PRE-JURASSIC SEDIMENTATION, TECTONISM AND STRATIGRAPHY IN SOUTHERN ALBERTA AND ADJOINING AREAS OF BRITISH COLUMBIA AND MONTANA

by

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ABSTRACT

The pre-Jurassic tectonic events of the area controlled the nature of sedimentation. These tectonic events were the result of movements of the members of the tectonic framework. The nature of the tectonic framework was established during Beltian sedimentation and was inherited by the Paleozoic era. During the Paleozoic era, the movements of various members of the tectonic framework resulted in four sequences or cycles of sedimentation.

Tectonism and its control upon sedimentation from Beltian to pre-Jurassic time is shown as Beltian sedimentation and the succeeding sedimentary cycles are discussed. Type localities are defined for the Beltian and Paleozoic strata of each sequence as they occur in the area. Problems of age determination for the stratigraphic units are discussed and the correlation of these units within and beyond the area presented. These correlations show the relationship of the stratigraphic nomenclature of Montana and Alberta.

Since the thesis is mainly limited to published information, it indicates the present status of published geological thought in the area.

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Chapter I

INTRODUCTION

This thesis presents an integrated study of the pre-Jurassic stratigraphy and sedimentation in southern Alberta and in the adjoining areas of British Columbia and Montana. An attempt is made to relate the cause--the tectonism, to the effect--the sedimentation. In most stratigraphic studies it is necessary to induce a regional concept based on specific evidence. Such a regional concept of the stratigraphy and sedimentation has been gradually derived for the thesis area, although certain unsolved stratigraphic problems break its continuity. Where a stratigraphic problem exists, one or more hypotheses which attempt to satisfy the specific evidence and yet fit harmoniously into the regional concept are presented. This thesis seeks to present the regional concept and examine the various hypotheses in the light of accumulated knowledge now available in published material.

The thesis area is defined as the area between the 48° and 50° parallels west from the fourth meridian to the western side of the Rocky Mountain trench (see Figure 1). In the body of the

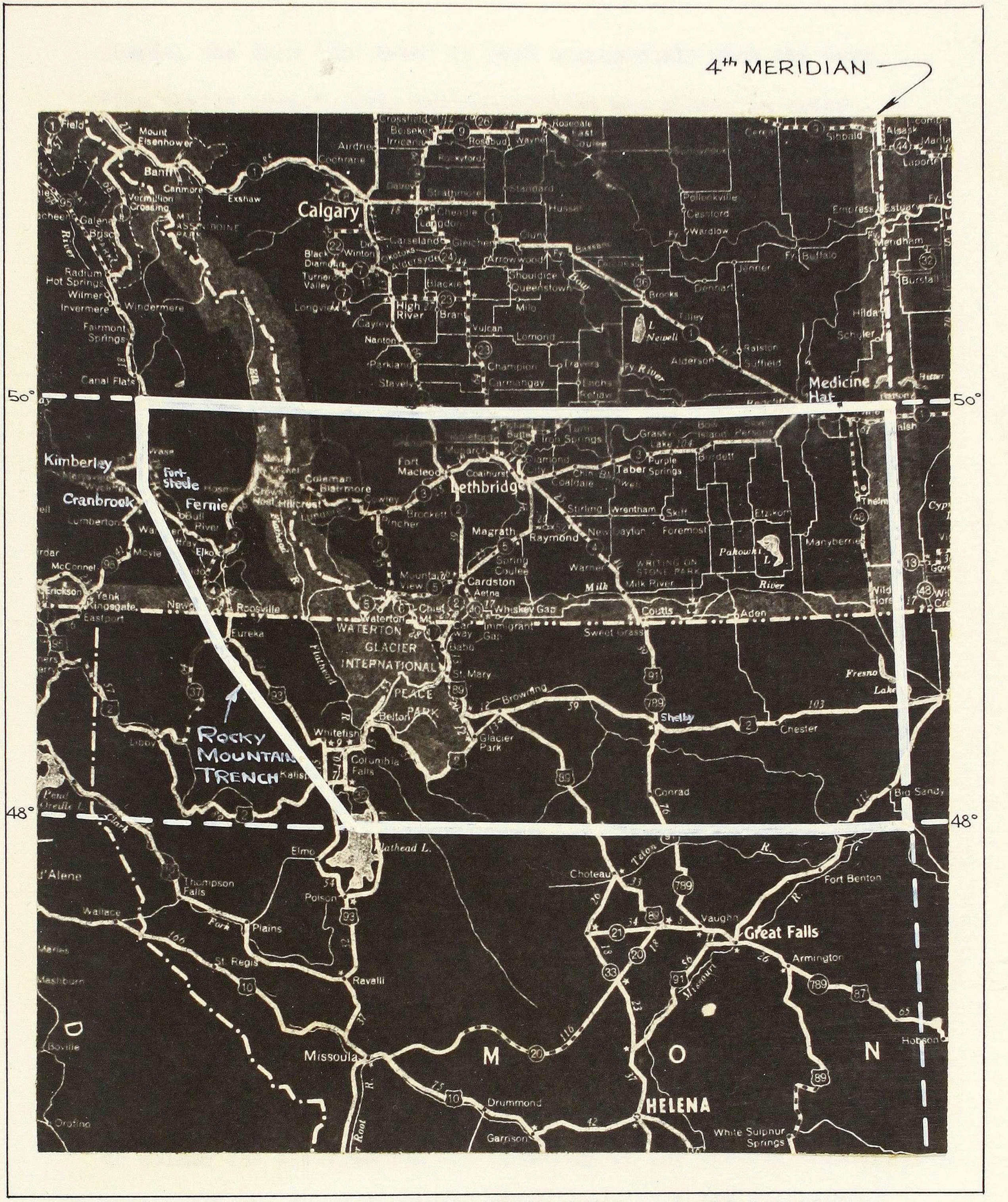

Figure 1. Index map of southern Alberta and adjacent parts of Montana and British Columbia, showing location of the thesis area.

thesis, the term "the area" is used synonomously with the term "the thesis area." This particular area was chosen in order that the thought of both American and Canadian geologists regarding the geological history of this part of North America could be utilized; also, the Canadian nomenclature could be correlated with the American counterpart. The area is suitable for a study of this nature as it contains portions of the two major tectonic units---the North American Cordilleran geosyncline and the North American interior craton, and two of the minor tectonic units---Montania, and the Sweetgrass arch. Three other minor tectonic units---the Central Montana trough, the Williston basin and the Wyoming shelf---are nearby. The interrelated movements of these units strongly influenced the nature of sedimentation and, therefore, the stratigraphy of southern Alberta, southeastern British Columbia and northern Montana.

The Pre-Cambrian and Paleozoic stratigraphy of the area is outlined in the following chapters. For each period or sedimentary sequence a stratigraphic type locality is established, and the stratigraphic units of the type locality are defined. The stratigraphic section at the type locality is correlated with other sections within and beyond the area. Special attention is drawn to local differences in nomenclature. Finally, an attempt is made to relate the distribution and lithology of the various stratigraphic units with the tectonic events which governed their deposition.

Many of the stratigraphic and sedimentary problems which still exist in the area are outlined. Undoubtedly some of these problems have been solved by individuals and organizations who have not as yet published their findings. Since this thesis utilizes mainly published information, it serves to illustrate the present position of published geological thought and data pertinent to the area and to present a comprehensive study of its sedimentation, tectonism and stratigraphy.

Chapter II

THE BELT SERIES

The Belt series, which is the lowest stratigraphic division to outcrop within the area, consists of clastic and non-clastic sediments with minor lavas and intrusive rocks. Portions of this series outcrop in British Columbia, Alberta, Idaho and Montana; their distribution in the area being restricted to regions lying south of the Crowsnest Pass, and along the Rocky Mountain trench. The Belt series in the area rests in progressive overlap, lying unconformably on Archean rocks (Walcott, 1906, p.18). The Belt series in turn is unconformably overlain by Paleozoic formations (Deiss, 1935, p.122).

The rocks of the Belt series were first described by Dawson (1875, pp.67-68) who assigned them to the Cambrian and younger systems. Dawson's work was followed by descriptions of the series by Bauerman (1885, pp.1-41) and then Walcott (1899, p.201), who named the series. However, the first detailed work was done by Willis (1902, pp.305-352) who assigned the Belt series to the Algonkian period. A detailed regional study of the Belt series published by Fenton and Fenton (1937) provides most of the information for the Pre-Cambrian portion of this thesis.

Areal Distribution and Facies Development

The regional study of the Belt series (Fenton and Fenton, 1937, p.1877) reveals this series to have various facies developments at different localities. These facies developments are illustrated by changes in "lithology, stratigraphic sequence, thickness, recorded conditions of deposition, fauna, and flora." The areal distribution of Belt outcrop is illustrated by Figure 2 which is subdivided to portray graphically the areal extent of the various facies. Fourteen sections of the Belt series are presented in Figure 3. The locations of twelve of these sections are indicated in Figure 2, while the remaining two sections (Sections 4 and 5) are located northwest of the area covered by Figure 2: Section 5--in the northwest corner of the thesis area, and Section 4--beyond the northwest corner of the thesis area. The geographical relationships of the six facies described on the following page are illustrated below by Figure 2; their stratigraphic relationships are illustrated by the correlation chart of the Belt series, Figure 3.

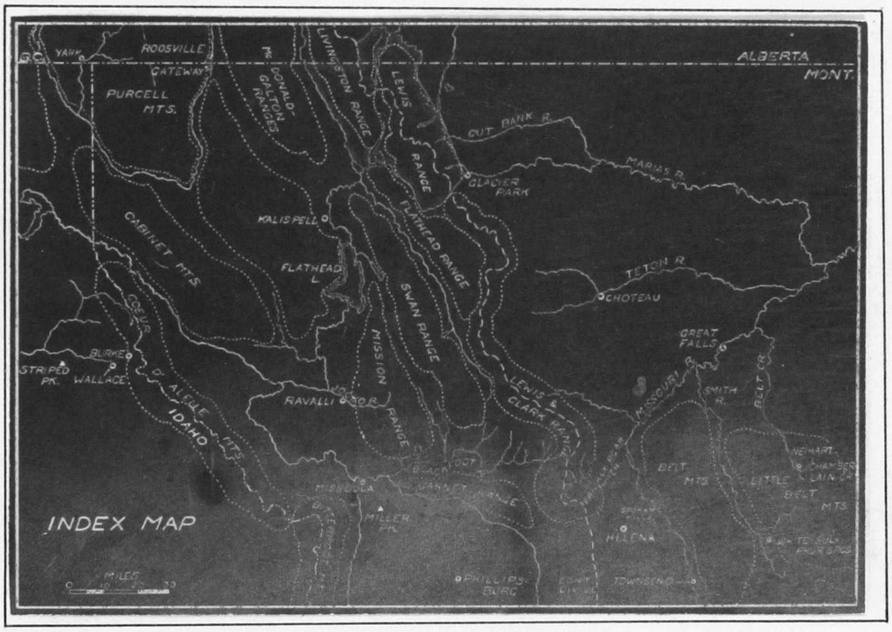

Figure 2. Distribution of Areas of Belt Outcrop
(Fenton and Fenton, 1937, p.1876)

Facies of the Beltian Sediments (Fenton and Fenton, 1937, p.1877)

Meagher Facies

Includes the standard section of the series in the Belt Mountains and probably the Little Belt section; extends westward to Prickly Bear Creek. Distinguished by great thickness of the Spokane and presence of Greyson member at its base. [Fig. 3; Sec.13 and 14]

Blackfoot Canyon Facies

Characterized by development of Grinnell and Appekunny silt-clay argillites in place of the calcareous Chamberlain and by great thickness of Siyeh, Spokane, and Sheppard or Helena, called "Upper Siyeh" by Clapp and Deiss. [Fig. 3; Sec. 12]

Glacier Park Facies

Development of the series in Glacier National Park, Montana, Waterton Lakes National Park, Alberta, westward to the Flathead trough. Grades into the dominantly clastic Purcell facies. [Fig. 3; Sec. 8]

Galton Facies

A transitional stage between the Glacier Park and Purcell facies. Distinguished from the former by more clastics in the Siyeh and Helena; from the latter by finer clastics below the Siyeh and presence of Altyn siliceous dolomites. [Fig. 3; Sec. 7]

Purcell Facies

Marked by abundant clastics throughout, with reduction of carbonate rocks. Quartzites, thick in lower portions, reach the known base [lowest observed member] of the Belt. [Fig. 3; Sec. 5 and 6]

Coeur d'Alene Facies

Closely related to the Purcell. Characterized by sandstones and argillaceous beds throughout the Striped Peak (= lower Spokane), by reduction of carbonate rocks in the Siyeh equivalent (lower Wallace), and by tripartite division of the Ravalli, which is clastic throughout. [Fig. 3; Sec. 1]

The interrelationship of the various facies of the Belt series will not be discussed further. However, the Belt series, as it is developed in the Glacier Park facies, will be described in detail in the following section.

Glacier Park Facies of the Belt Series

The Glacier Park facies is arbitrarily defined as the type section for the Belt series within the area, for the following reasons:

1) The standard section for this series is in the Belt Mountains, south of the area

2) The Glacier Park Facies occupies an intermediate position between Canadian and American occurrences of the series

3) The Glacier Park section is better known to Canadian geologists than other American sections of the series

4) A fairly complete section of Beltian sediments is in Glacier Park

The following description of the Glacier Park Belt section (see Figure 3; Section 8) represents extracts from Fenton and Fenton (1937, pp.1880-1904). The definition of each member, formation, and group is presented and the type locality of each stratigraphic unit is given. Igneous units which occur in the Belt series are also described.

An Outline of the Order of Presentation of the Various Stratigraphic Units of the Glacier Park Facies

RAVALLI GROUP

Definition and type locality

Ravalli Group

Grinnell Formation	-	Brief description
Appekunny Formation	-	Brief description
Altyn Formation	-	Brief description

Altyn Formation

Definition and type locality

Altyn Formation

Waterton Member	-	Definition and type locality
Hell Roaring Member	-	Definition and type locality
Carthew Member	-	Definition and type locality

Appekunny Formation

Definition and type locality

Appekunny Formation

Singleshot Member	-	Definition and type locality
Appistoki Member	-	Definition and type locality
Scenic Point Member	-	Definition and type locality

Grinnell Formation

Definition and type locality

Grinnell Formation

Rising Wolf Member	-	Definition and type locality
Red Gap Member	-	Definition and type locality
Rising Bull Member	-	Definition and type locality

PIEGAN GROUP

Definition and type locality

Piegan Group

Gateway (Sheppard) Formation	-	Brief description
Spokane Formation	-	Brief description
Siyeh Formation	-	Brief description

<u>Siyeh Formation</u>
Definition and type locality

Siyeh Formation

Collenia symmetrica Zone	-	Definition and type locality
Goathaunt Member	-	Definition and type locality
Collenia frequens Zone	-	Definition and type locality
Granite Park Member	-	Definition and type locality

<u>Spokane Formation</u>
Definition and type locality

<u>Sheppard Formation</u>
Definition and type locality

MISSOULA GROUP
Definition and type locality

Missoula Group

<u>Miller Peak Formation</u>	-	Definition and type locality
Kintla Member	-	Definition and type locality
Roosville Member	-	Definition and type locality
Mt. Rowe Member	-	Definition and type locality

<u>Undifferentiated Missoula Group</u>
Brief description

IGNEOUS ROCKS
General description

Early Kintla	-	Brief description
Late Spokane	-	Brief description
Early Spokane or Late Siyeh	-	Brief description
Late Grinnell	-	Brief description

The definitions of the various stratigraphic units of the Belt series as these units occur in the Glacier Park area are presented in detail in the following section.

Description of the Glacier Park Facies

The geographical positions mentioned in the following descriptions are indicated in Figure 4.

Figure 4. Map of Glacier and Waterton Lakes National Parks (Fenton and Fenton, 1937, p.1873)

RAVALLI GROUP

Definition: Dominantly clastic rocks which form the lowest major division of the Belt series in the Meagher, Blackfoot Canyon, Glacier Park, and Galton facies, but are underlain by the Prichard clastics in the Purcell facies. In the Glacier Park facies, they include the semi-clastic and carbonate Altyn formation, which presumably grades westwardly into clastics. Thickness 7,800 to 15,000 feet.

Type Locality: Hills along the Jocko River, near Ravalli, Montana.

Ravalli Group

	Feet
Grinnell Formation. Red with some green argillite, sandstone, and sandy quartzite..........	2000- 3500
Appekunny Formation. Green-gray to light- or dark-gray argillitic and sandy quartzite and quartzitic argillite; some massive whitish quartzite	3500-10,000
Altyn Formation. Impure, siliceous, argillaceous to sandy or pebbly limestone, with beds of calcareous, pebbly sandstone. Not exposed west of the continental divide	1400

Altyn Formation

Definition: Dolomites, limestones, limy argillites, sandstones, and minor mud breccias which form the lower calcareo-magnesian division in the Belt sediments of the Glacier Park facies. The sediments show considerable variety in color, texture, and bedding; they contain mud cracks, ripple marks, and many beds of flat-pebble and edgewise conglomerates. Their upper limit is the base of the Appekunny, with which they show some intergradation; their lower limit is concealed beneath the Lewis thrust. Thickness, 2180 to 2480 feet.

Type Locality: Cliffs at the foot of Appekunny Mountain, about a mile northeastward from Swiftcurrent Falls, Glacier National Park. Entire section exposed only in Waterton Lakes Park, where it is complicated by faults and folds.

Altyn Formation

Waterton Member

Definition: Dolomites, dark-gray and reddish, weathering to gray, reddish brown and buff, in beds 1 to 4 feet thick, Most beds are finely laminated, laminae numbering 10 to 60 per inch. No sand grains were noticed. Some strata suggest thickly bedded, limy argillites. Daly's analysis shows 28.60 per cent calcite, 21.17 per cent magnesium carbonate, and 34.47 per cent orthoclase.

The member grades upward into dolomites of the Hell Roaring member; its base is not visible; its known thickness is about 280 feet.

Type Locality: Cliffs at Cameron Falls on Cameron ("Oil") Creek, near Waterton Park.

Hell Roaring Member

Definition: Dolomite and dolomitic limestones, variably siliceous; blue-gray to greenish gray, weathering to gray, buff, or cream; beds 2 to 24 inches thick. Many beds show laminae of limestone and dolomite and apparently primary dolomite nodules, associated with biostromes of *Collenia albertensis* n. sp. Thickness estimated at 1200 to 1300 feet.

Type Locality: Hell Roaring Falls, Waterton Lakes Park. Well exposed on the eastern slope of Mt. Carthew.

Carthew Member

Definition: Magnesian limestones, dolomites, quartzites, and intermediate rocks which grade upward into the basal Appekunny. Colors range from blue-gray through buff to brown and dark brownish red; bedding is thin to thick. Red beds, especially, show thin laminae. Thickness is estimated at 700 to 900 feet.

Type Locality: Eastern cliffs of Cameronian Mountain above Cameron Creek, Waterton Lakes Park. Well exposed on the eastern face of Bertha Mountain, on slopes between Vimy Peak and the Narrows of Waterton Lake, and on the northern cliffs of Gable Mountain, Glacier National Park.

Appekunny Formation

Definition: Argillite interbedded with quartzite, conglomerate, and minor beds of argillaceous limestone; prevailingly green, greenish-gray to brownish, with some dull red, white, and purplish beds. Thin-bedded to thick-bedded, with fine laminae; massive only in quartz conglomerates and quartzites. Grades into adjacent formations. In its eastern phases, the thickness is 2500 to 5300 feet; in western, it is as much as 10,000 feet.

Type Locality: Appekunny Mountain, north of Swiftcurrent Valley, Glacier National Park.

Appekunny Formation

Singleshot Member

Definition: Argillites and quartzites, interbedded with buff to greenish siliceous dolomite and dolomitic sandstone. Pelitic rocks are gray, gray green, reddish, and black; quartzites are greenish, pink, or white. Mud cracks, ripple marks, and mud breccias are abundant. In some places, a basal coarse, pinkish sandstone rests on the Altyn with slight angular unconformity. Thickness 300 to 400 feet.

Type Locality: Singleshot Mountain near St. Mary Lake, Glacier National Park.

Appistoki Member

Definition: Gray, green, olive-brown, and rusty-gray argillites in thin minor but thick major beds, interbedded with thickly stratified, greenish, white, or pink quartzites. Flat-pebble breccias, mud cracks, and ripple marks are abundant; rain and sleet prints are present in some layers. This member intergrades with other members, yet preserves fairly well-marked limits. Thickness in the Lewis Range, 2000 to 2200 feet.

Type Locality: Appistoki Peak, near Two Medicine Lake, Glacier National Park.

Scenic Point Member

Definition: Argillites, sandstones, and gravelly conglomerates; green, purplish, buff, brown, and dull brownish-red at the type locality. Northward and westward from the type locality, the member grades into thickly bedded, coarsely mud-cracked argillites, which give way to thick quartzites and subordinate gray and iron-stained argillites. Mud breccias, mud cracks, and ripple marks are abundant. Thickness, 200 to 700 feet.

Type Locality: Scenic Point, overlooking Two Medicine Valley, Glacier National Park.

Grinnell Formation

Definition: Red or purplish argillites and white to light-green quartzites, lying between the Appekunny and the succeeding Piegan group. Textures, colours, and bedding are highly variable; ripple marks, mud cracks, and current marks are abundant, as are rain or hail prints in some members. Thickness, 1500 to 3500 feet.

Type Locality: Grinnell Point (Stark Point of some maps), at the head of Swiftcurrent, formerly McDermott Lake.

Grinnell Formation

Rising Wolf Member

Definition: A basal member, in which variable white and pink quartzites are interbedded with red argillites which range from laminae to strata 5 feet thick. Symmetrical and asymmetrical ripple marks are common; mud cracks are prevalent, as are cross-bedding, mud breccias, and mud balls. Thickness, 200 to 700 feet.

Type Locality: Southern slopes of Rising Wolf Mountain, Glacier National Park.

Red Gap Member

Definition: Argillites in thin minor and thick major beds; dominantly red, but incidentally brownish or green; interbedded with pink, white, or greenish-white quartzites, brown sandstones, and sandy argillites. Typically developed in the Lewis Range, north of Many Glaciers; recognizable elsewhere by its thick beds of red argillite with flat mud-crack polygons. Maximum thickness, 2800 feet.

<u>Type Locality</u>: Mountain between Red Gap and Ptarmigan Wall, Glacier National Park.

Rising Bull Member

<u>Definition</u>: Argillites, quartzites, and mud breccias forming the initial transition between the Grinnell and Siyeh; physical characteristics like those of the Rising Wolf. Thickness, 600 to 1100 feet.

<u>Type Locality</u>: Upper cliffs of Mt. Rockwell (Rising Bull of the Blackfeet), south of Upper Two Medicine Lake, Glacier National Park.

PIEGAN GROUP

<u>Definition</u>: Limestones, dolomites, and dominantly argillaceous clastics which lie between the Missoula and Ravalli groups. Despite variation, they form the sole dominantly calcareo-magnesian group in the Meagher facies and the second in the Glacier Park. Even in western facies, clastic strata contain much dolomite and lime. The group is characterized by great development of calcareous algae. Thickness, 2780 to 14,300 feet.

<u>Type Locality</u>: Piegan Mountain, Glacier National Park. Well exposed on Mounts Mould, Wilbur, Cleveland, Lineham, and other high peaks of the Glacier-Waterton region.

Piegan Group

	Feet
<u>Gateway (Sheppard) Formation</u>. Conglomerates, argillites, grits, siliceous dolomites, and limestones	1000
<u>Spokane Formation</u>. Argillites, purple and green, interbedded with sandy quartzites and porphyritic-amygdaloidal basalts (Purcell)	920 +
Argillites, purple and green; may include equivalents of the uppermost Siyeh in the Glacier Park and Galton facies..	500 +
<u>Siyeh Formation</u>. Limestone, thin-bedded to massive, siliceous "concretionary", gray; weathers gray or buff.........	1000
Argillites and sandstones, thin-bedded, green to purple; also a lenticular conglomerate, 200 feet thick.............	2000
	5420 +

Siyeh Formation

Definition: The second dominantly calcareo-magnesian formation in the Glacier Park facies. It includes argillites, quartzites, and extensive mud breccias, as well as thick algal deposits. Dominantly, it is dark gray to black; all dolomites weather buff or fawn. Their color of weathering is not mentioned in sections. Thickness, 2900 to 4000 feet in the Lewis Range; 5400 feet in the Blackfoot Canyon facies.

Type Locality: Mt. Siyeh, Glacier National Park.

Siyeh Formation

Collenia Symmetrica Zone

Definition: Upper phase of the transition between the argillitic and arenaceous Grinnell to the dolomitic and limy Siyeh. Quartzites, argillites, and argillaceous dolomites weather to green, brownish, or buff; purplish-red argillites are subordinate and are limited to the lower 75 feet. Grades into the member above. Thickness, 500 to 900 feet.

Type Locality: Ridge forming Cut Bank Pass, between the Cut Bank and the Dry Fork valleys, Glacier National Park. Well exposed on Dawson Pass and in cliffs near Grinnell Glacier.

Goathaunt Member

Definition: Limestones, dolomites, and subordinate oolites, dolomitic sandstones, and argillites, thickly bedded; prevailingly dark-gray. Mud breccias, commonly containing coarse sand and pebbles, are abundant in northern exposures. Mud cracks are common in carbonaceous layers; ripple marks are obscure. Collenia willisii n. sp. common, especially in the Lewis Range. Thickness, 2000 to 3200 feet.

Type Locality: South wall of the cirque between Mt. Goathaunt and Mt. Cleveland. Well exposed in high peaks of Waterton-Glacier Parks.

__Collenia frequens__ Zone

__Definition__: Dark-gray, crystalline to amorphous limestones in one or more massive biostromes with thinly bedded calcareous or dolomitic intercalations. Biostromes with thinly bedded calcareous or dolomitic intercalations. Biostromes consist of little except __Collenia frequens__ Walcott and __C. versiformis__ n. sp. Thickness, 100 to 156 feet.

__Type Locality__: Eastern slope of Swiftcurrent Pass on the granite Park trail. Illustrated by Campbell and the writers.

Granite Park Member

__Definition__: Magnesian limestones, oolites, argillites, and quartzites represent the final stage of Siyeh sedimentation. Colors range through gray, greenish gray, and brown; textures vary areally. Large colonies of __Collenia willisii__ n. sp. are abundant at several horizons. Thickness, 280 to 900 feet.

__Type Locality__: Cliffs of the Continental Divide southeastward from Granite Park, Glacier National Park, where the strata are crossed by a trail to the dike above Grinnell Glacier. Well exposed in Hole-in-the-Wall Basin, near Boulder Peak, and on the trail from Alderson to Carthew lakes, Waterton Lakes Park.

__Spokane Formation__

__Definition__: Argillaceous and arenaceous strata lying between the calcareo-magnesian formations of the Piegan group. The beds range from sandstones and soft shales to quartzites and argillites; dominantly red and green, though brown, buff, and gray are also seen. Thickness, 180 to 7400 feet.

__Type Locality__: Spokane Hills, east of Helena, Montana.

__Discussion__: Argillites, interbedded with green basalts, lie above the Siyeh formation, from Dawson Pass northward through Waterton Lakes Park and in the Purcell Range.

Sheppard Formation

Definition: Argillaceous and siliceous dolomites and magnesian limestones in thin strata but thick beds; dark-gray, green-gray, or brown. Basally, there are interbeds of greenish-white magnesian quartzites. Ripple marks, mud cracks, channel fillings, and edgewise mud breccias are characteristic, the latter chiefly in siliceous layers; there is little or no red argillite. This formation represents the final stage of Piegan calcareo-magnesian sedimentation. Thickness, 585 to 1500 feet.

Type Locality: Cliffs of the Lewis Range near Sheppard Glacier. Well exposed on Mt. Carthew, Boulder, and Swiftcurrent peaks, and mountains near Logan Pass, as well as in the valley of the Middle Fork of the Flathead River.

MISSOULA GROUP

Definition: Argillites, quartzites, and sandstones, with minor beds of conglomerate, limestone, and calcareous shale. Ripple marks, mud cracks, salt crystal casts, and rain prints are characteristic. Thickness, 10,000 to 18,000 feet.

Type Locality: Slopes east and west of Rattlesnake Creek, northeast of Missoula, Montana.

Missoula Group

Miller Peak Formation

Definition: Argillites, thinly bedded, dominantly green and red but with a buff-weathering member. Interbedded argillaceous quartzites and sandstones and two lenticular biostromes of limestone. This represents the initial stage of Missoula clastic sedimentation. Thickness, 2800 to 2900 feet.

Type Locality: Miller Peak, southeast of Missoula, Montana.

Kintla Member

Definition: Argillites and argillaceous sandstones, thinly bedded, dominantly bright red; thin beds of quartzite and pinkish gray limestone. Contains 30 to 40 feet of purplish amygdaloidal lava. Ripple marks, mud cracks, channels, rain prints, and casts of salt crystals are characteristic; algae are present only in dolomites, which they form. Thickness, 860 to 900 feet.

Type Locality: Pyramidal peaks of Akamina Ridge, west of Waterton Lakes National Park. Well exposed on Mt. Rowe, Mt. Carthew, Mt. Custer, and on Boulder Peak.

Roosville Member

Definition: Thin-bedded, fissile argillite and argillaceous sandstones, green, green-gray, and olive; weather rusty buff, light gray, or brown. Mud cracks, ripple marks, and salt crystals are common. Thickness, 550 to 1000 feet.

Type Locality: Three miles east-northeast of the Phillips Creek cascade, near Roosville, British Columbia.

Mt. Rowe Member

Definition: Red quartzites, in thin to thick beds, many of which show crossbedding, ripple marks, and mud conglomerates. The quartzites grade upward into rose-red argillites, which are thinly bedded and fissile. Thickness, about 1500 feet.

Type Locality: South crest of Mt. Rowe, near Akamina Pass, Waterton Lakes National Park.

Undifferentiated Missoula Group

About 4800 feet of argillites and sandstones overlies the Miller Peak formation in the Flathead Range. Small symmetrical ripple marks and interference marks are abundant, as are mud cracks, which enclose flat polygons in argillites and convex polygons in quartzites. Polygons range from 1 to 36 inches in width. Large ones are secondarily cracked. Rain prints are numerous in some layers; others show annelid burrows.

IGNEOUS ROCKS

The Belt series in the Glacier Park facies includes igneous rocks of two types: diabasic basalt lavas in the Grinnell, Spokane, and Kintla, and gabbro or gabbro-dorite sills and dikes cutting formations from the Altyn to the Spokane. In addition, there are minor exposures of augite-andesite, melanite, phonolite, and other rocks.

The earliest lava is the basic amygdaloidal basalt in the Rising Bull member of the Grinnell formation. It is composed largely of secondary chlorite, quartz, and calcite, with abundant labradorite crystals and pores filled by deep-green chlorite.

The second lava is the Purcell. At its most southerly exposures, west of Grinnell Mountain, the Purcell includes two major flows, the first, 30 to 42 feet in thickness, the second 18 feet thick. The basal 20 to 25 feet of the lower flow contains ellipsoids or "pillows", 10 to 25 inches in diameter, separated by cherty inclusions; the lavas surround detached masses of modified argillite 2 to 12 feet thick, the base [of the lava] being irregular. The upper 10 to 17 feet is a massive, ropy lava. The second main flow is massive and amygdaloidal, containing mud inclusions, steam tubes, and irregular cavities--evidences of subaqueous extrusion.

Northward, the thickness and number of flows increase. . . Daly's [1912, p.219] sections show 390 feet of amygdaloid, porphyry, and mud breccia in the Galton Range and 465 feet of varied lavas in the Purcell. "Pillows", irregular inclusions, vesiches, steam tubes, and ropy structure characterize the flows. Prevailing colors are dark blue green to olive green.

Sequence of igneous events in the Glacier Park facies:

Early Kintla	Basaltic flow, 40 feet thick; subaqueous.
Late Spokane	Basaltic flows, 35 to 275 feet thick; subaqueous.
Early Spokane or latest Siyeh	Intrusions in sheets and dikes, the latter as much as 300 feet wide (at the foot of Lake Janet). They rose within 350 feet of the top of the Siyeh.
Late Grinnell	Basaltic flow and copper-bearing intrusions. Flow 20 to 40 feet thick; probably subaqueous.

(Localized intrusions of undetermined dates; probably Altyn in part.)

Correlation of the Belt Series

A correlation of the Belt formations and members within and beyond the area is illustrated by Figure 3, which is essentially the work of Fenton and Fenton (1937, p.1878) with the exception of Sections 4 and 5. These two sections represent the work of Rice (1937, 1941).

Northwest of the Glacier Park section, two formations, which are stratigraphically lower than any occurring in Glacier Park, have been described by Schofield (1915) and Rice (1937, 1941). These two formations, the Fort Steele and the Aldridge, form the basal portion of the Belt series in the Cranbrook area. The Fort Steele and Aldridge formations are described in the following section.

Fort Steele and Aldridge Formations, Southeastern British Columbia

The Fort Steele formation, as described by Rice (1937, pp.4-6), is composed of a series of quartzites, argillites and limestones which have an exposed thickness of 7,000 feet and a possibly much greater total thickness. The Fort Steele formation lies conformably under the Aldridge formation but the lower contact is unfortunately obscured.

This formation contains at least four members. The lowest or "white quartzite" member has a minimum thickness of 1,000 feet. It is composed of pure quartzites and argillaceous quartzites with numerous white quartzitic beds up to 30 feet in thickness. This white quartzite member grades into the second or "striped argillite" member which is composed of 2,000 to 3,000 feet of alternating, narrow (approximately 1 inch) bands of dark grey argillite and white-to-grey quartzite. Above the "striped argillite" member lie 2,000 to 3,000 feet of massive, black calcareous-to-dolomitic argillite which contains in part minor white lines parallel to the bedding plane. This massive, dolomitic argillite member is overlain by the uppermost member of the formation which consists of 300 to 500 feet of massive, grey-green, dolomitic argillite grading laterally into bluish limestone. The type locality for the Fort Steele formation is on the spur from Lakit Creek to Lakit Mountain, near Fort Steele, British Columbia.

A fact of particular interest pointed out by Rice (1937, p.5) is the occurrence of carbonates in the Fort Steele formation. Previously, the oldest carbonates in British Columbia were found in the Kitchener formation--20,000 feet stratigraphically higher than the upper member of the Fort Steele formation. The presence of carbonates in the Fort Steele formation might eventually provide a clue to environmental conditions during early Proterozoic time once the relationship between the presence of organisms and the deposition of carbonates is thoroughly understood.

The Aldridge formation has been described by Rice (1937, pp.6-7) as a formation of tremendous thickness, not less than 16,000 feet. He described it as "composed essentially of grey, rusty weathering argillite and argillaceous quartzite", being predominantly argillite in the Rocky Mountains and argillaceous quartzite in the Purcell Range. Primary sedimentary structures such as "crossbedding, mud-cracks, and ripple-marks" are common in the Aldridge formation.

At the time Fenton and Fenton (1937) defined the Purcell facies, the Aldridge formation was thought to be the lowest stratigraphic unit of the Belt series. However, when Rice (1937) described the Fort Steele formation, it became the lowest outcropping horizon of the Belt series. The presence of carbonates in the Fort Steele formation alters the definition of the Purcell facies slightly (see preceding section, Facies of the Belt Sediments). The Purcell facies, however, is still dominantly clastic and the known base of the Belt series is still a quartzite.

Belt Paleogeography

The Belt sea, as illustrated in Figure 5, was essentially a long, narrow, shallow body of water (Fenton and Fenton, 1937, pp.1938-1940) which was particularly responsive to "variations in precipitation on adjoining lands" because of the limited influence which could be exerted upon it by the distant oceans. The margins

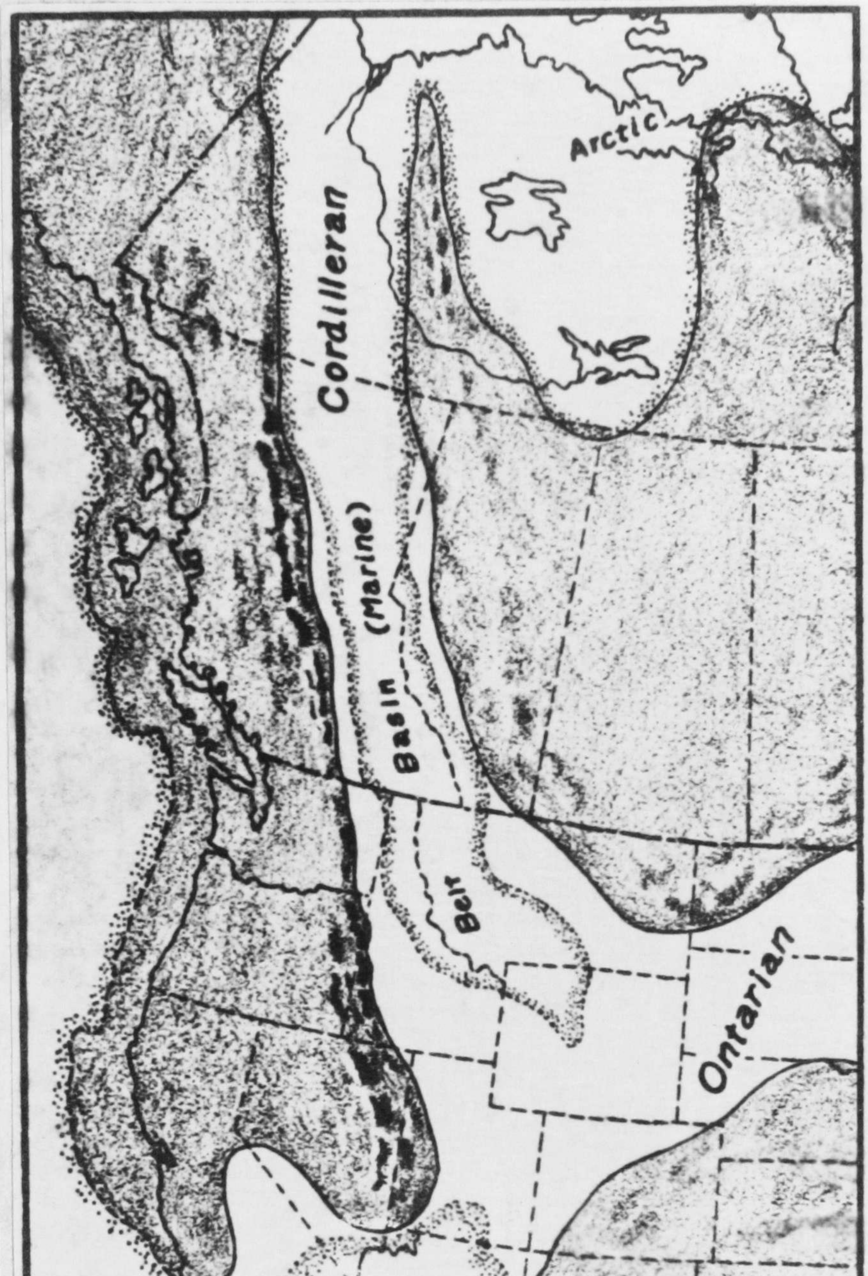

Figure 5. Belt paleogeography. Lands, dark; geosynclines, white; marine basins, stippled at borders. (Fenton and Fenton, 1937, p.1939)

of the sea, therefore, were somewhat brackish. During periods of drought or emergence the sea would become highly saline. There were apparently no great depressions or high areas within the trough, although an Algonkian archipelago in the vicinity of central western Montana and a large island in central southern Montana did exist (Deiss, 1935, pp.104-5). The members of this archipelago were composed of Archean granites, gneisses, and schists. The main axis of the trough lay to the west of the archipelago "from Ruby mountain northward to, and beyond the International Boundary, and westward through Idaho and into eastern Washington."

