complexes in the Alberta subsurface.

Where the carbonates of the upper part of the Leduc Cycles have prograded into the Jasper Basin from the surrounding carbonate complexes, they have generally been included within the Mount Hawk Formation. Examples of this usage are MacKenzie (1969, Fig. 6), Mountjoy (1965, Plate II) and Weissenberger and McIlreath (1988, p. 538, Fig. 5). Where the derived carbonate content decreases basinward, these beds have been included within the Perdrix Formation.

At a greater distance from the carbonate complexes, for instance at Roche Miette which is the type section of the Perdrix and Mount Hawk Formations, the top of the Perdrix Formation appears to be at the same stratigraphic level as the top of the Leduc carbonates. In this setting there is little bank-derived carbonate debris within the Perdrix, which includes some carbonate content in the lower part, but grades up to black organic-rich shale in the upper part. The reciprocal basin-fill of the Leduc, Upper Cycle is the lower Mount Hawk shale.

The recessive-weathering nature of the Perdrix lithology causes the stratigraphic relationships between the Perdrix and the carbonate complexes that discontinuously rim the basin to be poorly exposed, but in general the thick Perdrix carbonate units were derived from the carbonate complexes, whereas the black shale units represent reciprocal basin-fill.

The Nisku Cycle within the Jasper Basin is represented mostly by shale. Water depth appears to have been too great to promote active, benthonic coral growth, and the Nisku carbonates consist of grey brachiopod lime mud- to wackestone of the Mount Hawk Formation. The lime sediment was presumably derived for the most part from the surrounding carbonate complexes and is not recognizable at some localities within the basin. The Nisku Cycle also includes, or in some locations may consist entirely of, reciprocal grey shale basin-fill.

The Calmar-Blue Ridge Cycle is quite variable within the Jasper Basin. To the northwest of the Southesk Cairn Complex, the base of the cycle is a conspicuous silty limestone marker unit between 10 and 15 m thick. This unit was illustrated by MacKenzie (1965, Fig.2 ; 1969, Fig. 6) as a silt horizon at the base of the Ronde Member. It is called the "Doublet Silt Marker" in the present publication. Although it cannot be traced laterally into the surrounding carbonate complexes, it appears to be at the same stratigraphic level as the base of the Ronde in both the Southesk Cairn and the Miette Complexes, and thus may have been deposited during a period of exposure of the carbonate buildups. This silty marker horizon is only recognizable within the southern part of

Jasper Basin, below the latitude of the Miette Complex, and is not present at localities farther north, such as Roche Miette.

As the carbonates of the Calmar-Blue Ridge Cycle are followed from the carbonate complexes into Jasper Basin, the stromatoporoids and then the coral component are lost. The interval at first thickens into a foreslope, and then become thinner and changes facies to basinal lime mudstone(Figs. 62, 64). Small bioherms (Figs. 63, 65, 67) characterize the upper foreslope in an irregular halo along a portion of the southeastern margin of the Jasper Basin (Hedinger and Workum, 1988c), but are absent along the steeper northern margin which abuts the Ancient Wall Complex, and within the more central portions of the basin which were presumably located in water too deep to support active coral growth.

At the Toma Creek Margin of the Southesk Cairn Complex, the uppermost Frasnian coral-bearing beds of the Ronde Member are disconformably overlain by basal Famennian siliclastics of the Sassenach Formation. Basinward from this locality (e.g. Section 8-45-23A), carbonate sedimentation appears to have been continuous across the Frasnian-Famennian boundary. Oncolitic limestone containing a Cyrtospirier fauna gradationally overlies the highest Frasnian coral beds and is in turn sharply overlain by Sassenach siliciclastics. Here, the Frasnian-Famennian boundary appears to occur within the upper part of the Ronde Member (Cross-Section I-I').

The lower part of the Famennian Sassenach Formation is the reciprocal basin-fill of the Calmar-Blue Ridge Cycle. This unit is characterized by a thin basal siliciclastic interval overlain by interbedded limestone and shale, usually with a prolific brachiopod fauna. The wedge edge of this unit may be used to define the margin of the Jasper Basin.

The Wabamun Cycle is predominated by the Palliser Formation, but also includes the upper beds of the Sassenach Formation which prograded over the tops of the surrounding carbonate complexes.

Roche Miette

The Devonian stratigraphy at Roche Miette (S. 29, T. 43, R. 27 W5) is important for several reasons. It is the type section of the Flume, Perdrix and Mount Hawk Formations and the Ronde Member of the Southesk Formation (Fig. 73). These include the formations of the basinal facies, and yet, as originally pointed out by McLaren (1956, p. 16), this locality is transitional between a carbonate bank and basin. Whereas the two Leduc Cycles are typically basinal, there is a tongue of Southesk carbonate bank present in the upper part of the section. McLaren (1956, p. 16, 25 and Fig. 2) referred to this as the grey limestone member of the Mount Hawk Formation, and noted that it is of highly variable thickness, though 32 m were measured. Mountjoy (1965, p. 52, Plate VIII A, and Fig. 6) measured 34 m of these beds which he removed from the Mount Hawk and assigned to the Grotto and Arcs Members of the Southesk Formation. He did not formally redefine the Mount Hawk Formation (ibid., p. 27-28). By comparison with Section 27-47-25 at the head of Whitehorse Creek (Fig. 67) where the basal Ronde "doublet silt marker" is present, and by tracing beds from the north end of the Miette Complex to Roche Miette, the interval which Mountjoy interpreted as Arcs and Grotto at Roche Miette is herein considered to be a carbonate tongue of the lower Calmar-Blue Ridge Cycle. It is above the Nisku Cycle which at Roche Miete is a basinal interval within the Mount Hawk Formation. This correlation is based primarily on lateral continuity of strata and deposition style, and at present cannot be substantiated by paleontology. There are no known localities within the Rocky Mountains where the shelf carbonate facies of the Nisku Cycle prograde basinward beyond the shelf facies of the Calmar-Blue Ridge Cycle.

Central Jasper Basin

This area is characterized by an open marine limestone facies of the Beaverhill Cycle overlain mostly by thin basin-fill intervals of the overlying Frasnian cycles, and the thick basal Famennian Sassenach Formation. The area has been of particular interest because the Frasnian-Famennian boundary is well preserved in rocks which, at time of deposition, were in water at least 150 m deep (Geldsetzer et. al. 1987; Goodfellow et. al. 1988; McLaren, 1988). These papers discuss various aspects of this abrupt boundary which represents an extinction event that terminated the Frasnian benthonic fauna.

Above the top of the Beaverhill Cycle, carbonate sedimentation within Jasper Basin was unable to keep up with rising sea level, presumably because water depths were too great for active growth of corals and stromatoporoids. Throughout the more central parts of the basin it is impossible to recognize the Leduc and Nisku Cycles because large quantities of bank-derived carbonate debris were not being supplied.

Closer to the margins of the basin however, the cycles become recognizable. This is the case in the previously described Roche Miette area, at Brule Lake (Fig. 74) and south of the Ancient Wall Complex (e.g., Whitecap Creek, Section 21-48-2W6), where the Nisku and Calmar-Blue Ridge Cycles are recognizable (Fig. 77).

Biostratigraphy of the Jasper Basin Area

Beaverhill Cycle - Within the southern and central portions of the Jasper Basin, the Flume Formation can be subdivided into a basal limestone unit (=Utopia Member of Noble, 1970) and an upper cherty stromatoporoidal unit (Mountjoy, 1965). The Utopia Member is only sparsely fossiliferous, but at the southeastern margin of the Ancient Wall Carbonate Complex it carries Stearn's (1976) Assemblage I stromatoporoid fauna. Diagnostic species include: Stictostroma cf. S. jasperensis Stearn, Hammatostroma albertense Stearn, Trupetostroma lecomptei Stearn, Pseudoactinodictyon bullulosum Stearn and Amphipora ramosa (Phillips). The Utopia Member does not occur south of the Miette Carbonate Complex, as it onlaps the West Alberta Ridge.

The overlying cherty stromatoporoidal unit is only sparsely fossiliferous. Mountjoy (1965) recovered Atrypa multicostellata Kottlowski, A. sp. J and Allanaria allani Warren from it in the vicinity of the Miette Complex. Conodont recoveries from the unit are poor. The unit lies within Warren and Stelck's basal Frasnian Allanaria allani fauna, but occurs between McLaren's (1962) "Ladogioides" and Calvinaria variabilis athabascensis Zones (Fig. 10).

In the Ancient Wall area (northern portion of the Jasper Basin), the Utopia Member is underlain by dark weathering open marine limestone. The two units are included within Geldsetzer's (1988) "Lower Flume". These basal beds carry elements diagnostic of McLaren's "Ladogioides" Zone, and Raasch's DFR-3 Ladogioides kakwaenis Zone. The fauna includes Ladogioides kakwaensis (McLaren), Leiorhynchus russelli McLaren, Cyrtina billingsi Meek, Atrypa spp., and Schizophoria spp. Recent revision of the Givetian-Frasnian boundary (discussed in Braun, Norris and Uyeno, 1988, p. 99) suggests that the entire "Lower Flume" including the Utopia Member is now interpreted as being latest Givetian (Middle Devonian) rather than earliest Frasnian in age.

Leduc, Lower Cycle - The Lower Leduc is essentially eqivalent to the upper member of the Cairn Formation and reciprocal basin-fill of the Perdrix Formation in the Southesk Cairn, Miette and Ancient Wall Carbonate Complexes. The fauna is dominated by stromatoporoids, which are at some localities completely dolomitized and not identifiable to genus level. At the southeastern margin of the Ancient Wall Carbonate Complex this is not the case and Stearn (1967, 1976) was able to collect a diverse stromatoporoid fauna. His Assemblage 2 fauna occurs in both the "cherty stromatoporoidal" member of the Flume and the upper Cairn, so that it includes the upper part of the Beaverhill and Lower Leduc Cycles. Diagnostic elements include: Trupetostroma cervimontanum Stearn, T. warreni Parks, Ferestromatopora contexta Stearn, F. parksi Stearn, Anostylostroma cf. A. bailliei McCammon, Antelodictyon stelliferum Stearn, Stromatopora cygnea Stearn, S. mikkwaense Stearn, Hermatostroma haultainense Stearn and Actinostroma clathrum Stearn.

Leduc, Upper Cycle - The only known fauna from the Upper Leduc of the Jasper Basin comes from the southeastern margin of the Ancient Wall Carbonate Complex. It occurs within the "Lower Megabreccia Unit" which lies in the basal portion of the Mount Hawk Formation (Srivastava, Stearn and Mountjoy, 1972; Stearn, 1976). The fauna includes: Amphipora ramosa (Phillips), Stromatopora cygnea Stearn, Actinostroma clathratum Stearn, Stachyodes costulata Stearn, S. spongiosa Stearn, Trupestroma kakisaense Stearn, Strachyodes jonelrayi Stearn and Stictostroma maclareni Stearn.

Nisku Cycle - Jull (1976) and Mountjoy and Jull (1975, 1978) studied the small, coral-rich mud mounds growing on top of the "Upper Megabreccia Unit" located within the Mount Hawk Formation immediately adjacent to the southeastern margin of the Ancient Wall Carbonate Complex (Figs. 76, 78). These beds are clearly derived from the Upper Peechee interval (=Nisku Cycle equivalent) of the Ancient Wall Complex. Although their studies were primarly of a sedimentological-paleoecological character, Jull (ibid.) noted the occurrence of: Phillipsastrea nevadense (Stumm), P. exigua Smith, Macgeea solitara Hall, Smithiphyllum imperfectum (Smith), as well as Syringopora, Thamnopora, Aulopora, Alveolites, Atrypa spp., spiriferids and crinoids. From these same beds, Stearn (1976) obtained his Assemblage 4 stromatoporoid fauna, composed of: Amphipora ramosa (Phillips), Trupetostroma kakisaense Stearn, Stachyodes jonelrayi Stearn, Strictostoma maclareni Stearn, Talaestroma stelliferum Stearn and Ancylostroma phricum Stearn.

Strata north of the Southesk Cairn Complex and characterized by McLean and Sorauf (1988, p. 385) as being "Grotto-Arcs" equivalent have yielded: Smithiphyllum imperfectum (Smith), S. whittakeri (Pedder), S. occidentale Sorauf), Phillipsastrea nevadense (Strumm), P. woodmani (White), Macgeea telopea Crickmay and Pantophyllum camselli (Smith).

In a more basinal setting, Nisku Cycle shelf carbonates change facies to basinal beds of the Mount Hawk Formation, which carries the Calvinaria albertensis fauna.

Calmar-Blue Ridge Cycle - The Simla Member (Southesk Formation) represents the open marine shelf carbonates of the Calmar-Blue Ridge Cycle within Jasper Basin. The unit has a broad areal extent as it was able to prograde over basin-fill clastics of the Mount Hawk Formation beyond the limits of the Leduc carbonate buildups (Figs. 72, 74). Since its introduction (McLaren and Mountjoy, 1962), the Simla has undergone a complex nomenclatural history and alternately been assigned to either the Nisku or Calmar-Blue Ridge Cycles (see discussion under Ancient Wall Carbonate Complex, and Fig. 75). Faunal studies of the Simla clearly demonstrate that it belongs within the latter cycle, as it bears a diagnostic latest Frasnian (DRF-12) fauna.

Throughout much of the project area, carbonates of the Calmar-Blue Ridge Cycle are in a barren, peritidal facies that is included within the "Alexo Formation". Fossils only become common towards the northern part of the Southesk Cairn Complex, and are most abundant in the shelf margin and slope lithofacies. Within the Miette and Ancient Wall Complexes, the Simla is again in a barren, lagoonal lithofacies.

McLaren (1962, p. 4) first described a "characteristic late Frasnian fauna" from carbonates of the "Arcs member" (=Simla) in the Jasper Basin. He identified Pachyphyllumn cinctum (Smith), Thamnophyllum tructense (McLaren), Theodossia keenei Crickmay and "characteristic species" of Hypothyridina, Atrypa and Cranaena that he correlated with faunas recovered from the Kakisa Formation of the upper Mackenzie River area. Soon thereafter, McLaren (in McLaren and Mountjoy, 1962) described a Kakisa fauna from Ronde (=Simla) Member equivalents at Fiddle Divide (same area and stratigraphic level as Sections 23-46-25 Whitehorse Creek South and 27-46-25 Whitehorse Creek). The assemblage included: Thamnophyllum cf. T. tructense (McLaren), Thamnopora, Gypidula cf. cornuta Fenton and Fenton, Devonoproductus, Hypothyridina cf. sp. A, Atrypa cf. A. ciliipes Crickmay, A. spp. J and K, Theodossia keenei Crickmay and Athyris ap.

Stearn's (1976) stromatoporoid Assemblage 5 zone comes from strata of the "Arcs Member" (=Simla) at the southeastern margin of the Ancient Wall Complex. The fauna consists of eleven species, three of which (Trupestroma saintjeani Stearn, Stictostroma maclareni Stearn and Anostylostroma phricum Stearn) also occur in the Kakisa Formation.

Colonial rugose corals reached their greatest diversity and abundance in the late Frasnian (Sorauf and Pedder, 1986) just prior to their extinction at the Frasnian/Famennian boundary. McLaren and Sorauf (1988, p. 385) noted that "... the Ronde Member (=Simla) ... bears a rich rugose coral fauna, with many species in common with the Kakisa Formation ... Species currently recognized in the lower beds include: Medusaephyllum nevadense (Stumm), M. woodmani (White), Pantophyllum camselli (Smith), Smithiphyllum imperfectum (Smith), S. ventosum McLean and Pedder, and undescribed species of Peneckiella, Phillipsastrea, Disphyllum, Piceaphyllum and Hunanophrentis. Higher beds contain a more diverse fauna with Smithicyathus cinctus (Smith), Chuanbeiphyllum vesiculosum (Smith), Pachyphyllum mirusense McLaren, Medusaephyllum variabile Sorauf, Frechastrea whittakeri (Smith), Hexagonaria schucherti (Smith), H. caurus Smith, Smithiphyllum ventosum McLean and Pedder, S. frondosum McLean and Pedder, S. imperfectum (Smith), Hankaxis ostensus McLean and Pedder, Wapitiphyllum vallatum McLean and Pedder, W. exiguum McLean and Pedder, Bouvierphyllum maclareni McLean and Pedder, B. altum McLean and Pedder, B. cardinalense McLean and Pedder, Tarphyphyllum monkmanense McLean and Pedder, Pantophyllum camselli (Smith), Phacellophyllum tructense McLaren, Disphyllum catenatum Smith, Mictophyllum semidilatum Smith, "Ptychophyllum" kindlei Smith, Piceaphyllum modicum (Smith), Ceciliaphyllum bastillense McLean, Peneckiella sp., Disphyllum sp., Tarphyphyllum sp., Mictophyllum spp., Macgeea sp., Hunanophrentis sp., Piceaphyllum spp., Phillipsastrea sp., Pantophyllum sp., and Debnikiella sp.

The Simla changes facies basinward into clastics of the Mount Hawk Formation, which carry the Calvinaria albertensis fauna (see discussion following).

Jasper Basin-Central Area - The Perdrix Formation represents slope and basin facies and basin-fill clastics of the Leduc Cycles. The Maligne (Taylor, 1957) is the upper member of McLaren's (1956) redefined Flume Formation. It is included within the Perdrix in the present study. The thin-bedded limestone and shale of the lower Perdrix carry McLaren's (1962) Calvinaria variabilis athabascensis Zone, which is approximately equivalent to Warren and Stelck's (1956) Eleutherokomma leducensis fauna and Raasch's (in Dooge, 1966) DFR-5 Leiorhynchus athabaskense Zone. Common faunal elements include: Eleutherokomma jasperensis (Warren), Calvinaria variabilis athabascensis (Kindle), Allanaria minutilla Crickmay, Athyris parvula Whiteaves, Bactrites spp., Manticoceras sp., and tentaculitids. Corals are relatively rare within the lower Perdrix, but include Smithiphyllum crassatum McLean and Pedder and S. meridianum McLean and Pedder (McLean and Sorauf, 1988).

The remainder of the Perdrix Formation carries McLaren's (ibid) Calvinaria variabilis insculpta fauna. The assemblage is identical to the one that occurs in Cline Channel. Warren and Stelck's (1956) Buchiola retrostriata fauna is equivalent to this zone, but characteristic of an even more restricted and inhospitable environment. Within the Jasper Basin, Raasch's (in Dooge, 1966) threefold zonation of the Perdrix (DFR 6 to 8) is probably not readily distinguishable, although Receptaculites sp. (the DFR-7 indicator species) occurs flanking the lower Leduc at the Glacier Pass margin of the Ancient Wall Complex.

Klapper and Lane (1988) published a study of the conodont succession within the Perdrix-Mount Hawk-Simla interval near the southern and northern margins of the Jasper Basin (Cross-section J-J'). Their zonation represents a major advance in biostratigraphic calibration of the basinal succession. For the first time there is a biostratigraphic tool that is sensitive enough to date events within the Perdrix and, to a lesser extent, within the Mount Hawk-Simla interval. It also provides data on rates of sedimentation and basin infill during a portion of "Leduc" time (Cross-Section J-J'). Although the Perdrix at the southeastern margin of the Ancient Wall Complex is one third the thickness of its counterpart along the Nikanassin Range, both sections carry the same number of conodont zones. This implies that sedimentation rates were much slower in the former area than in the latter. If we assume that all of the conodont zones spanned an equal length of time, it is also evident that there was a marked decrease in sedimantation rate along the Nikanassin Range towards the end of Perdrix time.

In Jasper Basin, the Mount Hawk Formation encompasses equivalents of the Mount Hawk of Cline Channel, as well as basinal equivalents of both Nisku and the Calmar-Blue Ridge Cycles. Thus in the deepest portions of the Basin (i.e. the Cardinal River-Deception Creek area, Cross Section I-I') the Mount Hawk ranges from the top of the Perdrix Formation to the base of the lower Famennian Sassenach Formation. As the peripheries of the Basin are approached, bank carbonates of these Cycles encroach upon and change facies into laterally basinal facies of the Mount Hawk. These shelf-slope carbonates carry faunas which are markedly different from those found in the basinal sediments. This similarity in behavior of lithofacies and biofacies has led to some problems in the interpretation of the biostratigraphic zonation.

McLaren (1962, p. 4) recognized that in many areas of the the Jasper Basin the highest beds of the Mount Hawk Formation commonly consisted of massive, pale grey weathering carbonates of what he termed the "Arcs member". These beds carried a brachiopod and coral fauna equivalent in age to the Kakisa Formation or to Raasch's (in Dooge, 1966) DFR-12 Vandergrachtella (=Theodossia) scopulorum Zone. Based on later studies (McLaren and Mountjoy, 1962) it is evident that McLaren's "Arcs member" is actually the Simla Member.

McLaren (ibid., p. 5) also noted that in the deeper parts of the Jasper Basin (e.g. Deception Creek; see McLaren, 1956, p. 26) the "Arcs" (=Simla) lithofacies was absent and Mount Hawk shale carrying the Calvinaria albertensis fauna was directly overlain by early Famennian clastics of the Sassenach Formation. He inferred (ibid., p. 5) that these faunal relationships proved that the "latest Frasnian" carbonate unit had been removed by erosion. These conclusions were supported by Raasch (in Maurin and Raasch, 1972, p. 69; see also Raasch, 1988, p. 621) who indicated that an erosional unconformity existed between the Frasnian and Famennian within this area.

Cross-Section I-I' extends from the Toma Margin of the Southesk Cairn Carbonate Complex into the Cardinal River-Deception Creek area. It provides a transect of Calmar-Blue Ridge Cycle sedimentation from shelf (Sections 35-44-23, 3-45-23, 4-45-23; Fig. 61) to slope (Sections 8-45-23A-C; Fig. 63) to deep basin (Sections 18-45-13, 19-45-23; Fig. 64). Lateral correlations from bank to basin demonstrate that there is little missing section within the interval, but rather lateral facies change from shelf carbonates of the Simla to slope and basinal clastics of the Mount Hawk. The biofacies appear to conform to the same trends, so that whereas the DFR-12 fauna is characteristic of the shelf, it is replaced by the Calvinaria albertensis fauna in a basinal setting. The apparent juxtaposition of faunas is thus attributable to lateral facies/biofacies change rather than to erosion.

Klapper and Lane's (1988) study of the conodont succession within the Mount Hawk-basal Simla stratigraphic interval (Cross Section J-J') shows that these beds contain considerably fewer zones that the underlying Perdrix. This preliminary data does not bode well for the hope of a finer calibration of this interval. In addition, this fauna " ... above the level of Zone 5a ... is in a Polygnathus biofacies which makes correlation with the Palmatolepis biofacies of the standard zonation unresolavable at present (ibid. p. 469). Nevertheless, if each of the zones span roughly the same time period, it is obvious that sedimentation rates during the Mount Hawk were greater than during the Perdrix.

MIETTE CARBONATE COMPLEX

The Miette Carbonate Complex (Figs. 1, 68, 69) is exposed in the Rocky Mountain Front Ranges within Tps. 47 and 48, Rgs. 25 to 27W5 where the full buildup, approximately 150 km^2 in area, is carried by the Miette and McConnell thrust faults (Mountjoy, 1988, p. 497). The complex is located on the northwestern part of the West Alberta Ridge, and east of the Jasper Basin. Carbonates of the Nisku Cycle prograde to the east of the full carbonate buildup where they are well exposed along the Nikanassin Range (Figs. 70, 71).

The Complex was originally mapped and subsequently described by Mountjoy (1960, 1965, 1967), whose early work was the first to document an entire medium size carbonate complex within the Canadian Rocky Mountains. More recent studies by Noble (1970), Cook (1972), Cook et al. (1972), Hopkins (1972, 1977), Kobluk (1975), Mountjoy (1975, 1988), Mattes and Mountjoy (1980), and Mountjoy and Burrows (1982) have investigated several aspects of the Complex. It has received much attention partly because of its relatively easy access. Also dolomitization, which has profoundly altered most of the Frasnian carbonate rocks farther to the south, has affected the margins but has been only incipient within the interior where the full range of lithologies that characterize a stromatoporoid-dominated carbonate buildup are preserved as limestone.

Depositional Cycles

The depositional cycles recognized farther to the southeast are, for the most part, readily recognizable within the Miette Complex. They are similar to the six depositional stages of Mountjoy (1965, Fig. 8; 1988 Fig. 11), with stages 2 and 3 being the Leduc, Lower Cycle.

