PROVINCE OF ALBERTA

RESEARCH COUNCIL OF ALBERTA

BULLETIN 21

STRATIGRAPHY AND PETROLOGY OF THE LOWER CRETACEOUS BLAIRMORE AND MANNVILLE GROUPS, ALBERTA FOOTHILLS AND PLAINS

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Edmonton
1967

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Stratigraphy and Petrology of the Lower Cretaceous Blairmore and Mannville Groups, Alberta Foothills and Plains

ABSTRACT

The Lower Cretaceous Blairmore Group of the Alberta Foothills is a thick wedge of nonmarine detrital strata divisible into three formational units that correlate with the Mannville Group and overlying Joli Fou-Viking (Bow Island) succession of the Plains. The lower unit comprises a widespread basal conglomerate overlain by thin-bedded siliceous sandstone and dark silty shale, correlative with quartzose sandstone and shale in the lower part of the Mannville Group (McMurray Formation) in the Plains. The middle unit consists of thick, lensing, green, feldspathic sandstone, siltstone, and varicolored shale, with thin tuff and bentonite interbeds. These beds grade eastward into grey, feldspathic sandstone, dark silty shale, and thin coal beds that form the upper part of the Mannville Group in the Plains. The upper unit consists of lensing, grey, siliceous sandstone, siltstone, and varicolored shale, grading up in the southernmost Foothills into a thick succession of bedded pyroclastic detritus (Crowsnest Member). These beds grade laterally in the southwestern Plains into marine sandstone and shale of the Bow Island Formation but are absent to the north in the central Foothills owing to nondeposition or erosion.

The lower and middle Blairmore successions contain the same non-dicotyledonous flora which in the north-central Foothills and in the upper Mannville beds of the Plains is associated with foraminifera of middle Albian age. The upper Blairmore unit contains a dominantly dicotyledonous flora, correlating via the Bow Island Formation with the middle to late Albian Joli Fou-Viking succession of the central Plains. Together with the change in sandstone composition at the middle-upper Blairmore boundary, the marked difference in composition of the two Blairmore floras indicates a prominent break in deposition in the Alberta Foothills at the end of middle Blairmore time.

Petrographic analyses of both Foothills and Plains sandstones show that major changes in the detrital composition of the Blairmore-Mannville rocks coincide with formation boundaries. Sandstones from the lower and upper parts of the Blairmore Group contain abundant siliceous sedimentary or metasedimentary detritus, whereas those from middle Blairmore and upper Mannville strata contain abundant volcanic detritus. The volcanic material apparently originated from vents along the western margin of the depositional basin in southeastern British Columbia, spreading to the north and east across the Alberta Plains into western Saskatchewan.

Authigenic constituents, present as locally derived clastic material and as intergranular cements, also show marked differences in stratigraphic and geographic distribution. The distribution of silicate cements can be related partly to differences in the composition of the associated detritus, kaolinite and quartz being typical of the siliceous sandstones in the lower and upper parts of the Blairmore Group, and chlorite, illite, and laumontite of the volcanic sandstones in the middle part. However, the absence of chlorite cement from the coal-bearing middle Blairmore beds of the central Foothills and from the upper Mannville sandstones of the Plains, together with other evidence, shows that silicate cement composition is related to physico-chemical factors associated with deposition and later burial, as well as detrital composition. The distribution of authigenic dolomite and siderite also can be related to depositional factors, whereas calcite is erratically distributed as a sandstone cement in all the formations examined.

Variation in gross lithology, sandstone composition, and fossil content of the Blairmore and Mannville Groups can be used to divide the rocks into several laterally interfingering facies that are discordant with and in places cut across formation and time boundaries. Lower and middle Blairmore and correlative Mannville strata together form a major transgressive-regressive cycle of deposition associated with the invasion of the boreal Clearwater Sea, nonmarine, fluviatile sediments being present in the south and predominantly marine and shoreline sediments in the north. Upper Blairmore and correlative Plains strata form a separate cycle of sedimentation related to the northward transgression of the Gulfian Colorado Sea, exhibiting facies aspects similar to those of the underlying succession, but with a different paleogeographic distribution.

INTRODUCTION

Scope of the Report

Sedimentary rocks of Early Cretaceous age underlie the larger portion of the Western Canada Sedimentary Basin, including most of the province of Alberta and adjacent parts of northeastern British Columbia and southern Saskatchewan. Throughout the history of geologic exploration in this region, these strata have been the subject of considerable economic interest, originally for their coal deposits in the Rocky Mountains and Foothills, and more recently for their oil and gas deposits in the subsurface of the Plains.

This report describes the results of a stratigraphic and petrographic study of the Lower Cretaceous Blairmore and Mannville Groups of the Alberta Foothills and Plains. The investigation was restricted initially to the Blairmore Group in the outcrop belt of the southern and central Foothills but was extended later to include the subsurface Mannville Group of the central and northeastern Alberta Plains. The objective of the study is to define and correlate from lithologic, petrographic, and paleontologic data the various formational units and the facies into which these strata can be divided.

The report is divided into three parts. The first part describes the stratigraphy and age relationships: the formational units into which the Blairmore and Mannville Groups can be divided and their relationship to probable time-datum planes. The distribution of rock units and their floral and faunal assemblages is shown with the help of cross sections, and correlations with equivalent marine beds of the northern Plains and Foothills are discussed. The second part describes and compares the petrographic properties of the sandstones and discusses their origin and diagenesis. The third part presents a synthesis of the results, in which the relationships among formations, facies, and time units are defined in terms of the lithologic, petrographic, and paleontologic properties of the rocks.

Distribution and Sampling Localities

Rocks of the Lower Cretaceous Blairmore Group and correlative units have a wide distribution in Alberta. Near the southwestern margin of the province they form a wedge of detrital strata 1000 to 4000 feet thick that crops out along the strike of the Rocky Mountains Foothills. They thin to the east, underlying all of the southern and central Plains, where they are present only in the subsurface, and most of the northern Plains, where they crop out along the lower Peace and Athabasca Rivers and their tributaries.

Figure 1 shows the distribution of sampled outcrop and well sections with reference to the main physiographic and geographic divisions of the province.

Three complete or nearly complete sections (Mill Creek, Sheep River, and Ram River) and one partly exposed section (Cadomin) of the Blairmore Group in the southern and central Foothills were measured and sampled in 1956 and 1957. Samples from these sections, selected initially as standard or "type" sections for their respective regions of the Foothills, provided the basic petrographic and paleontologic data for dividing the Blairmore Group into component formations and facies. In addition, several partial sections of the Blairmore Group in adjacent parts of the southern and central Foothills were examined or sampled in 1956 and 1957, and later in 1960, to gain further stratigraphic control. The Lower Cretaceous section in the northern Foothills, at Belcourt Ridge, British Columbia, was sampled in 1960, mainly to determine the relationship of the partly marine Moosebar and Commotion Formations of this region to the continental succession of the southern and central Alberta Foothills.

Correlative strata of the Plains have been sampled at several widely spaced localities. Several cored sections of the subsurface Mannville Group from central and northeastern Alberta were sampled in 1959 to obtain petrographic and microfaunal data for comparison with Foothills sections. Outcrops of the Lower Cretaceous section exposed along the lower Peace River (Cadotte, Harmon, Notikewin, and Loon River Members and Formations) also were sampled in 1959, mainly for their microfaunal content. Recently, drilling samples of the Blairmore Group in the Turner Valley-Okotoks region of southwestern Alberta were examined

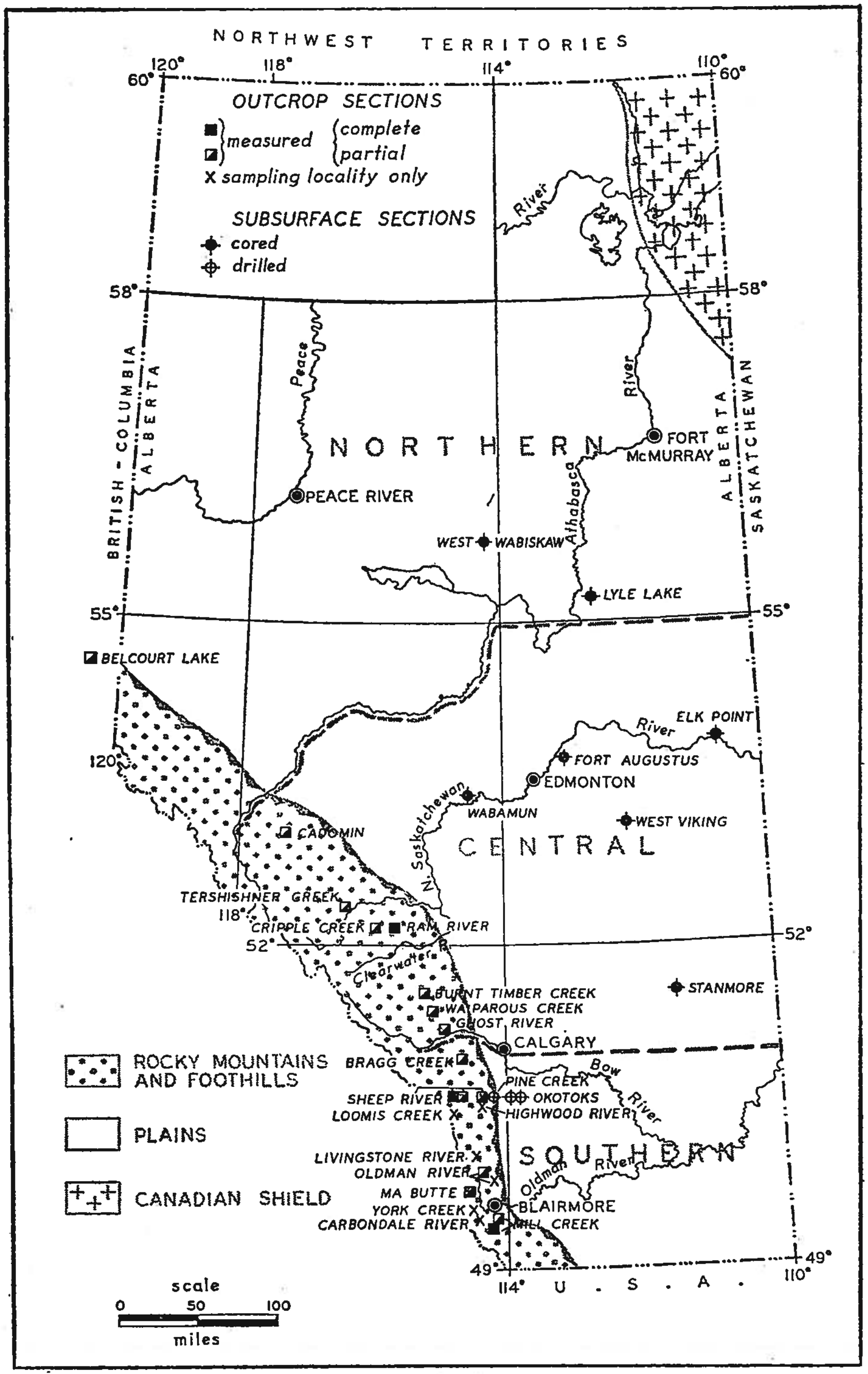

FIGURE 1. *Map showing the locations of sampled outcrop and subsurface sections of the Blairmore and Mannville Groups with reference to the major physiographic divisions of Alberta.*

to determine the relationship of the marine Bow Island Formation of the Plains to the Blairmore and basal Blackstone beds exposed in the Foothills to the west.

Previous Work

The Blairmore Group and correlative rock units of the Plains and northern Foothills have been studied at numerous localities throughout Alberta and northeastern British Columbia. The broader outlines of the stratigraphy of these rocks in the outcrop regions of the Foothills and northern Plains were first described by officers of the Geological Survey of Canada, engaged in reconnaissance geological surveys of Western Canada during the period between 1870 and 1914. Much additional data from these regions has been published subsequently, mainly in reports dealing with coal deposits of the Foothills and in map-area reports of the Foothills and northern Plains.

Various papers dealing specifically with the paleontology and stratigraphy of the Blairmore and Mannville Groups also have been published. The megaflora of the Blairmore Group in the Foothills was described initially by Berry (1929) and later by Bell (1956). The microflora from the lower part of the Blairmore Group and correlative strata of the Foothills and Plains has been described by Pocock (1962), and that of the Mannville Group by Singh (1964). The nonmarine megafauna of the Blairmore Group was described initially by McLearn (1929), and the associated nonmarine microfauna from both the Blairmore and Mannville Groups ("ostracode zone") by Loranger (1951). Lists of microfauna from various stratigraphic levels in the Blairmore and Mannville Groups also have been published by Mellon and Wall (1963).

Regional correlation of the Lower Cretaceous succession in the Western Canada Interior was first attempted by McLearn (1932, 1944). Interest in these rocks increased rapidly in the years following World War II owing to the search for oil and gas, with the result that several regional stratigraphic studies of the Blairmore and Mannville Groups and correlative strata have been published: the Mannville Group of east-central Alberta (Nauss, 1945); the Mannville Group and correlative strata of the central and northern Alberta Plains (Badgley, 1952); the Blairmore and Mannville Groups of the southern Alberta Foothills and Plains (Glaister, 1959); the Blairmore and Mannville Groups of the Alberta Foothills and central Plains (Mellon and Wall, 1963); the Lower Cretaceous strata of the northeastern British Columbia Foothills (Stott, 1963); the Mannville Group of the central Alberta Plains (Williams, 1963); and the McMurray Formation of northeastern Alberta (Carrigy, 1963). These investigations are concerned mainly with the correlation and distribution of gross lithologic units, although the petrographic properties of the rocks are discussed briefly by Glaister and by Mellon and Wall, and in greater detail by Williams and by Carrigy.

Acknowledgments

Part of the results incorporated in the report, dealing with the petrography of the Blairmore Group sandstones in the Foothills, forms the basis of a doctoral thesis submitted to the Pennsylvania State University in 1959. In this connection the writer gratefully acknowledges the generous assistance and advice of the late Professor P. D. Krynine, Department of Mineralogy and Petrology, Pennsylvania State University, under whose guidance the thesis was prepared.

Dr. C. R. Stelck, University of Alberta, identified the megafloral and megafaunal collections listed in the report, and Dr. J. H. Wall, Research Council of Alberta, helped sample cored sections of the Mannville Group and identified microfaunal collections connected with the investigation. To both of these individuals the writer is indebted for much friendly advice and discussion during the course of the investigation. The writer also thanks other colleagues at the Research Council, Mr. M. A. Carrigy and Dr. R. Green, for many helpful suggestions in preparing the manuscript for publication.

Messrs. K. Sanderson, G. Craig, and G. M. Gabert gave capable assistance during the field seasons of 1956, 1957, and 1960, respectively.

STRATIGRAPHY

Historical Review

Foothills

Lower Cretaceous rocks of the southern Alberta Foothills were first examined in some detail by G. M. Dawson (1886), who divided them into a lower coal-bearing series of sandstones and shales and an upper "barren" series of detrital strata, overlain in the Crowsnest Pass (Blairmore) region by a thick succession of tuffs and agglomerates. Dawson recognized the presence of two distinct floras in these rocks: an older, non-dicotyledonous flora from the lower, coal-bearing succession, and a younger, dicotyledonous flora from the upper part of the overlying "barren" series. The plant-bearing beds were separated stratigraphically by the lower part of the "barren" series, from which no fossils were obtained. On this basis Dawson (*ibid.*, p. 166) divided the rocks into a lower "Kootanie series", which included the coal-bearing beds and the unfossiliferous part of the overlying "barren" beds, and an upper "Dakota" unit, which included the dicotyledon-bearing strata between the "Kootanie series" and (where present) the overlying pyroclastic beds (Fig. 2).

At the same time Sir William Dawson, from a study of G. M. Dawson's plant collections, suggested a threefold division of the Lower Cretaceous of the southern Foothills based on the implied succession of fossil floras (J. W. Dawson, 1886): a lower "Kootanie series", an "Intermediate series", and an upper "Mill Creek series". The flora of the "Kootanie series" was composed entirely of non-dicotyledonous remains, whereas both the "Intermediate" and "Mill Creek" floras, collected from exposures along Oldman River and Mill Creek, north and south of the Crowsnest Pass respectively, contained dicotyledons. However, neither the boundaries nor the stratigraphic relationships of these "series" were defined in lithologic terms, and none gained acceptance as a formational unit.

Later investigators working in the coal basins of southwestern Alberta and adjacent British Columbia emended G. M. Dawson's (*op. cit.*) "Kootanie series" to include only the lower coal-bearing beds, later renamed the Kootenay Formation by Leach (1912). Dawson's "Dakota" unit also was revised to include the upper, "barren" part of the "Kootanie series" as well as the overlying dicotyledon-bearing beds. In this sense the two terms "Kootanie" (later Kootenay) and "Dakota" were applied as formational names to nonmarine Lower Cretaceous strata throughout the Alberta Foothills prior to 1914.

The term "Blairmore formation" was first used by Leach (1914) for a succession of nonmarine sandstones and shales exposed in the Foothills of southwestern Alberta, near Blairmore in the Crowsnest Pass (Fig. 1), which he had mapped previously as the "Dakota(?) formation". As originally defined, the Blairmore Formation included about 2000 feet of beds above a quartzite- and chert-pebble conglomerate at the top of the coal-bearing Kootenay Formation and below the succession of tuffs and agglomerates which Leach called the "Crowsnest volcanics". This definition was emended subsequently by Rose (1917), who included the conglomerate bed at the top of the Kootenay in the base of the Blairmore Formation, recognizing that a local disconformity is present at the base rather than the top of the conglomerate (Fig. 2). Neither Leach nor Rose recognized any lithologic break in the Blairmore succession of the Crowsnest Pass region, although McLearn (1916) noted a marked difference between the floras from the lower and upper parts of the formation, later confirmed by Berry (1929). However, McLearn (1929, p. 82) later stated that the marked break in the Blairmore floral succession did not appear to be associated with any change in lithology, and the formation was considered until recently to be a more or less homogeneous rock unit in the southern Alberta Foothills.

A short distance north of the Crowsnest Pass, the tuffs and agglomerates overlying the Blairmore Formation, now called the Crowsnest Formation, thin and disappear as a mappable unit, so that north of Oldman River in township 12, later investigators have placed the upper boundary of the Blairmore at the contact with the overlying marine shales of the Alberta Group (Benton or Colorado Shale of earlier reports). Thus, within the Foothills from the International Boundary to the Clearwater River, a distance of 200 miles, the name Blairmore has been used to designate those strata between the coal-bearing beds of the Kootenay Formation below and either the pyroclastic rocks of the Crowsnest Formation or the marine shales of the Alberta Group above.

No formal subdivision of the Blairmore succession in the southern Alberta Foothills has been proposed, although the formation has been accorded group status in recent years. However, several writers have described various lithologic units which, locally at least, can be used as stratigraphic markers. Some of the names associated with these units originated as drillers' terms in the Turner Valley oilfield and were subsequently used by Hume (1930, *et seq.*) in his descriptions of the Blairmore Formation in the Foothills southwest of Calgary. Hume (1938, 1939) divided the Turner Valley Blairmore succession into a lower and an upper part, using the top of a whitish quartzose sandstone that he called the Home Sand as the boundary (Fig. 2). The lower Blairmore was described as a succession of dark shales and calcareous sandstones with a coarse quartzose sandstone called the Dalhousie Sand at the base. The upper Blairmore consists of green and grey sandstones and shales with two locally developed sandy zones—the McDougall-Segur Sand and Stockmen's Sand—near the top of the formation.

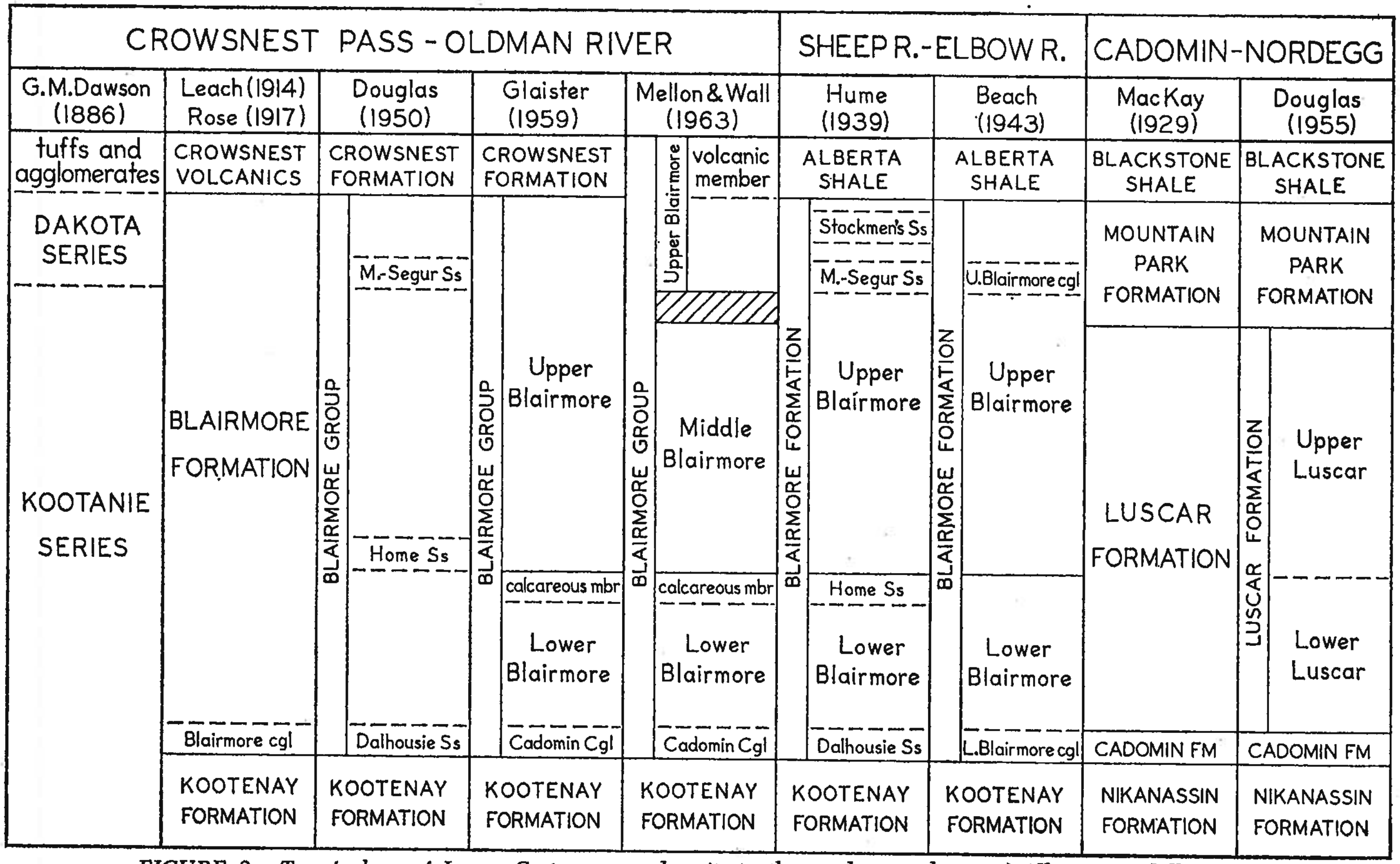

FIGURE 2. Terminology of Lower Cretaceous rock units in the southern and central Alberta Foothills.

Other investigators in the southern Foothills, except Douglas (1950), have not recognized the Home Sand outside of Turner Valley, although several have used thin but widespread fossiliferous calcareous beds present at or near the same level as the Home Sand to divide the Blairmore Group into informal lower and upper parts (Beach, 1943; Allan and Carr, 1947; Glaister, 1959). These beds, called the "calcareous" member by Glaister (*ibid.*), are widely distributed in the southern and central Foothills and extend into the subsurface Blairmore and Mannville Groups of the Plains, where they are commonly called the "ostracode zone" (Hunt, 1950). In contrast to the twofold division recognized by other investigators, Mellon and Wall (1963) have pointed out that the Blairmore Group of the southern Foothills can be divided into three distinct mappable units on the basis of sandstone composition and floral content, and that the overlying volcanic Crowsnest Formation of the southernmost Foothills is properly a member of the dicotyledon-bearing "upper Blairmore" formation. However, none of the various mappable units into which the Blairmore Group of the southern Foothills can be divided has been given a formal stratigraphic name.

In the central Alberta Foothills north of the Clearwater River, commercial coal beds are found in strata correlative with the lower and middle parts of the Blairmore Group in the southern Foothills, whereas they are thin in or absent from underlying Kootenay-equivalent strata. Because of their coal deposits these beds had been mapped as "Kootenay", until MacKay (1929a), recognizing their true relationship to the Kootenay-Blairmore succession to the south, suggested a new nomenclature for the nonmarine Lower Cretaceous strata of the north-central Foothills.

MacKay (*op. cit.*) divided the nonmarine Lower Cretaceous succession of the Cadomin and Mountain Park areas into four mappable units, which he called, in descending order, the Mountain Park, Luscar, Cadomin, and Nikanassin Formations (Fig. 2). He subsequently defined these units as follows (MacKay, 1930):

(1) *Mountain Park Formation* (400 feet): coarse, green, ridge-forming sandstone and green shale with lenses of chert-pebble conglomerate;

(2) *Luscar Formation* (1700 feet): soft grey sandstone and dark grey shale with commercial coal beds;

(3) *Cadomin Formation* (35 feet): resistant chert- and quartzite-pebble conglomerate;

(4) *Nikanassin Formation* (1900 feet): grey sandstone and dark grey shale with thin shaly coal beds.

Previous workers (Malloch, 1911; Allan and Rutherford, 1924) had mapped the coal-bearing beds—including the Nikanassin, Cadomin, and Luscar Formations—as "Kootenay Formation", but, as MacKay (*op. cit.*)

pointed out, although the Nikanassin flora is similar to the Kootenay flora of the southern Foothills, the Luscar flora is similar to the non-dicotyledonous flora found in the lower part of the Blairmore Group in the Crowsnest Pass. The Cadomin Formation was used, in the absence of other evidence, to differentiate the Nikanassin and Luscar Formations, being correlated on the basis of lithology and stratigraphic position with the basal Blairmore conglomerate of the southern Foothills.

The Mountain Park Formation is overlain sharply but conformably in the type area by marine shale of the Blackstone Formation, equivalent strata in the central and northern Foothills having been mapped previously as "Dakota Formation" (Malloch, *op. cit.;* MacVicar, 1920), "Sunset Sandstone" (MacVicar, 1924), and "MacLeod Member" (Allan and Rutherford, *op. cit.*). No floral remains were collected from the Mountain Park, and its relationship to the underlying Luscar Formation and to the Blairmore Group of the southern Foothills has remained somewhat obscure (Bell, 1956). MacKay (1929b) himself was unable to distinguish between the Luscar and Mountain Park Formations in the Brûlé coal basin north of Cadomin, and subsequent workers in adjacent parts of the central and northern Foothills, with the notable exception of Douglas (1955, 1958), generally have not recognized the Mountain Park as a discrete lithologic unit, including correlative strata with the underlying Luscar Formation for mapping purposes.

Plains

Lower Cretaceous strata of the Alberta Plains are exposed only in the northern part of the province, along the lower Athabasca and Peace Rivers and their tributaries, where they form a succession of nonmarine and marine sandy and shaly units up to 1500 feet thick.

The Athabasca River section, first described in some detail by McConnell (1893) and later by McLearn (1917) and Wickenden (1949), can be divided into five formational units, which are, in descending order (Fig. 3):

(1) *Pelican Sandstone*: marine sandstone and siltstone;

(2) *Joli Fou Shale*: dark grey marine shale;

(3) *Grand Rapids Formation*: feldspathic sandstone and siltstone with minor shale and lignite; shoreline to nonmarine;

(4) *Clearwater Formation*: glauconitic sandstone at base, overlain by dark grey shale, grading up into sandstone; marine;

(5) *McMurray Formation*: oil-impregnated quartzose sandstone and silty shale; nonmarine to shoreline.

The complete section of Lower Cretaceous strata along the lower Peace River was first described by McLearn (1919), who divided the succession into a lower shaly unit (Loon River Formation) and an upper sandy unit (Peace River Formation). Wickenden (1951) later redescribed the upper part of the succession, and Badgley (1952) subsequently emended Wickenden's outcrop divisions to include units recognizable in the subsurface of the Peace River region. Badgley's (*ibid.*) formational units are, in descending order (Fig. 3):

(1) *Peace River Formation*: divisible into a lower marine shale member (Harmon), a middle marine sandstone member (Cadotte), and an upper "continental" sandstone member (Paddy);

(2) *Spirit River Formation*: divisible into a lower marine shale member (Wilrich), a middle marine silty shale member (Falher), and an upper marine sandstone member (Notikewin);

(3) *Bluesky Formation*: marine glauconitic sandstone (present only in the subsurface);

(4) *Bullhead(?) Group*: nonmarine sandstone, shale, and coal; now commonly called the Gething Formation (present only in the subsurface).

In the Plains of central Alberta, Lower Cretaceous strata are known only from well samples. Before 1945 the succession of dominantly nonmarine strata between the Paleozoic carbonate rocks below and Cretaceous marine shales above was described commonly as "undivided Lower Cretaceous", although fossil evidence for such an age designation was lacking (Hume and Hage, 1941).

The first formal division of these rocks was proposed by Nauss (1945), who suggested the name Mannville Formation for the succession of sandstone, shale, and coal in east-central Alberta lying unconformably on Devonian strata and beneath marine shales of the Colorado Group (which Nauss called the Lloydminster Shale). Nauss divided the Mannville Formation into six members (Fig. 3), distinguished by differences in lithology and sandstone composition. The basal Dina Member consists mainly of uncemented quartz sand filling low areas in the underlying Paleozoic surface. The Cummings Member is a thin marine shale, which Nauss correlated with the Clearwater Formation of the lower Athabasca River area. The upper four members comprise a succession of sandstone, shale, and coal, dominantly of nonmarine origin, but none of these units appears to have any regional extent.

Knowledge of the nature and distribution of Lower Cretaceous strata of the central Alberta Plains increased rapidly following the discovery of oil in the Leduc area, south of Edmonton, in 1947. Layer *et al.* (1949) proposed an informal threefold division of the pre-Colorado Group Cretaceous strata of the Leduc area into a lower "quartz sand series" containing a fossiliferous calcareous shale unit at the top, an intermediate "glauconitic sand series", and an upper "coaly series". Hunt (1950) sub-

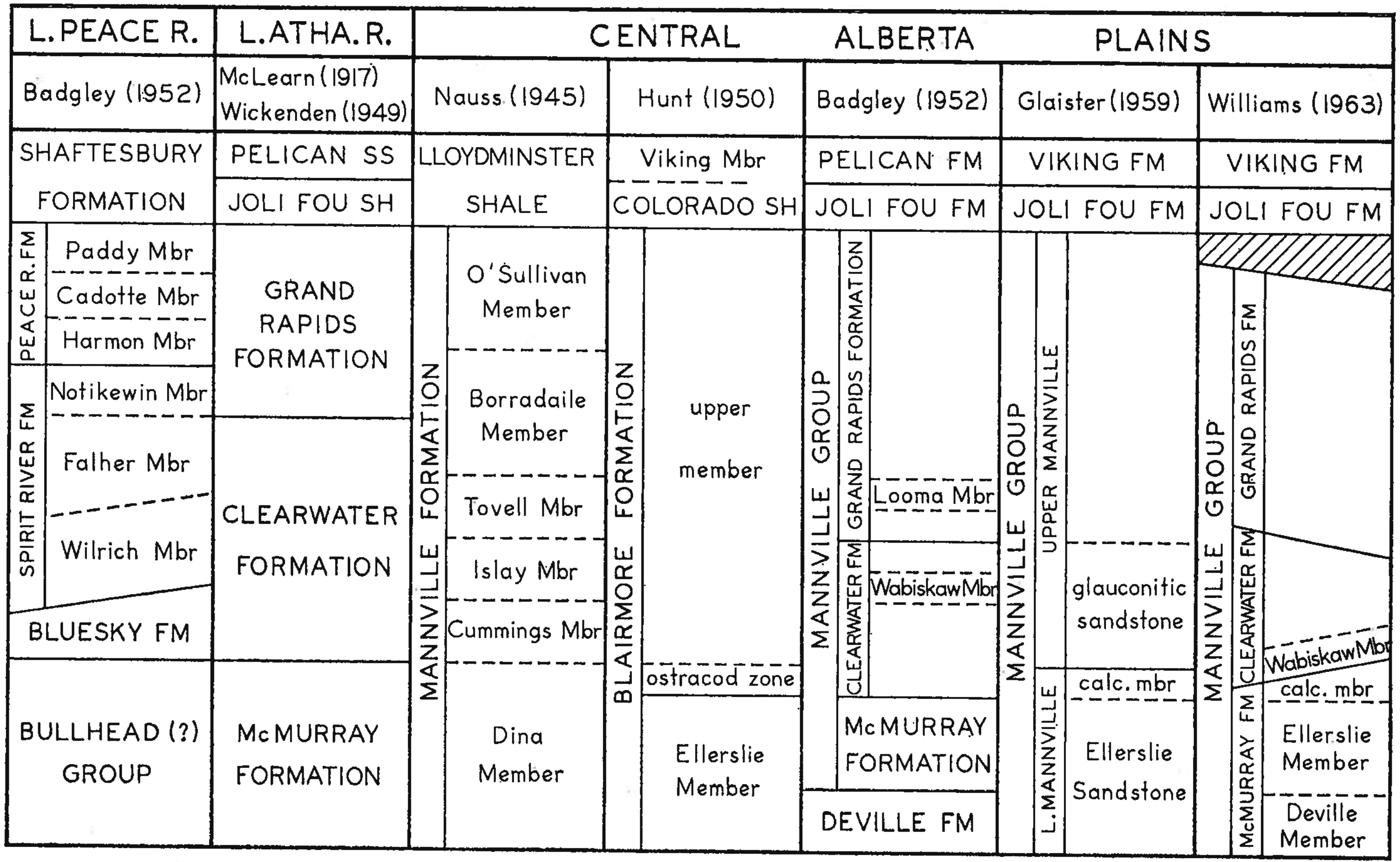

FIGURE 3. Terminology of Lower Cretaceous rock units in the central and northern Alberta Plains.

sequently correlated the Lower Cretaceous of the Leduc area with the Blairmore Formation of the Foothills, dividing the rocks into a lower Ellerslie Member and a "deltaic upper member" (Fig. 3). Hunt's Ellerslie Member is equivalent to the "quartz sand series" of Layer *et al.* (*ibid.*), excluding the fossiliferous shales at the top, and his "deltaic upper member" to the "glauconitic sand series" and "coaly series" of Layer *et al.* Hunt included the fossiliferous shales at the top of the "quartz sand series" in his "deltaic upper member", calling them the "ostracode zone", a name that since has gained wide usage in drilling terminology.

In contrast to Hunt's (*op. cit.*) usage of the Foothills name "Blairmore Formation", Badgley (1952) extended Nauss's (*op. cit.*) term "Mannville Formation" to include the pre-Colorado Group Cretaceous strata of the central Plains, raising the unit to group status. Although Badgley kept some of Nauss's member names for local lithologic units in east-central Alberta, he divided the Mannville Group into three formations corresponding to those of the lower Athabasca River area: the McMurray, Clearwater, and Grand Rapids Formations (Fig. 3). Badgley's McMurray Formation comprises the basal quartzose sands and shales beneath the "ostracode zone" and is equivalent to Hunt's (*op. cit.*) Ellerslie Member, excluding locally developed residual detritus at the base which Badgley called the Deville Formation. The "ostracode zone"—renamed the *Metacypris persulcata* Zone by Loranger (1951) and the *Metacypris angularis* Zone by Badgley (1952)—was recognized as a mappable unit, although its stratigraphic position remained ambiguous, for Badgley stated that the zone, generally found in his Clearwater Formation, is present in some wells in the top of the McMurray Formation. Badgley correlated the glauconitic sandstone and marine shale above the McMurray Formation with the Clearwater Formation, and the nonmarine beds above the Clearwater with the Grand Rapids Formation. However, he pointed out that the Clearwater-Grand Rapids contact is gradational and probably transgressive, and that "it might have been preferable to recognize these units as lithofacies of a combined Grand Rapids-Clearwater interval rather than as separate formations".

This suggestion was adopted by Glaister (1959) and Mellon and Wall (1963), who divided the Mannville Group into a lower and an upper formation, using the top of the "ostracode zone" (=Glaister's [*ibid.*] "calcareous" member) as the boundary (Fig. 3). However, Williams (1963) preferred to use Badgley's (*op. cit.*) formational names for the Mannville Group of the central Alberta Plains, redefining the McMurray Formation to include Badgley's Deville Formation at the base and Glaister's "calcareous" member at the top (Fig. 3). Thus, there is no general agreement as to the formational names or boundaries currently applied to the Mannville Group of the central Alberta Plains; Glaister's and Mellon and Wall's names are informal, whereas Badgley's and Williams' Clearwater and Grand Rapids Formations are laterally interfingering facies of the same formation, the contact between the two units being gradational and variable in stratigraphic position.

Blairmore Group

Crowsnest Pass

Rocks of the Blairmore Group crop out extensively in the Rocky Mountains and Foothills of southwestern Alberta, extending westward in the Crowsnest Pass region into the Fernie coal basin of adjacent British Columbia. They form a wedge of nonmarine detrital strata that thickens across the strike of the folded belt from 1000 to 1200 feet near the eastern edge of the Foothills in Alberta to possibly more than 5000 feet in the Fernie area (Rose, 1918; Norris, 1964).

Although the group has been mapped or examined at many localities in this region, most investigators, including Leach (1914), who named the unit, have described the rocks only in the most general terms. Only recently has any attempt been made to distinguish among the several mappable lithologic units into which the Blairmore Group of the southern Foothills can be divided.

The petrographic basis for lithologic division of the group in the Foothills of southwestern Alberta was described briefly by Douglas (1950), who correlated some of the thicker arenaceous units of the Blairmore Group in the Gap map-area north of the Crowsnest Pass with sandstones from similar stratigraphic levels in the subsurface Blairmore succession at Turner Valley. Glaister (1959) divided Blairmore sections on Mill Creek and Oldman River into two formations, using the top of thin, fossiliferous, calcareous beds 250 to 450 feet above the base of the group as a boundary between the two units. Both Douglas and Glaister regarded the overlying Crowsnest volcanic beds as a separate formation.

More recently Mellon and Wall (1963) divided the Blairmore Group of the Crowsnest Pass region into three formational units, which they called informally the lower, middle, and upper Blairmore formations. The upper boundary of the group was revised to include the Crowsnest volcanic beds as a member of the "upper Blairmore" formation and was placed at the contact with the overlying marine shale of the Alberta Group. These units are characterized not only by differences in lithology and sandstone composition, but also by differences in floral content, and can be traced along the strike of the southern Foothills to just north of the Bow River, a distance of about 140 miles.

Several sections of the Blairmore Group were measured or examined in the general Crowsnest Pass (Blairmore) region (Fig. 1), but only one of these, exposed along Mill Creek and its tributary, Gladstone Creek, in Tp. 5, R. 2, W. 5th Mer., is complete. This section is proposed as a composite type section of the Blairmore Group and can be divided into the lithologic units described in table 1. At this locality, 12 miles south of Lundbreck in the Crowsnest Pass, Blairmore strata are repeated by imbricate thrust faults to form three closely spaced sections exposed along the crest of a southeast-plunging anticlinal structure (Hage, 1943). The group is not completely exposed in any of the three sections (called here the eastern, central, and western sections, respectively), but a nearly complete composite section can be obtained (Fig. 4)[1]. The upper part of the group, including the Crowsnest Member, also is exposed several miles downstream, on the crest of a small anticline, in Tp. 6, Rs. 1 and 2, W. 5th Mer.