The western border of the trough (see Figure 5) is approximately parallel to its axis, extending northward from southwestern Idaho, through northeastern Washington and eastern British Columbia. The eastern shoreline of the Belt sea on the Pre-Cambrian granites of the Canadian Shield complex is largely hypothetical. Only in areas where concentrated drilling has been done is the shoreline placed with any degree of accuracy. In southern Alberta, the eastern limit of Belt sediment has been shown (McGehee, 1949, p.613) to be west of the Princess area of southeastern Alberta.

The area contributing the greatest amount of sediment to the Beltian trough was the highlands of southwestern Idaho (Fenton and Fenton, 1937, p.1940). In general, the hills on the western margin of the trough presumably supplied most of the sediment, which would be augmented in part by detritus from the archipelago and perhaps by very fine material from the distant lawlying eastern granitic shores.

The paleogeography of Beltian time is reflected in the facies changes of its sediments (Fenton and Fenton, 1937, pp.1935-1938). Carbonates of the eastern facies grade laterally into clastic members of the western facies, indicating a dominantly western source of sediment. All formations of the Glacier Park facies are essentially in gradational contact, joined by transitory members. These members indicate "shallowing and occasional emergence, with action of waves and currents, increased salinity of muds, and crystallization of salt." The Belt series would, therefore, seem to be "unified areally and vertically" with most of its sediments indicating a marine environment.

The present distribution and thickness of the Belt sediments in Montana are illustmated in Figure 6. It is important to note that the sediments of two troughs have been preserved. The northwest-trending trough, which contains a tremendously thick sequence of Belt sediments, was a structurally weak crustal zone and was inherited by the Paleozoic era as the Cordilleran geosyncline of Paleozoic geography. The east-trending trough, which contains a much thinner section of Belt sediments, was also inherited by the Paleozoic era as the consistently negative Central Montana trough of the Paleozoic cratonic area. The Montania area exhibited intermittent positive tendencies until Upper Devonian time and there is some

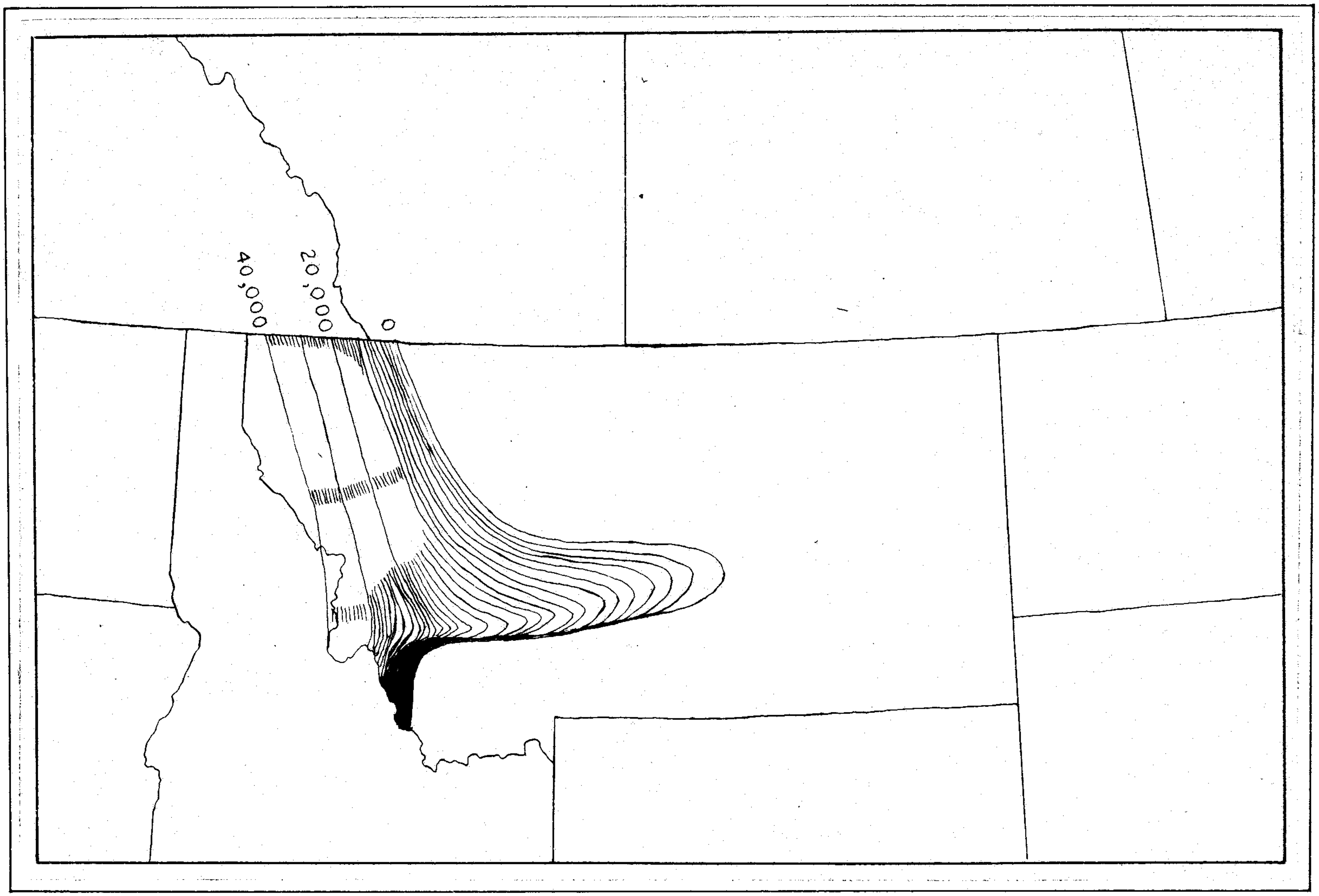

Figure 6. Distribution and thickness of Beltian strata in Montana, shown by generalized "form" isopachs. (Sloss, 1950, p.429)

evidence to suggest this tendency continued through triassic time. These units will be discussed in later chapters.

Post-Algonkian -- Pre-Cambrian Diastrophism

An unconformity between Beltian and Cambrian strata was first observed by Walcott (1899, pp.210-215) and later substantiated by other workers. Eventually, Deiss (1935) published a treatise on the nature of the unconformity, postulating the conditions responsible for its formation. He (Deiss, 1935, p.123) envisioned a major period of orogenic movement in western Montana, the original uplift of which ended Beltian sedimentation. In Montana, the effect of this orogeny (Deiss, 1935, pp.111-112) extended at least as far north as Pentagon Mountain (near latitude 48° at longitude 113°). Deiss stated that "local folds with dips of 30 degrees were produced, and the beds were elevated at least 20,000 feet above the surrounding region" producing the Helena mountains. This uplift, which marked the close of the Pre-Cambrian era, was followed by a long period of erosion--the Lipalian interval.

The Lipalian Interval

Erosion during the Lipalian interval reduced the high Helena mountain mass to near-peneplain conditions. Deiss (1935, p.124) supported this theory of a long and active period of erosion with the following evidence:

> That the Middle Cambrian sea-bottom, upon which the Flathead (basal Cambrian sands) was deposited, was a base-leveled plane, is substantiated by the distribution and remarkably uniform thickness [in a regional sense but with many local irregularities (Deiss, 1939, p.34)], lithologic character, and transitional sequence of the thin Flathead sandstone and the superjacent Wolsey shale. The writer believes it to be impossible for a formation to be deposited over 35,000 square miles to an average thickness of only 108 feet unless the surface upon which the formation was laid down was essentially a plane.

As a conclusion to his study, Deiss (1935, p.124) maintained that the existence of the unconformity between the Beltian and overlying strata, which resulted from an erosional interval of great magnitude, was "conclusive proof of the pre-Cambrian age of the Beltian sediments."

<u>Post-Beltian -- Pre-Cambrian Sedimentation</u>

Along the Rocky Mountain trench northwest of the area and in the Kootenay Lake - Revelstoke area, a group of sediments known as the Windermere series (Walker, 1926, pp.13-20) lies unconformably upon the Purcell series. The Windermere series is, in turn, unconformably overlain by Lower Cambrian strata. This series has been assigned a late Pre-Cambrian age by Rice (1941, p.24). However, Park and Cannon (1943) and Cheriton (1949) have considered at least part of it as early Paleozoic in age. As described by Walker (1926), the series consists of a lower formation, the Toby, composed of coarse clastic derivatives of the Purcell facies of the Belt series, and a thick upper series of volcanic and detrital clastics with minor carbonates. The Windermere series will not be described further except to show its relationship to the events which occurred in the area.

The Windermere series appears to be the result of rapid erosion and short transportation of sediments from an adjoining high land mass (Walker, 1926, p.15). Cheriton (1949, p.58) discussed the Windermere series and concluded that its source of sediment was the Purcell mountains. This conclusion was based partly on the work of Park and Cannon (1943) who, although they could not determine an area of provenance of sediments for the coarse basal conglomerate, found stratigraphic evidence of a source area north of northeastern Washington (Park and Cannon, 1943, p.13) for sediments immediately overlying the conglomerate. Rice (1941, p.23) did not suggest a source of sediment but stated that some fragments in the basal conglomerate of the Windermere series indicate a "granite intrusive source of at least some of the sediments." He also stated that "no granite of pre-Windermere age is known to be exposed in British Columbia." The ancestoral Purcell mountains (Rice, 1937, p.31) were probably the result of the same orogenic movements which built the Helena mountains in Montana (Deiss, 1935, p.106). The erosion of Archean gneiss and schist from the Helena mountains (Deiss, 1935, p.111) represents a possible source of the granitic material in the basal conglomerate of the Windermere series.

The orogeny which built the Helena and ancestoral Purcell mountains and closed Beltian sedimentation appears to have initiated sedimentation of the Windermere series. The Windermere series is, therefore, of the same age as the first part of the Lipalian interval. As the process of peneplanation continued into the latter part of the Lipalian interval, the areal extent of the erosion increased until it included the deposition area of the Windermere series.

Close of the Lipalian Interval

When the Lower Cambrian seas transgressed the area, closing the Lipalian interval, the sediments of the lowermost Cambrian formation, the Cranbrook, were deposited on the Lipalian peneplain. The nature of this peneplain has been previously described. It should be noted, however, that the peneplain was partially over areas of folded and eroded Beltian sediments and partially over areas of tilted (Walker, 1926, pp. 17,18) Windermere sediments. The result was an unconformable contact between Lower Cambrian and Windermere strata in the areas of Windermere sedimentation, and between Lower Cambrian, Beltian and older sediments in the areas of Beltian sedimentation.

Chapter III

TECTONISM AND SEDIMENTATION DURING THE PALEOZOIC ERA

The North American Cordilleran geosyncline and adjoining portions of the craton, in the vicinity of the 49° parallel, were inundated for much of Paleozoic time. In this area, sediments were received on a tectonic framework partially inherited from the Pre-Cambrian era. The movement of the various members, or elements, of this framework resulted in a cyclic type of deposition which largely controlled the nature of sedimentation from Cambrian to very late Paleozoic--pre-Middle Jurassic time. Sloss (1950) indicated the chief members of this tectonic framework which were active in the northwestern United States and southern Canada, and gave a regional picture of the resulting sedimentary cycles. Webb (1951) made a similar study for western Canada. This thesis employs the regional picture outlined by Sloss (1950) and Webb (1951) as a pattern into which may be fitted details of Paleozoic sedimentation, tectonism and stratigraphy for the thesis area.

Tectonic Framework During the Paleozoic Era

Within the area, the Paleozoic tectonic framework was composed of two major and two minor units. One major unit was the Cordilleran geosynclinal belt which occupied approximately the western quarter of the area (see Figure 7), and in which thicknesses

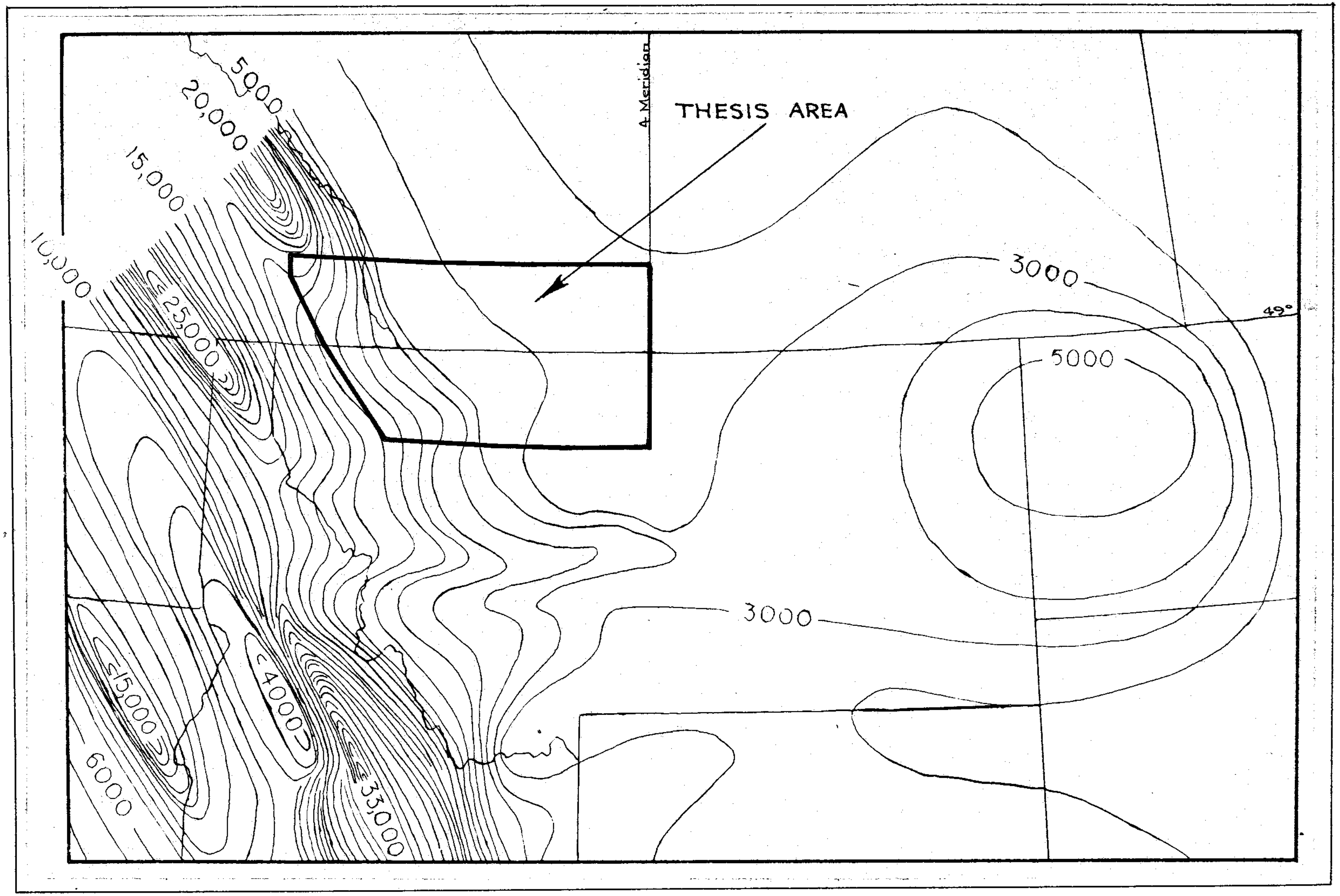

Figure 7. Thickness of Paleozoic strata, shown by generalized isopachs. (Sloss, 1950, p. 425).

of Paleozoic sediments in excess of 5,000 feet were preserved. The eastern three-quarters of the area represents a portion of the other major structural unit, the craton, which in general received less than 5,000 feet of sediments. One minor unit, namely, the Sweetgrass arch, was within the cratonic area. It is outlined in Figure 7 by a broad northeast-trending zone containing lesser amounts of Paleozoic sediments. The area to which the term "Sweetgrass arch" was applied "coincides roughly in position, but not in trend, with the Cretaceous and Tertiary Sweetgrass arch" (Sloss, 1950, p.428). Sloss (1950, p.428) has extended the use of this term--generally reserved for the Cretaceous and Tertiary structure--to include the Paleozoic feature. This usage has been followed in the present paper. The other minor unit, Montania, was an intermittently positive area variously lying within and along the eastern edge of the geosynclinal unit in northwestern Montana, southeastern British Columbia and southwestern Alberta. Its position, unfortunately, is not clearly depicted by the isopachs of Figure 7. The presence of Montania either as a land bridge or island at least during Beltian and Cambrian paleogeography has been shown by Deiss (1935, 1941). However, Kay (1951, p.8) believed the stratigraphic evidence used to substantiate the presence of the land bridge (Montania) during Lower Cambrian time may well be interpreted as merely indicating a sinuous Lower Cambrian coastline. Deiss (1941, pp.1101, 1104), however, indicated the presence of Montania in Middle and Upper

Cambrian time. Although Sloss (1950, p.431) did not present Montania as one of the tectonic units, he indicated this area as being devoid of Cambrian sediments. For the purposes of this paper, the term "Montania" refers to this area which exhibited intermittently positive tendencies during Paleozoic time, and to its island archipelago predecessor of the Beltian sea.

South of the area, an easterly trending zone of thick Paleozoic sediments joins the geosynclinal area with the Williston basin to the southeast of the area (see Figure 7). Both the Williston basin and the connecting trough--referred to by Sloss as the Central Montana trough--were negative areas through much of the Paleozoic era. North of the Central Montana trough, the Sweetgrass arch exhibited positive tendencies to a fluctuating degree, while south of the Central Montana trough, the Wyoming shelf exhibited very stable tendencies. The interrelationship between the movements of these structural units, and the relation of these movements to the nature of sedimentation is established for each sedimentary sequence.

Distribution of Sediments within the Geosyncline

Since deposition, the Paleozoic strata of the geosynclinal belt suffered deformation and, in part, intrusion and metamorphism. "Therefore," Sloss stated, "isopach values and patterns in Idaho and westernmost Montana [and British Columbia] are highly interpretive and subject to radical revision by workers who interpret the data differently." Such is the case in southern British Columbia near the 117° longitude where Sloss (1950, p.425) (see Figure 7) indicated the presence of 25,000 feet of Paleozoic sediments. Figures 15 and 17 show that he regarded 20,000 feet of these sediments as Cambrian in age, the upper 5,000 feet as Ordovician. Sloss (1950, p.434) described the Ordovician sediments as "black, siliceous, graptolitic shales" occurring "interbedded with thin and erratic greywackes." Sloss probably was referring to the Ordovician Ledbetter slate of northeastern Washington. Park and Cannon (1943, pp.19-22) gave the maximum thickness of the Ledbetter as 2,500 feet and correlated the formation with part of the Pend Oreille group which, in turn, was correlated with the Lardeau series. The thickness of the Lardeau series (Rice, 1941, p.21) was estimated to be between 10,000 and 15,000 feet. Park and Cannon (1943, p.6) correlated that portion of the Windermere series below the supposed Ledbetter equivalent and above the Irene volcanics, with strata in northeastern Washington of known and probable Cambrian age. They quoted Daly (1912) and Walker (1934) as giving a thickness of approximately 20,000 feet to this section. It appears probable, therefore, that the isopach pattern presented by Sloss (1950, p.425) of the Lower Paleozoic stratigraphy of southern British Columbia near longitude 117° is based largely upon the correlations of Park and Cannon (1943).

Rice (1941,p.24) and Lord,Hage and Stewart (1947,p.233) considered the Windermere series as being older than the Cranbrook formation which underlies the Eager formation of proven Lower Cambrian age. Both writers assigned the formation tentatively to a late Pre-Cambrian age, thereby differing with the interpretation of Sloss (1950).

The preceding discussion is presented not to prove the correct correlation of the Windermere series, but to present the possible source of information used by Sloss to postulate the thickness of Lower Paleozoic sediments in southern British Columbia near the 117° longitude. The problems involved in the stratigraphic analysis of the Windermere series are considered beyond the scope of this paper.

<u>Depositional Cycles</u>

A typical depositional cycle has been defined (Sloss, 1950, p.450) as having four stages:

(1) Transgressive overlap with relatively homogeneous and stable tectonism.

(2) Increasing definition of tectonic elements and their influence on sedimentation.

(3) Culmination of differentiation of tectonic framework into positive and negative elements.

(4) General uplift, with erosion of positive elements.

Within the area, four such cycles, or sedimentary sequences, occurred during the Paleozoic era. These sedimentary sequences, which were named and defined by Sloss (1950, p.450), are summarized briefly in the following section.

Paleozoic Sedimentary Sequences

Cycle One (Sauk Sequence)

Cycle one existed from Lower Cambrian to Lower Ordovician time and ended with the uplift of the Sweetgrass arch and the accompanying erosion of the Lower Ordovician sediments and, to some extent, Upper Cambrian sediments in the Sweetgrass arch area.

Cycle Two (Tippecanoe Sequence)

Cycle two included Middle and Upper Ordovician and all of Silurian time. This cycle ended, as did Cycle one, with the uplifting of the Sweetgrass arch and the subsequent eroding of Silurian and Ordovician sediments from the Sweetgrass arch area.

Cycle Three (Kaskaskia Sequence)

Cycle three began in the Lower or Middle Devonian and ended in the Lower Mississippian. Again, as with Cycles one and two, Cycle three ended with the usual uplift and erosion.

Cycle Four (Absaroka Sequence)

Cycle four has less distinct time limits. It began during early Upper Mississippian and was not completed until sometime in the Mesozoic era. Sloss was inclined to believe that the uplifting of the Sweetgrass arch which ended this stage occurred at a post-Triassic--pre-Middle Jurassic date.

These four Paleozoic sedimentary cycles form the basis upon which the sedimentation and stratigraphy of each period is outlined and discussed. An attempt is made to show how the detailed work of various authors has been used to formulate a regional concept of Paleozoic sedimentation. Possible variations to above interpretations of these cycles are introduced and considered.

Chapter IV

THE SAUK SEQUENCE

The Sauk sequence commenced during Lower Cambrian time with the transgression of the seas following the inherited geosynclinal area of the Pre-Cambrian during the first stage of the cycle. The second stage resulted in further transgression of the seas accompanied by definition of the tectonic elements and the deposition of Middle Cambrian sediments over most of the area. This definition of tectonic elements was culminated during stage three in late Upper Cambrian or early Lower Ordovician time when the Sweetgrass arch evidenced a positive tendency. During stage four—a general period of emergence—the Sauk sequence was terminated by the uplift and erosion of Lower Ordovician sediments, if such were deposited, and of varying amounts of Upper Cambrian sediments. The effects of this erosional stage were most pronounced on the strongly positive Sweetgrass arch. The paleogeography and stratigraphy of the Sauk sequence is considered in detail as each major time unit of the Cambrian is discussed.

Cambrian

Montania, the island barrier of the Pre-Cambrian seaway, was inherited by the Cambrian, and strongly influenced the nature of sedimentation throughout that period. It has been postulated (Deiss, 1941) that the Waucobian (Lower Cambrian) seas, approaching from the north and the south in narrow restricted troughs, were separated by Montania which formed a land bridge 550 miles wide in the Idaho area and that it was not until Middle Cambrian (Albertan) time that the Cordilleran seaways joined, inundating Montania and spreading eastward. However, during early Upper Cambrian (Croixan) time, the western part of Montania was uplifted and the entire seaway then lay to the east of Montania.

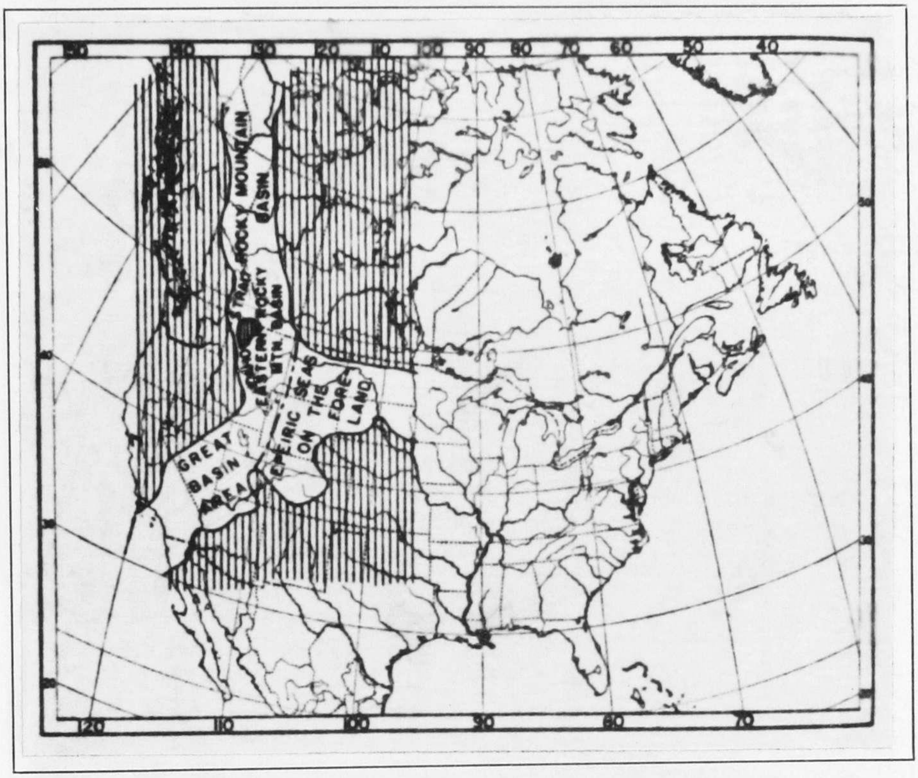

Figure 8. Synthetic map of Cambrian seaways in central Cordilleran region. (Deiss, 1941, p.1094)

As a result of non-deposition or erosion of Lower Devonian, Silurian and Ordovician sediments, Middle and Upper Devonian strata lie disconformably on eroded Middle Cambrian strata in the region of northwestern Montana. Figure 8 (Deiss, 1941, p.1094) indicates the various units of the Cordilleran seaways of the Cambrian.

Lower Cambrian

The Waucobian Cordilleran seaway, extending southward from the Arctic, flooded only the northwestern corner of the map area (Deiss, 1941). The distribution of Lower Cambrian strata within the area is therefore limited to southeastern British Columbia. The regional Lower Cambrian paleogeography, as interpreted by Deiss (1941), is shown in Figure 9.

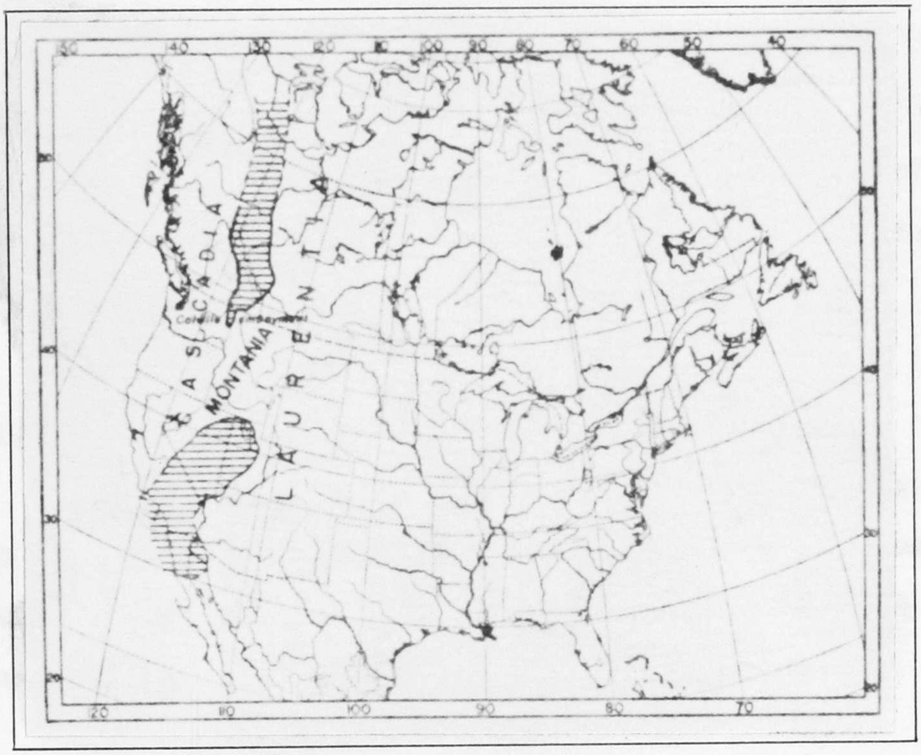

Figure 9. Map of late Waucobian lands and seaways in central Cordilleran region. (Deiss, 1941, p.1100)

A different interpretation of the paleogeography of Waucobian time was presented by Kay (1951, p.8), who doubted the existence of Montania as a land bridge during this time. His interpretation is presented in the following excerpt:

> Paleogeographers have frequently considered the western belt in Early Cambrian not to have had a single continuous geosyncline, but two geosynclines north and south of a land, Montania . . . . In southeastern British Columbia, the Lower Cambrian thins by overlap and coarsens southeastward . . . and the series is absent in western Montana . . . . This has been attributed to advance toward a transverse land joining the craton to Cascadia, a hypothetical borderland discussed later. The stratigraphy can as well be attributed to the most extensive early Cambrian sea shore having a sinuous trend more southerly than that of the preserved sections. The detritus would thus be the shore sediment laid along the margin of the cratonal land.

There is disagreement regarding the regional extent of the positive area. However, both writers recognize the existence of a positive area in the region referred to as Montania.

Lower Cambrian Formations of Southeastern British Columbia

Two formations occurring in the Cranbrook area have been assigned to the Lower Cambrian. They are the Cranbrook formation and the Eager formation, both of which have been defined and discussed in detail by Rice (1937, pp.18-21).

The Cranbrook Formation

The Cranbrook formation consists of "a series of quartzites, conglomerates and carbonate rocks" (Rice, 1937, p.18) with a 600-foot basal quartzite member resting unconformably on the Purcell series. This quartzite member is composed of white, rose-red, green-to-grey, massive, coarse-grained, siliceous rock in four-foot beds, with minor partings of argillite, and conglomerate. The formation contains such structures as ripple marks, cross-bedding and intraformational breccias. Rice (1937, p.19) noted that the base of the Fort Steele formation, the lowermost member of the Purcell series, is the only other formation in the area to contain a similar thickness of light-coloured siliceous rock.

The basal quartzite member grades upwards (Rice, 1937, p.19) "into thin-bedded, sandy magnesite which, in turn, grades into a bed of rock magnesite about 150 feet thick" at the type locality for the Cranbrook formation near Marysville, British Columbia. This part of the formation contains "a central band 30 to 50 feet thick" of "remarkably pure . . . coarsely crystalline, light creamy grey", buff-grey weathering magnesite.

The upper member of the Cranbrook formation varies from a quartzite into which the underlying magnesite grades in the Marysville area, to a "blue-grey, blue-weathering limestone" (Rice, 1937, p.19) in other localities.

Age of the Cranbrook Formation

The exact age of the Cranbrook formation is unknown. However, it must be younger than the Purcell series upon which it rests unconformably, yet older than the Eager formation which it underlies and which has been accurately dated as upper Lower Cambrian in age. Rice (1937, pp.20-21) argued that while it is conceivable that the Cranbrook formation may be "equivalent to the Pre-Cambrian, Upper Purcell, and Windermere series", the fact that it unconformably overlies the Purcell series and is lithologically dissimilar to the other sediments, presupposes it to be of Cambrian age. The only faunal evidence is annelid-like markings and "punctate" forms which are similar to "those found in the Lower Donald, suggesting that the Cranbrook formation is Paleozoic rather than Pre-Cambrian in age." The Donald overlies the Olenellus zone in the Dogtooth Range (Okulitch, 1949, pp.18-19). However, since the Olenellus-Bonnia zone, which will be discussed in a later section, has been proven to be the uppermost marker horizon of the Lower Cambrian, and since the Eager formation, which will be discussed in the following section, contains the Olenellus-Bonnia zone and overlies the Cranbrook formation, the Cranbrook formation cannot be correlated with the Lower Donald formation. The Cranbrook formation is regarded by the writer on the basis of its lithology and stratigraphic position as Lower Cambrian in age, representing the earliest Paleozoic sedimentation in the area.

The Eager Formation

The Eager formation is composed of argillaceous sediments which outcrop in the Cranbrook area of the Rocky Mountain trench. This formation was described (Rice, 1937, p.21) as consisting of dark grey, in part often blue-grey, olive-green or reddish, often rusty weathering, sometimes platy, argillites "distinguishable from the Aldridge argillite by a silky fibrous appearance."

The Eager formation is generally non-calcareous but contains minor beds of calcareous argillites and "small, light-coloured calcareous lenses an inch or so long" throughout much of the formation. Northeast of Wycliffe, British Columbia, the uppermost recognized member of the Eager formation is a "white and grey, crystalline limestone."

The Eager formation is believed to contain over 6,000 feet of strata resting with slight disconformity upon the Cranbrook formation. However, since the Eager-Cranbrook contact is obscured, the thickness of the Eager formation and the nature of the contact are unknown. The exact nature of the depositional environment of the Eager formation is unknown as it does not everywhere overlie the Cranbrook formation. These local absences of Eager sediments (Rice, 1937, p.21) may be due to lack of deposition which would suggest a local, multi-basinal type of environment; or alternatively, a local removal of Eager sediments by erosion. Because of the great thickness of the Eager formation and the slightness of the disconformity between the Eager and Cranbrook formations, the later theory of removal by erosion would seem the most credible.

Age of the Eager Formation

Rice (1937, p.21) credited Schofield with correlating the Eager formation with the lower part of the Burton formation, and Walker with correlating the Eager formation with the Mount Whyte formation of the Kicking Horse Pass area. Both these correlations were based on paleontological evidence. Problems arising from these two correlations are outlined in the following discussion, which should be read with reference to Figure 10 as it indicates the present accepted correlation of the Cranbrook and Eager formations.

Faunal Horizons	1 Mt. Bosworth B.C.	2 Ptarmigan Peak Alberta	3 Cranbrook B.C.
Olenellus-Bonnia ★	St. Piran ★ Sandstone 775'	St. Piran ★ Sandstone 230'	Eager ★ Formation 6000'(+)
		Fort Mountain Sandstone 865'	Cranbrook Formation 600'(+)
	Sections 1,2 - modified after Deiss (1940, p.783) including suggested revisions by Rasetti (1951, pp.53-62)		Section 3 -based on the work of Rice (1937) and Best (1952)

Figure 10. Correlation of Lower Cambrian Sections

The presence of the Olenellus-Bonnia faunal zone in the Eager formation (Best, 1952, p.3) enables this formation to be readily correlated with the Ptarmigan Peak section of the Field, British Columbia, area. Best (1952, p.3) has tentatively correlated the Eager formation with the Peyto limestone which, as defined by Rasetti (1951, p.55), is the uppermost member of the St. Piran formation. However, it must be noted that Deiss (1940, p.783) considered the Olenellus-Bonnia zone as representing the lowest member of the Mount Whyte formation. Rasetti (1951, p.57) carefully discussed Deiss's reasons for placing the Mount Whyte-St. Piran contact below the Olenellus-Bonnia zone and then stated his reasons for refuting Deiss's decision. Rasetti fully substantiated his decision to place the Olenellus-Bonnia zone in the St. Piran formation. Rasetti (1951, p.54) concluded:

> . . . all arguments favor placing the St. Piran-Mount Whyte boundary at the top and not at the base of the Olenellus-bearing limestone or calcareous sandstone, contrary to current usage.

This correlation, placing the base of the Middle Cambrian at the base of the Mount Whyte formation, which was redefined (Rasetti, 1951, p.54) as being above the Olenellus-Bonnia zone, will be used in this paper. Therefore, the Eager formation represents uppermost Lower Cambrian. The unfossiliferous Cranbrook formation might then be tentatively correlated with Fort Mountain sandstone which is the basal member of the Ptarmigan Peak section (see Figure 10).

Within the Cranbrook area, another formation, the Burton, was with some misgivings assigned a Middle Cambrian age by Schofield (1915, pp.43-47) who described it in some detail. This thesis agrees with Schofield's final decision to regard the Burton formation as being entirely of Middle Cambrian age. The problem of the age of the Burton formation is discussed at greater length in the following section.