The Beaverhill Cycle within the Miette Complex is represented by the 35 to 60 m thick Flume Member of the Cairn Formation (Mountjoy 1965, 1988). The lower beds of the Flume are capped by a distinctive light-weathering limestone unit between 5 and 9 m thick, which was named the Utopia Member by Noble (1970, p. 497). Cook (1972, Fig. 4, and p. 401-402) also recognized this unit and concurred with Noble in describing an unconformity at the top of the Utopia, which is characterized by a reddish oxidized erosion surface. The overlying portion of the Flume Member consists of lime packstone and grainstone interbedded with and culminating in a thick and massive stromatoporoid facies, which formed a topographic "high" beneath the Miette reef (Cook, ibid. Fig. 4). Within the basin surrounding the Miette Complex, the Beaverhill Cycle comprises the Flume Formation which consists mostly of lime mudstone to packstone, in part burrowed, with fewer stromatoporoids than beneath the Complex (Cook, ibid.). It appears that the thick stromatoporoid facies of the Beaverhill Cycle was localized above a paleotopographic "high" upon the underlying Lower Paleozoics; and that it, in turn, served as the platform for the overlying carbonates of the Miette Complex.

The Leduc, Lower Cycle is between 150 and 200 m thick and consists of grey stromatoporoidal limestone of the "upper member" of the Cairn Formation within the Miette Complex (Mountjoy, 1965, 1988), rimmed by massive light grey buildup margin dolomite. It also includes the Perdrix Formation which consists of interbedded distal tongues of the buildup interbedded with dark grey argillaceous carbonates which are reciprocal basin-fill units that onlap the Complex. These lithologies and stratigraphic relationships have been documented by Mountjoy (1965, 1988) and Noble (1970).

The Leduc, Upper Cycle approximates the Peechee Member within the complex where it is composed of slightly less than 100 m of grey Amphipora dominated limestone. It is also the lower part of the Mount Hawk Formation in the surrounding area. In close proximity to the complex, this cycle is usually represented by a basinal carbonate debris facies of the Peechee overlain by reciprocal basin-fill of argillaceous limestone of the Mount Hawk Formation (Fig. 68).

The Nisku Cycle consists of the Grotto and Arcs Members within the Complex. The Grotto is represented by 15 to 20 m of dark grey partly dolomitized limestone with common Amphipora. This is interpreted as the shallow water, restricted facies of a unit which farther to the southeast is characterized by abundant colonial corals. The Arcs Member typically comprises 50 to 60 m of light grey calcarenite. The top of the cycle is an unconformity. Carbonates of the Nisku Cycle prograde basinward for probably more than 10 km eastward beyond the margins of the underlying buildup within the Leduc Cycles, and retain their integrity as a distinct carbonate bank (Figs. 70, 71). This has been described by Mountjoy (1965, p. 20-21) and further illustrated by Hedinger and Workum (1988b). In this setting, the typical Grotto and Arcs lithologies are not present; and the cycle is characterized by a complex pattern of overriding foresetting beds of lime sand and gravel, which thicken and prograde basinward. Continuous exposure of the Nisku bank margin in the Nikanassin Range reveals that additional beds of onlapping carbonate rocks which thicken away from the Complex, are part of the Nisku Cycle. At a greater distance from the full Miette buildup, the argillaceous beds at the base of the Calmar-Blue Ridge Cycle are absent and the contact between the two cycles appears to be conformable (Fig. 71, left side).

The Calmar-Blue Ridge Cycle of the Miette Complex consists of the Ronde Member as used by Mountjoy (1965, p. 21-22). The lower 3 to 6 m of recessive weathering silty shale are overlain by approximately 30 m of even bedded, light grey, slightly dolomitic and silty lime mudstone and calcarenite. The upper contact of the cycle is a subtle unconformity beneath the overlying Sassenach Formation of the Famennian Wabamun Cycle.

ANCIENT WALL CARBONATE COMPLEX

The Ancient Wall Carbonate Complex constitutes the northern margin of the study area (Fig. 1). It outcrops along the Colin and Chetamon Thrusts in northwestern Jasper National Park and originally occupied an area of 1 500 km^2 (Fig. 2). Geldsetzer (1988, Fig. 2) extended the northeastern margin of the complex to encompass reefal strata exposed in the Persimmon Range, whereas Woodhead and Wright-Broughton (1967), Mountjoy (1978) and the present authors consider these carbonates to form the separate Berland Complex. The exposed margins of the Ancient Wall buildup are uniquely situated in that they adjoin two radically different basinal areas (Fig. 76). The southern margin borders the Jasper Basin, which was sediment starved during the Frasnian, whereas the northern (Glacier Pass) margin borders the Ireton Basin, which was wholly infilled prior to the deposition of the Calmar-Blue Ridge Cycle. The nature and timing of the basin-fill sequences is thus different on either flank of the complex, as is the response of the carbonates of the Calmar-Blue Ridge Cycle to this condition.

Initial work on the complex was carried out by Mountjoy (1962) who described its stratigraphy and lateral extent. Subsequent studies were conducted almost exclusively by Mountjoy's graduate students and co-workers. These include: McLaren and Mountjoy (1962), Mountjoy (1967), Stearn (1967), Toomey, Mountjoy and MacKenzie (1970), Cook et al. (1972), Hopkins (1972), Mountjoy et al. (1972), Srivastava, Stearn and Mountjoy (1972), Mountjoy and MacKenzie (1974), Coppold (1976), Stearn (1976), Hopkins (1977), Jull (1977), Mountjoy and Jull (1975, 1978), Mountjoy (1980), Mountjoy and Riding (1981), and Mountjoy (1987). In recent years, Geldsetzer (1982, 1988) has investigated the northern margin of the complex at Glacier Pass.

Over the years, much controversy has surrounded the stratigraphic nomenclature employed for the Southesk Formation of the Ancient Wall Complex. This is chronicled in Figure 75 and discussed below. At the heart of the problem lies the absence of a "Grotto facies" lithology (dark brown, bituminous, coral-rich dolomite) within the Southesk stratigraphic interval. Instead, stratigraphic equivalents of the Peechee, Grotto and Arcs Members are represented by some 200 m of light grey, massive, well-bedded and resistant weathering limestone and minor dolomite. Mountjoy (1962) and McLaren and Mountjoy (1962) assigned this interval to the "Lower Member" of the Southesk Formation. This unit is disconformably overlain by the Simla Member (McLaren and Mountjoy, op. cit., p. 7). The Simla consists of a basal argillaceous unit which forms a distinctive recessive interval along the length of the complex and an upper unit of thick-bedded, resistant weathering light grey limestone. The Simla carries a diagnostic latest Frasnian fauna (ibid. p. 8) and represents the Calmar-Blue Ridge Cycle within the Ancient Wall Complex.

Stratigraphic and biostratigraphic evidence notwithstanding, Mountjoy and MacKenzie (1974) discarded the Simla Member. They equated the lower silty unit and the basal, coral-rich portion of the upper limestone unit to the Grotto Member and the remainder of the upper limestone unit to the Arcs Member. Mountjoy and MacKenzie argued (ibid., pp. 4-12) that both of these members were at the same stratigraphic position and of similar lithology to the Grotto and Arcs Members at the type section of the Southesk Formation. While the upper Simla and the Arcs are of similar lilthology it is more difficult to reconcile equating the variegated red and green mudstone and dolomitic siltstone of the basal Simla with the typical Grotto facies. The positioning of the "new" Grotto at the top of the redefined Peechee (Fig. 75) also meant that the "new" Peechee was now nearly 200 m thick, more than double what would be expected from regional thickness trends. Despite these and other inconsistencies, this revised nomenclature became accepted. Although Mountjoy (1980, p. 326-327) recognized that the lack of the "Ronde Member" at Ancient Wall was anomalous, he postulated that it might still occur "high in the Arcs".

Geldsetzer (1982) reinstated the term Simla, raised to formational status, for the Calmar-Blue Ridge Cycle equivalents at the northwestern (Glacier Pass) margin and beyond. Mountjoy (1987, p. 5) has recently brought the argument full circle by acknowledging that the stratigraphic nomenclatural problem at Ancient Wall exists because "a distinctive Grotto Member is not recognizable" and that, based on "original paleontological data" the Simla is a younger and different stratigraphic unit than the Arcs and Grotto Members.

Beaverhill Cycle

At the southern margins of the Ancient Wall Complex, the Beaverhill Cycle is divisible into a lower member capped by a light grey limestone unit (Utopia Member of Noble, 1970) and an upper, cherty stromatoporoidal unit. At the northern margin, the Flume was subdivided by Geldsetzer (1988) into two informal members. The lower member included the Utopia Member at the top, plus some 40 m of dark, nodular and argillaceous lime mudstone carrying the Ladogioides kakwaensis fauna of McLaren (1962). This assemblage is not found south of Ancient Wall, demonstrating that the nose of the West Alberta Ridge plunges northwestward underneath the Ancient Wall Complex. The upper member is equivalent to the cherty stromatoporoidal unit. The top of the Flume at Glacier Pass is marked by a horizon of large spherical oncolites.

Leduc, Lower Cycle

This cycle backsteps the more areally extensive Flume platform and ranges in thickness from 140 to 170 m. The margins are dominated by stromatoporoid biostromes, whereas the interior consists of interbedded, variably Amphipora-rich carbonate mudstones. At Glacier Pass, the bank margin is encrusted with Receptaculites. Basinal sediments are characterized by dark grey to black, recessive lime mudstone and calcareous shale of the Perdrix Formation.

Leduc, Upper Cycle

The Leduc, Upper Cycle is represented by the basal 125 m of the Southesk Formation, or that portion of the Southesk underlying Mountjoy and MacKenzie's (1974, Fig. 4) "coral-stromatoporoid bioherms". The absence of a dark brown, coral-rich facies at the level of the Grotto stratigraphic interval precludes a more accurate definition. Based on the regional observations that Mount Hawk Formation clastics are the reciprocal basin-fill sediments of the Upper Leduc, and that the megabreccias (Srivastava, Stearn and Mountjoy, 1972; Coppold, 1976) derived from the "coral-stromatoporoid bioherms" occur in the basal portion of the Mount Hawk, one can postulate that the portion of the Southesk beneath the coral-stromatoporoid unit is equivalent to this cycle. While the Leduc bank margins are essentially coincident at the southern margin (Mount Haultain), the Leduc, Upper Cycle backsteps the Leduc, Lower Cycle by some three km at the northern (Glacier Pass) margin.

Nisku Cycle

The Nisku Cycle is represented by some 60 m of massive, light grey weathering limestone of the Arcs Member. At the southeastern margin (Mount Haultain), the Nisku bank edge is defined by a series of coral-stromatoporoid bioherms. The megabreccia deposits that occur within the basal portion of the Mount Hawk Formation at every margin of the complex (Cook et. al., 1972; Srivastava, Stearn and Mountjoy, 1972; Coppold, 1976; Geldsetzer, 1988) were derived from the collapse of large segments of the lower Nisku carbonate bank edge. At both the southern and northern margins, the Nisku bank edge appears to be coincident with that of the underlying Leduc, Upper Cycle.

The reciprocal basin-fill of the Nisku Cycle is a wedge of argillaceous rocks which thickens to a few tens of metres into the Jasper Basin, but which almost filled the Ireton Basin with at least 150 m of shale of typical Mount Hawk lithology. This is the "Lower Mount Hawk" of Geldsetzer (1988, Fig. 3). A thin upper Nisku carbonate overlies the Mount Hawk at Glacier Pass. (Geldsetzer, op. cit., Figures 3 and 4, referred to this as "Upper Mount Hawk"). This youngest Nisku carbonate cycle does not extend south of the Ancient Wall Complex.

Calmar-Blue Ridge Cycle

The Calmar-Blue Ridge Cycle is represented by the Simla Member (Formation of Geldsetzer, 1982, 1988 and Mountjoy, 1987). It consists of a recessive weathering basal mudstone and silty dolomite unit (Calmar equivalent) and a resistant upper limestone unit (Blue Ridge equivalent). Within the Ancient Wall Complex it is mainly composed of lime mudstone, with a thin, silty, coral-rich unit at the base marking the return of normal marine conditions after the post-Nisku hiatus. At the southern (Mount Haultain) margin, the Simla foresets into shale of the Mount Hawk Formation (Figs. 76 to 78). Because the Jasper Basin was not wholly filled at the close of Frasnian time, the remaining "hole" was then infilled by some 180 m of Sassenach Formation clastics. At the northern (Glacier Pass) margin, the Simla progrades as a coral-dominated biostrome over the thin upper Nisku carbonate cycle.

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APPENDIX 1

CROSS-SECTIONS, PLATES AND FIGURES

LIST OF 10 CROSS-SECTIONS
(in pocket)

STRATIGRAPHIC SECTIONS

Section No.: S.T.R. W5	Name	Lat. °N	Long. °W
27-5-5	South Lost Creek	49°25'	114°35'30"
2-7-5	Lynx Creek	49°32'	114°34'
30-20-9	Black Prince North	50°42'45"	115°14'15"
6-21-7	Mount Glasgow	50°45'20"	114°58'
12-21-8	Mount Romulus South	50°46'30"	114°15'30"
13-21-8	Mount Romulus	50°47'	114°49'50"
23-21-8	Shoulder Creek	50°48'	115°11'
26-21-8	Mount Fisher East	50°49'	115°00'45"
35-21-8	Mount Fisher Northeast	50°50'	115°00'30"
31-21-9	Fortress Mountain	50°49'40"	115°30'45"
15-22-8	Canyon Creek Headwaters	50°52'25"	115°01'50"
22-22-8	Mount McDougall South 1	50°53'40"	115°02'15"
26-22-8	Bryant Lake	50°53'45"	115°00'45"
27-22-8A	Wasootch Creek West	52°53'20"	115°01'40"
27-22-8B	Mount McDougall South 2	50°53'30"	115°02'15"
27-22-8C	Wasootch Creek East	50°54'20"	115°01'30"
27-22-10	Mount Buller	50°54'	115°18'45"
6-23-7	Mount Bryant North 1	50°56'	114°58'30"
1-23-8	Mount Bryant North 2	50°55'45"	114°59'30"
2-23-8	Mount Bryant North 3	50°55'55"	115°00'10"
9-23-8	Wasootch Creek North	50°56'15"	115°03'15"
36-23-9	Mount Lorette	50°00'10"	115°08'15"
36-24-9	Loder Lime	51°05'30"	115°08'45"
25-28-11A	Mount Oliver South	51°25'40"	115°24'30"
25-28-11B	Mount Oliver	51°25'30"	115°25'
36-28-11	Mount Oliver North	51°26'	115°25'30"
4-29-11	North Burnt Timber 1	51°27'30"	115°29'30"
10-29-11	North Burnt Timber 2	51°28'15"	115°28'
16-29-11	North Burnt Timber 3	51°29'	115°29'30"
22-29-11	North Burnt Timber 4	51°29'30"	115°28'
30-31-10	James Pass 1	51°41'00"	115°25'
36-31-11	James Pass 2	51°42'00"	115°25'
10-33-11	Willson Creek	51°49'20"	115°00'
21-33-11	Scalp Creek 1	51°50'30"	115°30'30"
29-33-11	Scalp Creek 2	51°51'15"	115°31'30"
30-33-11	Scalp Creek 3	51°51'45"	115°32'
36-33-12	Scalp Creek 4	51°52'45"	115°34'
1-34-12	Scalp Creek 5	51°53'	115°34'
2-34-12A	Scalp Creek 6	51°53'30"	115°36'
2-34-12B	Rocky Creek North	51°53'40"	115°37'
33-34-13	Washout Creek	51°47'45"	115°49'30"
18-35-15	Canary Creek	52°00'30"	116°08'
25-35-16	Hummingbird Main Branch	52°02'30"	116°11'
23-35-17	Whiterabbit Creek	52°01'20"	116°18'40"
19-36-14	Ram River 1	52°07'45"	115°59'
24-36-15	Deadfall Creek	52°07'50"	116°00'10"
25-36-15	Ram River 2	52°07'20"	116°00'15"
4-36-16A	Hummingbird South	52°03'30"	116°14'
4-36-16B	Hummingbird North	52°04°	116°14'

Section No.: S.T.R. W5	Name	Lat. °N	Long. °W
8-36-16	Hummingbird Basinal 1	52°05'	116°14'30"
25-36-17	Hummingbird Basinal 2	52°08'30"	116°18'
4-37-15	Cripple Creek South	52°09'15"	116°04'
8-37-15	Cripple Creek Northwest	52°10'10"	116°06'
13-37-16	North Ram River Gap	52°11'20"	116°09'
24-37-16	North Ram 1	52°12'	116°09'45"
26-37-16A	North Ram 2	52°12'15"	116°10'
26-37-16B	North Ram 3	52°12'20"	116°10'30"
33-37-16	Kiska Creek 1	52°13'	116°13'
5-38-16	Kiska Creek 2	52°14'	116°13'
6-38-16A	Kiska North 1	52°14'30"	116°16'30"
6-38-16B	Kiska North 2	52°14'20"	116°16'
6-38-18	Mount Stelfox	52°14'	116°33'
34-38-18	Littlehorn Creek	52°18'30"	116°31'05"
36-39-14	The Gap	52°24'	115°53'
7-39-18	Bighorn South 1	52°20'45"	116°35'15"
8-39-18	Bighorn South 2	52°20'10"	116°33'45"
19-39-18	Bighorn South 3	52°21'	116°35'30"
7-39-19	Job Pass	52°20'30"	116°43'10"
23-39-19	Bighorn River 1	52°22'10"	116°38'15"
25-39-19	Bighorn River 2	52°25'45"	116°36'
27-39-19	Bighorn River 3	52°23'	116°39'30"
34-39-19	Bighorn River 4	52°23'20"	116°39'15"
31-40-17	Wapiabi Gap North 1	52°29'30"	116°25'30"
33-40-17	Wapiabi Gap Southeast	52°29'	116°24'
16-40-19	Whisker Creek	52°26'30"	116°41'
4-40-20	Job Creek	52°24'30"	116°49'45"
6-41-17	Wapiabi Gap North 2	52°30'20"	116°25'
3-41-20	Opabin Creek Cirque	52°30'45"	116°47'30"
1-43-21	Saracen Head	52°40'15"	116°55'30"
31-43-21	Thistle Creek	52°45'	117°02'
20-44-22	Nomad Creek	52°49'	117°09'30"
35-44-23A	Toma North A	52°50'10"	117°13'45"
35-44-23B	Toma North B	52°50'10"	117°13'45"
36-44-23	Mt. Toma	52°50'	117°12'30"
4-45-23	Rocky Pass South	52°51'	117°16'
7-45-23	Cardinal River	52°52'20"	117°19'50"
3-45-23A	Mt. MacKenzie North	52°51'40"	117°15'
3-45-23B	Mt. MacKenzie North	52°51'10"	117°15'45"
8-45-23A	Mt. Cardinal A	52°51'30"	117°18'
8-45-23B	Mt. Cardinal B	52°52'	117°18'
8-45-23C	Mt. Cardinal C	52°51'30"	117°18'
11-45-23	Mt. MacKenzie East	52°50'30"	117°14'30"
19-45-23	Tripoli Mountain	52°54'	117°19'30"
22-45-24	Blackface Mountain	52°54'	117°24'20"
26-45-24	Mt. Cheviot West Spur	52°54'45"	117°21'45"
23-46-25	Whitehorse Creek South	52°59'	117°30'30"
27-46-25	Whitehorse Creek	52°59'30"	117°32'
7-47-24A	Mt. Gregg	53°02'30"	117°29'30"
7-47-24B	Mt. Berry	53°02'45"	117°30'
9-47-24	Luscar Mountain North	53°02'15"	117°27'

Section No.: S.T.R. W5	Name	Lat. °N	Long. °W
23-47-26	Section Creek	53°03'30"	117°41'
21-48-2W6	Whitecap Creek	53°09'	118°13'
6-49-2W6	Haultain Cirque	53°11'30"	118°17'

LEGEND FOR CROSS-SECTIONS

BASIC LITHOLOGIES

- Limestone
- Dolomite
- Shale, calcareous, dolomitic
- Siltstone
- Sandstone
- Breccia (limestone clasts)
- Nodular Limestone
- chert
- DF debris flow

bedding illustrated as thin, medium, thick and massive-bedded

resistance to weathering is self-explanatory

cross-bedding

FOSSIL COMPONENTS

- indeterminate skeletal debris
- brachiopod
- coral (solitary or tabulate or non-massive rugose)
- massive rugose coral (Phillipsastrea or Hexagonaria)
- bryozoan
- Tentaculites
- crinoid
- stomatoporoid
- Amphipora
- pelecypod
- gastropod
- ammonoid
- fish debris
- stromatolite
- oncolite
- spiriferid brachiopod
- R Receptaculites

APPENDIX 2

OUTCROP SECTIONS

This appendix consists of 103 Devonian outcrop sections which were measured and described within the project area. They are numbered according to their geographic location (e.g. Section 6-21-7 is located in Section 6, Township 21, Range 7W5N). These sections were studied during the summers of 1979 and 1980 during field investigations for Amoco Canada, which has subsequently released the data to the authors. The sections, augmented by published information and additional experience of the authors' form the lithological basis for this project.

The fossil identifications were made by A.S. Hedinger.

Standard formation nomenclature which, for the most part is consistent with prior usage designates different units within the sections. This nomenclature has been applied with some lithological, but little stratigraphic consistency. The following comments describe some of the nomenclatural usage which is inconsistent with prior usage.

"Alexo Formation" - The restricted inner detrital, unfossiliferous facies of the Calmar-Blue Ridge Cycle and the overlying basal siliciclastic beds of the Wabamum Cycle.

Simla Member - The normal marine, usually fossiliferous shelf carbonate facies of the Calmar-Blue Ridge Cycle. The facies change from "Alexo" to Simla is gradational and somewhat arbitrary. It occurs between Twps. 40-44.

Ronde Member - Units that have been previously referred to the Ronde within the Miette and the northern part of the Southesk Cairn Complexes (e.g. Mountjoy, 1965; MacKenzie, 1969) are assigned to the Simla in these sections. The term Ronde is not used.

Grotto Member - A dark dolomite facies of the Southesk Formation.

The Depositional Cycles recognized within the study are not labelled within the sections.

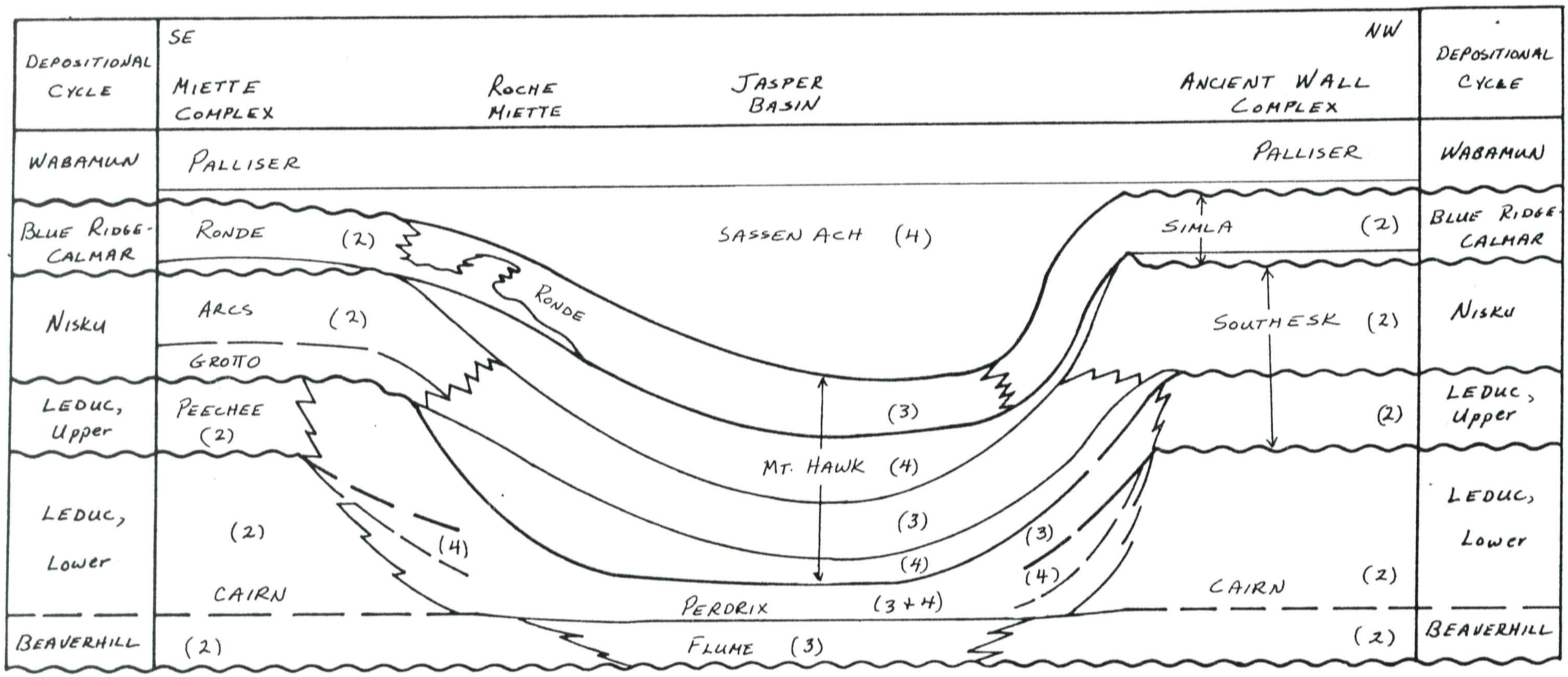


Figure 72: Diagrammatic cross-section, Miette to Ancient Wall Complex, across Jasper Basin. Facies numbers as in Figure 3.