Gladstone Formation

At the type locality in the central section on Gladstone Creek, the lower Blairmore unit, for which the name Gladstone Formation is proposed (Table 1), is 250 feet thick. In the eastern section on Mill Creek, Glaister (1959, section A-A′) obtained a thickness of about 275 feet, although the middle part of the formation is not exposed there.

In most parts of the southern Foothills, the Gladstone Formation can be divided into three parts, which are, in descending order:

(1) interbedded dark grey calcareous shale and silty limestone, with abundant freshwater invertebrates ("calcareous" member);

(2) dark grey, green, and red shale interbedded with dark grey calcareous siltstone and fine-grained sandstone;

(3) pale grey, coarse- to medium-grained siliceous sandstone, conglomeratic in most parts of the Foothills (basal member).

The basal unit on Gladstone Creek is 43 feet thick and consists of hard, brown-weathering, grey, medium-grained, crossbedded, quartzose, cherty sandstone lying disconformably on black shales and thin coal beds of the Kootenay Formation. The unit, correlative with the Dalhousie Sand of Turner Valley and the Cadomin Conglomerate of the north-central Foothills, is present at the base of the Blairmore Group throughout the folded belt, becoming thicker and coarser-grained towards the west. It is conglomeratic in most regions of the Foothills, containing pebbles and cobbles of white and pink quartzite and green, grey, and black chert and argillite in a coarse sandy matrix.

Towards the western margin of the outcrop belt, in the Rocky Mountains proper, several thick conglomerate beds appear in the lower part of

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[1] The lower part of the section, from 1050 to 1770 feet below the base of the Blackstone Formation, was measured in the central fault block on Gladstone Creek, in section 26, township 5. The central part of the section, from 580 to 1050 feet below the Blackstone contact, was measured in the eastern fault block on Mill Creek, in section 25, township 5, where Glaister (1959) measured his Blairmore section. The upper part of the section, to 580 feet below the Blackstone contact, was measured in the western fault block on Mill Creek, in section 13, township 5.

Table 1. Lithologic Divisions of the Type Blairmore Group and Adjacent Strata in the Crowsnest Pass Region, Southwestern Alberta

Group	Formation	Member	Lithology	Sandstone Composition	Fossil Content
ALBERTA	BLACKSTONE	SUNKAY	dark grey marine siltstone, shale	quartzose, cherty	*Dunveganoceras* spp. *M. manitobensis*
BLAIRMORE	MILL CREEK[1]	CROWSNEST	tuff, agglomerate	feldspathic, tuffaceous	dicotyledonous ("upper Blairmore") flora
			nonmarine varicolored shale, grey sandstone	quartzose, cherty	
	BEAVER MINES[1]		nonmarine varicolored shale, green sandstone; igneous pebble conglomerate	feldspathic; abundant volcanic detritus and chlorite cement	non-dicotyledonous ("lower Blairmore") flora; freshwater invertebrates
	GLADSTONE[1]	"calcareous" member	dark grey calc. shale, freshwater limestone		
			nonmarine varicolored shale, grey sandstone	quartzose, cherty, dolomitic	
		basal member	sandstone, conglomerate	quartzose, cherty	
	KOOTENAY		nonmarine dark grey shale, sandstone; coal	quartzose, cherty	non-dicotyledonous flora

[1] Proposed new names.

the Blairmore Group as well as in the upper part of the Kootenay Formation. Such a succession of conglomerates was first mapped by Leach (1902) in the Flathead area of southeastern British Columbia and later was correlated by Rose (1918) and MacKay (1934) with the basal beds of the Blairmore Group to the east. Newmarch (1953) described a succession of conglomerates (Elk Formation) from the nearby Fernie area to which he ascribed a Kootenay age on floral and lithologic evidence, distinguishing them from the overlying basal Blairmore beds, also conglomeratic. Similar conglomeratic beds present near the headwaters of the Highwood River in southern Alberta have been placed in the Blairmore Group (Pocaterra Member) by Allan and Carr (1947) and in the Kootenay Formation by Crockford (1949). However, from descriptions of these beds, both those near Fernie and on Highwood River, there does not appear to be any difficulty in distinguishing between upper Kootenay and basal Blairmore strata in the western outcrop regions; the Blairmore conglomerates differ from the Kootenay (or Elk) conglomerates both in composition and in the color of the associated shales (Newmarch, *ibid.*). Thus, Newmarch's Elk Formation appears to be a conglomeratic phase in the upper part of the Kootenay Formation, whereas the Pocaterra Member of Allan and Carr is the basal phase of the Blairmore succession. The "Elk conglomerates" of earlier investigators probably includes both Kootenay and Blairmore strata. Nowhere, however, is there any evidence to indicate a gradation between the two formations.

The upper contact of the basal sandstone is covered on Gladstone Creek but is conformable or gradational elsewhere. The succeeding strata consist in the lower part of grey, fine-grained, calcareous sandstone and siltstone interbedded with blocky, dark grey, green, and maroon mottled shale that grades into soft, dark grey, calcareous shale at the top.

The upper part of the formation, 35 feet thick, is composed of dark brown to grey, cryptocrystalline, silty limestone and hard, splintery, black, calcareous shale, abundantly fossiliferous at certain levels. Although the lithologies are gradational, three distinct limestone units can be distinguished, separated by shaly intervals (see Fig. 13, in pocket). The limestones are composed of thinly interbedded argillaceous and silty lenses a few inches thick, separated by well-developed ripple marks along which the beds tend to split. These beds, called the "calcareous" member by Glaister (*op. cit.*), form a thin but widespread lithologic marker at the top of the Gladstone Formation throughout the southern and central Foothills, extending into the Blairmore and Mannville Groups of the southern and central Alberta Plains.

No floral remains were collected from the Gladstone Formation along Mill and Gladstone Creeks, but a well-preserved fauna composed of pelecypods, gastropods, and ostracodes was collected from the "calcareous" member at three localities. The aggregate list of species includes:[1]

Mollusca
- *Musculiopsis* sp. cf. *M. russelli* MacNeill
- *Protelliptio douglassi* (Stanton)
- *Protelliptio* n. sp.
- *Protelliptio* sp. indet.
- *Campeloma* sp. aff. *C. harlowtonensis* (Stanton)
- *Margaritana* sp.
- *Margaritana*? sp.
- *Viviparus*? sp.

Ostracoda
- *Cypridea* sp. cf. *C. wyomingensis* Jones
- *Metacypris angularis* Peck.

The fauna is indicative of a freshwater environment.

Beaver Mines Formation

The middle Blairmore unit, for which the name Beaver Mines Formation[2] is proposed (Table 1), is 930 feet thick from composite measurements of the eastern and central sections on Mill and Gladstone Creeks. Glaister (1959) obtained a thickness of 830 feet for approximately the same interval on Mill Creek, and 1200 feet for a composite section on Oldman River, north of the Crowsnest Pass in the Gap map-area. The upper beds of the formation also were measured downstream on Mill Creek, in Tp. 6, Rs. 1 and 2, W. 5th Mer. (Fig. 4), and on Ma Butte, north of Coleman, in Tp. 9, R. 5, W. 5th Mer. (Fig. 5).

At the type section on Mill and Gladstone Creeks, the Beaver Mines Formation can be divided into a lower sandy part and an upper shaly part. A similar division of strata can be observed on Ma Butte.

The lower part is about 430 feet thick and has a sharp contact with dark silty limestones at the top of the Gladstone Formation. The basal beds comprise several feet of dark greenish-grey, noncalcareous shale and siltstone that grade up into dark green, fine-grained, crossbedded sandstone containing lenses of fine pebbles, some of which are of volcanic origin. This basal sandstone, about 35 feet thick, is present in all three fault blocks on Mill and Gladstone Creeks and appears to be correlative in stratigraphic position, if not in composition, with Douglas's (1950) "Home Sand" in the Gap map-area. The overlying 400 feet of beds contain two thick, green, medium- to coarse-grained, crossbedded, feldspathic sandstones separated by thin-bedded, dark greenish-grey shale, siltstone, and fine-grained, micaceous sandstone. These sandstones, 40 and 85 feet

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[1] Megafaunal collections from this and other localities mentioned subsequently were identified by C. R. Stelck; microfaunal collections were identified by J. H. Wall.

[2] From Beaver Mines Post Office, west of Pincher Creek.

thick, respectively, also persist across the strike of the exposures on Mill and Gladstone Creeks, although they show some variation in thickness and texture. The upper sandstone is associated with lenses of coarse igneous (volcanic) pebble conglomerate in nearby parts of the Beaver Mines map-area (Hage, 1943), similar in composition to other igneous pebble conglomerates reported from this part of the Blairmore Group elsewhere in the southern Foothills (Rose, 1917; Hage, 1946; Allan and Carr, 1947; Clow and Crockford, 1951).

The upper 500 feet of the formation consist of interbedded green, fine-grained, crossbedded, feldspathic sandstone, dark green, laminated siltstone, and blocky, varicolored shale (mudstone), the sandstones becoming thinner and finer-grained towards the top of the formation. Conversely, the proportion of shale increases upwards, and zones of banded or irregularly mottled red and green shale, although present in the lower part of the formation, become abundant in this interval. A thin bed of dark grey, fossiliferous, argillaceous limestone is present near the top of the formation in the western section on Mill Creek (Fig. 5).

Several partings or beds of soft, plastic, pale green or grey, bentonite-like clay up to several inches thick, commonly associated with thin beds of purplish-weathering, grey, cryptocrystalline rock resembling fine-grained tuff, were observed at various stratigraphic levels in the Beaver Mines Formation but are more abundant in the upper shaly part. Microscopic examination of these "tuff" beds neither precludes nor confirms a pyroclastic origin, although they contrast with the softer-weathering shales and siltstones in outcrop. These tuffs and bentonites, however, are not genetically related to the volcanic beds of the overlying Crowsnest Member, being separated from them by 200 to 400 feet of nonvolcanic sandstones and shales in the lower part of the Mill Creek Formation (Table 1).

Only the upper 200 feet of Beaver Mines strata are well exposed on Mill Creek downstream from the type section, in Tp. 6, Rs. 1 and 2, W. 5th Mer. These consist mainly of blocky, dark green shale and laminated siltstone with thin beds of red mottled shale near the top. (Fig. 4).

The upper beds of the Beaver Mines Formation also were measured on the east face of Ma Butte, north of Coleman, in Tp. 9, R. 5, W. 5th Mer., where the formation is approximately 1500 feet thick. The upper 300 feet of strata consist mainly of dark green, grey, and red mottled shale and dark green siltstone, with subordinate thin green sandstone beds (Fig. 5). Sandstones are thicker and more abundant in the lower part of the formation, which, however, is only poorly exposed along a saddle extending east from the butte.

Although comminuted carbonaceous matter is abundant in the Beaver Mines Formation of the southern Foothills, identifiable megafloral remains are restricted to relatively few thin dark grey, silty shale beds suitable for the preservation of the rather delicate non-dicotyledonous leaf impressions.

In all, thirteen suites of plants from six localities in the Crowsnest Pass region were collected from various levels in the Beaver Mines Formation. The aggregate lists of species for each locality are given below:

(1) Mill and Gladstone Creeks, Tp. 5, R. 2, W. 5th Mer. (type section); seven suites from six stratigraphic levels, ranging from 180 feet above the base to 300 feet below the top of the formation (Fig. 4):

Ferns
- *Cladophlebis virginiensis* Fontaine
- *Coniopteris* sp. aff. *C. brevifolia* (Fontaine)
- *Onychiopsis* sp. cf. *O. psilotoides* (Stokes and Webb)
- *Sphenopteris* sp. cf. *S. bidens* Bell
- *Sphenopteris brulensis* Bell
- *Sphenopteris* sp. aff. *S. brulensis* Bell
- *Sphenopteris latiloba* Fontaine
- *Sphenopteris* sp. cf. *S. latiloba* Fontaine
- *Sphenopteris mclearni* Bell
- *Sphenopteris* sp.

Gymnosperms
- *Pseudocycas* sp. cf. *P. unjiga* (Dawson)
- *Pterophyllum* sp.
- *Athrotaxites berryi* Bell
- *Pagiophyllum* sp. cf *P. magnifolium* Bell
- *Pityophyllum nordenskjoldi* (Heer)
- *Pityophyllum* sp.

Angiosperms
- *Sapindopsis* sp. aff. *S. angusta* (Heer).

(2) Mill Creek, Tp. 6, Rs. 1 and 2, W. 5th Mer.; one suite 130 feet below the top of the formation (Fig. 4):

Ferns
- *Cladophlebis* sp. cf. *C. virginiensis* Fontaine
- *Coniopteris* sp. cf. *C. yukonensis* Bell

Gymnosperms
- *Baiera* sp. cf. *B. gracilis* (Bean)
- *Ginkgo pluripartita* (Schimper)
- *Elatocladus smittiana* (Heer)
- *Pityophyllum* sp.

(3) Carbondale River, Sec. 8, Tp. 6, R. 3, W. 5th Mer.; two suites from an isolated outcrop of vertically dipping beds probably in the lower or middle part of the formation:

Ferns
- *Sphenopteris brulensis* Bell
- *Sphenopteris* sp. cf. *S. latiloba* Fontaine

Pteridosperms
- *Sagenopteris mclearni* Berry

Gymnosperms
- *Ginkgo pluripartita* (Schimper)
- *Ginkgo* sp. cf. *G. pluripartita* (Schimper)
- *Carpolithus* (*Ginkgo*?) sp.
- *Athrotaxites berryi* Bell
- *Elatocladus* sp. cf. *E. brevifolia* (Fontaine)
- *Nageiopsis* sp. cf. *N. striata* Bell.

(4) Ma Butte, Tp. 9, R. 5, W. 5th Mer.; one suite 45 feet below the top of the formation (Fig. 5):

Ferns
- *Cladophlebis* sp. cf. *C. virginiensis* Fontaine

Gymnosperms
- *Cycadella* sp.
- *Nilssonia brongniarti* (Mantell)
- *Pseudocycas*? n. sp.
- *Elatocladus brevifolia* (Fontaine)
- *Pagiophyllum* sp. cf. *Sphenolepidium sternbergianum* (Dunker).

(5) Oldman River, Sec. 31, Tp. 11, R. 3, W. 5th Mer.; one suite from the upper part of the formation (top not exposed):

Ferns
- *Cladophlebis* sp.

Gymnosperms
- *Ptilophyllum* sp.
- *Nilssonia* sp. cf. *N. canadensis* Bell
- *Nilssonia* sp. cf. *N. nigracollensis* Wieland
- *Athrotaxites* sp. cf. *A. berryi* Bell
- *Podozamites lanceolatus* (Lindley and Hutton).

(6) Livingstone River, Tp. 12, R. 3, W. 5th Mer., about 1 mile above the junction with White Creek; one suite from an isolated outcrop in the upper part of the formation:

Ferns
- *Sphenopteris latibola* Fontaine
- *Sphenopteris mclearni* Bell
- *Sphenopteris* sp.

Pteridosperms
- *Sagenopteris williamsii* (Newberry)

Gymnosperms
- *Podozamites lanceolatus* (Lindley and Hutton)

Angiosperms
- *Sapindopsis* sp.

The Beaver Mines flora, composed mainly of ferns and gymnosperms (ginkgos, cycads, and conifers), is synoymous with the "lower Blairmore" flora described by Berry (1929) and Bell (1956). Dicotyledonous (angiosperm) remains are extremely rare, being present in only two of the suites, one from the type section on Mill Creek and the other from Livingstone River. On Mill Creek *Sapindopsis* sp. is present in the highest suite collected, about 300 feet below the top of the formation, in which it is associated with *Cladophlebis virginiensis, Coniopteris* sp. aff. *C. brevifolia,* and *Athrotaxites berryi. Sapindopsis* sp. is also present in the suite collected from dark green siltstones on Livingstone River (listed above), presumably from the upper part of the formation, although its exact stratigraphic position is unknown. At both localities *Sapindopsis* is associated with diagnostic non-dicotyledonous "lower Blairmore" species. Previously McLearn (1929) had collected *Sapindopsis* fragments from the middle part of the Blairmore Group at two localities on Castle (now Carbondale) River, where they are associated in both places with abundant non-dicotyledonous species.

The only fauna collected from the Beaver Mines Formation is present in thin argillaceous limestone beds a few feet below the top of the formation in the western section on Mill Creek. The fauna contains the following species:

- Mollusca
  - *Protelliptio douglassi* (Stanton)
  - *Protelliptio hamili* (McLearn)
  - *Protelliptio* sp. cf. *P. reesidei* (Yen)
  - *Eupera onestae* (McLearn)
- Ostracoda
  - *Cypridea* sp. cf. *C. wyomingensis* Jones
  - *Heterocypris*? sp.
  - *Metacypris* sp.

A similar megafauna was collected by McLearn (*op. cit.*) from the upper part of the Blairmore Group on Carbondale (Castle) River, from beds probably at or near the top of the Beaver Mines Formation. *P. douglassi* and *P. hamili* also are common in the "calcareous" member at the top of the Gladstone Formation in the Crowsnest Pass (McLearn, *ibid.*), but the ostracodes are rather indeterminate forms, indicating only freshwater conditions of deposition (J. H. Wall, pers. comm.).

Mill Creek Formation

The upper beds of the Blairmore Group in the southern Foothills can be distinguished from those of the underlying Beaver Mines Formation on the basis of both sandstone composition and floral content. In the Crowsnest Pass region these beds include a lower succession of quartzose, cherty sandstones and varicolored shales, gradational into an upper succession of pyroclastic beds (Crowsnest "volcanics"), for which the name Mill Creek Formation[1] is proposed (Table 1).

Although the break in the floral succession of the Blairmore Group in the Crowsnest Pass region had been recognized earlier (McLearn, 1916), the break in sandstone composition in the upper part of the group was first described by Douglas (1950), who noted (p. 25-26) that conglomeratic sandstones near the top of the group in the Gap map-area differed "from the underlying sandstones in that they contain little or no ferro-magnesian minerals, which are abundant in beds lower in the Blairmore group". Glaister (1959) also described similar quartzose sandstones ("argillaceous protoquartzites") from the upper part of the group on Mill Creek and Oldman River, which he included with the underlying feldspathic sandstones in his "upper Blairmore" formation. In fact, these upper Blairmore quartzose sandstones are not only distinct from those of the underlying Beaver Mines Formation but also are associated with an entirely different flora, the boundary between the two sets of strata marking the locus of a regional break in sedimentation.

The Mill Creek Formation is 580 feet thick in the type section on Mill Creek, measured in the western fault block, in Sec. 13, Tp. 5, R. 2, W. 5th Mer. (Fig. 4). The formation also is exposed on Mill Creek in the eastern fault block, in Sec. 25, Tp. 5, R. 2, W. 5th Mer., and downstream on the crest of the anticline, in Tp. 6, Rs. 1 and 2, W. 5th Mer., but its thickness at these last two localities is uncertain owing to faulting and poor exposures.

The lower, sedimentary part of the Mill Creek Formation is 230 feet thick in the type section and approximately 300 feet thick in the eastern section. Correlative strata, poorly exposed on the vertically dipping northeast limb of the anticline downstream, in township 6, ranges 1 and 2, were estimated graphically to be 580 feet thick, being overlain by about 200 feet of tuffaceous beds assigned to the Crowsnest Member (Fig. 4). This gives an anomalously high total thickness of 780 feet for the formation there, which, if anything, should be thinner than the type section to the southwest. The excessive thickness at the anticlinal section is due probably to repetition of the lower, sedimentary beds by faulting, as postulated in figure 4, but, owing to poor exposures, there is no direct evidence for this.

The contact with the underlying Beaver Mines Formation appears sharp but locally conformable at all three localities. In the type section the contact is drawn at the base of dark grey siltstone lying on blocky, green shale of the Beaver Mines Formation. The siltstone, 8 feet thick,

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[1] From J. W. Dawson's (1886) "Mill Creek series", which he defined as those beds on Mill Creek, south of the Crowsnest Pass, from which G. M. Dawson collected a dicotyledonous flora. Although Bell (1956) has pointed out that the unit was not defined lithologically, the present study shows that these beds do indeed constitute a distinct formational unit.

grades up into 13 feet of pale grey, fine-grained, quartzose sandstone, overlain by fissile, black shale containing thin beds of grey, fine, calcareous siltstone. Similar hard, fissile, black shale interbedded with thin-bedded, grey, "fluted", calcareous siltstones are present at the base of the Mill Creek Formation in the eastern fault block (exposed near the top of a high cut on the southeast side of Mill Creek) and downstream in the anticlinal section, in sharp contact at both localities with dark green shale or argillaceous siltstone of the underlying Beaver Mines Formation.

That part of the Mill Creek Formation above the black shales and "fluted" siltstones at the base resembles the underlying Beaver Mines Formation in gross lithology, consisting of fine- to medium-grained cross-bedded sandstone interbedded with variable proportions of dark green and grey, laminated siltstone and blocky, varicolored shale. However, the sandstones of the two formations differ markedly in color and composition, those of the Mill Creek Formation varying from whitish quartzose types near the base to grey cherty sandstones above, grading into bluish-green, fine-grained, biotite-rich sandstones near the contact with the overlying volcanic beds. In the type section a thick, grey, coarse-grained, cross-bedded, cherty sandstone is present in the lower part of the succession but is absent from the eastern section, where several thin, silty sandstones separated by greenish-grey siltstone and shale are present at this level. The sandstone, about 75 feet thick, is overlain by about 65 feet of dark grey, plant-bearing siltstone and shale that grades into grey, fine-grained sandstone and red and green mottled shale beneath the tuffaceous beds of the Crowsnest Member. A similar grey, cherty sandstone is present about 30 feet above the base of the formation in the anticlinal section to the northeast, but the overlying strata are largely covered, except for several resistant thin siltstone and sandstone beds. (Fig. 4).

Several other partial sections of the Mill Creek Formation measured or examined in the Crowsnest Pass region match the exposures on Mill Creek in lithology, sandstone composition, and floral content. The best exposed of these is on Ma Butte, in Tp. 9, R. 5, W. 5th Mer., where much of the "upper" Blairmore flora originally described by McLearn (1929) was collected. The section, embracing the upper part of the Beaver Mines Formation and the lower part of the Mill Creek Formation, is compared with correlative strata in the type section on Mill Creek in figure 5.

The lower, sedimentary beds of the Mill Creek Formation are about 350 feet thick on Ma Butte, which is considerably to the west of the sections on Mill Creek. The boundary between the Beaver Mines and Mill Creek Formations is sharp and can be traced for more than a mile along the east face of the butte. When viewed from a distance, the contact is emphasized by a pronounced color break, the Mill Creek beds weathering to a distinctly lighter color than those of the Beaver Mines

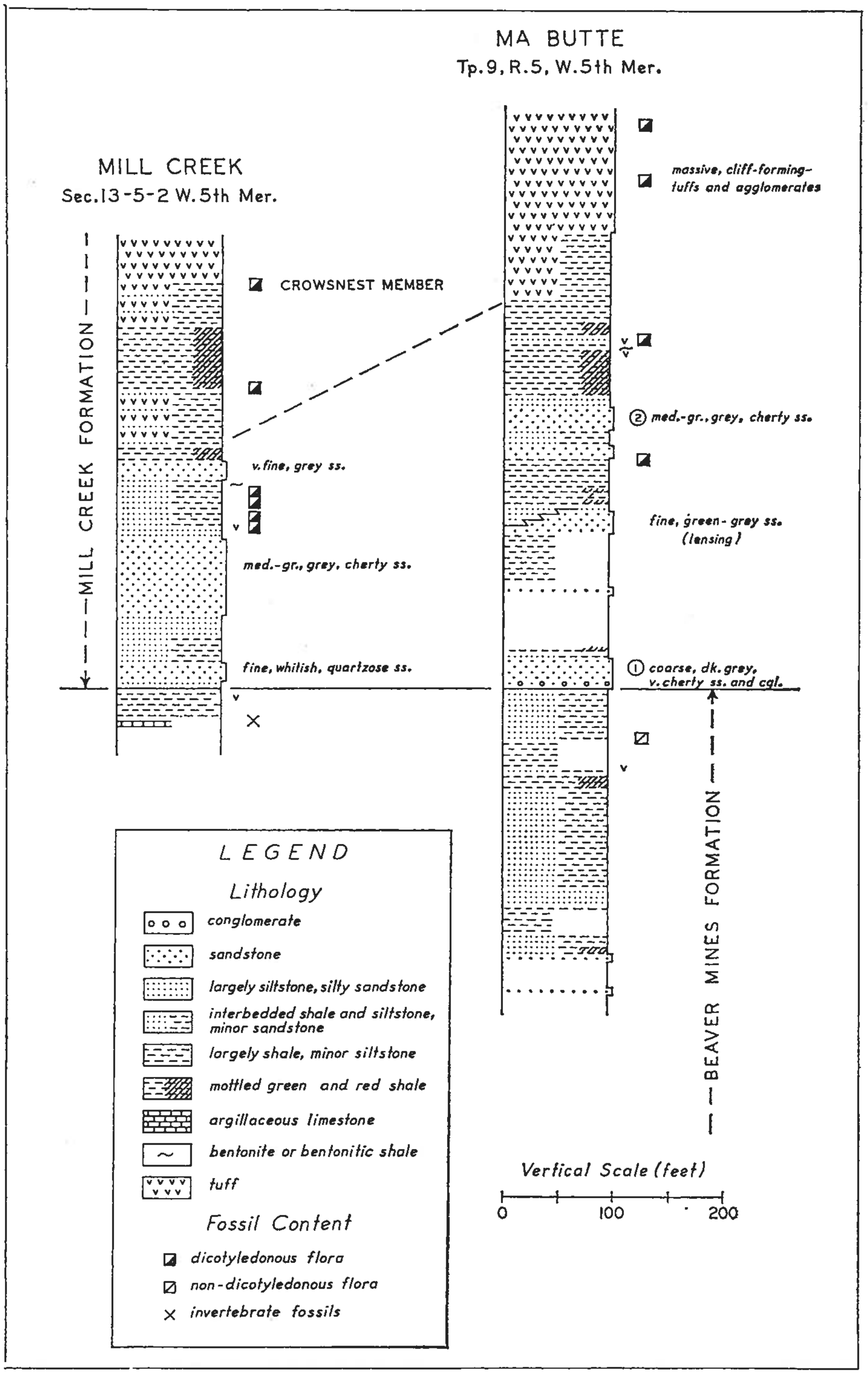

FIGURE 5. *Columnar sections showing the lithology and fossil content of the upper beds of the Blairmore Group (beneath the Crowsnest Member), Mill Creek and Ma Butte, southern Alberta Foothills (datum: base of the Mill Creek Formation).*

Formation. This color difference probably reflects basic differences in the composition of the shaly beds of the two formations.

The basal bed of the Mill Creek Formation (1, Fig. 5) is a thick, dark grey, coarse-grained, crossbedded, cherty sandstone, continuous along the outcrop face. Thin lenses of small chert pebbles are present in the lower part of the sandstone, which has a sharp, locally channeled contact with the underlying dark greenish-grey shale of the Beaver Mines Formation. (The channeled contact in itself is not evidence for a major break in sedimentation at the base of the formation, for many of the thick fluviatile sandstones in the Blairmore Group show evidence of local erosion at their lower contacts.) The basal sandstone grades up into a poorly exposed succession of dark green siltstone and varicolored shale that contains several lensing, grey, cherty, "salt-and-pepper"-type sandstones in the upper part. A second thick laterally persistent sandstone is present 225 feet above the base of the formation (2, Fig. 5). Green and red mottled shale is common above this sandstone, grading up into soft-weathering, tuffaceous shale that marks the base of the volcanic Crowsnest Member.

The upper part of the Mill Creek Formation in the Crowsnest Pass region consists of interbedded sedimentary and pyroclastic detritus mapped by previous workers as the Crowsnest "volcanics" or, later, Crowsnest Formation. These beds are included here as a member of the Mill Creek Formation, for they grade both vertically and laterally into cherty, quartzose sandstones and varicolored shales, similar to those in the lower part of the formation (MacKenzie, 1914; Hage, 1943; Douglas, 1951; Norris, 1955), and also contain the same dicotyledonous flora as the underlying beds.

The Crowsnest Member forms a wedge of strata, arcuate in plan, that attains an estimated maximum thickness of 1600 feet in the westernmost exposures, near Coleman in the Crowsnest Pass (Price, 1962). The unit thins and grades laterally into nonvolcanic detritus within short distances of Coleman, so that it is no longer recognizable as a mappable unit near the edge of the Foothills to the east, nor in the outcrop belt itself, north of the Oldman River in township 12.

Where well developed, the Crowsnest Member consists mainly of crudely bedded crystal and lithic tuffs and agglomerates, interbedded with rare thin flows and dykes near Coleman (Norris, *op. cit.*). Some of the material has been reworked by stream action, forming well-sorted volcanic conglomerate and sandstone associated with thin coal seams or carbonaceous shale. The rocks are highly feldspathic, containing abundant pink and white potash feldspar crystals, volcanic rock fragments, and lesser amount of pyroxenes, garnet, plagioclase, and analcite in a dark, cryptocrystalline groundmass. Primary rock types described by MacKenzie (*op. cit.*) indicate the alkaline nature of the parent magmas, being composed of trachyte, analcite-bearing "blairmorite", and latite in that order of abundance. Near the mappable boundaries of the member, the coarser pyroclastic beds grade into soft, bentonitic shale and hard, grey or purple, cryptocrystalline tuff interbedded with sedimentary detritus of nonvolcanic origin.

The upper boundary of the Crowsnest Member (or of correlative nonvolcanic strata to the north) with the marine beds of the Blackstone Formation is invariably sharp although locally conformable. In places, a few inches of chert-pebble conglomerate are present at the base of the Blackstone, whereas elsewhere dark grey Blackstone shale is in direct contact with orange-weathering bentonitic shale or tuff at the top of the Blairmore Group. However, the basal beds of the Blackstone Formation, comprising marine dark grey, silty shale and quartzose siltstone of the Sunkay Member, thin and disappear as the underlying volcanic beds thicken towards the centre of volcanism, somewhere west of Coleman. Thus, in the westernmost parts of the Foothills in the Crowsnest Pass region (Coleman, York Creek near Blairmore, Carbondale River), dark grey fossiliferous shales of the Vimy Member carrying the *Inoceramus labiatus-Watinoceras* fauna rest directly on the underlying Crowsnest Member; the absence of the Sunkay Member indicates that the volcanic beds formed a low, gently sloping landmass flanking the Colorado Sea to the east during early Blackstone time (see Fig. 10, in pocket).

The only well-exposed section of the Crowsnest Member examined in the course of the present study is in the western section on Mill Creek, where the thickness was calculated graphically to be approximately 350 feet. Hage (1943) estimated the thickness at 460 feet in the eastern section on Mill Creek, but the beds there are partly repeated by faulting (Glaister, 1959).

The member can be divided into two parts: a lower succession of fine tuffs and shaly beds 150 feet thick, and an upper succession of coarse tuffs and fine agglomerates 200 feet thick. The lower contact is drawn at the base of thin-bedded, hard, green and grey, fine tuffs and soft, tuffaceous, dark green and grey "speckled" shale lying above nontuffaceous red and green mottled shale (Fig. 4). These beds are succeeded by massive-weathering, blocky, bright red mudstone and thin cryptocrystalline tuff beds, with plant-bearing, green, fine-grained sandstone and dark silty shale at the base and near the top.

The upper part of the unit consists of crudely bedded, coarse, poorly sorted, green and grey, feldspathic, lithic and crystal tuff and fine agglomerate containing scattered ellipsoidal bombs of garnetiferous lithic tuff up to 3 feet in diameter. A thin bed of coarse, well-sorted, feldspathic tuff is present near the contact with the Blackstone Formation, which, although covered at this locality, is sharp but conformable where observed downstream.

The coarse tuffs and agglomerates in the upper part of the member thin rapidly to the northeast, so that in the anticlinal section in Tp. 6, Rs. 1 and 2, W. 5th Mer. (Fig. 4), Hage (*op. cit.*) assigned only the upper 30 feet of beds beneath the Blackstone Formation to the Crowsnest Formation. In figure 4 the lower boundary of the member is drawn at approximately 200 feet below the Blackstone contact, where the grey, cherty sandstones in the lower part of the Mill Creek Formation change to bluish-green, biotite-rich, tuffaceous sandstones. However, this boundary is arbitrary, and most of the beds included in the Crowsnest Member on this basis are composed mainly of reworked waterlain detritus that shows little megascopic evidence of a pyroclastic origin.

The lower part of the member at this locality is poorly exposed, consisting of varicolored shale and green, fine-grained sandstone overlain by soft-weathering, bentonitic shale slump. A soft, white-weathering, biotite-rich, quartzose sandstone is present about 50 feet below the top of the member beneath green and grey shale interbedded with hard, purplish-grey, cryptocrystalline tuff. A thin bed of hard, dark grey shale containing an exceptionally well-preserved dicotyledonous flora is present 5 feet below the sharp contact with dark grey, silty shale of the Blackstone Formation.

The relationship of the volcanic Crowsnest beds to underlying strata was examined at two localities north of the Crowsnest Pass. On Ma Butte, several miles north of and on strike with the outcrops west of Coleman, the lower contact appears gradational over a 50-foot interval of soft, green and grey, tuffaceous shale, overlain by 400 to 500 feet of massive, cliff-forming tuffs and agglomerates that form the crest of the butte (Fig. 5). The lower part of these beds is composed of fine, well-sorted, cross-bedded, feldspathic tuff that grades up into crudely stratified, coarse pyroclastic debris, not examined in detail.

To the northeast, in the Gap map-area, in Sec. 31, Tp. 11, R. 3, W. 5th Mer., the upper 150 feet of the Blairmore Group is exposed at the forestry trunk road bridge on the Oldman River (Fig. 10). There, the only part of the succession of obvious pyroclastic origin is a massive, soft-weathering, purplish-grey ash bed 15 feet thick, containing bombs of feldspathic tuff up to 2 feet in diameter, present about 100 feet below the Blackstone contact. The ash bed is underlain and overlain by 20 feet of tuffaceous, bentonitic shale and grey, fine tuff that grade below and above into greenish-grey, fine-grained sandstone and soft, green and grey, bentonitic shale, distinguishable from the nonvolcanic beds in the lower part of the Mill Creek Formation only in the finer details of mineral composition. South of this locality, on Dutch Creek, in Sec. 18, Tp. 11, R. 3, W. 5th Mer., a grey, coarse-grained, crossbedded, quartzose sandstone containing lenses of chert- and quartzite-pebble conglomerate is developed at or near the top of the formation, about 20 feet below the Blackstone contact and above any volcanic beds that might be assigned to the Crowsnest Member there.

No coarse pyroclastic beds have been reported from the northern or eastern parts of the Gap map-area, although Douglas (1950) has demonstrated the presence in the subsurface of the adjoining Callum and Langford Creeks map-areas of tuffaceous and bentonitic shales in the upper part of the Blairmore Group above a grey, coarse-grained sandstone that he correlated with the McDougall-Segur Sand of Turner Valley. Whether or not this sandstone marks the base of the Mill Creek Formation there or is the same laterally continuous sandstone from well to well is uncertain, but there is little doubt that the overlying tuffaceous shales grade laterally to the west and south into the coarser pyroclastic beds of the Crowsnest Member. Similar bentonitic shale and thin cryptocrystalline tuff beds persist in the upper part of the Mill Creek Formation at least as far north as Sheep River.

Fossil plants are abundant in the Mill Creek Formation of the Crowsnest Pass region, the predominantly dicotyledonous flora being more susceptible to preservation—especially in the arenaceous beds—than the more fragile non-dicotyledonous species in the underlying Beaver Mines Formation. In all, twenty-three suites of plants from ten localities were collected from the Mill Creek Formation: eighteen suites from the lower part of the formation, and five from the Crowsnest Member. The aggregate lists of species for each locality are given below:

(1) Mill Creek, Sec. 13, Tp. 5, R. 2, W. 5th Mer. (type section):

(a) lower part of formation; five suites from four stratigraphic levels, ranging from 150 to 180 feet above the base of the formation (Fig. 4):

Ferns
    Sphenopteris sp.
Gymnosperms
    Ginkgo n. sp.
    Nilssonia sp. aff. *N. canadensis* Bell
    Pseudocycas sp.
    Elatocladus sp. cf. *E. brevifolia* (Fontaine)
    Sequoia condita Lesq.
    Podozamites sp.
Angiosperms
    Araliaephyllum westoni (Dawson)
    Araliaephyllum sp.
    Celastrophyllum acutidens Fontaine
    Cinnamomoides ovalis (Dawson)
    Dicotylophyllum sp.

Ficus fontainii Berry
Ficus sp. cf. *F. fontainii* Berry
Fontainea grandiflora Newberry
Magnolia magnifica Dawson
Magnolia n. sp.
Magnolia sp.
Magnolia? sp.
Menispermites reniformis Dawson
Menispermites sp.
Platanus sp.
Populites dawsoni Bell
Populites sp. cf. *P. dawsoni* Bell
Populites n. sp.
Populites sp.
Trochodendroides potomacensis (Ward).

(b) Crowsnest Member; dicotyledon fragments (species indeterminate) from 275 and 370 feet above the base of the formation (Fig. 4).

(2) Mill Creek, Sec. 25, Tp. 25, R. 2, W. 5th Mer. (eastern section); lower part of formation; two suites from 125 and 275 feet above the base of the formation:

Gymnosperms
  Pseudoctenis? sp.
  Podozamites sp.
Angiosperms
  Celastrophyllum acutidens Fontaine
  Celastrophyllum sp.
  Fontainea grandiflora Newberry
  Fontainea sp.
  Magnolia magnifica Dawson
  Platanus sp.
  Populites dawsoni Bell
  Populites sp.
  Salix? sp.

(3) Mill Creek, Tp. 6, Rs. 1 and 2, W. 5th Mer.:

(a) lower part of formation; four suites from three stratigraphic levels, ranging from 120 to approximately 350 feet above the base of the formation (Fig. 4):

Ferns
  Gleichenites sp.
  Sphenopteris latiloba Fontaine
Gymnosperms
  Ginkgo n. sp.
  Pseudocycas sp. cf. *P. unjiga* (Dawson)

- *Brachyphyllum crassicaule* Fontaine
- *Elatocladus* sp. cf. *E. brevifolia* (Fontaine)
- *Sequoia condita* Lesq.
- *Podozamites stenopus* Lesq.
- *Podozamites* n. sp.

Angiosperms

- *Araliaephyllum westoni* (Dawson)
- *Celastrophyllum acutidens* Fontaine
- *Cinnamomoides ovalis* (Dawson)
- *Dicotylophyllum* sp.
- *Ficus fontainii* Berry
- *Fontainea grandiflora* Newberry
- *Fontainea* n. sp.
- *Magnolia* sp.
- *Menispermites reniformis* Dawson
- *Platanus* sp.
- *Populites dawsoni* Bell
- *Quercophyllum*? sp.
- *Salix inaequalis* Newberry
- *Salix*? sp.
- *Trochodendroides potomacensis* (Ward).