Middle Cambrian

During the Albertan epoch, Montania was more submerged than at any other time in the early part of the Paleozoic era

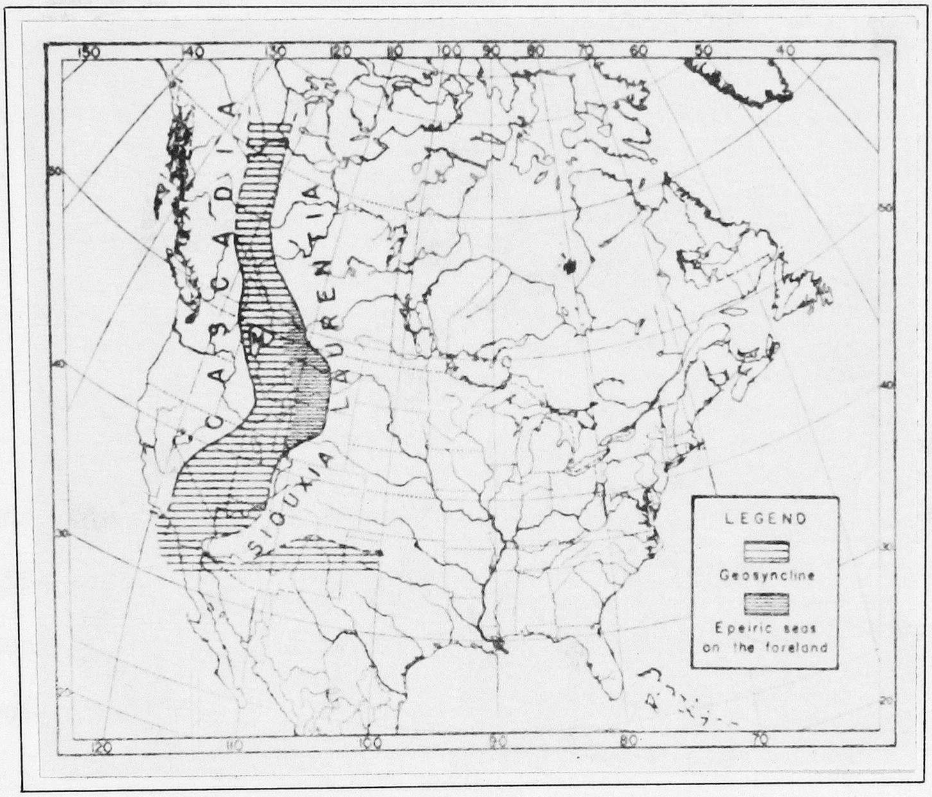

Figure 11. Map of Albertan lands and seaways in central Cordilleran region. (Deiss,1941,p.1101)

(Deiss, 1941, p.1101). Only a small island in northwestern Montana remained of the once great land bridge. The epeiric seas transgressed eastward over the foreland of the craton in the central Montana trough area (see Figure 11 on the preceding page). The coarse clastic basal member of the Middle Cambrian section was deposited by this sea. Deiss (1941, p.1103) described the nature of deposition of this basal member in the following manner:

> East of Montania the sea transgressed eastward over the peneplaned western edge of Laurentia, and in it was deposited the Flathead sandstone of Montana (Deiss, 1936, pp.1326-1328). As the sea quickly spread eastward it reworked the regolith and the sands brought in by streams, thus depositing a continuous spread of sand from west to east (Deiss, 1939a, p.60). Consequently the basal Albertan in Montana becomes progressively younger eastward . . . .
>
> The eastern edge of the geosyncline proper, in northern Montana, was close to the meridian 112° 30' because east of this line the sediments become more clastic, contain a larger number of intraformational conglomerates, and are much thinner . . . . The great proportion of carbonates in northwestern Montana indicate that Montania was lying nearly at sea level during most of the Albertan.

The type section for the Middle Cambrian has been arbitrarily defined as the northwestern Montana section (Deiss, 1939, p.55) because of its central location in the area. The correlations shown in Figure 12 are related to the northwestern Montana section, as presented in Section 4 of Figure 12.

Middle Cambrian Formations of Northwestern Montana

As late as 1938, the definitions for the Middle Cambrian formations of northwestern Montana were under continual revision. Deiss (1939) clarified the situation by defining and giving the thickness and description of each formation. At present, the Middle Cambrian is composed of nine formations (see Figure 12) in the following chronological order:

(1) Flathead sandstone
(2) Gordon shale
(3) Damnation limestone
(4) Dearborn limestone
(5) Pagoda limestone
(6) Pentagon shale
(7) Steamboat shale
(8) Switchback shale
(9) Devils Glen dolomite

Definitions of these formations, as outlined by Deiss (1939, pp.34-37), are presented below:

Flathead Sandstone

> . . . the thickness [of the Flathead sandstone] varies greatly within short distances in northwestern Montana . . . from deposition of greater thicknesses of sand in local depressions of the irregular Beltian land surface [the regional aspect of this surface being a 'base-leveled plane' (Deiss, 1935, p.124)]. The Flathead everywhere grades upward into the Gordon (basal Wolsey) through an interval of shaly sandstone, sandstone and sandy shale, and finally shaly sandstone intercalated with fissile shale. In many localities the transition is so uniform that a natural boundary separating the formations does not exist.
>
> These facts strongly support the conclusion that the variation in thickness of the basal sandstone (Flathead) is largely the result of horizontal and vertical gradation and that the Flathead and Gordon represent one continuous period of deposition.

Gordon Shale

. . . drab green and brown fissile micaceous shales and intercalated sandstones and limestones which overlie the Flathead sandstone everywhere in northwestern Montana.

The most striking characteristic of the Gordon shale is its drab green-gray and brown color combined with its fissility.

Fossils are extremely numerous and often well preserved in the upper chocolate-brown and underlying green fissile shales.

Damnation Limestone

The Gordon shale is overlain conformably in northwestern Montana by the Damnation limestone. The formation. . . consists of the combined original Damnation and Nannie Basin limestones. . . .

The diagnostic characteristics of the Damnation limestone are its position upon the Gordon shale; the bright-buff pebbly slopes at the base of the formation overlain by buff-gray cliffs; the coarsely oolitic, dark tan or blue-gray, thin-bedded fossiliferous limestone in the lower part; the fine-grained to chocolate-gray, thin- and irregular-bedded limestone in the upper three-fourths; the flakes, nodules, and locally thin bands of dull-buff arenaceous clay irregularly disseminated throughout the limestones; and the presence of the characteristic Glossopleura-Kootenia fauna in the basal 10 feet of the formation.

The Damnation limestone ranges in thickness from 100 feet to 225 feet and averages 155 feet throughout the area.

Dearborn Limestone

The Dearborn limestone lies conformably upon, but is clearly separated from, the hard chocolate-gray beds of the Damnation limestone everywhere in northwestern Montana. The Dearborn ranges in thickness from 272 feet to 363 feet on Kid Mountain and averages 298 feet.

The Dearborn formation consists of two parts: a lower shaly interval and a much thicker (average 263 feet, 80.2 m.) upper limestone interval.

Pagoda Limestone

The Dearborn limestone in northwestern Montana is overlain conformably and is often transitional into the Pagoda limestone which averages 305 feet and ranges in thickness from a minimum of 92 feet in the northern part of the area near Pentagon Mountain to a maximum of 396 feet in the southern part of the area on Kid Mountain. The formation thinned against the shore of the old Montana Island which lay north of Pentagon Mountain during Pagoda time.

The Pagoda limestone, except in the Pentagon region, consists of a lower shaly or thin-bedded part, and an upper massive, thick-bedded, more or less oolitic part.

Pentagon Shale

The Pentagon shale is present only in the northern part of the area in the Lewis and Clark Range, where it has been traced southward from Pentagon Mountain for 14 miles.

The Pentagon formation is not recognizable in any of the sections in the central and southern parts of northwestern Montana; and, although the formation may be partly equivalent to the upper and lower parts of the Pagoda and Steamboat limestones in these sections, no natural or recognizable boundaries and no fossils characteristic of the Pentagon shale are present.

Trilobites and brachiopods are most abundant in a 4-foot zone which lies approximately 30 feet above the base of the formation.

The most diagnostic character of the Pentagon shale is the presence of many trilobites and brachiopods in the lower half concentrated largely in the upper part of the lower 30 feet (9.1 m.) of the formation.

Steamboat Limestone

The Steamboat limestone overlies the Pentagon shale in the northern sections and the Pagoda limestone in the central and southern sections in northwestern Montana. The formation ranges in thickness from 216 feet near Pentagon Mountain to 353 feet on the ridge between Kid and Gordon mountains and averages 274 feet throughout the area.

The chocolate-gray and tan, generally thick-bedded, massive, hard limestone which weathers gray and forms drab-buff cliffs, irregularly and widely separated by one to four 2- to 14-foot intervals of dull-green fissile shale and nodular or shaly limestone, the presence of a Kochaspis fauna in the shaly interval near the middle of the formation, and the stratigraphic position of the formation upon the Pagoda or Pentagon formation and beneath the Switchback shale readily distinguish the Steamboat limestone everywhere in northwestern Montana.

Switchback Shale

The Switchback shale rests conformably upon the Steamboat limestone everywhere in northwestern Montana, and except for the Flathead sandstone, is the thinnest Cambrian formation in the area. Its maximum thickness, 253 feet, is developed on the ridge east of Kid Mountain, and its minimum thickness, 70 feet, on Scapegoat Basin.

The formation usually consists of green and gray, soft, slightly calcareous, more or less arenaceous, fissile to chunky shale, and interbedded gray, crystalline, thin- and flaggy-bedded, rusty-weathering limestone in the lower third to half; and buff-gray to brown, fine-grained, arenaceous, magnesian, massive limestone which weathers buff and forms plates or angular fragments in the upper two-thirds to one-half of the formation.

Fragmentary and unidentifiable fossils have been found in the limestones of the Switchback.

Devils Glen Dolomite

The Devils Glen dolomite is the thickest Cambrian formation and forms the top of the Middle Cambrian series in northwestern Montana. The formation rests conformably upon and is transitional downward into the Switchback shale wherever the two formations have been observed. The Devils Glen thickens from a minimum of 179 feet in the northern part of the area at Pentagon Mountain to a maximum of 565 feet in the southeastern part of the area near the Dearborn River and averages 353 feet (107.8) m.) throughout northwestern Montana. The great variation in the thickness of the formation, 386 feet (117.8 m.), seems to be the result of erosion between Upper Cambrian and Devonian time, and not of differential deposition.

The distinguishing characteristics of the Devils Glen are its extreme massiveness, prominent thick beds, high magnesian content which causes it to weather to sugary surfaces, and its tendency to form high rounded or sheer cliffs.

Fossils have never been found in the Devils Glen dolomite, and the high magnesian content precludes the possibility of any well-preserved ones being present.

The fauna of these formations, as reported by Deiss (1941), with the definitions of the formations, is included as an appendix to this thesis.

Middle Cambrian of Southern Alberta

In Canada, the Middle Cambrian of the southeastern Rocky Mountains and the southern Plains is relatively unknown. Approximately 70 miles north of the area along the foothills, Beach (1943) measured the Cambrian strata and subdivided it into four units. He tentatively assigned the entire section, totalling approximately 2,200 feet, to the Middle Cambrian (see Figure 12, Section 7). Farther north, the uppermost Cambrian unit of Beach (1943, pp.6-7 & 10), commonly known as the Ghost River formation, had previously been assigned a Devonian (?) age. The problem of the age of the Ghost River formation is fully discussed in the following chapter.

In the plains area of southeastern Alberta, Russell and Landes (1940, pp.6-9) described a cored section (Commonwealth-Milk River; Lsd. 8, Sec. 9, Twp. 3, Rge. 15, W.4) from approximately 15 miles north of the international border. They summarized their detailed description of the Cambrian section as consisting of "about 465 feet predominantly limestone and dolomite, underlain by 42 feet of shale." Russell and Landes (1940, p.9) lacked sufficient evidence to correlate their Cambrian section with other known sections in northwestern Montana or the Bow-Kicking Horse Pass area of the Canadian Rockies. They considered it wiser not to apply stratigraphical names to their Cambrian section until such time as future drilling revealed the presence of a basal clastic member which could be correlated with the Flathead sandstone of northwestern Montana. However, they did present a generalized section of the Cambrian formations of southern Montana (Russell and Landes, 1940, p.8). Deiss (1936, pp.1257-1338), however, had previously redefined many of the Cambrian formations of southern Montana. As a result, the term "Yogo limestone" was dropped entirely from the literature (p.1337). The Dry Creek shale was redefined (pp.1336-7) as "the youngest Cambrian formation" and the Park shale as the "youngest Middle Cambrian formation." The The section as presented by Russell and Landes (1940) has been compared in Figure 13 with the same section as redefined by Deiss (1936).

Figure 13.

TABLE OF FORMATIONS FOR THE LITTLE BELT MOUNTAINS, MONTANA

as presented by Russell and Landes (1940, p.8)

Age		Little Belt Mountains
Upper Cambrian	Yogo Limestone	
Middle Cambrian	BARKER FORMATION	Dry Creek shale Pilgrims limestone Park shale Meagher limestone Wolsey shale Flathead quartzite

The above correlation as corrected to conform with Deiss (1936), who redefined the Cambrian formations.

Age	Little Belt Mountains
Upper Cambrian	Dry Creek shale Pilgrims limestone
Middle Cambrian	Park shale Meagher limestone Wolsey shale Flathead quartzite

Middle Cambrian of Southeastern British Columbia

The Burton formation of southeastern British Columbia was assigned by Schofield (1915, p.47), with some misgivings, to a Middle Cambrian age. The formation was described (Schofield, 1915, p.43) as consisting of 74 feet of limestones and shales underlain by 3 feet of calcareous grit with a 1-foot basal conglomerate member. The presence of an Albertella fauna in the upper portion of the formation implies a lower Middle Cambrian age for that part of the formation. Schofield was tempted to place the coarse clastic lower member of the Burton formation in the Lower Cambrian, although he lacked paleontological evidence. However, it would appear more probable that the basal Burton clastics represent the introduction of Middle Cambrian sedimentation and therefore are stratigraphically related to the Flathead sandstone.

Overlying the Burton formation is the Elko formation. Schofield (1915, p.47), who examined these sediments, stated that while the exact contact was not exposed, there was no evidence of any structural unconformity between the two formations. He defined the Elko formation, which has a thickness of 1,000 (+) feet, in the following manner:

> The lower 30 feet of the Elko formation is composed of massive, grey, siliceous limestone, weathering grey, containing indistinct coral-like forms. The limestone by gradual transition, passes into a cream coloured siliceous dolomite in massive beds averaging about 6 feet in thickness.

(Ram Creek Section from an unpublished Schofield manuscript)

Lacking decisive faunal evidence, Schofield (1915, p.49) quoted Mr. L.D. Burling as believing, for various reasons, the age of the Elko formation to be Cambrian (post-Burton) and not some undetermined age in the post-Upper Cambrian—pre-Upper Devonian interval.

In the Flathead area, British Columbia, Crabb (1951, p.21) mentioned the presence of 50 to 100 feet of sandstones, quartzites and shale which he assigned to a Cambrian age and correlated with the Ghost River formation. This correlation will be discussed in the following chapter under the section concerning the Ghost River formation.

Upper Cambrian

The amount and areal distribution of Upper Cambrian sediments within the area is relatively small compared with the widespread, thick, Middle Cambrian section. This lack of Upper Cambrian strata resulted partially from non-deposition and partially from erosion of the Upper Cambrian strata during stage four of the Sauk sequence which occupied some portion, or all of the post-Cambrian—pre-Middle or Upper Devonian interval. Our present knowledge of the amount of distribution of Upper Cambrian sediments in the area is limited to meager paleontological data from a few scattered bore holes in southern Alberta.

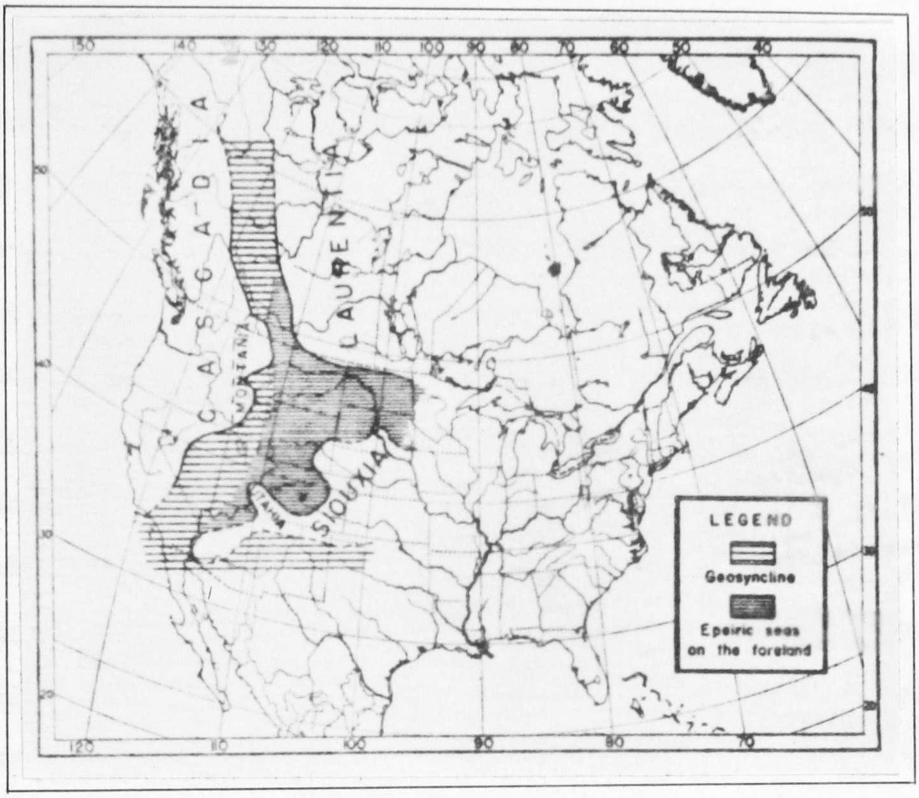

Figure 14. Croixan Seaways.
(Deiss, 1941, p.1104)

The paleogeography of Upper Cambrian time (Deiss, 1941, pp.1104-1110), which is depicted in Figure 14, saw a narrowing of the extensive geosynclinal seaway accompanied by more widespread flooding of the western side of the craton in the central area of North America. The Idaho strait of Albertan time was obliterated by pre-Croixan epeirogenic movements which elevated the old "Montania" area forcing the western shore of the sea, which lay near the 112° longitude at the 49° parallel, eastward during the Croixan epoch until by the end of the epoch the western shoreline lay nearly 100 miles east of the 112° longitude. Withdrawal of the Croixan sea and the ensuing period of erosion ended the Sauk sequence.

The erosional period at the close of Croixan time, which left a marked erosional surface on the Devils Glen formation of northwestern Montana, apparently removed all Upper Cambrian sediment in the area (Lord, Hage and Stewart, 1947, p.249). However, immediately northeast of the area, McGehee (1949, p.612) reported the presence of *Dicellomus* cf. *D. occidentalis* Bell, *Dicellomus* cf. *D. amblia* Bell, and *Linnarsonella* sp. from Imperial Provost No. 2 (Lsd. 1, Sec. 33, Twp. 37, Rge. 3, W.4) which, according to W.C. Bell (University of Minnesota), indicated an early Upper Cambrian age. It seems probable, however, that while Upper Cambrian strata may be present in adjoining areas, the statement made by McGehee (1949, p.612) that "most of the Cambrian beds represented in the plains are believed to be lower Upper Cambrian in age" does not apply to the thesis area. Within the area, Middle Cambrian sediments comprise the largest portion of the Cambrian section, with a large section of Lower Cambrian sediments being present in southeastern British Columbia and possibly minor Upper Cambrian remnants present in extreme eastern areas.

Lithology, Thickness and Distribution of Cambrian Sediments

The lithology, thickness and distribution of Cambrian sediments are illustrated by Figure 15. Additional data on the thickness and distribution of Cambrian sediments in Canada are shown in Figure 16. While these two authors do not agree on a

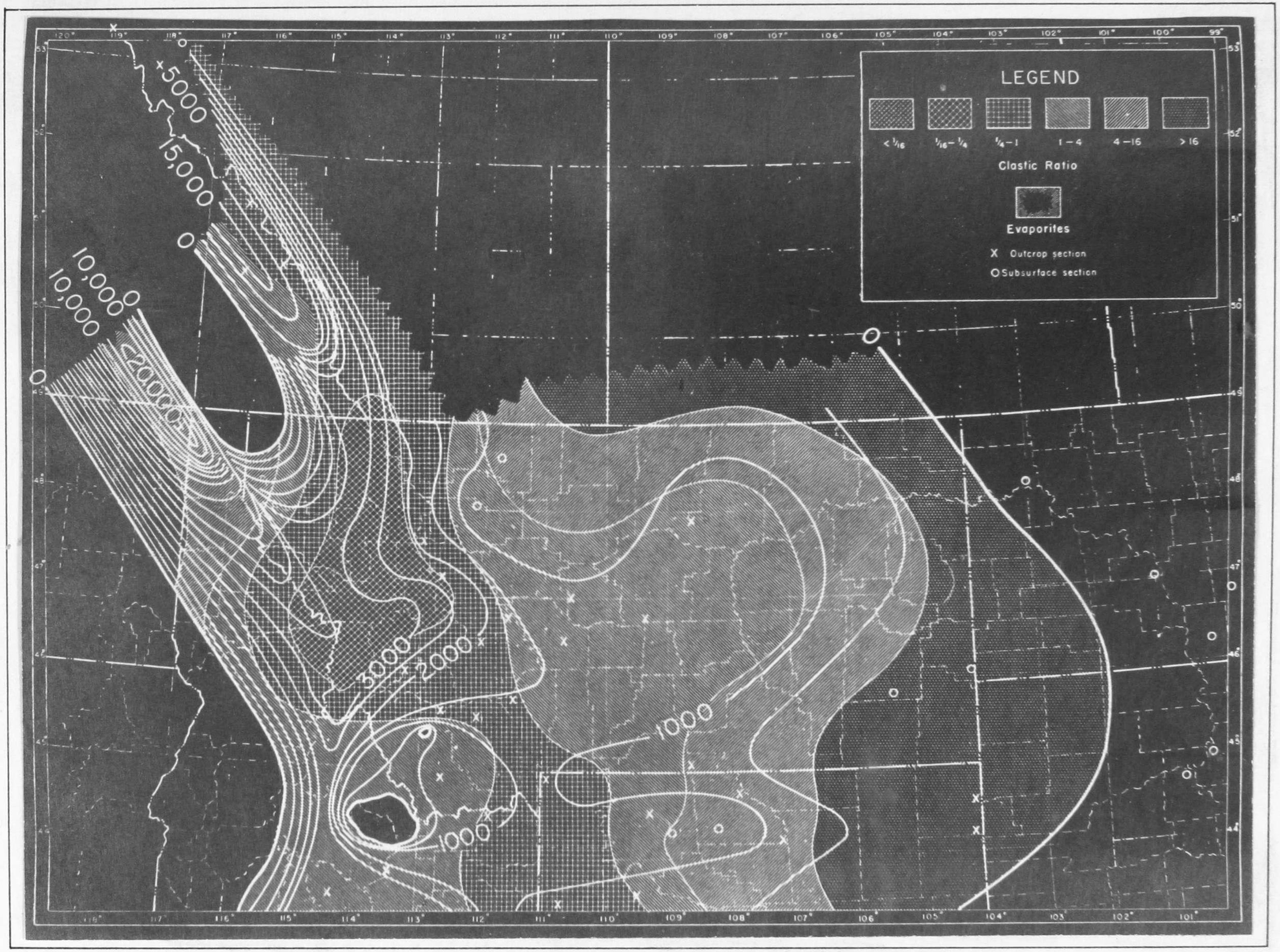

Figure 15. Isopach and lithofacies of Cambrian system. (Sloss, 1950, p.431)

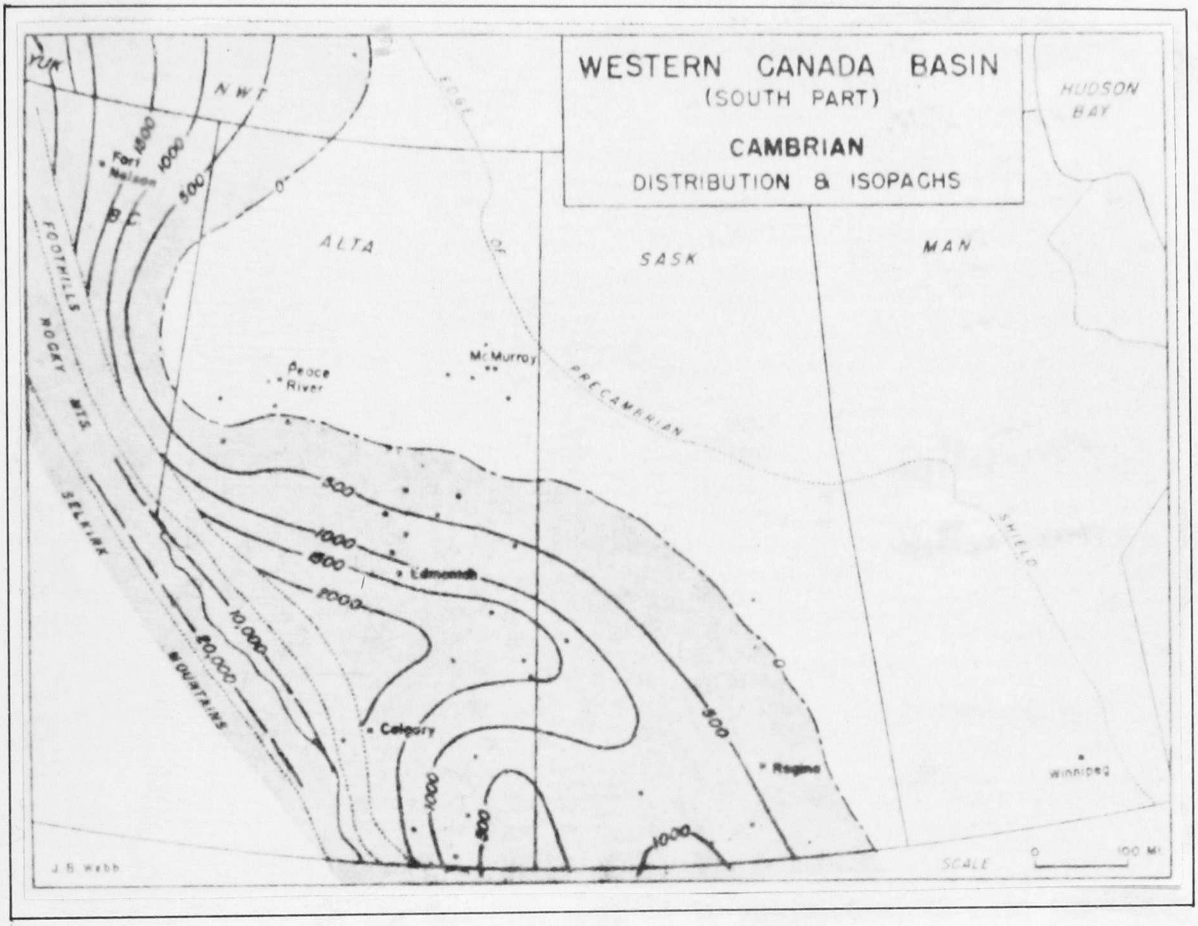

Figure 16. Present distribution and isopachs of Cambrian system. Small circles are locations of control wells. (Webb, 1951, p.2295)

few minor points, in general, their work concurs so that they tend to supplement and substantiate each other.

The lithology of the Cambrian sediments, as shown in Figure 15, is based on non-clastic -- clastic ratios for the entire Cambrian section. The ratios used are shown in the following table (Sloss, 1950, pp.424-426):

Greater than	16	....	more than 94% clastic
	16 - 4	....	94% to 80% clastic
	4 - 1	....	80% to 50% clastic
	1 -1/4	....	50% to 20% clastic
	¼ -1/16	....	20% to 6% clastic
Less than	1/16	....	less than 6% clastic

Sloss (1950) considered all detrital rocks, such as conglomerates, sandstones, siltstones and shale, as clastics, while he classified all chemical rocks, such as limestones, dolomites, cherts, and evaporites, as non-clastics. On the maps of such units as the Devonian and Mississippian, where evaporites compose significant units, Sloss (1950) further segregated the evaporites from the non-clastics.

On the Cambrian map, it is interesting to note that both eastern and western borders of the trough contain coarse clastics. The degree of clasticity diminishes towards the center of the trough with the least clastic portion centered around the junction of the Central Montana trough and the geosyncline. Two major loci of non-deposition are postulated in Figure 15: one near the Idaho-Montana-British Columbia border and the other in central Idaho. The first of these loci is in the area of Montania; the second lies along the ancient archipelago of the Pre-Cambrian geosyncline.

Chapter V

THE TIPPECANOE SEQUENCE

The Tippecanoe sequence (Sloss, 1950, p.450) occupied the time interval following the erosion of the Upper Cambrian sediments and preceding Upper Devonian sedimentation. There is less data, and, therefore, more speculation, regarding the geological events of this sequence than for any other. The result is a conflict of ideas among the principal authorities on western Canadian stratigraphy regarding the sedimentation and tectonism which accompanied the Tippecanoe sequence.

It is the purpose of this chapter to define the formations which may possibly be assigned to this sequence; to indicate their position and relationship in the stratigraphic section; and, if possible, to show the effect of the tectonic pattern upon the distribution and lithology of the sediments.

Ordovician

No sediments of Ordovician age are known within the area. However, a thin section of Ordovician sediments occurs in southwestern Saskatchewan. Other Ordovician sediments in adjoining areas are the thick shale sequence of the south-central Rocky Mountain trench area of British Columbia and a thick shale section in Idaho. The distribution of these sediments is shown in Figures 17 and 18. The zero isopach on each map indicates the margins of the sediment after the fourth, or erosional, stage of the Tippecanoe

Figure 17. Isopach and lithofacies of Ordovician system. (Sloss,1950,p.435)

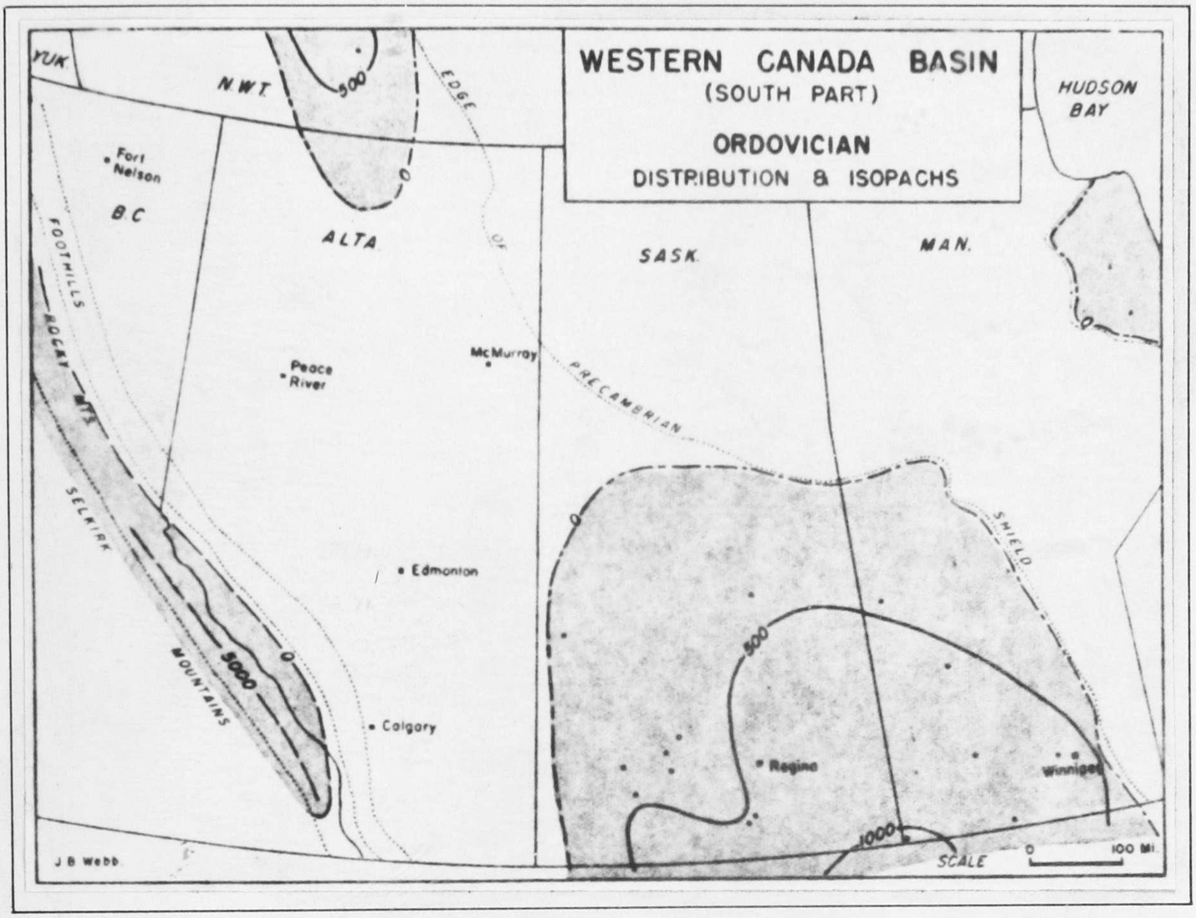

Figure 18. Present distribution and isopachs of Ordovician system. (Webb, 1951, p.2297)

sequence. These two maps, however, indicate disagreement regarding the distribution of Ordovician sediments in Saskatchewan.

McGehee (1949, p.611) offered paleontological proof of the existence of Ordovician sediments in the extreme southwestern portion of Saskatchewan. The Verbata Gas and Oil Limited well, "Verbata #2", (Lsd. 7, Sec. 24, Twp. 41, Rge. 24, W.3) encountered and cored 94 feet (4,327' to 4,421') of highly fossiliferous limestone which, according to McGehee, contained the following fauna:

Sowerbyella sp.
Rafinesquina sp.
Campylorthis or *Strophomena*
Streptelasma type cup corals

McGehee quoted P.S. Warren (University of Alberta) as saying:

> . . . the fauna has the aspect of the Ordovician of the northern sea, which, on the basis of outcrops in areas to the east and north, may be considered Upper Ordovician or Richmond in age. . . .

The above data must, therefore, lead to an adjustment in the position of the lower erosional edge of the Ordovician as shown in Figure 17, which, in this respect, brings Figures 17 and 18 into agreement.

The lithology of the Ordovician sediments is shown in Figure 17. The geosynclinal area is shown to contain more clastic sediments than the cratonic area. The sediments on the craton are more clastic in the eastern than in the western portion of the cratonic area. There is meager evidence in this lithofacies map to indicate the nature of Montania during the deposition of these sediments. However, it would appear that Montania was negative or only slightly positive during Ordovician time since there is no evidence of westward coarsening of the sediments over the central cratonic area.

The geosyncline, as illustrated in Figure 17, was a rather complex unit. The problem of the nature of the Ordovician geosyncline is considered beyond the scope of this thesis. However, the reasoning used by Sloss (1950) to postulate a thick Ordovician section in south-central British Columbia (see Figure 17) is discussed in Chapter III.

Silurian -- Pre-Upper Devonian Interval

There is very little agreement between Sloss (1950,p.437) and Webb (1951, pp.2298-2301) as to the nature of paleogeographic events in western North America during the Silurian -- pre-Upper Devonian interval. Figure 19 illustrates the distribution of what Sloss (1950) regarded as Silurian sediments. However, Webb's map of the Silurian and Middle Devonian, presented as Figure 20, showed little agreement with Figure 19. The disagreement is mainly the result of assigning the controversial Elk Point and the Ghost River formations to different periods. Sloss (1950) apparently considered these formations to be Middle or Upper Devonian since he included them in his isopach-lithofacies map (Sloss, 1950, p.438) for the Devonian system. However, Webb (1951, p.2298) considered the Elk Point formation as "chiefly Silurian with a possibility of Middle Devonian beds being included in the upper part." The Elk Point formation will be defined and the problem of its age discussed in the following section.