PLATE I

Representative Lithologies

Ia: Mudcracks in argillaceous silty dolomite typical of the inner detrital facies, "Alexo Formation", Calmar-Blue Ridge Cycle, lens cap 5.5 cm. Littlehorn Creek, S.34, T.38, R18W5.

Ib: Cross-bedded quartz sandstone, basal Sassenach Formation, upper member, Wabamum Cycle, hammer head 15 cm wide. Rocky Pass, S.4, T.45, R23W5.

Ic: Dolomitized cross-bedded lime sand, shelf carbonate facies, Cairn Formation, Leduc, Lower Cycle, 21 mm coin. Owen Creek, S.35, T.35, R20W5.

Id: Stromatoporoid packstone, calcitic fossils in partially dolomitized matrix, margin of carbonate shelf, Ronde Member, Calmar-Blue Ridge Cycle, 24 mm coin. Toma Creek, S.35, T.44, R23W5.

Ie: Pelecypod (megalodont) coquina, margin of carbonate shelf, Ronde Member, Calmar-Blue Ridge Cycle, 17.5 cm wide hammer head. Toma Creek, S.35, T.44, R23W5.

If: Disphyllid biostrome, corals in growth position, dolomitized, Leduc, Upper Cycle; 15 cm wide hammer head. Cripple Creek, S.9, T.37, R15W5.

1a

1b

1c

1d

1e

1f

PLATE II

Representative Lithologies

IIa: Stromatoporoid biostrome, Cairn Formation, Leduc, Lower Cycle, 15 cm wide hammer head. Wapiabi Gap, S.32, T.40, R17W5.

IIb: Stromatactis dolomite, slope facies, Perdrix Formation, Leduc, Lower Cycle; 15 cm wide hammer head. Hummingbird Creek, S.9, T.36, R16W5.

IIc: Debris flow, carbonate bank-derived lithoclasts basinward of Southesk Cairn Complex, Perdrix Formation, hammer head 15 cm wide. Wapiabi Gap, S.32, T.40, R17W5.

IId: Interbedded argillaceous nodular limestone and calcareous shale with bioclastic debris typical of near-reef Perdrix Formation, 19.5 cm wide hammer head, Wapiabi Gap, S.32, T.40, R17W5.

IIe: Limestone coquina, brachiopods (mostly Atrypa) rugose corals, Thamnopora, cylindrical bryozoans in limey shale matrix, basin-fill facies, tongue of Mount Hawk Formation, coin 21 mm wide. Hummingbird Creek, S.9, T.36, R16W5M.

IIf: Stylolitized dolomitized calcarenite, shelf carbonate facies, horizontal bedding, Leduc Cycles, illustrating some of the diagenesis that has affected the Devonian, lens cap 5.5 cm, Lac de Arcs, S.16, T.24, R9W5.

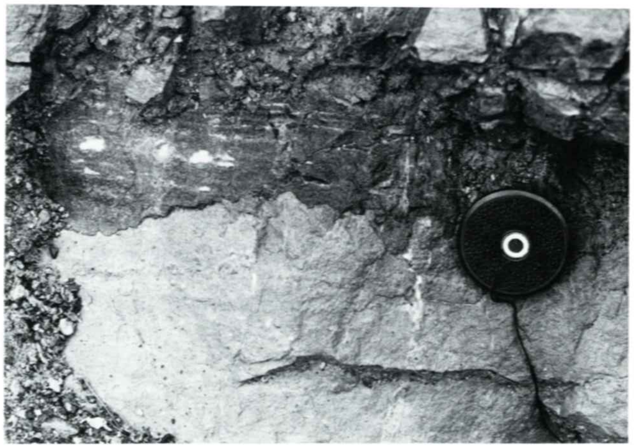
II a

II b

II c

II d

II e



II f

LIST OF FIGURES

Figure 17: Reef-to-offreef relationships, north end of Lynx Creek reef, view to southwest, reef has been overthickened by thrust faults, Lynx Creek, S1, 2, T7, R5W5M.

Figure 18: Contact, algal stromatolites at the base of the Palliser Formation over the top of the "Alexo Formation. South Lost Creek, Flathead Range, S34, T5, R5W5.

Figure 19: Contact. The Upper Cambrian erosion surface has been incised by a channel, infilled by ?Middle Devonian clastics of the Yahatinda Formation and overlain by the Upper Devonian Cairn Formation, approximately 500 m of section. Wasootch Creek, S33, T22, R8W5.

Figure 20: Devonian section, showing patch reefs in upper part of Cairn Formation interior of Fairholme Carbonate Complex, head of Wasootch Creek, S27, T22, R8W5.

Figure 21: Subaerial exposure surface within Peechee Formation, interior of Fairholme Carbonate Complex. Roadcut outcrop, Trans Canada Highway at Lac de Arcs, S21, T24, R9W5.

Figure 22: Typical appearance of interior of major Frasnian carbonate bank. Type area of Fairholme Group, Rocky Mountain Front Range above Loder Lime Plant, S36, T24, R9W5.

Figure 23: Diagrammatic cross-section, Burnt Timber Embayment of Fairholme Carbonate Complex, Alberta.

Figure 24: Distal bank margin of Fairholme Carbonate Complex to left, Burnt Timber Embayment to right, "Peechee facies" of the Cairn Formation. Mount Oliver, S36, T28, R11W5.

Figure 25: Distal debris flow of Leduc, Lower Cycle at south margin of Burnt Timber Embayment, a few hundred m north of Figure 24. S36, T28, R11W5.

Figure 26: Satellite pinnacle reef, Peechee facies of Leduc, Lower Cycle, Burnt Timber Embayment, North Burnt Timber Creek, S34, T28, R11W5.

Figure 27: Lateral facies change within Beaverhill Cycle, bank to right, Burnt Timber Embayment to left, the Leduc, Lower Cycle. North margin Burnt Timber Embayment, S22, T29, R11W5.

Figure 28: North margin, Burnt Timber Embayment, bank to right, basin to left, bank margin in Leduc, Lower Cycle. North Burnt Timber Creek, S16, T29, R11W5.

Figure 29: Basinal Fairholme section within Scalp Creek Embayment, west half T33, R11W5.

Figure 30: North margin Scalp Creek Embayment, Peechee facies of Leduc, Lower Cycle, head of Rocky Creek, S2, T34, R12W5.

Figure 31: Interior of Fairholme Carbonate Complex North of Scalp Creek Embayment. Head of Rocky Creek, S2, T34, R12W5.

Figure 32: Contact, Upper Devonian Cairn Formation directly overlying Upper Cambrian dolomite. Hummingbird Creek, S23, T35, R15W5.

Figure 33: Leduc, Upper Cycle changes facies from light Peechee to dark Grotto lithology toward Cline Channel. Five km northwest of South Ram River, S20, T36, R14W5.

Figure 34: Leduc, Upper Cycle in dark grey "Grotto" facies, 5 km southeast of Cripple Creek margin, northeast quarter, T36, R15W5M.

Figure 35: Cripple Creek bank margin, within the upper part of Leduc, Lower Cycle, north flank of Fairholme Carbonate Complex, S4, 9 T37, R15W5.

Figure 36: Cripple Creek basinal section, south side of Cline Channel. S8, 9, T37, R15W5.

Figure 37: Massive bedded foreslope limestone of Leduc, Upper Cycle progrades toward right (basinward) above Perdrix basin-fill, 5 km northwest of Cripple Creek margin. Southeastern side of North Ram River, S18, T37, R15W5.

FIGURE ANNOTATIONS

Mr - Rundle
Mb - Banff — Mississippian

Pa - Palliser

"Carbonate" Units

Si - Simla
Ar - Arcs
Gr - Grotto
Pe - Peechee
C - Cairn

Sx - Southesk

C - Cambrian

"Clastic" Units

Sa - Sassenach

Al - Alexo
MH - Mount Hawk

Px - Perdrix
F - Flume

Yh - Yahatinda

Depositional Cycles

C-BR - Calmar-Blue Ridge

N - Nisku

L, U - Leduc, Upper

L, L - Leduc, Lower

Bh - Beaverhill

Facies Groups

1 Inner detrital clastic carbonates, evaporites

2 Shelf carbonates

3 Slope and basin carbonates and shale

4 basin-fill with no shelf correlatives

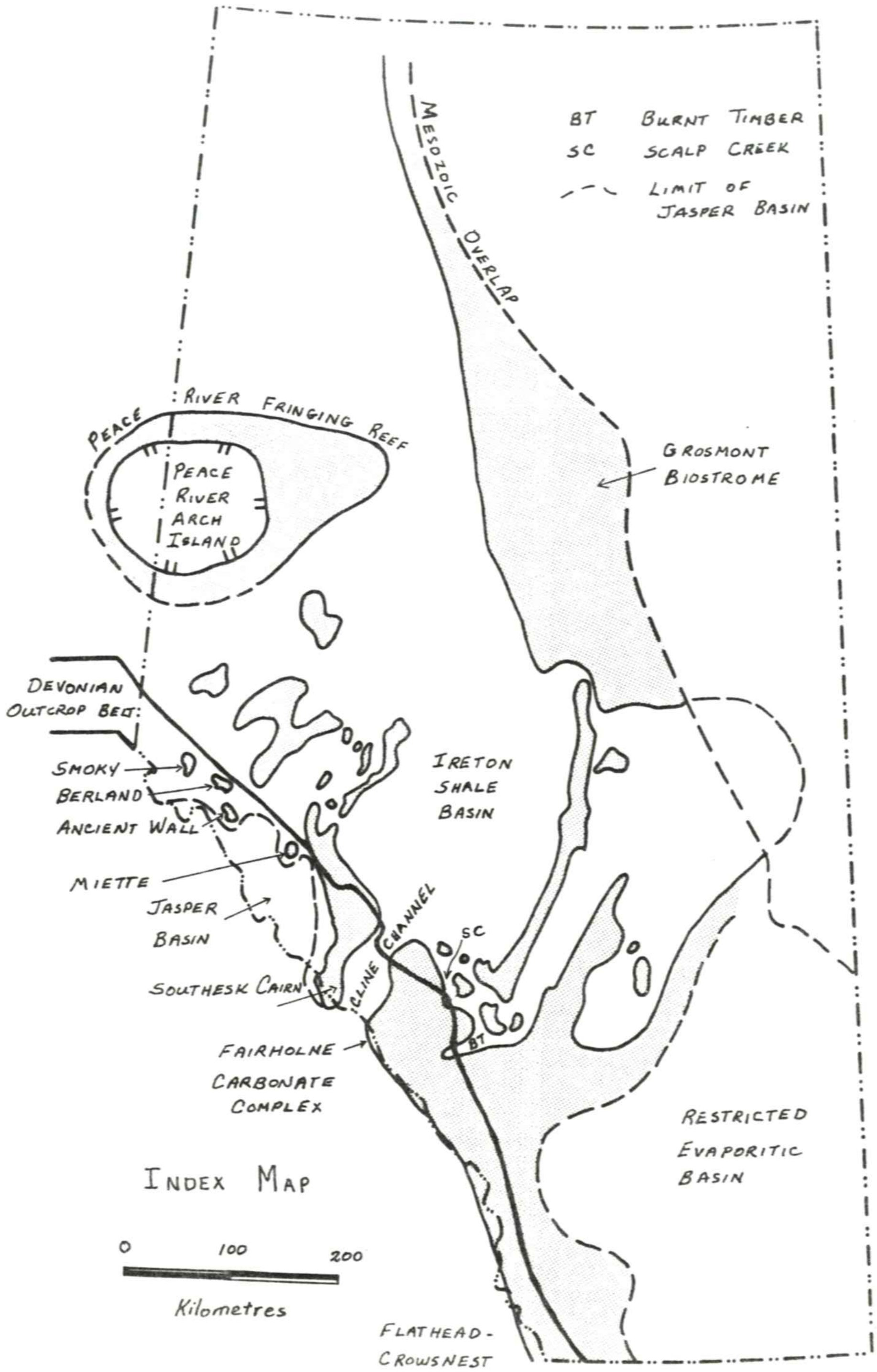


Figure 1: Index map of Alberta showing distribution of the major Fairholme carbonate complexes (stippled). Modified from Belyea (1964, Fig. 6-16) Woodhead and Wright-Broughton (1967), Mountjoy (1980), Workum (1983), and Andrews (1988). Devonian outcrop belt of southwestern Alberta is outlined, --- approximate limit of Jasper Basin, BT - Burnt Timber Embayment, SC - Scalp Creek Embayment.

Figure 2: Map showing surface distribution of the Devonian in part of the Canadian Rocky Mountains (in pocket).

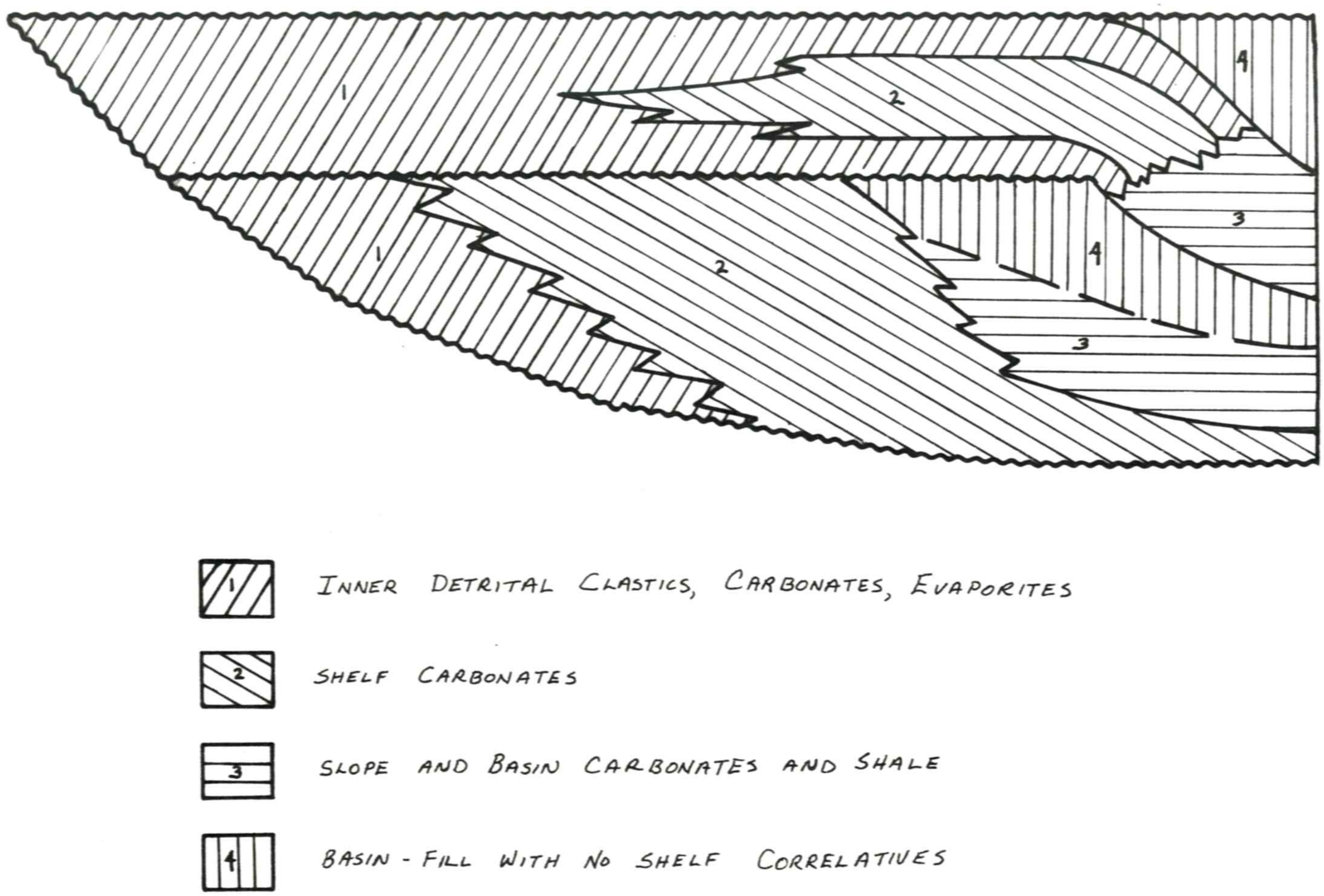


Figure 3: Generalized facies of the Fairholme Group. This figure illustrates two depositional sequences (cycles), a lower transgressive and an upper regressive sequence. Five such cycles are recognizable within the project area. These facies numbers are used on the following Figures.

1 - inner detrital clastics, carbonates, evaporites
2 - shelf carbonates
3 - slope and basin carbonates and shale
4 - basin-fill with no shelf correlatives

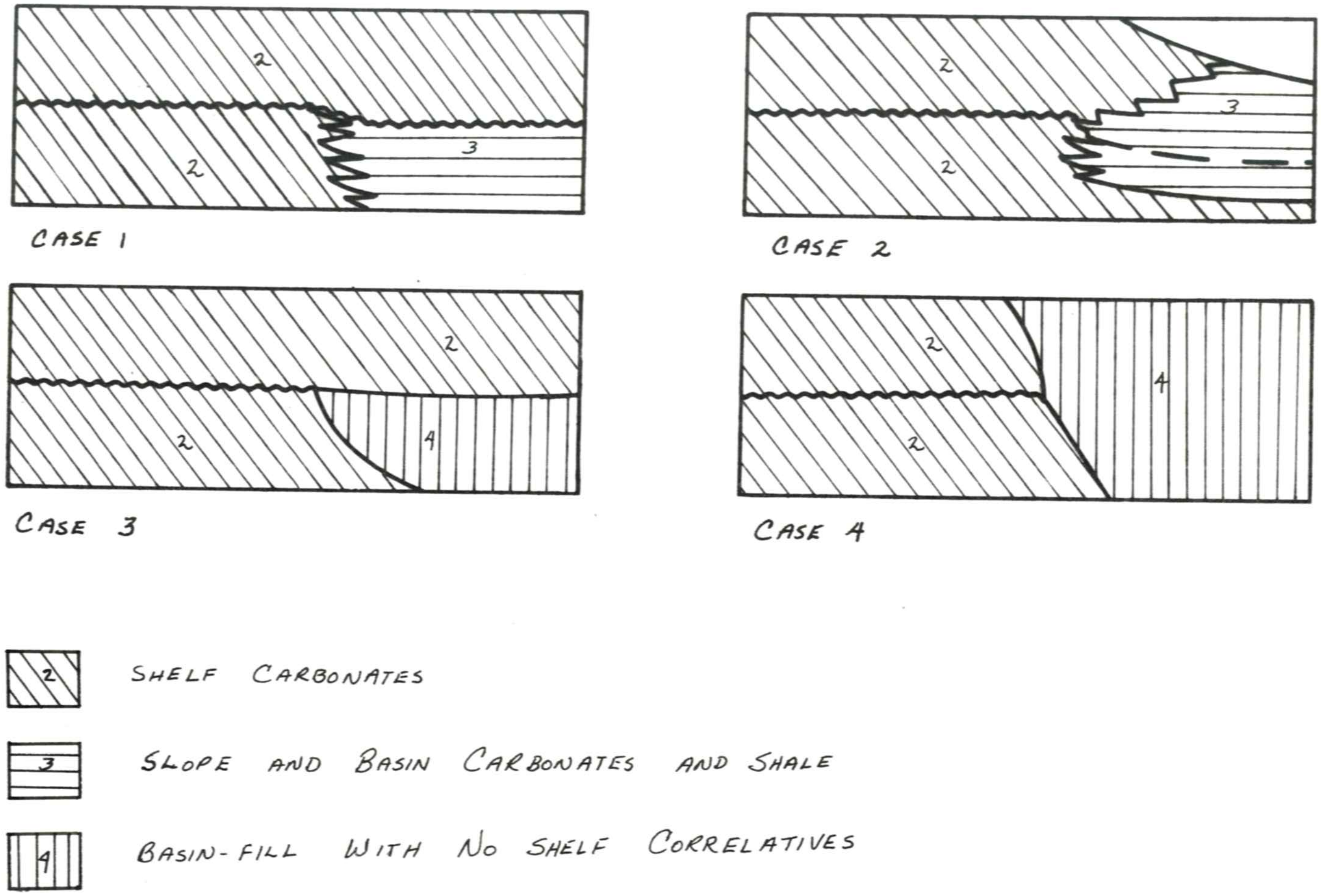


Figure 4: Fairholme sedimentary styles. Representation of four different types of relationships between two superimposed depositional cycles.

Case 1 illustrates lateral facies change from shelf to basinal carbonate in lower sequence with minimal associated thickness change. This allows overlying sequence to continue over the underlying facies change with little change in thickness or lithology.

Case 2 illustrates lateral facies change from shelf to basinal carbonate in lower sequence with significant associated thickness change. This causes overlying sequence to change facies and thickness into deeper water lithology.

Case 3 illustrates carbonate bank margin in lower sequence followed by deposition of basin-fill allowing overlying sequence to continue over the underlying margin without interruption as in Case 1.

Case 4 illustrates carbonate bank margin in lower sequence followed by a period of non-deposition. This results in the overlying sequence being limited laterally by the limits of the underlying sequence. The basin-fill postdates the upper carbonate bank sequence. Facies numbers as in Figure 3.