(b) Crowsnest Member; two suites from 5 and 170 feet below the top of the formation, the lower suite containing only *Platanus* sp. (Fig. 4):

Ferns

- *Cladophlebis alberta* (Dawson)
- *Cladophlebis* sp. cf. *C. alberta* (Dawson)
- *Cladophlebis* sp. cf. *C. oerstedi* (Heer)
- *Onychiopsis psilitoides* (Stokes and Webb)

Angiosperms

- *Araliaephyllum westoni* (Dawson)
- *Celastrophyllum acutidens* Fontaine
- *Cinnamomoides ovalis* Dawson
- *Cinnamomoides* sp. cf. *C. ovalis* Dawson
- *Cinnamomoides* sp.
- *Fontainea grandiflora* Newberry
- *Menispermites* sp.
- *Platanus* sp.
- *Populites dawsoni* Bell
- *Sapindopsis* sp. cf. *S. angusta* (Heer)
- *Sapindopsis* sp. cf. *S. brevifolia* Fontaine
- *Sapindopsis* sp. cf. *S. magnifolia* Fontaine
- *Sterculia* sp.

(4) Lynx Creek, Sec. 12, Tp. 6, R. 4, W. 5th Mer., above the junction with the Carbondale River; lower part of formation; one suite from black silty shale about 50 feet below the contact with the Crowsnest Member:

- Gymnosperms
  - *Podozamites lanceolatus* (Lindley and Hutton)
- Angiosperms
  - *Sapindopsis* sp.

(5) Carbondale River, Sec. 12, Tp. 6, R. 4, W. 5th Mer.; lower part of formation; one suite from dark grey siltstone 220 to 260 feet below the lowest exposures of the Crowsnest Member (intervening section covered):

- Ferns
  - *Sphenopteris latiloba* Fontaine
- Gymnosperms
  - *Pseudocycas* sp. cf. *P. unjiga* (Dawson)
  - *Sequoia condita* Lesq.
  - *Desmiophyllum* (*Podozamites*?) sp.
- Angiosperms
  - *Celastrophyllum acutidens* Fontaine
  - *Dicotylophyllum* sp.
  - *Fontainea grandiflora* Newberry
  - *Platanus* sp.

(6) York Creek, Sec. 34, Tp. 7, R. 4, W. 5th Mer.; lower part of formation; one suite from fine grey sandstone about 70 feet below the lowest exposures of the Crowsnest Member (intervening section covered):

- Angiosperms
  - *Alnus*? sp.
  - *Cinnamomoides ovalis* (Dawson)
  - *Fontainea grandiflora* Newberry
  - *Magnolia* sp.
  - *Menispermites reniformis* Dawson
  - *Platanus* sp.
  - *Populites dawsoni* Bell.

(7) Coleman, Sec. 7, Tp. 8, R. 4, W. 5th Mer., road outcrops west of the town; one suite from the lower part of the Crowsnest Member:

- Ferns
  - *Cladophlebis* sp. cf. *C. alberta* (Dawson)
  - *Cladophlebis* sp.
- Gymnosperms
  - *Elatocladus* sp. aff. *E. brevifolia* (Fontaine)
  - *Pagiophyllum* sp.

(8) Ma Butte, Tp. 9, R. 5, W. 5th Mer.: (a) lower part of formation; two suites from 210 and 320 feet above the base of the formation (Fig. 5):

- Ferns
  - *Sphenopteris mclearni* Bell

- Gymnosperms
    - *Pseudocycas* sp.
    - *Elatides* sp. cf. *E. splendida* Bell
    - *Pagiophyllum* sp. cf. *Sphenolepidium sternbergianum* (Dunker)
- Angiosperms
    - *Cinnamomoides* sp.
    - *Ficus?* sp.
    - *Magnolia* sp.
    - *Myrtophyllum boreale* Seward and Conway
    - *Platanus* sp.
    - *Populites dawsoni* Bell
    - *Sapindopsis* sp.
    - dicotyledon indet.

(b) Crowsnest Member; two suites from 465 and 575 feet above the base of the formation (Fig. 5):

- Angiosperms
    - *Cercidophyllum* sp.
    - *Ficus fontainii* Berry
    - *Magnolia magnifica* Dawson
    - *Magnolia* sp. cf. *M. magnifica* Dawson.

(9) Dutch Creek, Sec. 18, Tp. 11, R. 3., W. 5th Mer.; upper part of formation; one suite from a coarse-grained, sparsely conglomeratic sandstone about 20 feet below the exposed base of the Blackstone Formation:

- Angiosperms
    - *Menispermites reniformis* Dawson
    - *Populites* sp.

(10) Oldman River, Sec. 31, Tp. 11, R. 3, W. 5th Mer.; upper part of formation; one suite from dark grey siltstone 70 feet below the base of the Blackstone Formation, above a 15-foot tongue of tuff and agglomerate (Fig. 10, in pocket):

- Ferns
    - *Sphenopteris* sp. aff. S. *mclearni* Bell
- Angiosperms
    - *Cinnamomoides ovalis* (Dawson)
    - *Platanus* sp.
    - *Sapindopsis?* sp.
    - *Trochodendroides potomacensis* (Ward).

The flora of the Mill Creek Formation, synonymous with Berry's (1929) and Bell's (1956) "upper Blairmore" flora, is composed mainly of dicotyledonous species that range through both the lower sedimentary beds and the upper Crowsnest Member. It contrasts markedly in composition with the flora of the underlying Beaver Mines Formation ("lower Blairmore" flora), in which only rare dicotyledons are found; furthermore, few of the Beaver Mines non-dicotyledonous species range into the overlying beds, and there is no evidence to indicate a gradual transition from the older to the younger flora. This sharp break in the floral succession is in itself strong evidence for a major break in sedimentation at the top of the Beaver Mines Formation, coinciding with the pronounced change in sandstone composition at that level.

No faunal remains were found in the Mill Creek Formation of the Crowsnest Pass region.

Sheep River

In the northern part of the southern Foothills, between the Highwood and Bow Rivers, the Blairmore Group is known mainly from summary descriptions of outcrop sections in map-area reports, and from Hume's (1938, 1939) descriptions of the group in the subsurface of the Turner Valley oilfield, near the eastern margin of the Foothills.

Several Blairmore sections were measured in this region, from near the western edge of the Foothills on Sheep River to near Okotoks in the adjacent Plains (Fig. 6, in pocket). The main outcrop localities are on Sheep River: on the west flank of the Green Mountain syncline, in Sec. 19, Tp. 19, R. 5, W. 5th Mer. and Sec. 24, Tp. 19, R. 6, W. 5th Mer.; on the east flank of the Green Mountain syncline, in Sec. 35, Tp. 19, R. 5, W. 5th Mer.; and on the crest of the Highwood anticline, in Sec. 33, Tp. 19, R. 3, W. 5th Mer. Subsurface sections examined are in three wells drilled just east of the folded belt, between Turner Valley and Okotoks: Shell-Anglo Canadian Pine Creek No. 1, in Sec. 12, Tp. 20, R. 2, W. 5th Mer.; Christie-Mitchell-Ranchmen's Okotoks 10-23, in Sec. 23, Tp. 20, R. 29, W. 4th Mer.; and Ranchmen's No. 1, in Sec. 13, Tp. 20, R. 29, W. 4th Mer.

The Blairmore Group on Sheep River can be divided at all localities into the same three formations observed in the Crowsnest Pass, with an aggregate thickness of 1820 feet in the western outcrop locality (Sec. 1, Fig. 6), thinning to about 1000 feet of strata near the eastern edge of the Foothills (Sec. 5, Fig. 6). Southwest of Sheep River, near the headwaters of the Highwood River, Allan and Carr (1947) estimated the group to be 3300 feet thick in the Rocky Mountains proper.

Gladstone Formation

The Gladstone Formation is 510 feet thick in the western outcrop section (Sec. 1, Fig. 6), where it can be divided into three parts as on Mill Creek. Similar beds also are exposed on the east flank of the Green Mountain syncline (Sec. 2, Fig. 6), where Glaister (1959) estimated their thickness to be 475 feet, but are sheared and contorted there and were not measured in detail.

The basal unit comprises 27 feet of grey, coarse-grained, crossbedded, cherty sandstone interbedded with quartzite- and chert-pebble conglomerate, with disconformable lower and sharp upper contacts. The overlying 450 feet of strata consist of a monotonous succession of thin-bedded, grey, fine-grained, quartzose sandstone, dark grey, laminated siltstone, and dark grey and greenish-grey shale. The sandstone beds are thicker and coarser in the lower part, grading up into finely laminated, silty beds, commonly calcareous. The "calcareous" member at the top of the formation is more argillaceous than on Mill Creek, comprising about 30 feet of hard, black, calcareous shale with dark grey, ripple-marked, silty limestone in the middle (see Fig. 13 for detail). The unit is only sparingly fossiliferous.

The Gladstone Formation is correlative with Hume's "lower Blairmore" succession at Turner Valley to the east, described as interbedded calcareous sandstone and dark shale, 150 to 200 feet thick, with a coarse-grained, quartzose sandstone called the Dalhousie Sand at the base, and a fine-grained, well-sorted, quartz sandstone called the Home Sand at top (Hume, 1938, 1939). A sandy interval called the "Crooked Hole sand" is developed locally in some wells, and thin, calcareous sandstones containing nonmarine invertebrates are present near the top of the unit, beneath the Home Sand. This succession of strata is well developed in the Shell-Anglo Canadian Pine Creek No. 1 well (Sec. 5, Fig. 6), just east of Turner Valley, and matches, except for the presence of the Home Sand, the general succession of beds in outcrops to the west.

The Home Sand itself is not recognizable in outcrops on Sheep River, nor in the two wells drilled near Okotoks to the east. Conversely, the "calcareous" member is absent from the Turner Valley-Pine Creek area, being replaced there by the Home Sand, the quartzose composition of which indicates that it belongs in the Gladstone rather than in the overlying Beaver Mines Formation. The writer's interpretation is that the Home Sand is a local arenaceous phase of the "calcareous" member, developed through sorting and concentration of the coarser quartzose detritus at the top of the Gladstone Formation over a structural high present in the Turner Valley area during Early Cretaceous time. The similar development of local quartzose sandy beds (Jumpingpound Sand) in the second "white-speckled" shale zone of the overlying Blackstone Formation in the Turner Valley-Jumpingpound region (Fig. 8) indicates that such a local high persisted into Late Cretaceous time in this part of the Foothills.

Fossils were collected from the Gladstone Formation on Sheep River at three stratigraphic levels in the western outcrop section (Sec. 1, Fig. 6).

A non-dicotyledonous flora was collected from dark grey shale above the basal conglomerate and contains the following species:

Pteridosperms
  Sagenopteris williamsii (Newberry)
Gymnosperms
  Athrotaxites berryi Bell
  Pityophyllum nordenskjoldi (Heer)
  Podozamites sp. cf. *P. lanceolatus* (Lindley and Hutton).

Megafaunal remains were collected from a thin calcareous shale bed 330 feet above the base of the formation and from the "calcareous" member at the top. The aggregate list of species includes:

Mollusca
  Murraia sp. cf. *M. fabensis* McLearn
  Protelliptio sp.
  Eupera onestae (McLearn)
Ostracoda
  genus and sp. indet., subquadrate form
  genus and sp. indet., bean-shaped form.

Beaver Mines Formation

The Beaver Mines Formation is well exposed on both flanks of the Green Mountain syncline (Secs. 1, 2; Fig. 6), although the upper beds are faulted out at both localities.

The western section is 920 feet thick, closely resembling the type section on Mill Creek in gross lithology. The contact with the underlying "calcareous" member is sharp, being marked by 3 inches of chert-pebble conglomerate that grades up into dark greenish-grey shale and siltstone. The lower 700 feet of beds consist of blocky, green and grey shale, dark green, laminated siltstone, and green, fine-grained sandstone, interbedded with several thick, green, medium- to coarse-grained, crossbedded, feldspathic sandstones. The upper 200 feet of section is composed of soft, red and green mottled shale and green siltstone containing large brown-weathering calcareous concretions, grading up into dark greenish-grey shale and siltstone which is folded and thrust over younger Mill Creek Formation strata to the east. Thin cryptocrystalline tuff beds and bentonite partings were observed in both the lower and upper parts of the formation.

Beaver Mines strata are about 800 feet thick on the east flank of the Green Mountain syncline, but the succession there is difficult to interpret owing to the presence of small folds and faults of unknown displacement in the upper part (Sec. 2, Fig. 6). The upper 200 feet of Blairmore strata on opposite banks of the river do not match, and it appears that the stream bed extends across a transverse fault zone along which most of the Mill Creek Formation and the upper beds of the Beaver Mines Formation have been faulted out. The measured section is on the north side of the river.

The lower part of the Beaver Mines Formation consists mainly of interbedded dark green and grey shale and siltstone with thin green sandstone beds. Thicker, coarse-grained sandstones are confined to the upper part of the succession, with minor repetition of beds by faulting. The red and green mottled shales observed in the upper part of the western section are either absent or faulted out, younger Mill Creek beds being faulted over dark grey shale and green siltstone carrying a non-dicotyledous flora.

The Beaver Mines Formation thins to about 600 feet of strata near the eastern edge of the Foothills, where it forms the lower part of Hume's (1938) "upper Blairmore" succession at Turner Valley, between the Home and McDougall-Segur Sands (Sec. 4, Fig. 6). In wells to the east (Secs. 5, 6; Fig. 6), the formation is about 500 feet thick, consisting of pale grey, buff-speckled, fine-grained, kaolinitic sandstone interbedded with pale green to dark grey shale and siltstone. A zone of dark grey shale containing thin coal beds or partings is developed about 150 feet above the base of the formation in the Turner Valley and Okotoks areas, but none of the thicker arenaceous beds appears to have any lateral continuity, like, for example, the underlying Home Sand at the top of the Gladstone Formation.

Non-dicotyledonous plant remains were collected from the Beaver Mines Formation at both outcrop localities on Sheep River. The aggregate lists of species for each locality are given below:

(1) Sheep River, Sec. 24, Tp. 19, R. 6, W. 5th Mer.; eight suites from seven stratigraphic levels, ranging from 440 feet above the base to about 50 feet below the top of the section (Sec. 1, Fig. 6):

- Ferns
  - *Acrostichopteris* sp. cf. *A. foliosa* (Fontaine)
  - *Cladophlebis porsildi* Seward
  - *Cladophlebis strictinervis* (Fontaine)
  - *Cladophlebis virginiensis* Fontaine
  - *Gleichenites* sp. cf. *G. nordenskjoldi* (Heer)
  - *Onychiopsis* sp. cf. *O. psilitoides* (Stokes and Webb)
  - *Sphenopteris brulensis* (Bell)
  - *Sphenopteris* sp. aff. *S. goepperti* (Dunker)
- Pteridosperms
  - *Sagenopteris mclearni* Berry
  - *Sagenopteris williamsii* (Newberry)
  - *Sagenopteris* sp. cf. *S. williamsii* (Newberry)
- Gymnosperms
  - *Ginkgo nana* Dawson
  - *Ginkgo* sp. cf. *G. pluripartita* (Schimper)
  - *Nilssonia canadensis* Bell
  - *Pseudoctenis hazeltonensis* Bell
  - *Athrotaxites berryi* Bell
  - *Elatides* sp.
  - *Elatocladus brevifolia* (Fontaine)

Pityophyllum nordenskjoldii (Heer)
Sequoia? sp.
Podozamites sp.

(2) Sheep River, Sec. 35, Tp. 19, R. 5, W. 5th Mer.; two suites from 5 and 190 feet below the faulted upper contact of the formation (Sec. 2, Fig. 6):

Ferns
    Cladophlebis sp. cf. *C. alberta* (Dawson)
    Cladophlebis porsildi Seward
    Cladophlebis virginiensis Fontaine
    Sphenopteris sp. cf. *S. latiloba* Fontaine
    Sphenopteris sp.
Pteridosperms
    Sagenopteris mclearni Berry
Gymnosperms
    Athrotaxites berryi Bell
    Elatides sp. cf. *E. curvifolia* (Dunker)
    Elatides sp.

Mill Creek Formation

The upper beds of the Blairmore Group on Sheep River, correlative with the Mill Creek Formation of the Crowsnest Pass region, crop out on both flanks of the Green Mountain syncline (Secs. 1, 2; Fig. 6) and on the crest of the Highwood anticline to the east (Sec. 3, Fig. 6).

In the western outcrop locality (Sec. 1, Fig. 6) the upper 390 feet of Blairmore strata, above the faulted upper contact with the Beaver Mines Formation, are assigned to the Mill Creek Formation. The beds consist mainly of dark grey, green, and abundant mottled and banded red shale interbedded with dark green and grey siltstone. Thin beds of grey, fine-grained, crossbedded, quartzose sandstone, similar to those near the base of the formation on Mill Creek, are present near the base of the succession, contrasting markedly in appearance and composition with the green, feldspathic sandstones in the Beaver Mines Formation. Although no sandstones are well developed in the upper part of the formation at this locality, a short distance downstream on the crest of a small anticline, in Sec. 19, Tp. 19, R. 5, W. 5th Mer., a thick, dark grey, coarse-grained, cherty sandstone is present near the top of the formation, grading laterally along the outcrop into siltstone and shale (Secs. 1, 2; Fig. 7). Thin, purplish-grey, cryptocrystalline tuff beds and bentonite partings are scattered throughout the upper 300 feet of the formation, but there are no coarse pyroclastic beds to indicate which part of the succession, if any, is correlative with the Crowsnest Member to the south. The upper contact with the Blackstone Formation is sharp.

Only the upper 90 feet of Mill Creek beds are exposed on the east flank of the Green Mountain syncline (Sec. 2, Fig. 6), the lower portion of the formation having been faulted out. These consist mainly of dark green and grey shale with minor tuffs and sandstones in the lower part. The upper contact is conformable, dark grey Blackstone shale lying sharply on dark grey siltstone containing abundant dicotyledon remains. The lower contact is placed at the base of 10 to 12 feet of pale green, medium-grained sandstone in fault contact with dark green siltstones of the Beaver Mines Formation carrying a non-dicotyledonous flora. The microscopic composition of the sandstone confirms its position in the Mill Creek Formation, differing markedly from the composition of the underlying feldspathic sandstones in the Beaver Mines Formation.

The most easterly outcrops of Blairmore strata on Sheep River are on the crest of the Highwood anticline, where the upper beds of the Mill Creek Formation are repeated by a series of minor faults and folds (Sec. 3, Fig. 6). The section on the east flank of the structure, in Sec. 33, Tp. 19, R. 3, W. 5th Mer., consists of about 100 feet of thin, greenish-grey, fine-grained sandstones and dark, plant-bearing shale beneath the Blackstone Formation. A section was examined upstream in Sec. 29, Tp. 19, R. 3, W. 5th Mer., where a thick, coarse-grained, cherty sandstone is present near the top of the group, apparently lensing out to the east.

The base of the Mill Creek Formation is not exposed at this locality on Sheep River, but the complete succession of strata crops out on Highwood River, several miles to the south, in Sec. 34, Tp. 18, R. 3, W. 5th Mer. There, the formation consists of dark green and grey shale with thin sandstone interbeds, the lowest of which rests sharply on dark green shale and siltstone of the Beaver Mines Formation. However, although the section is poorly exposed, no thick sandstone beds corresponding to those at Turner Valley were observed. The estimated maximum thickness of the formation is 300 feet.

Plant remains were collected from the Mill Creek Formation at three localities on Sheep River. Species lists for each locality are given below:

(1) Sheep River, Sec. 24, Tp. 19, R. 6, W. 5th Mer.; one suite from 140 feet below the top of the formation (Sec. 1, Fig. 6):

- Ferns
  - *Sphenopteris* sp.
- Gymnosperms
  - *Ginkgo* n. sp.
  - *Widdringtonites* sp.
- Angiosperms
  - *Araliaephyllum*? sp.
  - *Celastrophyllum acutidens* Fontaine
  - *Fontainea grandiflora* Newberry
  - *Magnolia* sp.

Menispermites reniformis Dawson
Myrtophyllum boreale Seward and Conway
Platanus sp.
Sapindopsis belviderensis Berry.

(2) Sheep River, Sec. 35, Tp. 19, R. 5, W. 5th Mer.; one suite from dark silty shale immediately below the Blackstone contact (Sec. 2, Fig. 6):

Ferns
  Acrostichopteris? foliosa (Fontaine)
Gymnosperms
  conifer indet.
Angiosperms
  Araliaephyllum westoni (Dawson)
  Cinnamomoides sp.
  Dicotyllophyllum sp.
  Fontainea grandiflora Newberry
  Magnolia sp.
  Menispermites reniformis Dawson
  Platanus sp.
  Populites dawsoni Bell
  Sapindopsis angusta Heer
  Sapindopsis sp.

(3) Sheep River, Sec. 33, Tp. 19, R. 3, W. 5th Mer.; one suite from 90 feet below the top of the formation (Sec. 3, Fig. 6):

Angiosperms
  Araliaephyllum westoni (Dawson)
  Magnolia sp.
  Menispermites reniformis Dawson
  Platanus sp.

Dicotyledon fragments also were observed 20 feet below the top of the formation at this locality.

The composition of the flora confirms the correlation of these beds with the Mill Creek Formation of the Crowsnest Pass region.

Bow Island Problem

The Blairmore Group of the southern Foothills thins abruptly as it is traced east in wells from the margin of the Foothills into the adjacent Plains. Conversely, the basal beds of the marine Blackstone Formation (Colorado Group of the Plains), beneath the "Fish-scale" marker bed, thicken in the western part of the Plains to form a succession of dark marine shales and sandstones 200 to 400 feet thick called the Bow Island Formation. The generally accepted interpretation of this phenomenon is that the upper continental beds of the Blairmore Group interfinger to the east with marine Bow Island strata (Scruggs, 1956; Glaister, 1959), as shown in figure 8, but no concrete basis for such a correlation has been published to date. The local, lensing nature of gross lithologic units in the upper part of the Blairmore Group in the Foothills precludes any such correlation based on gross lithology or related electric-log properties of the rocks alone.

Within the outcrop belt of the southern Foothills, there is no evidence that any of the Blairmore beds are of marine or shoreline origin, and, although the Mill Creek Formation can be distinguished on petrographic and floral grounds from the underlying Beaver Mines Formation, the two formations resemble each other closely in gross lithology and implied conditions of deposition. The main break in sedimentation in the Lower Cretaceous succession of this region is marked by the invariably sharp contact between the nonmarine Blairmore beds and the overlying marine Blackstone shales, a contact that can be placed consistently throughout the length and breadth of the Foothills within a fraction of an inch.

There is no evidence of marine intertonguing in the upper part of the Blairmore Group in the subsurface of Turner Valley, at the eastern edge of the Foothills on Sheep River, which Hume (1938, 1939) described as a succession of green and grey sandstones and shales, 900 to 1000 feet thick, between the Home Sand and the Blackstone Formation, with two thick sandy intervals locally present in the upper part of the group (Sec. 4, Fig. 6). The lower of these two sandy intervals, the McDougall-Segur Sand, attains a maximum thickness of 200 feet, consisting of grey "salt-and-pepper"-type sandstone, locally conglomeratic[1], separated by shaly beds. No prominent sandstones are present at this level in outcrops on the Sheep or Highwood Rivers, but Beach (1943) described a similar conglomeratic sandstone from 300 feet below the top of the group in the nearby Moose Mountain map-area, which he called the "upper Blairmore conglomerate". Both the McDougall-Segur Sand and the "upper Blairmore" conglomerate are, from their stratigraphic position and general description, almost certainly at or near the base of Mill Creek-equivalent beds in their respective areas.

Hume's upper sandy interval, the Stockmen's Sand, about 100 feet below the top of the Blairmore Group, is thinner and less persistent than

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[1] These and similar conglomerates reported from the upper part of the Blairmore Group at widespread localities in the southern Foothills (Douglas, 1950; Anderson, 1951; Price, 1962; Norris *et al.*, 1965) should not be confused with lenses of igneous pebble conglomerate present locally in the underlying Beaver Mines Formation. The latter are composed mainly of volcanic pebbles, whereas the younger conglomerates, which are developed locally at different stratigraphic levels in beds assigned here to the Mill Creek Formation, are composed mainly of chert and quartzite pebbles with minor amounts (less than 10 per cent) of igneous pebbles. In this light Norris's (*ibid.*) proposal to extend Hume's term McDougall-Segur "to include all those late Lower Cretaceous horizons containing igneous pebbles, whether in outcrop or in the subsurface, throughout the southeastern Canadian Cordillera" and to use the term as a time surface hardly merits serious consideration. The fact is that conglomerates containing igneous pebbles are present at widely separated stratigraphic levels in the middle and upper parts of the Blairmore Group in the southern Foothills, from just above the "calcareous" member on Mill Creek (Fig. 4) to within a few feet of the top of the group on Dutch Creek, a tributary of Livingstone River.

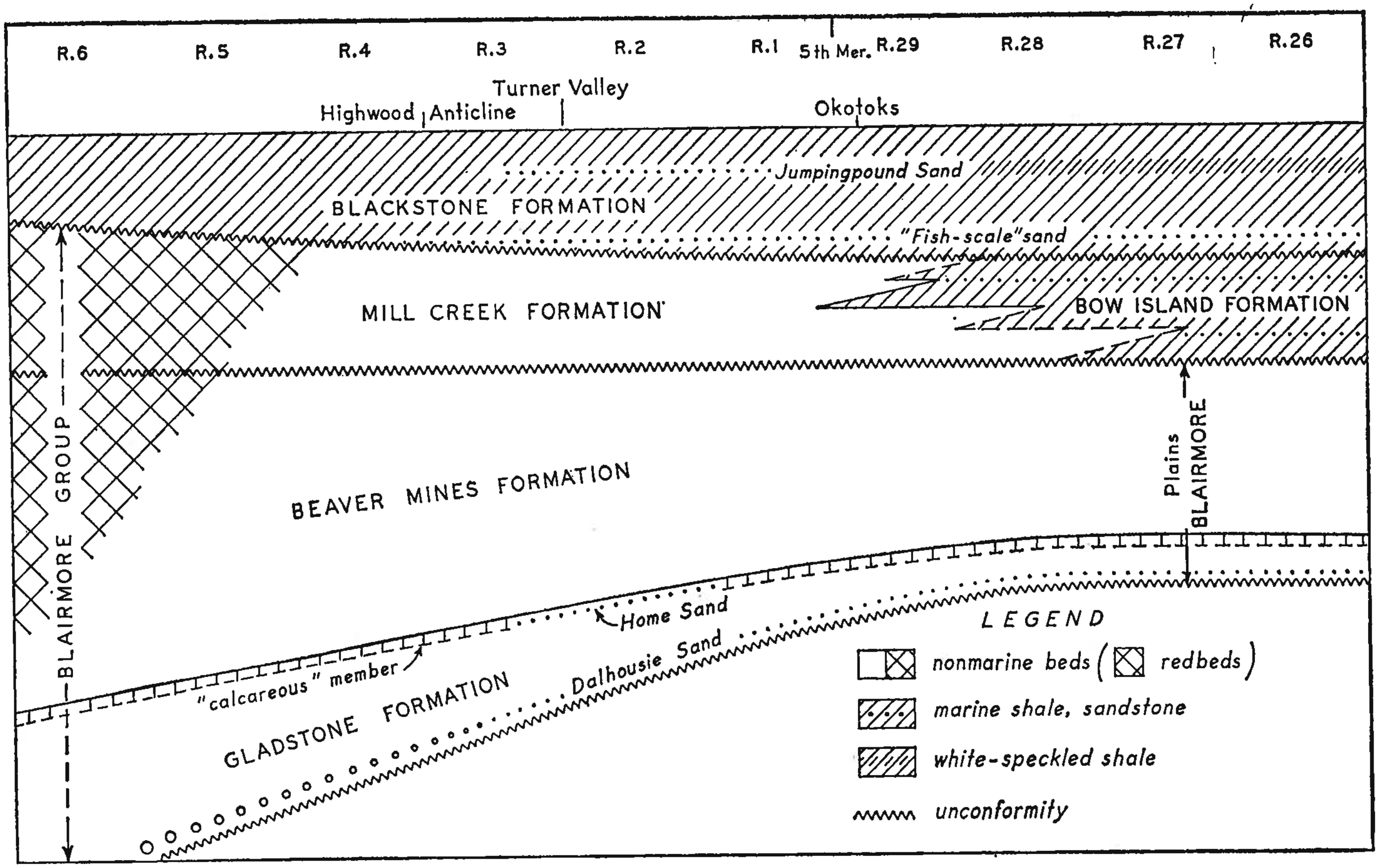

FIGURE 8. Schematic cross section showing the stratigraphic relationship of the nonmarine beds of the Blairmore Group to the marine beds of the Blackstone and Bow Island Formations across the strike of the folded belt and western Plains, Sheep River district, southern Alberta Foothills and Plains (datum: base of the Mill Creek Formation).

the McDougall-Segur Sand. It correlates in approximate stratigraphic position with the thick, lensing, cherty sandstones near the top of the group on the Highwood anticline and on the west flank of the Green Mountain syncline (Fig. 7) to the west.

The correlation of the upper 300 to 350 feet of Blairmore strata at Turner Valley with the Mill Creek Formation of outcrop localities is confirmed by detailed examination of sample cuttings from the three wells drilled in the Plains to the east of Turner Valley (Figs. 6, 7, in pocket). The one well, Shell-Anglo Canadian Pine Creek No. 1, is in gently dipping beds just to the east of the folded belt and exhibits essentially the same succession of Blairmore strata observed at Turner Valley (Sec. 5, Fig. 6). The upper Blairmore beds above the Home Sand are about 800 feet thick, consisting of green and dark grey shale interbedded with pale greenish-grey to white, kaolinitic sandstone. The contact with the overlying Blackstone Formation appears sharp, and there is no evidence that the Blairmore beds grade into or interfinger with marine Blackstone-type shales.

The quality of the samples from the upper part of the Blairmore Group and their similarity in gross lithology makes differentiation of Beaver Mines and Mill Creek strata in the Pine Creek well difficult from binocular examination of sample cuttings alone. However, thin-section examination of sample cuttings shows a marked break in sandstone composition between 230 and 350 feet below the Blairmore-Blackstone contact. Sandstones 100 and 230 feet below the contact (approximately correlative with the Stockmen's and McDougall-Segur Sands of Turner Valley) are quartzose, cherty rocks similar to sandstones of the Mill Creek Formation to the west, whereas those at 350 and 470 feet contain abundant feldspathic and volcanic detritus, similar to those in the upper part of the Beaver Mines Formation. Thus, the contact between the two formations can be placed between 230 and 350 feet below the top of the Blairmore Group, although its exact position is uncertain.

The same break in sandstone composition is present in the upper part of the Blairmore Group, between 230 and 350 feet below the Blackstone contact, in the Christie-Mitchell-Ranchmen's Okotoks 10-23 well, 16 miles east of Turner Valley (Sec. 6, Fig. 6). On this basis the base of the Mill Creek Formation is drawn arbitrarily at the base of a thick sandy interval, at about the same stratigraphic level as the base of the McDougall-Segur Sand at Turner Valley, about 300 feet below the top of the Blairmore Group. The upper 210 feet of Blairmore beds above this sandstone consist of dark grey to pale green shale and siltstone, and whitish, fine-grained, cherty, quartzose sandstone, with traces of coal in the upper part. These beds have been assigned to the Bow Island Formation rather than the Blairmore Group in the Oil and Gas Conservation Board Schedule of Wells (1958), presumably on the basis of their electric-log profile, although the only visible break in the lithology of the drilling samples is at the top of the interval, where Blairmore-type beds are in contact with dark grey Blackstone-type shales, about 40 feet below the base of the silty "Fish-scale" marker bed.

The relationship between the Blairmore Group and the Bow Island Formation can be determined more accurately in drilling samples from Ranchmen's No. 1 well, an older well drilled with cable tools about one mile southeast of the Christie-Mitchell-Ranchmen's Okotoks 10-23 well. The lithology of the upper Blairmore-lower Blackstone succession in the Ranchmen's No. 1 well (Fig. 7) is similar to that observed in the Okotoks 10-23 and Pine Creek No. 1 wells, except for the presence of dark grey Blackstone-type shale in the upper 135 feet of the Blairmore section in the Ranchmen's No. 1 well. This shale, probably of marine origin, is interbedded with typically drab grey and green shale and cherty, kaolinitic sandstone and becomes less abundant towards the Blackstone contact. The Blairmore-Blackstone contact is sharp, being placed about 60 feet below the top of the well-developed "Fish-scale" sand. The lower contact of the dark grey marine(?) Blairmore shales is also sharp, scattered glauconitic sandstone fragments and abundant shell remains being present near the base.

Thin-section studies show major breaks in sandstone composition at the top of the Blairmore Group (between the "Fish-scale" sand and the highest Blairmore sandstone) and also between 300 and 400 feet below the top of the Blairmore Group in the Ranchmen's No. 1 well. The lower break corresponds to the break in composition between Mill Creek- and Beaver Mines-type sandstones, the contact between the two formations being drawn at the base of a thick sandy interval 300 feet below the Blackstone-Blairmore contact and 165 feet below the base of the marine(?) shales in the upper part of the Blairmore Group (Fig. 7, in pocket). These latter presumably correlate with the upper beds of the Bow Island Formation to the east, grading laterally into continental Mill Creek beds to the west.

East of Okotoks the Bow Island Formation thickens at the expense of the Blairmore Group to form a succession of marine shales and cherty sandstones 300 to 400 feet thick (Fig. 8). It is reasonable to assume that the base of this succession is correlative with the base of the Mill Creek Formation to the west, which marks a widespread disconformity within the Blairmore Group of the southern Foothills. Similarly, the upper boundary of the Bow Island-Mill Creek succession is disconformable, being overlain by progressively older Blackstone strata to the north and east. Thus, the upper boundary of the "Blairmore Group" of the southern Plains is generally correlative with the upper boundary of the Beaver Mines Formation in the Foothills. However, near the western margin of the southern Plains, the upper boundary of the Blairmore Group is variable in stratigraphic position, owing to the interfingering of the Bow Island and Mill Creek Formations and to the criteria used to define it. The upper boundary of the Beaver Mines Formation is a more consistent datum plane, although difficult to determine accurately in the subsurface of the eastern Foothills and adjacent Plains in the absence of petrographic data.

Bow to Red Deer Rivers

Lower Cretaceous strata of the south-central Foothills, between the Bow and Clearwater Rivers, have received little attention from stratigraphers, partly owing to limited exposures and partly to the lack of commercial coal deposits in them. In gross aspect the Blairmore succession is similar to that south of the Bow River, grading north of the Red Deer River into the coal-bearing succession described by MacKay (1929b) from the north-central Foothills. Thus, the name Blairmore Group has been retained in the south-central Foothills for post-Kootenay, pre-Blackstone nonmarine strata, although, as discussed below, the upper beds of the group are absent a short distance north of the Bow River. Throughout most of the central Foothills the basal beds of the Blackstone Formation are in sharp contact with nonmarine beds of the Blairmore Group containing a non-dicotyledonous "lower Blairmore" flora.

Several partial Blairmore sections were measured between the Ghost and Red Deer Rivers along the eastern margin of two closely spaced, west-dipping fault blocks (Fig. 1): on Ghost River, in Tp. 27, R. 7, W. 5th Mer.; Waiparous Creek, in Tp. 28, R. 8, W. 5th Mer.; Burnt Timber Creek, south branch, in Tp. 30, R. 9, W. 5th Mer.; Burnt Timber Creek, north branch, in Tp. 30, R. 9, W. 5th Mer.; and Burnt Timber Creek, main branch, in Tp. 30, R. 9, W. 5th Mer.

The Blairmore Group in this area probably comprises between 1400 and 1800 feet of beds, divisible on the Ghost River into three formational units. North of the Ghost River only the lower two units are present.

Gladstone Formation

The lower unit, the Gladstone Formation, is either faulted or poorly exposed at the localities listed above. On Waiparous Creek the formation was estimated graphically to be about 570 feet thick, consisting of a basal conglomerate overlain by thin-bedded, dark grey, carbonaceous shale, dark grey, laminated siltstone, and grey, fine-grained sandstone with fossiliferous, calcareous siltstone or silty limestone in the upper 100 feet. The beds are darker, more carbonaceous, and more arenaceous than those on Sheep River, but no identifiable plant remains or coal seams were observed. The "calcareous" member at the top of the formation is about 25 feet thick, consisting of fissile, dark grey, calcareous shale and siltstone with a thin fossiliferous limestone bed 10 feet below the top, underlain by dark grey, fine, ripple-marked, calcareous sandstone and siltstone.

A similar succession of strata was observed to the north on Burnt Timber Creek, but the sections there are highly sheared and faulted.

Beaver Mines Formation

The upper beds of the Blairmore Group are well exposed at three localities on Burnt Timber Creek, south of the Red Deer River: on the north and south branches just above their junction, and 4 miles to the east on the main branch, downstream from the forestry trunk road. The underlying Gladstone Formation is folded and faulted in the western sections and is largely covered in the eastern section.

The upper beds, between the "calcareous" member and the Blackstone Formation are estimated mainly from graphic measurements to be 900 feet thick in the western section on the north branch, and 870 feet thick in the eastern section on the main branch (Sec. 6, Fig. 10, in pocket). The contact with the underlying "calcareous" member appears sharp at both localities, where thin-bedded, dark grey, calcareous shale is overlain by dark grey, noncalcareous shale and siltstone of the Beaver Mines Formation. The lower 500 feet of Beaver Mines strata are composed of dark greenish-grey shale, dark green siltstone, and green, fine- to medium-grained sandstone. In the eastern section these beds are overlain by green, medium- to coarse-grained, crossbedded, feldspathic sandstone 200 feet thick, represented in the western section by two sandstones, 40 and 65 feet thick, separated by siltstone and shale. The upper 175 to 250 feet of Blairmore beds consist of green and grey shale and siltstone with subordinate green, feldspathic sandstone beds 1 to 15 feet thick. Thin cryptocrystalline tuffs, brecciated tuffs, and bentonitic shales were observed in the upper 50 feet of beds, which are in sharp contact with dark grey, silty shale of the Blackstone Formation.

Although a thorough search of the uppermost Blairmore beds at all three localities on Burnt Timber Creek failed to yield any well-preserved floral remains (the only identifiable plants, composed of non-dicotyledonous species, were collected from about 500 feet below the top of the group in the eastern section), the chloritic, feldspathic composition of the sandstones near or at the top of the group, beneath the Blackstone Formation, shows conclusively that these beds are correlative with Beaver Mines strata to the south. Grey, quartzose sandstones a short distance above the Blairmore contact are separated from the latter by dark grey

Blackstone-type shale and siltstone carrying a post-"Fish-scale" sand microfauna (Wall and Germundson, 1963) and are part of the Blackstone succession rather than the Blairmore Group. Thus, the dicotyledon-bearing Mill Creek Formation of the Blairmore Group in the southern Foothills is absent from this locality, the correlative interval being marked by a disconformity at the top of the Blairmore Group.

Mill Creek Formation

Exactly where the Mill Creek Formation disappears from the stratigraphic succession of the south-central Foothills is uncertain, owing to lack of good exposures between the Bow and Red Deer Rivers.

Correlative beds are undoubtedly present in the western part of the Foothills south of the Bow River, above the base of Beach's (1943) "upper Blairmore" conglomerate, 300 to 400 feet below the top of the Blairmore Group in the Moose Mountain area. To the east, at Bragg Creek (Fig. 1), upper Blairmore beds are exposed on the crest of a tightly folded anticline on Elbow River, in Sec. 22, Tp. 23, R. 5, W. 5th Mer. The section, near the eastern edge of the Foothills, consists of two thick, pale grey, medium- to coarse-grained, cherty sandstones separated by 150 feet of poorly exposed dark green and grey shale, siltstone, and fine-grained, greenish-grey sandstone, apparently of nonmarine origin. No diagnostic plant remains were found, but the composition of the sandstones corresponds to those of the Mill Creek Formation on Sheep River. Thus, although neither the upper nor the lower contact of the formation is exposed, the unit is at least 200 feet thick there.