Elk Point Formation

The formation was first named and defined in 1949 by McGehee (1949, p.613). He stated that he believed that "the red shale, salt, dolomite and anhydrite section", which underlies the

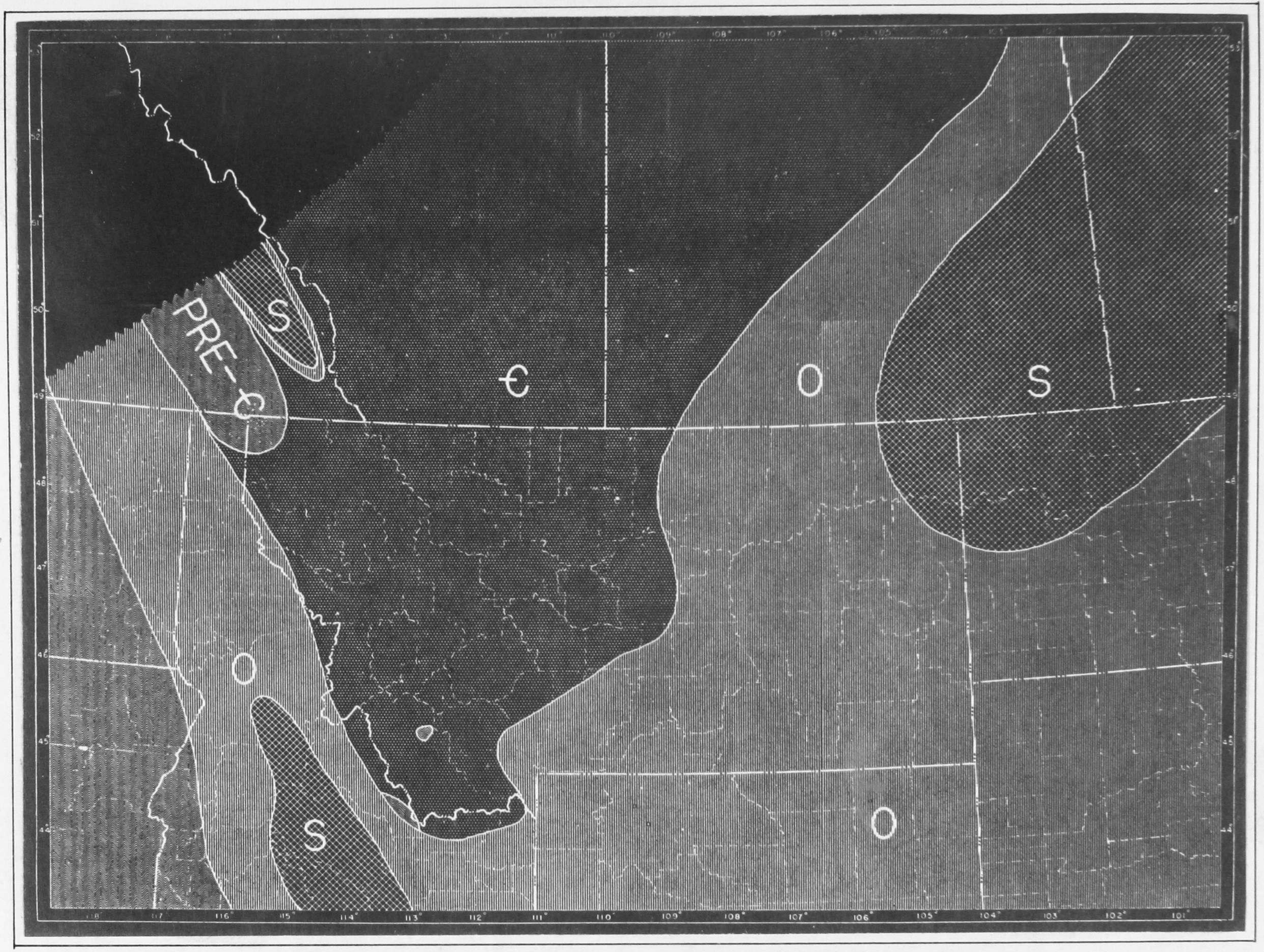

Figure 19. Pre-Middle Devonian paleogeology, showing areal geology of erosion surface over which transgressive Devonian sediments were deposited. (Sloss, 1950, p.436)

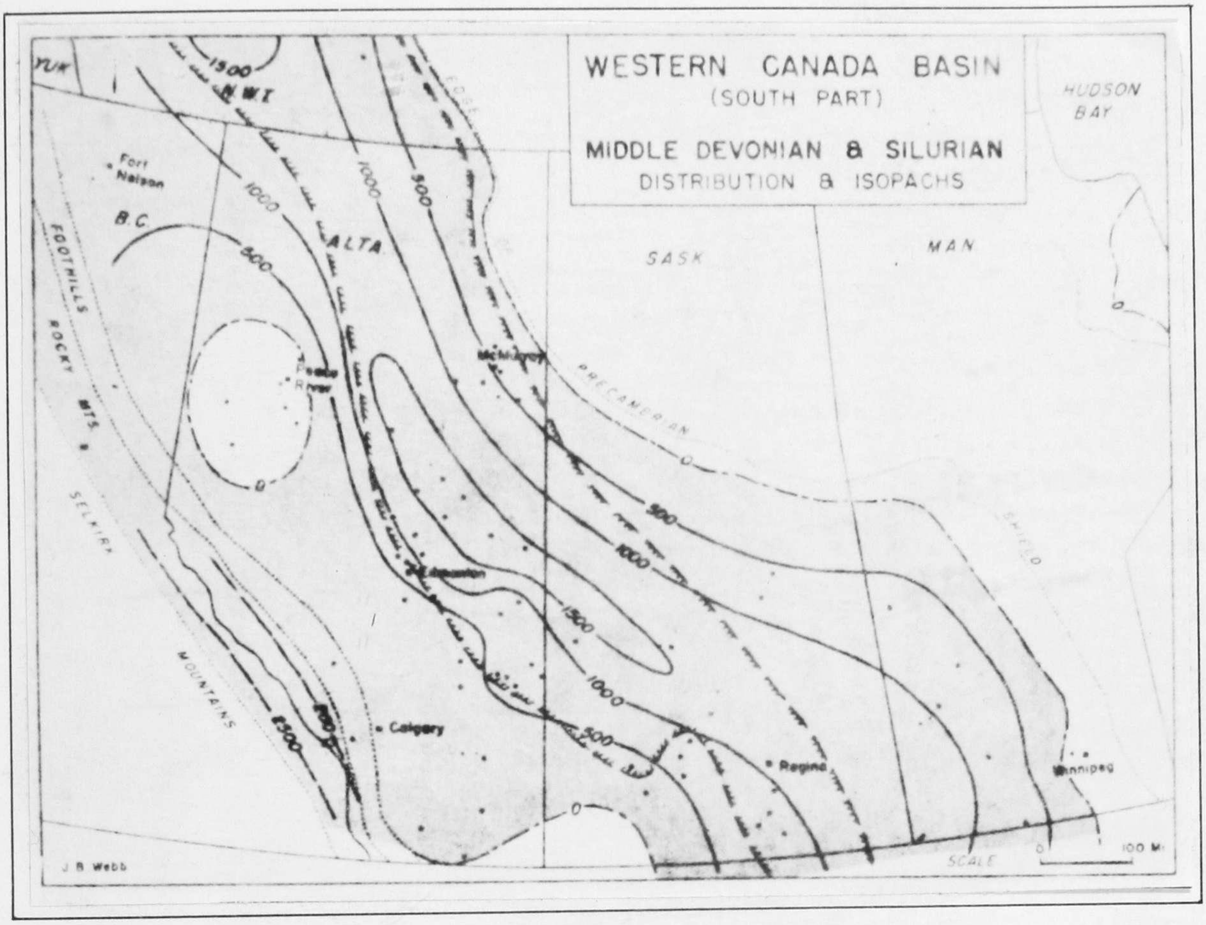

Figure 20. Present distribution and isopachs of Middle Devonian-Silurian. Hachured lines enclose belt of salt deposition. (Webb, 1951, p.2299)

Waterways formation (Upper Devonian) and overlies the Pre-Cambrian, Cambrian, or Ordovician sediments in western Canada, was one formational unit. He designated this unit as the Elk Point formation. McGehee described the most distinctive features of the Elk Point formation as being "two prominent red shale markers near the top and a salt member that extends over a large part of Alberta." The areal distribution of this salt member as compared with the extent of the formation is shown by Figure 20. McGehee (1949, pp.609, 610) gave a detailed description of the Elk Point formation at its type locality of Elk Point, Alberta, in the northeastern and central portion of that province. Of greater significance in regard to this study, however, are McGehee's remarks (1949, p.608) regarding the nature of the Elk Point formation in southern Alberta. He described it as consisting of

> . . .shaly mottled red and green dolomites, interbedded with anhydrite and thin dense slightly silty to argillaceous dolomites and anhydritic limestones. The commonly conspicuous red shales marking the top of the Elk Point are here represented as reddish mottled dolomite and anhydrite lying below the thick Upper Devonian marine limestone.

The isopachs on Figure 20 indicate the thickness and distribution of the Elk Point formation and suggest a thickness variation of zero to a probable maximum of 250 feet within the area.

Age of the Elk Point Formation

The age of the Elk Point formation has always been a difficult problem. The following quotations from McGehee (1949) summarize the information available regarding the age of this formation at the time he defined it:

> The age of the Elk Point formation is not definitely established. Silurian age is suggested by the fact that massive Silurian dolomite at Portage au Pas on the Clearwater River appears to dip beneath the Waterways beds at McMurray. It also appears that the salt springs found below Silurian gypsum near Fitzgerald occupy the same general position as the salt member of the Elk Point section

at McMurray. On the other hand, paleontological evidence from cored wells is reported to suggest Middle Devonian age for the Elk Point beds. Additional paleontological evidence is needed to determine the age of these strata with certainty. (p.613)

The fossil content of the Elk Point formation is slight, the section being composed mainly of dolomite, anhydritic limestones, anhydrites, and salt, and as far as the writer is aware, no diagnostic types have been found. According to R.T.D. Wickenden, a poor specimen of brachiopod was collected by him below the salt member in V.C.O. No. 15 at 3,931 feet. A.E. Wilson considered the specimen a pentamerid form and, although uncertain of identification, she believed it suggestive of a Silurian type. Scattered fossil molds of brachiopods, bryozoans, and crinoid stems, small ostracods, and small seed-like fossils resembling Trochiliscus have been found in some of the studies. These Trochiliscus forms are recorded below the first massive salt and are known from the Devonian, and if proved to be of a diagnostic type, would date the age of the salt. Peck (4) states that Charophyta oogonia (Trochiliscus) are widely distributed in the Middle and Upper Devonian of North America. The writer has considered that the preponderance of evidence indicated a Silurian age for this sequence including the salt.

However, P.S. Warren has recently disclosed new evidence regarding the age of these beds. He reports having identified Middle Devonian fossils from below the first salt from cores from a well, drilled since the writer left Alberta, in Lsd. 11, Sec. 11, T. 50, R. 17, W. of 4th Meridian. If the salt referred to belongs in the Elk Point formation, this would date at least the upper part of that formation as Middle Devonian. (p.610)

Later papers by Webb (1951, p.2298) and Andrichuk (1951, pp.2375-2376) regard the upper one-third of the formation as Devonian—probably Middle Devonian—in age. Webb (1951, p.2298), although he lacked positive proof, assigned the lower two-thirds of the formation to the Silurian age. Andrichuk (1951, pp.2375-6), however, preferred to assign this portion of the formation to a Silurian (?) age.

Recently, Crickmay (1954, p.151) re-examined the earlier paleontological evidence and concluded the following:

> Most of the paleontological evidence has become available since McGehee's work was done. The evidence available at that time was interpreted in such a way as to suggest a Silurian age for the Elk Point formation. For instance, stringocephalids seem to have been regarded mistakenly as pentamerids—an error that is possible in very poorly preserved fossils. The positive evidence of the charophytes was not understood and disregarded. Hence, McGehee's conclusion was that the Elk Point was mainly of Silurian age. It is now concluded that it is entirely of Middle Devonian age.

Crickmay (1954,pp.154,157) claimed a Middle Devonian age for the Elk Point formation because:

(1) "the Elk Point is overlain disconformably by limestones . . . [of Middle Devonian age], [and] its upper limit is within the Middle Devonian." (This evidence would indicate that the Elk Point is at least not younger than Middle Devonian. In itself, however, it does not prove a Middle Devonian age for the Elk Point.)

(2) Stringocephalus, Sphaerospongia and Atrypa artica, which are found in the upper two-thirds of the formation, are definitely of Middle Devonian age.

(3) Regarding the age of the basal one-third of the formation, Crickmay reasoned that because of suggestive fossil evidence

in Manitoba and Alberta, together with "the apparent continuity of the sections and lack of evidence of an internal hiatus, and finally the repeated recurrence of the same lithologic types throughout, it seems well assured that the Elk Point represents one lithogenetic episode and hence time limits within one epoch, the Middle Devonian."

The Elk Point may be regarded tentatively, therefore, as Middle Devonian in age, remembering that the age of the lower one-third of the formation has not been conclusively proven and may in fact be somewhat older than Middle Devonian, although present information would indicate that this is not the case.

Silurian (?) Strata in Wateron Park

In 1932, Hume (1932, p.7B) observed a group of sediments in the Waterton Lakes area which he regarded as probably Silurian in age. These sediments are in the basinal area of the Lewis thrust-sheet east of the British Columbia-Alberta border and approximately seven miles north of the U.S.A.-Canada border. Hume's statement regarding the lithology, stratigraphic relationship and possible age of these sediments is as follows:

> Above the Cambrian shales, in the area north of the Akamina Valley Oil Company's property, is a series of hard and gritty, massive limestones. In this area about 600 feet of these beds form a massive mountain in the centre of the Waterton Lakes-Flathead Basin structure and farther north it seemed as if a

much greater thickness occurred. The limestones contain many poor corals and although these are difficult of definite determination they indicate a Silurian age.

These Silurian (?) strata have not been described by any more recent worker, although their presence is mentioned by Crabb (1951, p.22) and by Harker, Hutchinson and McLaren (1954, p.53). In general, recent writers seem to have given little or no consideration to Hume's observation.

It must be remembered that the strata mentioned by Hume are part of the gigantic Lewis overthrust sheet. As the exact horizontal displacement of this thrust-sheet is unknown, it may be assumed that the present location of these sediments is probably considerably east and perhaps somewhat north of their locus of deposition.

Ghost River Formation

This formation is one of the most controversial formations occurring within the area. The formation's areal distribution is limited to the geosynclinal area of Alberta, where it outcrops at numerous localities along the front range of the Rocky Mountains. The Ghost River formation has been described by deWit and McLaren (1950, p.3) as follows:

Ghost River Formation (C.D. Walcott, 1923)

The age of the Ghost River formation is uncertain.

Lithology: siltstone, vari-coloured, dolomitic and shaly, and dolomite. The formation forms a conspicuous buff to ochre weathering band. Intraformational conglomerates, mud-cracks, casts of salt crystals, and ripple-marks occur locally.

Thickness: maximum, 250 feet.

Type Locality: Ghost River canyon north of the Devils Gap (Lake Minnewanka).

Representative sections are exposed at Roche Miette, Prospect Mountain, and near Exshaw above Loder lime-kiln.

The upper contact (Fox, 1953, p.191) of the Ghost River formation with the overlying "Fairholme or Flume formation, depending on locality", is disconformable and even "nonconformable in places." The lower contact (McLaren, 1953, p.89) of the formation is unconformable on strata of proven Middle and Upper Cambrian age.

No description of any occurrence of the Ghost River formation within the area could be found in the available literature. However, deWit and McLaren (1950, p.3) stated that "near Crowsnest Pass, the Ghost River has not been described by name, but published and unpublished sections indicate that it is almost certainly represented" in that region.

Age and Correlation of the Ghost River Formation

As yet, no conclusive proof has been found to date accurately the Ghost River formation. It has been tentatively assigned to all the intervals from Middle Cambrian to basal Upper Devonian. This paper does not pretend to solve this problem, nor does the writer mean to infer by including a discussion of the formation in this section, that the Ghost River formation is proven Lower or Middle Devonian in age. In the following table, an attempt has been made to illustrate the present tendency to regard the Ghost River as Devonian:

Author	Year and Page		Age of Ghost River Fm.
McConnell	1887	p. 20D	Devonian
Walcott	1923	pp.463-4	Middle Cambrian (implied)
Beach	1943	p. 10	Middle Cambrian
Sloss and Laird	1947	p.1427	Upper Devonian
deWit and McLaren	1950	p. 3	Age unknown
Webb	1951	p.2299	Middle Devonian and Silurian
Andrichuk	1951	p.2376	Middle Devonian
McLaren	1953	p. 93	Middle Devonian

McConnell (1887) was the first worker to assign a Devonian age to the Ghost River formation. He based this decision on his interpretation of the stratigraphic evidence. Walcott (1923) interpreted the same stratigraphic evidence differently and decided that the Ghost River formation was probably of Middle Cambrian age. Beach (1943), working with a section approximately thirty miles south of Bow River, collected some trilobites from what he believed to be the Ghost River formation. These were identified as Ehmania by Dr. C.E. Resser of the United States National Museum, thus placing the formation into the Middle Cambrian. The faunal evidence of Beach (1943) is weakened by the reported (North, 1953, p.110) presence of Ehmania from immediately below the Ghost River beds in the Kananaskis area, approximately twenty miles west of Beach's (1943) area. Clark (1949, pp.623-25) maintained that the trilobites described by Beach were from Cambrian strata underlying the true Ghost River formation. Sloss and Laird, who were working in Montana, found conodonts in their basal Devonian formation, Unit C, which were of Senecan (Upper Devonian) age. They correlated the Ghost River formation with their Unit C — a formation which possesses the same stratigraphic relationships as the Ghost River formation (see Figures 26 and 27). The Ghost River formation has also been correlated with the Elk Point formation of the plains (Webb, 1951, p.2299). Evidence regarding this correlation will be presented in the following section. It may be stated, however, that the Ghost River formation is most probably related to some portion of the Elk Point formation in time—if not as an actual facies equivalent of that portion.

Andrichuk (1951, pp.2388-2392) presented a lithofacies-isopach study of what he termed the "basal Devonian unit" (see Figure 21). He included in this unit: the Ghost River formation, the Elk Point formation, Unit C of Montana and the basal Devonian unit of Sloss and Laird (1947, p.1413) (see Figures 26 and 27). All these formations are the result of the sedimentation of reworked Sauk sediments plus varying quantities of non-clastic sediments and, as a result, are similar in many respects. However, the time relationship between these formations is poorly understood as yet. Sloss and Laird (1947, p.1413) believed that the basal Devonian stratigraphic unit transgressed time and is somewhat younger in Montana than in Canada. This is probably true if only the lower portion of the Elk Point formation is

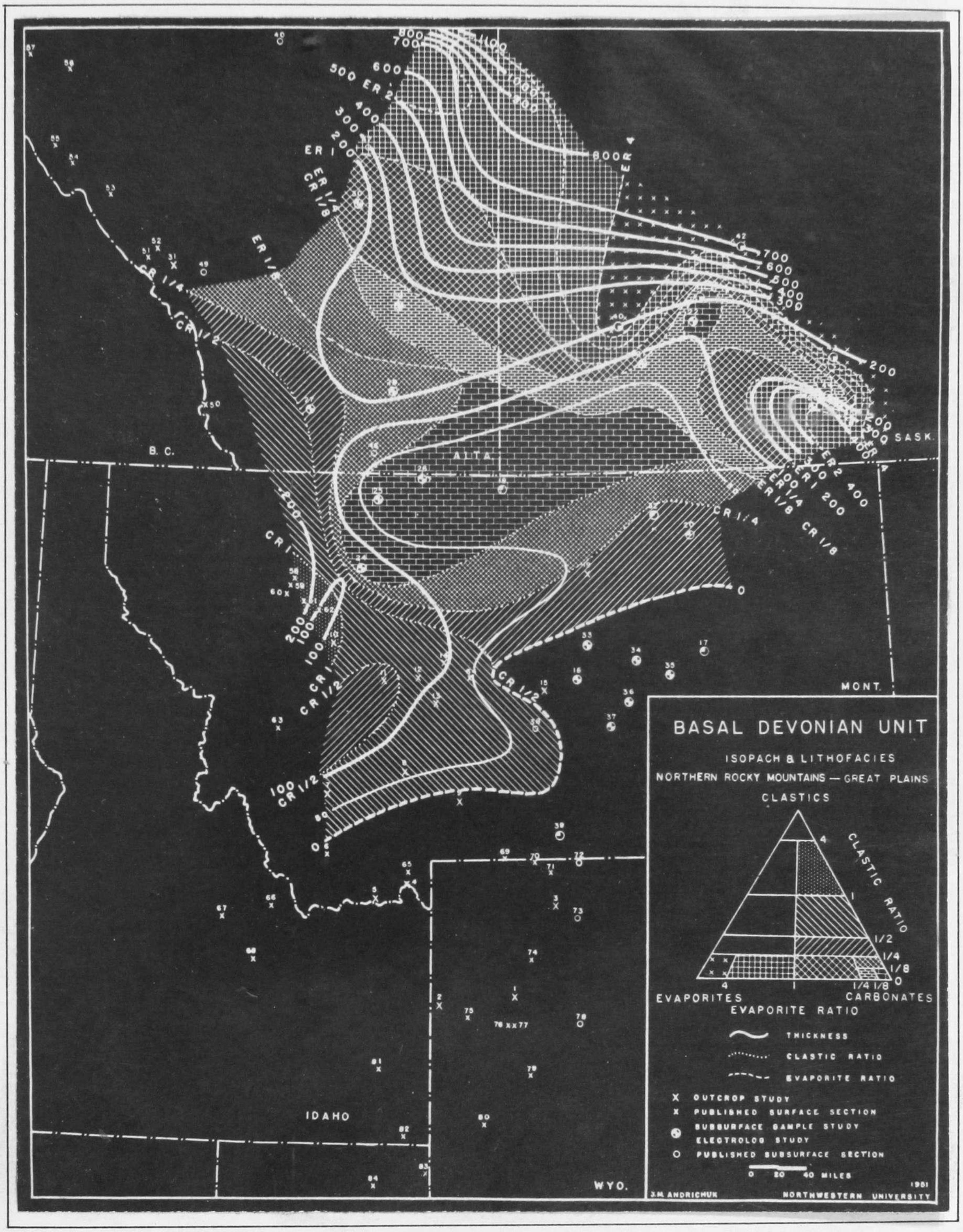

Figure 21. Isopach and lithofacies map of basal Devonian unit in northern Rocky Mountain and Great Plains areas. (Andrichuk, 1951, p.2387)

correlated with the basal Devonian unit (Sloss and Laird, 1947), since the Elk Point seas apparently transgressed southward. Actually, the Montana section probably represents deposition at a time of near maximum inundation, as does Unit C and the Ghost River (see following section) and therefore is a time correlative of some portion of the Upper Elk Point formation--probably below the upper massive salt member.

The lithofacies pattern shown in Figure 21 indicates a non-clastic evaporite area generally east of the Sweetgrass arch, with more clastic deposition west and south of the arch. There is evidence of a source of sediment near the ancient Montania area. However, the suitability for lithofacies study of such a group of strata as has been used for Figure 21 is questionable, as the relatively thicker Elk Point sediments contain a much higher percentage of carbonates and evaporites than the other formations comprising the basal Devonian unit. The clastic ratios for the reworked Sauk sediments have become disproportionate in their areal relationship. If only the basal Elk Point strata had been considered in relation to the other formations, an entirely different relationship would be revealed. This proposed lithofacies study might clarify the stratigraphic relationship between the Ghost River, Elk Point, Unit C, and basal Devonian formations, as it would illustrate the nature of sedimentation but exclude the time factor.

Tectonism During the Tippecanoe Sequence

Several theories regarding tectonism during the Tippecanoe sequence have been advanced by prominent authors. These authors agree that thick sections of Ordovician and Silurian (?) sediments were deposited in the geosyncline, with the possible exception of the Montania area where the picture becomes indistinct. However, these authors show little agreement regarding the nature of sedimentation over the cratonic area. Figures 17 and 18, which indicate the distribution, lithology and thickness of Ordovician sediments, have the zero isopach located on the perimeter of Ordovician sediments as it was located at the end of stage four, the erosional stage, of the Tippecanoe sequence.

Sloss (1950, pp.434-437) theorized that since the Ordovician sediments bordering the present eastern limit of the Sweetgrass arch were non-clastic in nature--thereby indicating no shoreline facies--it would be fair to deduce from this evidence that non-clastic Ordovician and Silurian (?) sediments covered much, if not all, of the Sweetgrass arch. Uplift and erosion, particularly of the Sweetgrass arch in pre-Middle Devonian time (Sloss, 1950, p.439) resulted in the pre-Middle Devonian paleogeography as depicted in Figure 19. It is important to remember that Sloss (1950) considered the Ghost River formation and the Elk Point formation as post-Lower Devonian in age.

Webb (1951, pp.2296-2300) recognized, as did Sloss (1950), that the zero isopach of Figures 17 and 18 do not represent the shoreline of the Ordovician seas at the time of maximum submergence of the Sweetgrass arch. However, since no Silurian sediments are recognized by Webb in the eastern Rocky Mountains (ignoring Hume, 1932), he (Webb, 1951, p.2298) considered it probable that at least the western portion of the Sweetgrass arch was not inundated during Ordovician time. Webb (1951, p. 2298) further disagreed with Sloss (1950) by postulating a broad uplift of the Sweetgrass arch during Upper Ordovician or Lower Silurian time, accompanied by erosion which removed the Ordovician sediments to their present position. Over this erosional surface, the Silurian Elk Point sea transgressed.(Webb, 1951, pp.2298-2300) depositing basal Elk Point sediments. This sea persisted, resulting in the deposition of upper Elk Point and Ghost River sediments during Lower (?) and Middle Devonian time. The distribution and thickness of these formations are shown in Figure 20. Deposition of Ghost River and Elk Point sediments was followed by pre-Upper Devonian erosion. This erosional period coincides in time with stage four of the Tippecanoe sequence, (Sloss, 1950, p.450). However, whereas Sloss (1950) considered the deposition of the Elk Point sediments as following the erosion of Silurian (?) and Ordovician strata, Webb (1951) considered the Elk Point sediments as being deposited during the Silurian - Middle Devonian interval. Sloss made no reference to the erosional disconformity which Webb described as being caused by a "relatively brief emergence and probably slightly eastward truncation" of the Elk Point and Ghost River formations. It would appear, therefore, that there is stronger evidence for placing the Elk Point and Ghost River formations in the Tippecanoe sequence than in the following Kaskaskia sequence.

Deiss (1941) took a very decisive stand regarding the tectonism of the post-Cambrian--pre-Late Devonian period. He stated (Deiss, 1941, p.1110):

> After the Cambrian, Montania remained above sea level, at least throughout its western part, until possibly late in the Devonian. During the Ordovician, marine waters in central Montana never reached west beyond the 110th meridian.

Therefore, Deiss (1941) would have considered the Tippecanoe sequence as defined by Sloss (1950) as being non-existent in northwestern Montana, with Sauk erosion continuing until the Kaskaskian (Upper Devonian) seas inundated the area.

The theories forwarded by Sloss (1950), Webb (1951) and Deiss (1941) as outlined above are obviously not in agreement. The writer presents a theory in the following section which seems to conform to the data available and yet draws the three preceding theories into partial harmony.

A Theory on the Sequence of Tippecanoe Events

Certain basic assumptions must be accepted before this theory regarding the sequence of events during the Tippecanoe sequence can be considered. These assumptions are outlined below:

(1) The Elk Point formation contains no hiatus.

(2) The Ghost River is at least a partial correlative of the Elk Point formation in time.

(3) The strata in Waterton Park mentioned by Hume (1932) as Silurian (?) is post-Cambrian--pre-Upper Devonian in age.

Accepting the above assumptions, it is possible to consider the events of the Tippecanoe cycle as occurring in the following sequences:

(1) Inundation of the geosyncline during Ordovician time with deposition of thick clastic sections in British Columbia and Idaho. Montania and the Sweetgrass arch remained positive, while seas flooded the eastern portion of the cratonic foreland.

(2) Regression of the sea in the cratonic area, accompanied by erosion of Ordovician sediments from the eastern limb of the Sweetgrass arch.

(3) Advance of the Elk Point seas westward across the cratonic area east of the Sweetgrass arch during some undetermined period, possibly as late as early Middle Devonian. In the geosyncline, sedimentation continued from Ordovician into Silurian (?) time in British Columbia and Idaho.

(4) For some unknown period of time, Montania was inundated by Tippecanoe seas and received the sediments mentioned by Hume (1932). Montania was then re-elevated and apparently remained positive until post-Ghost River -- pre-Fairholme time, since Clow and Crockford (1951) made no mention of the Ghost River formation in the Carbondale River area south of the Crowsnest Pass. It is, of course, possible that Tippecanoe erosion is responsible for this lack of Ghost River sediments in southwestern Alberta.

(5) Over the cratonic area, the slow, westerly advancing Elk Point seas transgressed the eastern portion of the Sweetgrass arch. This advance was probably delayed by minor periods of regression resulting in the deposition of evaporites.

(6) At some unknown time, probably during Middle Devonian or possibly very early Upper Devonian time in more southern parts of the area, a period of maximum submergence occurred. Montania and possibly the crest of the Sweetgrass arch remained positive. However, Webb indicated by his map (Webb, 1951, p.2299) (see Figure 20) that he believed the cratonic and geosynclinal seas actually joined, inundating the crestal area of the Sweetgrass arch. The sediments deposited on the foreland along the western side of the Sweetgrass arch formed the Ghost River formation.

(7) Regression of the seas, after this period of maximum inundation, began the erosional stage of the Tippecanoe sequence in the west. Withdrawal of the seas east of the Sweetgrass arch was slow and accompanied by the deposition of the upper massive salt member and subsequent somewhat anhydritic sediments. As the Elk Point seas withdrew, the Tippecanoe erosional surface was extended eastward.

It is interesting to observe that (1) if the above sequence of events is correct in principle, and (2) if the Ghost River formation is a true correlative of Unit C, the lowest Upper Devonian formation of northwestern Montana, and (3) if the upper massive salt member of the Elk Point formation was deposited during the regressive phase after the period of maximum submergence, then the upper massive salt and successive members of the Elk Point formation (or correlatives) must be early Upper Devonian in age in the southern part of the area. This deduction does not agree with the evidence supplied by Crickmay (1954, p.154) which indicates a Middle Devonian age for at least the upper part of the Elk Point formation. The two apparently contradictory ages given to the Tippecanoe erosional stage may be reconciled if the erosional stage transgressed time, being Middle Devonian in age in central Alberta and becoming progressively younger to the south until it became early Upper Devonian in age in northern Montana.

The erosion during stage four of the Tippecanoe sequence was apparently quite active, but of short duration. The Kaskaskian seas then inundated the area, commencing the third Paleozoic sedimentary cycle.

Chapter VI

KASKASKIA SEQUENCE

The Kaskaskia sequence, which was the third sedimentary cycle of the Paleozoic era, was defined by Sloss (1950, p.451) as including the interval from Middle or Upper Devonian to late Middle Mississippian (Meramecian) time. Sloss included as the basal part of the Kaskaskia sequence, sediments comprising the Ghost River, Unit C and Elk Point formations. However, this thesis, for the reasons set forth in Chapter V, considers the Kaskaskia sequence as excluding the Ghost River, Unit C and Elk Point formations, which have been assigned to the Tippecanoe sequence. It must be remembered that if the short-lived erosional stage of the Tippecanoe sequence transgressed the Middle-Upper Devonian time boundary, the lower limit of Kaskaskia sedimentation also transgressed the same time boundary. The Rundle formation and its stratigraphic correlatives, which comprise the uppermost unit of the Kaskaskia sequence occurring within the area, has been truncated by the erosional stage of the Kaskaskia and Absaroka sequences. Although some sediments along the western edge of the area and a thick section of sediments south of the area represent sedimentation during the Absaroka sequence, the Kaskaskia sequence was the last Paleozoic cycle from which major thicknesses of sediments still remain over the greater part of the area.

The stratigraphy of the Kaskaskia sequence within the area, accompanied by some lithofacies interpretations of its various units, is presented in the following sections of this chapter. Correlations of the type section of the area with other type sections beyond the area is indicated. Finally, an attempt is made to show the influence of the various tectonic units on the nature of sedimentation during the Kaskaskia sequence.

Stratigraphy of the Kaskaskia Sequence

This chapter will concern itself mainly with the Devonian and Mississippian sections in the following three areas: Crowsnest Pass, Alberta; the southern Alberta plains; and northwestern Montana. The correlation of these sections with each other and with sections beyond the area is shown in Figure 22. Figure 23 gives the preferred nomenclature of Kaskaskian formations within the thesis area. The Crowsnest Pass section is arbitrarily designated as the type section for the area and all other sections will be considered with reference to it.

History of the Kaskaskian Nomenclature in Canada

In 1887, McConnell made the first formational subdivision of the Upper Paleozoic section in the Canadian Rocky Mountains. Most of this work was done in the Bow River region which has remained the type section of "formations recognized over extensive areas in the eastern Rockies" (Beach, 1943, p.10). Beach (1943,

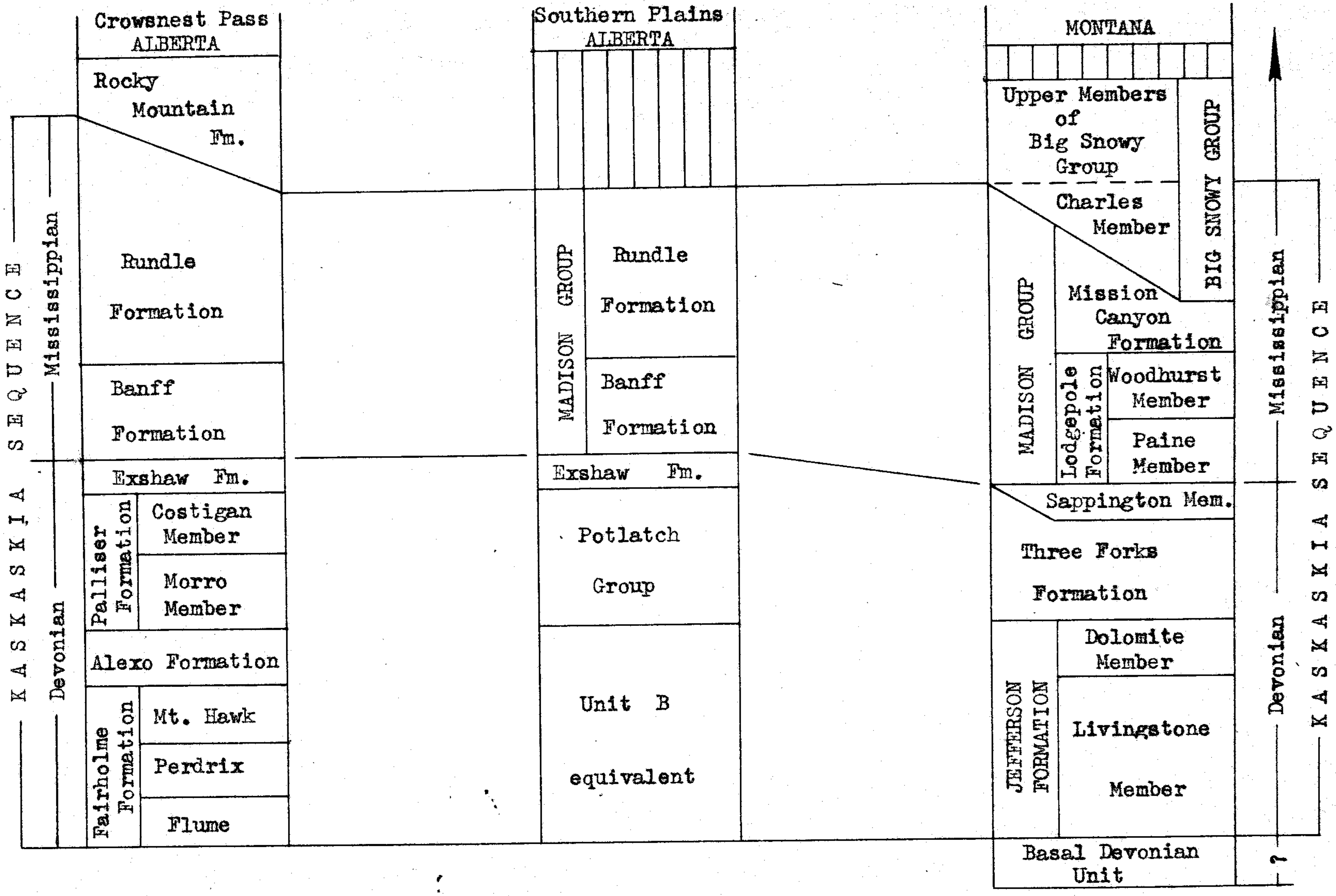

Figure 23. Kaskaskian Formations of the Area.

pp. 10-11, 18, 23) summarized the history of the development of the Kaskaskian nomenclature for the Rocky Mountain region. Figures 24 and 29 show this development graphically, as it was outlined by Beach.

Devonian Stratigraphy of the Area

The Devonian stratigraphy will be described as it occurs in the general Crowsnest Pass area of southwestern Alberta. However, it is necessary, when describing the areal extent and correlations of the various formations, to introduce nomenclature used in Montana. While the Devonian formational names used in Montana are not defined and discussed, the nomenclature, lithology, development and distribution are indicated in Figures 26 and 27, which follow the discussion of the Palliser formation.