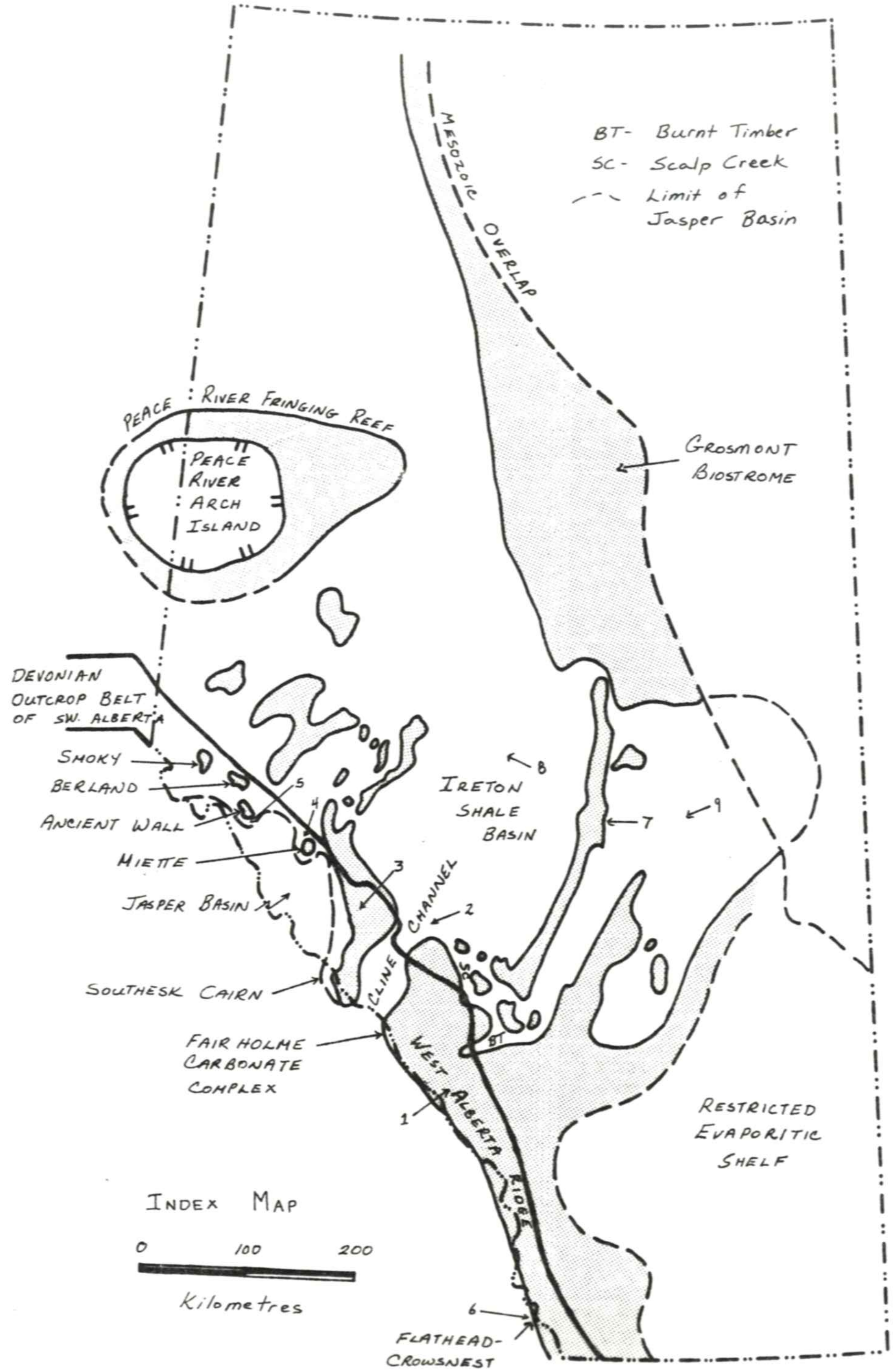


Figure 5: Index Map showing location of type sections of surface lithostratigraphic units, and subsurface units utilized for depositional cycles- Numbers denote location of type sections:

1 - Fairholme Group, Peechee, Grotto, Arcs Members
2 - Alexo Formation
3 - Cairn, Southesk Formations
4 - Flume, Perdrix, Mount Hawk Formations, Ronde Member
5 - Sassenach Formation, Simla Member
6 - Hollebeke, Borsato Formations
7 - Woodbend, Winterburn Groups, Leduc, Ireton, Nisku, Calmar, Graminia Formations
8 - Blue Ridge Member
9 - Beaverhill Lake Group

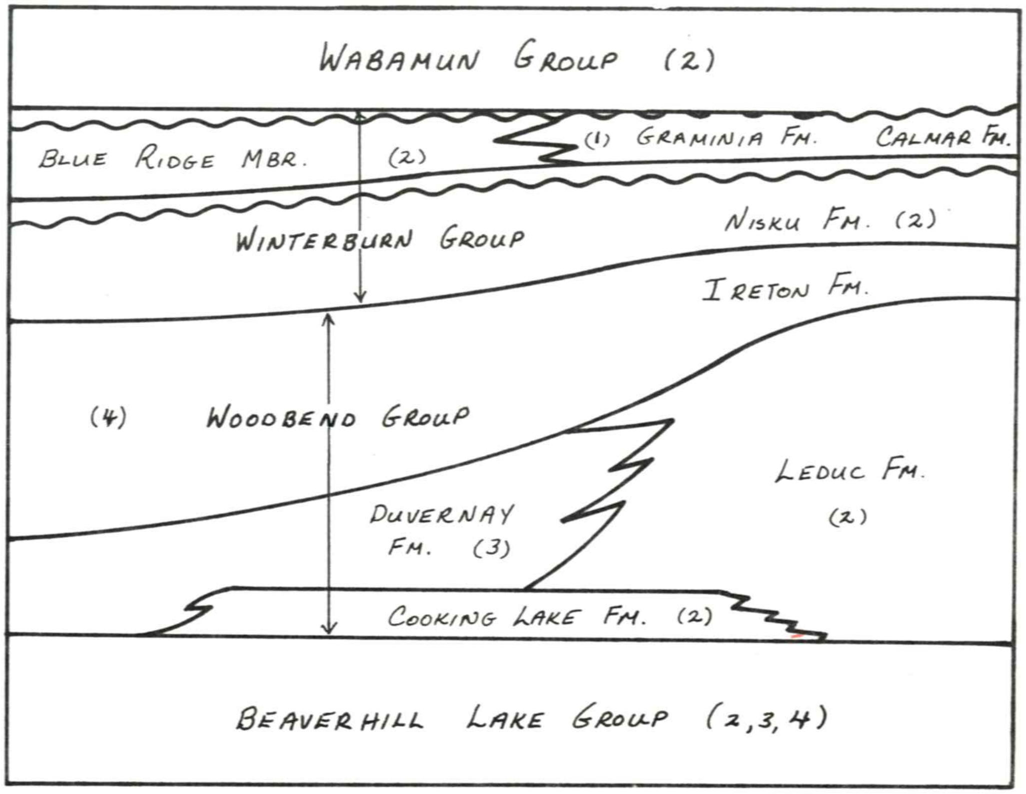


Figure 6: Diagrammatic section illustrating "reef" to "off-reef" relationships in the vicinity of the subsurface type sections of central Alberta. Facies numbers as in Figure 3.

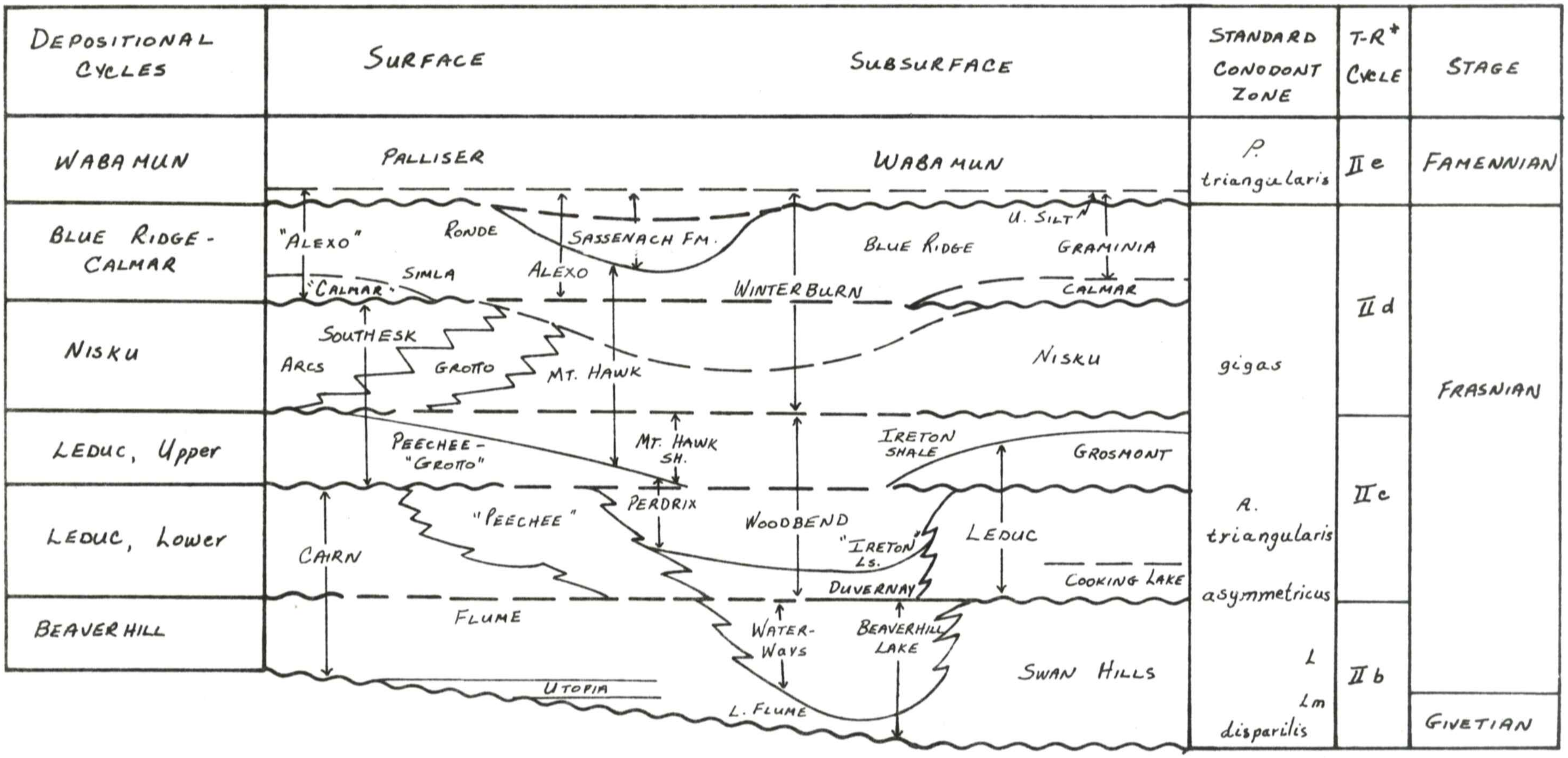


Figure 7: Lithostratigraphic nomenclature, central Alberta, surface to subsurface, showing relationship between formations and depositional cycles. Bases of transgressive cycles are illustrated as horizontal lines. * T-R cycles after Johnson et al. (1985), Sandberg et al. (1988).

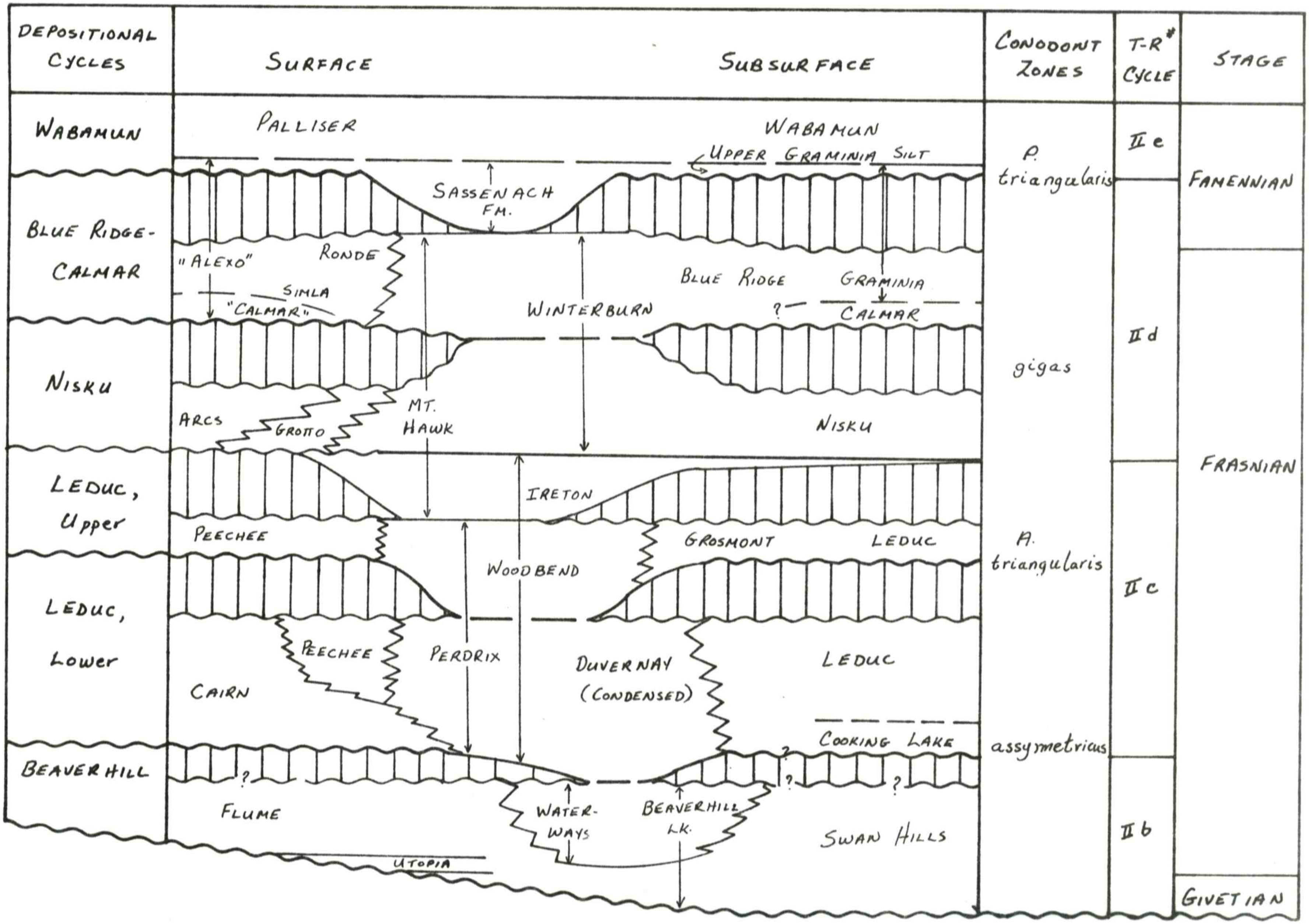
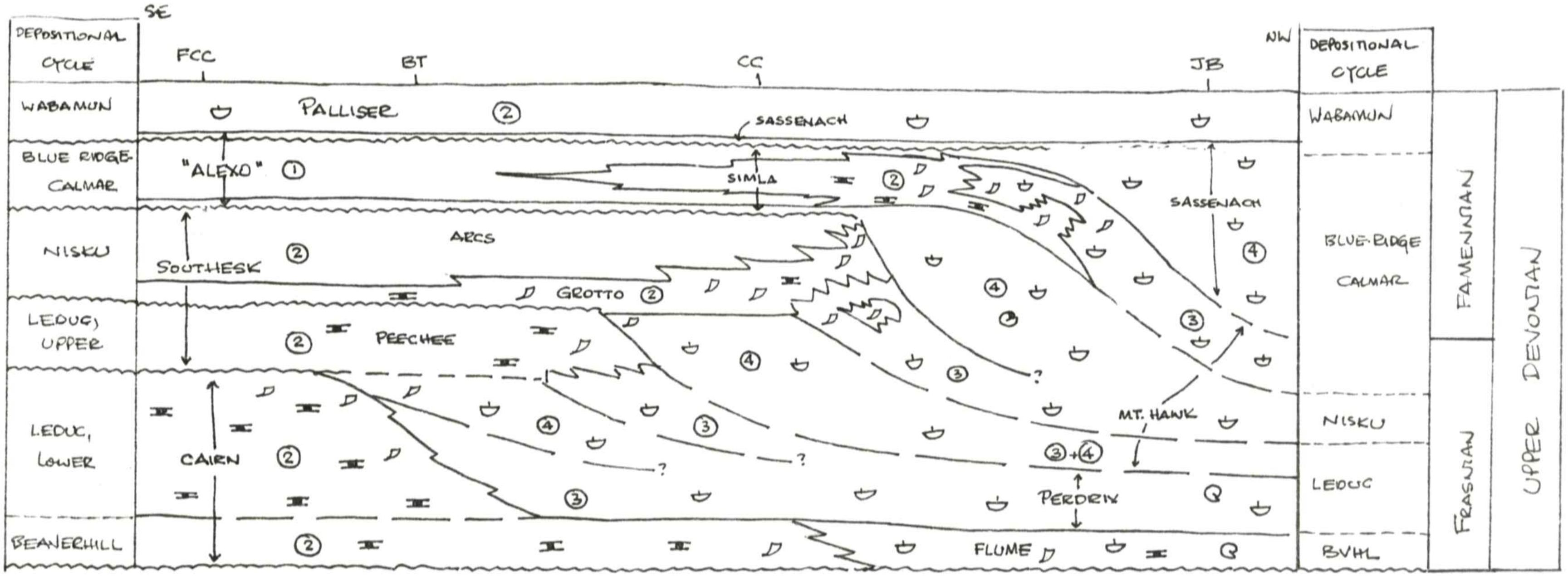


Figure 8: Lithostratigraphic nomenclature, central Alberta, surface to subsurface, showing relationship between formations and depositional cycles. Horizonal component is distance, vertical component is time. * T-R cycles after Johnson et al. (1985), Sandberg et al. (1988).

FIGURE 9: DISTRIBUTION OF MAJOR MACROFOSSIL GROUPS WITHIN THE FRASNIAN OF THE ALBERTA FRONT RANGES. Facies as in Figure 3
FCC = Fairholme Carbonate Complex
BT = Burnt Timber Embayment
CC = Cline Channel
JB = Jasper Basin



STROMATOPOROIDS
CORALS
BRACHIOPODS
AMMONOIDS

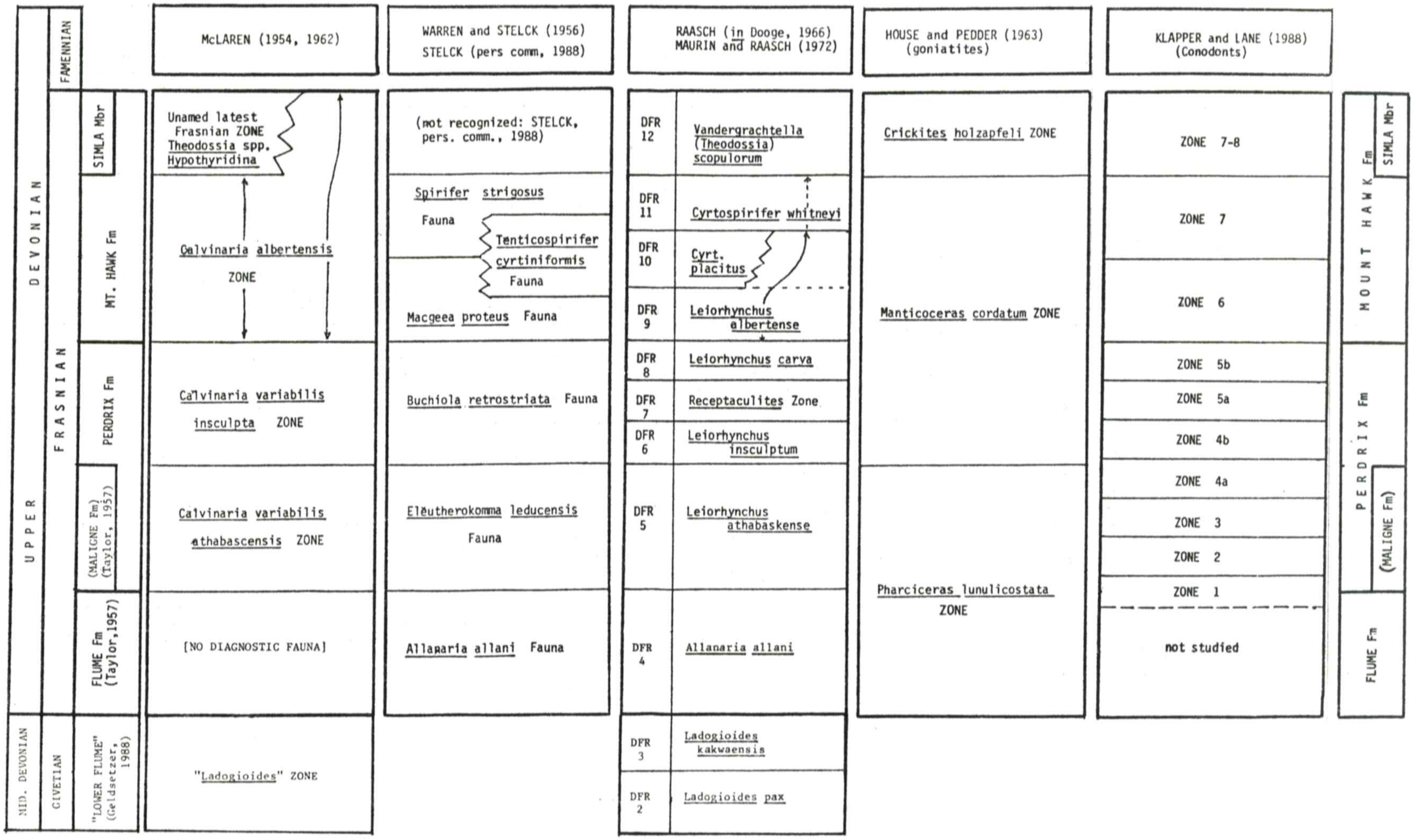


Figure 10: Comparison of slope - basinal biostratigraphic schemes, Alberta Rocky Mountains.

<table>
<tr><th></th><th rowspan="2">DEPOSITIONAL CYCLE</th><th colspan="3">This Paper</th><th colspan="2">Stearn, 1976*</th><th rowspan="2">STROMATOPOROID ZONE</th></tr>
<tr><th></th><th>Fm</th><th colspan="2">Mbr</th><th colspan="2">Mbr</th></tr>
<tr><td rowspan="7">FRASNIAN</td><td rowspan="2">BLUE RIDGE-CALMAR</td><td rowspan="4">SOUTHESK Fm</td><td rowspan="2">SIMLA Mbr</td><td></td><td colspan="2">ARCS</td><td>ZONE 5</td></tr>
<tr><td>silt</td><td colspan="2">GROTTO</td><td></td></tr>
<tr><td>NISKU</td><td colspan="2" rowspan="2">Lower SOUTHESK (undivided)</td><td colspan="2" rowspan="2">PEECHEE</td><td>ZONE 4</td></tr>
<tr><td>LEDUC, UPPER</td><td>ZONE 3</td></tr>
<tr><td>LEDUC, LOWER</td><td rowspan="3">CAIRN Fm</td><td colspan="2">UPPER Mbr</td><td colspan="2">UPPER Mbr</td><td rowspan="2">ZONE 2</td></tr>
<tr><td rowspan="2">BEAVERHILL</td><td rowspan="2">FLUME Mbr</td><td>"Upper Cherty"</td><td rowspan="2">FLUME Mbr</td><td>"Upper Cherty"</td></tr>
<tr><td>UTOPIA</td><td></td><td>ZONE 1</td></tr>
</table>

[* Stratigraphy based on Mountjoy and MacKenzie, 1974]

FIGURE 11: STROMATOPOROID ZONATION OF THE SOUTHERN MARGIN OF THE ANCIENT WALL CARBONATE COMPLEX [after STEARN, 1976]

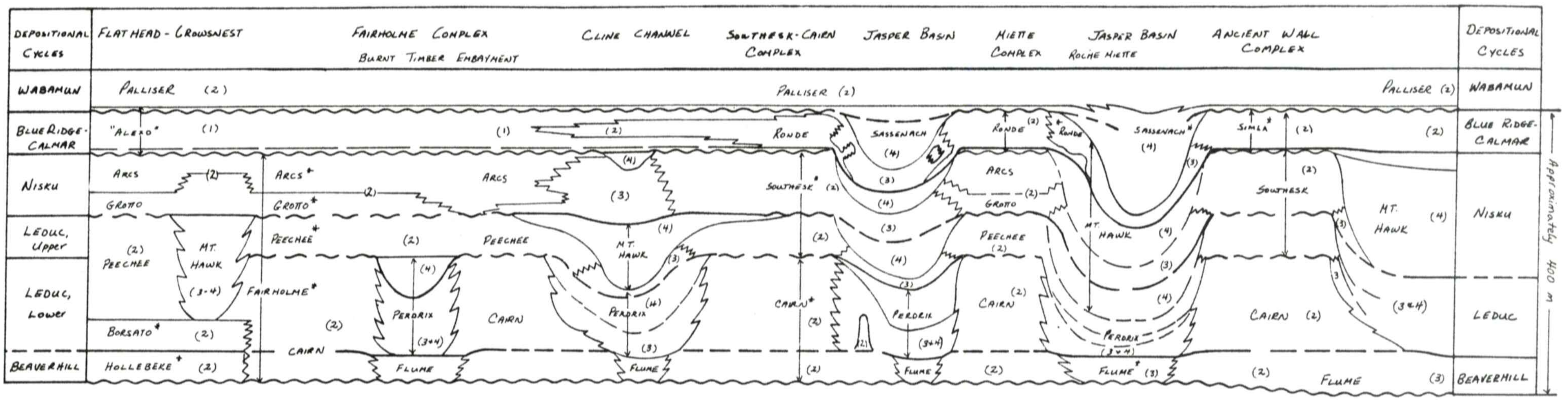


Figure 12: Diagrammatic cross-section from Flathead - Crowsnest area to northwest of Ancient Wall Complex, southwestern Alberta, approximately 600 km. Unconformities separating depositional sequences are shown as horizontal lines. Type sections indicated by *. Facies numbers as in Figure 3.

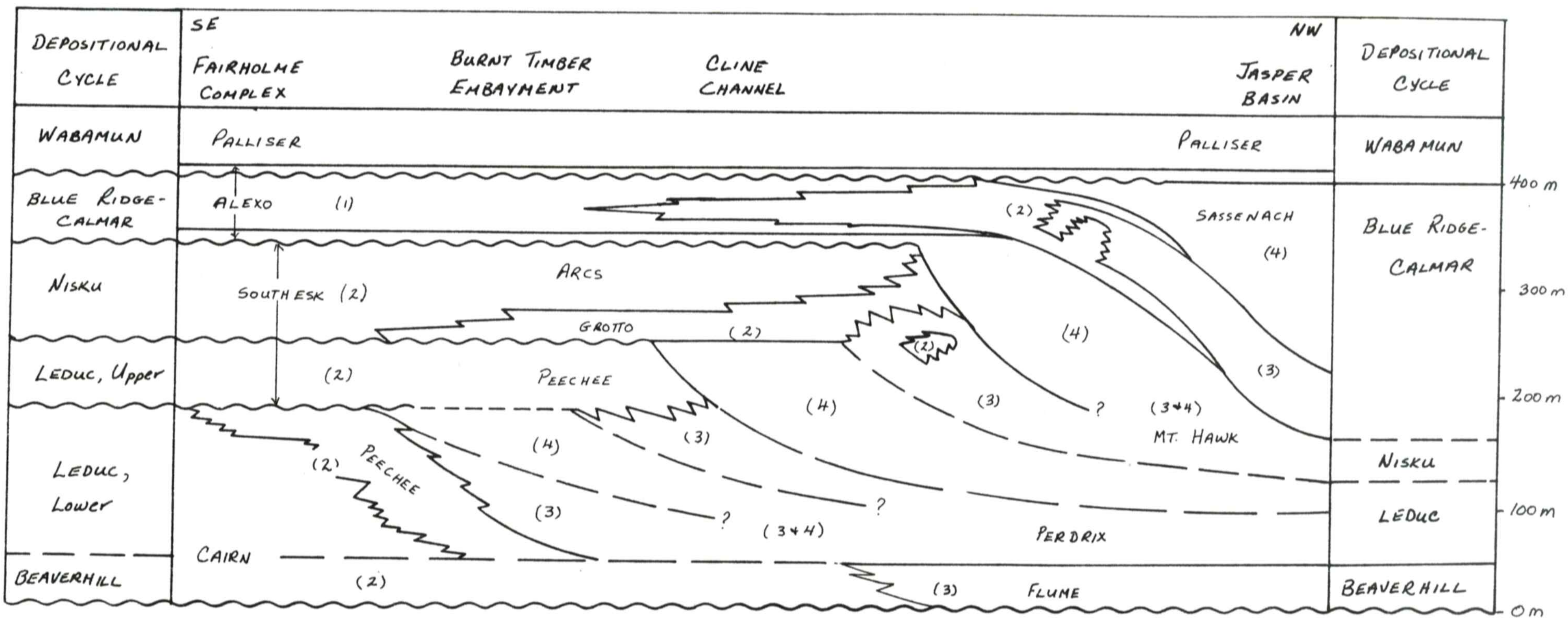


Figure 13: Composite facies diagram, Fairholme Carbonate Complex to Jasper Basin, Alberta. Facies numbers as in Figure 3.