Blairmore beds are not exposed in the Bow River valley, but the upper part of the group crops out a few miles to the north on Ghost River on the crest of a small anticline (Sec. 5, Fig. 10, in pocket). The upper 50 feet of beds, beneath the Blackstone contact, consist of dark green shale and siltstone with 15 feet of pale greenish-grey, coarse-grained, cherty sandstone at the top. Thin-section examination of the sandstone shows it to be similar in composition to sandstones from the Mill Creek Formation south of the Bow River. About 200 to 300 feet below this sandstone a similar sandstone containing scattered chert pebbles crops out, at approximately the same level as the conglomeratic sandstone described by Hume (1936) from the hills north of the river, which he correlated with the McDougall-Segur Sand of Turner Valley. Scattered outcrops of dark green siltstones and fine-grained sandstones are present about 50 to 75 feet below the pebbly sandstone on Ghost River, containing poorly preserved conifer and cycad remains. Thus, it seems likely that the pebbly sandstone marks the approximate base of the Mill Creek succession there, in which case the formation is from 200 to 300 feet thick on Ghost River.

On Waiparous Creek, 10 miles north of and on strike with the Ghost River outcrops, the highest Blairmore strata consist of 50 to 75 feet of ridge-forming, green, medium-grained sandstone with a high chlorite and feldspar content, similar to the thick sandstones in the Beaver Mines Formation on Sheep River and Burnt Timber Creek. However, as the beds between this sandstone and the overlying Cardium Formation are not exposed, the thickness and nature of younger Blairmore strata, if present, cannot be determined.

Thus, the Mill Creek Formation apparently disappears from the Blairmore succession somewhere between the Ghost River and Burnt Timber Creek, over a distance of 20 miles. There is no evidence to indicate that this happens by lateral interfingering with the basal marine beds of the Blackstone Formation, which in this region are distinctly younger than the "Fish-scale" sand or Bow Island beds of the southern Plains. The logical interpretation, therefore, is that the formation is absent either through nondeposition or erosion.

Ram and North Saskatchewan Rivers

In the Foothills north of the Clearwater River, commercial coal beds are present in the lower part of the Blairmore Group, whereas they are thin in or absent from the underlying Kootenay (Nikanassin) Formation. Also, the thin but persistent "calcareous" member at the top of the Gladstone Formation, valuable as a stratigraphic marker in the southern Foothills, is absent as a distinct lithologic unit. Consequently, throughout most of the north-central Foothills, Blairmore strata have been divided into MacKay's (1929b) Cadomin, Luscar, and Mountain Park Formations, except in the south, between the Clearwater and North Saskatchewan Rivers, where the name Blairmore has been retained or the Luscar and Mountain Park Formations have been mapped as a unit.

Exposures of the Blairmore Group were examined at three localities in this part of the Foothills, across the strike of the outcrop belt between the North Saskatchewan and Ram Rivers (Fig 9, in pocket). The only complete section is on Ram River, above its junction with the North Ram River, in Tps. 37 and 38, R. 12, W. 5th Mer. The section is near the eastern edge of the Foothills, on the flanks of the Ram anticline, and is repeated in part by minor faults and folds.

The composite thickness of the Blairmore Group there is 1170 feet[1], considerably less than the thickness of 2017 feet reported earlier by Evans

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[1] The upper 380 feet of beds were measured in a high cut in Sec. 31, Tp. 37, R. 12, W. 5th Mer., and the lower 790 feet (excluding the basal sandstone) in a series of smaller exposures downstream in townships 37 and 38. The basal beds were measured on the east flank of the Ram anticline, in Sec. 12, Tp. 38, R. 12, W. 5th Mer. Evans' (1930) thickness is undoubtedly excessive, including beds repeated by faulting.

(1930), who included the basal beds of the Blackstone Formation in the Blairmore Group. The succession can be divided into two formations, correlative with the Gladstone and Beaver Mines Formations of the southern Foothills.

Gladstone Formation

The Gladstone Formation is 460 feet thick, consisting of a basal sandstone unit and an overlying succession of dark grey shale, laminated siltstone, and thin-bedded sandstone, calcareous and fossiliferous in the middle part (Fig. 9). The beds are approximately equivalent to Douglas's (1955) "lower Luscar" unit in the Nordegg map-area to the northwest and contrast with the overlying coal-bearing part of the Beaver Mines Formation in both sandstone composition and bedding features.

The basal unit comprises 80 to 100 feet of pale grey, fine- to coarse-grained, crossbedded, quartzose sandstone with scattered chert and quartzite pebbles in the lower 15 feet. The contact with underlying thin-bedded sandstones of the Nikanassin Formation is sharp and uneven with evidence of local channeling.

The succeeding 50 feet of strata are composed of thin-bedded, dark grey, plant-bearing shale and fine-grained sandstone with a thin coal seam near the top. These grade in turn into a succession of finely laminated, dark grey shale and "varved" siltstone, interbedded on a very fine scale with grey, fine-grained, ripple-marked sandstone (see Fig. 13 for detail). The beds are markedly calcareous and fossiliferous and contain abundant brown-weathering claystone nodules and partings. The upper limit of the calcareous beds is marked by a thin coal seam, overlain by 80 feet of thin-bedded, dark grey, noncalcareous shale and siltstone that grades up into fine-grained, ripple-marked, quartzose sandstone. These beds are in contact with 3 feet of hard, grey, fine-grained sandstone with small chert pebbles in the upper part, separated from the thick feldspathic sandstones of the overlying Beaver Mines Formation by a 5-foot covered interval[1]. The "calcareous" member as such is no longer recognizable at this latitude, presumably having graded laterally into the calcareous shales and sandstones lower in the section.

Plant fossils were collected from two levels, 130 and 160 feet above the base of the formation, between the basal sandstone and the calcareous beds. They include the following aggregate list of species:

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[1] Whether this sandstone belongs in the Gladstone Formation or is the basal bed of the Beaver Mines Formation is uncertain (Fig. 13, in pocket). It was treated as the latter for sampling purposes, and subsequent analysis showed it to contain small amounts of feldspars and volcanic rock fragments (Fig. 10, in pocket).

Ferns
- *Coniopteris brevifolia* (Fontaine)

Gymnosperms
- *Ginkgo* sp. cf. *G. pluripartita* (Schimper)
- *Pterophyllum rectangulare* Bell
- *Ptilophyllum hirtum* Bell
- *Athrotaxites berryi* Bell
- *Elatides* sp. cf. *E. curvifolia* (Dunker)
- *Podozamites lanceolatus* (Lindley and Hutton).

In addition, invertebrate remains were collected from several levels in the calcareous beds, ranging from 170 feet above the base to 105 feet below the top of the formation. These include the following species:

Mollusca
- *Anadonta*? sp.
- *Astarte*? sp.
- *Corbula* sp. cf. *C. palliseri* McLearn
- *Murraia*? sp.
- *Musculiopsis russelli* MacNeill
- *Musculiopsis*? sp.
- *Protelliptio* sp. cf. *P. hamili* (McLearn)
- *Yoldia*? sp.
- *Unio*? sp.
- *Campeloma* sp.
- *Mesoneritina* sp.
- *Rubyella* sp.
- turritellid gastropod

Ostracoda
- *Candona stirlingensis* Loranger
- *Metacypris persulcata* Loranger (not Peck)
- genus and sp. indet., subquadrate form
- genus and sp. indet., bean-shaped form.

Although the fauna appears more diverse than that from the Gladstone Formation of the southern Foothills, most of the forms are too poorly preserved for even generic identification. However, those that are identifiable or are closely comparable with described species indicate a freshwater to brackish rather than a marine environment.

Beaver Mines Formation

The Beaver Mines Formation is 710 feet thick on Ram River and is divisible into two parts, correlative with the coal-bearing upper part of the Luscar and overlying Mountain Park Formations of other investigators. The lower part (Luscar facies) is 400 to 470 feet thick, and the upper part (Mountain Park facies) is 240 to 310 feet thick, the thicknesses depending on where the gradational boundary between the two divisions is drawn (Fig. 9). Apart from the presence of coal in the lower beds, the only megascopic distinction between the two sets of strata, at this locality and elsewhere, appears to be in the color of the beds, especially the sandstones. Sandstones in the lower part are pale to medium grey rocks, cemented by illite or kaolinite and quartz, and contain abundant brownish-red siderite pellets; those in the upper part are green or greenish-grey rocks, cemented in part by chlorite, and contain few or no siderite pellets. However, all of these sandstones—Luscar- or Mountain Park-type—contain essentially the same detrital constituents, which include abundant feldspars and volcanic rock fragments, and can be distinguished from the underlying Gladstone Formation sandstones by their composition and bedding features.

The lower 325 feet of the Beaver Mines Formation on Ram River is composed mainly of thick-bedded, friable-weathering, pale to dark grey, medium- to coarse-grained, crossbedded sandstone, separated by thinner, partly covered intervals of dark grey, laminated siltstone, shale, and coal. The basal sandstone is 95 feet thick and contains thick lenses of poorly sorted, large, brown claystone nodules in the lower part (Fig. 9). The conglomerate was probably derived from local reworking of partially consolidated penecontemporaneous sediments, for bedded claystone nodules and lenses up to 3 feet thick are common throughout the overlying strata to the top of the formation. The upper part of the basal sandstone, together with the overlying sandstone, is dark grey and fetid, owing to the presence of a hydrocarbon(?) cement that may have collected earlier in the history of the rocks as oil over the crest of the then-growing Ram anticline.

Two thick coal seams are associated with the thick, friable-weathering, pale grey sandstones in the upper part of the sandy succession, 230 and 310 feet above the base of the formation. The lower seam is about 14 feet thick (including shaly interbeds in the upper part), and the upper 7 to 8 feet thick. The two seams also are exposed on the North Ram River above the junction with the main Ram River, where the lower seam is 10 feet and upper about 13 feet thick.

The upper part of the formation consists mainly of laminated, dark grey and green shale and siltstone, brown-weathering, nodular claystone partings, and thin, green, fine-grained sandstone beds. A coal seam 1 to 2 feet thick is present 460 feet above the base of the formation, above which the arenaceous beds take on a distinct green color. Thin-bedded siltstone and fine-grained sandstone above the coal seam grade laterally along the face of the cut in Sec. 31, Tp. 37, R. 12, W. 5th Mer. into a thick, green, medium-grained sandstone that elsewhere might be mapped as the base of the Mountain Park succession. A similar pale green, coarse-grained, feldspathic sandstone containing scattered chert and volcanic pebbles is present at or near the top of the formation on the North Ram River, well above the level at which the lensing sandstone on the main Ram River is developed, grading laterally into dark green siltstone and shale at the top of the formation at the latter locality.

The contact of the Beaver Mines Formation with dark grey silty shale of the Blackstone Formation is sharp but apparently conformable over a distance of several hundred feet. A persistent thin-bedded, quartzose, cherty sandstone 25 to 30 feet thick, with lenses of chert pebbles at the top, is present about 20 feet above the contact, grading below into dark grey Blackstone-type shale and siltstone in sharp contact with soft, orange-weathering Blairmore shale. The sandstone contains abundant fish scales and extends throughout most of the map-area, where it was included by Evans (*op. cit.*) and Henderson (1945) in the top of the Blairmore Group. However, shales underlying a similar sandstone on Cripple Creek to the west contain a microfauna (*Miliammina manitobensis* fauna) found beneath the "Fish-scale" marker bed of the Plains to the east (Wall and Germundson, 1963). The sandstone, therefore, belongs to the basal part of the Blackstone Formation, being the southernmost extension of the "Fish-scale" sand in the Alberta Foothills. South of this latitude post-"Fish-scale" sand beds rest directly on the Blairmore Group (Wall and Germundson, *ibid.*).

The upper beds of the Blairmore Group also were examined on Cripple Creek, west of the Ram River section, in Sec. 28, Tp. 37, R. 14, W. 5th Mer. Erdman (1946) estimated the thickness of the Blairmore (Luscar-Mountain Park) Group to be 1450 feet a few miles to the south on Lynx Creek, but only the upper 700 feet of beds, equivalent to the middle and upper parts of the Beaver Mines Formation, are well exposed on Cripple Creek (Fig. 9).

The upper part of the succession is similar to that observed on Ram River, except that a thick, resistant, pale green, medium-grained, Mountain Park-type sandstone is present about 160 feet below the top of the formation. The contact with the Blackstone Formation, although covered, can be placed 25 to 35 feet below a conglomeratic, quartzose sandstone ("Fish-scale" sand), also present to the east on Ram River.

The base of the Mountain Park facies is drawn at the base of a pale green, medium-grained sandstone, 40 feet thick, about 500 feet below the Blackstone contact. Strata below this datum (Luscar facies) are poorly exposed and folded, consisting of laminated dark grey shale and siltstone and pale grey, fine-grained sandstone containing abundant brownish siderite pellets. Elsewhere in the area Erdman (*op. cit.*) reports coal seams up to 4 feet thick in Luscar-type beds, but their relationship to the section on Cripple Creek is uncertain.

Beds adjacent to the Luscar-Mountain Park boundary were examined at one other locality in this part of the Foothills, on the north side of the North Saskatchewan River, in Tps. 38 and 39, R. 17, W. 5th Mer. The exposures are near the western edge of the Foothills where the combined thickness of the Luscar-Mountain Park succession is about 3000 feet (Douglas, 1955). However, only 600 to 700 feet of beds, approximately correlative with the middle part of the Beaver Mines Formation, are exposed on Tershishner Creek (Fig. 9).

The upper part of the measured section is on the east slope of a high ridge, on the northwest side of Tershishner Creek, in township 39, range 17. The ridge is capped by a thick, resistant, pale green, conglomeratic sandstone, mapped as Mountain Park Formation by Douglas (*op. cit.*). The sandstone is underlain by about 300 feet of dark greenish-grey shale and siltstone, with dark green siltstone and fine-grained sandstone more abundant in the lower part. Reddish-brown siderite pellets are present in the greenish sandstone at the base of this interval, which marks the approximate base of the Mountain Park facies.

The lower 125 feet of exposed section consists of dark grey shale and siltstone, with subordinate pale grey, buff-speckled, fine-grained sandstone. An interval of crushed coal 10 to 12 feet thick is present about 35 feet above a thick, pale grey sandstone at the base of the succession, and coaly talus was observed beneath the sandstone.

A similar succession of Luscar-type beds was measured on the North Saskatchewan River near the mouth of Tershishner Creek, in township 38, range 17. There, two crushed coaly intervals, 1 and 5 feet thick, were observed, interbedded with dark grey shale and siltstone and pale grey, fine-grained sandstone. The relationship of these beds to the first section is uncertain, but the top of the succession is below the base of the Mountain Park-type beds shown in figure 9.

Plant fossils are abundant in both the Luscar and Mountain Park facies of the Beaver Mines Formation in this part of the Foothills, especially in the dark grey shales and siltstones adjacent to coal seams in the lower part of the formation. Well-preserved suites of plants were collected from various stratigraphic levels in the three measured sections and from isolated exposures on North Ram River, ranging from 235 feet above the base of the formation on Ram River to within 40 feet of the top on Cripple Creek (Fig. 9). However, at the time of writing only those suites from the Ram and North Ram Rivers were specifically identified, the aggregate lists of species for the Luscar and Mountain Park facies at these two localities being given below:

(1) Ram River, Tps. 37 and 38, R. 12, W. 5th Mer.: (a) Luscar facies; three suites from three stratigraphic levels, ranging from 235 to 360 feet above the base of the formation (Fig. 9):

- Ferns
  - *Sphenopteris* sp. cf. *S. bidens* Bell
- Pteridosperms
  - *Sagenopteris williamsii* (Newberry)
- Gymnosperms
  - *Ginkgo* sp. cf. *G. pluripartita* (Schimper)
  - *Nilssonia canadensis* Bell
  - *Ptilophyllum montanense* (Fontaine)
  - *Athrotaxites berryi* Bell
  - *Elatides* sp. cf. *E. curvifolia* (Dunker)
  - *Elatides* n. sp.
  - *Pityophyllum* sp.

(b) Mountain Park facies; six suites from four stratigraphic levels (one uncertain), ranging from 460 feet above the base to 50 feet below the top of the formation (Fig. 9):

- Ferns
  - *Cladophlebis virginiensis* Fontaine
  - *Cladophlebis* sp.
  - *Coniopteris brevifolia* (Fontaine)
  - *Gleichenites*? sp.
  - *Sphenopteris latiloba* Fontaine
- Pteridosperms
  - *Sagenopteris mclearni* Berry
- Gymnosperms
  - *Ginkgo* sp. cf. *G. pluripartita* (Schimper)
  - *Ginkgo* sp.
  - *Ptilophyllum montanense* (Fontaine)
  - *Athrotaxites berryi* Bell
  - *Elatides* sp. cf. *E. curvifolia* (Dunker)
  - *Elatides brevifolia* (Fontaine)
- Angiosperms
  - *Sapindopsis*? sp.

(2) North Ram River, Tp. 38, R. 12, W. 5th Mer.: (a) Luscar facies; two suites from isolated outcrops beneath the thick coal seams in the lower part of the succession:

- Bryophytes
  - *Thallites* sp. cf. *T. zeilleri* Seward
- Ferns
  - *Cladophlebis* sp.
  - *Coniopteris berryi* Bell

Sphenopteris acrodentata Fontaine
Sphenopteris erecta Bell
Sphenopteris sp. cf. *S. mclearni* Bell

Pteridosperms
Sagenopteris williamsii (Newberry)

Gymnosperms
Ctenopteris sp. cf. *C. insignis* Fontaine
Nilssonia canadensis Bell
Pseudocycas dunkeriana (Goeppert)
Elatocladus brevifolia (Fontaine)
Podozamites sp.

(b) Mountain Park facies; two suites from isolated outcrops in the upper part of the formation:

Ferns
Cladophlebis parva Fontaine
Coniopteris? sp.

Pteridosperms
Sagenopteris sp. cf. *S. mclearni* Berry

Gymnosperms
Ginkgo sp. cf. *G. pluripartita* (Schimper)
Nilssonia canadensis Bell
Athrotaxites berryi Bell
Elatides sp. cf. *E. curvifolia* (Dunker)
Elatocladus brevifolia (Fontaine)

Both the Luscar and Mountain Park floras are composed of essentially the same elements, consisting almost entirely of non-dicotyledonous species that collectively are synonymous with Bell's (1956) "lower Blairmore" flora from the Crowsnest Pass region. The only dicotyledonous remains consist of a leaf fragment doubtfully identified as *Sapindopsis* sp., from 65 feet below the top of the succession on Ram River, where it is associated with abundant non-dicotyledonous remains. The overwhelming non-dicotyledonous aspect of the flora to within 50 feet of the top of the Blairmore Group on Cripple Creek and Ram River confirms the correlation of the upper Blairmore beds at this latitude with the Beaver Mines Formation to the south; strata correlative with the Mill Creek-Bow Island succession of the southern Foothills and Plains are absent from this part of the Foothills.

Cadomin

A single section of Blairmore strata was examined in the northern part of the central Foothills, at Cadomin, in what may be considered the type area of the Cadomin, Luscar, and Mountain Park Formations (although MacKay [1929a] did not designate nor describe any one section as the type section). The section is partially exposed in railway cuts, just east of the thrust fault underlying the Nikanassin Range, in Sec. 5, Tp. 47, R. 23, W. 5th Mer. and Sec. 31, Tp. 46, R. 23, W. 5th Mer. The beds have been subjected to considerable folding and possibly faulting, which, coupled with the generally poor exposures, makes accurate determination of thicknesses impossible. Nevertheless, intervals representative of the Cadomin, Luscar, and Mountain Park Formations can be measured, and a general idea of the succession obtained (Sec. 8, Fig. 10, in pocket).

Gladstone Formation

The lower part of the section, correlative with the Gladstone Formation of this report and the Cadomin and lower Luscar beds of MacKay (*op. cit.*) is from 400 to 800 feet thick. The basal member, the Cadomin Conglomerate, is 35 to 40 feet thick, consisting of sandy pebble conglomerate in the lower part, grading in the upper 10 feet into pale grey, medium-grained, cherty sandstone. The pebbles, up to 6 inches in diameter, are composed of well-rounded white and pink quartzite, and grey to black chert or argillite. Both contacts are sharp: the lower with thin-bedded coaly shale and silty sandstone of the Nikanassin Formation, and the upper with dark grey shale of the Luscar facies.

The lower beds of the Gladstone Formation for an unknown distance above the basal conglomerate are folded and poorly exposed, consisting mainly of dark grey, fine-grained, cherty sandstone interbedded in units 5 feet thick or less with dark grey, carbonaceous siltstone and silty shale. The upper 200 feet of beds, beneath the marine member of the Beaver Mines Formation, are similar to the lower beds, except for a higher proportion of sandstone, and contain several thin sheared coaly beds a few inches to 2 feet thick, associated with abundant plant and scattered invertebrate remains. No lithologic unit corresponding to the "calcareous" member of the southern Foothills was observed (Fig. 13), although the upper 15 to 20 feet of strata—consisting of dark grey shale and siltstone—contain abundant ostracodes, separated from the overlying marine shale tongue by 6 inches of claystone with a thin pelecypod coquina at the top.

An invertebrate megafauna collected from dark grey, calcareous shale 70 feet below the top of the formation contains the following species:

- Mollusca
    - *Murraia* sp. cf. *M. fabensis* McLearn
    - *Murraia* n. sp.
    - *Musculiopsis* sp. cf. *M. russelli* MacNeill
    - *Campeloma* sp. indet.

A microfauna from dark grey, silty shale at the top of the formation contains the following species:

Ostracoda
- *Cypridea* sp.
- *Metacypris persulcata* Loranger (not Peck)

The environmental significance of the faunas, although suggestive of near-shore, brackish-water conditions, is indeterminate. The ostracode fauna possibly indicates a lagoonal environment, transitional to the marine open-sea environment that apparently prevailed during the deposition of the overlying foraminifera-bearing beds.

Beaver Mines Formation

The upper part of the Cadomin section, correlative with the Beaver Mines Formation of this report and the upper Luscar and Mountain Park beds of MacKay (*op. cit.*), is 1000 to 1500 feet thick, although owing to folding the formation appears to be much thicker. The lower contact of the formation is drawn at the base of a blocky, dark grey shale unit 20 feet thick, lying sharply but conformably on fossiliferous claystone at the top of the ostracode-bearing beds. The shale, marine in origin, contains abundant foraminifera, including rare calcareous forms, the following species having been identified (Mellon and Wall, 1963):

- *Haplophragmoides* spp.
- *Psamminopelta* sp. cf. *P. bowsheri* Tappan
- *Gyroidina* sp. cf. *G. nitida* (Reuss)
- *Quadrimorphina albertensis* Mellon and Wall.

The last two species have a wide distribution in correlative marine strata of the northern Foothills and Plains and permit correlation of the marine tongue at Cadomin with the lower part of the Moosebar Shale in northeastern British Columbia (Mellon *et al.*, 1963).

The interval between the marine shale member and the overlying coal-bearing strata is largely covered, except for sparse outcrops of dark grey, silty shale and sandstone near the top of the interval containing comminuted fish remains. The covered interval is succeeded by a pale grey, medium-grained, crossbedded, moderately feldspathic sandstone 50 feet thick, beneath the coal seam (Jewel seam) formerly mined at Cadomin (estimated by MacKay [1930] to be 28 feet thick). A similar thick, grey sandstone 50 to 75 feet above the Jewel seam marks the exposed top of the Luscar-type beds.

The succession of strata between the coal-bearing beds and the Mountain Park-type beds at the top of the section is folded and largely covered, about 200 feet of folded Mountain Park-type beds being exposed beneath the base of the Blackstone Formation. The lower part of this interval is occupied by a resistant, green, feldspathic sandstone unit 165 feet thick, with several feet of fine chert-pebble conglomerate 60 to 70 feet above the base. The sandstone grades above into dark green shale and siltstone, in sharp contact with dark grey, silty shale of the Blackstone Formation, which carries a pre-"Fish-scale" sand, post-Joli Fou microfauna (J. H. Wall, pers. comm.).

A flora collected from dark greenish-grey shale about 20 feet below the Blackstone contact contains the following species (Fig. 10):

- Ferns
  - *Cladophlebis munda* (Dawson)
  - *Cladophlebis parva* Fontaine
  - *Sphenopteris goepperti* (Dunker)
  - *Sphenopteris* sp. cf. *S. mclearni* Bell
- Gymnosperms
  - *Pityophyllum nordenskjoldi* (Heer)
  - *Pseudocycas* sp. cf. *P. unjiga* (Dawson)
  - *Athrotaxites berryi* Bell.

The composition of the flora confirms the correlation of the type Mountain Park beds with the Beaver Mines Formation of the southern Foothills.

Mannville Group

Central and Northeastern Plains

Lower Cretaceous rocks of the Foothills extend east from the margin of the folded belt to form a relatively thin but widespread blanket of interbedded marine and nonmarine detrital strata under the Alberta Plains. The rocks have been investigated at various levels, regionally and locally, so that their general features—thickness, gross lithology, and correlation—are well known in most Plains regions (Badgley, 1952; Glaister, 1959; Williams, 1963). However, the interrelationships of some of the stratigraphic units involved is uncertain, as is the correlation of these units with the much thicker outcrop succession in the Foothills.

Seven complete or nearly complete cored sections of Lower Cretaceous strata from widely spaced localities in the central and northeastern Alberta Plains (Fig. 1) were measured and sampled in detail. The well locations and thicknesses of strata involved are given in table 2, and cross sections showing the correlation of rock units and facies in east-west and north-south directions across the Plains are given in figures 11 and 12 (in pocket).

Lower Cretaceous strata of the central Alberta Plains can be divided into three basic units, of which the lower two form the Mannville Group, and the upper the marine Joli Fou-Viking shale-sandstone complex. The Mannville Group, divided previously into "lower Mannville" and "upper Mannville" formations (Mellon and Wall, 1963), is correlated with the

Table 2. Locations and Thicknesses of Sampled Subsurface Sections of the Mannville Group and Joli Fou-Viking Formations in the Central and Northeastern Alberta Plains

WELL	LOCATION	THICKNESS (FEET)		
		Mannville Group		Viking-Joli Fou
		lower	upper	
Brook Stanmore No. 1	Sec. 22-30-11 W. 4th Mer.	absent	355	205
Anglo-Canadian, Home, C. & E. West Viking No. 1	Sec. 11-48-15 W. 4th Mer.	120	335	150
Anglo-Canadian Wabamun No. 1	Sec. 10-51-4 W. 5th Mer.	120	490	165
Anglo-Canadian, Home, C. & E. Ft. Augustus No. 1	Sec. 29-55-21 W. 4th Mer.	375	480	135
Anglo-Canadian Elk Point No. 1	Sec. 26-56-5 W. 4th Mer.	absent	445	145
Barnsdall Lyle Lake No. 1	Sec. 24-72-17 W. 4th Mer.	absent	535	130
Barnsdall West Wabiskaw No. 1	Sec. 17-78-2 W. 5th Mer.	95	715	90

Gladstone and Beaver Mines Formations of the Blairmore Group in the Foothills, and the Joli Fou-Viking Formations with the Mill Creek-Bow Island Formations in the southern Foothills and Plains.

McMurray Formation

The "lower Mannville" formation is renamed here the McMurray Formation, after Williams' (1963) definition of that unit, which implies correlation with the type McMurray Formation along the lower Athabasca River in northeastern Alberta. There is some justification, other than an implied correlation, for extending the name McMurray Formation into the subsurface of central Alberta:

(1) the strata are of mainly nonmarine origin in both central and northeastern Alberta;

(2) the upper boundary of the formation in both regions marks a change from quartzose sandstone to overlying feldspathic sandstones rich in volcanic detritus;

(3) the persistent fossiliferous beds ("ostracode zone") at or near the top of the formation in central Alberta are locally present in the outcrop region, as on Hangingstone River (Russell, 1932);

(4) residual deposits developed through weathering of the underlying Paleozoic carbonates are present locally at the base of the formation in both central and northeastern Alberta.

However, to the west near the margin of the Foothills in central Alberta, and to the northwest in the Whitecourt-Peace River districts, where quartzose McMurray-type sandstones grade laterally into the more heterogeneous, cherty sandstones of the Cordilleran region, it appears advisable to retain the Foothills names, Gladstone or Gething Formations, for lower Mannville-equivalent strata.

The McMurray Formation lies unconformably on Mississippian and Devonian carbonates over most of the central Alberta Plains, overlapping on older Cretaceous(?) or Jurassic detrital strata in the western part of the region (Williams, *op. cit.*). The thickness of the formation is a function mainly of the relief on the underlying Paleozoic surface, varying from 0 to about 400 feet within relatively short distances. The formation is absent from three of the wells studied and attains a maximum thickness of 375 feet in the Fort Augustus No. 1 well, situated over a linear depression in the Paleozoic surface called the "Edmonton Channel" by Williams (*ibid.*).

Where present, the formation can be divided into two, locally three, units or members. The basal member (Williams' [*op. cit.*] "Deville Member"—after Badgley, 1952) is present only locally, consisting in the basal part of red and green waxy shale, chert fragments, and siderite pellets, grading up into dark brown shale interbedded with poorly sorted quartz siltstone and fine-grained sandstone. The strata are interpreted as residual or poorly sorted detritus resulting from the weathering of the underlying Paleozoic carbonates, although truly residual material appears to be confined to the basal few feet of strata above the Paleozoic contact. The thickness of the member depends mainly on where the upper, gradational contact is drawn, varying from less than 20 feet in the West Viking No. 1 well to 75 to 125 feet in the Fort Augustus No. 1 well.

The middle member of the McMurray Formation (Williams' [*op. cit.*] "Ellerslie Member"—after Hunt, 1950) consists of dark grey, silty shale, laminated siltstone, and white, fine-grained, kaolinitic, quartz sandstone, grading into overlying shaly calcareous beds of the "ostracode zone". The unit varies in thickness from less than 25 feet in the Wabamun No. 1 well to 175 to 225 feet in the Fort Augustus No. 1 well, the thickness depending on where the lower contact is drawn. The beds contain few megafossils other than scattered fish scales, rare pelecypod fragments, and carbonized plant remains.

The upper member (Williams' [*op. cit.*] "calcareous" member—after Glaister, 1959) consists of hard, dark grey, calcareous shale and siltstone containing abundant invertebrate remains from which the name "ostracode zone" is derived (Hunt, 1950). The "calcareous" member forms a relatively well-defined lithologic unit throughout much of central and northeastern Alberta and is correlative with the fossiliferous beds at the top of the Gladstone Formation in the southern and south-central Alberta Foothills. A comparison of these beds in the Foothills and central Plains is given in figure 13 (in pocket).

The unit is present in four of the seven wells examined, ranging in thickness from 10 to 15 feet in the West Viking No. 1 well, to 45 feet in the Wabamun No. 1 well. In both the Wabamun No. 1 and West Wabiskaw No. 1 wells the "calcareous" member is in sharp contact with glauconitic, sandy shales of the overlying upper Mannville succession, whereas in the West Viking No. 1 and Fort Augustus No. 1 wells it is overlain by 40 to 50 feet of noncalcareous, unfossiliferous (except for rare pelecypod fragments), laminated, dark grey shale, siltstone, and fine-grained quartz sandstone, in sharp contact with the overlying glauconitic beds. These strata are stratigraphically and petrographically analogous to the succession of thin-bedded black shales and quartzose sandstones overlying the fossiliferous beds of the Gladstone Formation on Ram River (Fig. 9) and have been assigned here to the McMurray Formation on the basis of their quartzose composition and the absence of glauconite or foraminifera. However, Williams (*op. cit.*) has included these beds in the Fort Augustus No. 1 well in the base of his Clearwater Formation, preferring to draw the upper boundary of the McMurray Formation at the top of the "calcareous" member. Although Singh (1964) has shown that microplankton of probable marine origin are present in these beds, demonstrating the gradational nature of the microfloral and microfaunal assemblages across the McMurray-Clearwater boundary in the Fort Augustus No. 1 well, the marked lithologic-petrographic break in the Mannville succession there and in the West Viking No. 1 well is above the "calcareous" member.

The "calcareous" member is characterized by abundant invertebrate remains, including pelecypods, gastropods, and ostracodes of nonmarine and near-marine (brackish-lagoonal) origin. Microfaunal lists are given in a previous paper (Mellon and Wall, 1963), in which Wall compared the ostracode assemblages—dominated by the species *Metacypris*—from the Gladstone Formation of the Foothills with those from the "calcareous" member in three of the wells described here (West Wabiskaw No. 1, Fort Augustus No. 1, and Wabamun No. 1 wells). Wall pointed out that the assemblage from the type Gladstone Formation on Mill Creek is dominated by freshwater forms, distinct from the brackish-water assemblages found in the central Foothills and Plains. In northeastern Alberta, in the West Wabiskaw No. 1 well, the calcareous *Metacypris*-bearing beds beneath the glauconitic sand (Wabiskaw Member) at the base of the upper Mannville interfinger with strata containing the marine ostracode *Cytheridea*, associated there with abundant agglutinated foraminifera. Similarly, to the east on the lower Athabasca River, dark grey shale and oil-saturated sand in the upper part of the type McMurray Formation, correlative with the "calcareous" member to the west and south, contain abundant agglutinated foraminifera (Mellon and Wall, 1956), the presence of which demonstrates the gradational nature of the McMurray-Clearwater faunal succession in northeastern Alberta. However, the break in sandstone composition at the top of the McMurray succession is still recognizable in the Wabiskaw and lower Athabasca River areas (Carrigy, 1963), as well as in the central Plains, being associated in the latter region with a more pronounced faunal break, marked by the sudden appearance of foraminifera in basal upper Mannville strata. An analogous situation prevails in the Foothills at the contact between the Gladstone and Beaver Mines Formations; at Cadomin the break in the lithologic-faunal succession appears gradational or at least conformable, becoming more pronounced towards the southern Foothills where the contact probably marks the locus of a minor disconformity.

Fort Augustus Formation

The name Fort Augustus Formation is proposed here for the upper part of the Mannville Group in the central Alberta Plains, above the "calcareous" member of the McMurray Formation (where present) and below the marine Joli Fou Shale. The name is taken from the Anglo-Canadian, Home, C. and E. Fort Augustus No. 1 well[1], 25 miles northeast of Edmonton, in Lsd. 7, Sec. 29, Tp. 55, R. 21, W. 4th Mer., where the proposed type section of the formation is present between depths of 2427 and 2900 feet.

These strata were assigned previously to the "upper Mannville" formation by those (Glaister, 1959; Mellon and Wall, 1963) who considered them a homogeneous unit in contrast to the underlying McMurray Formation, or to the Clearwater and Grand Rapids Formations by those (Badgley, 1952; Williams, 1963) who considered them sufficiently diverse in lithology to be divided into a lower shaly marine unit and an upper sandy non-marine unit. Although the Fort Augustus Formation is correlative with the type Clearwater and Grand Rapids Formations of the lower Athabasca River area, there are good reasons for not extending these names into central Alberta:

(1) in the central Plains the main break in the faunal succession of the Mannville Group coincides with the top of the McMurray Formation. In contrast, elements of the Clearwater microfaunal assemblage grade into strata assigned to the Grand Rapids Formation by Badgley (*op. cit.*) and Williams (*op. cit.*)

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[1] A cored section of the Mannville Group and adjacent strata from this well is stored at the Oil and Gas Conservation Board, Calgary.

(2) the main break in lithology and sandstone composition within the Mannville Group also coincides with the top of the McMurray Formation. In contrast, the Clearwater facies grades into the overlying Grand Rapids facies with no consistent break in lithology or sandstone composition. The use of an arbitrary electric-log or lithologic datum to define the Clearwater-Grand Rapids boundary is impractical owing to the local lensing nature of the beds involved.

(3) the Clearwater-Grand Rapids contact is diachronous. The type Clearwater is composed mainly of shale that grades laterally into sandy beds towards central Alberta, as continental Luscar-type beds displace the marine Grand Rapids sandstones in the upper part of the succession. Thus, Badgley's (*op. cit.*) and Williams' (*op. cit.*) Clearwater Formation in the Fort Augustus No. 1 well is composed mainly of marine (or littoral) sandstones that are lithologically and genetically similar to the Grand Rapids sandstones of the type outcrop area to the north.

The Fort Augustus Formation of the central Plains shows considerable variation in thickness, in part owing to the irregular topography of the underlying surface, and in part owing to regional paleogeographic factors. Thus, although the formation as a whole tends to thicken in a northwesterly direction, towards the Peace River basin (or in a westerly direction near the margin of the Foothills), marked local variations in thickness are found in the east-central and south-central Plains where the strata were deposited over local "highs" in the Paleozoic surface which were only partly covered by the underlying quartzose and calcareous McMurray sediments (Williams, *op. cit.*). In the seven wells examined, the formation varies in thickness from 335 feet in the West Viking No. 1 well to 720 feet in the West Wabiskaw No. 1 well.

The lower contact of the formation is sharp, being drawn at the top of the Paleozoic carbonates where the McMurray Formation is absent, or at the top of the "calcareous" member or associated quartzose sandstones and siltstones where the McMurray Formation is present. In all of the wells except Brook Stanmore No. 1, the basal beds consist of dark grey, glauconitic shale, or poorly stratified, sandy shale, overlain generally gradationally by pale grey, fine-grained, glauconitic sandstone interbedded with argillaceous sandstone containing dark grey clay pockets and partings. This unit is called the Wabiskaw Member (Badgley, *op. cit.*) from the West Wabiskaw No. 1 well, where it is 87 feet thick. Elsewhere, the unit varies considerably in glauconite content, texture, and thickness, ranging from 23 feet in the Fort Augustus No. 1 well to approximately 135 feet in the Wabamun No. 1 well. The upper contact is generally sharp, although in the West Viking No. 1 and Elk Point No. 1 wells the upper sandy beds grade into overlying silty or shaly strata.

The remainder of the Fort Augustus Formation consists in general of laminated pale to dark grey shale and siltstone and pale grey, fine- to medium-grained, feldspathic sandstone in beds ranging from a few inches to several tens of feet in thickness. The sandstones are mainly soft and kaolinitic, with hard, thin, calcareous intervals, and most contain abundant pale brown siderite pellets like the Luscar-type sandstones in the lower part of the Beaver Mines Formation in the north-central Foothills. Thin coal beds are present in the upper part of the formation in the Wabamun No. 1, West Viking No. 1, and Fort Augustus No. 1 wells, in association with well-preserved plant fossils. Other megascopic organic remains are rare, although the primary lamination of many of the silty and shaly beds is obliterated or disturbed by numerous blebs and tubes of fine sand or silt, probably owing to the action of burrowing organisms. The upper contact with the Joli Fou Formation is sharp, although thin quartzose siltstone or sandstone beds beneath the Joli Fou shales proper in several of the wells may have been reworked during the initial stages of the Joli Fou marine transgression. These strata (Badgley's [*op. cit.*] St. Edouard Member) have been included here in the Fort Augustus Formation.