Fairholme Formation

This formation, named by Beach (1943), has its type locality in the Bow River area in the front range of the Rocky Mountains. Subsequent work by deWit and McLaren (1950) divided the Fairholme formation, as defined by Beach (1943) (see Figure 24), into two formations. The name "Fairholme" was applied to the lower formation, while the upper one was called the "Alexo" formation. deWit and McLaren then subdivided the redefined Fairholme formation into upper and lower members, which were described by them in the following manner:

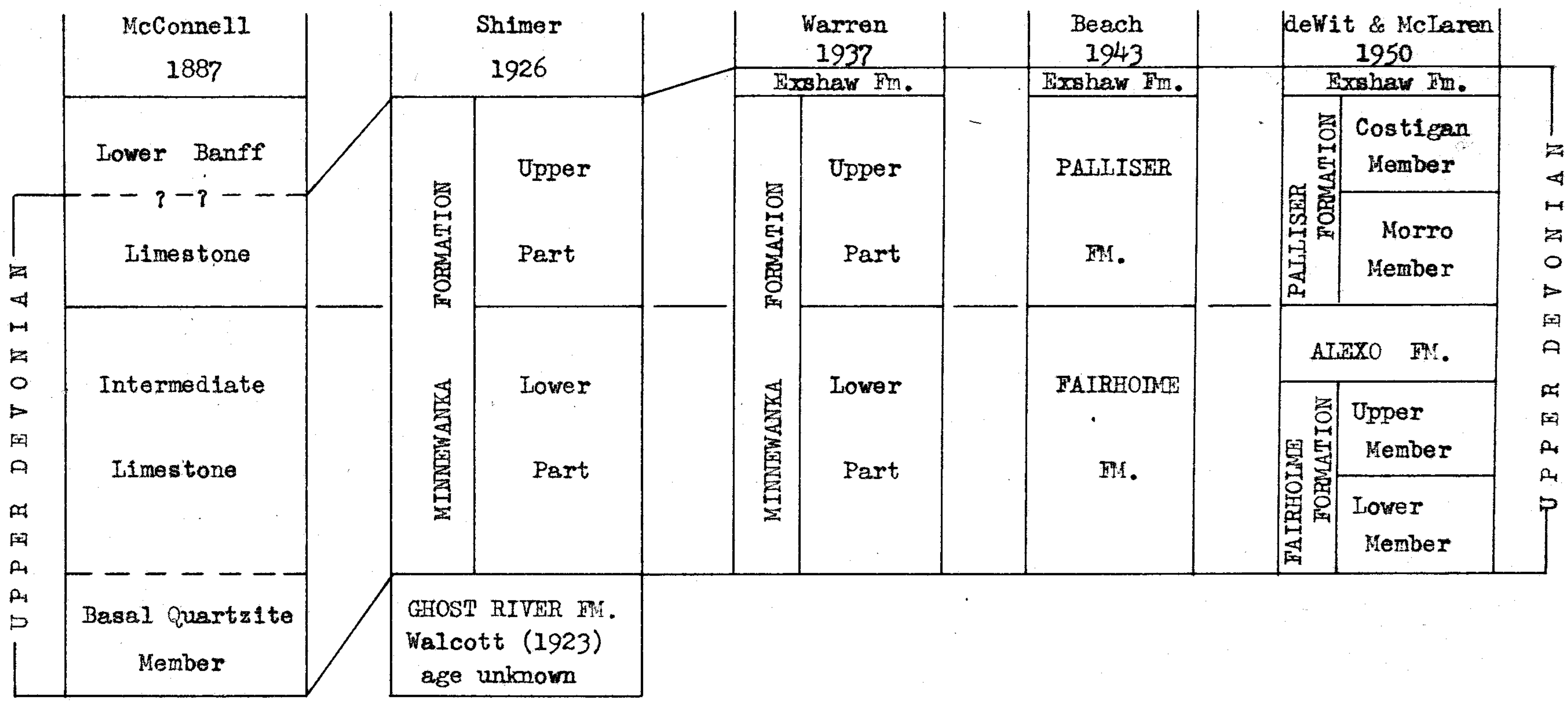

Figure 24. Historical Development of Upper Devonian Nomenclature in Western Canada.

<u>Lower Member</u>: (deWit and McLaren, 1950, p.3)

<u>Lithology</u>: dolomite, massively bedded, light grey to black, mostly coarsely crystalline; characterised by reefs full of stromatoporoids, corals, brachiopods, and other fossils; scattered silty layers, especially in the lower part of the section.

<u>Thickness</u>: maximum, 1,000 feet.

<u>Type locality</u>: The Devils Gap, Lake Minnewanka.

The contact with the underlying rocks is apparently conformable at all places examined. The member is probably in part correlative with the Flume formation, which has a similar facies.

<u>Upper Member</u>: (deWit and McLaren, 1950, pp.3-4)

<u>Lithology</u>: much like the lower member, but in general more thinly bedded. <u>Disphyllum</u>-type corals are common.

<u>Thickness</u>: maximum, 850 feet.

<u>Type locality</u>: The Devils Gap. Lake Minnewanka.

The upper member can possibly be correlated with the Mount Hawk formation of Jasper Park and with the upper part of the dolomite and dark limestone series of Crowsnest Pass.

The lower member of the Fairholme formation is believed to be (deWit and McLaren, 1950, p.4) a southern equivalent of the Flume formation of the Jasper area (see Figure 22) which possesses similar lithology and fauna. The upper member of the Fairholme formation holds the same stratigraphic position as the combined Perdrix and Mount Hawk formations of the Jasper section (deWit and McLaren, 1950, p.5) and may be equivalent to them. Recently, deWit (1953, p.107) subdivided the Fairholme formation of the Crowsnest Pass section into Mount Hawk, Perdrix and Flume equivalents as shown by Section 5 of Figure 22.

Age of the Fairholme Formation

Beach (1943, p.15) could not find sufficient paleontological data to date the Fairholme formation accurately. He assigned the formation to an Upper and/or Middle Devonian age. Warren (1949, p.566) considered the Fairholme formation as the basal member of the Upper Devonian. However, if the suggested correlation (Sloss and Laird, 1947, p.1427) of the Ghost River formation with Devonian Unit C (as discussed in Chapter V) is correct, then where the Ghost River, Elk Point or Unit C formations do occur in the southern part of the area, they may possibly be the lowest Upper Devonian strata present. In any case, it is improbable, for reasons presented in Chapter V, that the lower boundary of the lower member of the Fairholme formation and equivalent members is coincident with the Upper-Middle Devonian time boundary.

Alexo Formation

This formation was named by deWit and McLaren (1950, p.6), who defined it as follows:

<u>Lithology</u>: limestone, bedded and brecciated; some fine sandstone; dolomite; all containing or interbedded with silt. . . . Limestone breccias, which are present at several places in the Alexo, may have been caused by collapse following the solution of evaporites.

<u>Thickness</u>: 100 to 620 feet.

<u>Type locality</u>: The Gap (Brazeau Range)

Facies changes in this formation are common (deWit and McLaren, 1950, p.6). The Alexo formation as it occurs in the Crowsnest Pass is a silty dolomite which becomes more clastic in the southwestern areas where it has been observed by the writer near Elko, British Columbia, displaying a quartzitic texture. In the central Alberta plains section, the Alexo equivalent occurs as a zone of dolomitic silt to which Layer (1949, pp.591-2) applied the name "Darling silt." This name was not used by deWit and McLaren because it had been occupied prior to Layer's paper (1949) (deWit and McLaren, 1950, p.6) by another unrelated stratigraphic unit.

<u>Age and Correlation of Fairholme and Alexo Formations</u>

There is considerable confusion in the literature regarding the correlation of the Fairholme and Alexo formations, as they occur in the front ranges of the southern Alberta Rocky Mountains, with their counterparts northward and in the plains. Fox (1953, p.192) correlated the Fairholme formation "with the 'Waterways' and Jefferson groups of the southern Alberta Plains and the basal Devonian and Jefferson formation of Montana." However, this correlation is not in agreement with the stratigraphic and paleontological studies of Sloss and Laird (1947), who correlated the Limestone member of the Jefferson formation of the plains and Unit B of northwestern Montana (Figure 22, Sec. 7,8 and 9) with the combined Fairholme and Alexo formations. The evidence for this correlation by Sloss and Laird (1947, p.1427) was the presence of a Spirifer jasperensis zone faunal assemblage in the correlated formations (see Fossil Zones of the Upper Devonian following). The strata of the southern Alberta plains correlated with Unit B by Sloss and Laird (1947, p.1426) is referred to by them as the "Waterways" formation. Fox (1953) assigned the name "Waterways" to the basal part of the section, applying the name "Jefferson" to the upper portion.

The correlation of the Fairholme formation with the Mount Hawk, Perdrix and Flume formations will be discussed later in the chapter under the heading Reef and Off-Reef Facies of the Alexo and Fairholme Formations.

The Alexo formation, which Fox (1953, p.194) regarded "as deserving only member status", was correlated by him with the Calmar silt of central Alberta and "with the lower part of the Potlatch group of the southern Alberta plains and perhaps with the basal part of the Three Forks of Montana." This is not in agreement with the paleontological evidence of Warren and Stelck (1950, pp.66-68) which indicated that the entire Winterburn formation is the Alexo equivalent in central Alberta. In Montana, Unit A_2 of northwestern Montana and the dolomite member of the Jefferson formation in the Montana plains area contain a coral assemblage (Sloss and Laird, 1947, pp.1427-1428) which is correlated with the coral zone of the Palliser formation. Since this coral zone is post-Alexo, the Potlatch group, of which Unit A_2 is the basal member, and the Three Fork formation, which overlies the Dolomite member of the Jefferson formation carrying this coral zone, cannot be considered true correlatives of the Alexo formation. It would appear that the correlations made by Fox (1953, p.194) between the mountain section and the plains of southern Alberta and Montana are incorrect with reference to time. If a correlative unit for the Alexo formation, with the proper time relationship, exists in the plains area, it must be found in the upper portion of the Limestone member of the Jefferson formation. It must be remembered that even in the front range, the Alexo formation exhibits a strong tendency to change facies. It is not, therefore, a unit which is likely to maintain its identity over an extensive area. Furthermore, if a unit shows this tendency to change facies in a trend subparallel to the major controlling tectonic units, it is more liable to increase this tendency in a direction across the controlling framework.

Reef and Off-Reef Facies of the Alexo and Fairholme Formations

Much has been written regarding the "reef" and "off-reef" facies of the Fairholme formation. The problem will not be discussed in this thesis; however, a graphic summation of the

Figure 25.

REEF AND OFF-REEF FACIES OF THE ALEXO AND FAIRHOLME FORMATIONS
(McLaren, 1953, p.91)

<table>
<tr><th colspan="3">Reef Sequence
("Carbonate")</th><th colspan="3">Off-Reef Sequence
("Clastic")</th></tr>
<tr><td>Palliser
600'-1000'</td><td colspan="5">Massive and bedded limestones</td></tr>
<tr><td>Alexo
150'-250'</td><td colspan="2">Thin-bedded, silty dolomites, and fine grained, laminated dolomites</td><td>Alexo
200'-600'</td><td colspan="2">Variable silty limestones and dolomites and shales</td></tr>
<tr><td rowspan="4">Fairholme
1000'-1700'</td><td rowspan="2">Upper</td><td rowspan="2">"White reefs," rare "black reefs," coral beds, and bedded dolomites</td><td>Mt. Hawk
200'-500'</td><td colspan="2">More or less argillaceous bedded lime-stones with coral beds common at top</td></tr>
<tr><td>Perdrix
300'-500'</td><td colspan="2">Calcareous shales becoming non-calcareous at base</td></tr>
<tr><td rowspan="2">Lower</td><td rowspan="2">"Black reefs," stromatoporoid and <u>Amphipora</u> beds, and bedded dolomites</td><td rowspan="2">Flume
150'-400'</td><td>Upper</td><td>Argillaceous limestones</td></tr>
<tr><td>Lower</td><td>Stromatoporoid and <u>Amphipora</u> beds, and bedded dolo-mites</td></tr>
</table>

relationships involved, as presented by McLaren (1953, p. 91) has been reproduced in Figure 25.

A point of interest discussed by McLaren (1953, pp.91-92) was the usage of the term "Blackface Mountain shale." According to him, the term as originally defined by Kelly (1936) has been misused in the literature several times, resulting in confusion as to the exact meaning. Therefore, McLaren (1953, p.92) regarded it advisable that this term, the "Blackface Mountain shale", "be discarded."

Palliser Formation

This formation was named by Beach (1943) (see Figure 24) who described it in some detail (Beach, 1943, pp.15-17). In 1950, deWit and McLaren subdivided the formation into a lower member, the Morro, and an upper member, the Costigan, which they described as follows (deWit and McLaren, 1950, pp.6-7):

> ### Morro Member
>
> Lithology: limestone, finely crystalline to dense, dark grey or brownish grey, massive; in part vaguely bedded and in places altered to dolomite; cliff-forming; commonly characterized by dolomite tracery on weathered surfaces. The lower contact is generally transitional with the Alexo formation. At Sulphur Mountain, the Morro member is in part brecciated, and is completely dolomitized.
>
> Thickness: maximum, 950 feet.
>
> Type Area: front ranges of the Rocky Mountains near Bow River. Representative sections are exposed near Crowsnest Pass and Roche Miette.

Costigan Member

Lithology: limestone, bedded, fossiliferous; in places underlain by a variable thickness of thin to medium-bedded dolomite and layers of limestone breccia.

The lower part of the Costigan member contains cyclical units of thinly bedded, platy dolomite, overlain by brecciated or crenulated limestone. These units, although they contain less silt, are strongly reminiscent of those in the Alexo formation and, in part, even of those in the Ghost River. They have an aggregate thickness of 75 feet at Grotto Mountain and at Mount Costigan (The Devils Gap); about 200 feet at The Gap (Brazeau Range); and nearly 350 feet at Limestone Mountain.

The lower part of the Costigan member is not fossiliferous. The upper part consists of 50 to 100 feet of bedded limestone, and carries a distinctive fauna.

The Palliser is in part brecciated (deWit, 1953, p.107) similar to the Potlatch formation of the plains area.

Correlation of the Palliser Formation

The Palliser formation of the mountain front area is correlated (see Figures 22 and 23) with the Potlatch formation of northwestern Montana and the southern Alberta plains, with the Wabamun formation of the central Alberta plains, with the Dolomite member of the Jefferson formation, and with the Three Forks formation of Montana. The correlation of the diagnostic coral and Cyrtospirifer zones of the Palliser formation is carried into the plains area of Alberta and Montana, and into northwestern Montana (Sloss and Laird, 1947, p.1428). In the Three Forks area of Montana, a sandy facies called the Sappington member has developed in the upper part of the Three Fork formation. Where this facies has developed, the Cyrtospirifer fauna, typical of the upper part of the non-clastic Palliser formation, has been replaced by a Syringothyris fauna.(Sloss and Laird, 1947, p.1428).

Exshaw Formation

The Exshaw formation, as it occurs in the front range of the Rocky Mountains, has recently been described by Fox (1953, p.196) in the following manner:

> Type Locality: Jura Creek, one mile east of Exshaw and two miles north of the Calgary-Banff highway.
>
> Derivation of Name: From the village of Exshaw.
>
> Character: The Exshaw formation is composed of black, fissile, noncalcareous to slightly calcareous shale, containing small amounts of pyrite which, on weathering, may produce a rusty, blotchy stain on the outcrop. The contact with the overlying Banff shales may be sharp or gradational. In one place, where the upper contact is sharp, the writer found a few pea-sized, rounded, black chert nodules in the top of the Exshaw.
>
> Thickness: Type section 33 feet, average about 20 feet.
>
> Upper Contact: Usually conformable and often gradational. There may be a slight disconformity in some places.
>
> Overlain by: Banff formation.
>
> Lower Contact: Disconformable. (Fox, 1953, p.194)
>
> Underlain by: Palliser formation. (Fox, 1953, p.194)
>
> Fauna: Very small, containing Spirifer louisianensis, Aganides, etc.

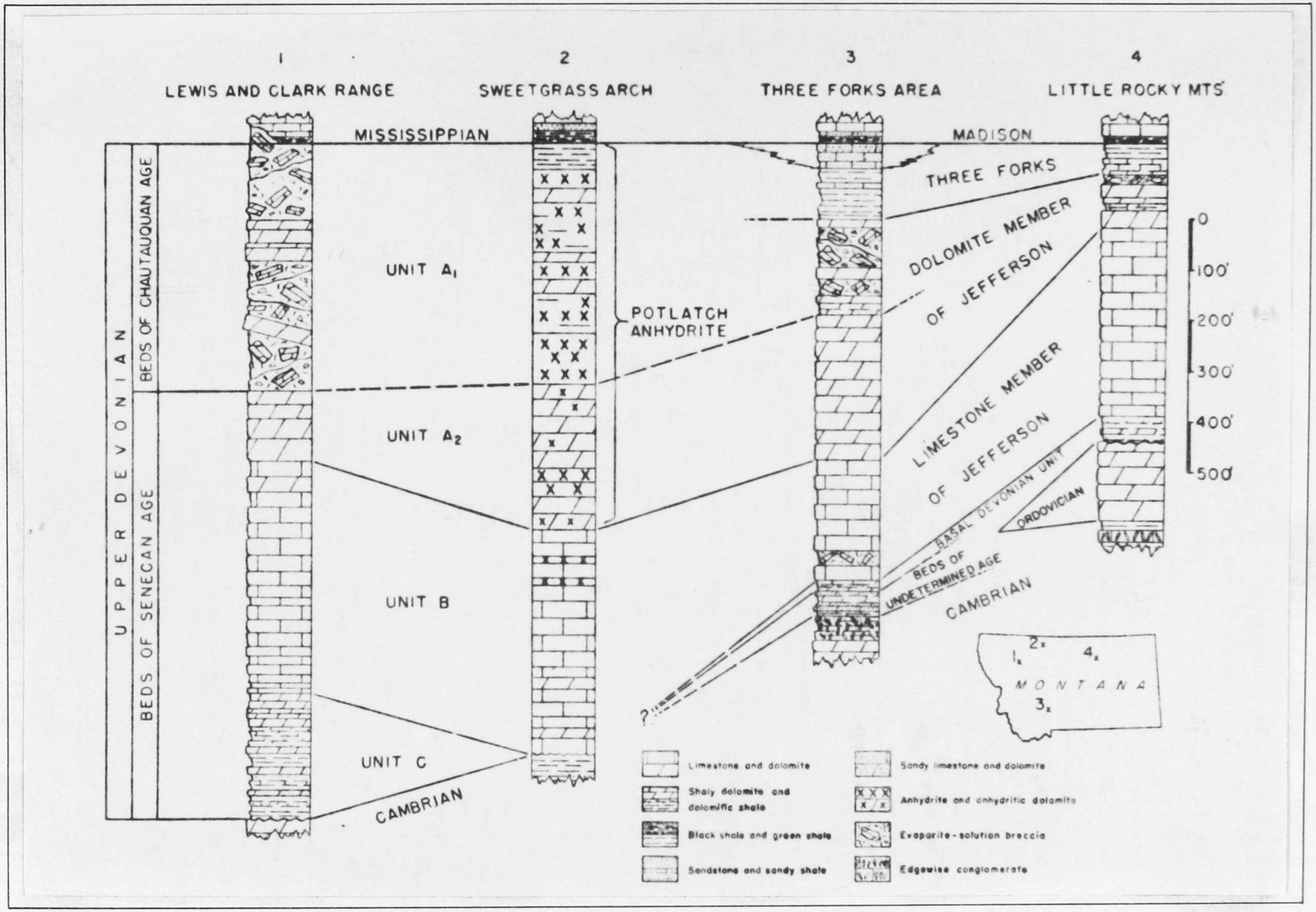

Figure 26. Generalized stratigraphic columns illustrating Devonian correlations in central and northwestern Montana. (Sloss and Laird, 1947, p.1414)

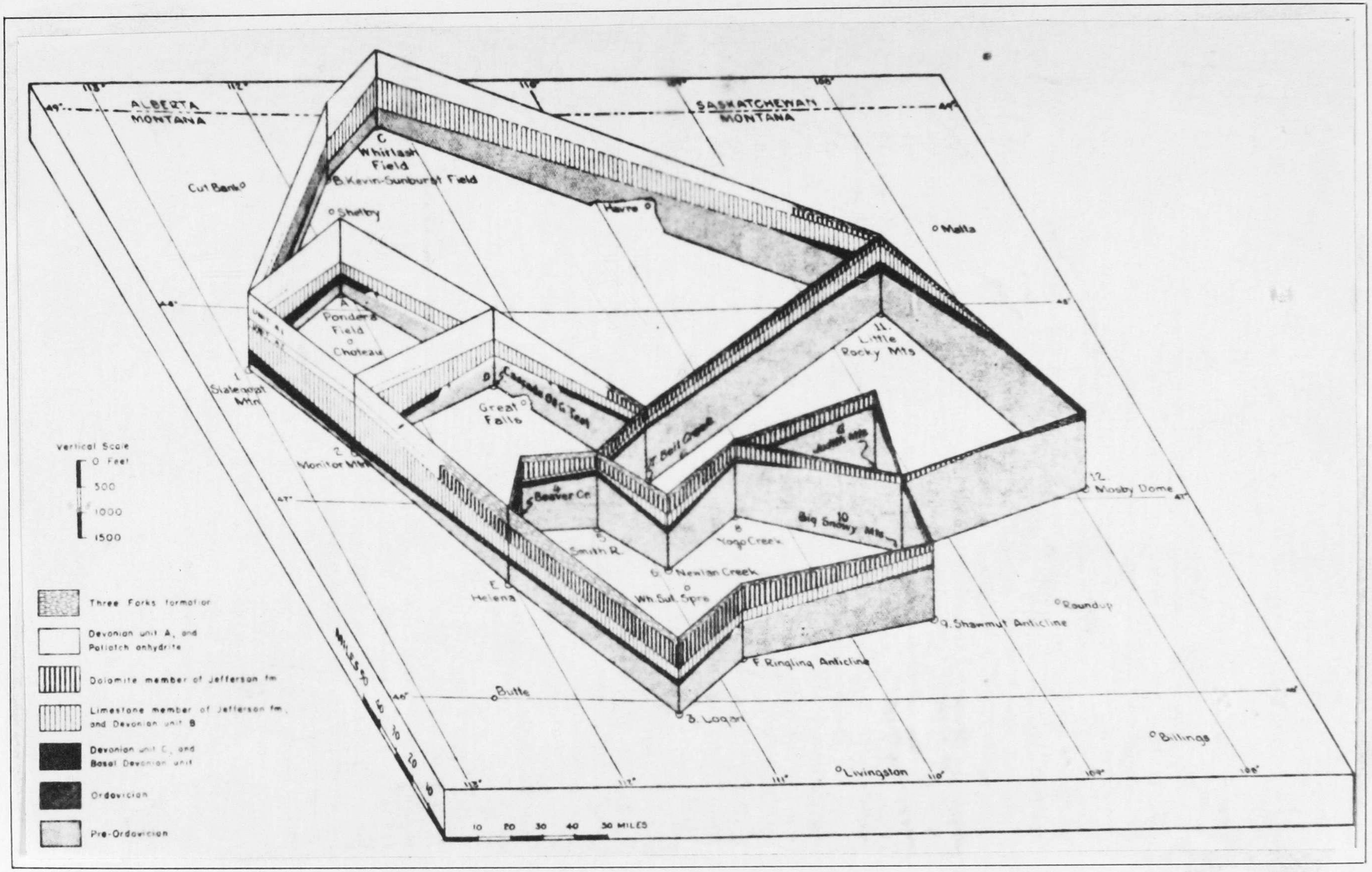

Figure 27. Devonian strata in central and northwestern Montana. (Sloss and Laird, 1947, p. 1408)

Correlation: The Exshaw is recognized throughout southern Alberta, except where it has been removed by post-Palaeozoic erosion.

Comments: The Exshaw shale was originally included with the Banff formation.

Age and Correlation of the Exshaw Formation

Warren (1937, pp.454-457) separated the "black shales" at the base of the Banff formation from the overlying "argillaceous limestone unit." He gave formational status to the black shale unit, naming it the Exshaw formation largely on the basis of mega-fossils, which he believed indicated an Upper Devonian age for the black shale unit (see discussion under Fossil Zones of the Upper Devonian). However, the formation continues to be generally accepted as representing the introduction of the Missi-ssippian cycle of sedimentation.

Throughout the plains area of southern Alberta and Montana, a black shale persists in the same stratigraphic position as the Exshaw shale of the mountain front. In Montana, this black shale forms the basal unit of the Paine member of the Lodgepole formation (Sloss and Hamblin, 1942, p.317). The disconformity which exists between the Exshaw and Palliser formations in the front range does not exist in the plains, where Sloss and Hamblin (1942, p.309) and Sloss (1950, p.439) considered the contact between the Exshaw equivalent and the Three Forks formation (Palliser equivalent) to be conformable. Therefore, while the disconformity found in the front range indicates tectonic movements in the geosynclinal area in late Devonian or very early Mississippian time, there is no indication of a major emergence of the entire area at that time. The Kaskaskia sequence continued and the Mississippian cycle of sedimentation was initiated.

Warren (1949) also mentioned the presence of conodonts in the Exshaw shale (see discussion under <u>Fossil Zones of the Upper Devonian</u>). However, no identification of these conodonts was published. Other workers have also collected conodonts from the Exshaw and equivalent shales, among whom were Cooper and Sloss (1943, p.168), who summarized their work in the following statement:

> Fifty-four species of conodonts are recognized in a black shale member (Exshaw equivalent) which occurs at the base of the Lower Mississippian Madison group over a wide area extending from Alberta and western North Dakota to southwestern Montana. On the basis of the conodont evidence this horizon is correlated within the Kinderhook of the Mississippi Valley and adjacent areas.

They (Cooper and Sloss, 1943, p.169) believed that "the mega-fauna of the Exshaw is a relic of the Upper Devonian preserved through isolation in the black shale environment which excluded the immigration of new forms."

The age of the Exshaw formation seems, therefore, to remain in doubt. Our knowledge of the subject may be summarized in the following three points:

1) The mega-fauna indicates an Upper Devonian age.

2) The micro-fauna indicates a Mississippian age.

3) The stratigraphic relationships imply the commencement of a new cycle of sedimentation.

Meanwhile, for the purposes of lithogenetic and cartogenetic study (Sloss and Laird, 1947, p.1420), the Exshaw formation and equivalent units must be considered as the basal member of the Mississippian sequence as evidenced by the stratigraphic relationships of the formation.

Origin of the Exshaw Shale

It is difficult to envision the environmental conditions which would result in the deposition of such a widespread, relatively thin, organic shale as the Exshaw, without postulating accentuated tectonic influence. However, there is no evidence of such tectonic activity during the deposition of this formation. Sloss and Hamblin (1942, p.324) offered a possible solution by hypothesizing a widespread shallow sea segregated into many "more or less isolated basins." Periodic flooding of this multi-basinal province by clastic-laden seas from the west, plus erosion of the weakly positive inter-basinal areas, provided the clastic material for the Exshaw shale. This hypothetical environment offers one possible explanation for the sometimes conformable—sometimes disconformable—contact between the Exshaw and the underlying strata.

<u>Fossil Zones of the Upper Devonian</u>

The Upper Devonian section of western Canada was divided into five fossil zones by Warren (1949) and into fourteen fossil zones by Warren and Stelck (1950). While the latter is a more detailed publication and a valuable reference, it is easier to grasp an understanding of the fossil zones of the Upper Devonian from the earlier paper. Therefore, this thesis will make use of the first paper (Warren, 1949) in which the five fossil zones, as shown in Figure 22, are related (Warren, 1949, p.566) to sections 1 and 7 of Figure 22.

The <u>Tornoceras</u> zone, the uppermost of the five fossil zones, is "restricted to the Exshaw shale" (Warren, 1949, p.568) and to its stratigraphic equivalents. This zone is characterized by "a considerable abundance of <u>Tornoceras</u> cf. <u>T</u>. <u>uniangulare</u> (Conrad) and some poorly preserved pelecypods." Warren (1949), p.568) noted the presence of conodonts in this zone. However, he stated no age determination for these conodonts. As American geologists have identified the conodont fauna in the Exshaw equivalent as Mississippian in age, and as the Exshaw shale is generally conceded to belong to the Mississippian cycle of sedimentation, it would appear imperative that an accurate age be determined for the conodont fauna of the Exshaw shale. It apparently remains for the age identification of these conodonts to decide whether the <u>Tornoceras</u> fauna, as identified by Warren (1949), is as diagnostic of an Upper Devonian age for the Exshaw shale, as has hitherto been assumed.

The *Cyrtospirifer* zone underlies the *Tornoceras* zone and generally includes "the upper 600-800 feet" (Warren, 1949, p.568) of the Palliser formation. The *Cyrtospirifer* zone is characterized by the following fauna:

Productella coloradoensis Kindle
Camarotoechia horsfordi Hall
Camarotoechia nordeggi Kindle
Leiorhynchus, several species
Cyrtospirifer cf. *C. whitneyi*
Athyris angelica Hall

Warren (1949, p.568) noted that the *Cyrtospirifer* zone may contain two sub-zones as indicated below:

Cyrtospirifer Zone	Upper sub-zone	*Camarotoechia nordeggi* *Athyris angelica*
	Lower sub-zone	*Leiorhynchids*

Dolomitization destroyed many of the fossils in the *Cyrtospirifer* zone.

A coral zone, which has often been badly damaged by dolomitization, underlies the *Cyrtospirifer* zone. Although corals are not abundant, "*Diphyphylum*" *colemanse* Warren, *Cladopora* sp., and *Phillipsastrea* characterize the coral zone. The coral zone is noted (Warren, 1949, p.569) as probably overlapping the underlying *Spirifer jasperensis* zone and the overlying *Cyrtospirifer* zone.

Spirifer jasperensis Warren is the marker for the *Spirifer jasperensis* zone. This zone, which occupies most of the Upper Devonian strata below the coral zone, contains an abundance of the following fauna:

Cladopora sp.
"*Diphyphyllum*" *colemanse* Warren
Lingula spatulata Vanuxem
Chonetes deflecta Hall
Productella hallana Walcott
Schizophoria striatula Schlotheim
Leiorhynchus athabaskense Kindle
Leiorhynchus albertense Warren
Pugnax sp.
Spirifer raymondi Haynes
Martinia nevadensis Walcott
Atrypa, many species
Cyrtina rockymontana Warren
Bactrites aciculum Hall
Goniatites of the *Manticoceras* type
Buchiola retrostriata von Buch
Entomis serratostriata Sandberger

The *Spirifer jasperensis* zone in the "Blackface Mountain shale" and equivalent strata may be divided into two sub-zones as indicated below:

Spirifer jasperensis zone

- Upper sub-zone
  - *Atrypa*
  - *Schizophoria*
  - *Leiorhynchus albertensis*
  - *Cyrtina rockymontana*
  - *Productella hallana*
  - *Chonetes deflecta*
  - *Spirifer jasperensis*
  - *Spirifer raymondi* Haynes cf. *S. mucronatus* Conrad
- Lower sub-zone
  - *Atrypa* (maximum development of the genus)
  - *Schizophoria*

The lower part of the Spirifer jasperensis zone below the "Blackface Mountain shale" is dominated by the following fauna:

Spirifer jasperensis
Leiorhynchus
Productella hallana
Martinia, many species
Martinia nevadensis Walcott
Buchiola retrostriata
Entomis serratostriata
Atrypa (present but not abundant)

The Spirifer jasperensis zone, therefore, occupies the greatest thickness and most fossiliferous part of the Upper Devonian sediments of any of the described fossil zones.

The lowest fossil zone of the Upper Devonian strata is the Stromatoporoid zone which occurs in the Flume and equivalent formations. The Stromatoporoids occur "in thick beds or reef" (Warren, 1949, p.570) usually dolomitized so that specific identification is difficult.

The five Upper Devonian fossil zones described above are chiefly useful as guides or aids in other phases of stratigraphic work rather than as markers of specific limited horizons. For more detailed paleontological studies, Warren and Stelck's (1950) more limited faunal zones may be of greater value.

Two additional papers have been published very recently discussing stratigraphic paleontological relationships in the Upper Devonian strata of western Canada. These papers are not dealt with in this thesis other than to state briefly new information particularly affecting the thesis area. One paper, by Fox (1954), is chiefly concerned with the clarification of the Upper Devonian nomenclature north of Crowsnest Pass. Paleontological evidence is presented which indicates that the _Tornoceras_ zone and at least part of the _Cyrtospirifer_ zone (Warren, 1949) may be of Mississippian age. Fox (1954, p.130) suggests that the Devonian-Mississippian boundary may be within the Palliser formation "possibly as far down as the base of the Costigan member."

The other paper, by McLaren (1954), is chiefly concerned with the zonation of the Upper Devonian sediments by means of rhynchonellids. The relationship of the stratigraphic units to the rhynchonellid zones and the principal fossils of each zone is presented in Figure 28. McLaren (1954, pp.167-168) also considers the problem of the age of the Exshaw formation and concludes that while the original faunal assemblage of the _Tornoceras_ zone as presented by Warren (1937) indicated an Upper Devonian age, this faunal evidence was insufficient to make this age determination conclusive. McLaren (1954, p.168) does not offer an alternative age for the Exshaw formation.

Mississippian Stratigraphy of the Area

The Mississippian sediments seem to represent a major sedimentary cycle within the Kaskaskia sequence. This cycle commenced with the deposition of the Exshaw shale and continued until the close of the sequence when, throughout the area, the Mississippian strata suffered erosion. In addition to this, the

FORMATIONS		RHYNCHONELLID ZONES	IMPORTANT FOSSILS
EXSHAW			
PALLISER	Costigan Member	*Nudirostra utahensis ventricosa*	*Productella* cf *plicata*, *Cyrtospirifer* cf *kindlei*, *Strophopleura notabilis*,
PALLISER	Morro Member	*Nudirostra gibbosa seversoni*	*Productella lata*, *Camarotoechia banffensis*, *C nordeggi*, *Cyrtospirifer* cf *animasensis*, *Tenticospirifer* cf *conoideus*, *Cyrtiopsis* sp
ALEXO		*Nudirostra gibbosa walcotti*	*Cyrtospirifer* sp (with low angle apsacline interarea), *Athyris* cf *angelicoides*, *Leptodesma* sp
MOUNT HAWK		*Nudirostra albertensis*	*Hypothyridina* cf *emmonsi*, *Pugnoides calvini*, *Grunewaldtia*, *Cyrtospirifer* cf *whitneyi* *Spirifer strigosus*, *Tenticospirifer* cf *cyrtiniformis* *Thomasaria rockymontana*
PERDRIX		*Nudirostra insculpta*	*Calvinaria? inelegans*, "*Martiniopsis*" cf *nevadensis*
FLUME	Upper Member	*Nudirostra athabascensis*	*Atrypa missouriensis* Kindle 1909 (non Miller), *Eleutherokomma* cf *hamiltoni*, *E* cf *leducensis*, *Ambothyris* cf *sublineata*, "*Spirifer*" *jasperensis*, *Athyris parvula*, *Bactrites* spp
FLUME	Lower Member	*Pugnoides kakwaensis*	*Atrypa* cf *albertensis*, *A* cf *independensis* *Spirifer* cf *engelmanni*, *Cyrtina billingsi* *Athyris* small sp
Ghost River, Ordovician or Cambrian			

GSC

Figure 28. Rhynchonellid zones of Upper Devonian in the Canadian Rocky Mountains. (McLaren, 1954, p.160)

erosional stage of the Absaroka sequence, which entirely removed Absarokan sediment from all but the extreme western and southern parts of the area, further eroded the Kaskaskia sediments. The result of the second period of erosion was a major unconformity between Kaskaskian and Absarokan sediments and the overlying Jurassic.

The Mississippian formations of the Kaskaskia sequence have been described as they occur in southwestern Alberta. The correlation of these formations in southwestern Alberta with their correlatives in Montana is shown in Figure 30 (see under <u>Correlation of the Banff and Rundle Formations</u> following).

Banff Formation

The Banff formation as it occurs in the Crowsnest Pass area has been described (Beales, 1950, Table 1) as follows:

> <u>1,200± feet</u>
>
> Black shale and argillaceous limestone, with chert.
> The upper 1,000± feet consist of calcareous shale
> and cherty argillaceous limestone.
> The lower 150 to 200 feet are thin-bedded black shales.

However, this description includes the Exshaw formation which occupies the lower 44 feet (deWit, 1953, p.106) of the basal shale member. A more complete description of the Banff formation was presented by Douglas (1953, p.78) in which he described the formation as it occurs in the Mount Head area of the upper Highwood

River valley, a few miles north of the area along the front range of the Rocky Mountains.

Banff formation	Thickness Feet
Upper part	
Coarsely crystalline limestone with argillaceous matrix, interbedded with finely crystalline argillaceous limestone and 30 feet of arenaceous granular dolomite in middle	150
Middle part	
Finely crystalline, argillaceous limestone and dolomitic limestone, sparsely cherty, with rare, thin, medium-crystalline limestone.	600
Lower part	
Finely laminated shale with fine-grained, arenaceous, granular dolomites at top and base	180
Underlying beds---Exshaw formation	

The Banff formation is essentially a "transitional" formation (Fox, 1953, p.197) -- from Exshaw clastics to lower Banff clastics and carbonates -- to upper Banff carbonates and minor clastics -- to Rundle non-clastic sediments. The Exshaw-Banff contact is "usually conformable and often gradational" with a slight disconformity in some areas, while the Banff-Rundle contact is usually conformable but with slight disconformity observed in the Moose Mountain area (Fox, 1953, p.196). Since the Banff-Rundle contact is gradational, it was necessary to define the contact arbitrarily. This was done by Warren (1927, p.27) who placed it at "the bottom of the lowest bed of coarse-grained limestone." This basal Rundle strata was described by Douglas (1950, p.13) as "coarsely crystalline, light grey weathering limestone."

Rundle Formation

A brief description of this formation as it occurs in the Crowsnest Pass is given in the following excerpt by Beales (1950, Chart 1):

> 1,600 to 5,300 feet
>
> Grey limestone with chert, fossiliferous in places; uniform sequence of thick, massive beds of light grey, coarse-grained limestone, with minor fine-grained dark grey beds; the uppermost 300± feet consist of thin-bedded, buff weathering, fine-grained beds. The formation thins to the east. There is no apparent break with the underlying Banff formation.

North of the Crowsnest Pass in the Gap area of the Livingstone Range, Douglas (1950, pp.12-17) subdivided the Rundle formation into four members on the basis of its lithology. These members he described as follows (Douglas, 1950, p.13):

	Thickness Feet
Overlying beds—Rocky Mountain formation?	
Contact disconformable?	
Rundle formation	
Member D:	
Fine-grained, blocky, grey limestones; fine-grained, buff dolomite; chert and limestone breccias; crossbedded, arenaceous dolomite; thin, porous limestone; green shale	250
(Member D now included in Rocky Mountain formation)	

Member C:

Massive to thin-bedded, fine-grained, black limestone, very hard, dense, and brittle, breaking with a conchoidal fracture; some thin, black, calcareous shale and buff, coarsely crystalline limestone 200

(Member C now uppermost member of Rundle formation)

Member B:

Thin-bedded to platy, fine-grained, argillaceous dolomite, weathering buff to dark brown; massive, fine-grained, cherty, grey limestone and dolomite 480

Member A:

Massively bedded, grey dolomite, grey weathering, with chert in stringers and blebs; massively bedded, buff, coarsely crystalline, grey limestone, light grey weathering; with basal bed 80 feet thick 790

Total thickness of Rundle formation 1,720

Contact conformable

Underlying beds—Banff formation

Recently, Douglas (1953, p.68) tentatively divided the Rundle into two formations raising the Rundle formation to "group status" (see Figure 29). The lower formation he named the Livingstone formation, which is equivalent to Member A of the Gap section. The upper formation he named the Mount Head formation, which is equivalent to Members B and C of the Gap section. Member D of the Gap section is now considered to be the basal member of the Rocky Mountain formation. Douglas (1953, p.68) has further divided the Rundle Group of the Mount Head area so that the Livingstone formation has been subdivided into two members, while the Mount Head formation has been subdivided into six members.