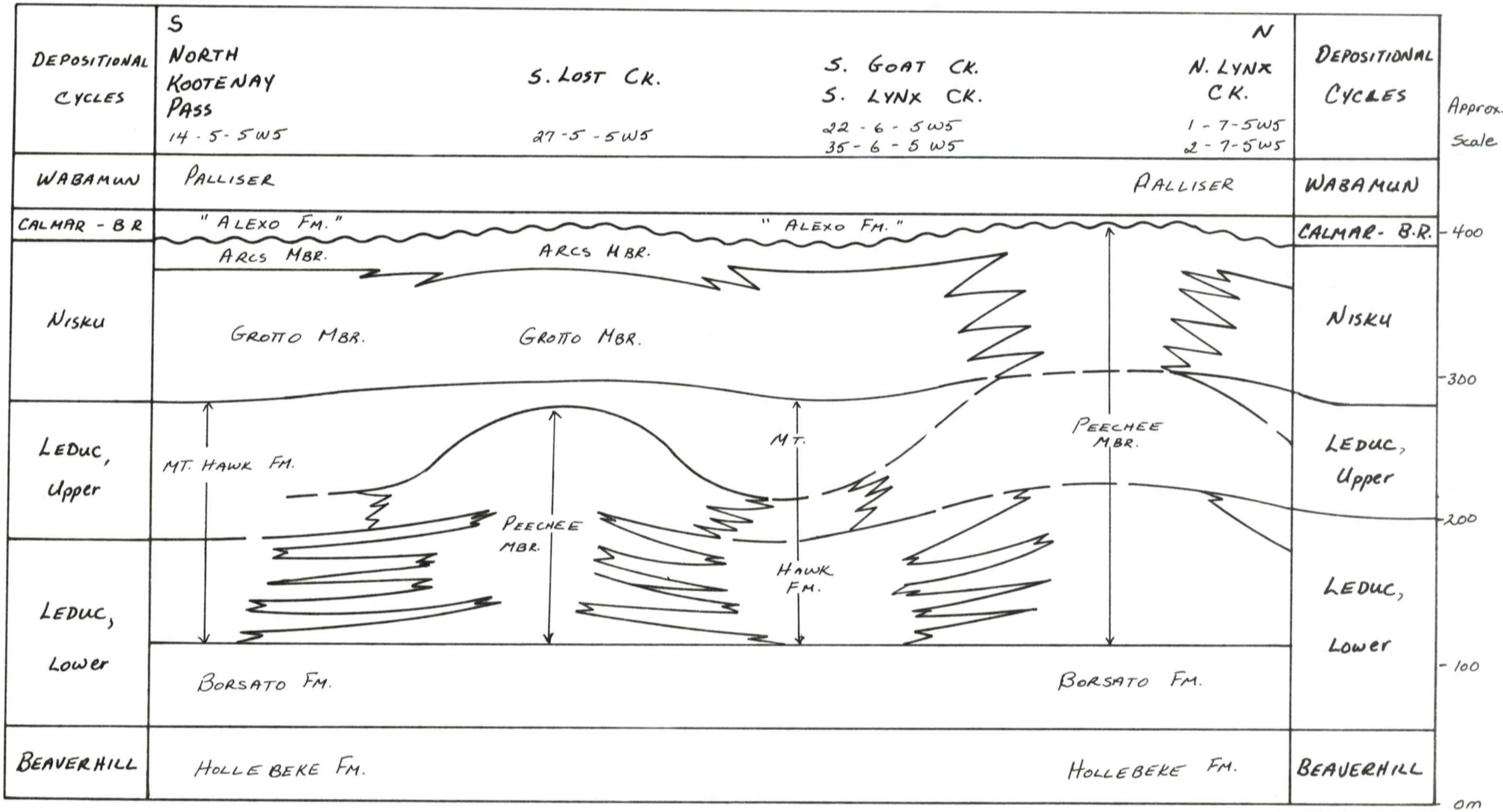


Figure 14: Diagrammatic cross-section showing comparison between Devonian depositional cycles and formation nomenclature of Price (1964, 1965), Flathead - Crowsnest Pass Area, thrust faults removed, true thickness of Hollebeke Formation is unknown.

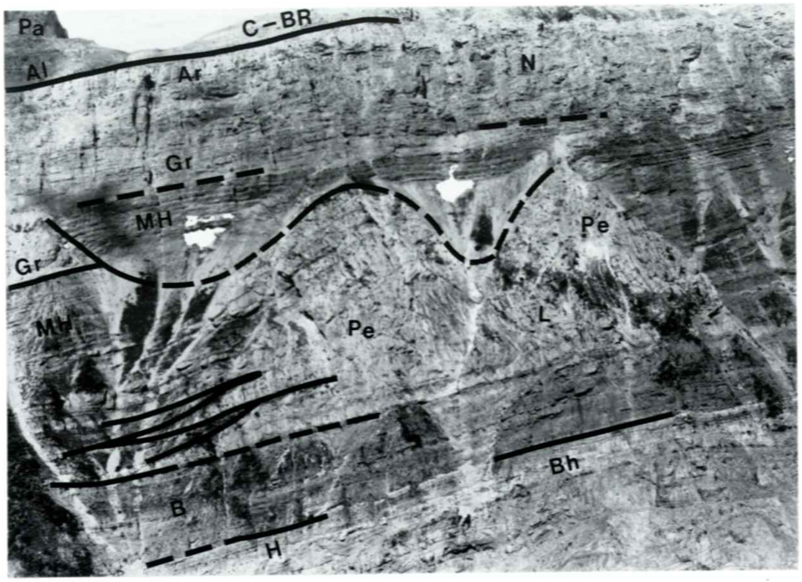


Figure 15: Dolomitized patch reefs, Leduc Cycles, showing lateral interfingering with Mount Hawk Formation, **H** - Hollebeke, **B** - Borsato Formation. Approximately 500 m of section, head of South Lost Creek, Flathead Range, S34, T5, R5W5.

Figure 16: Basinal Devonian section, Flathead Range, **H** - Hollebeke, **B** - Borsato, **Mb** - Mississippian Banff, **Mr** - Rundle, view to north 1 km north of South Lost Creek reefs, S34, T5, R5W5.

Figure 17: Reef-to-offreef relationships, north end of 'Lynx Creek reef, view to southwest, reef has been overthickened by thrust faults, **H** - Hollebeke, **B** - Borsato, **Mb** - Mississippian Banff, **Mr** - Rundle, Lynx Creek, S1,2, T7, R5W5M.

Figure 18: Contact, algal stromatolites at the base of the Palliser Formation over the top of the "Alexo Formation". Contact is at 15 cm wide hammer head. Stromatolites characterize this contact, but are not present everywhere within the project area. South Lost Creek. Flathead Range, S34, T5, R5W5.

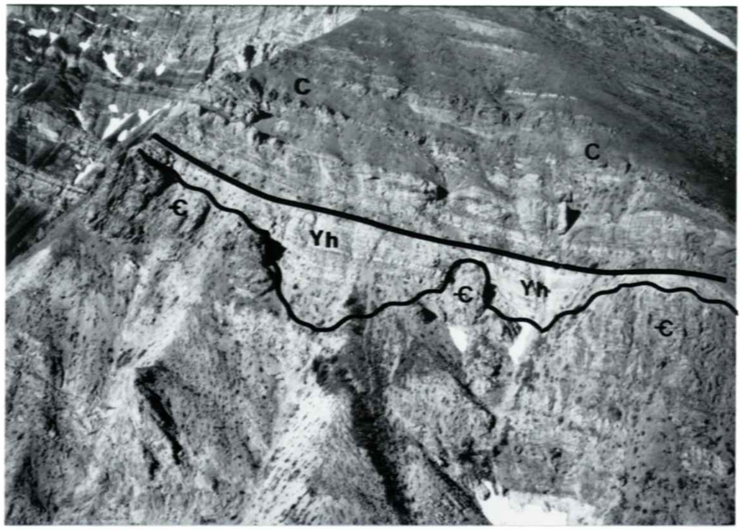


Figure 19: Contact. The Upper Cambrian erosion surface has been incised by a channel, infilled by ?Middle Devonian clastics of the Yahatinda Formation and overlain by the Upper Devonian Cairn Formation, approximately 500 m of section. Wasootch Creek, S33, T22, R8W5.

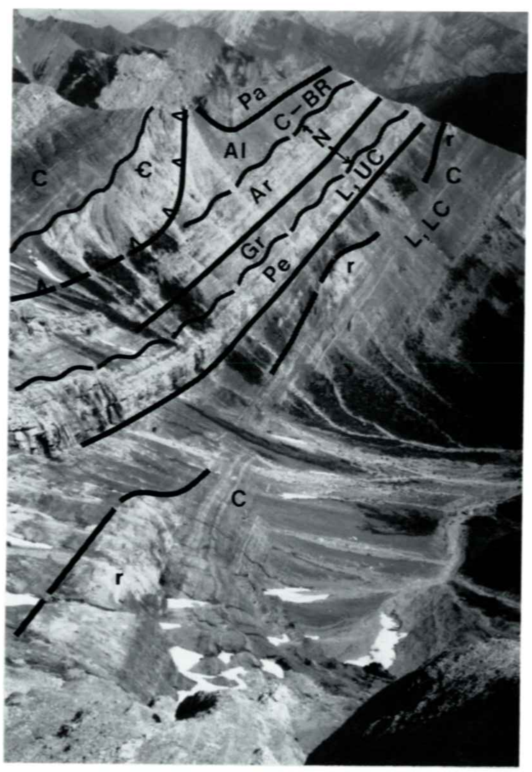


Figure 20: Devonian section, showing patch reefs (**r**) in upper part of Cairn Formation interior of Fairholme Carbonate Complex, arrows on hanging wall of thrust fault, Top Cambrian to base Palliser approximately 400m, view is to northwest. Head of Wasootch Creek, S 27, T22, R8W5.

Figure 21: Subaerial exposure surface within Peechee Formation, interior of Fairholme Carbonate Complex. Roadcut outcrop, Trans Canada Highway at Lac des Arcs, S21, T24, R9W5.

Figure 22: Typical appearance of interior of major Frasnian carbonate bank. Type area of Fairholme Group, Rocky Mountain Front Range above Loder Lime Plant, S36, T24, R9W5.

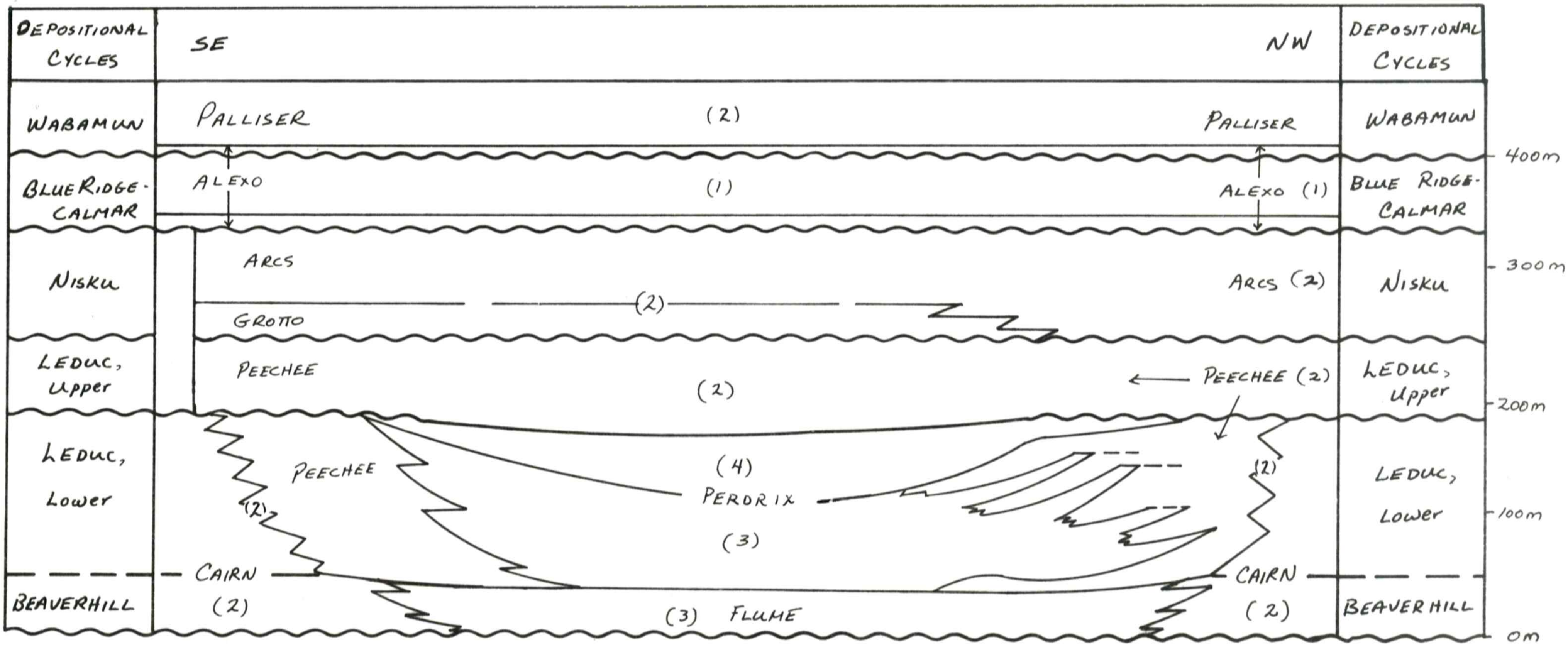


Figure 23: Diagrammatic cross-section, Burnt Timber Embayment of Fairholme Carbonate Complex, Alberta. Facies numbers as in Figure 3.

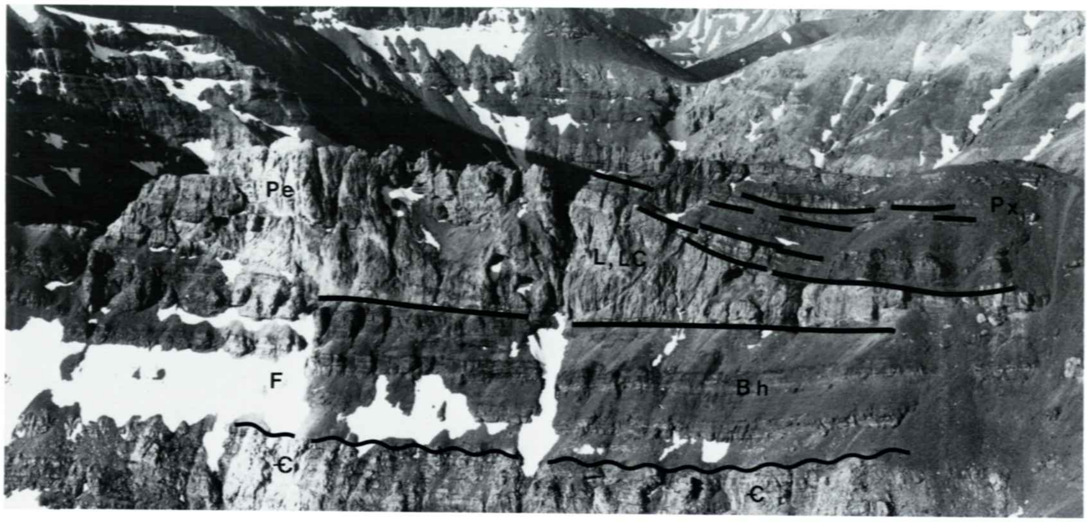


Figure 24: Distal bank margin of Fairholme Carbonate Complex to left, Burnt Timber Embayment to right, "Peechee facies" of Cairn Formation to left inter-fingering with and onlapped by open marine Perdrix Formation to right, Approximately 100 m of Devonian section in foreground, view to southwest. Mount Oliver, S.36, T.28, R11W5.

Figure 25: Distal debris flow of Leduc, Lower Cycle at south margin of Burnt Timber Embayment, a few hundred m north of Figure 24. Arrows point to allochthonous blocks which range from less than 1 cm to several m in size. S36, T28, RIIW5.

Figure 26: Satellite pinnacle reef, Peechee facies of Leduc, Lower Cycle, 2 km northwest of southeast margin, Burnt Timber Embayment, view to southeast, approximately 200 m of Devonian Section. North Burnt Timber Creek, S34, T28, RIIW5.

Figure 27: Lateral facies change within Beaverhill Cycle, bank to right, Burnt Timber Embayment to left, the Leduc, Lower Cycle bank progrades basinward beyond the Beaverhill Cycle bank margin. North margin Burnt Timber Embayment, S22, T29, RIIW5.

Figure 28: North margin, Burnt Timber Embayment, bank to right, basin to left, bank margin in Leduc, Lower Cycle. Perdrix carbonate basin-fill causes Leduc, Upper Cycle to prograde basinward across the Embayment. View is to northwest, approximately 500 m of Devonian section, North Burnt Timber Creek, S16, T29, RIIW5.

Figure 29: Basinal Fairholme section within Scalp Creek Embayment, M - Mississippian, view to northwest, west half T33, RIIW5.

Figure 30: North margin Scalp Creek Embayment, Peechee facies of Leduc, Lower Cycle at right side of photograph becomes thinner toward the left and into the embayment. The section has been tectonically overthickened. View to south, head of Rocky Creek, S2, T34, R12W5.

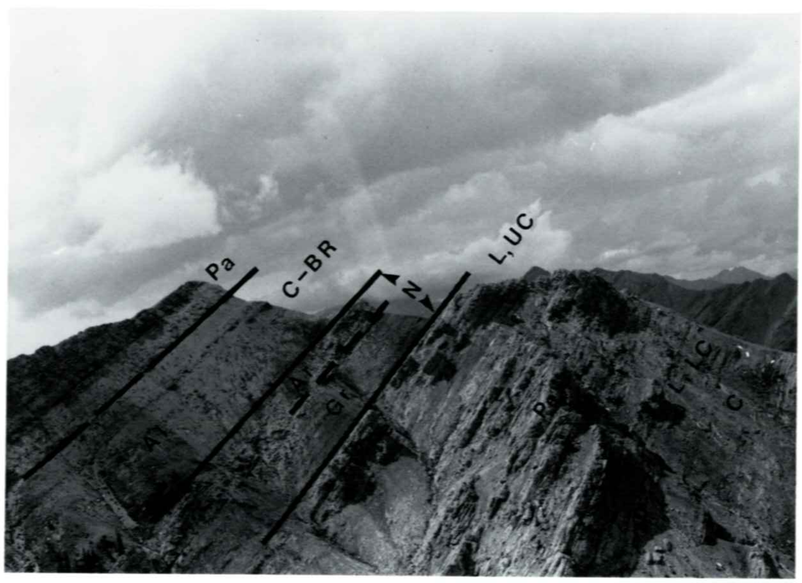


Figure 31: Interior of Fairholme Carbonate Complex North of Scalp Creek Embayment, view to west. Head of Rocky Creek, S2, T34, R12W5.

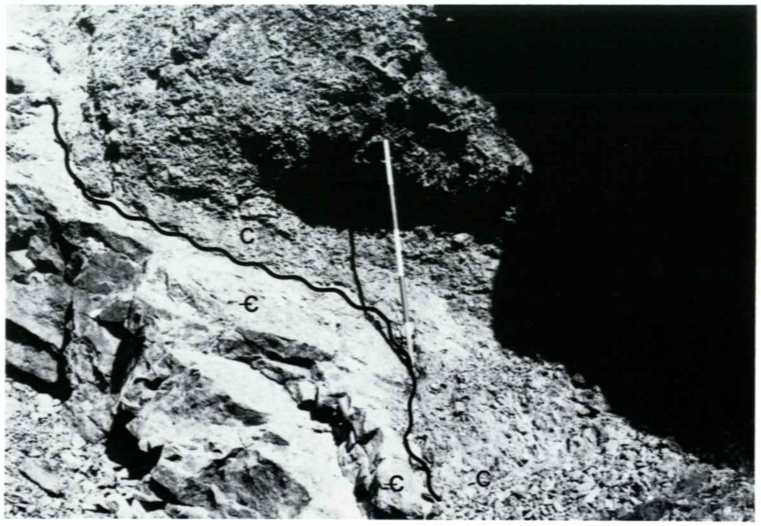


Figure 32: Contact, Upper Devonian Cairn Formation directly overlying Upper Cambrian dolomite. No obvious erosion at unconformity, which represents a 150 m.y. hiatus and is at base of the 5 foot staff. Hummingbird Creek, S23, T35, R15W5.

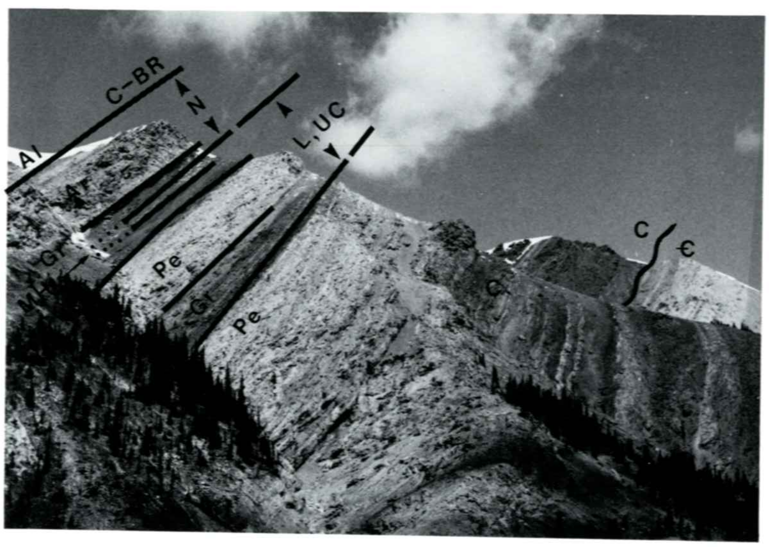


Figure 33: Leduc, Upper Cycle changes facies from light Peechee to dark Grotto lithology toward Cline Channel, view to northwest. Five km northwest of South Ram River, S20, T36, R14W5.

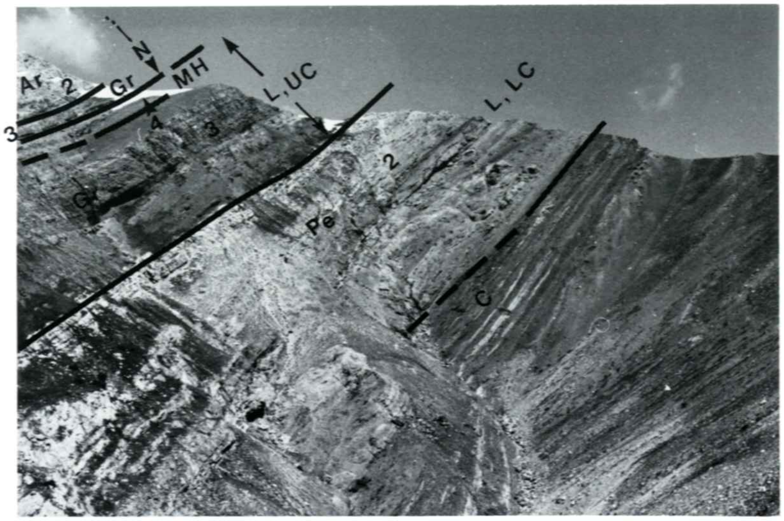


Figure 34: Leduc, Upper Cycle in dark grey "Grotto" facies, 5 km. southeast of Cripple Creek margin, view to northwest, northeast quarter, T36, R15W5M.

Figure 35: Cripple Creek bank margin, within the upper part of Leduc, Lower Cycle, north flank of Fairholme Carbonate Complex, view to southeast, Cline Channel to right. S 4,9. T37, R15W5.