The distinction between marine and nonmarine phases of the Fort Augustus Formation cannot be made on the basis of gross lithology alone, although some features, such as cyclical variation in lithology and grain size, are helpful when used in conjunction with other data. The primary criterion used here is the distribution of foraminifera, which are common locally in five of the wells studied. Foraminifera are absent from the Brook Stanmore No. 1 well, where the entire formation appears to be of nonmarine origin, and also from the West Viking No. 1 well, although the shales at the base of the formation there appear to be marine from their abundant glauconite content. In the three centrally located wells—Wabamun No. 1, Fort Augustus No. 1, and Elk Point No. 1 wells—foraminifera are found in the lower and central parts of the formation, extending to within 140 feet of the top of the unit in the type Fort Augustus No. 1 well. The upper coal-bearing beds in the Wabamun No. 1 and Fort Augustus No. 1 wells appear to be mainly of nonmarine origin[1], but there is some doubt about the status of correlative beds in the Elk Point No. 1 well, where neither coal nor plant remains were found in beds above the foraminifera-bearing strata. In the two northern wells—Lyle Lake No. 1 and West Wabiskaw No. 1 wells—foraminifera are abundant in most of the shaly strata, and the Fort Augustus Formation there is probably entirely marine in origin. However, only in the West Wabiskaw No. 1 well do the lithology and microfaunal succession correspond to those of the type Clearwater-Grand Rapids succession to the

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[1] Singh (1964) has described microplankton of marine or brackish-water origin in beds 75 feet below the top of the formation in the Fort Augustus No. 1 well.

east; to the south, strata assigned to the Clearwater Formation by previous investigators (Badgley, *op. cit.;* William, *op. cit.*) are more similar to the sandy Grand Rapids Formation of the type area.

The Fort Augustus microfaunal assemblages are composed mainly of agglutinated foraminifera, with less common calcareous foraminifera and rare marine ostracodes. Calcareous foraminifera are present in the lower part of the formation in the Fort Augustus No. 1 and Lyle Lake No. 1 wells, and throughout the lower and central parts of the formation in the West Wabiskaw No. 1 well (Fig. 12). Both agglutinated and calcareous forms constitute part of a single faunal assemblage that apparently attains its peak abundance in species and numbers in the type Clearwater Formation along the lower Athabasca River (Stelck *et al.,* 1956) and in the upper beds of the Loon River Shale along the lower Peace River (Wickenden, 1951). Faunal lists for four of the five wells from which foraminifera were recovered (Wabamun No. 1, Ft. Augustus No. 1, Lyle Lake No. 1, and West Wabiskaw No. 1 wells) are published elsewhere (Mellon and Wall, 1963).

Megascopic plant remains are abundant at certain levels in the upper part of the Fort Augustus Formation in the Brook Stanmore No. 1, West Viking No. 1, Fort Augustus No. 1, and Wabamun No. 1 wells, where they are associated with thin coal beds and carbonaceous shale. In the type Fort Augustus No. 1 well the plant-bearing beds interfinger with marine foraminifera-bearing shales in the upper part of the formation, their distribution demonstrating the progressive but fluctuating transition from marine to shoreline or continental conditions of deposition there during Fort Augustus time.

The suites are composed entirely of non-dicotyledonous elements, although only those from the Fort Augustus No. 1 well have been specifically identified at the time of writing. These are from six stratigraphic levels, ranging from 270 feet above the base to within 15 feet of the top of the formation (Figs. 11, 12), and contain the following aggregate list of species:

Ferns
    Cladophlebis sp.
    Sphenopteris brulensis Bell
Pteridosperms
    Sagenopteris sp. cf. *S. elliptica* Fontaine
Gymnosperms
    Nilssonia canadensis Bell
    Ptilophyllum sp. cf. *P. hirtum* Bell
    Ptilophyllum montanense (Fontaine)
    Athrotaxites berryi Bell
    Cyparissidium? *gracile*? Heer
    Pagiophyllum ambiguum Heer.

All of these species are characteristic elements of Bell's (1956) "lower Blairmore" flora in the Foothills, and their presence in the Fort Augustus Formation confirms the correlation of that unit with the Beaver Mines Formation of the Blairmore Group in the Foothills.

Joli Fou and Viking Formations

The marine Joli Fou and Viking Formations overlie the Mannville Group in most of the central and northeastern Alberta Plains. These strata were not examined in detail, but some remarks as to their distribution and correlation are in order.

The two formations actually constitute a single genetic unit, analogous to the Clearwater and Grand Rapids facies of the underlying Fort Augustus Formation, bounded by breaks in sedimentation at the base and top. They comprise a succession of black, fissile shale (Joli Fou) that grades up into dark grey, laminated, silty shale and siltstone interbedded with pale grey, fine- to medium-grained, cherty, quartzose sandstone (Viking). The lower boundary of the Joli Fou Shale appears sharp in cores, being placed at the contact beween white, fine-grained, quartzose sand and silt (Badgley's [1952] St. Edouard Member) at the top of the Fort Augustus Formation and black fissile shale. The basal beds of the Joli Fou are commonly fossiliferous, containing abundant *Inoceramus* remains and agglutinated foraminifera that decrease in species and numbers towards the contact with the overlying sandy beds.

The Viking Formation is quite complex in detail, varying widely in thickness and lithology in the seven wells examined. The sandstones tend to be fine-grained, glauconitic, and kaolinitic, with much fine-scale slumping and interbedding of dark grey shale and siltstone. The coarser sands tend to be concentrated near the top of the succession, which is in sharp contact with dark grey, silty shale of the overlying Colorado Group. Although the fossil content of the Viking is sparse (Stelck, 1958), the beds appear to be of marine or shoreline origin.

The total thickness of the Joli Fou-Viking succession varies from 90 to 205 feet in the wells examined (Table 2), increasing to the south and east where the beds interfinger with the marine Bow Island Formation of the southern Plains (Glaister, 1959). Thus, indirectly, the beds correlate in part or in whole with the nonmarine upper beds of the Blairmore Group (Mill Creek Formation) in the southern Foothills. However, the beds thin and disappear towards the western margin of the central Plains, so that in the outcrop belt of the central Foothills the basal Blackstone shales of post-Viking age rest directly on the Beaver Mines Formation of the Blairmore Group, correlative with the Fort Augustus Formation of the Plains. The details of the disappearance of the Joli Fou and Viking Formations in the western part of the central Plains cannot be demonstrated in figure 11 owing to lack of control, but in the absence of any marked erosional unconformity at the top of the Blairmore Group in the Foothills, and in view of the progressive thinning of the Joli Fou and Viking beds to the north, it appears likely that the beds overlap onto and pinch out against the upper surface of the Beaver Mines Formation in much the same way as progressively younger basal Blackstone strata overlap westward on the upper surface of the Mill Creek Formation in the Sheep River-Turner Valley region (Fig. 8).

AGE AND CORRELATION

Both the Blairmore and Mannville Groups of the southern and central Alberta Foothills and Plains have long been recognized as Early Cretaceous in age from gross floral and faunal evidence. Correlative strata of partly marine origin in northern Alberta and northeastern British Columbia have been dated more precisely on the basis of ammonites and associated microfauna, but the stratigraphic relationships of these beds to the mainly continental strata of central and southern Alberta until recently have been uncertain, owing to the widely spaced nature of stratigraphic control points and to the lack of detailed paleontologic data from intermediate areas.

The succession of floral and faunal zones in the Lower Cretaceous strata of Alberta and northeastern British Columbia is reviewed below and related to the various major rock units now recognized in the Foothills and Plains of these regions.

Floral Zones

The floras of the Foothills Blairmore Group and underlying Kootenay Formation were first collected systematically by McLearn (1929) from the Crowsnest Pass region. McLearn's collections were described by Berry (1929), and subsequently by Bell (1956), who included in his report much new data on the Kootenay and Blairmore floras of the southern and central Alberta Foothills, and on the Nikanassin, Luscar, Gething, and Commotion floras of the northern Alberta and British Columbia Foothills. Additional floral lists for the Gething and Commotion Formations in northeastern British Columbia were published recently by Mellon *et al.* (1963) and Stott (1963).

These data have been combined with the species lists given in this report in compiling the data illustrated in figure 14, which shows the stratigraphic distribution of the relative proportions of megafloral species, grouped into six taxonomic divisions, for the Blairmore Group and adjacent strata of the Alberta and British Columbia Foothills. Sources of data are:

Dunvegan flora: Bell, 1963.

Mill Creek flora: Bell, 1956 ("upper Blairmore" flora); this report.

upper Commotion flora: Bell, 1956 (Commotion flora); Mellon *et al.*, 1963 (upper flora); Stott, 1963 (Boulder Creek flora).

lower Commotion flora: Mellon *et. al.*, 1963 (middle flora); Stott, 1963 (Gates flora—may include some "upper Commotion" species).

Beaver Mines flora: Bell, 1956 ("lower Blairmore" flora—may include some Gladstone species); this report.

Gething flora: Bell, 1956; Mellon *et. al.*, 1963 (lower flora); Stott, 1963.

Gladstone flora: this report.
Kootenay and Nikanassin floras: Bell, 1956.

The oldest Mesozoic flora of the Alberta Foothills is that of the Kootenay and Nikanassin Formations. The flora, entirely non-dicotyledonous, contains a higher proportion of ginkgo and cycadaceous species than the younger Cretaceous floras of the Foothills, as well as abundant ferns and conifers. Most of the species are long-ranging forms and extend up into the overlying Blairmore Group.

Bell (1956) favors a Barremian age for the Kootenay flora, although an ammonite of Late Jurassic (Portlandian) age has been found in the basal Kootenay sandstone in the Fernie area of southeastern British Columbia (Frebold, 1957). As there is no valid evidence for a break in deposition at the top of the basal Kootenay sandstone (a shoreline deposit separating the underlying marine Fernie beds from the overlying coal measures), the Kootenay flora must be partly, if not entirely, Jurassic in age. However, the upper age limit of the Kootenay flora is debatable; there is no evidence at present to indicate the magnitude of the disconformity at the boundary with the overlying Blairmore Group, nor has the lower part of the Blairmore Group itself been dated with precision.

Two distinct floras are found in the Blairmore Group of the Alberta Foothills, described by Berry (1929) and later by Bell (1956) as the "lower Blairmore" and "upper Blairmore" floras. In the southern Foothills plant remains are scarce in or absent from the Gladstone Formation, and the "lower Blairmore" flora is confined mainly to the Beaver Mines Formaiton[1]. In central Alberta elements of this flora are common in both the Gladstone and Beaver Mines Formations, extending north into the Luscar facies of the northern Foothills (Bell, *ibid.*), and the Gething and Commotion Formations of northeastern British Columbia (Bell, *ibid.;* Mellon *et al.*, 1963; Stott, 1963). Elements of the "lower Blairmore" flora are also common in the continental phases of the Fort Augustus Formation in the central Plains.

The "lower Blairmore" flora is composed mainly of non-dicotlyedonous species, with ferns predominating. The flora has many species in common with the underlying Kootenay flora but can be distinguished from it by the presence of abundant pteridosperms (*Sagenopteris* and allied forms) and certain species of conifers, notably species of *Elatocladus, Elatides,* and *Athrotaxites* (Bell, *op. cit.*). Bell also has called attention to the fact that rare dicotyledonous remains are associated with the "lower Blairmore" flora in the upper part of its range in the Crowsnest Pass region. The dicotyledons, identified by Bell (*ibid.*) as *Sapindopsis angusta,* were

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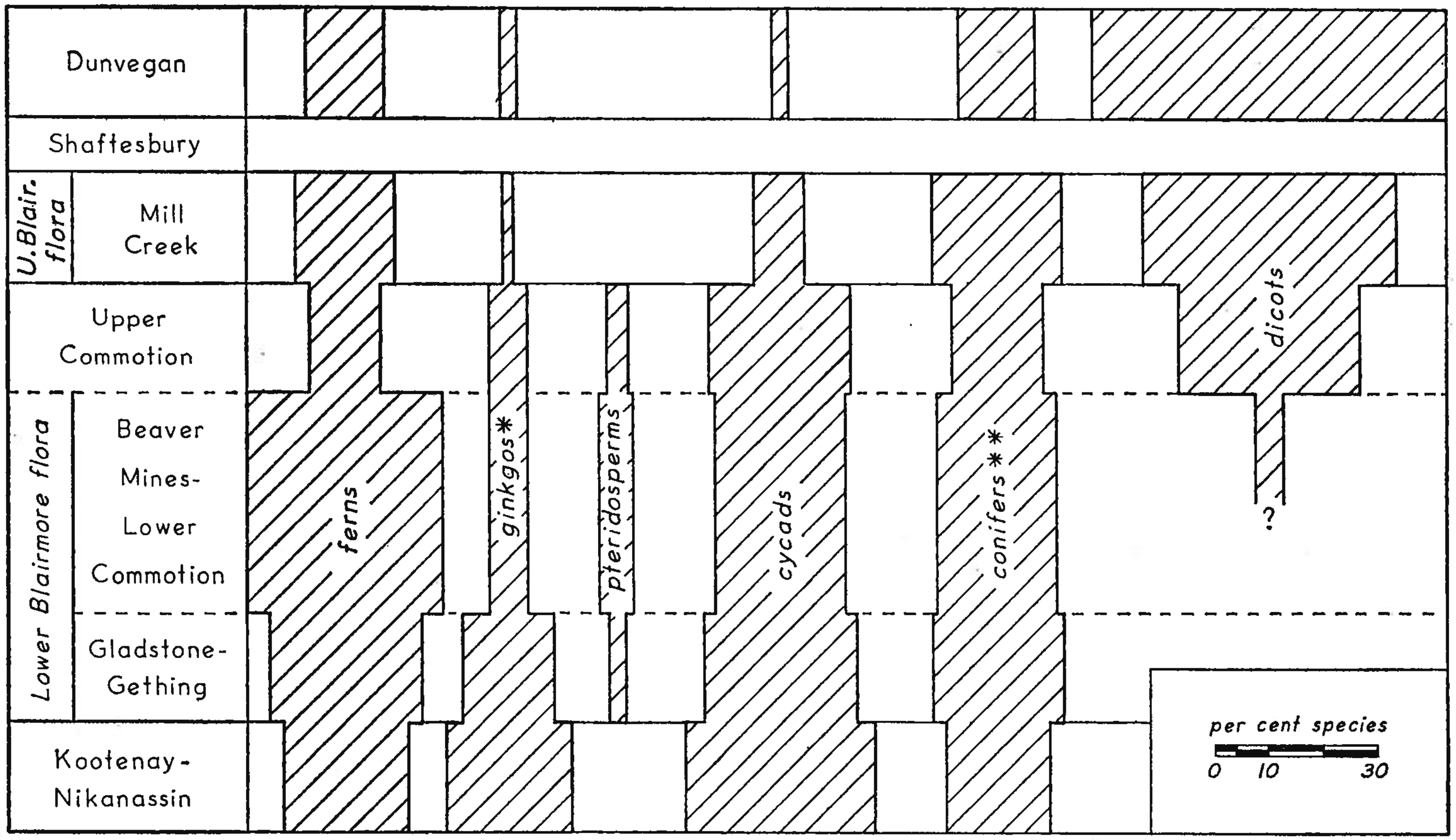
[1] All of McLearn's (1929) "lower Blairmore" floral collections from the Crowsnest Pass region appear to come from above the "calcareous" member at the top of the Gladstone Formation, as do all of the writer's "lower Blairmore" collections from the southern Foothills, except one (Sheep River).



* including allied forms   ** including _Podozamites_ and allied forms

FIGURE 14. Relative abundances of plant species grouped according to major taxonomic divisions in beds of late Jurassic? to mid-Cretaceous age, Alberta and northeastern British Columbia Foothills.

collected originally by McLearn (1929) from two localities on Carbondale (Castle) River, presumably from the middle or upper part of the Beaver Mines Formation. In addition, the writer has collected *Sapindopsis* from the upper part of the Beaver Mines Formation in the type Mill Creek section, from an isolated outcrop of the formation on Livingstone River (stratigraphic level unknown), and from near the top of the formation on Ram River (Mountain Park facies). At all of these localities, *Sapindopsis* is associated with typical non-dicotyledonous species of the "lower Blairmore" flora.

The stratigraphic significance of dicotyledons in the Beaver Mines Formation should not be overestimated. The remains are fragmental and too rare to be of any value in dividing the "lower Blairmore" flora of the Foothills into subfloras with zonal significance. Nor can any valid distinction be made from available data among "lower Blairmore" floral zones on the basis of non-dicotyledonous species; the same species appear to range throughout the Gladstone and Beaver Mines Formations of southern and central Alberta, the Luscar and Mountain Park facies of northern Alberta, and the Gething and Commotion Formations of northeastern British Columbia. Apparent differences in the relative proportions of non-dicotyledonous species among these floras[1] in figure 14 are probably due to insufficient samples rather than to any geologic factor.

In the Foothills of northeastern British Columbia, characteristic non-dicotyledonous species of the "lower Blairmore" flora range through the Gething and most, if not all, of the Commotion Formation. In addition, in the upper part of the Commotion Formation on Belcourt Ridge (upper part of Stott's [1963] Gates Member), several species of dicotyledons, including *Sapindopsis* sp. cf. *S. magnifolia*, are associated with abundant non-dicotyledonous remains (Mellon *et al.*, 1963). Bell (1956) had listed previously four dicotyledonous species from the upper beds of the formation on Commotion Creek, and Stott (*ibid.*) recently has reported additional dicotyledonous species from the formation in this general area, mainly from his Boulder Creek Member, above the dicotyledon-bearing beds described by Mellon *et al.* (*ibid.*)[2].

In terms of number of species, the dicotyledonous aspect of the upper Commotion assemblage is impressive (Fig. 14) and indicates a younger age for the flora than that of the Beaver Mines flora of the Alberta Foot-

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[1] Bell's (1956) Luscar flora species lists have not been used in compiling figure 14, as the Luscar flora includes species from strata correlative with the Beaver Mines and Gladstone Formations of this report. Bell's "lower Blairmore" flora from the central and southern Alberta Foothills also probaby includes some Gladstone assemblages, although the great majority of these collections undoubtedly come from beds correlative with the Beaver Mines Formation of this report.

[2] Stott (*op. cit.*) also lists two dicotyledonous species among the predominantly non-dicotyledonous flora from his Gates Member. His Gates flora is included in figure 14 with the lower Commotion-Beaver Mines flora, although its range may overlap with that assigned here to the "upper Commotion" flora.

hills. However, in terms of specimens collected, dicotyledonous remains are relatively rare. This fact, coupled with comparison of the non-dicotyledonous elements common to both floras, indicates that the age difference is slight. The close affinity of the lower and upper Commotion floras is further emphasized by comparison of the latter with the dominantly dicotyledonous flora found in the upper part of the Blairmore Group (Mill Creek Formation) in the southern Foothills.

The precise age of the "lower Blairmore" flora is debatable if based on megafloral comparisons alone. Berry (*op. cit.*) assigned to it a late Aptian or Albian age, whereas Bell (*op. cit.*) favors an Aptian or even Barremian age. The upper interval through which the flora ranges in central Alberta now can be dated more precisely as middle Albian from the associated microfauna (Mellon and Wall, 1963). Both the lower and upper Commotion floras can be similarly dated from the associated microfauna and megafauna (Mellon *et al.*, 1963; Stott, *op. cit.*). However, the lower age limit of the "lower Blairmore" flora is still uncertain, for no diagnostic marine fossils have been described from the lower interval (Gladstone and Gething Formations) through which the flora ranges.

The "upper Blairmore" flora is restricted to the southern Alberta Foothills, where it ranges through strata assigned here to the Mill Creek Formation, including the volcanic Crowsnest Member. Mainly dicotyledonous, the flora can be distinguished from the "lower Blairmore" and upper Commotion floras on several counts, including:

(1) the abundance of dicotyledons, both in terms of species and specimens;

(2) the replacement of older Cretaceous ginkgo species—*Ginkgo pluripartita, G. lepida, G. nana,* and *G. digitata*—by a distinct new species of *Ginkgo;*

(3) the absence of the characteristic lower Blairmore-upper Commotion pteridosperm, *Sagenopteris;*

(4) the absence or rarity of certain lower Blairmore and upper Commotion gymnosperms, such as *Nilssonia, Elatocladus, Elatides,* and *Athrotaxites.*

Thus, although the relative abundance of dicotyledons is the salient feature of the "upper Blairmore" flora, the change in the composition of the non-dicotyledonous portion of the flora is also pronounced.

None of the previous workers appears to have been aware of the important break in sedimentation that marks the base of the Mill Creek Formation in the southern Foothills, and it has been tacitly assumed that the two Blairmore floras of this region are part of a continuous evolutionary succession, being separated in the Crowsnest Pass region by an interval of unfossiliferous beds. The presence of rare *Sapindopsis* fragments in the upper part of the lower flora's range-interval seems to support this thesis. There is, however, no gradation between the two Blairmore floras of the southern Foothills; a non-dicotyledonous flora has been collected on Ma Butte to within 50 feet of the base of the Mill Creek Formation, whereas floral collections from the lower part of the Mill Creek Formation on Mill Creek are composed mainly of dicotyledons. No moderately dicotyledonous transitional flora, such as that found in the upper part of the Commotion Formation in northeastern British Columbia, has been found in the Blairmore Group of the southern and central Alberta Foothills.

Bell (1956) assigned an Albian age to the "upper Blairmore" flora, which is indicated but not proven by comparison with other floral assemblages of the Foothills and Plains. The flora is definitely younger than the middle Albian upper Commotion flora (Stelck, 1958) but is older than the Cenomanian Dunvegan flora of northern Alberta and British Columbia (Bell, *ibid.*), included in figure 14 for comparison. However, other evidence shows that the Mill Creek Formation is older than the "Fish-scale sand" marker bed of the Plains and Foothills (widely accepted as marking the Lower-Upper Cretaceous boundary in these regions), in which case the "upper Blairmore" (Mill Creek) flora can be assigned a late middle or late Albian age.

Faunal Zones

The nonmarine megafauna of the Blairmore Group was first described by McLearn (1929) from the Crowsnest Pass region. The associated microfauna has been since described or recorded from a number of localities in the Foothills and Plains (Loranger, 1951; Badgley, 1952; Mellon and Wall, 1963).

Consisting of various species of pelecypods, gastropods, and ostracodes, the fauna (*Protelliptio hamili* fauna) is restricted throughout most of the southern and central Foothills and Plains to the "calcareous" member at the top of the Gladstone and McMurray Formations, although in the Crowsnest Pass region elements of the fauna are present at or near the top of the Beaver Mines Formation on Carbondale (Castle) River (McLearn, *op. cit.;* Clow and Crockford, 1951)[1] and on Mill Creek (this report). *Protelliptio* sp. cf. *P. hamili* (McLearn) also has been reported from the Mill Creek Formation on Ma Butte (C. R. Stelck, pers. comm.) and from the Goodrich Formation of northeastern British Columbia (Stott, 1963), its presence in these formations supporting McLearn's (*ibid.*) interpretation of the Blairmore megafauna as a community of long-ranging species. In the north-central Foothills the "calcareous" member grades

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[1] The exact location and stratigraphic level of McLearn's locality (*op. cit.*, DA-4) is uncertain but appears to be the same as Clow and Crockford's (*op. cit.*).

laterally into shale and sandstone, and the nonmarine pelecypods and gastropods of the southern Foothills appear to be largely replaced by a fauna (*"Astarte" natosini* fauna of McLearn, 1944) indicative of a brackish-water environment. Farther north only marine invertebrates have been reported from the correlative Gething Formation of British Columbia (Stott, *ibid.*).

A similar geographic change in the composition of the "calcareous" member microfauna is apparent. The ostracode assemblage of the southern Foothills is dominated by freshwater forms, whereas those in the central Foothills and Plains indicate a brackish-water environment, transitional to the marine environment that prevailed in the overlying Clearwater Formation (Wall, *in* Mellon and Wall, 1963). In northeastern Alberta the ostracode-bearing beds interfinger with or are replaced by foraminifera-bearing shales in the upper part of the McMurray Formation (Mellon and Wall, 1956, 1963), although in the McMurray area a megafauna (*Elliptio biornatus* fauna) grossly similar to the fresh- or brackish-water faunas of the Alberta Foothills has been described from near the top of the formation (Russell, 1932).

There is little doubt that the distribution of nonmarine Blairmore and Mannville faunas is related to environmental rather than evolutionary factors. Certainly, their restriction throughout most of the Alberta Foothills and Plains to a narrow stratigraphic interval ("calcareous" member) does not indicate the total ranges of the species involved, for where conditions favorable to their presence prevailed at later times, elements of these faunas are found, as in the upper part of the Beaver Mines Formation and in the Mill Creek Formation of the Crowsnest Pass region. Thus, the nonmarine faunal assemblages of the Blairmore and Mannville Groups have little value as indicators of precise age.

The Blairmore and Mannville Groups of southern and central Alberta can be dated more precisely through correlation with partly marine strata in northern Alberta and adjacent British Columbia, where the general succession of faunal zones has been established. The megafaunas of this area were first described in broad outline by McLearn (1944) and McLearn and Kindle (1951), and subsequently in more detail by Stelck *et al.* (1956), who also outlined the correlative succession of microfaunal zones in parts of northern Alberta and northeastern British Columbia. Additional data on the distribution of megafaunal assemblages in the Foothills of northeastern British Columbia were published recently by Stott (1963).

The generalized succession of Lower Cretaceous megafaunal indices in northern Alberta and adjacent British Columbia is:

Neogastroplites	Upper Albian
Inoceramus comancheanus	Middle-Upper Albian
Gastroplites	Middle Albian
Lemuroceras-Beudanticeras	
Cleoniceras	Lower Albian

Cleoniceras has been described only from northern Alberta, where it is found in the lower Loon River Shale (Stelck, 1958), together with an undescribed microfaunal assemblage (J. H. Wall, pers. comm.). *Cleoniceras* is early Albian in age.

Elements of the *Lemuroceras-Beudanticeras* fauna of McLearn (1944) have been described from various localities in the northern Plains and Foothills, ranging through the Clearwater and upper part of the Loon River Formations of northern Alberta, and the Moosebar and lower part of the Commotion (Gates Member) Formations of northeastern British Columbia. *Lemuroceras* is succeeded in the Peace River Foothills and Plains region by species of *Gastroplites*, found in the upper part of the Commotion Formation and equivalent strata in northeastern British Columbia (McLearn, *ibid.;* Stelck *et al.,* 1956; Stott, 1963), and in the Cadotte Member of the Peace River Formation in Alberta (Wickenden, 1951).

The *Lemuroceras-Beudanticeras* and *Gastroplites* faunas are associated with a single long-ranging foraminiferal assemblage, recorded from various localities in the northern and central Plains and Foothills (Wickenden, *op. cit.;* Mellon and Wall, 1956; Stelck *et. al., op. cit.;* Mellon and Wall, 1963; Mellon *et al.,* 1963). Although the microfaunal zones proposed by Stelck *et al.* (*ibid.*) for the type Clearwater Formation are locally recognizable elsewhere, stratigraphic and geographic variation among species is due mainly to environmental rather than evolutionary factors (Mellon and Wall, 1963). Thus, although the lower part of the interval through which the fauna ranges (Moosebar, upper part of the Loon River, and lower part of the Clearwater Formations) contains both calcareous and agglutinated foraminifera, the latter range up into younger strata, including the *Gastroplites*-bearing beds of northwestern Alberta and adjacent British Columbia.

Both the *Lemuroceras-Beudanticeras* and *Gastroplites* faunas, and the associated microfauna, are middle Albian in age.

The *Inoceramus comancheanus* fauna is found in the lower part of the Joli Fou Shale on the lower Athabasca River (Wickenden, 1949) but has not been identified in the western Plains or Foothills outcrop sections. It is associated with a distinct microfaunal assemblage, the *Haplophragmoides gigas* fauna, which has a wide distribution in the central and southern Plains (Wickenden, 1941; Nauss, 1947; Stelck *et al.,* 1956). However, no ammonites have been described from this interval, which is assigned a late middle Albian age by Stelck (1958).

The *Neogastroplites* fauna is restricted geographically to northeastern British Columbia, where it ranges through the upper part of the Hasler Shale and the Goodrich (Sikanni) Sandstone in the Foothills to below the "Fish-scale" marker bed in the correlative Shaftesbury Formation of the Plains (McLearn and Kindle, 1951; Stelck *et al.*, 1958; Stott, 1963). The megafaunal elements of this zone appear to be lacking in correlative strata to the east and south, but the associated microfauna (*Miliammina manitobensis* fauna) has been found at widely scattered localities in the Alberta Foothills and Plains (Wall and Germundson, 1963), below the "Fish-scale" marker bed. The fauna is late Albian in age.

Correlation of the Blairmore Group and Equivalent Strata

Charts showing the correlation of Lower Cretaceous rock units in the Alberta Foothills and Plains and the Foothills of northeastern British Columbia are illustrated in figures 15 and 16, together with the generalized succession of floral and marine faunal zones. In practice, the base of the Lower Cretaceous is placed at the base of the Blairmore and Mannville Groups, although, as noted above, the Kootenay and correlative formations of the Foothills and western Plains may include beds of Early Cretaceous age.

Gladstone and McMurray Formations

In the southern Foothills the Lower Cretaceous Blairmore Group is divisible into three formational units. The lower unit, the Gladstone Formation, is correlative from floral, petrographic, and stratigraphic evidence with the lower part of the Luscar and the Gething Formations of the central and northern Foothills, and the McMurray and Gething Formations of the Plains. The base of this succession, marked in the Foothills by a persistent basal conglomerate (Cadomin Conglomerate), is the locus of a widespread regional unconformity, overlying successively older Mesozoic and Paleozoic strata to the east and north.

In the southern Foothills and in most of the southern and central Alberta Plains, thin calcareous shales and limestones ("calcareous" member) carrying a nonmarine fauna are present at or near the top of the Gladstone and McMurray Formations. The upper boundary of the "calcareous" member coincides in most localities with an abrupt break in lithology and sandstone composition—from underlying cherty or quartzose sandstones to the feldspathic, volcanic sandstones of the Beaver Mines and Fort Augustus Formations. In the Foothills the break between the

Gladstone and Beaver Mines Formations appears sharpest in the south, where it probably marks the locus of a minor disconformity, becoming less pronounced to the north. In the north-central and northern Foothills, the contact is drawn at the base of a marine shale tongue (Moosebar Shale) that lies conformably on the Gladstone-Gething succession and extends into adjacent parts of the Plains. The base of the marine beds (Clearwater, Loon River, and Moosebar Formations) probably defines a consistent time-datum plane in most of central and northern Alberta and northeastern British Columbia, except in the northernmost parts of the basin where the Gething and McMurray Formations interfinger with marine shales in the lower parts of the Buckinghorse and Clearwater Formations (Mellon and Wall, 1956; Pelletier and Stott, 1963; Carrigy, 1963). However, in northeastern Alberta at least, the change in sandstone composition at the top of the McMurray Formation is still evident, even although the upper beds of the formation are gradational in a faunal and lithologic sense with the overlying beds of the Clearwater Formation (Carrigy, *ibid.*).

The age of the Gladstone and correlative nonmarine formations is uncertain from megafloral and faunal evidence. Microfloral evidence from the McMurray Formation of the Plains is similarly controversial: Pocock (1962) has assigned these beds a Neocomian age, whereas Singh (1964) has suggested that they range from late Barremian(?) to early Albian, pointing out that the McMurray microflora grades without break into the overlying beds, dated as middle Albian from microfaunal evidence. Moreover, the Gladstone, Luscar, and Gething Formations of the Foothills also contain essentially the same megaflora ("lower Blairmore" flora) as overlying beds of middle Albian age.

An Albian age for at least the upper part of the McMurray and correlative nonmarine strata is supported by the former's apparent stratigraphic relationship to the Loon River Shale of northwestern Alberta. In northeastern Alberta the McMurray Formation interfingers in its upper part with marine shales carrying a Clearwater microfaunal suite, associated in the overlying beds with ammonites of middle Albian age. Although the lower stratigraphic boundary of the Clearwater microfauna is not precisely known, the fauna apparently overlies the microfauna found in the lower part of the Loon River Shale to the northwest, which is associated with *Cleoniceras* of early Albian age. As the McMurray Formation is thin or absent there, the most logical interpretation is that it disappears in part or in entirety by interfingering to the northwest with the lower part of the Loon River Shale. If this is so, then the widespread quartzose nonmarine beds that form the base of the Lower Cretaceous succession throughout most of Alberta and northeastern British Columbia are younger (early Albian) than the floral evidence suggests. Moreover, if a Late Jurassic age for the Kootenay and correlative formations is accepted, then

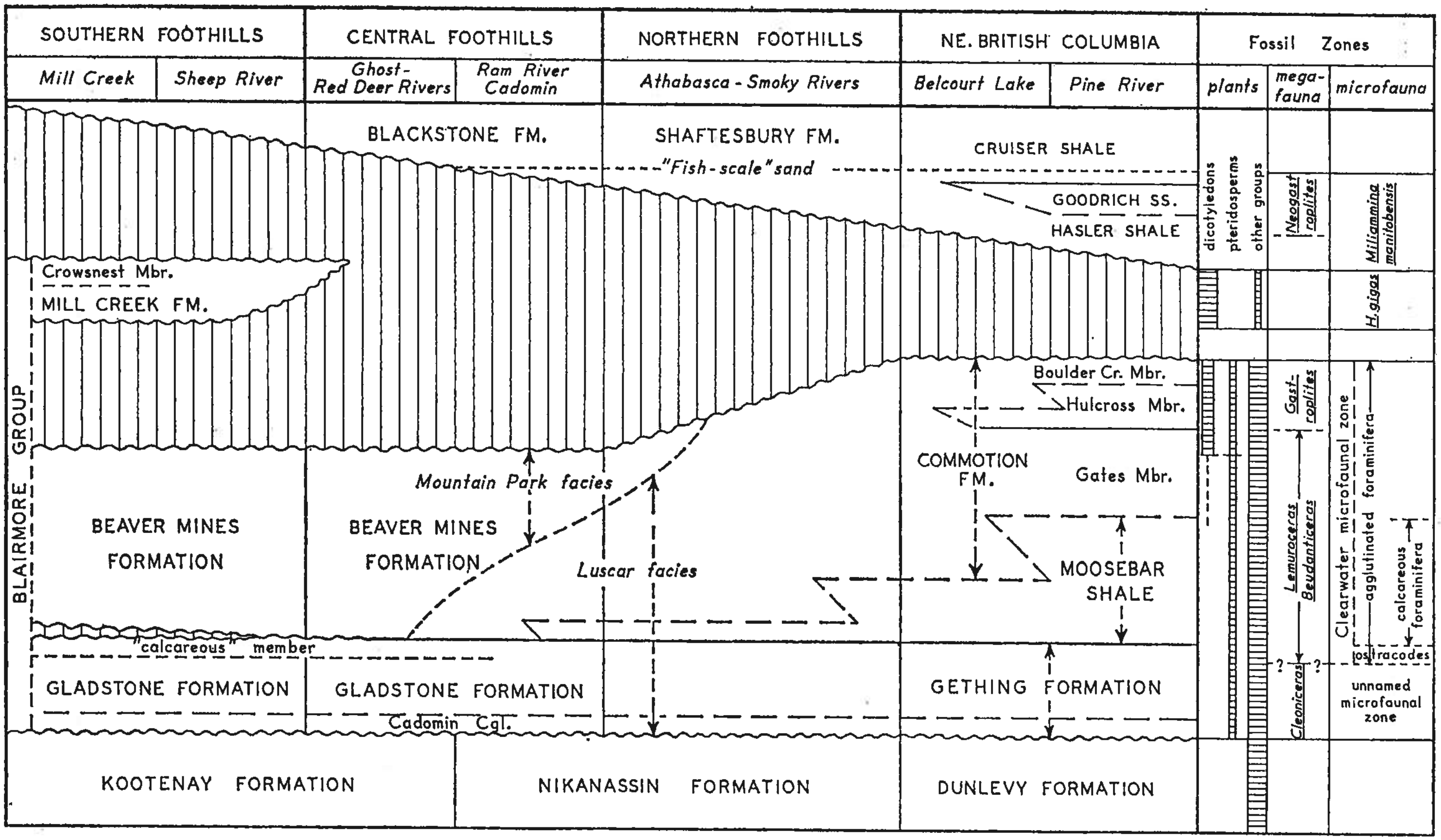

FIGURE 15. Chart showing correlation of Lower Cretaceous strata, Alberta and northeastern British Columbia Foothills.

a large part of Early Cretaceous time, equivalent to the Neocomian and Aptian Stages of Europe, is represented by the unconformity at the base of the Blairmore-Mannville succession in Alberta.

Beaver Mines and Fort Augustus Formations

Strata correlative with the middle unit of the type Blairmore Group can be traced throughout the Alberta Foothills and Plains into adjacent parts of northeastern British Columbia. In the southern and central Foothills the Beaver Mines Formation is of nonmarine origin, containing elements of Bell's "lower Blairmore" flora as well as rare freshwater invertebrates. A marine shale tongue carrying a Clearwater foraminiferal assemblage appears at the base of the formation in the north-central Foothills and extends north into British Columbia where it thickens at the expense of overlying beds to become the Moosebar Shale (Stott, 1960, 1963). Post-Moosebar strata assigned to the Mountain Park and Luscar beds of the Alberta Foothills and the lower part of the Commotion Formation in northeastern British Columbia are correlative with the middle and upper parts of the Beaver Mines Formation, all containing the same non-dicotyledonous "lower Blairmore" flora.

A similar distribution of strata exists in the Plains. In southern Alberta the Beaver Mines Formation is correlative with the upper part of the Plains "Blairmore", which is largely or entirely of nonmarine origin. In central Alberta the Beaver Mines Formation can be traced into the upper part of the Mannville Group, defined here as the Fort Augustus Formation. The lower part of the Fort Augustus Formation is marine and contains a Clearwater foraminiferal assemblage; the upper part is of shoreline and nonmarine origin and contains a "lower Blairmore" megaflora. The marine beds thicken to the north, grading into the Clearwater and Loon River Formations, whereas the overlying nonmarine beds thin and are replaced in the northern Plains by shoreline beds, such as the Grand Rapids and Notikewin Sandstones.