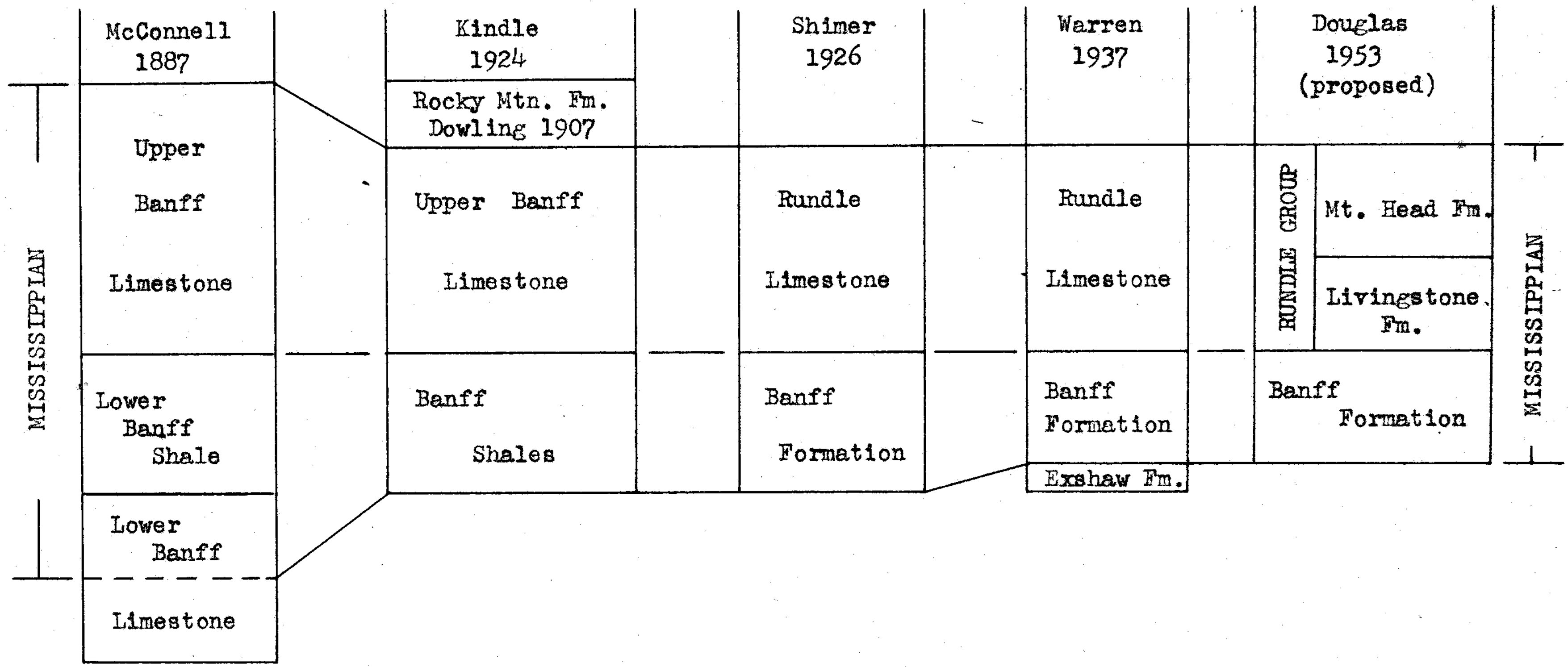

Figure 29. Historical Development of Mississippian Nomenclature in Western Canada.

In 1948, Laudon (1948) published a paper stating his paleontological and stratigraphic evidence for an erosional break within the Rundle and equivalent formations which could be correlated from the central Canadian Rocky Mountains to the upper Mississippi valley and New Mexico (Laudon, 1948, p.288). He described this unconformity as it occurs in the Banff area in the following excerpt (Laudon, 1948, p.296):

> The Meramec portion of the Rundle formation rests with marked unconformity on limestones of late Kinderhook age in the Banff area. The contact is everywhere overlain by basal shaly zone that often carries phosphatic concreations and fish teeth. The change in lithology is abrupt, although both are limestones. Typical St. Louis lithology appears immediately above this contact. Sufficient work was not completed in the area to determine the amount of relief of the Kinderhook surface.

Canadian geologists have neither refuted nor substantiated this work done by Laudon. However, when Douglas (1953, p.68) subdivided his Rundle group, he placed the contact between the Mount Head and Livingstone formations below the arenaceous, often shaly, dolomitic or limy Wileman Member of the Mount Head formation, and above the upper coarsely crystalline limestone Turner Valley member of the Livingstone formation. Therefore, Laudon (1948) and Douglas (1953) seem to agree that a two-fold formational division should be placed at the base of the intermediate shale in the Rundle formation. Douglas (1953), however, made no mention of the presence of an unconformity at this horizon nor at any horizon within his Rundle group.

Correlation of the Banff and Rundle Formations

The combined Banff and Rundle formations hold the same stratigraphic position as the Madison group of the southern Alberta plains and Montana, as illustrated in Figure 23 and Figure 30. On stratigraphic and lithological evidence (Sloss and Hamblin, 1942), the Rundle formation has been correlated with the Mission Canyon formation, and the Banff formation has been correlated with the Lodgepole formation, minus the basal shale which is equivalent to the Exshaw formation. However, Brown (1952, pp.75-80) showed that certain faunal groups found in the Rundle formation of the Canadian Rocky Mountains also occur in the Upper part of the Big Snowy group of eastern Montana which belongs to the Absaroka sequence. He has not ascertained whether these faunal assemblages are accurate index faunas. However, he prepared a chart (Figure 31) showing possible correlation of the Banff and Rundle, based on these faunas. It appears, therefore, that the Rundle formation is an equivalent stratigraphic unit to the Mission Canyon formation but represents a prolonged interval of sedimentation. This theory is substantiated by the fact that while the formations are lithologically similar, and indicate similar environments, the Rundle section of the front range has an average thickness of 3,000 feet as compared with a probable average thickness in the Mission Canyon formation of approximately 700 feet (pre Absarokan erosion) (Sloss and Hamblin, 1942, pp.319-324). Sloss (1950, p.442) observed that a "pronounced disconformity" separated Kaskaskian and Absarokan sediments throughout the area except in the geosyncline and near the

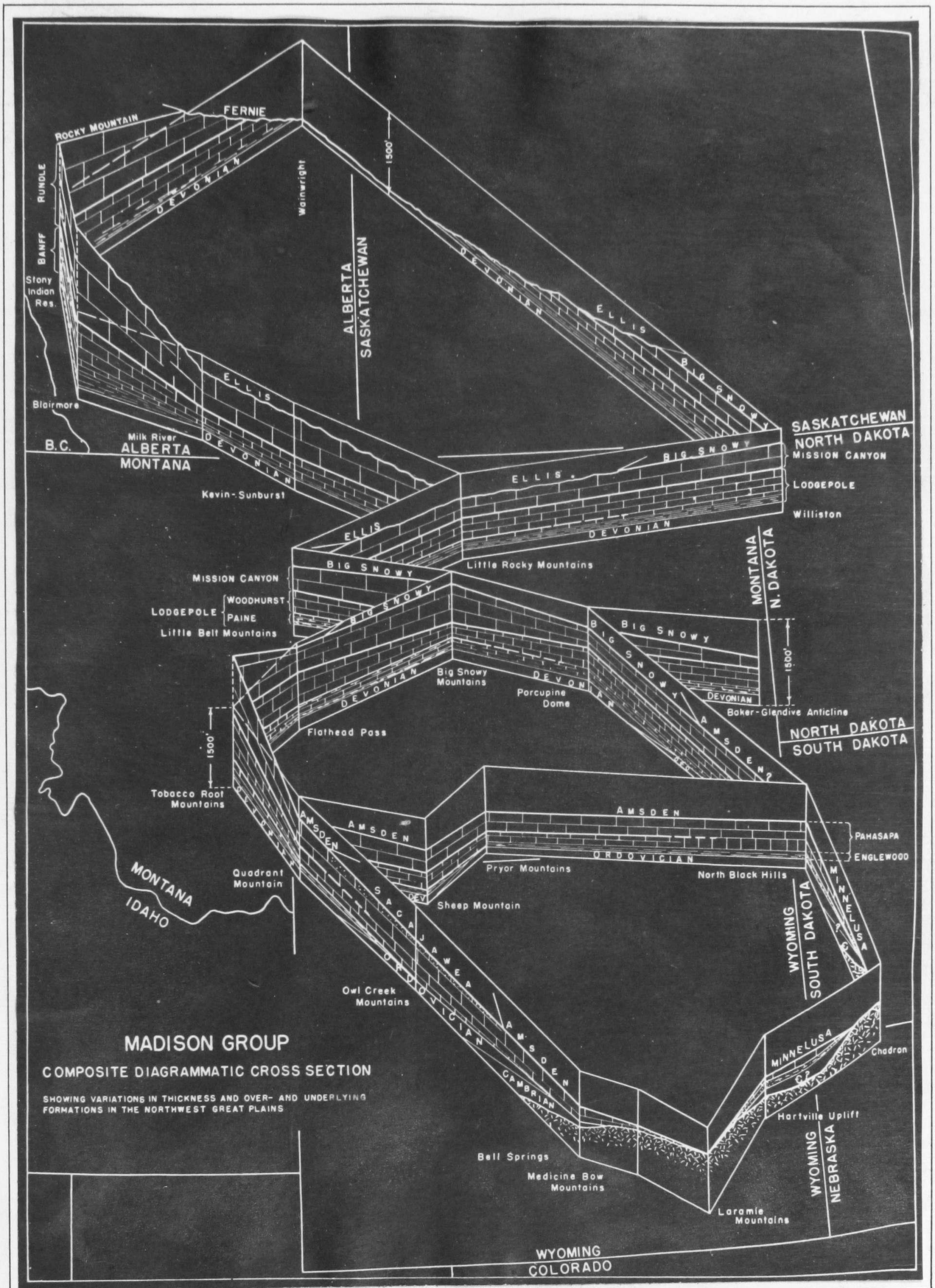

Figure 30. Madison group. Composite diagrammatic cross section. (Sloss and Hamblin, 1942, p.310)

MOUNT GREENOCK AREA (PRESENT STUDY)		OUTER ATHABASCA VALLEY	BOW VALLEY: BANFF (Warren, 1927)		BOW VALLEY: LAKE MINNEWANKA (Shimer, 1926)		BOW VALLEY: MOOSE MOUNTAIN (Beach, 1943)		CROWSNEST VALLEY (Warren, 1927, 1933)		MONTANA (Scott, 1935, Sloss, Hamblin, 1942, Perry, Sloss, 1943; Laird, 1947)	N.W. WYOMING (Branson, 1937)	SCALE OF REFERENCE
				Rocky Mountain formation	Indefinite faunule	Rocky Mountain formation				Rocky Mountain formation	Quadrant	Quadrant	Permian?
				Rocky Mountain formation	Indefinite faunule	Rocky Mountain formation				Rocky Mountain formation	Quadrant	Quadrant	Penn?
S. n. sp. A faunule	Moosehorn Greenock formation	Greenock formation	S. cf. pelloensis faunule	Rundle formation	S. cf. pelloensis faunule	Rundle formation	S. cf. pelloensis faunule	Rundle formation	S. cf. pelloensis faunule	Rundle formation	Amsden formation	Amsden formation	Chester
S. n. sp. A faunule	Moosehorn Greenock formation	Greenock formation	S. cf. pelloensis faunule	Rundle formation	S. cf. pelloensis faunule	Rundle formation	S. cf. pelloensis faunule	Rundle formation	S. cf. pelloensis faunule	Rundle formation	Big Snowy group	Sacajawea formation	Meramec
S. minnewankensis faunule	Rundle formation	Rundle formation	S. rundlensis zone; Burlington-like faunule	Rundle formation; Banff Upper	S. minnewankensis faunule	Rundle formation	S. rundlensis zone; Burlington like faunule	Rundle formation; Banff Upper	S. rundlensis zone	Rundle formation; Banff formation	Madison Mission Canyon formation	Madison group	Osage
S. albertensis faunule; S. cascadensis faunule; G.S.C.	Banff formation group	Banff formation	Kinderhook fauna	Middle; Lower formation	Kinderhook fauna	Banff formation	Kinderhook fauna	Middle; Lower formation		Banff formation	Lodgepole formation group	Madison group	Kinderhook

Figure 31. Table showing tentative correlation of Carboniferous strata in the northern Rocky Mountains, based on faunal studies. (Brown, 1952, p.76)

axis of the Williston basin. Since the Williston basin was a locus of deposition of Big Snowy sediments, it is conceivable that some faunas present in the Mission Canyon sediments persisted through the period of clastic deposition of the Kibbey formation and on into late Mississippian time. Therefore, it is possible for the post-Charles sediments of the Big Snowy group, which belong to the Absaroka sequence of sedimentation, to carry certain fauna found in the Rundle sediments of the Kaskaskia sequence.

It must be remembered that geologists working in Montana consider the basal shale of the Paine member of the Lodgepole formation as Mississippian in age. While recognizing that the equivalent strata, the Exshaw formation, probably belongs to the Mississippian cycle of sedimentation, Canadian geologists have generally regarded the Exshaw as Devonian for reasons previously presented in the discussion of the Exshaw formation.

In the plains area of southern Alberta and Montana, the Mississippian strata belonging to the Kaskaskia sequence are assigned to the Madison group (Figure 23). The present distribution and thickness of this group are illustrated in Figure 32. The area has suffered two major periods of tectonic unrest since Kaskaskian sedimentation: late Kaskaskian and late Absarokan; and three periods of erosion: Kaskaskian, Absarokan and current, since the deposition of the Madison sediments. Therefore, while the isopachs in Figure 32 generally delineate the tectonic elements

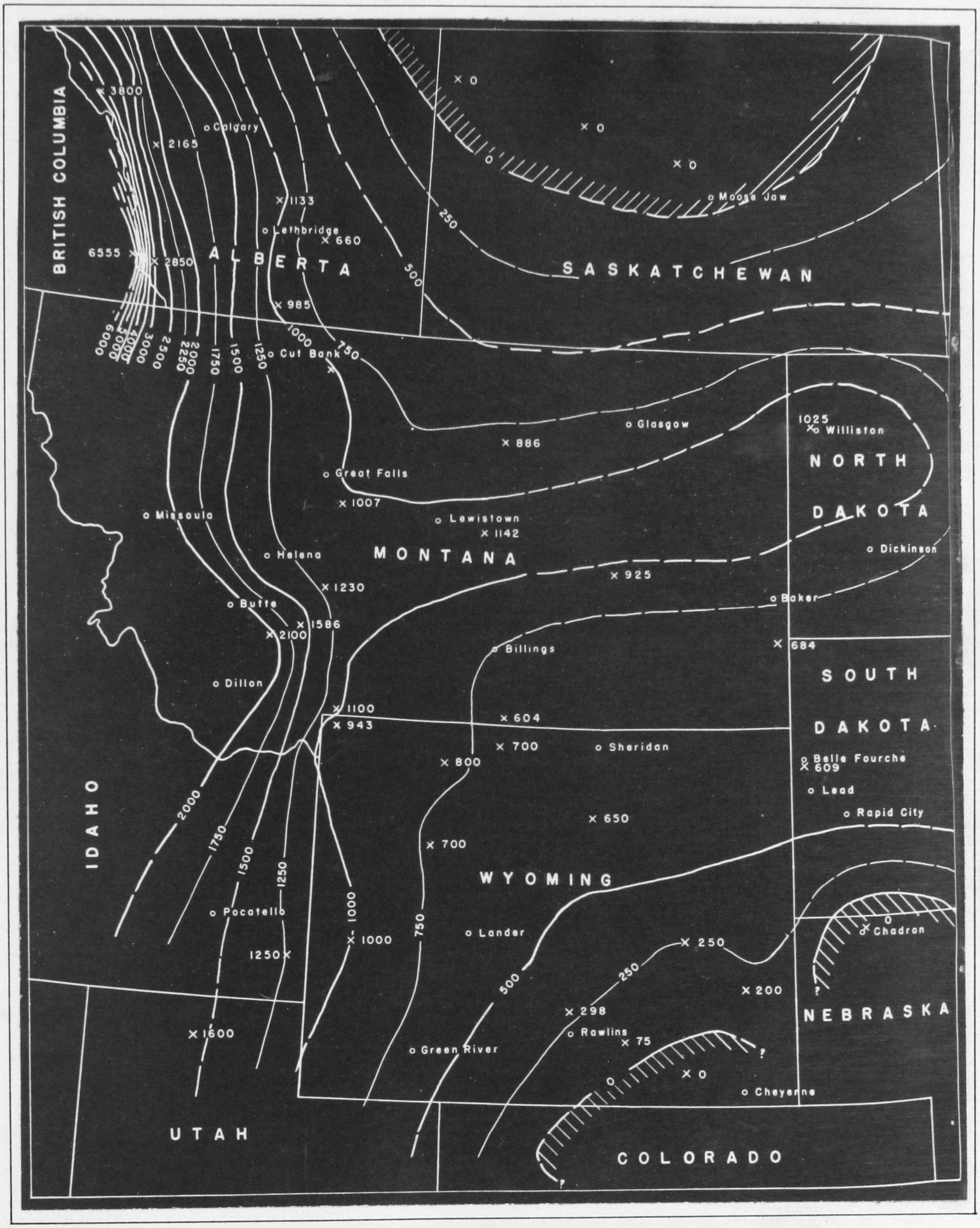

Figure 32. Thickness of Madison group subsequent to late Paleozoic and early Mesozoic erosion. (Sloss and Hamblin, 1942, p.306)

of the area as outlined in Chapter III, this map in itself does not indicate that these elements were differentiated during Madison deposition, but merely that they were differentiated during and/or since Madison deposition.

Yakinikak Formation, Montana

Willis (1902, pp.316, 324) applied the name "Yakinikak" to a limestone formation outcropping in the MacDonald Range west of the north fork of the Flathead River in the vicinity of the 49° parallel. Willis observed that the Yakinikak formation rests conformably on a quartzite formation. Sloss (1945, p.309) and Crabb (1951, pp.31-32) believed that the Yakinikak formation actually represented part of the upper Rundle formation, the formation of which the MacDonald Range is largely composed (Crabb, 1951, p.31) which, with the Rocky Mountain ("quartzite") formation, was overturned and thrusted from the west over Beltian sediments. The term "Yakinikak formation" is now unnecessary and should be regarded as obsolete.

Kaskaskian Sediments in the Rocky Mountain Trench

In the Cranbrook, British Columbia, area, Schofield (1915, pp.53-56) described two formational units to which he assigned Devonian-Carboniferous ages. The lower unit consists of 150 (+) feet of "massive to thin-bedded siliceous limestones" with a "brecciated and recemented sandy limestone" basal member. This formational unit was assigned to a Devonian Jefferson (?) age and was referred to as the Jefferson (?) formation on the basis of the following fauna, which were collected from it and identified by Dr. Kindle (Schofield, 1915, p.54):

Atrypa reticularis
Spirifer piononensis
Stropheodonta sp. undet.
Schizophoria cf. *striatula*
Orthothetes chemungensis var. *arctostriatus*

The basal contact of the Jefferson (?) is obscured, but is apparently disconformable on the Purcell series.

The upper formational unit consists of approximately 1,000 feet of "grey, crystalline limestone" containing the following fauna identified by Dr. P.E. Raymond (Schofield, 1915, p.56), as indicating a "Mississippian age (Lower Carboniferous)":

Camarophoria explanata (McChesney)
Camarotoechia cf. *C. metallica* (White)
Composita madisonensis (Girty)
Cleiothyrdina crassicardinalis (White)
Spirifer cf. *S. centronatus* (Winchell)
Productella cooperensis (Swallow)

Schofield (1915, p.55) named this upper unit the "Wardner" formation. The contact between the Jefferson (?) formation and the Wardner formation is obscured, but Schofield (1915, p.55) believed this contact to be conformable. The upper surface of the Wardner formation is eroded and covered by Pleistocene glacial deposits.

The restricted distribution of the Jefferson (?) and Wardner formations makes it difficult to fit these sediments into the lithofacies and isopach studies illustrated in this chapter. If the present thickness of these sediments approaches the uneroded thickness of Kaskaskian sediments in this area, it would imply a tremendous thinning in the area generally believed to be within the geosynclinal unit. Detailed studies of these Devonian-Carboniferous strata in the Rocky Mountains, made in the light of recent detailed studies of Kaskaskian sediments in the Rocky Mountains and plains area, may provide considerable evidence regarding the tectonic events of the Kaskaskia sequence.

<u>Charles Formation</u>

During stage three of the Kaskaskia sequence, the Williston basin exhibited a strong negative tendency, thus forming a locus of accumulation for the Charles formation. The areal distribution of the Charles formation, which was limited to the Williston basin, and its stratigraphic relationship to overlying and underlying strata is depicted in Figure 30 and Figure 33. The Charles formation is the basal member of the Big Snowy group, the remainder of which will be discussed in the following chapter.

The Charles formation is chiefly an evaporitic unit (Perry and Sloss, 1943, pp.1299-1301) "characterized by light-colored earthy limestones and dolomites . . .interbedded with evaporites (chiefly anhydrite) in beds approaching 100 feet in

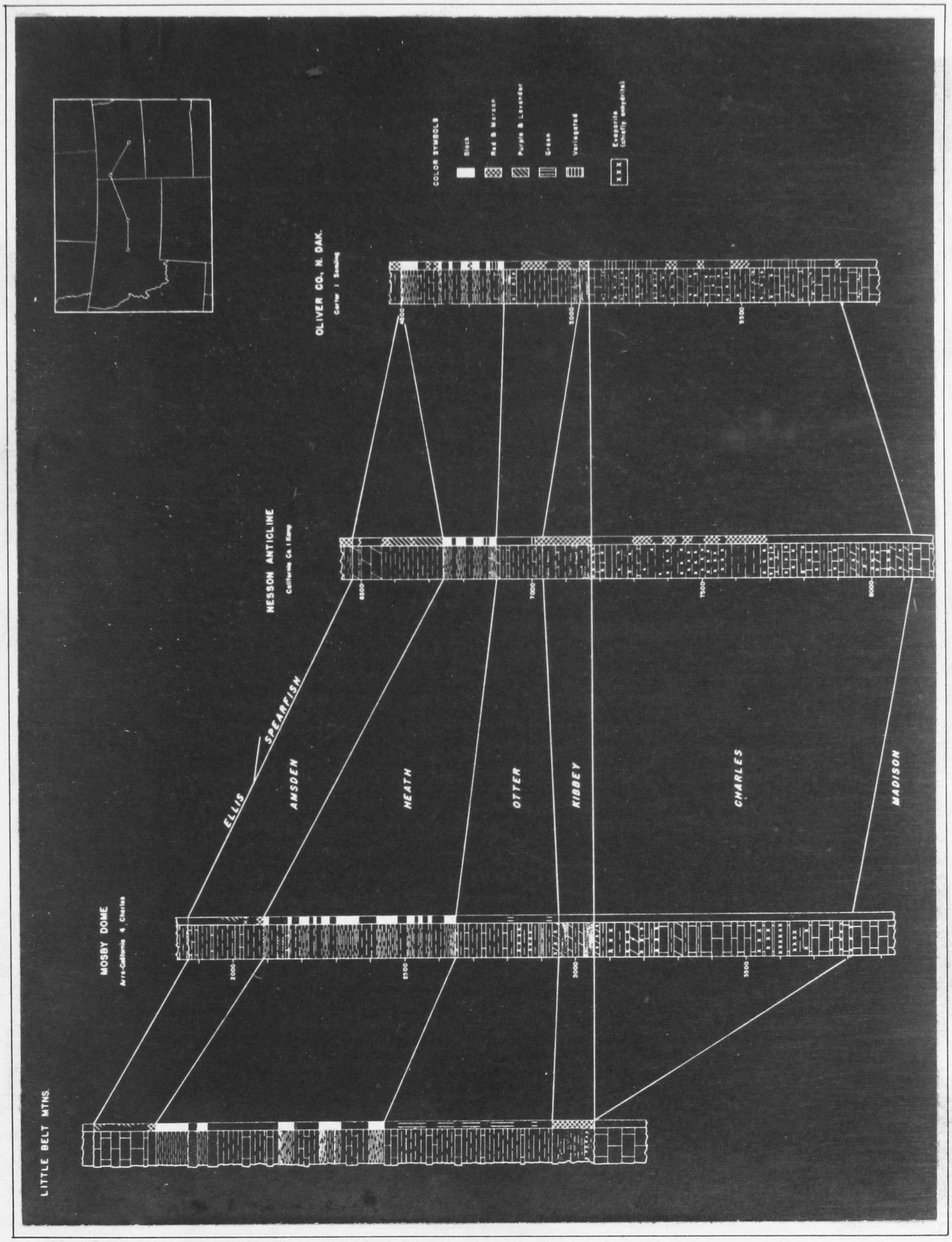

Figure 33. Eastward Development of the Big Snowy Group.
(Perry and Sloss, 1943, p.1294)

thickness." Salt and vari-coloured shales are common while the top few beds are often sandy. The Charles formation is inferred (Perry and Sloss, 1943, p.1301) to be in conformable, probably gradational, contact with the underlying Mission Canyon formation. The contact of the Charles formation and the overlying Kibbey formation has been considered gradational (Perry and Sloss, 1943, p.1301). Sloss (1950, p.444), however, stated that a disconformity exists between these formations except in the axial area of the Williston basin.

The Charles formation was assigned to the Big Snowy group by Seager (1942, p.864), who named and defined the unit. However, if the regional interpretation as presented in this thesis is correct, and the Kibbey sandstone represents the commencement of sedimentation of a new regional tectonic and sedimentary sequence, then the Big Snowy group contains sediments belonging partially to the Kaskaskia sequence and partially to the Absaroka sequence. The advisability of retaining such a group classification would appear to be questionable. Perhaps, once the regional data is fully established and proven, it would be more desirable to remove the Charles formation from the Big Snowy group in order to satisfy the regional conditions, than to continue to regard the formation as a member of the group on the basis of local evidence.

Tectonism and Its Effect Upon Sedimentation During the Kaskaskia Sequence

The Kaskaskia sequence exhibited the four stages (Sloss

1950, pp.439, 451) which typify the Paleozoic sequences. It varied from the other sequences, however, in the interrelationship of the various stages. Stage one, in which the various tectonic members are undifferentiated, existed until late Upper Devonian time. Stage two, the differentiation of the various tectonic elements, was a gradual stage continuing until late Mission Canyon deposition. Stage three, the culmination of the differentiated tectonic elements, was relatively more sudden, resulting in the cessation of deposition in the Sweetgrass arch area, and continued deposition in the geosyncline and the Williston basin: the upper part of the Rundle formation being deposited in the geosyncline, and the Charles formation being deposited in the Williston basin. Stage four, the erosional stage, resulted in erosion throughout the area "except in the geosyncline and along the axis of the Williston basin." (Sloss, 1950, p.444). This late Kaskaskian surface was then covered with clastic sediment by the onlapping Absarokan sea.

The Devonian sediments of the Kaskaskia sequence have been analyzed by Andrichuk (1951), who made a detailed lithofacies study of these sediments. His lithofacies and isopach interpretation of Upper Devonian sediments is presented in Figure 34. This study contains those Devonian sediments assigned to the Kaskaskia sequence in Figure 23, including the basal Devonian unit (Sloss and Laird, 1947) of Montana, and excluding the Exshaw formation. The study also excludes such formations

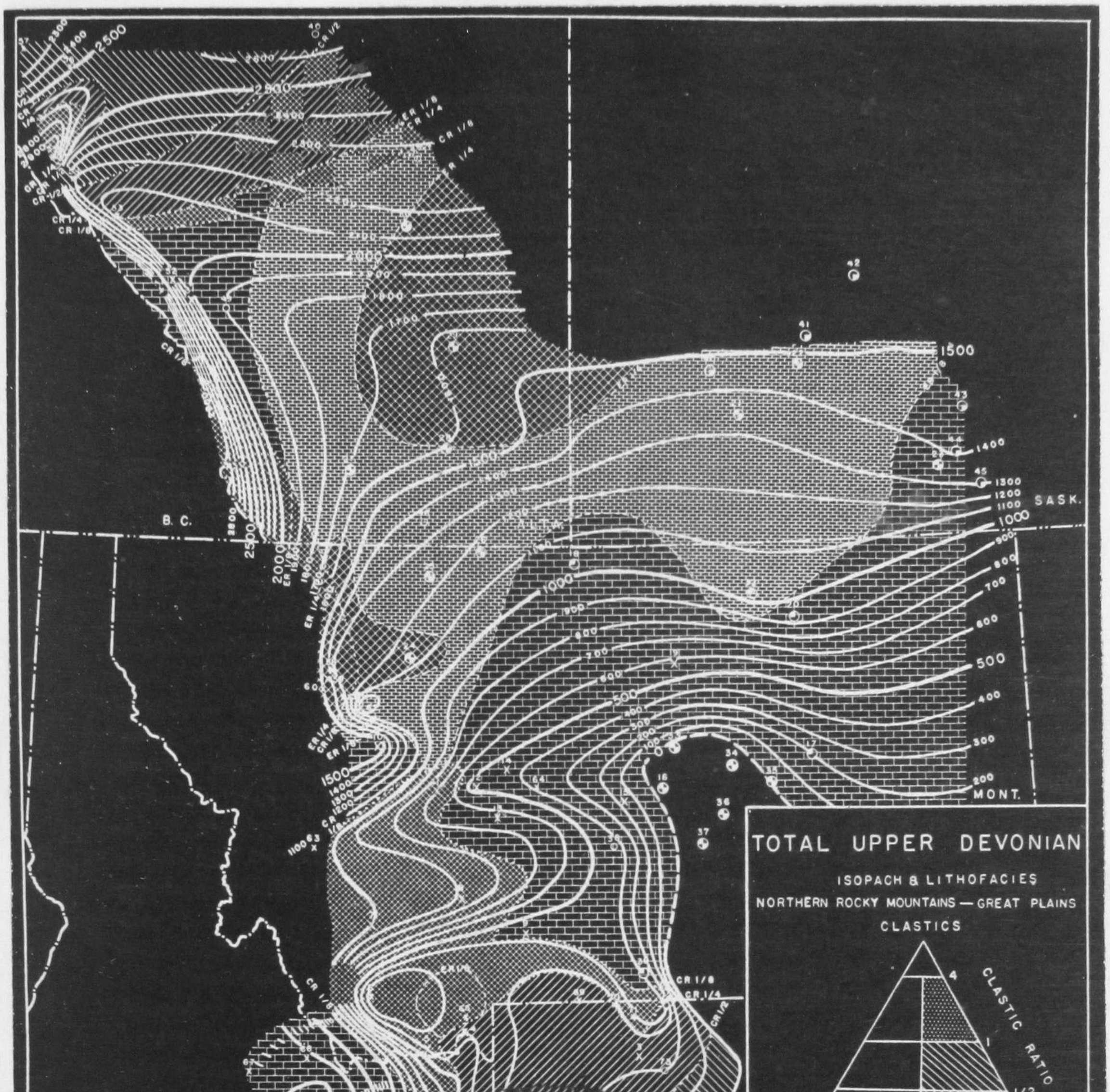

Figure 34. Isopach and lithofacies map of total Upper Devonian in northern Rocky Mountain and Great Plains areas. (Andrichuk, 1951, p.2383)

as the Elk Point, Ghost River and Unit C of Montana, which have been previously assigned to the Tippecanoe sequence. Figure 34 indicates a widespread, highly non-clastic, carbonate-rich environment of sedimentation. The lithofacies pattern does not, apparently, reflect any control over the nature of the sedimentation by the various tectonic elements. The isopachs, however, show rapid thickening westward in the geosynclinal area, but do not indicate any differentiation of the tectonic elements of the craton. An exception to this statement is the Wyoming shelf south of the area, which persisted as a low positive element upon which the seas onlapped throughout Upper Devonian time.

The Upper Devonian sediments represented in Figure 34 have been subdivided by Andrichuk (1951) into three units, for which isopach-lithofacies studies were prepared. The lower unit has been named the lower limestone unit (Andrichuk, 1951, pp.2376-2378) and includes "all but the uppermost beds of the Fairholme formation" and equivalent strata in the plains area. The lithofacies and isopach interpretation of the lower limestone unit is presented in Figure 35. It is again apparent that the only tectonic elements affecting sedimentation are the geosyncline and the Wyoming shelf. The clastic area in the northwest is interpreted (Andrichuk, 1951, p.2394) as indicating a source of sediments to the northwest beyond the limits of this work.

The next unit studied by Andrichuk (1951, pp.2380-2382) was named the dolomite-evaporite unit, illustrated in Figure 36.

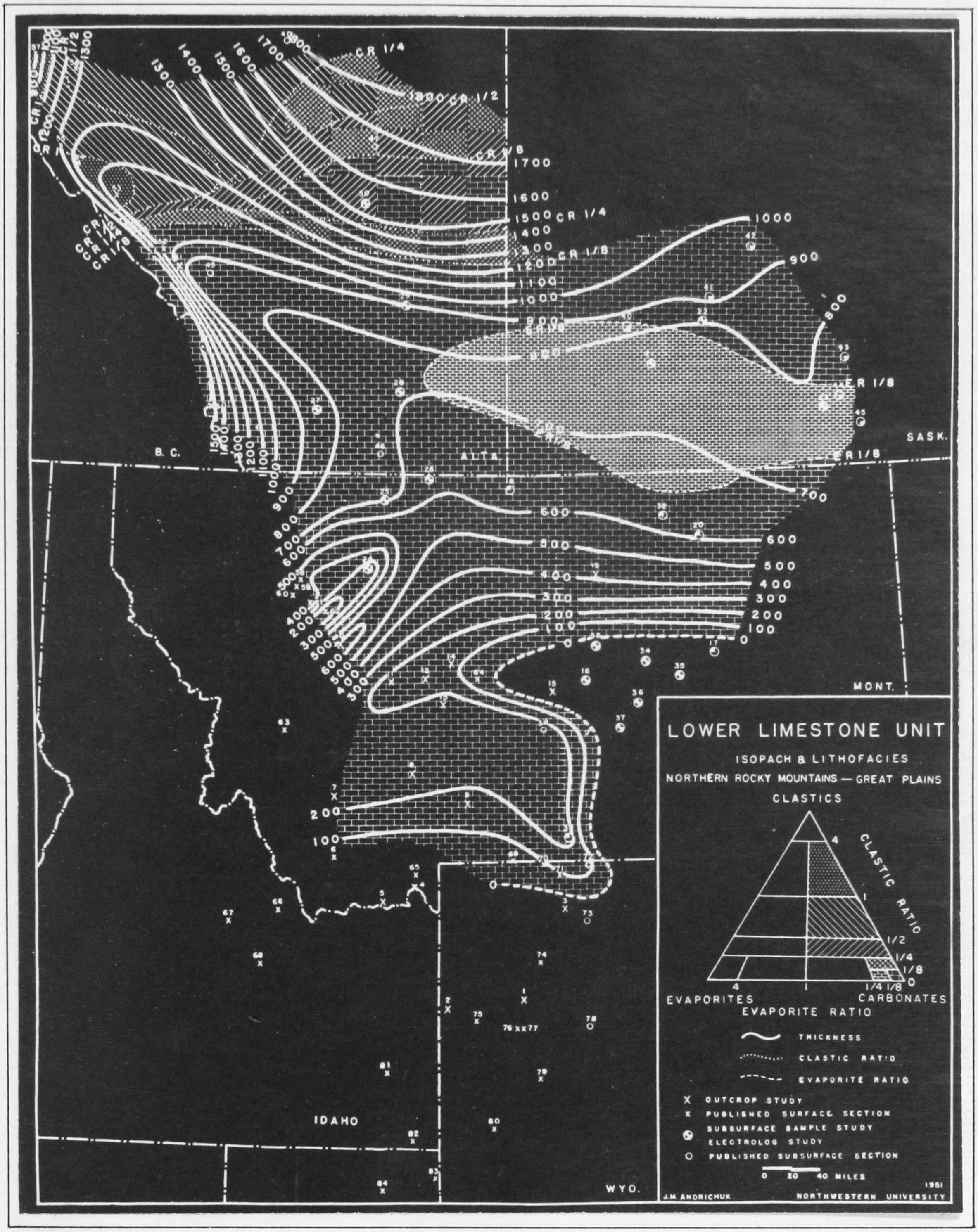

Figure 35. Isopach and lithofacies map of lower limestone unit in northern Rocky Mountains and Great Plains areas. (Andrichuk, 1951, p.2391)

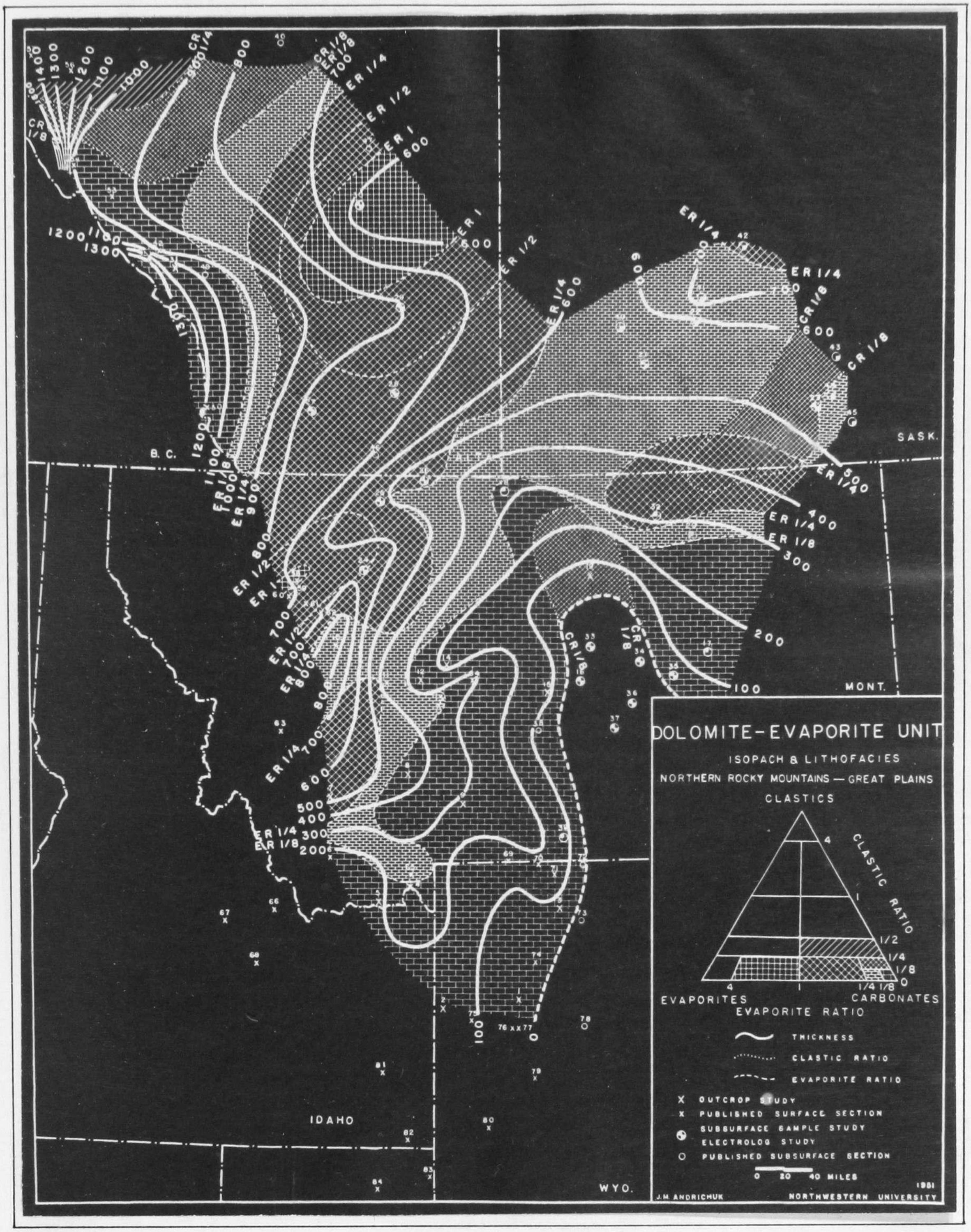

Figure 36. Isopach and lithofacies map of dolomite-evaporite unit in northern Rocky Mountain and Great Plains areas. (Andrichuk, 1951, p.2397)

This unit includes the uppermost beds of the Fairholme formation, the Alexo formation, and all but the uppermost beds of the Palliser formation. These formations and their equivalents are illustrated in Figure 23. As shown in Figures 34 and 35, with the exception of the Wyoming shelf, the tectonic elements of the craton do not influence the isopach pattern to any marked degree, although the western trend in the northern areas graduates towards the northwest. While an evaporitic area developed in east-central Alberta, a somewhat clastic area persisted in the northwest. Andrichuk (1951, p.2399) believed the evaporite development was controlled by the development of a reef-complex between it and the clastic area. He considered this reef-complex, which restricted the southward circulation of the waters from the northwest, combined with a decrease in the rate of subsidence in the Sweetgrass arch area, to be responsible for the increased evaporitic ratio in this area.