Figure 36: Cripple Creek basinal section, south side of Cline Channel, view to northwest. Leduc, Upper Cycle progrades basinward above Lower Leduc basin-fill. S 8,9, T37, R15W5.

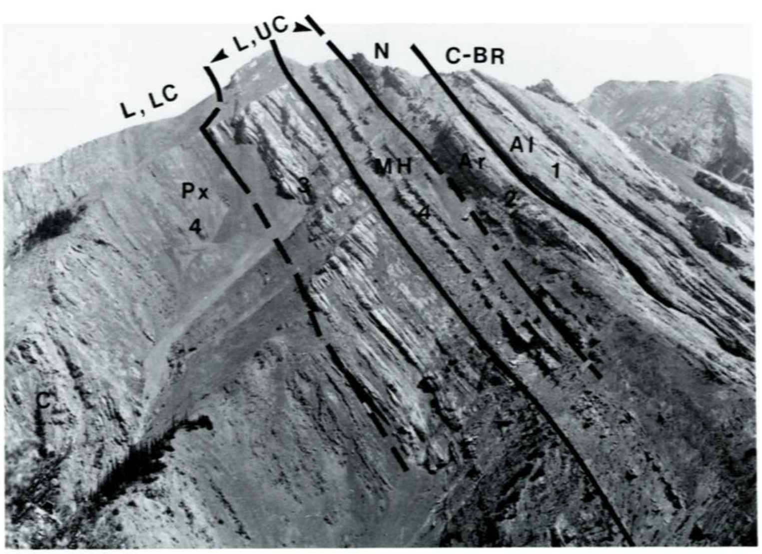


Figure 37: Massive bedded foreslope limestone of Leduc, Upper Cycle progrades toward right (basinward) above Perdrix basin-fill, 5 km northwest of Cripple Creek margin, view to southeast. One km northeast of this locality the Leduc, Upper Cycle carbonates foresets into the upper Perdrix Formation. Southeastern side of North Ram River, S.18, T.37, R15W5.

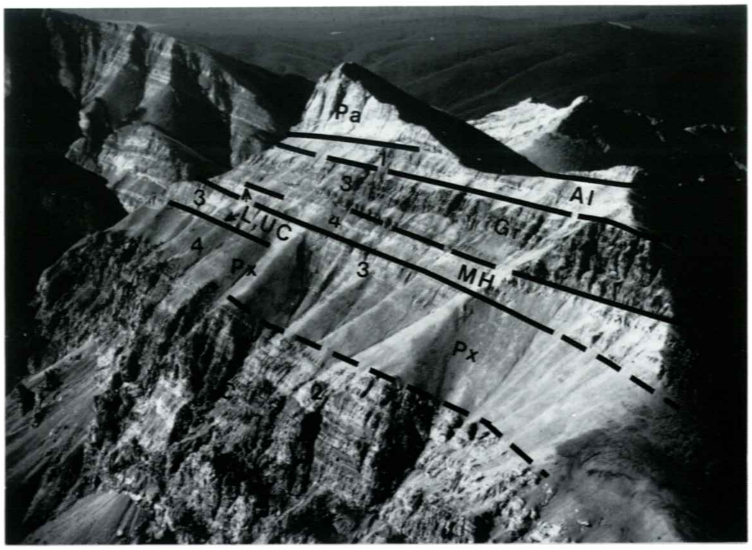


Figure 38: Lower foreslope of Leduc, Upper Cycle foresetting into upper part of Perdrix Formation to right, 6 km northwest of Cripple Creek margin, view to southeast. Northwest side of North Ram River, S24, T37, R16W5.

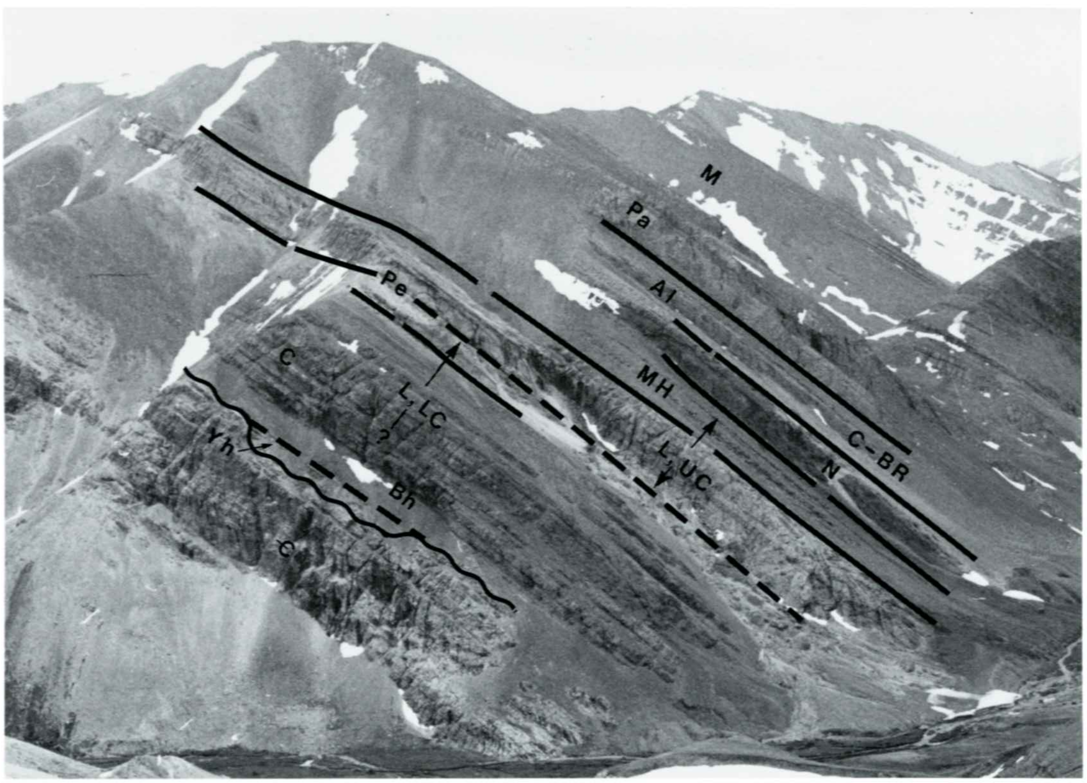


Figure 39: Hummingbird bank margin; Leduc, Upper Cycle, north flank of Fairholme Carbonate Complex, view to southeast. The light grey "Peechee" dolomite is absent northwest of Hummingbird Creek. Contact between Leduc, Lower and Upper Cycles appears to occur within the "Peechee". S4, T36, R16W5.

Figure 40: Hummingbird basinal section, across the valley northwest from Figure 39, view to northwest, S4, T36, R16W5.

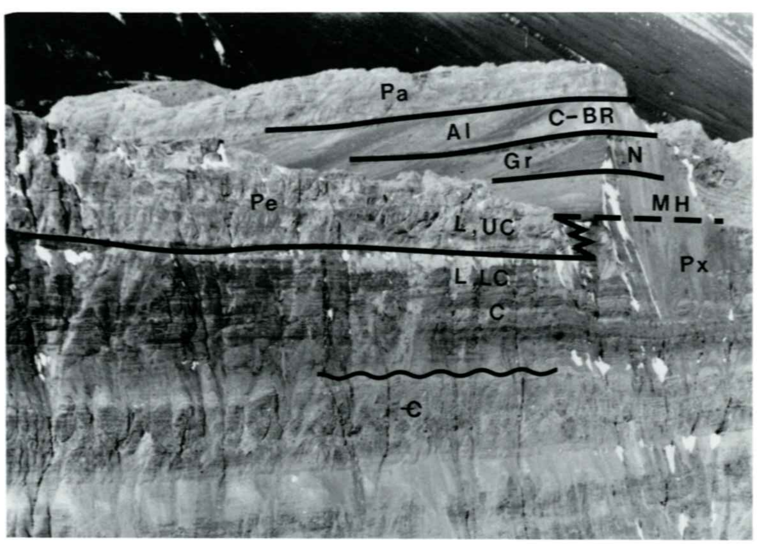


Figure 41: Whiterabbit margin, Leduc, Upper Cycle; northwestern flank Fairholme Carbonate Complex, view to southwest, S18, T35, R16W5.

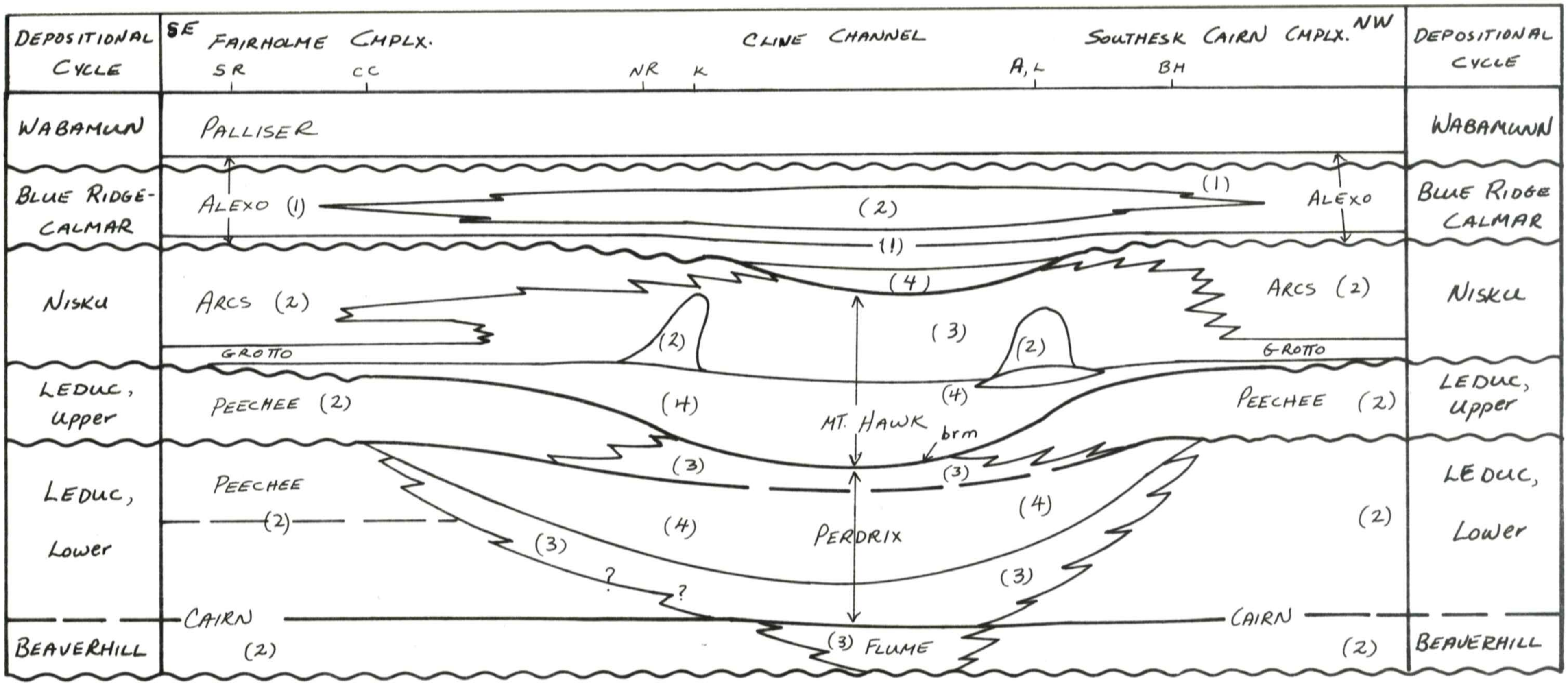


Figure 42: Diagrammatic cross-section, Cline Channel, Alberta. SR - South Ram River, CC - Cripple Creek, NR - North Ram River, K - Kiska, A - Allstones Creek, L - Littlehorn Creek, BH - Bighorn River, brm - "basinal rusty marker". Facies numbers as in Figure 3.

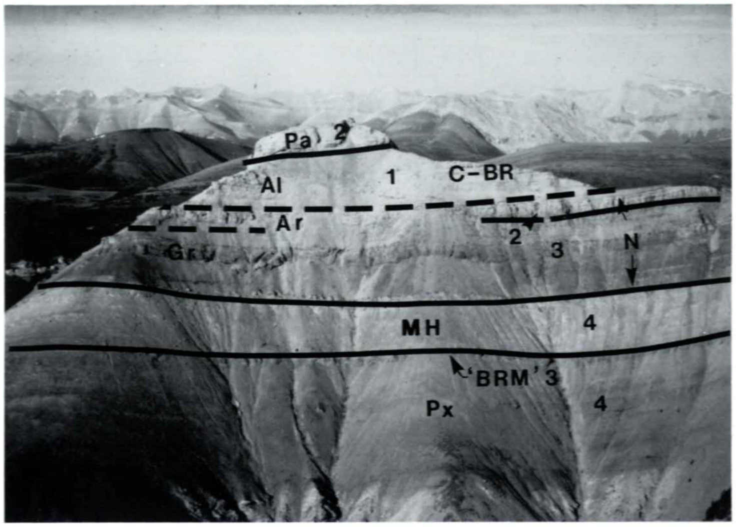


Figure 43: Cline Channel 2 km northwest of North Ram River and 1 km northwest of Figure 38, view to southwest. S.24, T.37, R16W5.

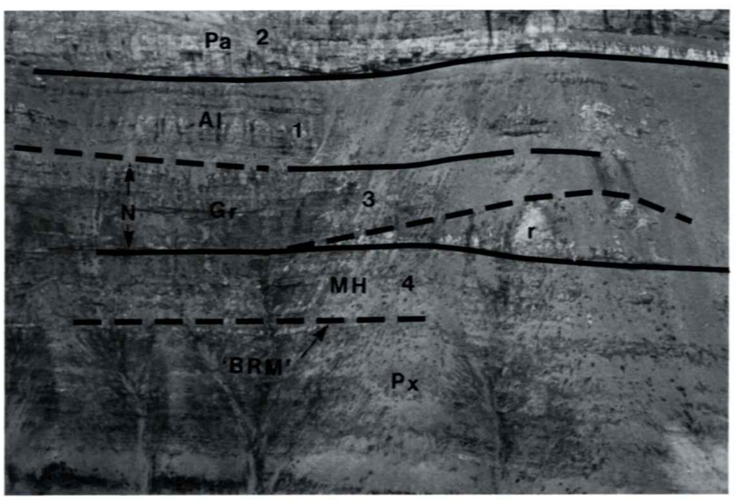


Figure 44: Coral bioherm developed in open marine facies of Nisku Cycle within Cline Channel, view to south. Kiska Creek, S6, T38, R16W5.

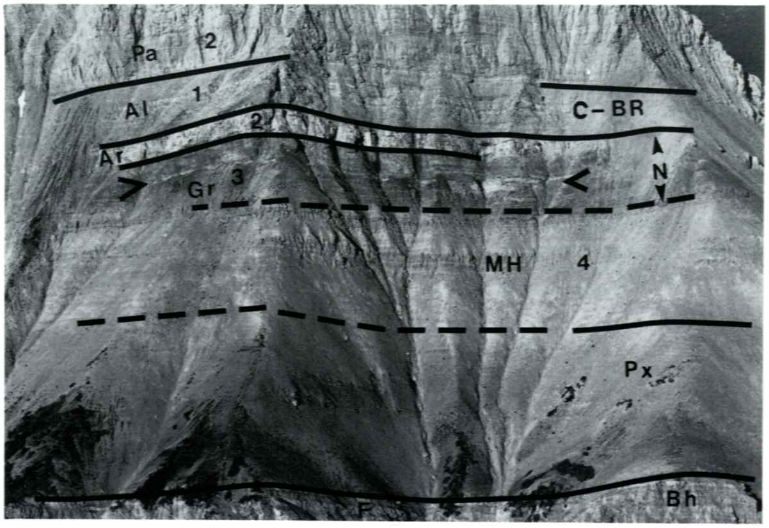


Figure 45: Dolomitized coral biostrome in open marine facies of Nisku Cycle within Cline Channel, north of Mt. Stelfox, view to southwest, S31, T37, R18W5.

Figure 46: Coral bioherm within Nisku Cycle, developed above limestone "swell" in underlying Mount Hawk basin-fill within Cline Channel, view to southwest. Littlehorn Creek, S33, T38, R18W5.

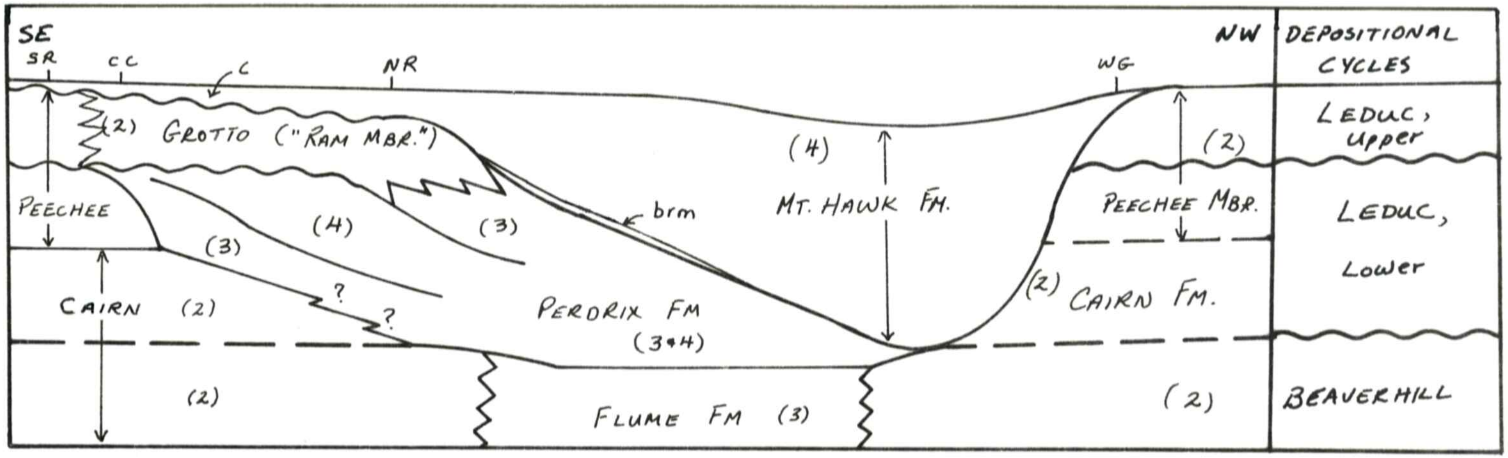


Figure 47: Diagrammatic cross-section of Cline Channel, Cripple-North Ram to Wapiabi Gap, after Workum and Hedinger (1987). Note the asymetric geometry of the Mount hawk basin-fill created by correlating across thrust sheets from Cline Channel into the Ireton Basin. brm - " basinal rusty marker", CT - Cripple Tongue, SR - South Ram River, CC - Cripple Creek, NR - North Ram River, WG - Wapiabi Gap. Facies numbers as in Figure 3.

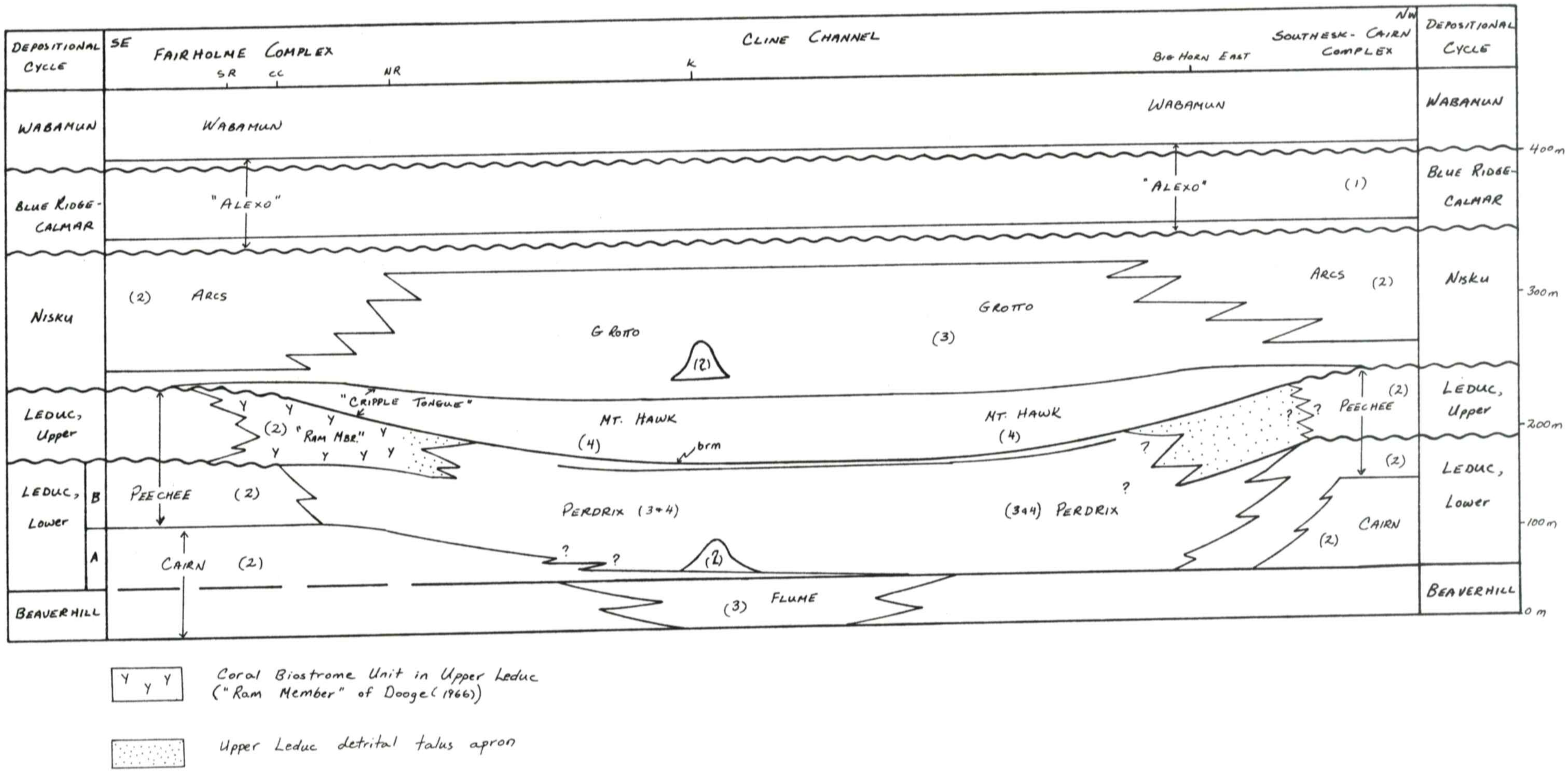


Figure 48: Diagrammatic cross-section of Cline Channel, Cripple-North Ram to Bighorn East. SR - South Ram River, CC - Cripple Creek, NR - North Ram River, K - Kiska. Facies numbers as in Figure 3.

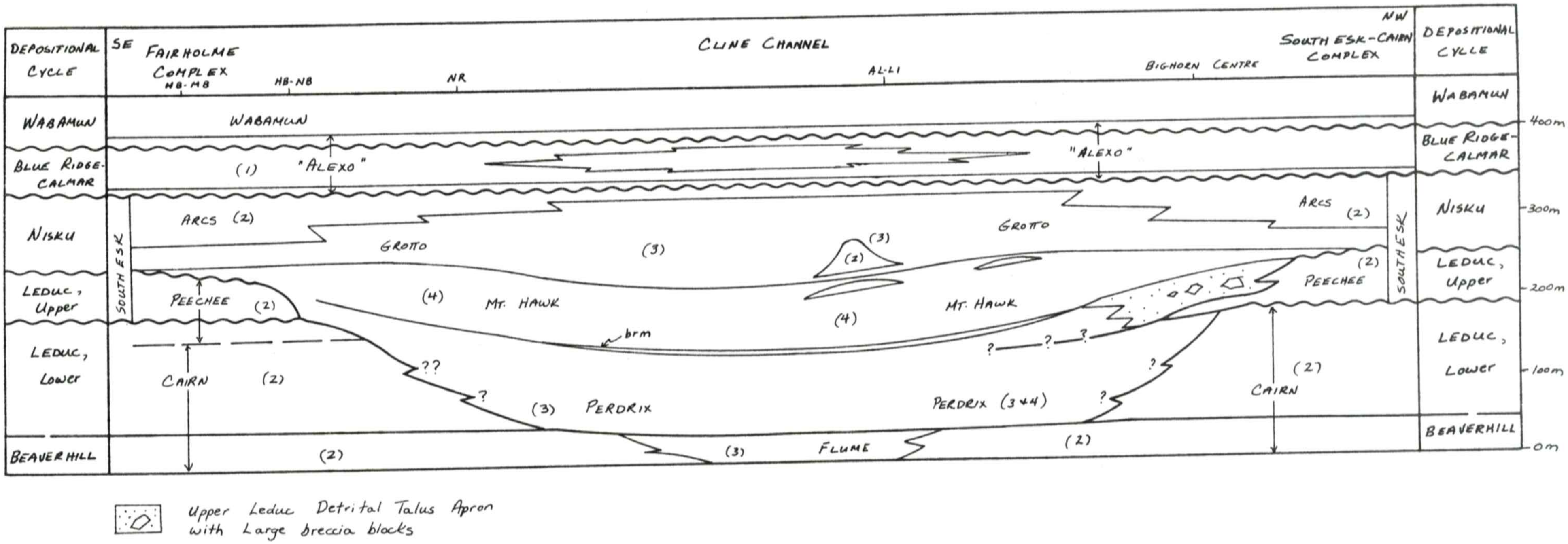


Figure 49: Diagrammatic cross-section of Cline Channel, Hummingbird to Bighorn Centre. HB-MB - Hummingbird Creek Main Branch, HB-NB - Hummingbird Creek North Branch, NR - North Ram River, AL-LI Allstones Creek/Littlehorn Creek, brm - "basinal rusty marker". Facies numbers as in Figure 3.