The sharp but generally conformable nature of the contact at the base of the Beaver Mines-Fort Augustus succession has been noted. Except in the northernmost Plains, the appearance of marine strata at the base of these units is coincident with the sharp break in sandstone composition at the top of the Gladstone and McMurray Formations and probably marks a consistent time-datum plane, at least in comparison with the diachronic gradational contact at the base of the overlying nonmarine Commotion or Grand Rapids-type beds. However, the upper boundary of the Beaver Mines and correlative formations is marked by a regional disconformity (Figs. 15 and 16), and the upper beds of the succession are not everywhere of the same age. Thus, the upper part of the Commotion Formation in northeastern British Columbia contains a moderately dicotyledonous

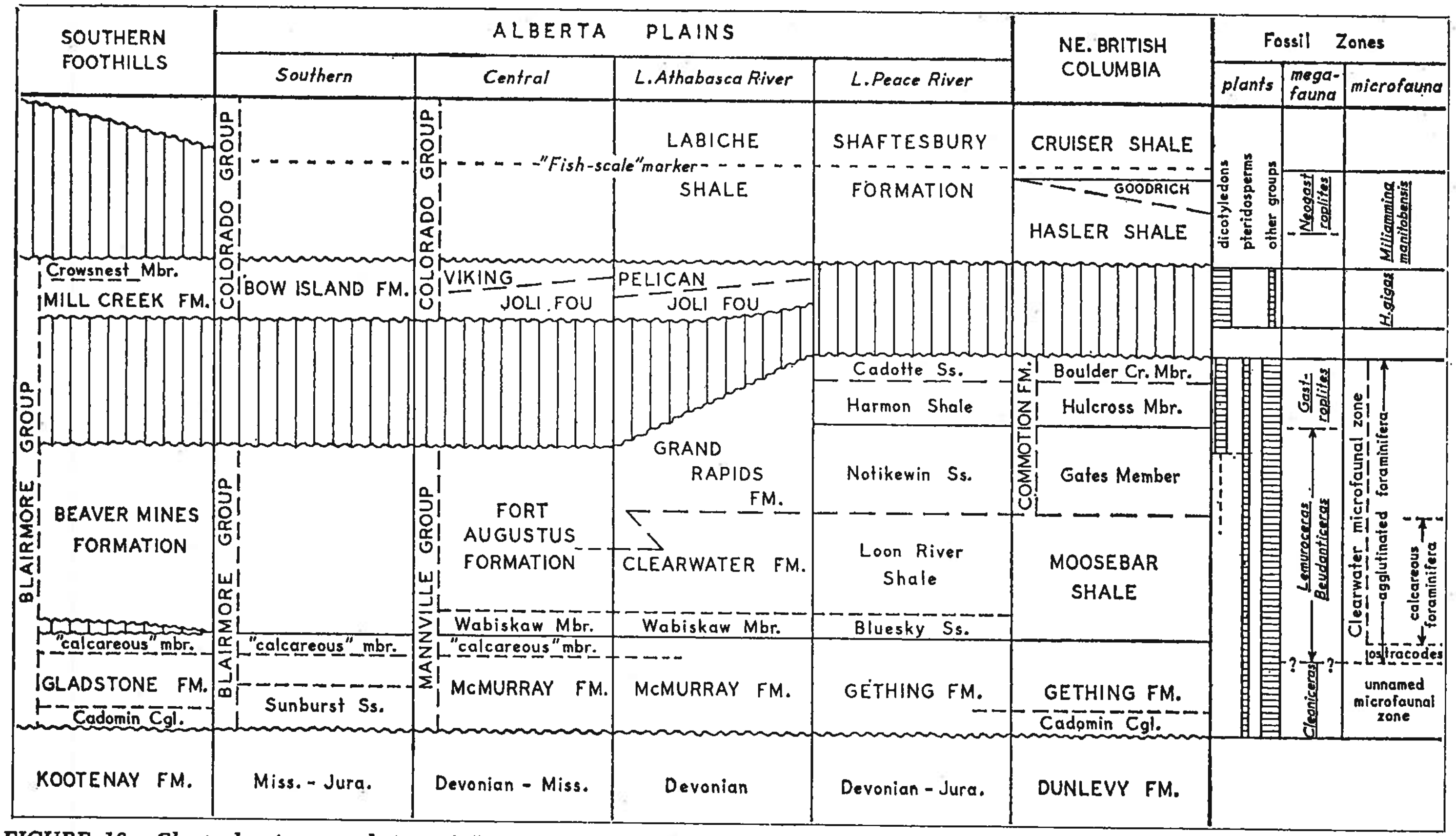

FIGURE 16. Chart showing correlation of Lower Cretaceous strata of the Alberta Plains with those of the southern Alberta and northeastern British Columbia Foothills.

flora that is distinctly older than the Mill Creek ("upper Blairmore") flora of the southern Foothills, but which appears to be slightly younger than the flora in the upper part of the Beaver Mines (including the Mountain Park facies) and Fort Augustus Formations of the southern and central Foothills and Plains. Upper Commotion-equivalent strata were either never deposited in these regions or have been removed by erosion. In the northern Plains the upper Commotion beds (Hulcross and Boulder Creek Members) are correlative with the Harmon Shale and Cadotte Sandstone of northwestern Alberta, for the strata at both localities are encompassed by the *Gastroplites* faunal Zone. However, no diagnostic floral or faunal remains have been described from the Grand Rapids Formation in northeastern Alberta, so that the exact position of this unit relative to the *Gastroplites* Zone is uncertain.

The age of the Beaver Mines and Fort Augustus Formations and correlative strata of the northern Plains and Foothills, including the upper part of the Commotion Formation and the Cadotte Sandstone, is middle Albian from faunal evidence.

Mill Creek Formation and Correlative Strata

The upper unit of the type Blairmore Group, the Mill Creek Formation, is present only in the southern Foothills; north of the Bow River the formation thins and disappears either through nondeposition or erosion, for in most parts of the central Foothills marine Blackstone shales lie disconformably on Beaver Mines strata containing a non-dicotyledonous "lower Blairmore" flora.

In the outcrop belt of the southern Foothills, the Mill Creek Formation appears to be of entirely nonmarine origin and carries a dominantly dicotyledonous flora of post-Commotion age (Bell's [1956] "upper Blairmore" flora.) Near the eastern margin of the Foothills, the formation interfingers laterally with marine beds that can be traced into the Bow Island Formation of the southern Alberta Plains, as evidenced by petrographic and lithologic data. The Bow Island Formation in turn can be traced into the thinner Joli Fou-Viking (Pelican) shale-sandstone complex of central and northeastern Alberta (Glaister, 1959), so that, indirectly, the Mill Creek Formation and its flora can be correlated with beds containing the well-known *Haplophragmoides gigas* microfauna[1].

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[1] The results of a recent palynologic study of the lower part of the Colorado Group (including the Joli Fou-Viking beds) in the Fort Augustus No. 1 well (G. Norris, in press) support this correlation by showing a marked break in the microfaunal succession at the Mannville Group-Joli Fou boundary. Several species of angiosperm pollen are present in the Joli Fou-Viking beds, their appearance coinciding with a change in the distribution of non-dicotyledonous spores and pollen at the top of the Mannville Group. The change in microfaunal composition at this level is analogous in many respects to the change observed in megafloras at the top of the Beaver Mines Formation in the Blairmore Group of the southern Foothills.

All the evidence points to a pre-"Fish-scale" sand, post-Commotion age for the Mill Creek Formation of the southern Foothills, in which case both the lower and upper boundaries of the formation must be coincident with disconformities of considerable magnitude (Fig. 15). The magnitude of the lower disconformity is indicated in the southern Foothills by the marked difference between the Beaver Mines and Mill Creek floras, the intermediate upper Commotion flora being absent. A similar break in the microfaunal succession in correlative strata of the central and northern Plains is found in passing from the long-ranging species of the Clearwater faunal zone to the basal Joli Fou *Haplophragmoides gigas* fauna. As Stelck (1958) has noted, this lithologic-faunal break at the base of the Joli Fou Shale is coincident with a fundamental change in the paleogeography of central Alberta near the end of middle Albian time, that is, with the withdrawal of the boreal Clearwater-Loon River Sea and the sudden transgression of the Gulfian Bow Island-Joli Fou Sea.

The magnitude of the disconformity at the top of the Mill Creek Formation is demonstrated by the relationship in the Foothills of the upper beds of the Blairmore Group to the basal beds of the overlying Blackstone and correlative Shaftesbury Formations. Locally, the contact between the two units, although sharp, appears conformable, but nowhere is there the slightest evidence to show that the pyroclastic or detrital strata of the Blairmore Group grade laterally or vertically into the shaly marine beds at the base of the Blackstone Formation.

The Blackstone Formation is thinnest in the Crowsnest Pass region, where the base of the *Inoceramus labiatus* Zone rests directly at York Creek and at Coleman on the thick pyroclastic beds of the Crowsnest Member. There is no interfingering of the two units, and it is evident that the volcanic beds formed a local topographic high over which successively younger Blackstone beds transgressed during late Albian and Cenomanian time. North of the Crowsnest Pass the basal beds of the Blackstone Formation thicken to form the silty Sunkay Member (Stott, 1963), which rests on successively older Blairmore strata to the north: on the Crowsnest Member south of the Oldman River, on sedimentary beds of the Mill Creek Formation between the Oldman and Ghost Rivers, and north of the Ghost River on the Beaver Mines Formation (Fig. 10). The thickening of the Sunkay Member northward along the Foothills is accompanied by the appearance in these beds of successively older microfaunal zones (Wall and Germundson, 1963). The oldest of these zones is the pre-"Fish-scale" sand *Miliammina manitobensis* Zone, which is found at the base of the Blackstone in the Ram River region and which can be traced into the lower part of the Shaftesbury Formation in the northern Plains and Foothills. The pre-*Inoceramus labiatus* portion of the succession thickens rapidly in the northern Foothills to form a thick wedge of marine and nonmarine beds that includes the lower part of the

Kaskapau and the entire Dunvegan Formations, and the upper part of the Fort St. John Group (post-Commotion beds), equivalent to about 300 to 400 feet of Sunkay strata in the central Alberta Foothills. Although the fauna recovered from the basal part of this succession in northeastern British Columbia is scant (Stelck *et al.*, 1956), the available data show that a post-Viking microfaunal assemblage succeeds the upper Commotion flora there. In this case strata correlative with the Mill Creek and Joli Fou-Viking Formations are absent from this region, as in the central and northern Alberta Foothills, the top of the Commotion Formation or correlative strata marking the locus of a regional disconformity.

A similar situation exists along the western margin of the Plains, where in southern Alberta marine shales between the Bow Island Formation and the "Fish-scale" sand ("Grit bed" of Turner Valley) overlap unconformably onto continental strata of the Mill Creek Formation (Fig. 8). In central Alberta the Joli Fou-Viking succession itself must overlap unconformably on the eroded surface of the Beaver Mines Formation in the western part of the Plains (Fig. 11), for, as Stelck (1958) has pointed out, the Mountain Park "formation" of the Cadomin area is in no way correlative with the Joli Fou-Viking succession, as indicated by Glaister (1959). The Mountain Park is a chloritic, non-coal-bearing facies of the Beaver Mines Formation and contains a non-dicotyledonous flora considerably older that that found in the Viking-equivalent Mill Creek Formation of the southern Foothills. It is directly overlain in the north-central Foothills by basal Blackstone shales carrying the *Miliammina manitobensis* fauna (J. H. Wall, pers. comm.).

Similarly, the Joli Fou-Viking (Pelican) succession appears to be absent from the northwestern Plains of Alberta and adjacent British Columbia. Correlative strata are not to be found in the Cadotte Sandstone and Harmon Shale of the lower Peace River, for these beds are not only correlative with the pre-Mill Creek upper Commotion beds of the Foothills from megafaunal evidence but also contain a Clearwater microfaunal assemblage that is distinct from the Joli Fou fauna to the east and south (Mellon and Wall, 1963). Stelck (1958) and Oliver (1960) support this thesis, although they suggest that Wickenden's (1951) "continental" member (Paddy Member) at the top of the Cadotte Sandstone represents a shoreline or continental phase of the marine Joli Fou-Pelican succession to the east. However, there is no concrete petrographic or fossil evidence to support such an interpretation; the type Paddy Member is more likely a poorly sorted, local lagoonal phase of the marine Cadotte Sandstone, which itself grades laterally and vertically into marine shale a short distance north of the type locality. In the subsurface to the south and east, the Paddy and Cadotte may be expected to interfinger laterally with coal-bearing nonmarine beds at the top of the Fort Augustus Formation, overlain disconformably there by the Joli Fou Shale.

In summary, the Mill Creek Formation of the southern Foothills is a continental phase of the Bow Island or Joli Fou-Viking Formations of the Plains, the latter units forming a wedge of marine strata that thins and disappears towards the margin of the central Foothills and northwestern Plains. The relationship of the Mill Creek ("upper Blairmore") flora to other floras of the Foothills and Plains indicates a late Albian or early Cenomanian age for the unit. However, correlative rock units in the Plains can be dated as late middle to early late Albian from their stratigraphic position.

PETROGRAPHY

Sampling and Analytical Procedures

Sampling Localities

One of the objectives of the investigation was to determine petrographic criteria that together with lithologic and paleontologic data would be useful in discriminating among the mappable units of the Blairmore and Mannville Groups.

For this purpose the sand-size phases of the rocks were sampled at various localities shown in figure 1. The three formations of the Blairmore Group (excepting the volcanic Crowsnest Member at the top of the group in the southernmost Foothills) were sampled at widely scattered outcrop localities in the southern and central Foothills and also in the subsurface near the eastern margin of the southern Foothills, between Turner Valley and Okotoks. However, at only two of the outcrop localities (Mill Creek and Sheep River) are all of the units present; most sections are only partly exposed, and the upper (Mill Creek) formation is absent throughout most of the central Foothills. Cored subsurface sections of the Mannville Group were sampled at several localities in the Plains, but sandstones from only the upper part of the group (Fort Augustus Formation) were examined in detail. Only a few sandstones from the underlying McMurray Formation (present in only four of the seven wells sampled) were thin-sectioned, as sandstones from this part of the Mannville Group already have been described by Williams (1963).

The distribution of modally analysed samples is listed in table 3 by formations and localities. Also, spot samples taken from key stratigraphic levels at these and other localities not listed were examined qualitatively to gain additional control.

At most localities an attempt was made to distribute the samples as evenly as possible throughout the stratigraphic succession, but owing to covered or missing intervals, or to the local distribution of sandstones in some sections, this was not always possible. For example, most of the sandstone beds in the Gladstone Formation are confined, at least in the southern and south-central Foothills, to the lower part of the formation; the middle and upper parts of the formation consist mainly of siltstone, shale, and impure limestone, too fine-grained for conventional microscopic analysis. The same problem is met in sampling the other two formations of the Blairmore Group, although the distribution of sandstones in these is more uniform.

Most of the modally analysed samples are very fine to medium-grained sandstones (Fig. 17). Undoubtedly some bias is involved in

Table 3. Locations and Distribution of Petrographically Analysed Blairmore and Mannville Sandstones

Sampling Locality	Location	Reference	Sample Distribution by Formations			
			GL[1]	BM[1]	FA[1]	MC[1]
Mill Creek	Tp. 5, R. 2, W. 5th Mer.	Figs. 10, 37	4	20		4
Ma Butte	Tp. 9, R. 5, W. 5th Mer.	Fig. 5		1		4
Oldman River	Sec. 31-11-3 W. 5th Mer.	Fig. 10				4
Oldman River	Sec. 26-10-3 W. 5th Mer.	Fig. 10	4			
Sheep River	Sec. 19-19-5 W. 5th Mer.	Figs. 10, 37	4	20		6
Sheep River	Sec. 35-19-5 W. 5th Mer.	Fig. 51		2		1
Pine Creek*	Sec. 12-20-2 W. 5th Mer.	Figs. 6, 51		2		2
Okotoks*	Sec. 23-20-29 W. 4th Mer.	Figs. 6, 51		4		4
Okotoks*	Sec. 13-20-29 W. 4th Mer.	Fig. 51		1		4
Burnt Timber Cr.	Tp. 30, R. 9, W. 5th Mer.	Fig. 10		1		
Burnt Timber Cr.	Tp. 30, R. 9, W. 5th Mer.	Fig. 10	4	1		
Tershishner Cr.	Tp. 39, R. 17, W. 5th Mer.	Fig. 37		3		
Ram River	Tp. 37, 38, R. 12, W. 5th Mer.	Figs. 10, 37	4	20		
Cadomin	Tp. 46, 47, R. 23, W. 5th Mer.	Figs. 10, 37		6		
Stanmore*	Sec. 22-30-11 W. 4th Mer.	Fig. 39			3	
West Viking*	Sec. 11-48-15 W. 4th Mer.	Fig. 39			4	
Wabamun*	Sec. 10-51-4 W. 5th Mer.	Fig. 39			4	
Fort Augustus*	Sec. 29-55-21 W. 4th Mer.	Fig. 39	2[2]		4	
Elk Point*	Sec. 26-56-5 W. 4th Mer.	Fig. 39			4	
Lyle Lake*	Sec. 24-72-17 W. 4th Mer.	Fig. 39			3	
West Wabiskaw*	Sec. 17-78-2 W. 5th Mer.	Fig. 39			4	

* Subsurface section.

[1] GL, Gladstone Formation; BM, Beaver Mines Formation; FA, Fort Augustus Formation; MC, Mill Creek Formation.

[2] McMurray Formation.

limiting samples to this size-interval, for, although conglomerates are relatively rare in both the Blairmore and Mannville Groups, the sandstones show all gradations into siltstones, and siltstones into silty shales or mudstones. The problem of defining "sandstone" is especially difficult for the Gladstone Formation in the Foothills and for the Mannville Group in the Plains, which contain a high proportion of finely laminated beds that exhibit marked variation in lithology (from shale, through siltstone, to fine sandstone) at all levels of stratification. The problem was met in part by predetermining the number of samples to be taken from arbitrary stratigraphic intervals at each locality and then by randomly selecting samples from the thickest sandstone beds present. The sampling procedure appears to have yielded comparable sets of samples for the units involved, certainly sufficient to show major stratigraphic and geographic differences in sandstone composition in the Blairmore and Mannville Groups.

The stratigraphic distributions of samples are given in tables 8 to 13 in the Appendix.

Analytical Techniques

Of the several hundred sandstone samples collected from Blairmore and Mannville strata, 156 were selected for petrographic analysis. The composition and grain size of each sample were determined from conventional thin sections averaging 2 by 3 centimeters in dimensions, cut perpendicular to the bedding and in some cases stained with special reagents to distinguish among different types of feldspars, carbonates, or clay minerals.

Modal analyses were obtained from point counts of each thin section, the number and spacing of points per sample depending on the relationship of the traverses to the bedding and the size of the thin section. Modal analyses of most of the Foothills samples are based on counts of 400 points per sample, arranged in 8 traverses of 50 points each taken parallel to the bedding. Grain size was determined by measuring the maximum diameter of 32 randomly selected quartz grains in each sample, 4 on each traverse. In theory, arranging the traverses parallel to the bedding should detect any microscopic differences in sorting, although, in practice, the traverses commonly transect the lamination visible in most samples owing to small-scale crossbedding and slump structures. Modal analyses of sandstones collected subsequently from some Foothills and all Plains localities are based on counts of 200 points per sample traversed across the bedding, and grain-size estimates on measurements of 12 quartz grains per sample. Although the precision associated with these estimates (especially with grain size) is lower than that associated with estimates based

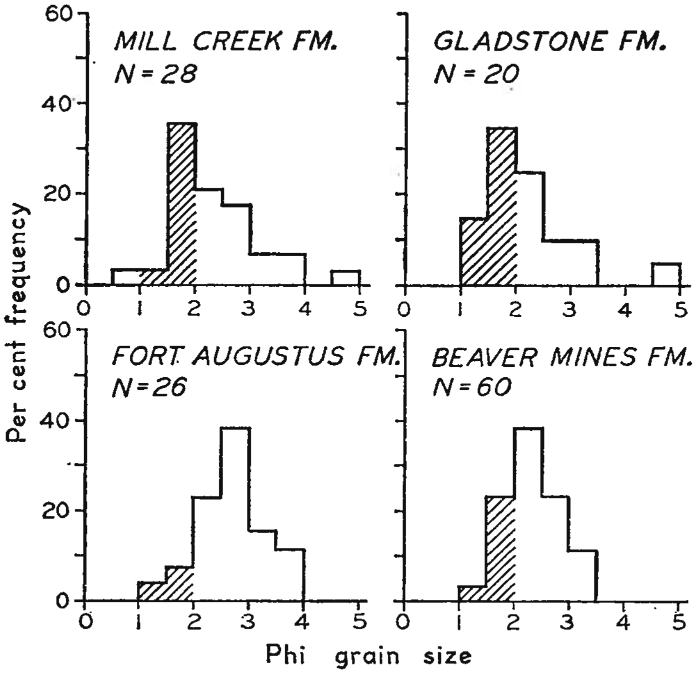

FIGURE 17. Size-frequency distribution of modally analysed sandstones from the Blairmore and Mannville Groups.

on 800 points and 32 grains per sample, it is sufficient to detect differences among samples, as duplicate counts of several thin sections have shown.

Certain of the modally analysed samples were selected for more detailed identification of accessory "heavy" minerals, feldspars, or clay minerals using staining or X-ray diffraction techniques. Sample preparation procedures involving the separation, mounting, and identification of these constituents are described in detail elsewhere: where special comment is required, it is included in the descriptions of constituents.

Composition

Definitions of Terms

The basic textural elements of a rock are grains, matrix, and cement (Krynine, 1948). The first two groups constitute the transported elements of a sediment, the larger grains forming a rigid clastic framework, and the relatively smaller matrix particles forming an interstitial filling. In practice, a complete size gradation exists in most sandstones between particles classed as "grains" and "matrix", the distinction between the two types of detritus being based on arbitrary textural or compositional criteria.

A further distinction exists among the transported or abraded constituents of a sediment with respect to their origin: those brought into the basin of deposition from some distant source region, and those derived locally through redistribution of mechanically or chemically deposited material within the basin of deposition. The latter include a wide variety of fragmental material—shell and bone fragments, fecal pellets, wood and coal fragments, ooliths, and various kinds of rock fragments—that in carbonate rocks make up the bulk of the clastic framework grains. The only locally derived detritus generally recognizable in detrital silicate rocks is composed of argillaceous rock fragments sufficiently coherent to survive moderate abrasion and local transportation: most are derived from the breakup of temporarily deposited mudstone or siltstone subsequently subjected to more vigorous current action. Some of this locally formed material, described at a megascopic level as intraformational conglomerate or "mud" pebbles, can be distinguished from admixed detrital grains, but in many cases there are no clear-cut textural or compositional features to distinguish between the two types of detritus.

Cements are those constituents formed within a sedimentary rock during or after burial and compaction of the clastic constituents. Commonly called authigenic (or secondary), they are deposited in the intergranular pore spaces, in many cases reacting with or replacing the surrounding grains and matrix to varying degrees. Usually distinguished by their characteristic texture and distribution, cements compete for the same space in the rocks as matrix, the two constituents forming an intimately intergrown, finely crystalline, intergranular paste of mixed origin in many sandstones.

Associated with the deposition of cements are metasomatic phenomena, such as replacement of feldspar by calcite. Less extreme metasomatic processes result in the *in situ* alteration of earlier constituents through addition of water and partial removal of some of the more soluble chemical components, such as the alteration of feldspar to kaolinite. Recrystallization denotes alteration in the shape or internal structure of a textural element without a change in chemical composition, such as the inversion of aragonite to calcite in shell fragments. All of these postdepositional processes appear to operate more or less concurrently in the buried sediment, overlapping during the early stages of diagenesis with the mechanical effects of compaction, ultimately leading to the formation of a completely lithified sediment.

In classifying the constituents of the Blairmore and Mannville sandstones for point-counting purposes, an attempt has been made to distinguish among the various textural elements of the rocks where possible. However, this is not feasible in all cases, and a modification of an ideal classification scheme has been adopted. The major groups of constituents, according to the order in which they are described, are:

(1) *detrital constituents*: includes all granular detritus (other than carbonates) derived from some distant source or from within the basin of deposition;

(2) *matrix*: includes both fine-grained clastic detritus and an unknown amount of authigenic material;

(3) *carbonates*: includes clastic and authigenic carbonates;

(4) *authigenic silicates;*

(5) *hydrocarbon cements;*

(6) *miscellaneous constituents*: includes minor constituents of mixed origin.

Detrital Constituents

Quartz

Detrital quartz is a common constituent of most sandstones, being present as monomineralic single or aggregate grains (quartzite fragments, chert) and in discrete rock fragments of heterogeneous composition and origin. However, for point-counting purposes the term quartz is restricted here to single grains and coarsely crystalline quartzite fragments, distinct from that in chert and other rocks fragments and from quartz cement.

Quartz grains are most abundant in the siliceous sandstones of the Gladstone Formation, although the amount varies widely from sample to sample (Fig. 18). They are least abundant in sandstones of the Beaver Mines and Fort Augustus Formations, the Mill Creek Formation sandstones containing intermediate although highly variable amounts.

Most of the quartz is present as single grains, which show marked differences in the degree of rounding among formations (Pls. 6, 7). That in the Gladstone and lower part of the Mill Creek Formations is remarkably well rounded where the original (precementation) detrital grain boundaries can be observed; however, development of authigenic quartz overgrowths in most sandstones has obscured the detrital outlines of the grains, increasing the individual grain sizes (areas) by as much as 30 per cent and imparting to the grains an interlocking, angular appearance (Pl. 21). In addition, postdiagenetic folding has led in some sandstones to the development of undulose extinction patterns and incipient fracture planes that cut across grains and overgrowths alike, although even in these rocks traces of originally well-rounded grain boundaries persist. Most of the quartz in the Gladstone and Mill Creek Formations sandstones appears to be of second-cycle sedimentary or metasedimentary origin, derived from orthoquartzites or metaquartzites like those preserved as pebbles and cobbles in the conglomeratic phases of both formations.

Most of the quartz in the volcanic sandstones of the Beaver Mines and Fort Augustus Formations is markedly angular; less than 10 per cent of the grains show evidence of rounding, and well-rounded grains are rare. Abraded grains are more common in some of the sandstones in the marine facies of the Fort Augustus Formation, but even in these rocks angular quartz is predominant. A few grains show traces of primary crystal faces, and some are hexagonal in outline, which features indicate a volcanic origin. Such an origin is also indicated by the presence of embayments and feldspar inclusions or intergrowths in some grains and the general absence of undulose extinction or bubble trains, features common to plutonic or metamorphic quartz. Angular quartz grains are common also in some of the sandstones in the Mill Creek Formation, which contain moderate amounts of volcanic and feldspathic detritus. Authigenic quartz overgrowths are generally absent or poorly developed in most of the Beaver Mines and Fort Augustus Formations sandstones, except those in the coal-bearing Luscar facies of the north-central Foothills.

From 10 to 25 per cent of the quartz grains in most sandstones are composed of coarsely crystalline aggregate grains, the proportion increasing with the sample grain size. These can be divided into:

(1) fine- to medium-grained, silica-cemented orthoquartzite fragments;

(2) sheared and crushed metaquartzite fragments;

(3) coarsely crystalline, interlocking igneous (plutonic) quartz;

(4) comb (vein) quartz.

Orthoquartzite fragments, consisting of rounded quartz grains cemented by quartz or chert, are present at all stratigraphic levels but are most abundant in sandstones of the Gladstone Formation, in which they are difficult to distinguish in many cases from interlocking silica-cemented single quartz grains. Sheared metaquartzite fragments are most common in the Mill Creek Formation, in association with abundant fine-grained metasedimentary detritus, but are difficult to distinguish from sheared or crushed single quartz grains, also presumably of metamorphic origin. Aggregate quartz grains of probable granitic origin were observed in some of the coarser sandstones of the Beaver Mines Formation in the Foothills, grading with the addition of feldspar intergrowths into igneous rock fragments. However, no attempt has been made to differentiate quantitatively the various types of single and aggregate quartz grains in the different formations, owing to the difficulties involved in classifying them precisely.

Chert

Chert is the other common detrital siliceous constituent in the Blairmore and Mannville sandstones. It is composed of interlocking subequant quartz crystals less than 30 microns in diameter, grading with increasing

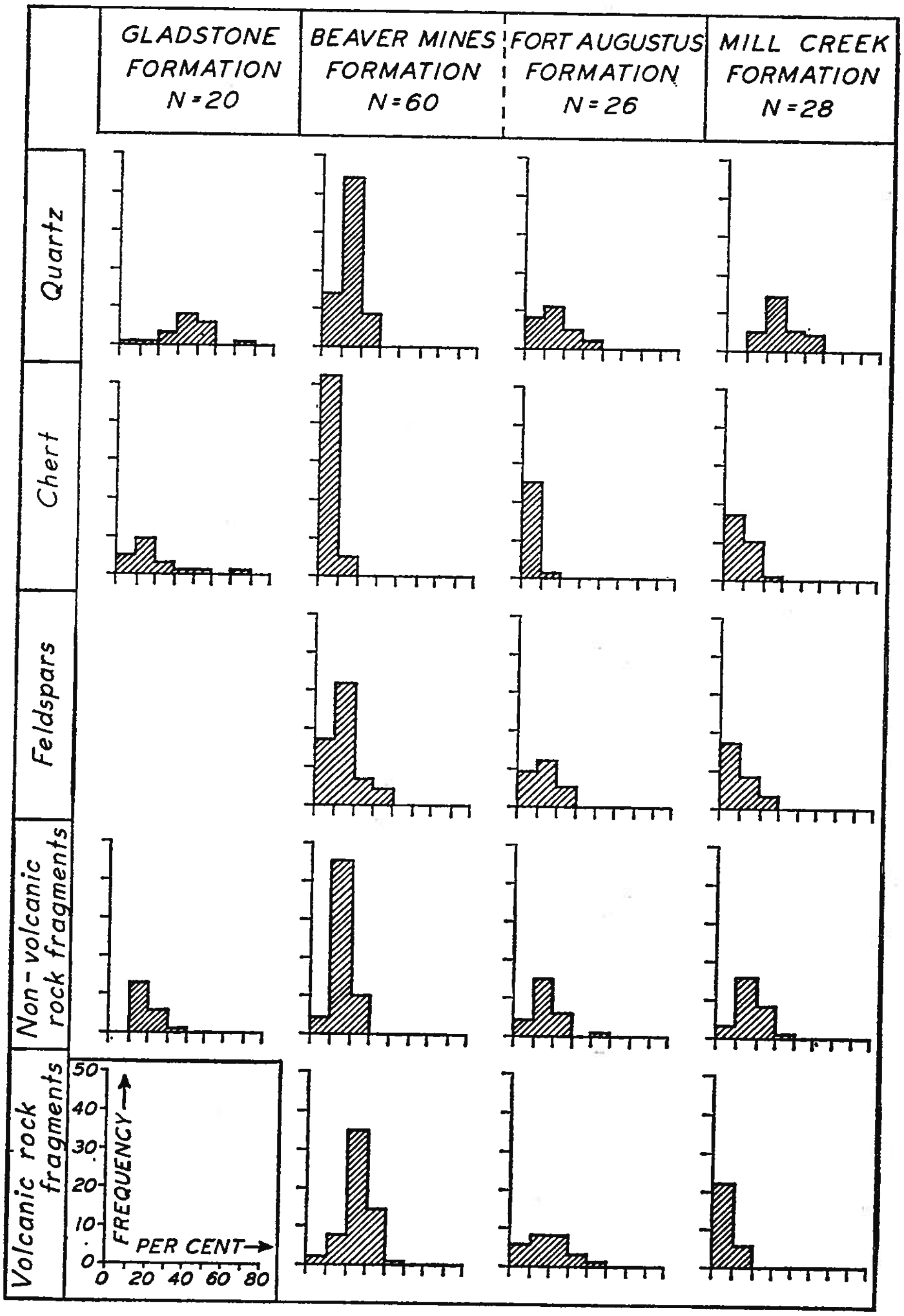

FIGURE 18. Percentage-frequency distributions of major detrital constituents in modally analysed sandstones from the Blairmore and Mannville Groups.

crystal size into quartzite or vein quartz. However, the distinction between chert and quartzite is generally clear, with few gradational grains being present. Chalcedony, a fibrous form of microquartz, is rare.

Chert is most abundant in sandstones of the Gladstone and Mill Creek Formations (Fig. 18), especially in the coarser-grained rocks, in which it is concentrated to form local chert-rich lenses or laminae (Pl. 23). Lesser amounts are present in the Beaver Mines and Fort Augustus Formations sandstones.

Chert grades with the addition of finely divided organic or argillaceous matter into siliceous rock fragments, or with the addition of dolomite inclusions into clastic carbonate fragments. It also forms the groundmass of some of the volcanic rock fragments in the Beaver Mines and Fort Augustus Formations, being difficult to distinguish from microcrystalline intergrowths of quartz and feldspar (felsite). However, silicified carbonate rhombs and organic structures in many of the grains suggest a sedimentary origin for most of the chert in the Blairmore and Mannville sandstones, which is associated with abundant clastic dolomite in many of the sandstones from the Gladstone Formation. Such an origin is confirmed by the inverse relationship between the average amounts of chert and igneous detritus in the four formations under consideration (Fig. 18).

Feldspars

Feldspars are present as single or aggregate monomineralic grains and also as a constituent of finely crystalline volcanic rock fragments, treated as a separate constituent in point counts. Thus, the actual feldspar content of the rocks is considerably greater than that obtained from point counts (except for the Gladstone Formation sandstones), referring only to single and coarsely crystalline aggregate grains.

Feldspars are generally abundant in sandstones of the Beaver Mines and Fort Augustus Formations. Trace to moderate amounts are present in most of the Mill Creek Formation sandstones, but only rare grains were observed in sandstones from the Gladstone Formation (Fig. 18).

In general, feldspars can be distinguished from quartz by the presence of twinning or zoning, the presence of cleavage, refractive indices, and by their cloudy appearance due to alteration. However, differentiation of the two constituents becomes more difficult with decreasing grain size, and doubtful grains have been counted as quartz.

Feldspars are divisible into two major groups, plagioclase and potash feldspars, which, although distinguishable on the basis of various optical properties (Winchell, 1951), are more easily identified in thin sections by means of staining techniques (Chayes, 1952). The relative percentages of the two groups of feldspars[1] in sandstones from the Beaver Mines and Fort Augustus Formations, determined from selected samples stained with sodium cobaltinitrite, are, by localities:

	plagioclase	*potash feldspars*
Foothills		
Mill Creek	96	4
Sheep River	97	3
Ram River	98	2
Plains	62	38

The Foothills (Beaver Mines) sandstones contain only minor amounts of potash feldspars, concentrated mainly in the lower and middle parts of the formation in association with potash-bearing volcanic rock fragments. In contrast, the Plains (Fort Augustus) sandstones contain moderate to abundant amounts of potash feldspars, as single grains and in the groundmass of volcanic rock fragments, at all stratigraphic levels. Most is in the form of untwinned orthoclase or sanidine grains, with small amounts of microcline and perthite. Potash feldspars are also the dominant group in the underlying quartzose sandstones of the McMurray Formation in the Plains (Williams, 1963), but both potash and plagioclase feldspars are virtually absent from correlative sandstones in the Foothills. Potash feldspars appear to be rare in the moderately feldspathic sandstones of the Mill Creek Formation in the Foothills, although they are abundant in the pyroclastic beds of the Crowsnest Member in the Blairmore region.

Plagioclase is the most abundant feldspar in the Blairmore and Mannville sandstones, forming well over one half of the detrital constituents in some of the Beaver Mines sandstones, if the amount present in volcanic rock fragments is included. One third to one half of the grains show diagnostic albite twinning in thin sections, with Carlsbad twinning less common and pericline twinning rare. The apparent lack of twinning in many grains is undoubtedly due in part to orientation. Zoned feldspars are rare, except in some of the thick, coarse-grained sandstones near the top of the Fort Augustus Formation in the Plains.

The range in plagioclase composition in the Beaver Mines and Fort Augustus Formations was estimated by determining the approximate refractive indices of basal cleavage flakes in grain mounts (Tsuboi's technique, *in* Winchell, 1951). Several grains were measured from each of 19 samples, selected from different stratigraphic levels and localities.

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[1] Potash feldspars are defined as those grains with more than 25 per cent of the surface stained, for the distribution of sodium cobaltinitrite stain on optically homogeneous grains is inexplicably patchy in some sandstones, especially those from the Foothills.

The percentage of plagioclase varieties in the two formations based on these data is:

Formation	*albite*	*oligoclase*	*andesine*
Beaver Mines	38	55	24
Fort Augustus	29	38	33

This range in composition also is indicated by measurements of the maximum extinction angles of albite twins in thin sections and grain mounts (Michel-Levy's technique, *in* Winchell, *op. cit.*), which show that more than 95 per cent of the plagioclase in both formations varies in composition between sodic andesine (Ab_{60}-Ab_{70}) and albite (Ab_{90}-Ab_{100}). The data are insufficient to detect any stratigraphic variation in feldspar composition, although there is generally less variation in plagioclase composition within than among individual sandstones. However, the Foothills sandstones appear to contain more sodic plagioclase than correlative Plains sandstones, although the latter contain a much higher proportion of potash feldspars.

The composition of plagioclase in sandstones from the Mill Creek Formation was not investigated.

As a group the feldspars vary widely in morphology and degree of alteration or replacement (Pls. 8, 9). Many grains are nearly square to rectangular with only slight evidence of abrasion, resembling feldspar phenocrysts present in many of the larger volcanic rock fragments. These grade into more irregularly shaped, angular to moderately rounded grains that tend to have one or more straight borders paralleling cleavage planes or crystal faces. Composite grains tend to be irregular in outline, grading with decreasing grain size into felsitic rock fragments.

Most of the feldspars show some signs of alteration, reflected in their slightly cloudy appearance in thin sections, and many grains have been partly or completely replaced in some samples by clay minerals, zeolites, or calcite. Calcite replacement, especially of potash feldspars, is particularly widespread, and partial replacement by kaolinite, illite, and laumontite is also common in some samples. Most of these replacement or alteration phenomena appear to be connected with postdepositional authigenic processes, discussed in detail in a subsequent section of the report.

Most of the feldspars in the Blairmore and Mannville sandstones are of obvious volcanic origin, derived from the breakup of finely crystalline extrusive rocks in the source area or brought into the basin of deposition directly as pyroclastic debris. The close relationship between the amounts of feldspar grains and volcanic rock fragments is shown in figure 19, where the mean locality percentages of each constituent for three of the formations involved show a marked positive correlation. Plots of indi-

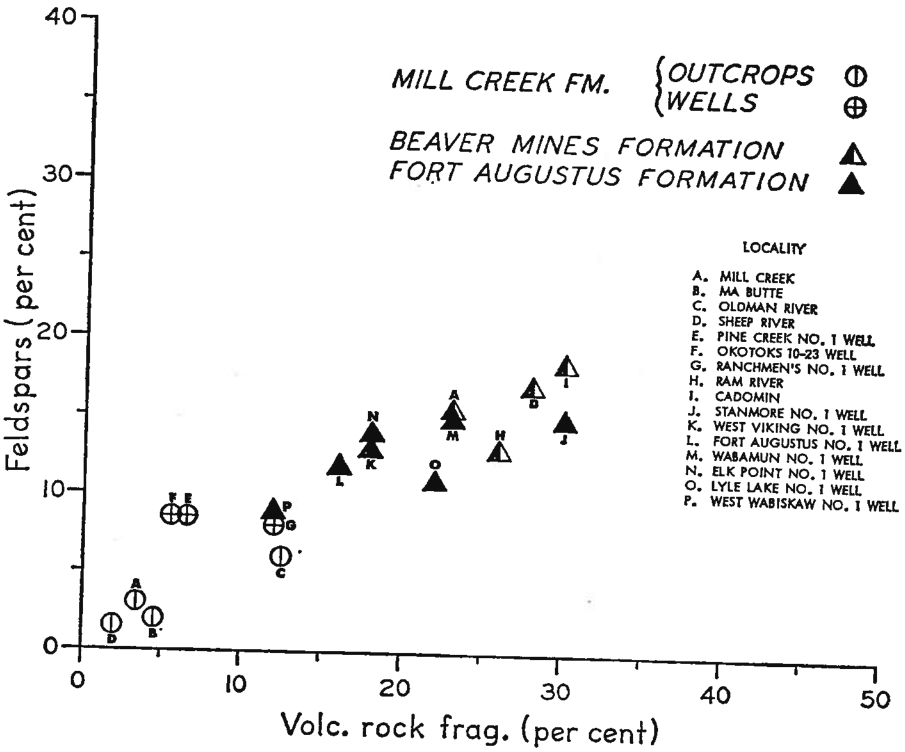


FIGURE 19. Scatter diagram showing the relationship between the average percentages of volcanic rock fragments and feldspars in modally analysed sandstones from the Blairmore and Mannville Groups. Samples are grouped by formation and locality.

vidual sample percentages for the two constituents show the same trend, although the scatter of points is much greater, mainly owing to the influence of local sorting factors.