The final stage of Devonian sedimentation was the deposition of those sediments assigned by Andrichuk (1951, p.2382) to his post-evaporite unit. This unit is composed of the upper few beds of the Palliser formation and equivalent strata, but it excludes the Exshaw formation which Andrichuk regarded as belonging to the Mississippian cycle of sedimentation. The deposition of the post-evaporite unit marked the development of stage two of the Kaskaskia sequence. Figure 37 illustrates the depositional areas of this clastic unit with occasional areas of non-deposition

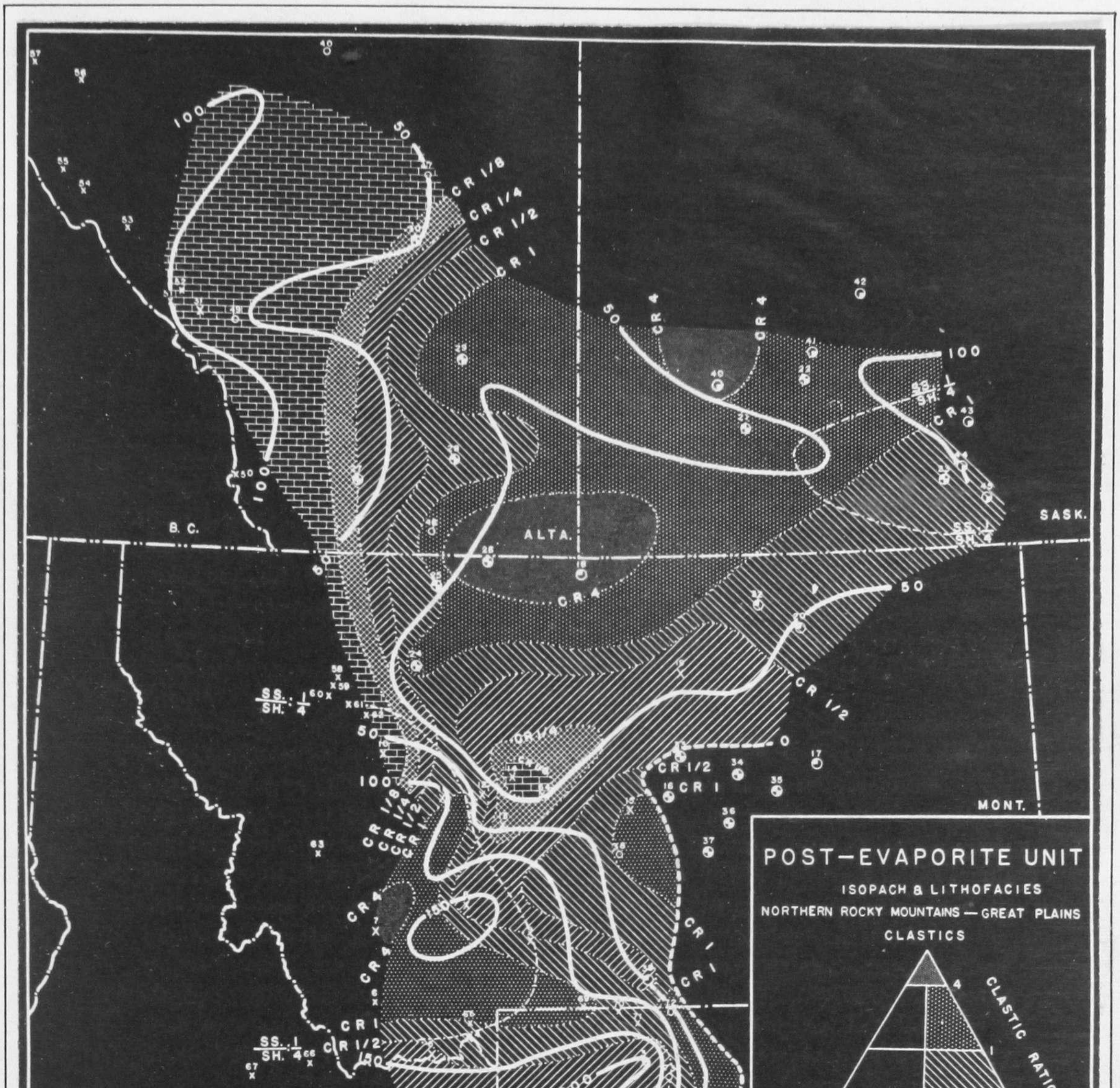

Figure 37. Isopach and lithofacies map of post-evaporite unit in northern Rocky Mountain and Great Plains areas. (Andrichuk, 1951, p.2402)

over the Sweetgrass arch. In the southeast, the Wyoming shelf became strongly positive, supplying the clastic material for the Sappington member of the Three Forks formation (see Figure 23). The black shales introduced the Mississippian cycle of sedimentation. These shales were deposited on the post-evaporite unit throughout the area. Over most of the area these shales and the underlying strata are in conformable contact. Along the geosyncline and in the area of the Wyoming shelf, however, this contact becomes increasingly disconformable, adding further evidence of activity of the tectonic elements towards the close of the Devonian period.

The Mississippian sediments of the Kaskaskia sequence have been analyzed by Sloss (1950, pp. 441-444), who presented a lithofacies-isopach map of this group of sediments, shown in Figure 38. Unfortunately, there is no published lithofacies study of portions of these sediments similar to the work done by Andrichuk (1951) on the Upper Devonian. However, Figure 38 indicates the effect on sedimentation of the various tectonic elements. The isopach pattern makes the tectonic framework easily discernable. The evaporitic Charles formation, deposited late in the Kaskaskia sequence, resulted in an evaporitic facies which outlines the Williston basin and indicates the position of the Central Montana trough. To the west, the geosyncline shows greater thicknesses of sediments than the craton; while to the southwest, in Idaho, the geosyncline contains "siliceous

Figure 38. Isopach and lithofacies of Lower Mississippian (Kinderhookian, Osagian, and Meramecian series). Evaporite area is intended to include points at which ratio of evaporites to other non-clastics exceeds 1:10. (Sloss, 1950, p.440)

argillites and greywackes" (Sloss, 1950, p.442), indicating eugeosynclinal conditions. The presence of coarse conglomerates in Idaho "suggests an orogenic source area on the west" (Sloss, 1950, p.444). The Sweetgrass arch exhibits thinning of sediments and, in general, coarser sediments than adjoining areas. These sediments become increasingly clastic to the northeast. However the Mississippian Kaskaskian sediments are predominantly carbonate-rich and in this respect they are similar to the Upper Devonian Kaskaskian sediments.

Cycles of Sedimentation within the Kaskaskia Sequence

Within the Kaskaskia sequence, there were three separate sedimentary cycles, which apparently existed throughout most or all of the area: two in the Upper Devonian, and one in the Mississippian. The first cycle corresponds to the lower limestone unit of Andrichuk (1951), the second cycle includes the dolomite-evaporite unit and the post-evaporite unit of Andrichuk (1951), while the third and final cycle commenced with the deposition of the Exshaw shale and equivalent strata, and was terminated by Kaskaskian erosion. Within these three cycles, many authors have noted various types of sedimentary--sometimes interformational, and sometimes intraformational. Authors who have written or remarked on this subject include: Andrichuk (1951), Beales (1950), and deWit and McLaren (1950). The cycles within the Kaskaskia sequence will not be discussed further in this thesis except to mention the probability that, whether of large or small magnitude, they reflect some sort of tectonic control--the smaller intraformational cycles possibly indicating a "pulsation" movement in the tectonic framework.

Evidence Regarding Westward Thinning of Kaskaskian Sediments

Data presented by Crabb (1951, p.28) regarding the thickness of the Kaskaskian strata in the Elko, British Columbia, area, if correct, strongly alters the isopach interpretation of these sediments as presented in various illustrations throughout the chapter. Crabb gave the thickness of the Rundle and Banff formations as 4,985 feet and 1,070 feet respectively in the Crowsnest Pass, while the same formations have respective thicknesses of 2,555 and 580 feet at Elko, approximately 24 miles southwest of the Crowsnest Pass. The base of the Devonian is obscured at both localities but Crabb intimated a similar thinning of the Devonian sediments between these localities. If this data is correct, it may indicate one of two tectonic features in this area during the Kaskaskia sequence:

1) It may indicate the western limit to the geosynclinal unit, which might also be indicated by the Jefferson (?) and Wardner formations to the northwest.

2) It may indicate a persistence of a submerged but dominantly positive "Montania" area within the geosynclinal unit.

Further data supporting the theory of shallow submergence and perhaps neighboring emergence of this area during the Kaskaskia sequence is found in the Alexo formation, which, as previously described, becomes more predominantly clastic in the Elko area than in the Crowsnest Pass.

Chapter VII

ABSAROKA SEQUENCE

The last Paleozoic sedimentary sequence, the Absaroka, is not so well substantiated by actual data as are the previous three sequences. As defined by Sloss (1950, p.451), the Absaroka sequence commenced during Upper Mississippian time and continued until "post-Triassic, pre-Middle Jurassic time" when it was closed by a major period of uplift and erosion. This period of erosion removed the Absarokan sediments, where such were deposited, from most of the area. However, strata which may be assigned to the Absaroka sequence are present in the front range of the Rocky Mountains, south of the central portion of the area, and adjoining the southeastern corner of the area.

Canadian Stratigraphy of the Absaroka Sediments

Two formations which outcrop in the front range of the Rocky Mountains are assigned to the Absaroka sequence. These are:

1) the Rocky Mountain formation which is the uppermost Paleozoic formation in that area;

2) the Spray River (?) formation which probably represents Lower and Middle (?) Triassic sedimentation in the area.

These two formations are described and discussed in the sections following.

Rocky Mountain Formation

The Rocky Mountain formation, as it occurs in the Crowsnest Pass, has been briefly described as follows (Beales, 1950, Table 1, after Warren, 1933):

> 350 to 800 feet
>
> Grey or buff dolomites, sandstones, or sandy dolomites, with chert nodules; a few quartzites, and a thin layer of nodular phosphate in the top beds. The formation thins to the east and thickens to the west; no break was apparent with the underlying Rundle formation.

This formation as it occurs near Elko, British Columbia, southwest of the Crowsnest Pass, is described by Crabb (1951, pp.27, 28) as "a series of light-grey, fine-grained, buff and brown weathering, calcareous quartzites, chert, dolomites and limestones, measuring 530 feet in thickness." Thin-section studies by Crabb (1951) showed the calcareous quartzite to be composed of approximately 20% detrital quartz and chert--"the remainder being very fine dolomite and calcite."

North of the Crowsnest Pass in the Mount Head area, Douglas (1953, p.75) subdivided the Rocky Mountain formation into two units and described the formation in the following manner:

	Thickness Feet
Overlying beds--Triassic Spray River formation in outcrop sections and Jurassic Fernie group in Flat Creek well.	
Rocky Mountain formation	
Upper part	
Arenaceous, granular dolomite; sandstone and massive chert	45

Etherington Member

Upper part
Arenaceous, granular dolomite, partly cherty; finely crystalline dolomite 130

Middle part
Arenaceous, granular limestone, partly cherty; medium-crystalline limestone; medium-crystalline porous dolomite 60

Lower part
Green shale and finely crystalline limestone and dolomite 100

In Flat Creek well the Fernie group lies in contact with middle and lower parts in successive fault slices.

The Rocky Mountain-Rundle contact has been described by Crabb (1951, pp.27, 31), Warren (1927, p.34), and Beales (1950, p.45) as conformable. Beales (1950, p.71) referred to this contact as "in places arbitrary", inferring gradation in lithology, while Douglas (1950) described the lower member of the Rocky Mountain formation as Member D of the underlying Rundle formation. However, Webb (1951, p.2305) and Fox (1953, p.197) stated that the Rocky Mountain-Rundle contact was disconformable, although they gave neither references nor evidence for their statement.

The Rocky Mountain-Spray River (?) contact has been described as conformable in the Crowsnest Pass area by Warren (1927, p.34) and MacKay (1932, p.16B), and south of the Crowsnest Pass by Crabb (1951, p.33). North of the Crowsnest Pass, an unconformity between the Rocky Mountain formation and the Spray River formation has been described in the Livingstone range by Douglas (1950, p.19), and near Banff by Warren (1927, p.39). It appears that a disconformity developed between the Paleozoic and Mesozoic sediments in the geosynclinal areas north of the Crowsnest Pass.

A point of interest is an unconformity within the Rocky Mountain formation. Douglas (1950, p.18) described the contact between his Member D of the Rundle formation and the overlying "Rocky Mountain formation" as an angular unconformity and provided a photograph as evidence. Later, however, Douglas (1953, p.68) considered his Member D to be the basal member of the Rocky Mountain formation. Therefore, the unconformity must now be considered as occurring within the Rocky Mountain formation. Since such an unconformity has not been reported in adjoining areas, it may be regarded at present as of only local significance. The descriptions of Member D, basal Rocky Mountain formation, and the underlying Member C of the Rundle formation (Douglas, 1950, p.16) would seem to indicate a gradational contact. This brings Douglas' (1950) description of the Rocky Mountain-Rundle contact into agreement with the authors previously quoted. Perhaps the original report by Douglas (1950) of an unconformity between the Rundle and Rocky Mountain formations, now proven to be within the Rocky Mountain formation, was the reason Webb (1951) and Fox (1953) referred to this contact as disconformable.

The Rocky Mountain formation was assigned by various authors to a Pennsylvanian or Permian age (Wheeler, 1942, p.1839).

Wheeler (1942, p.1839) identified a collection of selachian teeth from phosphatic horizons which occur in the upper part of the formation (Fox, 1953, p.198) as Helicoprion cf. H. ferrieri (Hay). On the basis of this identification, he assigned the Rocky Mountain formation "to the Guadalupian series of the Permian system." However, Crabb (1951, p.27) collected specimens of Spirifer rockymontana (?) Marcou indicative of a Pennsylvanian age from the basal strata of the formation. Warren (1947, p.1238) subdivided the Rocky Mountain formation into a lower and an upper member. The lower member, he considered to be "probably of Pennsylvanian age" while the upper member he considered to be probably Permian in age. These age determinations seem to satisfy the present paleontological evidence. Therefore, the Rocky Mountain formation is herein considered to be of Permo-Pennsylvanian age.

Spray River (?) Formation

The Spray River (?) formation is the name given to a group of somewhat clastic sediments overlying the Rocky Mountain formation and underlying Jurassic sediments in the Rocky Mountains of southern Alberta. The Spray River name is applied with reservation to the Triassic sediments of the southern Alberta mountains, since the exact relationship of the southern occurrences with the Spray River type section near Banff has not been determined.

The Spray River (?) formation as it occurs in the Crowsnest Pass was described by MacKay (1932, p.16B) in the following manner:

> Overlying the Rocky Mountain Quartzite in the Crowsnest section is a thickness of 350 feet of massive, brownish, sandy quartzites and thin, shaly sandstones. These beds are devoid of fossils and their age is doubtful. They differ in lithological character from the underlying quartzites, but lie conformably upon them with no appearance of an erosional contact. On their lithological resemblance to beds in the Spray formation of Banff area and their similar stratigraphic position, they are for the present correlated with them. . . .

Warren (1933, p.157) quoted Telfer as giving a probable thickness for the Spray River (?) formation in the Lizard Range, west of Fernie, British Columbia, of 1700 feet (see Telfer, 1933, p.572). This thickness is questioned in this thesis since the writer has observed numerous thrust faults within the Lizard Range and is inclined, therefore, to regard Telfer's thickness of the formation as due to repetition by thrust faulting. The thickness is also questioned since it appears incongruous with the thicknesses of the formation near the Crowsnest Pass and near the 49° parallel, given by Telfer (1933, pp.568, 572) as 450 and 300 feet, respectively.

Near the 49° parallel and west of the Flathead River, Crabb (1951, p.33) described the Spray River (?) formation as "roughly 400 feet of unfossiliferous, thin-bedded, reddish weathering, shaly sandstones" overlying the Rocky Mountain formation "with apparent conformable relationship." He mentioned the presence of "poorly preserved and unidentifiable ammonites" in the formation. Fox (1953, p.199) mentioned the presence of ammonites in the Spray River formation which are regarded as Lower and perhaps Middle Triassic in age. It would seem, therefore, that the somewhat clastic sediments overlying the Rocky Mountain formation in the area are the southern equivalent of the Spray River formation. The age of this Spray River (?) formation is probably Lower and Middle (?) Triassic.

The Rocky Mountain-Spray River contact has previously been described as conformable in Canadian areas south of the Crowsnest Pass, becoming disconformable north of the Crowsnest Pass. The contact of the Spray River (?) formation with the overlying Jurassic Fernie formation has been termed disconformable by Webb (1951, p.2308) and Fox (1953, p.199). However, MacKay (1932, p.16B) examined the Spray River (?)-Fernie (Jurassic) contact in the Crowsnest Pass and described the Spray River beds as merging "imperceptibly" into the basal phosphatic beds of the Fernie. If this observation is correct, then it implies that Upper Triassic sediments are present in this locality and that deposition was more or less continuous from Upper Triassic to Lower Jurassic.

Montana Stratigraphy of the Absaroka Sequence

As has been previously stated, most of the sediments in Montana which belong to the Absaroka sequence are to be found south and southeast of the area. However, since these sediments must be considered in interpreting the events of the Absaroka sequence within the area, they are here briefly described.

Big Snowy Group

This group is composed of four formations which are, chronologically: the Charles, the Kibbey, the Otter, and the Heath formations. The general lithology and eastward development of the Big Snowy group are illustrated in Figure 33 (see Chapter VI), while the areal relationship of the group to the area is shown in the fence graph, Figure 30 (see Chapter VI). The Charles formation was discussed in Chapter VI as it represents the uppermost Kaskaskia sediments. Brief descriptions of the other formations of the group are presented below (abstracts from Perry and Sloss, 1943, pp.1297-99):

> Kibbey Formation: In outcrop the Kibbey formation is dull, brick-red, dolomitic, shaly sandstone, devoid of fossils, and locally containing beds of gypsum.... The Kibbey rests disconformably on the Mission Canyon limestone (Madison), filling channels and solution cavities, some of which may be 300 feet beneath the top of the limestone....
>
> Where the Charles formation is present the base of the Kibbey is not easily defined, because a gradational transition is present from the anhydritic limestone of the Charles into the sandy beds of the Kibbey.
>
> Otter Formation: In outcrop the Otter formation is characterized by vivid green shales, intercalated with gray shales and fossiliferous oolitic limestones. In the subsurface the green shales can not be traced far east of the Big Snowy Mountains, being replaced by variegated and red shales....

Heath Formation: In outcrop the Heath is characterized by an abundance of black, fissile, conodont-bearing shales, intercalated with gray shales, massive brownish sandstones containing plant fragments and commonly cross-bedded, and minor gray limestones.

The age of the Big Snowy group is considered to be late Mississippian--in part, Pennsylvanian (Brown, 1952, p.7). The Kibbey formation is the basal member of the Absaroka sequence in Montana.

Amsden Formation

The usage of the term "Amsden formation" underwent several changes until Perry and Sloss (1943, p.1293) clarified the literature by using the name "Amsden" to apply specifically to the shaly, in part carbonate-rich strata, bearing Chesterian fauna, overlapping and resting with "angular unconformity" on the Big Snowy group, and conformably underlying the Pennsylvanian Quadrant formation. The stratigraphic position, relationship and lithology of the Amsden formation are illustrated in Figure 33 (see Chapter VI).

Quadrant Formation

The Quadrant formation (Perry, 1937, p.15) consists of a series of buff-to-cream colored, in part calcareous sandstones and quartzites. The formation is in general unfossiliferous; however, foraminifera (Fusilina), of Pennsylvanian age, have been collected from it. The basal part of the formation contains cross-bedding which Perry (1937, p.15) considered to be indicative of an eolian origin.

Phosphoria Formation

The distribution of the Phosphoria formation is limited to southwestern and southern Montana. The formation is described by Clapp (1932, p.21) as "cherty phosphatic limestone, grey, quartzite, and red shales" resting conformably on the Quadrant formation. The Phosphoria formation is regarded as Permian in age. The lithology and stratigraphic position of this formation show a marked similarity to the upper, often phosphatic, zone of the Rocky Mountain formation, as described by Telfer (1933, pp. 569-572).

Chugwater (Spearfish) Formation

The terms "Chugwater and "Spearfish" are used for the same strata in southern Montana and the Black Hills, North Dakota, respectively.

The Chugwater (Spearfish) formation is described by Perry (1937, p.15) in the following manner:

> The Chugwater (Spearfish) beds are conspicuous because of the bright to dark red sandy shale and sandstone which contrast sharply with the brown and gray color of associated strata. The Chugwater (Spearfish) can be traced readily by its flaming shade of red. Pure granular gypsum occurs near the top of the formation in a bed 5 to 40 feet thick, and gypsum seams and veinlets streak through the lower part of the formation. Green shales a few feet thick may be interbedded with the normal red sediments near the top or bottom.

The Phosphoria-Chugwater (Spearfish) contact is referred to by Sloss (1950, p.448) as "apparently conformable."

Correlation of Absaroka Sediments

Correlation of Absarokan sediments is difficult because of limited areal distribution and a generally low fossil content. However, correlation of the southwestern Alberta section with the Montana section has been made on the basis of published information from which the writer has drawn his own conclusions. The correlation of these two sections is illustrated in Figure 39, with a discussion of this correlation presented in the following paragraphs.

The Rocky Mountain formation occupies the same stratigraphic interval as the combined Kibbey, Otter, Heath, Amsden, Quadrant and Phosphoria formations in Montana, shown in Figure 39. However, while the Rocky Mountain formation is of Permo-Pennsylvanian age, the Montana section is Chesterian (Upper Mississippian)--Permo-Pennsylvanian. In the previous discussion, it was shown that the upper part of the Rocky Mountain formation carries a similar fauna to the Phosphoria formation, while the lower part of the Rocky Mountain formation carries a Pennsylvanian fauna, as does the Quadrant formation. However, there is no zone reported at the base of the Rocky Mountain formation which carries a Chesterian fauna similar to the Amsden, Heath, Otter and Kibbey sections in Montana, although the Upper Rundle of the Kaskaskia sequence carries some Chesterian corals (V.J. Okulitch - personal communication).

The possibility that certain Mississippian organisms managed to survive the interval of clastic sedimentation (Kibbey formation) which accompanied stage four of the Kaskaskia sequence and, with the return of more stable water conditions, persisted through Amsden deposition, has been discussed previously in Chapter VI. Perhaps a more obvious solution might simply be that stage one of the Absaroka sequence commenced later in the west than in the southeast. If this were the case, however, the Kaskaskia deposition must have continued for a longer period in the west than in the southeast, since the Rundle-Rocky Mountain contact is conformable. Both possibilities seem to satisfy the Rocky Mountain-Phosphoria, Quadrant, Amsden, Heath, Otter, Kibbey stratigraphic correlation.

The correlation and age representation of the Big Snowy, Amsden and Quadrant strata, as presented by Brown (1952, p.76) and shown in Figure 31 (Chapter VI), are here considered to be questionable. The definition of the Amsden formation as redefined by Perry and Sloss (1943, p.1293) required that use of this name be restricted to the strata bearing a Chesterian fauna, all Pennsylvanian strata being assigned to the Quadrant formation. This obviously necessitates placing the Big Snowy group completely within the Mississippian. It is also probable that the term "Quadrant" should be restricted more to the

Pennsylvanian strata, with the Permian age being reserved for the Phosphoria and equivalent strata.

The Spray River (?) formation is correlated with the Chugwater (Spearfish) formation of Montana. Both occupy the same stratigraphic interval (see Figure 39) and both are Triassic in age. Although the exact age range of either formation is not clear, the contact between them and the underlying Permian strata is conformable in southwestern Alberta and in Montana. Therefore, the age of the Spray River (?) and Chugwater (Spearfish) formations may be assumed to be in part Lower Triassic.

Distribution, Thickness, and Lithofacies of the Absaroka Sediments

A series of isopach-lithofacies maps for the Paleozoic portion of the Absaroka sediments in Montana and adjoining areas were presented by Sloss (1950, pp.444-450). These maps, in conjunction with various other isopach maps of these sediments, can be used to gain an understanding of the regional features of Absarokan sedimentation.

The lithofacies study of the Kibbey, Otter, Heath and Amsden formations is presented in Figure 40. It illustrates a general condition of carbonate-rich, somewhat clastic sedimentation in the geosyncline, Central Montana trough and Williston basin, thereby indicating differentiation of the tectonic elements early in the Absaroka sequence. In central Idaho, a thick section

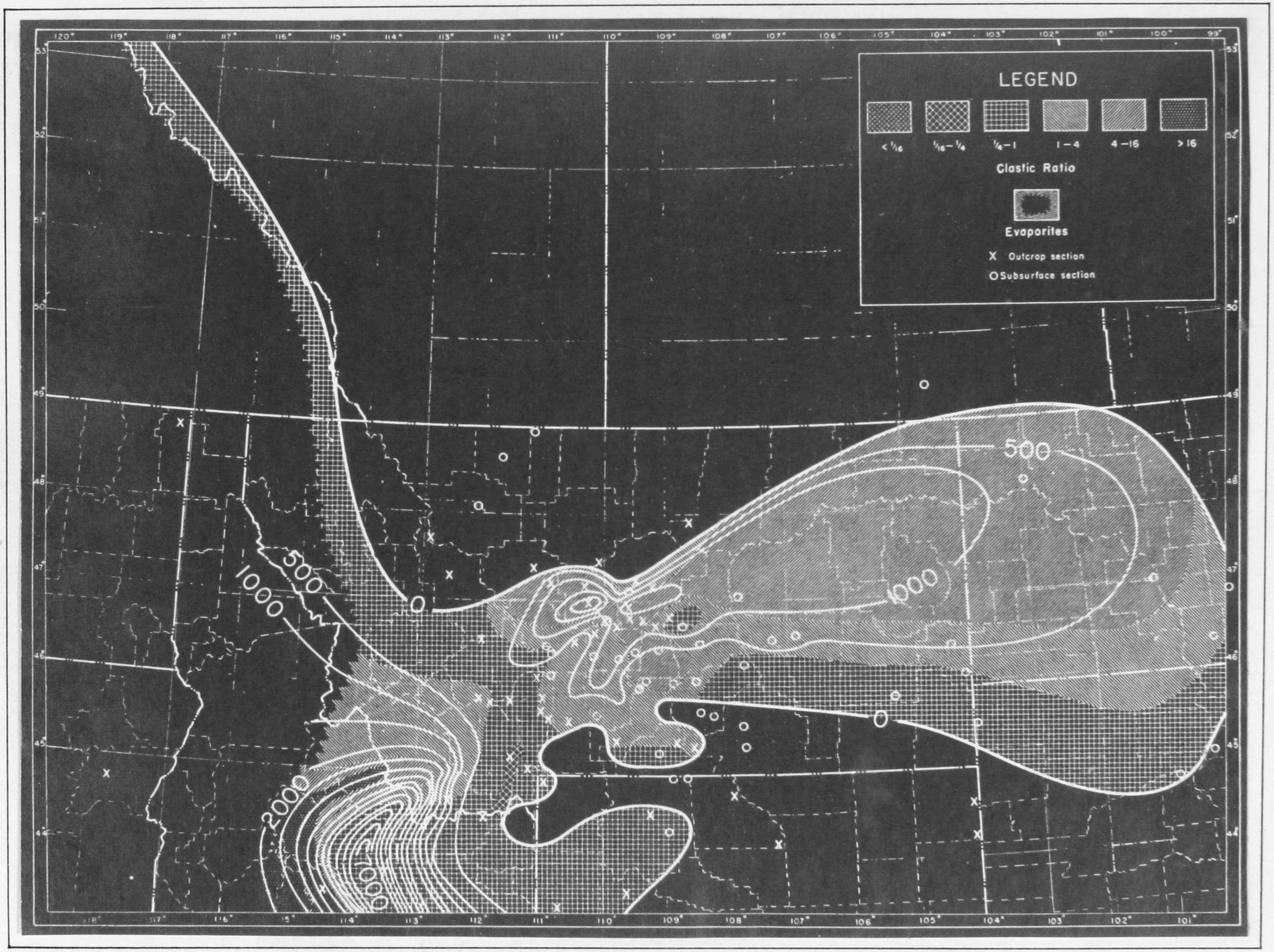

Figure 40. Isopach and lithofacies of Upper Mississippian (Chesterian) (Sloss, 1950, p.443)

of typical eugeosynclinal sediments was deposited (Sloss, 1950, p.445). Figure 41 indicates the distribution and thickness of the Big Snowy group, and also indicates the presence of Chesterian sediments near the Alberta-Saskatchewan-Montana border. The presence of this outlier of Big Snowy strata implies that the southern part of the Sweetgrass arch received sediments for at least a portion of the Absaroka sequence.

The Pennsylvanian (presumably Quadrant) sediments are represented in Figure 42, while Permian (presumably Phosphoria) sediments are represented in Figure 43. Both figures show the distribution of carbonate-rich clastics in the geosyncline, the Central Montana trough, and over the Wyoming shelf. The Sweetgrass arch, however, lacks these sediments. In central Idaho, eugeosynclinal deposition continued after Upper Mississippian time (Sloss, 1950, pp.447-448) and eventually the Permian eugeosyncline was partially closed by vulcanism.

No lithofacies maps are available for the Permo-Pennsylvanian (Rocky Mountain formation) sediments of the Canadian geosyncline. However, Figure 44 shows the distribution and thickness of these sediments.

The distribution and thickness of the Triassic (Spray River formation) sediments are shown in Figure 45. No lithofacies map is available for the Triassic sediments of Montana, whose distribution is limited and patchy.