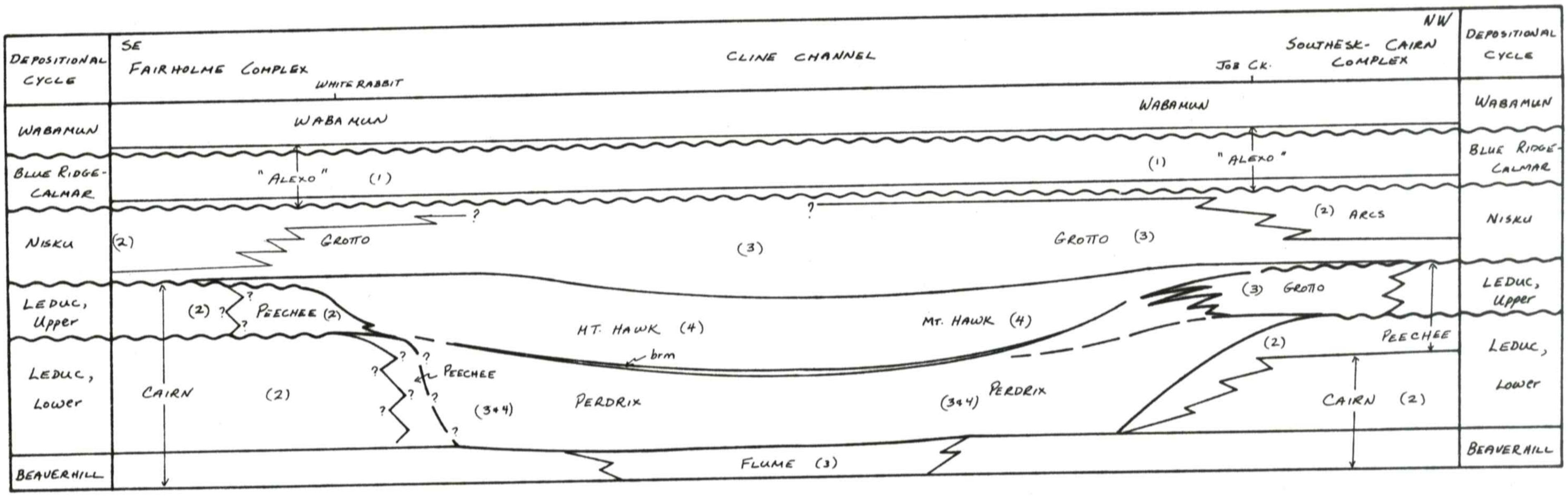


Figure 50: Diagrammatic cross-section of Cline Channel, Whiterabbit to Job Creek. brm - "basinal rusty marker". Facies numbers as in Figure 3.Figure 47: Diagrammatic cross-section of Cline Channel, Cripple-North Ram to Wapiabi Gap.

Figure 51: Combined lateral facies change and interfingering within Leduc, Lower Cycle, Peechee at left, Perdrix basin to right, view to northwest, Bighorn East margin of Southesk Cairn Complex, S.2, T.40, R19W5.

Figure 52: Bank margin in Leduc, Upper Cycle backsteps Leduc, Lower Cycle, arrows point to large bank-derived debris flow blocks incorporated within slope facies of Perdrix Formation, Bighorn Centre margin of Southesk Cairn Complex, view to northwest, S.27, T.39, R19W5.

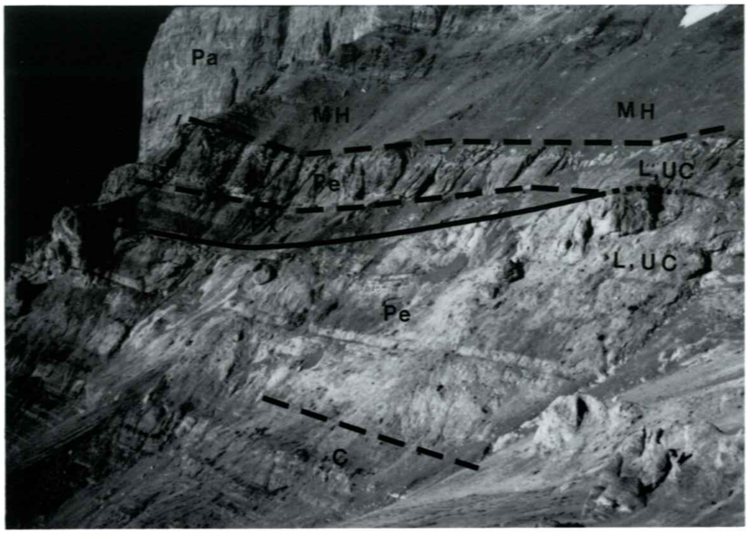


Figure 53: Leduc, Upper Cycle progrades to left, basinward, over Lower Cycle, Job Margin of Southesk Cairn Complex, view to southwest, S4, T40, R20W5.

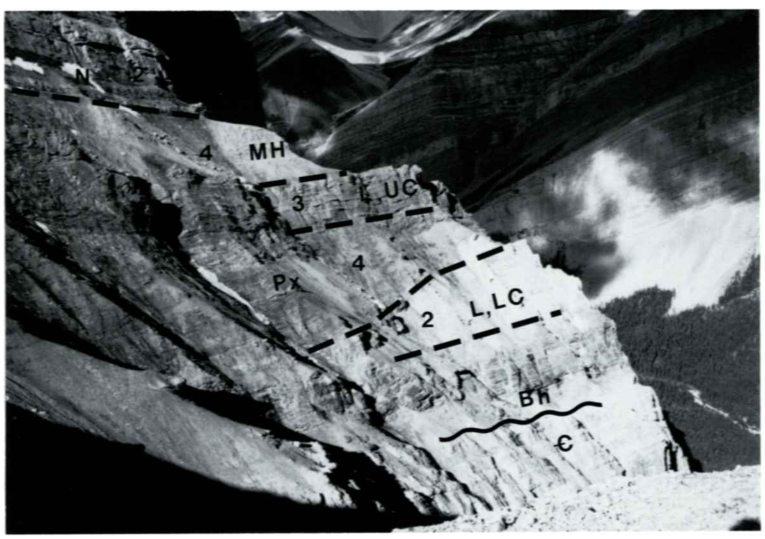


Figure 54: Leduc, Lower Cycle bank margin onlapped by Perdrix basin-fill, overlain by stromatactis dolomite of Leduc, Upper Cycle, view to southwest. Job margin of Southesk Cairn Complex, S34, T39, R20W5.

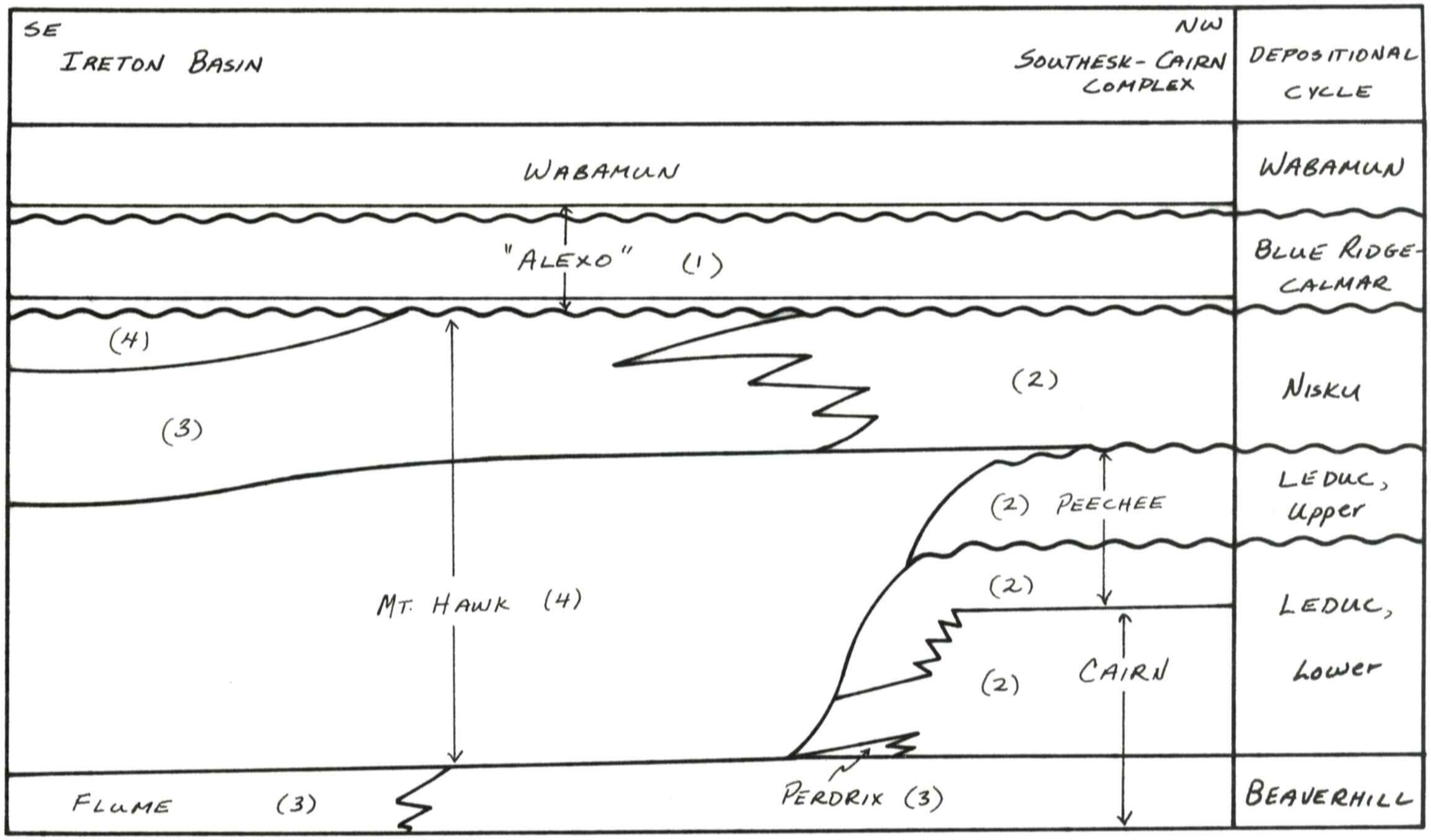


Figure 55: Diagrammatic cross-section, Wapiabi Gap Margin, Southesk Cairn Carbonate Complex.

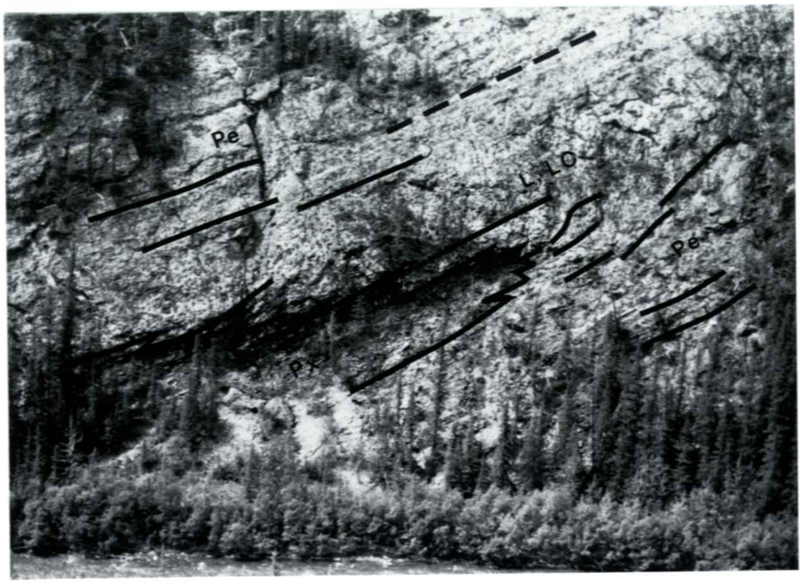


Figure 56: Leduc, Lower Cycle bank progrades over and changes facies to Perdrix Formation, toward left (basinward) side of photograph, view to southwest. Wapiabi Gap margin of Southesk Cairn Complex, S32, T40, R17W5.

Figure 57: Exhumed bank margin of Leduc, Lower Cycle, depositional slope approximately 15°, view to southeast. Wapiabi Gap margin of Southesk Cairn Complex, S.32, T.40, R17W5.

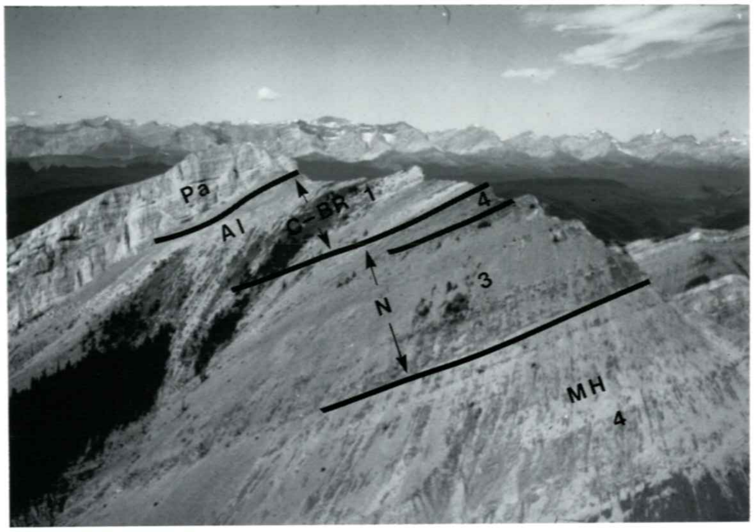


Figure 58: Barren open marine carbonates of the Nisku Cycle prograde basinward above 150 m of Mount Hawk shale, the basin-fill of the Leduc, Upper Cycle, view to west. Wapiabi Gap margin of Southesk Cairn Complex, S33, T40, R17W5.

Figure 59: Bank interior, Southesk Cairn Complex illustrates the problem in defining the boundary between the dark grey Cairn, and light grey Southesk Formation view to west. Saracen Head, S1, T43, R2IW5.

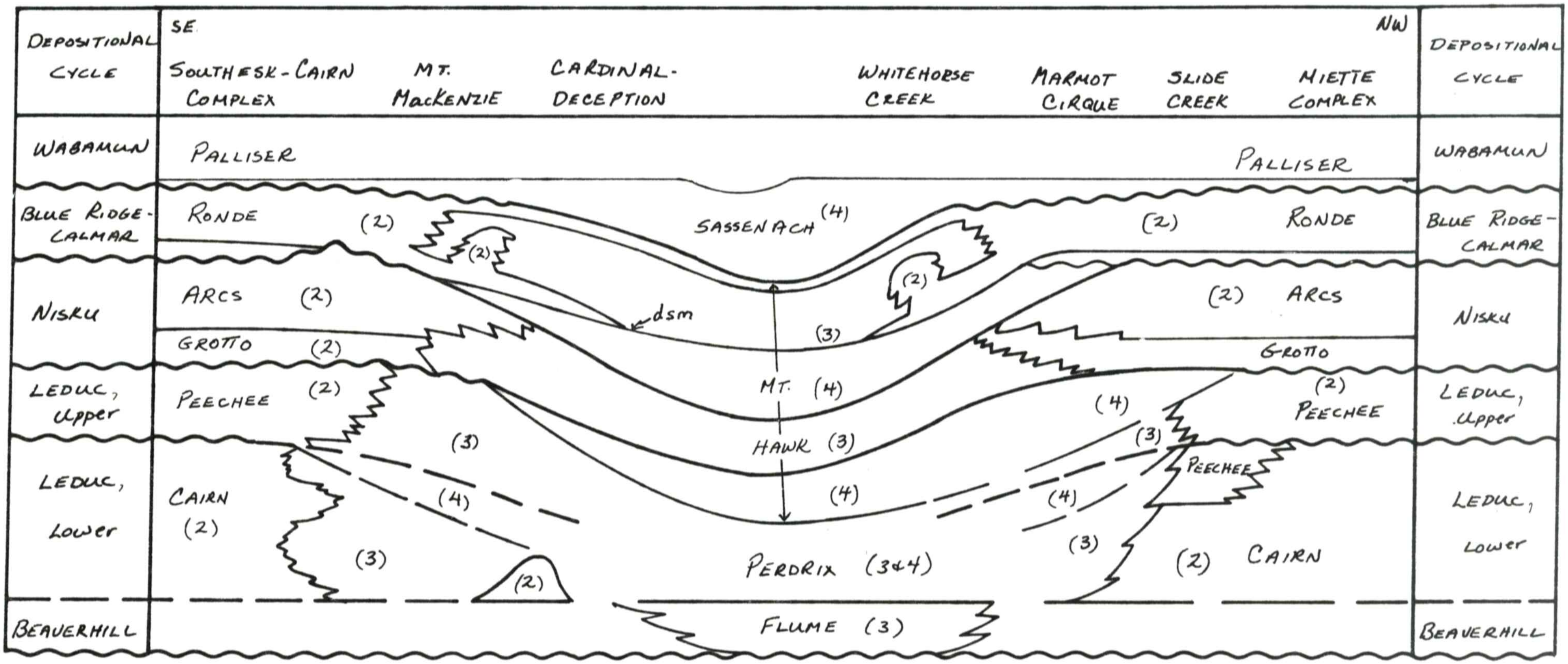


Figure 60: Diagrammatic cross-section, Southesk Cairn Complex to Miette Complex, Alberta, dsm - "doublet silt marker". Facies numbers as in Figure 3.

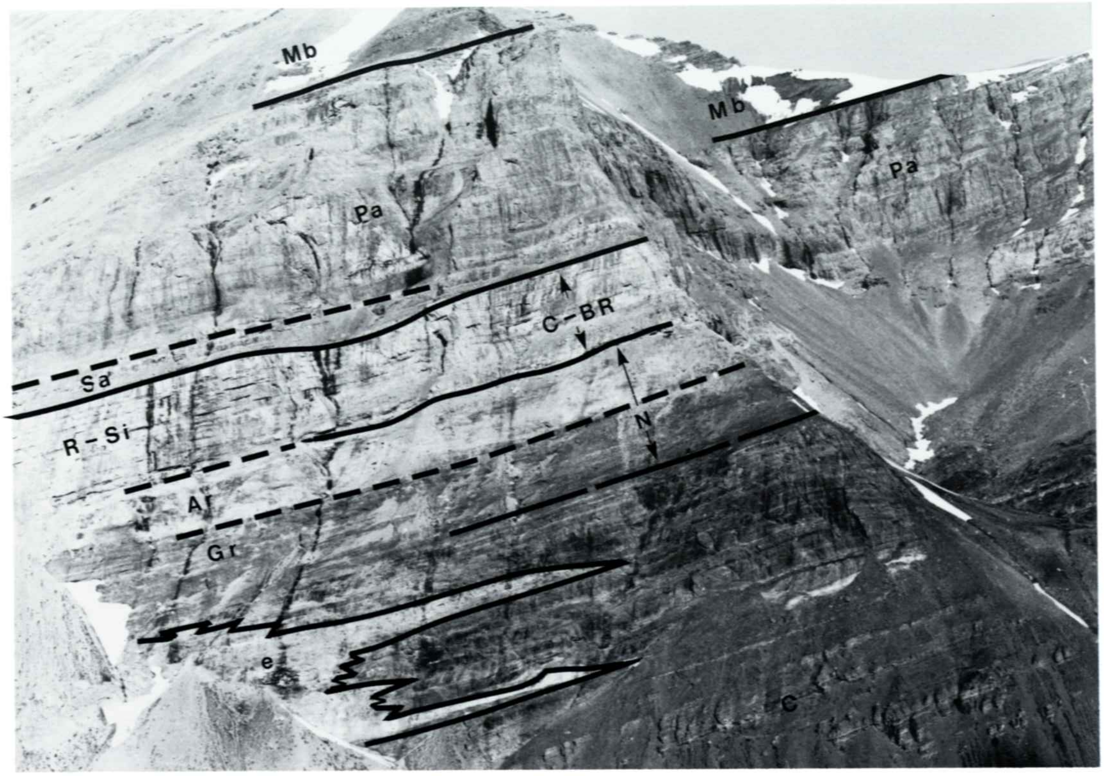


Figure 61: Lateral facies change from carbonate bank of both Leduc Cycles on left to basinal Perdrix Carbonates to right, view to northwest. Western margin Southesk Cairn Complex at Toma Creek, southeast side of Mt. MacKenzie, S.2, T.45, R23W5.

Figure 62: Bank (left)-to-basin (right) facies change within Calmar-Blue Ridge Cycle, view to east. West side of Mount MacKenzie, western flank Southesk Cairn Complex, S.3, T.45, R.23W5.

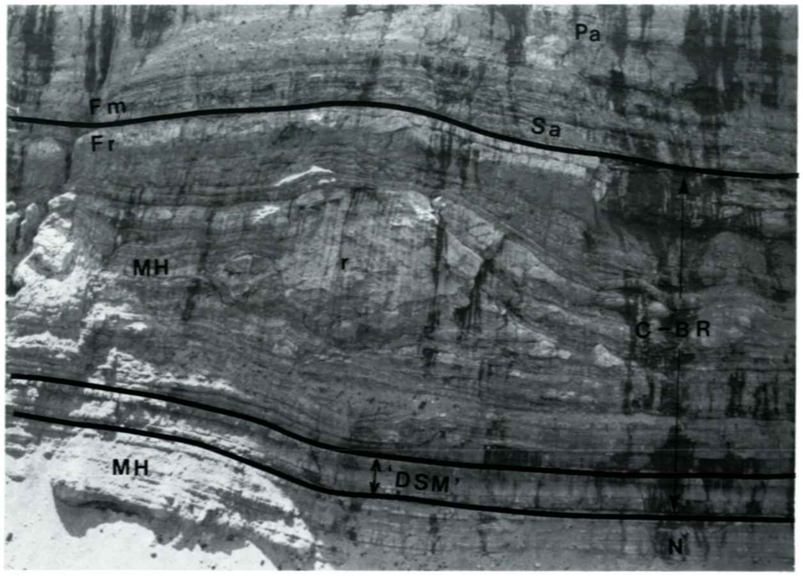


Figure 63: Coral dominated bioherm within foreslope facies of Calmar-Blue Ridge Cycle, view to south, 2 km west of Mount MacKenzie, S4, T45, R23W5.

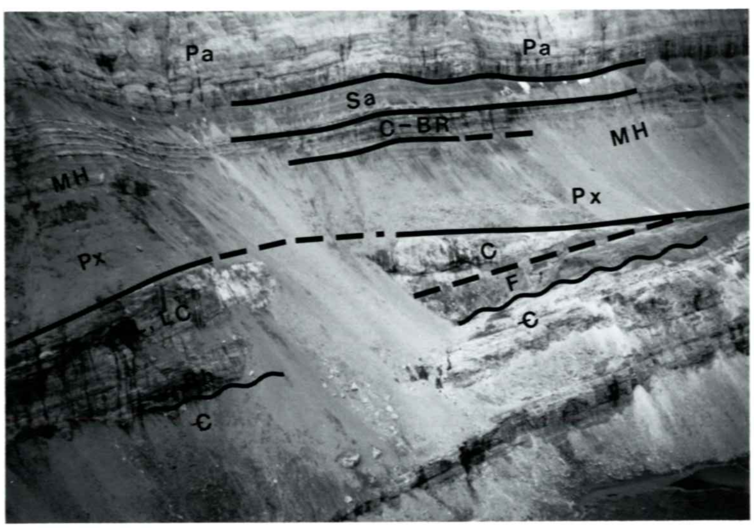


Figure 64: Patch reef in lower part of Leduc, Lower Cycle, onlapped by Perdrix Formation basin-fill; view to west, southern Jasper Basin to the northwest of the Southesk Cairn Complex. Head of Cardinal River, S22, T45, R24W5.