Direct evidence for this relationship is found in thin sections, in which tabular plagioclase phenocrysts are observed to be a common constituent in many chloritic or felsitic volcanic rock fragments in both Foothills and Plains sandstones (Pl. 8, Fig. 2). Potash feldspars are present largely as single grains or in the groundmass of associated volcanic rock fragments, although they are present also as phenocrysts in some of the volcanic pebbles collected from the Beaver Mines Formation on Highwood River (see below). However, a close correlation exists between the distribution of potash feldspar as single grains and in volcanic rock fragments, indicating that most is of extrusive rather than plutonic origin. In contrast, the feldspars in the McMurray Formation sandstones of the Plains—largely orthoclase (Williams, *op. cit.*)—show no association with volcanic rock fragments and are probably of plutonic (Shield) origin.

Rock Fragments

Rock fragments—exclusive of quartzite, chert, and carbonates—are the most abundant group of constituents in the Blairmore and Mannville sandstones. They consist of finely crystalline, generally polymineralic aggregates that are difficult to classify descriptively or genetically because of their fine grain size and variable composition. In addition, owing to their relatively soft, flexible nature, many rock fragments tend to rupture *in situ* under compactive pressure after burial, with the result that there are all gradations between discrete grains and patches of interstitial "matrix" mixed with subsequently deposited authigenic cements. Nevertheless, an attempt has been made here to distinguish between rock fragments and derived matrix, and to divide rock fragments into two genetic groups—volcanic and nonvolcanic—on the basis of composition and texture.

Nonvolcanic Rock Fragments. Nonvolcanic rock fragments are abundant in most of the sandstones examined, particularly in those from the Mill Creek Formation (Fig. 18). Most are of sedimentary or metasedimentary origin, but, owing to lack of diagnostic compositional or textural features in some grains, this group undoubtedly includes a small proportion of cryptocrystalline volcanic rock fragments in post-Gladstone Formation sandstones.

Nonvolcanic rock fragments can be divided into two groups: those transported from some distant terrain to the site of deposition (detrital), and those derived from penecontemporaneous erosion of partially lithified sediments within the basin of deposition (local). Although detrital fragments are more abundant, local material is common in many sandstones, especially in the silty sandstones of the Gladstone Formation and in the fine-grained, laminated sandstones of the Fort Augustus Formation. Although not conspicuous at a megascopic level, local detritus is present as relatively flexible, generally elongate patches of mudstone or siltstone, contorted and broken up to varying degrees by the surrounding more rigid grains (Pl. 10, Fig. 2; Pl. 11, Fig. 1). In a few sandstones these grade into large irregular patches of shale or siltstone that have been transported only short distances while in a plastic state, or less commonly into rounded mudstone pebbles that evidently have undergone more prolonged abrasion prior to final deposition. At the other end of the scale, they grade through small subequant fragments, corresponding to the size of the admixed detrital grains, into irregular patches of intergranular matrix, impregnated to varying degrees by authigenic clay mineral cements. The larger fragments are composed mainly of very fine, micaceous or cryptocrystalline detritus, with variable amounts of silt-size quartz, kaolinite, or authigenic dolomite. Although these are generally distinguishable from associated detrital fragments owing to their large size, the similar composition and size of many of the smaller detrital and local fragments makes discrimination of the two groups difficult in many sandstones. For this reason both types of rock fragments have been combined into several descriptive groups shown in figure 20 without reference to their origin.

The main basis for classification of nonvolcanic rock fragments is the composition of the finely crystalline groundmass: whether micaceous, chloritic, opaque, or cryptocrystalline. Many contain scattered grains of angular silt-size quartz and are classed as siltstones where the amount exceeds 25 per cent, regardless of groundmass composition. These grade into fragments composed of interlocking silt-size quartz with minor amounts of impurities, best described as impure siltstone or metaquartzite.

Micaceous rock fragments are composed of oriented micromicaceous (sericite, illite) aggregates with minor amounts of chlorite, quartz, and opaque matter. Although some are local shale fragments in various stages of disaggregation (Pl. 11, Fig. 1), most are slate or phyllite fragments of low grade metasedimentary origin (Pl. 9, Fig. 2; Pl. 13, Fig. 1), grading with the addition of quartz into metasiltstone or impure metaquartzite. They also grade into finely crystalline chloritic rock fragments, which form an analogous series of local and metasedimentary rock fragments in many samples, although generally less abundant than their micaceous counterparts. Also included with micaceous fragments are minor amounts of glauconite pellets, common in the marine arenaceous beds (Wabiskaw Member) at the base of the Fort Augustus Formation (Pl. 11, Fig. 2). Several sandstones show all gradations between unaltered micromicaceous slate or metasiltstone fragments and bright green, homogeneous glauconite grains (Pl. 12, Fig. 2), the latter having been derived from alteration of micaceous fragments in the basin of deposition probably before burial and certainly before cementation.

Translucent to opaque, pale brown to black, cryptocrystalline fragments of diverse composition and origin form the bulk of the nonvolcanic rock fragments in many sandstones (Pl. 12, Fig. 1). They are divided in figure 20 into two groups, opaque and cryptocrystalline, according to the amount of opaque matter present. Most appear to be composed of cryptocrystalline quartz with variable amounts of micas, chlorite, iron oxides, bituminous matter, and graphite, grading with increasing grain size and decreasing amounts of opaque matter into micaceous or chloritic rock fragments or, more commonly, chert. Although some of this detritus consists of local shale fragments in various stages of oxidation, most appears to be of detrital origin, consisting of hard, organic or siliceous argillite and microchert, with minor amounts of graphitic slate or schist.

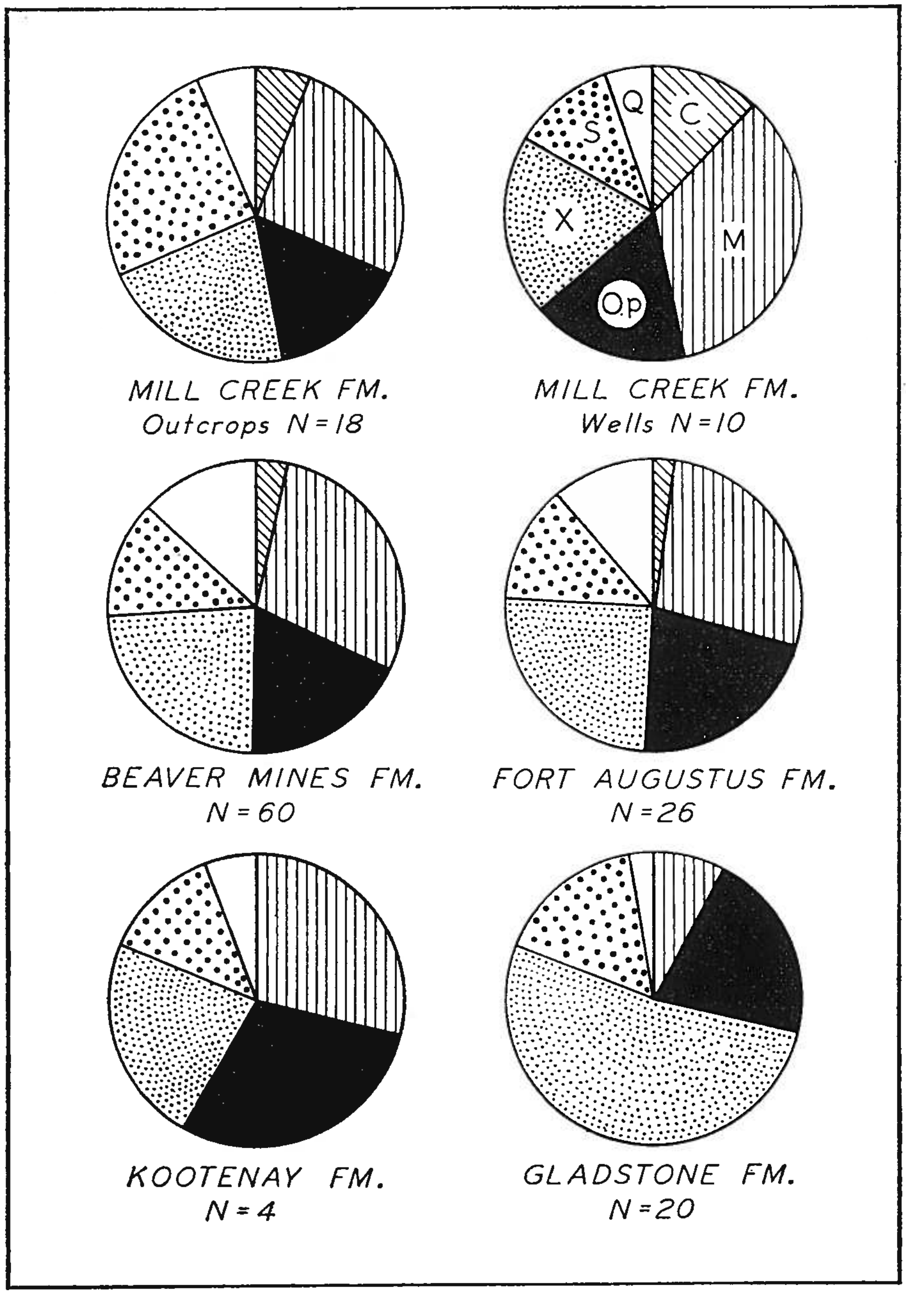
Some fragments, in the middle and upper parts of the succession, are probably of volcanic origin but lack diagnostic compositional or textural criteria to define them as such.

The composition of nonvolcanic rock fragments by formations (including those in four samples of the Kootenay Formation from the southern Foothills) is shown in figure 20. The salient feature of the diagrams is the relative scarcity or absence of micaceous and chloritic rock fragments in the siliceous sandstones of the Gladstone Formation, those present being largely of local origin. This accords with the lack of other metamorphic detritus in the Gladstone sandstones—garnet, muscovite, biotite—and the abundance of cryptocrystalline siliceous rock fragments and chert derived from an essentially unmetamorphosed sedimentary terrain. In contrast, micaceous and chloritic metasedimentary detritus is relatively common in the younger Blairmore and Mannville sandstones, especially in those from the upper part of the Mill Creek Formation, in association with abundant volcanic detritus. Their predominance in the detrital fraction of the nonvolcanic rock fragments in these units would be even more pronounced if this fraction could be separated from admixed detritus of local origin and from misclassified cryptocrystalline volcanic rock fragments.

Volcanic Rock Fragments. Rock fragments of volcanic origin are abundant in many of the Blairmore and Mannville sandstones, although their distribution is stratigraphically more restricted than those of nonvolcanic origin. They are most abundant in the Beaver Mines Formation sandstones of the Foothills, in which they comprise about one third of the total arenaceous detritus by volume, and are only slightly less common in the correlative Fort Augustus Formation sandstones of the Plains. They are present in trace to moderate amounts in sandstones of the younger Mill Creek Formation of the southern Foothills but appear to be absent from sandstones of the older Gladstone and McMurray Formations of the Foothills and Plains (Fig. 18).

Although generally distinguishable from nonvolcanic detritus, volcanic rock fragments are difficult to classify precisely owing to their fine particle size and to their wide variation in texture. Their main constituents are chlorite, feldspars, and quartz, with minor sericite (or illite), epidote, sphene, ilmenite, leucoxene, hematite, and biotite. They are divided in figure 21 into five groups, mainly on the basis of groundmass composition, although many contain microlites or phenocrysts of plagioclase or chloritized mafic minerals. Partial replacement by calcite or clay minerals, apparently postdepositional diagenetic phenomena, are common in some samples.

Chloritic volcanic fragments are especially common in sandstones of the Beaver Mines Formation in the Foothills, in which they are associated with abundant chlorite cement (Pl. 9). The groundmass is mainly finely



MILL CREEK FM.
Outcrops N=18

MILL CREEK FM.
Wells N=10

BEAVER MINES FM.
N=60

FORT AUGUSTUS FM.
N=26

KOOTENAY FM.
N=4

GLADSTONE FM.
N=20

FIGURE 20. *Pie diagrams showing the relative proportions of nonvolcanic rock fragment types in modally analysed sandstones from the Blairmore and Mannville Groups and Kootenay Formation. Key (upper right):* (C) *chloritic,* (M) *micaceous,* (Op) *opaque,* (X) *cryptocrystalline,* (S) *silty,* (Q) *quartzitic.*

crystalline, green, isotropic chlorite, intergrown with minor quartz or plagioclase, with interstitial ilmenite, leucoxene, or epidote. Many fragments have a felted or trachytic texture owing to the presence of clusters of slender plagioclase microlites, grading into microporphyritic types composed of lath-like or tabular plagioclase phenocrysts set in a homogeneous chloritic groundmass. The mafic constitutents, with the exception of rare biotite and secondary epidote, are invariably altered to chlorite; in fact, some of the more homogeneous chloritic fragments may be altered mafic grains.

With decrease in chlorite content, the volcanic detritus described above grades into finely crystalline quartzo-feldspathic rock fragments, shown in figure 21 as felsite. These consist largely of dense, finely crystalline, felsophyric or orthophyric intergrowths of quartz and feldspars, with minor chlorite, epidote, and iron ores. The cryptocrystalline nature of some suggests on original glassy groundmass, whereas relict structures in others show that they have been silicified to form finely crystalline quartz aggregates resembling chert. Many grains are microporphyritic, containing tabular plagioclase or rarely quartz crystals; potash feldspar, although common as single grains in many sandstones, is almost invariably confined to the groundmass of the associated volcanic rock fragments. With increasing crystallite size, felsite grades into equigranular feldspathic or quartzo-feldspathic aggregates, presumably derived from the coarser-grained or hypabyssal phases of the more abundant finely crystalline extrusive rocks. A few such rock fragments have a microgranitic texture, although detritus indicative of coarsely crystalline plutonic rocks is scarce.

In addition to the chloritic or felsitic volcanic detritus described above, a small proportion of these fragments is composed of micaceous (sericite-illite) or opaque (leucoxene, hematite) matter with traces of plagioclase microlites or phenocrysts. Many are altered chloritic or felsitic fragments, and some may be altered feldspar grains or mafic minerals.

The salient features of the igneous detritus in the Blairmore and Mannville sandstones are:

(1) its volcanic aspect. Although there is large variation in textures, most of the rock fragments are finely crystalline types of extrusive origin, and there is a conspicuous scarcity of coarsely crystalline plutonic detritus in all of the sandstones examined.

(2) the abundance of chlorite and the predominance of plagioclase over quartz and potash feldspar, especially in the Foothills sandstones. Where present, quartz and potash feldspar are confined almost invariably to the groundmass of the rock fragments, even although single grains of quartz and potash feldspar of probable volcanic origin are present in the same sandstone.

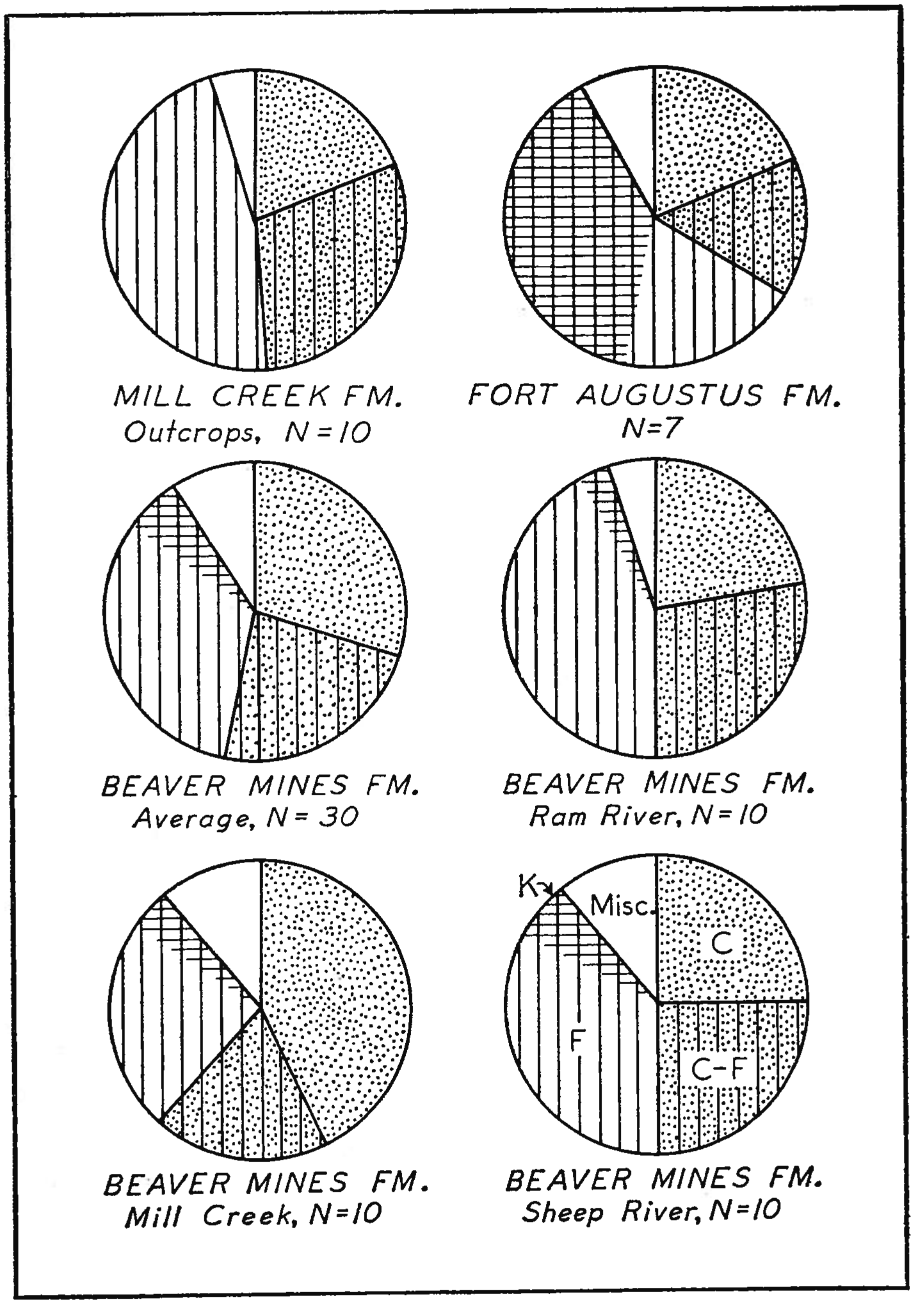


FIGURE 21. *Pie diagrams showing the relative proportions of volcanic rock fragment types in selected groups of modally analysed sandstones from the Blairmore and Mannville Groups. Key (lower right):* (C) *chloritic,* (C-F) *chloritic-felsitic,* (F) *felsitic,* (K) *potash feldspar-bearing,* (Misc.) *miscellaneous types.*

(3) the absence or extreme scarcity of amphiboles and pyroxenes both in rock fragments and as discrete grains, and the abundance of secondary epidote and leucoxene in the Beaver Mines Formation sandstones of the southern Foothills. The petrographic evidence suggests that mafic constituents formed only a small portion of the bulk of volcanic detritus initially, and much of that originally present has since been altered to chlorite.

In detail, the compositional range of the parent rocks appears variable, encompassing basic types rich in chlorite and sodic plagioclase (andesite or spilite), through intermediate types composed largely of plagioclase and quartz (dacite), to more acidic, potash feldspar-bearing varieties (latite or rhyolite). Figure 21 gives some idea of the geographic and stratigraphic variation in gross composition of the volcanic rock fragments observed in the Blairmore and Mannville sandstones, based on point counts of some of the coarser-grained sandstones. The sandstones of the Foothills Beaver Mines Formation contain a relatively high percentage of chloritic volcanic detritus, most abundant in the southern Foothills, and a consistently low proportion of potash-rich detritus both in rock fragments and as single grains. There is some evidence that the volcanic detritus in the formation becomes less chloritic northward along the strike of the Foothills, in accordance with the gradual change from the green, chlorite-cemented Mountain Park-type sandstones of the southern Foothills to the coal-bearing, kaolinitic Luscar-type beds in the lower part of the formation in the central Foothills. Also, the volcanic detritus in the Beaver Mines Formation of the southern Foothills is associated with abundant secondary epidote, which is absent from correlative sandstones north of the Bow River or in the Plains. In contrast, the sandstones of the Fort Augustus Formation in the Plains contain moderate to abundant amounts of potash-bearing feldspars and felsite fragments, whereas chlorite-rich volcanic fragments are scarce (although what appear to have been chloritic volcanic fragments in some of the nonmarine sandstones near the top of the formation in several wells have been altered during diagenesis to limonitic or kaolinitic aggregates—Pl. 8, Fig. 2).

Volcanic rock fragments observed in sandstones from the Mill Creek Formation of the southern Foothills are similar in composition and texture to those in the underlying Beaver Mines Formation, although the amount and distribution of potash feldspar in the rocks is uncertain owing to the fact that only a few of the thin sections were stained. Felsitic rock fragments predominate, with plagioclase the main or only phenocryst constituent; mafic minerals, other than biotite, are either absent or altered to chlorite. However, Anderson (1951) reports the predominance of granitic rock types in igneous pebbles from two conglomerate beds in the southern Foothills, which he correlates with the McDougall-Segur Sand of Turner Valley. The conglomerates, composed mainly of quartzite and chert pebbles, appear to be local pebbly phases of lensing, coarse-grained sandstones in the lower part of the Mill Creek Formation, well below the base of the volcanic Crowsnest Member, which is composed mainly of pyroclastic detritus also rich in potash feldspars.

To determine the composition of the volcanic detritus in the Beaver Mines Formation more accurately, several hundred pebbles were collected from a thick, lensing igneous pebble conglomerate in the middle of the formation that outcrops west of the Highwood River, in Sec. 17, Tp. 17, R. 6, W. 5th Mer. The conglomerate is described by Allan and Carr (1947, p. 30) as about 85 feet thick, grading laterally into coarse-grained sandstone a short distance to the north. The unit is present at approximately the same stratigraphic level as similar igneous pebble conglomerates reported from the Blairmore Group in other parts of the southern Foothills.

Fifty of the pebbles ranging from 2 to 6 inches in size were randomly selected and thin-sectioned. Of these, 36 are of primary igneous origin, and the rest are of sedimentary or pyroclastic origin, including 8 quartzites, 3 cherts, 2 lithic tuffs, and 1 feldspathic siltstone (arkose).

The igneous pebbles are grouped according to composition and texture in table 4. Five of the rocks (group A) are finely crystalline intrusive types, and the remainder are porphyritic rocks of presumably extrusive origin. Although the relative amounts of feldspars and quartz are variable, most of the rocks are oversaturated leucocratic types of intermediate to acid composition, with a pronounced scarcity of mafic minerals in both the groundmass and phenocryst fractions. Most show signs of deuteric or postmagmatic alteration, as evidenced by partial replacement of feldspars by sericite and epidote, and the widespread alteration of mafic constituents to chlorite and iron ores.

The five intrusive rocks are finely crystalline equigranular to porphyritic types, ranging in composition from diorite to granite. All contain excess quartz, with only trace to minor amounts of mafic constituents (biotite, epidote, chlorite), but vary widely in the proportions of plagioclase and potash feldspar. One has the composition of a diorite, two are subporphyritic quartz monzonites, and two are aplites. Their textures suggest that they are marginal phases of more extensive intrusive bodies, in which case they may represent the hypabyssal phases of the more abundant extrusive rocks with which they are found.

The extrusive rocks are dominantly finely crystalline, sparsely porphyritic, leucocratic types that range in composition from dacite to rhyolite. Megascopically, they consist of white or pink feldspar and rare quartz phenocrysts in a cryptocrystalline groundmass that varies from pale green to dark blue or red. A few are banded, and most are cut by joints or thin quartz-filled veinlets.

Plagioclase phenocrysts are present in all of the rocks, whereas potash feldspar and quartz are present in only a few. Mafic minerals are scarce and where present are largely altered to epidote or to chlorite and iron ores. The average size of the feldspar and quartz phenocrysts ranges from 0.20 millimeters to 1.64 millimeters, a few individual crystals ranging up to a centimeter in maximum dimension. Mafic phenocrysts are much smaller.

Groundmass textures range from cryptocrystalline to relatively coarse, with equigranular felsophyric texture predominating over trachytic and spherulitic textures. Relict perlitic structure was observed in a few rocks, indicating an originally glassy nature for the groundmass. A few rocks contain scattered quartz-filled vesicles, and a few are brecciated or contain small trachytic rock fragments of local origin.

The rocks are divided in table 3 into five groups on the basis of composition. The first group (group B) contains both plagioclase and potash feldspar phenocrysts, with or without quartz phenocrysts. Biotite or altered hornblende is present in three rocks, but the average mafic content is low. The groundmass composition is variable, with potash feldspar the dominant salic constitutent in five of the seven rocks. The rocks range in bulk composition from dacite (or trachyandesite) to rhyolite (or trachyte), having an average composition corresponding to quartz latite.

The second group (group C) contains both plagioclase and quartz phenocrysts, potash feldspar being confined to the groundmass. Two rocks contain trace amounts of biotite, and one a moderate amount of altered hornblende. The groundmass composition is more variable than that of group B above, with either plagioclase or potash feldspar the dominant constituent. The composition range is from dacite to quartz latite, with an average composition corresponding to dacite.

The remaining rocks contain plagioclase as the only phenocryst constituent, with the exception of minor mafic minerals. They are divided into three groups on the basis of the dominant groundmass mineral, although this is difficult to determine in some cases. The first two groups (groups D and E) contain potash feldspar and plagioclase as their main groundmass constituents, respectively, with subordinate amounts of quartz, chlorite, epidote, leucoxene, and iron ores. The mafic constituents, mainly pyroxenes or hornblende originally, with minor biotite, are largely altered to chlorite or epidote, although small diopsidic crystals are preserved in one rock. Most contain some excess quartz and range in composition from dacite (group E) to quartz latite (group D).

The rocks of group F contain only trace amounts of plagioclase phenocrysts in a finely crystalline felsophyric groundmass of quartz and

Table 4. Percentage Composition and Classification of Thirty-six Igneous Pebbles from a Conglomerate Bed in the Beaver Mines Formation on Highwood River

GROUP	NUMBER OF SAMPLES	MODAL ANALYSES							GROUNDMASS COMPOSITION	ROCK TYPE (average)
		Phenocrysts[1]								
		p	k	q	m	o	Ground-mass	Veins, Vesicles		
A	5	31.2	35.8	25.2	4.0	3.6	—	0.2		quartz monzonite
B	7	9.7	7.4	1.1	2.1	0.4	78.4	0.7	k > p > q	quartz latite
C	5	21.2	—	3.2	1.8	0.8	71.8	1.2	p > k > q	dacite
D	5	17.6	—	—	4.0	0.4	74.2	3.8	k > p > q	quartz latite
E	9	12.8	—	—	1.8	1.1	81.4	2.9	p > k > q	dacite
F	5	1.8	—	—	—	—	95.2	3.0	q > p + k	dacite(?)

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[1] p, plagioclase; k, potash feldspars; q, quartz; m, mafic minerals; o, other constituents.

feldspars or quartz alone. Megascopically, they resemble chert and appear to be either originally glassy phases of the rocks described above or possibly devitrified or silicified tuff.

Although some of the igneous pebbles described above could be broken down to form fine-grained volcanic detritus similar to the felsitic material present in the Beaver Mines sandstones, noticeable discrepancies exist between the compositions of the pebbles and the sand-size volcanic particles that form much of the arenaceous detritus in the Beaver Mines Formation sandstones of the southern Foothills. The salient differences are:

(1) the absence of chloritic, plagioclase-bearing basic volcanic rock types (andesites or spilites) from the pebble conglomerate;

(2) the scarcity or (more commonly) lack of potash feldspars in the volcanic rock fragments and feldspars of the sandstones.

The potash feldspar-rich sandstones of the correlative Fort Augustus Formation in the Plains more nearly resemble the Highwood volcanic pebbles in gross composition, but even these contain chloritic (or originally chloritic) volcanic detritus that does not correspond to that observed in the Foothills conglomerate bed. On the other hand, the pebbles do match the sand-size detritus of the Foothills sandstones in the scarcity and widespread alteration of mafic minerals, the abundance of secondary epidote, and the abundance of plagioclase in the coarser phenocryst and sand-size fractions of the rocks.

The discrepancies in composition between the volcanic content of the conglomerate and the sandstones can be attributed to several factors. The first is that the pebbles are a biased sample, which implies that a composite sample of similar conglomerates from different localities would correspond more closely to the igneous detritus in the sandstones of the formation. In this light the Highwood bed may contain an unusually high amount of detritus from geographically restricted potash feldspar-rich extrusive rocks to the west, intercalated among more basic volcanic rocks that contributed much of the igneous material to the formation. Certainly, the distribution of potash feldspars in the Beaver Mines Formation appears highly localized in time and space, undoubtedly due to the restricted distribution of this type of detritus in the source region to the west.

Or the Highwood pebble sample may be "biased" in the sense that it contains only those rock types more resistant to abrasion, in which case the harder, more acidic volcanic rocks would persist in the conglomeratic phases of the formation, whereas the softer, chlorite-rich, basic varieties would break down to form the bulk of the sand-size volcanic detritus. Some evidence for this is found in the composition of the nonvolcanic fraction of the Highwood conglomerate pebbles, composed largely of quartzite and chert, whereas softer slate and argillite fragments are dominant in the Beaver Mines Formation sandstones. There is also good evidence from thin sections that the chlorite-rich fragments in the sandstones are relatively soft in comparison with the felsitic types, showing all stages of disaggregation between discrete rounded grains and squeezed patches of intergranular "matrix" formed during compaction. In such a case the volcanic pebbles in the Highwood conglomerate are hardly representative of the bulk of the volcanic detritus in the formation as a whole, but indicate the composition only of a particular size fraction.

Accessory Detrital Minerals

Accessory detrital constituents are most abundant in sandstones of the Beaver Mines Formation in the Foothills. They are divided into two groups: micas, including chlorite, and more or less subequant "heavy" minerals with a specific gravity exceeding 2.85.

Micas. Micas are found as relatively large, platy grains, lath-like in thin sections cut perpendicular to the bedding, that because of their shape tend to segregate along certain bedding planes, forming fissile, mica-rich laminae in many of the sandstones. They are relatively soft and flexible, and many grains have been compressed or bent by compaction of the surrounding, more rigid grains. Like associated heavy minerals, they are most abundant in the finer-grained sandstones.

Of the three major types of micaceous minerals, biotite is the most abundant, forming as much as 5 per cent of the detritus in some of the finer-grained Beaver Mines Formation sandstones (Pl. 13, Fig. 2). In thin sections biotite appears as fresh, dark brown to reddish-brown, pleochroic laths, which grade into partly altered greenish-brown flakes, less markedly pleochroic and with lower birefringence. In grain mounts, many of the less altered reddish-brown grains show idiomorphic hexagonal outlines in contrast to the ragged appearance of most greenish-brown partially chloritized grains (Pl. 14, Fig. 2). Although most, if not all, of the biotite in the Blairmore and Mannville sandstones is of volcanic origin, the difference in degree of alteration and in idiomorphism may indicate two different modes of emplacement: reworked versus pyroclastic. Certainly, some of the biotite has been brought in as a component of chloritic or felsitic volcanic rock fragments, in which it appears to be the only unaltered mafic constituent. However, the amount originating in this fashion does not account for the amount of fresh idiomorphic biotite in the rocks, especially abundant in heavy mineral separates from some of the Fort Augustus Formation sandstones. This biotite, along with much of the idiomorphic quartz and potash feldspar grains of probable volcanic origin, is interpreted as pyroclastic detritus, derived from rhyolitic ash falls contemporaneous with the erosion and redeposition of the more basic chlorite- and plagioclase-rich volcanic detritus in both the Foothills and Plains sandstones.

Scattered grains of greenish chlorite are present in many sandstones, distinct from the brownish-green, partly altered biotite flakes described above. Although their origin is not obvious, their distribution correlates with that of biotite, and many are probably altered hornblende or biotite grains of volcanic origin. Finely crystalline chlorite is present in some of the associated metasedimentary rock fragments, but none appears to be so coarsely crystalline as to form large discrete flakes upon disaggregation.

Muscovite is extremely rare in most of the sandstones examined, although trace amounts were observed in sandstones from the Gladstone and Mill Creek Formations in the Foothills.

Heavy Minerals. These constituents can be divided into opaque and nonopaque fractions, of which the latter are the more easily identified. Like the associated micaceous minerals, they are most abundant in fine-grained sandstones, tending to segregate along certain bedding planes to form millimeter-thick placers rich in heavy minerals. Although usually present in only trace amounts in most sandstones, they are particularly abundant in those from the Beaver Mines Formation in the Foothills, forming up to 1 or 2 per cent of the detritus by volume in some samples.

To determine their composition and relative amounts more precisely, the heavy mineral fractions of several sandstones from each of the formations studied were separated and mounted. The average composition of the nonopaque heavy mineral fraction in each formation is shown in table 5, based on point counts of 25 to 250 grains per sample. The opaque constituents—largely ilmenite, leucoxene, altered volcanic rock fragments, and authigenic pyrite—were not studied in detail.

The nonopaque heavy minerals can be grouped into several assemblages according to their probable origin:

(1) stable suite: zircon, tourmaline, rutile;

(2) volcanic suite: epidote, sphene, apatite, zircon, tourmaline (with biotite and chlorite);

(3) pyroclastic suite: apatite (with biotite);

(4) metamorphic suite: garnet, staurolite, chloritoid, and kyanite.

The stable suite constitutes those minerals able to survive several cycles of erosion and deposition. Thus, they form the bulk of the nonopaque heavy mineral assemblages in sandstones from the Gladstone and Mill Creek Formations, composed mainly of reworked sedimentary or metasedimentary detritus. Trace to moderate amounts of zircon and tourmaline also are present in sandstones from the Beaver Mines and

Table 5. Average Percentage Composition of Nonopaque Heavy Mineral Residues from Sandstones of the Blairmore and Mannville Groups

Formation	No. of Samples	Location	Constituents[1]									
			Z	T	R	Ep	Sph	Ap	Ga	St	K	Ch
Gladstone	5	Foothills	80	13	5	—	—	2	—	—	—	—
Mill Creek	5	S. Foothills	82	13	3	—	—	2	1	—	—	—
Beaver Mines	6	S. Foothills	18	2	tr	59	4	10	5	—	—	—
Beaver Mines	6	C. Foothills	57	16	2	—	tr	21	4	—	—	—
Fort Augustus	7	Plains	23	9	4	—	1	34	23	4	tr	3

[1] Z, zircon; T, tourmaline; R, rutile; Ep, epidote; Sph, sphene; Ap, apatite; Ga, garnet; St, staurolite; K, kyanite; Ch, chloritoid.

Fort Augustus Formations, although some, if not most of these constituents are of volcanic origin, as suggested by the angularity of the grains and the predominance of one variety of blue tourmaline, also observed in volcanic pebbles. In contrast, the bulk of the zircon and tourmaline in the Gladstone and Mill Creek Formations is well rounded (Pl. 14, Fig.1), and various colored tourmaline varieties are present.

The volcanic suite consists of heavy minerals derived from the breakdown of volcanic rocks, as opposed to those brought directly into the basin of deposition as pyroclastic debris. In the Beaver Mines Formation of the southern Foothills, the suite is dominated by floods of secondary epidote (including zoisite), with minor amounts of sphene, zircon, tourmaline, and apatite, all observed in volcanic pebbles or rock fragments together with biotite and secondary chlorite. However, in the Foothills north of the Ghost River and in the central Plains, epidote is absent from sandstones equally rich in volcanic detritus, which contain only minor amounts of heavy minerals compared with correlative sandstones of the southern Foothills. Amphiboles and pyroxenes, which normally might be expected to be abundant in such rocks (as they are in some of the younger Cretaceous sandtones of Alberta), are virtually absent from both Foothills and Plains sandstones, except for rare, doubtfully identified grains of hornblende in one or two samples. Apparently these minerals, not especially common in the parent volcanic rocks to begin with, were largely altered to chlorite prior to deposition of the Blairmore-Mannville sediments, for there is little evidence to suggest that they have been removed subsequently by intrastratal solution.

The reason for separating apatite from the other volcanic accessory minerals is its inferred pyroclastic origin, although some is undoubtedly of reworked detrital origin. This interpretation is based mainly on its idiomorphic habit, distribution, and close association with idiomorphic biotite (Pl. 14, Fig. 2). Present largely as stubby to slender, prismatic crystals, apatite is distributed erratically in all parts of the stratigraphic succession, being most abundant in the Fort Augustus Formation sandstones in the Plains. In grain mounts the mineral forms from 0 to 75 per cent of the nonopaque fraction and is almost invariably found with corresponding amounts of idiomorphic biotite. The sample distributions of both constituents are independent of the amount of other volcanic detritus, and both are interpreted as being of pyroclastic origin, together with much of the volcanic quartz and potash feldspars in the rocks.

The last group of nonopaque heavy minerals comprises those of primarily metamorphic origin. Colorless, angular garnet is the most abundant of these minerals, being present in at least trace amounts in most of the sandstones examined, except those from the Gladstone Formation of the Foothills. It is most common in sandstones from the Fort Augustus

Formation, in which small amounts of staurolite, chloritoid, and rare kyanite are also present. These last-named constituents, abundant in heavy mineral residues from the McMurray Formation of northeastern Alberta (Mellon and Wall, 1956; Carrigy, 1963), are also present in small amounts in the underlying quartzose sandstones of the McMurray Formation in the central Plains (Williams, 1963) but are not recognizable in heavy mineral residues from Foothills sandstones. In the McMurray Formation they are associated with quartzose detritus derived from the Shield to the east, and their presence in the overlying sandstones of the Fort Augustus Formation indicates dilution by Shield-derived detritus of the more abundant volcanic and metasedimentary detritus originating from the Cordilleran region to the south and west.

Matrix

By definition, matrix consists of the finer-grained detritus in a rock that, owing to its particle size, forms an interstitial paste or filling among the larger "framework" grains (Krynine, 1948). Thus, matrix is a textural term, comprising the clay- or silt-size particles in sandstones, or sand-size particles in conglomerates.

In practice, matrix is difficult to determine quantitatively, owing to its intimate association with the other finely crystalline constituents of sedimentary rocks. Much of the so-called "matrix" in sandstones is derived, as Griffiths (1960) has pointed out, from the breakup *in situ* of finely crystalline rock fragments under compactive pressures to form patches of intergranular clayey or silty material that impart a poorly sorted appearance to many sandstones. In such sandstones all gradations exist between discrete sand-size rock fragments and irregular patches of derived matrix, the observed particle size-distribution of the rocks bearing little relation to that which existed at the time of deposition.

Compounding the difficulties involved in distinguishing between rock fragments and matrix is the fact that many sandstones, including most of the Cretaceous and Tertiary sandstones of Alberta, contain abundant authigenic clay mineral cements. Usually distinguishable on the basis of texture and intergrowth relationships, clay mineral cements are commonly intergrown, however, in many sandstones with patches of argillaceous matrix, the two constituents forming an intergranular paste of mixed origin. In fact, most "matrix" in sandstones is probably impregnated to some degree with authigenic cements on a submicroscopic scale, impossible to detect using standard microscopic equipment. Undoubtedly much of the so-called "argillaceous matrix" in many sandstones described in the literature is of partly, if not wholly, authigenic origin, and failure to recognize these constituents as such has led to erroneous conclusions concerning the classification and origin of many sedimentary rocks[1].