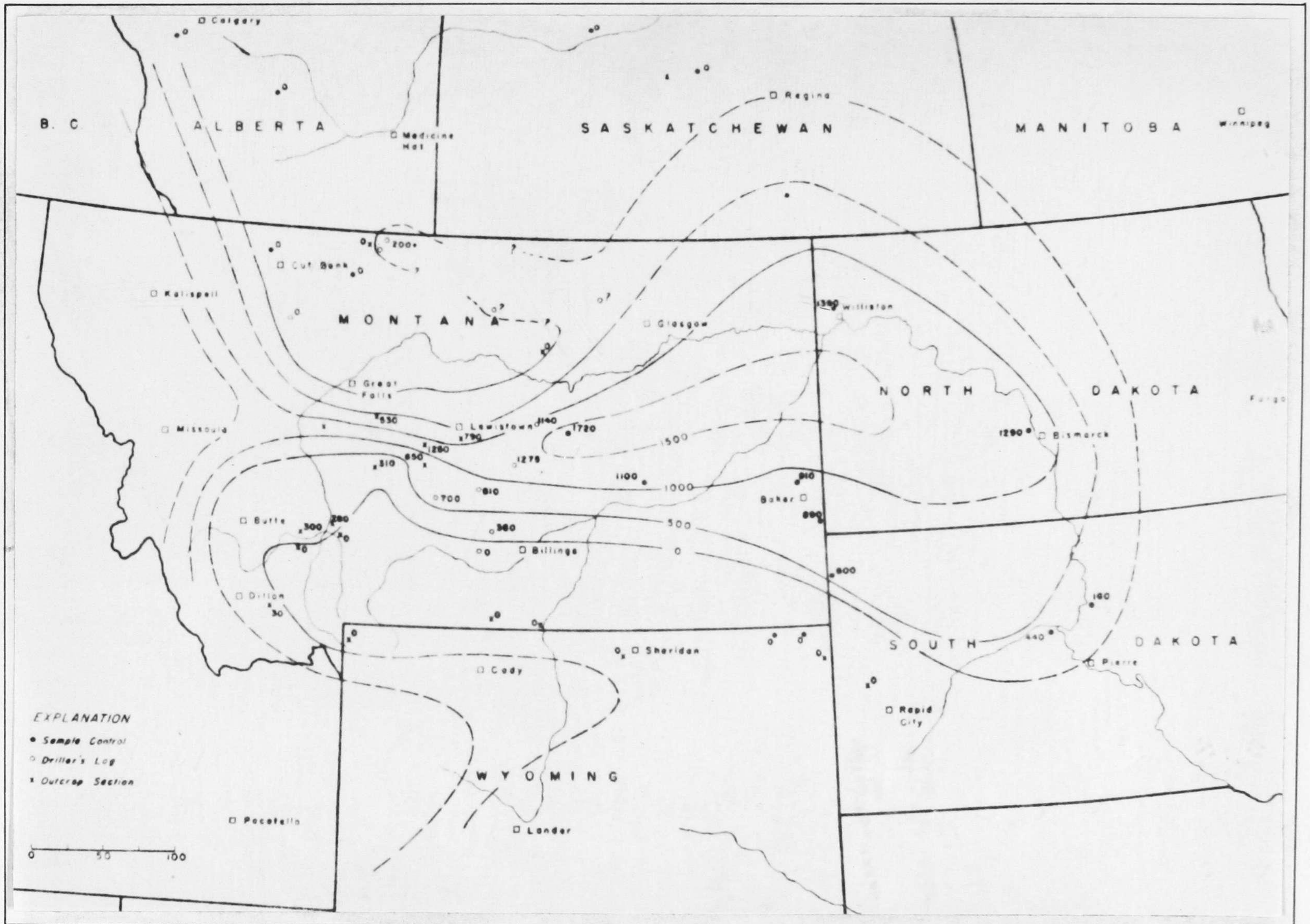

Figure 41. Isopach map of Big Snowy group showing distribution and thickness subsequent to late Paleozoic and early Mesozoic erosion. (Perry and Sloss, 1943, p.1289)

Figure 42. Isopach and lithofacies of Pennsylvanian system. (Sloss,1950,p.446)

Figure 43. Isopach and lithofacies of Permian system. (Sloss, 1950, p. 449)

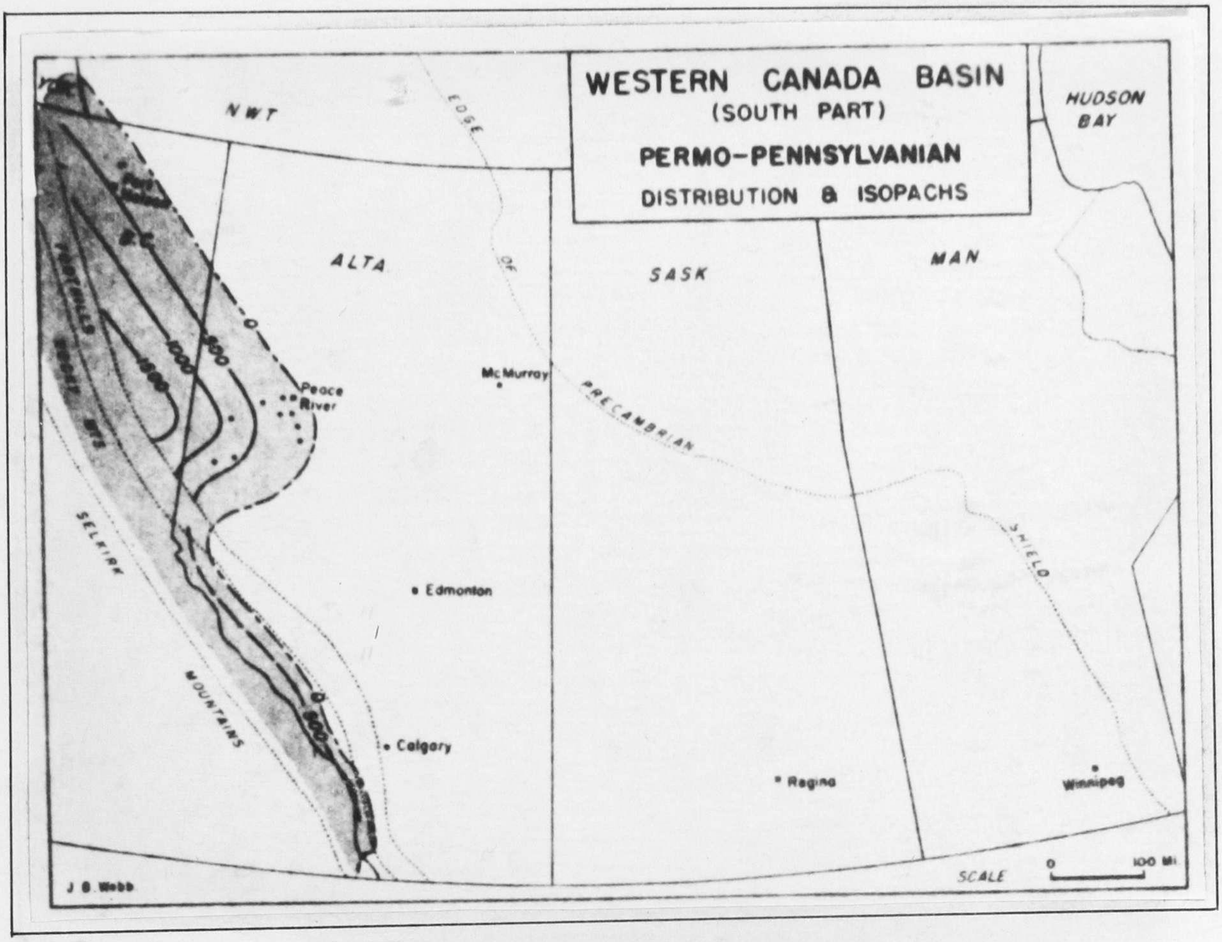

Figure 44. Present distribution and isopachs of Permo-Pennsylvanian. (Webb, 1951, p.2306)

There is considerable evidence of southward thinning of the Rocky Mountain and Spray River (?) formations in the area north of ancient Montania. Crabb (1951, p.28) gave the thickness of the Rocky Mountain and Spray River (?) formations as 1,100 feet and 350 feet, respectively, at the Crowsnest Pass. Twenty-four miles to the southwest at Elko, British Columbia, the Rocky Mountain formation is 532 feet thick (Crabb, 1951, p.28). The thickness of

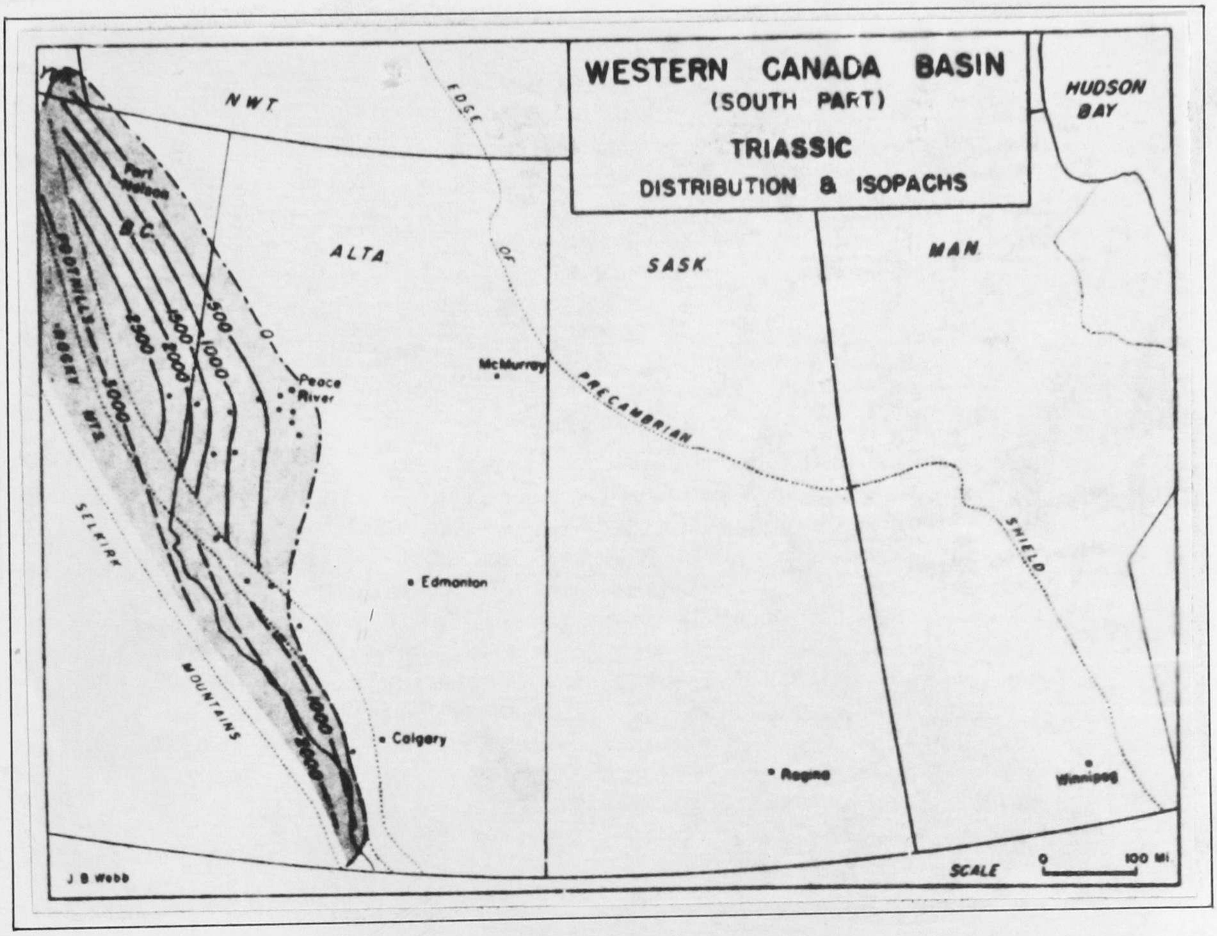

Figure 45. Present distribution and isopachs of Triassic System. (Webb, 1951, p.2307)

the Spray River (?) formation in the Lizard Range, which is immediately north of Elko, British Columbia, has already been discussed. To the southeast of Elko, in the Flathead valley, Crabb (1951, p.33) noted the presence of 400 feet of Spray River (?) strata which diminished to 300 feet at the 49° parallel (Telfer, 1933, p.572). The thickness of Rocky Mountain strata south of the Crowsnest Pass becomes increasingly less to the south until it is only 100 feet thick (Crabb, 1951, p.32) near the Flathead River at the 49° parallel. This data may indicate an ancestoral Montania still exerting positive tendencies through Permo-Pennsylvanian and Triassic time. However, there is at present insufficient evidence to reach a definite conclusion regarding this late Paleozoic—early Mesozoic "Montania."

<u>Tectonic Events of the Absaroka Sequence</u>

As previously indicated, evidence relating to the events of the Absaroka sequence has been partially destroyed by a strenuous period of erosion representing stage four of the sequence. However, where a complete stratigraphic section of post-Kaskaskian --pre-Jurassic sediments has been preserved, there is no evidence of a major regional disconformity within these sediments. It would seem probable, therefore, that the definition of the Absaroka sequence by Sloss (1950, p.451) is correct and that one, and only one, major sedimentary sequence occurred in post-Kaskaskian--pre-Jurassic time.

During stage four of the Kaskaskia sequence, the seas had withdrawn to the geosyncline and the axial area of the Williston basin, with the remainder of the area suffering erosion. The commencement of the Absaroka sequence saw the transgression of the seas over part of the erosional surface. Figure 41 indicates that the overlapping Absarokan seas covered at least the southern portion of the Sweetgrass arch. It is probable, however, that the

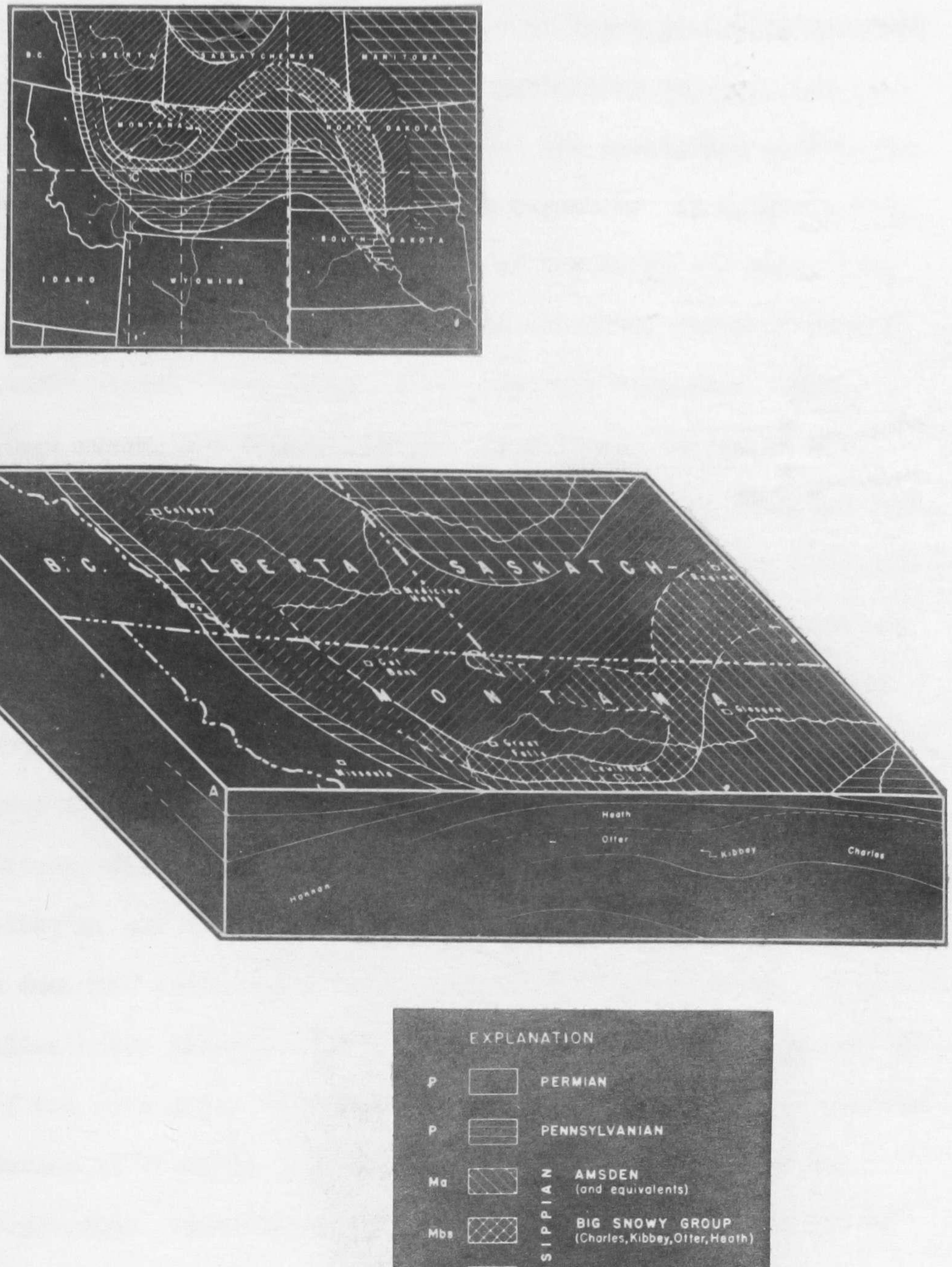

Figure 46. Post-Paleozoic -- pre-Mesozoic paleogeography and structure. (Perry and Sloss, 1943, pp.1290-91)

geosyncline and the Williston basin at least partially retained their negative tendency from late Kaskaskian to Absarokan time, while the Central Montana trough and the Sweetgrass arch became defined very early in the Absaroka sequence. It appears, then, that stage one, the transgression of the seas, and stage two, the differentiation of the tectonic elements, occurred almost simultaneously very early in the Absaroka sequence. During stage three, the culmination of the differentiation of the tectonic elements, the Sweetgrass arch became the dominant feature and was strongly positive; the geosyncline was a restricted narrow, shallow basin, and the Central Montana trough remained shallow with the seas onlapping over the Wyoming shelf to the south. Stage four, the erosional stage, resulted in widespread, deep erosion of the entire area. The resulting unconformity between Jurassic strata and Mississippian strata in southern Alberta, and Upper Devonian strata in east-central Alberta is a dominant sedimentary feature in Alberta and Montana. Figure 46 illustrates diagrammatically the surface and subsurface geology of the area prior to Mesozoic sedimentation. Since the distribution of Triassic sediment is very restricted, Figure 46 represents essentially the geology of the area at the end of the Absaroka sequence, prior to Jurassic sedimentation.

Chapter VIII

SUMMARY

This summary indicates the main geological events and problems of the pre-Jurassic sedimentation, tectonism, and stratigraphy of southern Alberta and adjoining areas of British Columbia and Montana. Conclusions to some of the problems and possible solutions for others which have been discussed in the thesis are stated. No attempt is made to summarize the complete sequence of pre-Jurassic geological events which occurred in the area.

The Belt series contains the oldest known strata to outcrop in the area. The series is subdivided regionally into six facies, the Glacier Park facies being defined for the purposes of this thesis as the type section. The various stratigraphic units of the facies are defined and their type localities stated. In addition, two basal formations of the Purcell facies, the Fort Steele and the Aldridge, are described, as both formations are stratigraphically lower than any outcropping formation of the Glacier Park facies. The lithological changes within the Belt series are gradational, both laterally and vertically, indicating that the Belt series is a unified stratigraphic division.

Beltian and Lipalian paleogeography is described. Three tectonic elements--the geosyncline, the ancestoral "Central Montana trough", and Montania--are shown to have been functional during Beltian sedimentation. The close of Beltian sedimentation was caused by orogeny, which introduced the Lipalian interval. As this orogeny built the Helena Mountains in the area and the ancestoral Purcell Mountains west of the area, coarse clastics were deposited unconformably on the Purcell series northwest of the area. While these sediments (the Windermere series) are not described in detail, their stratigraphic and time relationship to sediments within the area are indicated.

A resume' of the tectonic and sedimentary events of the Paleozoic era which occurred in the area is presented. The tectonic framework upon which Paleozoic sediments were received was principally inherited from Beltian time. The nature and interrelationship of the various members of this tectonic framework governed Paleozoic sedimentation in the area. During the Paleozoic era, four great sedimentary sequences--the Sauk, the Tippecanoe, the Kaskaskia and the Absaroka--developed, each sequence representing a four-stage depositional cycle. The four sedimentary sequences are shown to be the result of a recurring sequence of tectonic events.

The Sauk sequence, the first of the four Paleozoic sedimentary sequences, commenced during Lower Cambrian and continued until Lower Ordovician time. The erosional stage of the sequence removed most of the Upper Cambrian and some Middle Cambrian strata from the area. The distribution of Cambrian strata after Sauk erosion revealed that the tectonic elements which controlled sedimentation during Beltian deposition had indeed been inherited by the Paleozoic era. Montania was indicated as a dominant feature influencing Cambrian sedimentation in the area.

Southeastern British Columbia is defined as the type locality for the Lower Cambrian strata within the area. A correlation of the southeastern British Columbia section with the well-known Kicking Horse Pass section is presented together with a discussion of the age of the Olenellus-Bonnia zone. A very late Lower Cambrian age was accepted for the zone, establishing the Eager formation of southeastern British Columbia, which contains the zone, as the uppermost Lower Cambrian formation of the area.

The Middle Cambrian type locality for the area is chosen as northwestern Montana. The stratigraphic units of this section are defined and a faunal list for the various formations appended. The controversial Burton formation and the overlying Elko formation of southeastern British Columbia are described. The basal member of the Burton formation, which had been assigned a Lower Cambrian (?) age, is assigned to the Middle Cambrian as a probable stratigraphic equivalent of the basal Middle Cambrian Flathead sandstone. An accompanying correlation chart indicates the Middle Cambrian sections within and beyond the area.

Upper Cambrian strata are believed to be missing in the area, although their presence in adjoining areas has been definitely established. The lack of these sediments is attributed to Sauk erosion of the greater Sweetgrass arch area.

The second Paleozoic sequence, the Tippecanoe (as defined by Sloss, 1950), occupied the post-Cambrian--pre-Devonian interval. This thesis suggests that the upper limit of the Tippecanoe be placed at the late Middle to early Upper Devonian erosional surface. Sediments on the craton which may be assigned to this interval have, in general, not been assigned definite age limits. These sediments are introduced and described.

The Elk Point formation, which is limited to the northeastern portion of the area, is described and the problem of its age discussed. The Ghost River formation, which has a very limited distribution in the north-central part of the area, is also discussed. From regional studies, the Ghost River formation appears to be the stratigraphic and time equivalent of some portion of the upper part of the Elk Point, probably some portion a short distance below the upper massive beds of the Elk Point. The correlation of the Ghost River formation with the lowermost Upper Devonian strata of northwestern Montana, Unit C, is established. A discussion of the relationship of the basal Elk Point, Ghost River, and Unit C to the basal Devonian unit of central and eastern Montana shows these units to be stratigraphically related; their relative stratigraphic positions transgressing time, being older in the north and west than in the southeast.

Several theories are presented regarding tectonism during that portion of Paleozoic time assigned to the Tippecanoe sequence. The major differences between these theories are indicated and a unifying theory of events presented which draws the preceding theories into closer agreement.

The Kaskaskia sequence, third of the Paleozoic sequences, occupied Upper Devonian and Mississippian time in the western part of the area but was apparently terminated in pre-Upper Mississippian time in the eastern part of the area. More detailed information regarding stratigraphy and sedimentation is available for the Kaskaskia sequence than for any other Paleozoic sequence. The Kaskaskian stratigraphic section as it occurs in southwestern Alberta is correlated with sections within and beyond the area.

The Crowsnest Pass area is designated as the type locality for the Upper Devonian formations of the area. Historical development of the Upper Devonian nomenclature is graphically illustrated and each stratigraphic unit defined and described. The Alexo formation is discussed with particular reference to the proper correlation of this formation with its equivalent of the plains.

Special attention is given to the problems of the age and stratigraphic position of the Exshaw formation. Stratigraphically, the Exshaw belongs to the Mississippian sedimentary cycle, while, paleontologically, the Exshaw has been assigned to the Upper Devonian age. More recent studies suggest a possible

Mississippian age, though the formation continues to be regarded as Upper Devonian at present. A possible explanation is outlined for the origin of the black shales of which the Exshaw is comprised. The unconformity at the base of the Exshaw is not considered to represent a regional break in sedimentation. Since the Exshaw shale does not introduce a new regional sedimentary sequence but merely the commencement of a cycle within the Kaskaskia sequence, the relative significance of the problems presented by the Exshaw have been overemphasized in the past.

The type section for the Mississippian strata of the Kaskaskia sequence within the area is defined as the area north of the Crowsnest Pass in the front range of the Rocky Mountains. The Mississippian stratigraphic units are described as they occur at this locality. The historical development of the nomenclature of these sediments is illustrated graphically, and a recent revision of the nomenclature of the Rundle formation (by Douglas, 1953) introduced.

The Charles formation, the uppermost member of the Kaskaskia sequence in the eastern portion of the area, is described. While this formation does not have a stratigraphic equivalent in the western portion of the area, it is shown to be equivalent in time to part of the upper Rundle formation.

The tectonic events and the effect of these events upon Kaskaskian sedimentation are outlined and discussed. Several lithofacies maps are introduced for portions of the Kaskaskian section. Two explanations for the apparent age variation of the Kaskaskian erosional surface are considered. Evidence is presented suggesting the existence of a positive-tending area in the vicinity of ancient Montania. This evidence is considered to be indicative, but not conclusive.

The Absaroka sequence, the last of the Paleozoic sequences, occupied the interval from Upper Mississippian to pre-Lower Jurassic time. Within the area, the distribution of sediments belonging to this sequence is limited to the northwest. The Absaroka section, as it occurs in that part of the area, is described. Absarokan sections south and southeast of the area are also described, and are correlated with the southern Alberta section.

It is shown that no major regional break occurred in the sedimentation of the Absaroka sequence. The end of the Paleozoic era was not, therefore, a major regional event in the area. Disconformities between various horizons in the Kaskaskian sediments were of purely local significance.

The erosional period which ended the Absaroka sequence was a major geological event in western Canada. The erosion was very active, stripping off the Absaroka sediments and part of the Upper Mississippian strata from much of the area. The result was a major unconformity between sediments of the Paleozoic sequences and the overlying Jurassic sediments.

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Appendix

FOSSILS OF THE MIDDLE CAMBRIAN

The following faunal list accompanies the description of Middle Cambrian formations of northwestern Montana, as presented in Chapter IV. These fauna are described by Deiss (1939) as being present in the Middle Cambrian formations at that locality.

GORDON SHALE

Albertella helena Walcott

Alokistocare charax (Walcott)

Anoria baton (Walcott)

Clavaspidella bela (Walcott)

Elrathia candace (Walcott)

E. pylas (Walcott)

Glossopleura belesis (Walcott)

Kochina americana (Walcott)

Ptarmingia gordonensis Resser

Strotocephalus gordonensis Resser

Vanuxemella contracta (Walcott)

Zacanthoides cnopus Walcott

DAMNATION LIMESTONE

Alokistocare? scapegoatensis Deiss

Glossopleura alta Deiss

G. fordensis Deiss

G. inornata Deiss

G. minima Deiss

G. perryi Deiss

G. thomsoni Deiss

Glyphaspis levis Deiss

Kootenia erromena Deiss

K. exilaxata Deiss

K. fragilis Deiss

K. infera Deiss

K. latidorsata Deiss

K. scapegoatensis Deiss

Solenopleurella pagodensis Deiss

DEARBORN LIMESTONE - no fauna listed

PAGODA LIMESTONE

"Agnostus" hastatus Deiss
Amecephalus diffundatus Deiss
Bathyuriscus? rugosus Deiss
Bolaspis globulifera Deiss
B. grandis Deiss
B. minuta Deiss
B.? unica Deiss
B. vera Deiss
Ehmania brevis Deiss
E.? brevis Deiss
E. grandis Deiss
E. inconstans Deiss
Ehmania planiorata Deiss
E. sexannulata Deiss
E. transversa Deiss
Elrathina erecta Deiss
E. hybrida Deiss
E. lickensis Deiss
E. nodulosa Deiss
Glyphaspis delicata Deiss
G. paucisulcata Deiss
G. robusta Deiss
G. storeyi Deiss
Kootenia varia Deiss

PENTAGON SHALE

"Agnostus" brevispinus Deiss
"A" robustus Deiss
Anomalocephalus ornatus Deiss
Bathyuriscus formosus Deiss
Clappaspis concava Deiss
C. convexa Deiss
C. hebetis Deiss
C. lickensis Deiss
Elrathiella nitida Deiss
E. plana Deiss
E. recta Deiss
E. sulcata Deiss
E. tenuis Deiss
E. unisulcata Deiss
E. valens Deiss
Elrathina convexa Deiss

PENTAGON SHALE (continued)

Clappaspis mcnairi Deiss

C. obscura Deiss

C. papulata Deiss

C. singularis Deiss

C. striata Deiss

C. typica Deiss

Ehmania convexa Deiss

E.? elongata Deiss

E. exilis Deiss

E.? incerta Deiss

E. perfecta Deiss

E. sulcata Deiss

E.? unispinata Deiss

Elrathiella convexa Deiss

E. crassiorata Deiss

E. manifesta Deiss

Elrathina fecunda Deiss

E. oculineata Deiss

Kootenia pariquadriceps Deiss

K. serrata (Meek)

K. cf. serrata (Meek)

K. subequalis Deiss

Parehmania arcuata Deiss

P. cf. arcuata Deiss

P. concava Deiss

P. princeps Deiss

P.? quadrata Deiss

P. storeyi Deiss

Rowia cylindrica Deiss

R. delicata Deiss

R. granulata Deiss

R. vulgata Deiss

STEAMBOAT LIMESTONE

Coelaspis prima Deiss

Glossocoryphus cliffensis Deiss

G. typus Deiss

Glyphaspis dearbornensis Deiss

G. indenta Deiss

G. similis Deiss

G. cf. similis Deiss

Kochaspis dearbornensis Deiss

K. resseri Deiss

K. unzia (Walcott)

K. upis (Walcott)

Mcnairia inornata Deiss

Thomsonaspis obscura Deiss

T. striata Deiss

SWITCHBACK SHALE - no fauna listed

DEVILS GLEN DOLOMITE - no fauna listed

Figure 39. Correlation of Absarokan Formations.

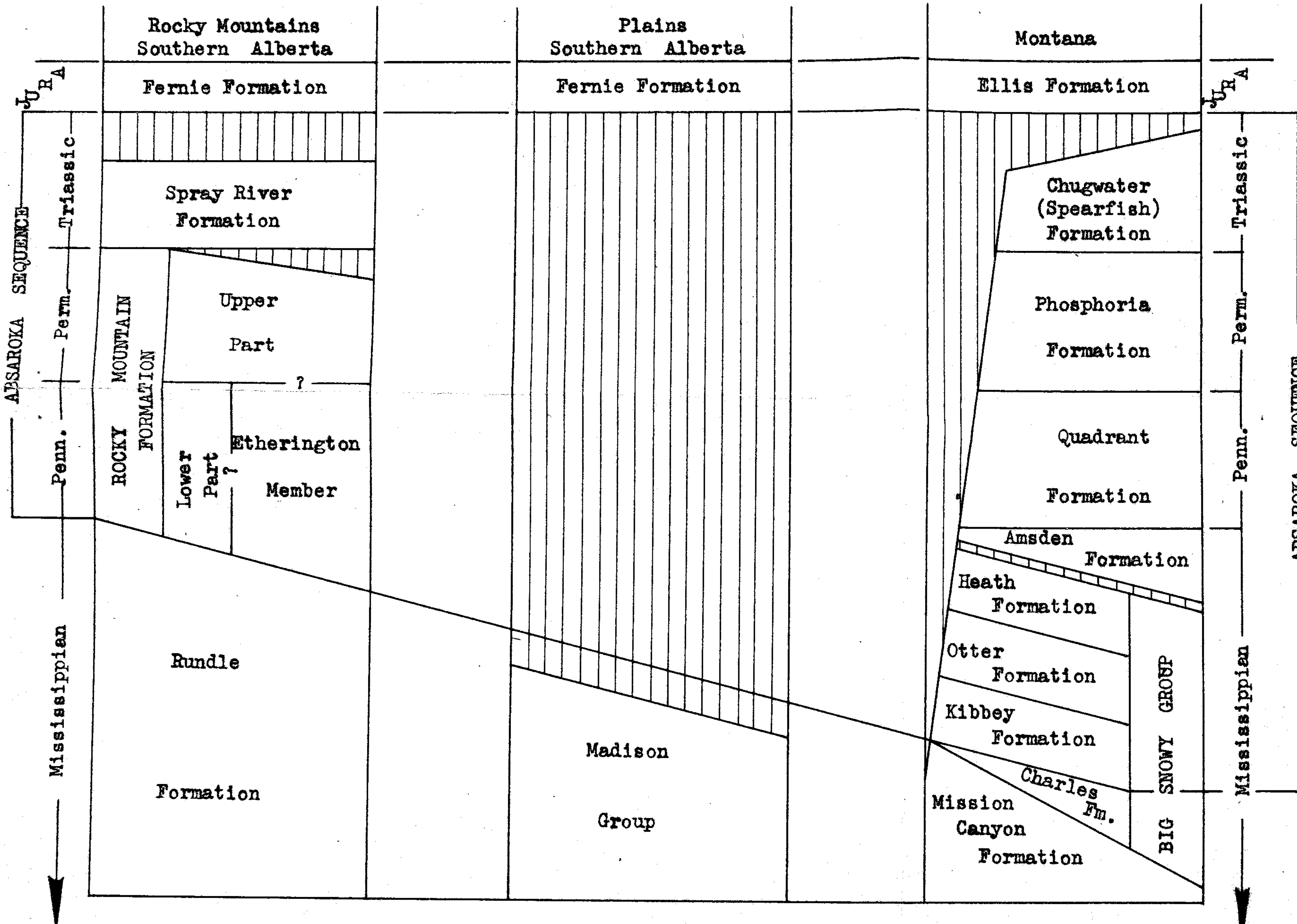

Figure 22.

Correlation Chart of Upper Devonian Formations.

Figure 12.

Correlation of Middle Cambrian

1 Mt. Bosworth B.C. (Deiss, 1940)	2 Ptarmigan Peak Alberta (Deiss,1940)	3 Mt. Assiniboine B.C. (Deiss,1940)	4 Northwestern Montana (Deiss,1939)	5 Nixon Gulch Montana (Deiss,1940)		6 Southern Alberta Plains (Russell & Landes) (1940)		7 Moose Mtn. and Morley Areas, Alta. (Beach,1943)		8 Southeastern British Columbia (Schofield,1915)
Upper Cambrian	Upper Cambrian	Uppar Cambrian	Upper Devonian	Upper Cambrian	HORIZONS NOT CORRELATED	Upper Devonian ?	HORIZONS NOT CORRELATED	Upper Devonian	HORIZONS NOT CORRELATED	
Eldon dolomite 1110'	Eldon dolomite 1230'	Eldon dolomite unmeasured	Devils Glen dolomite 350'	Park Shale 167'		Present but not differentiated 510'		Formation "D" (Ghost River Fm.) 260-300'		Elko Formation 1000'+
Stephen Formation 470'	Stephen Formation 315'	Stephen Formation unmeasured	Switchback Shale 108'	Meagher limestone 347'				Formation "C" 236'		?
Cathedral dolomite	Cathedral dolomite 620'	Cathedral dolomite 1000'	Steamboat limestone 274'	Wolsey shale 354'				Formation "B" 629'		Burton Fm. 80'(?)
Ptarmigan limestone 195'	Ptarmigan limestone 460'	Naiset Formation 475'	Pentagon shale 215'	Flathead Sandstone 160'				Formation "A" 1570'+		
Mt. Whyte Formation 285'	Mt. Whyte Formation 275'	Gog Formation 1235'	Pagoda limestone 305'							
			Dearborn limestone 313'							
			Damnation limestone 155'							
			Gordon shale 221'							
			Flathead sandstone 94'							

Figure 3.

Correlation Chart of the Belt Series.

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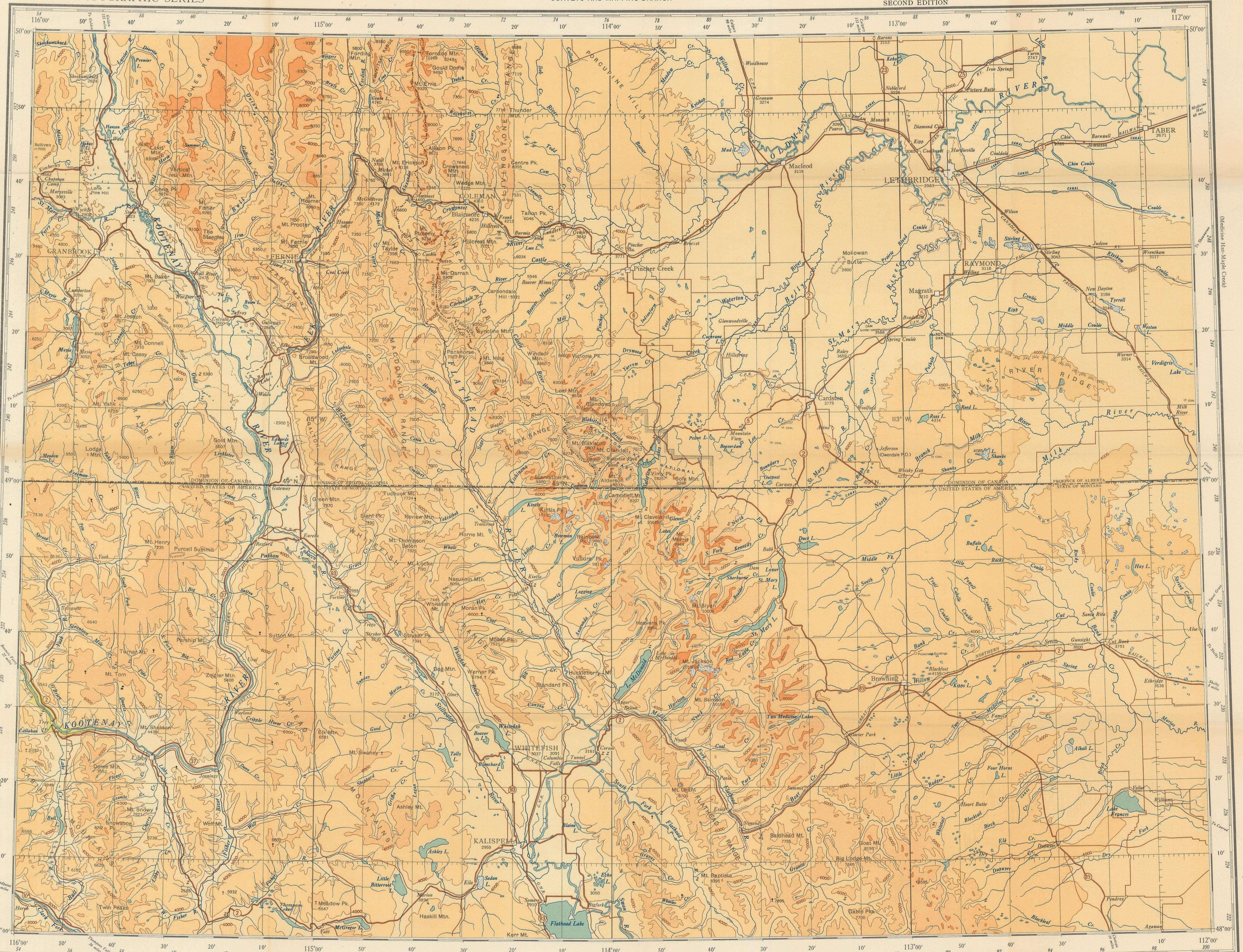
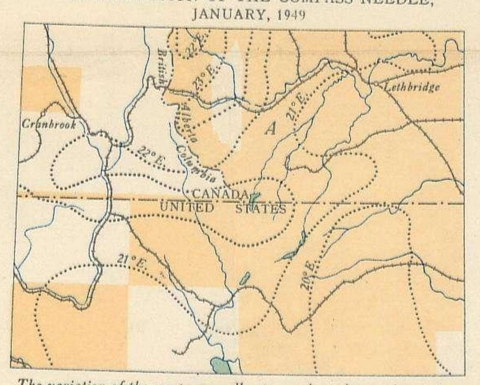


THE VARIATION OF THE COMPASS NEEDLE, JANUARY, 1949



The variation of the compass needle at any place along a dotted line is the variation given on that dotted line. At other places the variation is between those given on the neighbouring dotted lines; thus at the place marked A, because it is halfway between the two dotted lines marked 21° E. and 22° E., the variation is 21°30′ east of true north.
The variation of the compass needle is decreasing 3 minutes annually.
The areas accurately mapped and contoured shown thus .....

REFERENCE

Boundary international
" provincial or state
" township
" national park
Railway: steam, double track
" " single track — station
Abandoned railway grade
Main highways with route numbers — 1
Secondary roads
Marsh or swamp
Non-permanent lake
Glacier
Cities and large towns
Towns and villages
Mine
Height in feet — 3000
Lookout tower — *with telephone* T.
Ranger cabin — *with telephone*

CRANBROOK – LETHBRIDGE

BRITISH COLUMBIA–ALBERTA

Scale 8 miles to 1 inch or 1 : 506,880

Miles 8 6 4 2 0 8 16 24 32 Miles

NOTE: Grid squares may be drawn on this map by joining the corresponding divisions shown along the outer border. The even number of the squares are given along the outer border.

Price 25 cents

Copies may be obtained from the Map Distribution Office, Department of Mines and Technical Surveys, Ottawa.

ALTITUDE TINTS

1000 2000 3000 4000 6000 8000 Above 8000

Datum is mean sea level.

Compiled, drawn and printed at the office of the SURVEYOR GENERAL AND CHIEF, HYDROGRAPHIC SERVICE, Ottawa, 1938.
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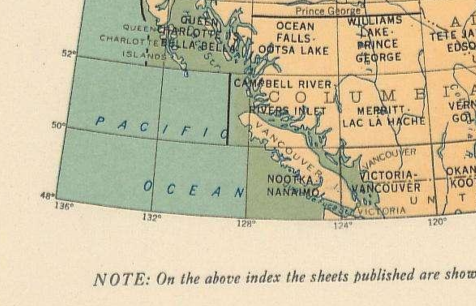

NOTE: On the above index the sheets published are shown tinted in colour.