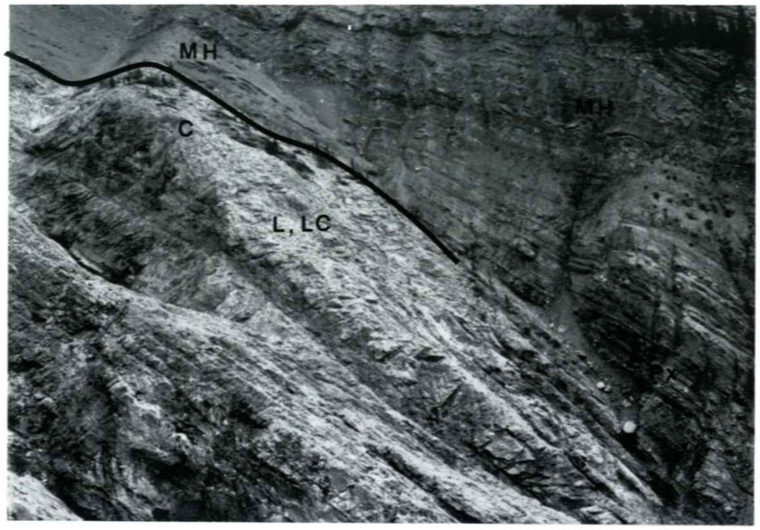


Figure 65: Patch reef in lower part of Leduc, Lower Cycle, lateral facies change to basinal carbonates in lower right part of photograph, view to east, southeastern Jasper Basin northwest of Southesk Cairn Complex, Deception Creek, S1, T45, R24W5.

Figure 66: Patch reef within open marine Mount Hawk facies of Calmar-Blue Ridge Cycle, view to west, Whitehorse Creek, southeastern Jasper Basin, S27, T46, R25W5.

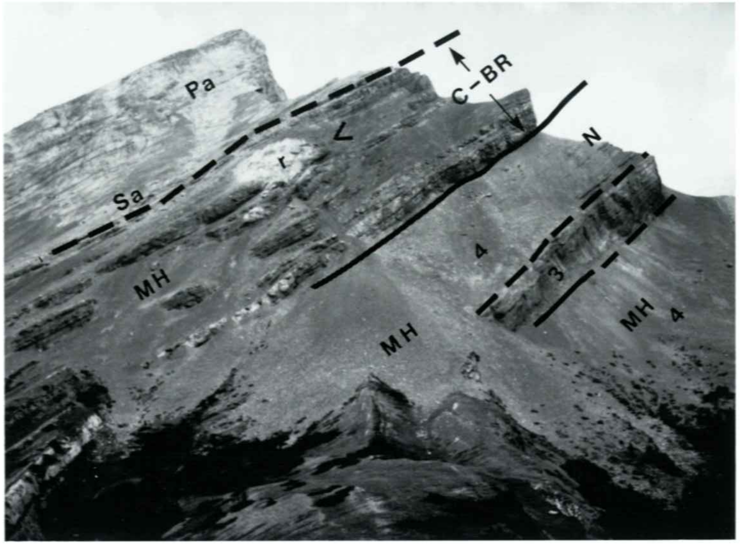


Figure 67: Mount Hawk Formation with patch reef in open marine facies of Calmar-Blue Ridge Cycle, compare this to Figure 73, **dsm** - doublet silt marker. Head of Whitehorse Creek, S27, T46, R25W5.

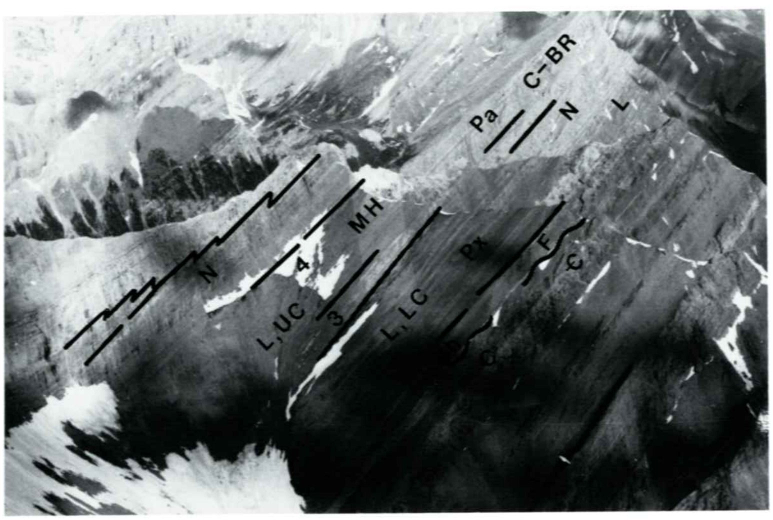


Figure 68: South margin of Miette Complex, view to northwest, note basinward-prograding Leduc, Upper Cycle and foresets in Nisku Cycle, view to northwest. Foreground is in S8, T47, R25W5, Miette Complex in background.

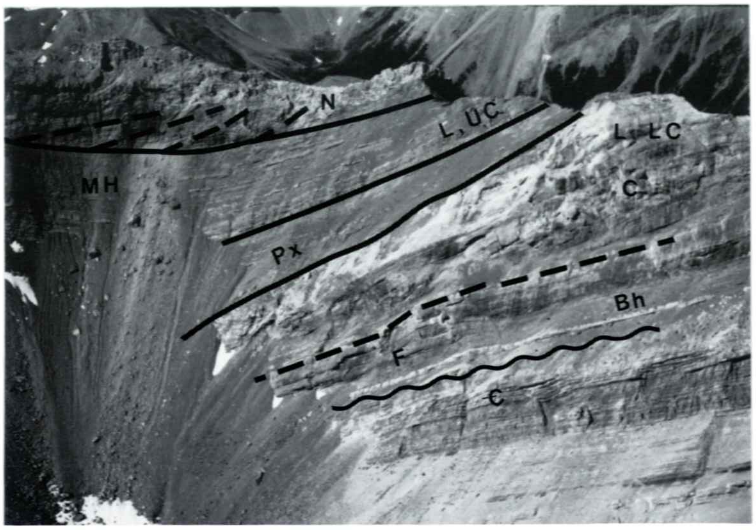


Figure 69: South margin of Miette Complex, light grey bank margin dolomite of Leduc, Lower Cycle is onlapped by dark grey Perdrix basin-fill; note Nisku Cycle beds foresetting strongly to the left (south) in upper part of photograph. Marmot Cirque, Miette Range, S17, T47, R25W5.

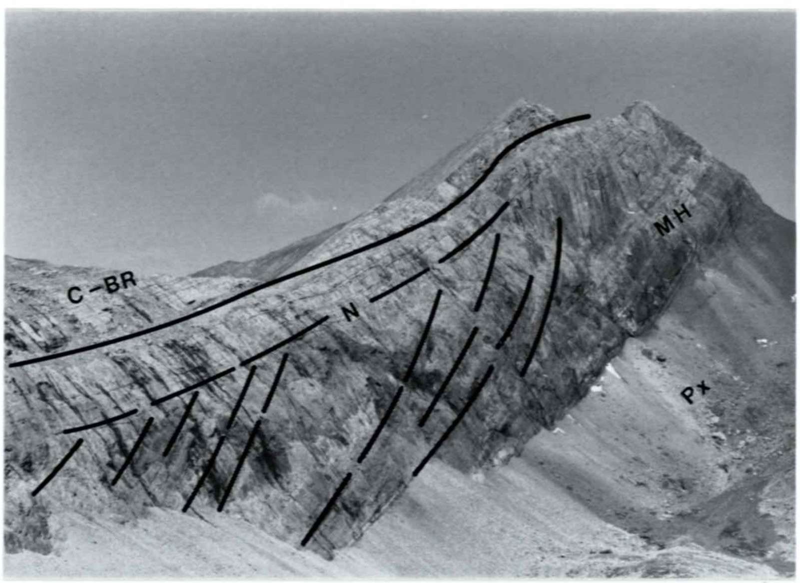


Figure 70: Detrital carbonates of the Nisku Cycle prograde basinward from the southeast margin of the Miette Complex, Nikanassin Range. Note intra-Nisku unconformity, view to northwest, S7, T47, R24W5.

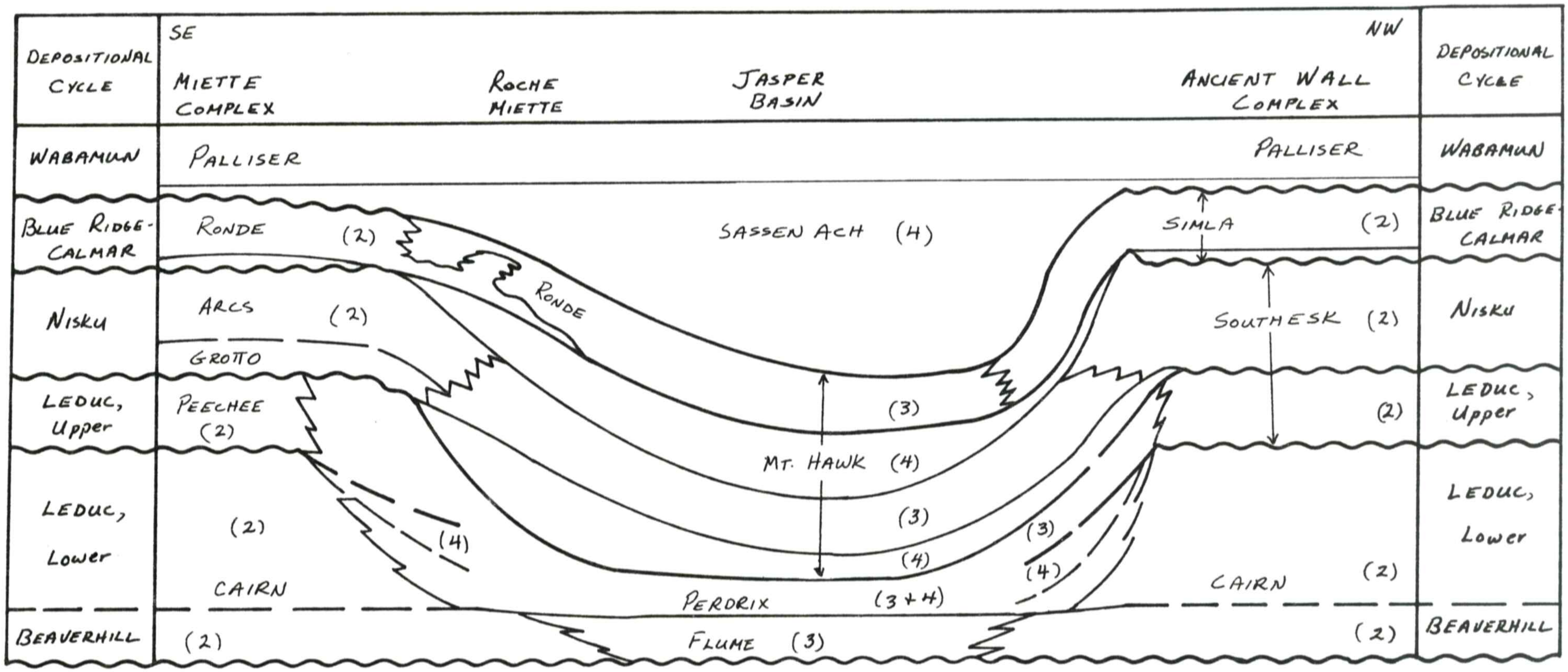


Figure 72: Diagrammatic cross-section, Miette to Ancient Wall Complex, across Jasper Basin. Facies numbers as in Figure 3.

Figure 71: Nisku bank margin progrades from right to left, accompanied by extra Nisku section. Calmar Shale and sub-Calmar unconformity are lost to left side of photo. View to southwest, this photo is a few hundred m to the left (south) of Figure 70.

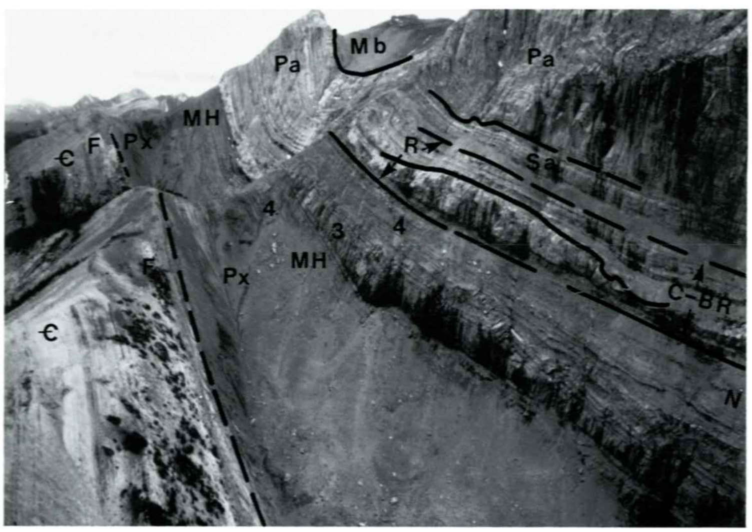


Figure 73: Roche Miette, type section of Flume, Perdrix and Mount Hawk Formations, and Ronde Member, view to southeast, compare this to Figure 67, S29, T48, R27W5.

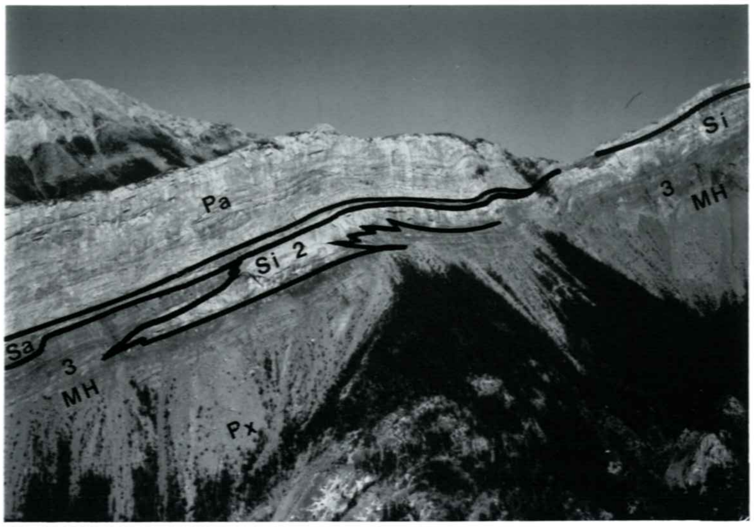


Figure 74: Bank-to-basin stratigraphic relationships within Calmar-Blue Ridge Cycle, basin to left, view to northwest. Brule Lake, S21, 28, T49, R27W5.

Figure 77: Basinal section 3km southeast of south margin Ancient Wall Complex. Distal carbonate tongues of the Complex are recognizable, especially of the Calmar-Blue Ridge Cycle, view to southwest, S21, T48, R2W6.

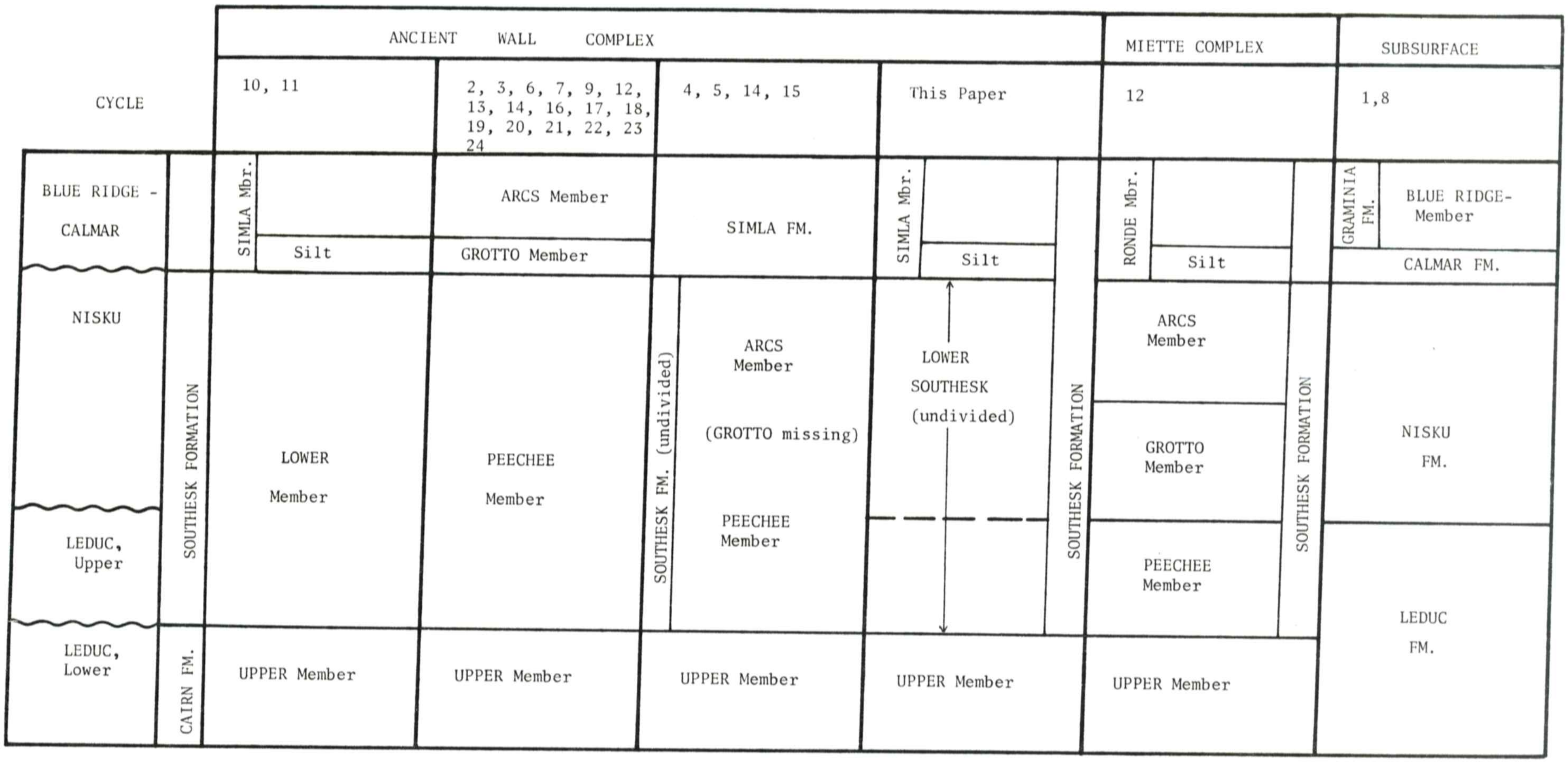


Figure 75: Evolution of formational nomenclature, Ancient Wall Carbonate Complex.

Cited References for Figure 75

No.	Reference
1	Choquette [1955]
2	Cook, McDaniel, Mountjoy and Pray [1971]
3	Coppold [1976]
4	Geldsetzer [1982]
5	Geldsetzer [1988]
6	Hopkins [1972]
7	Hopkins [1977]
8	Imperial Oil Limited, Geological Staff [1950]
9	Jull [1977]
10	McLaren and Mountjoy [1962]
11	Mountjoy [1962]
12	Mountjoy [1965]
13	Mountjoy [1967]
14	Mountjoy [1980]
15	Mountjoy [1987]
16	Mountjoy, Cook, Pray and McDaniel [1972]
17	Mountjoy and Jull [1975]
18	Mountjoy and Jull [1978]
19	Mountjoy and MacKenzie [1974]
20	Mountjoy and Riding [1981]
21	Srivastava, Stearn and Mountjoy [1972]
22	Stearn [1967]
23	Stearn [1976]
24	Toomey, Mountjoy and MacKenzie [1970]

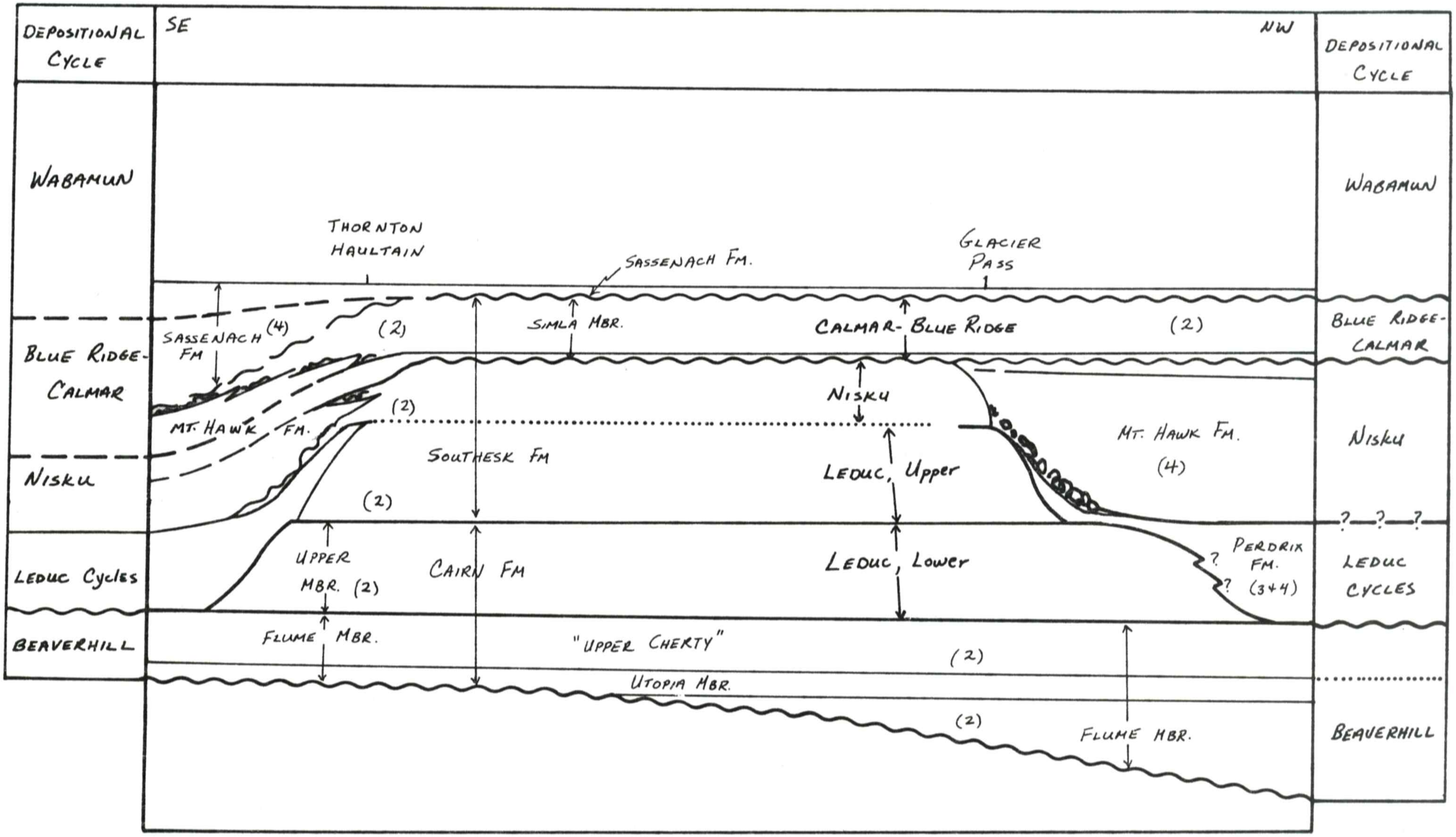


Figure 76: Diagrammatic cross-section, Ancient Wall Carbonate Complex. Facies numbers as in Figure 3.

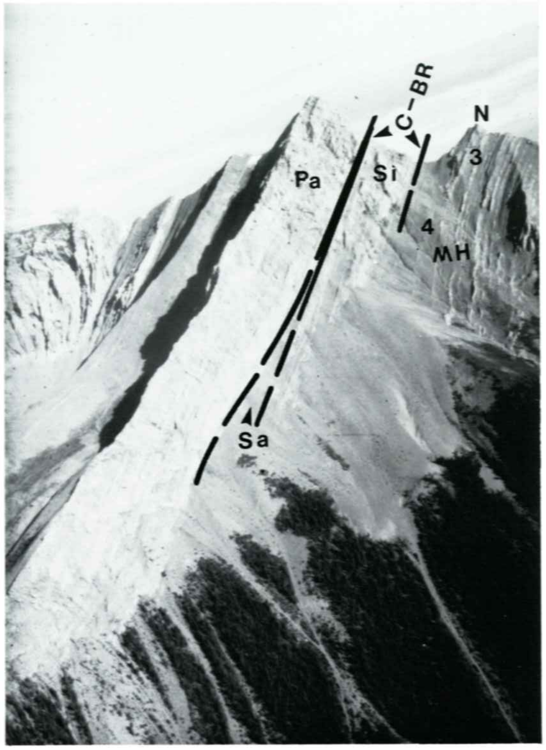


Figure 78: South margin Ancient Wall Complex, Jasper Basin in foreground. Haultain Margin, S31, T48, R2W6.

Figure 79: Contact, "Alexo" (Calmar - Blue Ridge Cycle) unconformably overlies Arcs dolomite (Nisku Cycle), hammer head 15 cm wide, south end of Berland Complex, Persimmon Range, S19, T52, R4W6.