Frequency distributions of matrix percentages in the Blairmore and Mannville sandstones are shown in figure 22. Much of this material is derived from the breakup of large, locally derived shale or siltstone fragments to form interstitial patches of micaceous or chloritic clay-size detritus mixed with variable amounts of angular silt grains (Pl. 10, Fig. 2; Pl. 11, Fig. 1). Some volcanic rock fragments are also particularly susceptible to disaggregation, forming patches of chloritic matrix in many of the Beaver Mines and Mill Creek Formations sandstones, which are difficult to distinguish from chlorite cement in the absence of microlites or other structures (Pl. 9, Fig. 2). Other types of rock fragments appear more resistant to disaggregation, although many are contorted or squeezed by adjacent more rigid grains, reducing the porosity in much the same manner as the less cohesive, matrix-forming elements. Thus, although there is a rather diffuse inverse correlation between the amounts of matrix and authigenic cements in the Blairmore and Mannville sandstones (Fig. 23)[2], variation in cement distribution can be explained more readily in terms of the total amount of porosity-destroying elements.

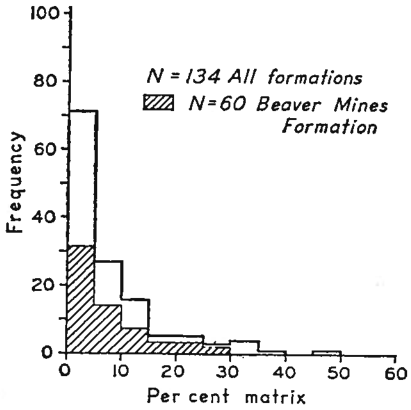

FIGURE 22. Percentage - frequency distribution of fine-grained clastic matrix in modally analysed sandstones from the Blairmore and Mannville Groups.

In general, the matrix content of the rocks increases with decreasing grain size, as shown in figure 23 for sandstones of the Beaver Mines

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[1] The term "greywacke" is a good example. Although most recent investigators, beginning with Pettijohn (1949), have stressed textural parameters in defining greywacke, the supposedly poor sorting and abundant clay "matrix" of many such rocks is undoubtedly due to the effects of compaction and cementation described above. The term greywacke is used here in a compositional sense, as suggested by Krynine (1948) and more recently by Huckenholz (1963), i.e. sandstones with a relatively high proportion of finely crystalline micaceous or chloritic detritus, either in the form of rock fragments or derived matrix (not cements).

[2] Samples in figure 23 are from three localities: Mill Creek, Sheep River, and Ram River. Total cements (calcite plus authigenic silicates) are corrected for the amount of replacement calcite; however, nine carbonate-rich samples are excluded from the diagrams owing to destruction of the original depositional fabric.

Formation. This apparent increase is in part due to the limitations of the microscope, in that it becomes progressively more difficult to distinguish among the various constituents of the finer-grained rocks. Thus, there is a tendency in point-counting these sandstones to group rock fragments, intergranular detritus, and clay cements as unresolved matrix, whereas in fact such rocks may be just as well sorted in a relative sense as coarser-grained sandstones. Another problem is met in dealing with finely layered rocks composed of interbedded laminae of silty shale and well-sorted, fine-grained sandstone a few millimeters to a centimeter in thickness,

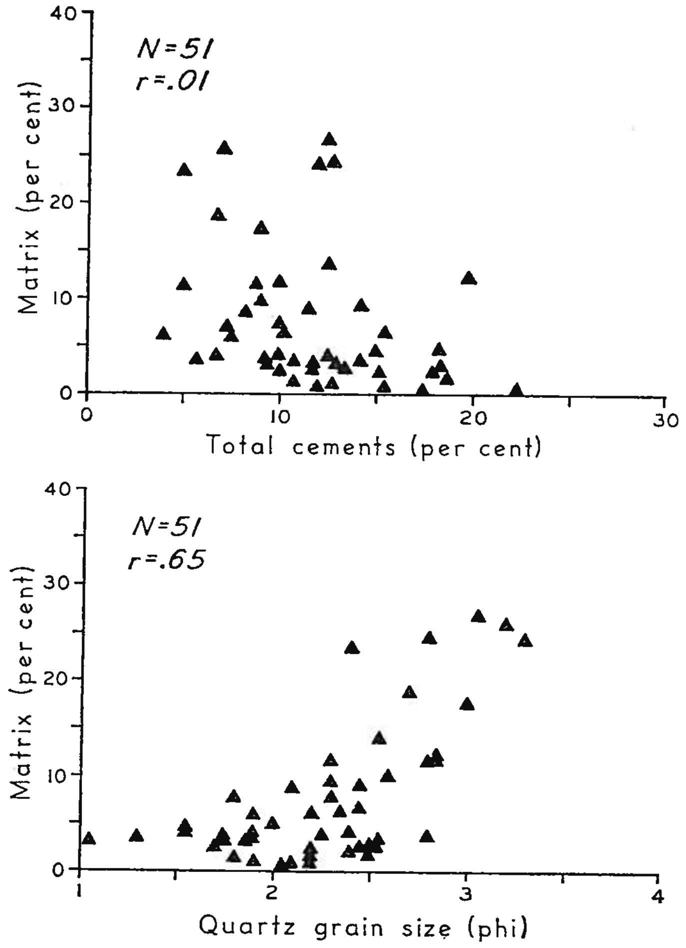

FIGURE 23. Scatter diagrams showing the relationships between matrix content and cement content and matrix content and quartz grain size in modally analysed sandstones from the Beaver Mines Formation (sampling localities: Mill Creek, Sheep River, Ram River).

especially common in the Gladstone and Fort Augustus Formations (Pl. 10, Fig. 1). If the thin section of such a rock is considered to be a representative sample, then the argillaceous laminae are composed mainly of matrix-forming elements relative to the arenaceous laminae, although they actually constitute two distinct, relatively well-sorted phases interbedded on a very fine scale. However, for practical purposes all shaly detritus and silt grains less than 32 microns in size have been included here with matrix, together with unresolved intergranular clayey constituents of mixed detrital and authigenic origin.

Carbonates

This group of minerals includes both transported and authigenic constituents, but, owing to the difficulty in discriminating between these two genetic types in some samples, they are grouped here according to composition rather than origin.

The carbonates present are calcite, dolomite, and siderite, in that order of abundance. Calcite is a more or less ubiquitous constituent in all phases of the Blairmore and Mannville sandstones, whereas dolomite and siderite are more restricted in distribution.

Calcite

Calcite is the most abundant carbonate in the Blairmore and Mannville sandstones, most containing at least trace amounts. With rare doubtful exceptions, most of the calcite is of authigenic origin, precipitated as an intergranular cement or as a metasomatic constituent replacing other detrital or authigenic constituents of the rocks.

Perhaps the most striking attribute of calcite is its erratic distribution, shown in figure 24 for all samples combined. Of 134 sandstones from four formations, 82 contain 1 per cent or less calcite, 30 contain from 1 to 5 per cent, and 22 contain from 5 to 55 per cent. Thus, the frequency histogram is highly skewed, most of the calcite in each formation being concentrated in relatively few rocks.

The patchy distribution of calcite is also apparent in outcrops and thin sections. On a megascopic scale, close examination of most outcrop or subsurface sections shows that most of the calcite in arenaceous strata is concentrated in irregular lenses a few inches to several feet thick, paralleling the bedding and contrasting in weathering habit or resistivity with adjacent noncalcareous parts of the same stratum. Intrastratal segregation of calcite appears to be particularly marked in sandstones of the Fort Augustus Formation, which contain either trace or very abundant amounts of calcite, with few intermediate values.

Calcite segregation is even more noticeable in thin sections, as shown schematically in figure 25. In most sandstones, which contain only trace amounts of calcite, the mineral is distributed more or less evenly as small, anhedral crystals filling isolated pores or replacing grains—usually feldspars (Pl. 15, Fig. 2) or volcanic rock fragments—in contrast to the bulk of the sandstones, cemented by authigenic quartz, clay minerals, or zeolites, or some combination of these minerals. With increasing calcite content (1 to 15 per cent), the distribution of authigenic cements becomes more heterogeneous, owing to the tendency of calcite to fill clusters of adjacent pores as large, optically continuous, poikilitic crystals up to a centimeter or more in maximum dimension. The proportion of noncarbonate cements is inversely proportional to the amount of calcite present, so that those sandstones in which the amount of calcite equals or exceeds the total amount of original intergranular pore space (15 to 20 per cent by volume) are cemented entirely by large patches of sparry calcite, except for trace amounts of noncarbonate cements (Pl. 16). In a few sandstones in which the amount of calcite is greatly in excess of the maximum amount of pore space, the mineral is distributed as small subequant patches, grading in some rocks into irregular fibrous aggregates with a spherulitic extinction pattern. In these sandstones calcite has played essentially a metasomatic role, partially replacing the detrital constituents and obliterating the original clastic framework of the rocks. Thus, the remaining grains and patches of matrix tend to "float" in a groundmass of anhedral or fibrous authigenic calcite (Pl. 17, Fig. 1).

The ultimate origin of calcite in the Blairmore and Mannville sandstones is uncertain. Griffiths (1958, 1960) has suggested that the irregular sample distribution of carbonates in sandstones (in comparison with the normal or symmetrical sample distribution of authigenic quartz) indicates the redistribution of originally transported material, but there is little textural evidence to suggest such an origin for the bulk of the calcite in the sandstones described here, in contrast to the granular, clastic texture of much of the dolomite. Several sandstones, for example, contain abraded dolomite grains partly engulfed by anhedral calcite cement, but only rarely contain similar grains composed of calcite (Pl. 17, Fig. 2). In general, the distribution of calcite in the Blairmore and Mannville

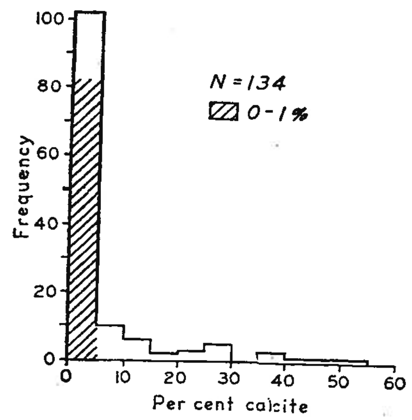

FIGURE 24. Percentage - frequency distribution of authigenic calcite in modally analysed sandstones from the Blairmore and Mannville Groups.

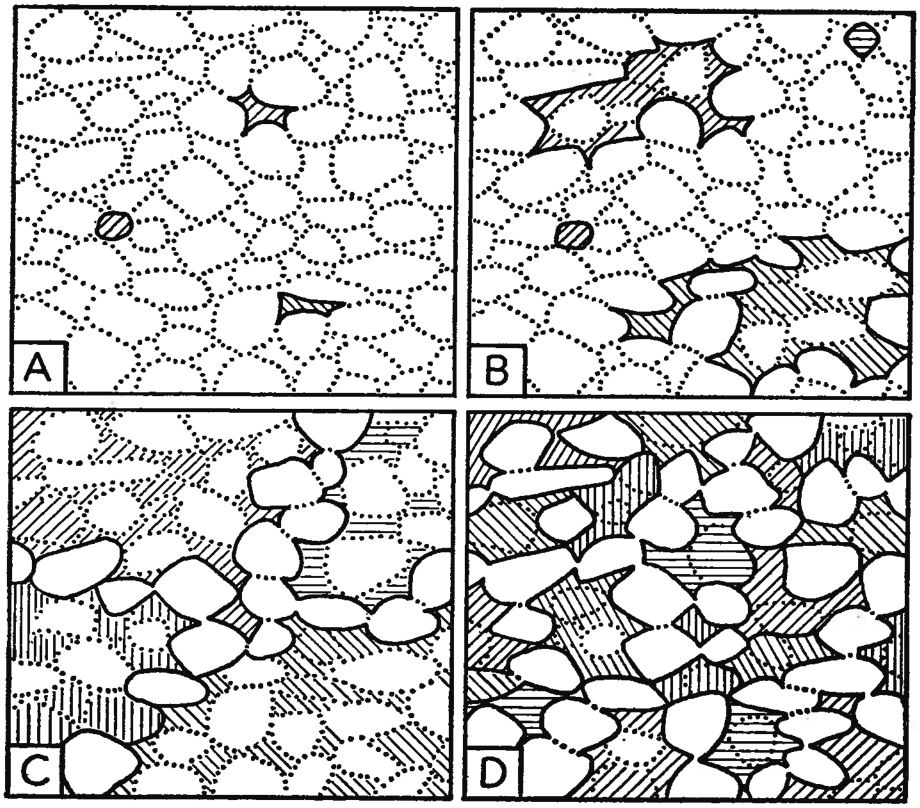

FIGURE 25. Stages of calcite cementation showing the progression from (A), *sandstones containing trace amounts of authigenic calcite* (*barred*); *to* (B) *and* (C), *sandstones containing small to moderate amounts as large poikilitic patches filling part or all of the available pore space; to* (D), *rocks containing abundant calcite as small subequant patches filling both available pore space and replacing many grains.*

sandstones does not appear to be related to that of other carbonates, nor to changes in the bulk composition of the sandstones from the different formations involved.

At the intrastratal level, the distribution of calcite appears to be governed at least partly by textural inhomogeneities in the rocks, detecable even in thin sections (Mellon, 1964). In a few sandstones calcite forms microscopic elongate patches of sparry cement that parallel bedding planes, themselves indicative of minute vertical variations in texture. In other sandstones irregular calcite-cemented areas, although not visibly related to the lamination, have impregnated the more loosely packed portions of the rocks, the remaining portions being cemented by authigenic silicates. In this light the erratic distribution of calcite has no obvious bearing on the ultimate origin of the mineral but rather illustrates the extremely local level at which authigenic processes operate.

Dolomite

Dolomite is more restricted in its distribution than calcite, but even in those parts of the stratigraphic succession in which it is not present are excluded from consideration (most of the Beaver Mines and Mill Creek Formations in the Foothills), its sample frequency distribution is just as erratic as that of calcite. That is, most of the dolomite is concentrated in relatively few rocks, the majority of the potentially dolomite-bearing sandstones containing only trace to moderate amounts.

Several kinds of dolomite are present in the Blairmore and Mannville sandstones, but their genetic relationships are not completely clear, nor can they always be distinguished in thin sections. These are:

(1) abraded polycrystalline aggregates	detrital (distant source) or chemiclastic (locally derived);
(2) abraded rhombic crystals	chemiclastic;
(3) rhombi inclusions in chert or rock fragments	detrital or authigenic (metasomatic), or both;
(4) irregular polycrystalline aggregates	recrystallized(?);
(5) overgrowths on abraded grains	authigenic.

The first two types are distinguished by their granular texture, consisting of rounded monomineralic grains that obviously have been abraded during transportation before reaching the final site of deposition. Most common are well-rounded, polycrystalline grains composed of small, densely packed, subrhombic crystals ranging in size from coarse silt to cryptocrystalline clay-size particles. Some contain quartz silt grains or chert inclusions, grading into chert or argillite fragments containing rhombic dolomite inclusions, the transported origin of which is indicated in a few grains by the truncated rhomb boundaries at the margin of the parent rock fragment. Associated with these polycrystalline fragments in most sandstones are large single crystals, rhombic or lath-like in habit, the size-distribution of which conforms approximately to that of the other constituents in the rocks. The crystals exhibit all stages of rounding, from well-rounded to angular rhombic grains, the idiomorphism of many being due to the development of secondary dolomite overgrowths on an abraded nucleus subsequent to deposition. Both the abraded boundaries and size-distribution of these crystals indicate their transported origin.

Where dolomite is present in small amounts (less than 5 per cent of the total constituents), it appears to consist mainly or entirely of transported detritus, such as that described above. However, in those sandstones containing more than 5 per cent dolomite, the mineral is present in authigenic form as well: there are all gradations between abraded detrital or chemiclastic grains, through irregular or idiomorphic crystal aggregates of uncertain origin, to intergranular dolomite cement of authigenic origin (Fig. 26).

Dolomite of indisputable authigenic origin is found as clear, optically continuous overgrowths on transported grains (Pl. 18), similar in habit to overgrowths on detrital quartz grains. In such cases the nucleus is a single rounded crystal distinguishable from the overgrowth by the trace of the original grain wall, or by a slight discoloration in the nucleus due to organic matter or incipient oxidation prior to cementation. In some sandstones the overgrowths tend to be idiomorphic, imparting an angular rhombic appearance to the originally rounded grain, whereas in others the overgrowth is irregular in outline, conforming to the boundaries of the surrounding grains (Pl. 19, Fig. 1). Where the nucleus is a polycrystalline aggregate, adjacent patches of dolomite cement are present as anhedral, colorless crystals that bear no obvious crystallographic relation to the adjacent grain. Development of secondary overgrowths appears to be more common in some sandstones than in others, for in some the dolomite grains show no evidence of recrystallization or enlargement; all of the dolomite in them appears to be of transported origin.

Some sandstones contain, in addition to distinctly abraded grains, scattered subhedral or euhedral dolomite crystals or crystal aggregates of variable size and shape without definite textural evidence for either a transported or authigenic origin (Fig. 26). Many of the crystal aggregates, from their size and spatial relationships to the surrounding nondolomitic constituents, appear to be of originally transported origin, recrystallized to conform to the contours of adjacent grains during diagenesis. In two dolomite-rich sandstones from the Luscar facies of the Beaver Mines Formation on Ram River, the mineral is intimately mixed with authigenic calcite to form a finely crystalline groundmass of fibrous or granular carbonates that has largely replaced many of the clastic textural elements in the rocks, including some of the noncarbonate grains and matrix. In other sandstones from the same locality, much of the dolomite has retained its clastic texture, in contrast to the anhedral habit of subsequently deposited calcite cement. Thus, some evidence exists for local redistribution of some of the dolomite, but the amount involved and the conditions necessary for recrystallization are uncertain.

Although some distinction can be made between transported and authigenic dolomite, the ultimate origin of much of the mineral in the sandstones under investigation is debatable. Sabins (1962), for example, distinguished between two types of transported dolomite found in Cretaceous sandstones from widespread localities in the western United

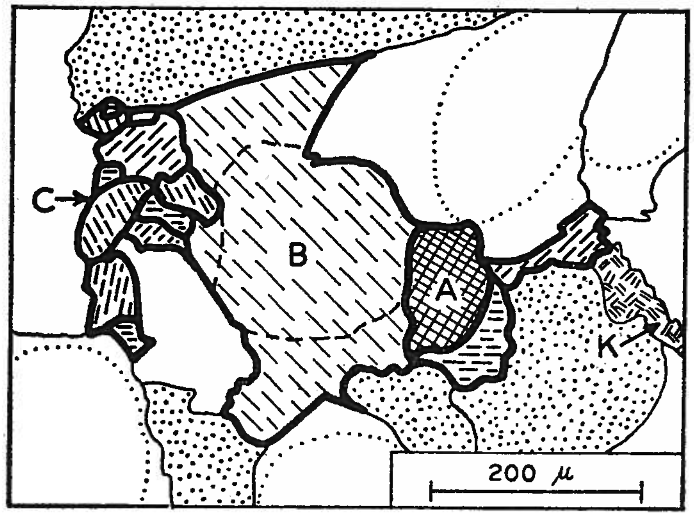

FIGURE 26. *Camera lucida sketch showing the distribution of dolomite (heavy lines) in a portion of sample 57-25 (Compare Plates 18, 19). (A), rounded cryptocrystalline fragment of clastic origin. (B), anhedral patch of "sparry" dolomite composed of a rounded single crystal nucleus (dashed line) and optically continuous overgrowths. Smaller "sparry" dolomite patches to the right of (A). (C), cluster of anhedral dolomite crystals, probably of detrital origin but partly redistributed? Quartz is colorless; chert and rock fragments are stippled. Note the presence of large quartz overgrowths and authigenic kaolinite (K).*

States and Canada, corresponding to the abraded polycrystalline and single crystal grains described above. The polycrystalline type he labelled "detrital", derived from some distant source terrain, and the single crystal type "primary", on the supposition that large single crystals could be formed only at the site of sedimentation, although reworked and abraded prior to final deposition and burial. Sabins stated that detrital dolomite can be found in any sandstone close enough to the source of sediments, whereas "primary" (chemiclastic) dolomite is found only in littoral or marine sandstones. He distinguished both types of transported dolomite from "secondary" dolomite, present as small idiomorphic rhombs "floating" in patches of calcite cement, and thus presumably of late metasomatic origin.

The textural properties and interrelationships of the various types of dolomite in the Blairmore and Mannville sandstones do not lend themselves to such a simple, unequivocal hypothesis of origin and distribution. It is true that the littoral and marine sandstones of the Fort Augustus and Bow Island Formations contain trace to moderate amounts of abraded rhombic crystals, in contrast to correlative nonmarine sandstones that contain little or no dolomite, but in nearly all cases such crystals are associated with abraded polycrystalline grains interpreted by Sabins (*op. cit.*) as detrital. This is true even of the marine glauconitic sandstones at the base of the Fort Augustus Formation (Wabiskaw Member) in the eastern Plains, which are several hundred miles from any possible detrital source area. Moreover, both types of transported dolomite are abundant in sandstones of the Gladstone Formation in the Foothills, which from their lithology and fossil content appear to be of nonmarine origin, at least in the southern and south-central Foothills. Thus, it appears likely that both types of dolomite can have a common, chemiclastic origin, although probably mixed in some sandstones with truly detrital carbonates derived from some distant source area. A detrital source for some of the dolomite in the Gladstone and Luscar sandstones of the Foothills is especially feasible, for these beds are not only relatively close to the source terrain but are also contiguous with the coal-bearing Gething and Commotion Formations of the northern Foothills in which both calcite and dolomite of indisputably detrital origin are abundant (Mellon *et al.*, 1963). In contrast, the nonmarine Luscar-type beds of the Fort Augustus Formation in the Plains to the east contain little or no dolomite, owing in part to their distance from the source area.

The general hypothesis of dolomite distribution and origin is shown in figure 27. All of the dolomite in the rocks is suggested as being of ultimate detrital origin, redistributed in part through subsequent authigenic processes and local resedimentation. Undoubtedly, some was temporarily redistributed through solution and reprecipitation as rhombic crystals in partly lithified silty clays within the basin of deposition, which were later broken up and redeposited to form partly dolomitized mudstone fragments and slightly abraded single crystals of local origin. Such mudstone fragments are common in sandstones from the Gladstone Formation and from the marine portions of the Fort Augustus Formation, in which they are associated with other types of transported and authigenic dolomite, as well as abraded rhombic crystals. Possibly some of the polycrystalline dolomite grains formed in the same way, from the disaggregation of more completely dolomitized rocks, such as sample 56-26, a fine-grained sandstone from the Gladstone Formation which consists of scattered quartz grains and rock fragments "floating" in a groundmass of finely crystalline, granular dolomite (Pl. 6, Fig. 1).

Evidence of postdepositional (diagenetic) redistribution of dolomite is provided by the presence of authigenic dolomite overgrowths on abraded grains and the apparent local recrystallization of detrital or chemiclastic grains to form irregular polycrystalline aggregates or masses of fibrous, spherulitic carbonate. In this connection some of the smaller idiomorphic crystals associated with interstitial matrix in a few rocks may be of metasomatic origin, emplaced in the more permeable parts of the sandstone during diagenesis through solution and reprecipitation. Evidence for such a process is found in a few sandstones, in which small dolomite rhombs of late authigenic origin are observed "floating" in kaolinite cement. However, considerable uncertainty still exists in determining the paragenesis and origin of much of the dolomite in the Blairmore and Mannville sandstones.

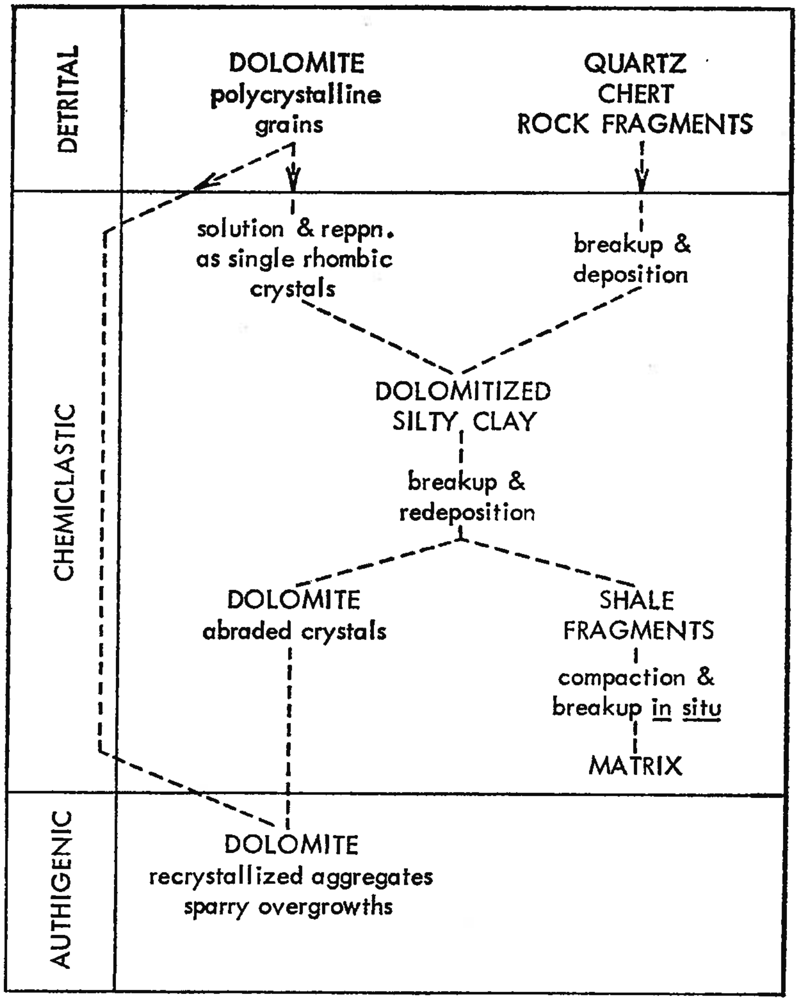

FIGURE 27. Chart showing the hypothetical sequence of formation proposed for different types of dolomite observed in modally analysed sandstones from the Foothills Gladstone Formation.

Siderite

Siderite is the least abundant of the three carbonates, being confined to the lower part of the Beaver Mines Formation (Luscar facies) in the central Foothills, and to the Fort Augustus Formation in the Plains. However, although more restricted in distribution than either calcite or dolomite, its sample distribution in sandstones susceptible to its presence shows essentially the same highly skewed, erratic frequency as those of the other two carbonates.

All carbonates identified as siderite are of local origin, formed through breakup and resedimentation of siderite-rich muds in penecontemporaneously deposited sandstones. These clastic fragments are conspicuous in hand specimens as dark brown to reddish, ovoid pellets averaging a millimeter or more in size, generally distributed in thin lenses paralleling the bedding, giving some sandstones a banded or speckled appearance.

In thin sections the pellets appear to be composed largely of finely crystalline, pale to dark brown carbonate, identified from staining tests and X-ray diffraction patterns as siderite. Layered structure (Pl. 19, Fig. 2) is apparent in many pellets owing to parallel orientation of elongate silt-size siderite crystals ranging in size from a few to 50 microns; others composed of subequant to cryptocrystalline siderite with no visible orientation appear homogeneous. The pellets show all stages of oxidation, both in outcrop and subsurface sandstones, grading from pale brown, transparent aggregates to dark red or brown, opaque masses composed of felty limonite and cryptocrystalline siderite.

The pellets vary widely in shape: from elongate masses flattened parallel to the bedding (Pl. 20, Fig. 2), through irregular subequant ovoids, to layered vermicular aggregates elongated perpendicular to the bedding (Pl. 20, Fig. 1). Many show some signs of postdepositional deformation, having been compacted and deformed by the surrounding grains during the early stages of diagenesis, prior to cementation. Thus, they appear to have been in a plastic state during or immediately after deposition, like the large argillaceous mudstone fragments present in many of the sandstones.

Both their size and apparently plastic state during deposition show that the pellets have a local clastic origin, although their mode and exact locus of formation is uncertain. They are present only in the Beaver Mines and Fort Augustus Formations; in the Foothills they are confined to the coal-bearing Luscar facies of the central Foothills, whereas in the Plains they are distributed erratically in both the marine and nonmarine phases of the Fort Augustus Formation in all of the wells examined. In both regions the pellet-bearing sandstones are interbedded with thin but numerous beds of dense siderite-rich claystone (ironstone), whereas both pellets and ironstone beds are absent from or are uncommon in correlative non-coal-bearing strata in the southern and central Foothills. Thus, the close geographic distribution of both types of siderite suggests a common origin, possibly through local erosion (channeling) and resedimentation of bedded siderite as pellets in penecontemporaneously deposited sandstones, analogous to the concentration of reworked ironstone nodules in the "claystone conglomerate" at the base of the Beaver Mines Formation on Ram River (Fig. 9).

More directly, there appears to be a close relationship between siderite pellets and micas in some sandstones, flakes of biotite or chlorite forming a nucleus or framework about which the pellet was constructed. In such cases the mica was attacked along the basal cleavage planes, expanded by crystallization of granular siderite, and ultimately replaced to form rectangular or vermicular aggregates of finely crystalline layered siderite (Pl. 19, Fig. 2). Scattered pellets containing traces of replaced and expanded mica grains demonstrate various stages in this process in several sandstones. Similar but smaller grains of partly replaced biotite are present in a few sandstones from the southern Foothills, although the carbonate involved is calcite rather than siderite. This process, however, undoubtedly took place outside of the sandstones in which the siderite pellets are found, probably in those parts of the basin subjected to strongly reducing conditions, the pellets having been subsequently transported and in some cases partly oxidized prior to final deposition and burial. In this connection the authigenic cements in the pellet-bearing sandstones contain no siderite but consist rather of quartz and clay minerals (kaolinite and illite), with variable amounts of calcite.

Authigenic Silicates

These constituents include a variety of noncarbonate minerals that, like calcite, act both as intergranular pore-filling agents or as metasomatic constituents replacing more unstable types of grains and matrix, forming up to 30 per cent of the total constituents by volume in some of the sandstones (Fig. 28). They are divisible into three groups on the basis of composition: quartz, clay minerals, and zeolites (laumontite).

Quartz

Authigenic quartz, like detrital quartz, is a ubiquitous constituent of most sandstones, and few of the Blairmore or Mannville sandstones fail to contain at least trace amounts.

The morphology and abundance of authigenic quartz depends on the amount of detrital quartz and other authigenic minerals present. It is most abundant in the more siliceous sandstones of the Foothills (Gladstone and Mill Creek Formations) as overgrowths on detrital quartz grains, although the amounts present in this form are difficult to determine owing to the fact that the original grain outlines have been masked by secondary enlargement. However, the nucleus-overgrowth interface is evident in a few grains in each sandstone, for which the ratio of authigenic to detrital quartz can be determined. From these data the total amount of authigenic quartz can be estimated by extrapolation, although the reliability of the results is uncertain.

In some of the more siliceous sandstones, quartz overgrowths have filled most or all of the intergranular pore space to form patches of seemingly angular quartz grains with irregularly interlocking boundaries (Pl. 21). In adjacent parts of the same or other sandstones, the grains may be only partly cemented by quartz, in which case the central parts of the intergranular areas are filled by clay minerals (kaolinite or illite) or carbonate cements adjoining marginal quartz overgrowths (Fig. 29). Where in contact with other authigenic minerals, especially carbonates, the overgrowths tend to be idiomorphic, forming smooth, straight crystal faces in sharp contact with calcite or dolomite. From their spatial relationships to the other constituents in the rocks, the overgrowths appear to have formed during the early stages of diagenesis, before the emplacement of other authigenic cements.

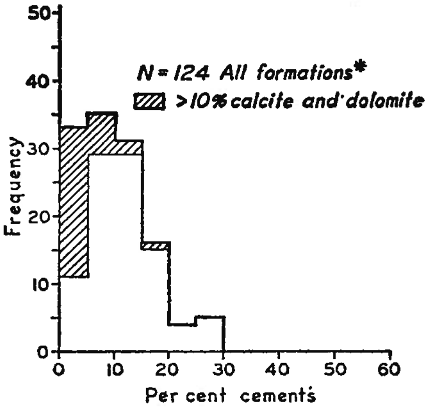

*FIGURE 28. Percentage-frequency distribution of intergranular silicate cements in modally analysed sandstones from the Blairmore and Mannville Groups (*excluding 10 Mill Creek Formation subsurface sandstones from three wells in the Turner Valley-Okotoks region).*

In many of the chlorite-rich sandstones in the Foothills, authigenic quartz is found as small, subequant, intergranular crystals with no obvious relationship to detrital quartz grains. Presumably this is partly due to the scarcity of detrital quartz in these sandstones, but it is also due to the early formation of authigenic chlorite as a rim about the grains, which has apparently inhibited or prevented the deposition of quartz overgrowths on detrital nuclei. Thus, quartz fill the remaining residual parts of the pore spaces, either completely or in various textural arrangements with calcite, clay minerals, or laumontite (Pl. 15, Fig. 1; Pl. 23).

Chert cement is rare in both the siliceous and chloritic phases of

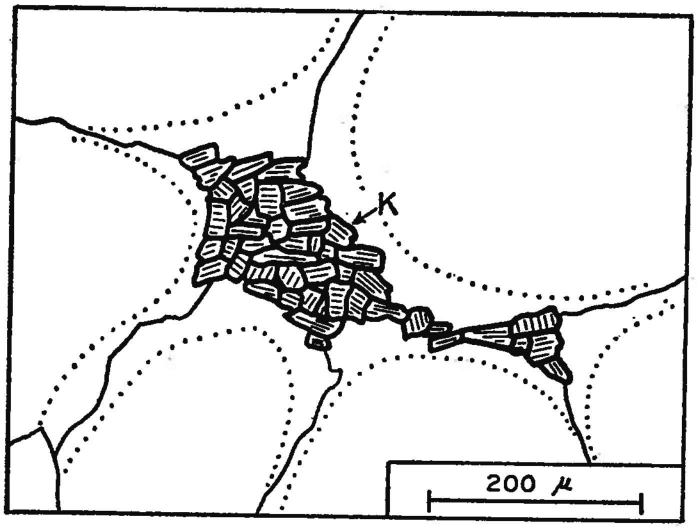

FIGURE 29. Camera lucida sketch showing the distribution of cements in sample 57-17, siliceous sandstone from the Gladstone Formation. Most of the original pore space is filled by authigenic quartz as overgrowths on detrital quartz grains (stippled boundaries), the remainder being filled by tightly packed kaolinite books (K).

the rocks, although common in certain sandstones from other regions. It was observed only in subsurface samples of cherty sandstones from near the top of the Blairmore Group (McDougall-Segur and Stockmen's Sands) in the Pine Creek No. 1 well (Pl. 22).

Clay Minerals

Authigenic clay minerals form the bulk of the cements in many of the Blairmore and Mannville sandstones and are generally present in at least trace amounts in the remainder. They compete for the same space in the sandstones as the other authigenic constituents, having been deposited from solutions in intergranular pores, but should be differentiated from similar clastic clay-size detritus (matrix) which is of fundamentally different origin. Both types of clayey constituents—transported and authigenic—in many cases are intergrown or difficult to distinguish, especially in the finer-grained sandstones, and consequently are lumped together by most petrographers as "argillaceous matrix", a term which has little descriptive or genetic significance.

Four basic types of authigenic clay minerals are present in the Blairmore and Mannville sandstones. Optical and physical properties useful to their identification in thin sections are listed in table 6, together with the gross feldspar content of the associated sandstones.

In general, authigenic clay minerals form finely crystalline aggregates corresponding in size and shape to the intergranular pores of the sandstones, which range up to several hundred microns in diameter, although averaging much less. They are often intergrown, either with each other, or with authigenic quartz or clay matrix, so that their separation for more precise identification (by X-rays or chemical analysis) is difficult or impossible. However, tentative identifications of these constituents based on thin section observations usually are confirmed by X-ray diffraction powder patterns of bulk samples (which contain both detrital and authigenic clay-size constituents), or more accurately by X-ray microcamera patterns of individual clay mineral aggregates analysed *in situ* (Carrigy and Mellon, 1964).

Kaolinite. Kaolinite is the most common authigenic clay mineral in the Blairmore and Mannville sandstones, being present in a wide variety of sandstones that range in composition from dominantly siliceous to those composed largely of volcanic detritus.

Kaolinite is found in thin sections as colorless aggregates composed of densely packed, vermicular crystallites averaging 5 to 10 microns in diameter. Superficially, these aggregates resemble chert cement, but their birefringence is lower and their refractive index higher than that of quartz. Crystallite size appears to vary widely: some aggregates seem cryptocrystalline under crossed nicols (an effect possibly enhanced by the low birefringence), whereas in others individual books can be easily distinguished. However, X-ray microcamera films of both types yield spotty diffraction patterns, in contrast to the sharp, continuous Debye-Sherrer rings from authigenic chlorite or illite; even the finest varieties of kaolinite appear to be coarsely crystalline in comparison with other clay cements, a difference not obvious from thin section observations.

In addition to the more finely crystalline types of kaolinite, large, vermicular or fan-shaped particles up to 100 or 200 microns in length were observed in a few sandstones. Some of these (possibly dickite, rather than kaolinite, as reported by Williams [1963] from the McMurray Formation of east-central Alberta) appear to be authigenic, but some may be of clastic origin. Similar but smaller kaolinite particles are scattered throughout some of the mudstone fragments in many of the sandstones, apparently having formed through authigenic processes in partly lithified clay beds prior to reworking and final burial, in much the same way as some of the dolomite in the rocks.

Kaolinite is the only visible authigenic constituent in a few sandstones (Pl. 24; Pl. 25, Fig. 1), but in most it is associated with other authigenic constituents. Commonly, it is found with authigenic quartz as shown in figure 29, filling the central or residual portions of the intergranular areas

Table 6. Properties of and Sandstone Composition Associated With Authigenic Clay Mineral Cements in the Blairmore and Mannville Groups

SPECIES	COMPOSITION (Idealized)	PROPERTIES				FELDSPAR CONTENT OF ASSOCIATED SANDSTONES
		Color	Birefringence	Ref. Index[2]	Habit	
kaolinite	$Al_4\ Si_4\ O_{10}\ (OH)_8$	colorless	low	high	equigranular	variable
montmorillonite[1]	$(Al,\ Mg)_2\ Si_4\ O_{10}\ (OH)_2$	pale green to brown	low to moderate	low to moderate	fibrous, vermiform	moderate to abundant
illite	$K(Al,\ Fe)_3\ Si_3\ O_{10}\ (OH)_2$	colorless	moderate	low	equigranular, fibrous	moderate
chlorite	$(Mg,\ Fe)_6\ AlSi_3\ O_{10}\ (OH)_8$	green	isotropic	high	fibrous	moderate to abundant

1 *sensu lato*; 2 compared with that of Canada balsam (1.54).

not occupied by marginal quartz overgrowths. It is similarly distributed in some sandstones partly cemented by chlorite (Pl. 23) or montmorillonite (Pl. 25, Fig. 2), as finely crystalline aggregates marginal to but not intergrown with fibrous chlorite or montmorillonite deposited as a coating on the pore walls. In a few sandstones kaolinite appears to be intergrown with fibrous illite or cryptocrystalline montmorillonite, although, normally, contacts between authigenic clay cements are sharp.

In a few rocks kaolinite is not only present as a pore-filling cement but has partly replaced some of the feldspar grains. However, this mode of emplacement appears uncommon; certainly, in the kaolinite-cemented siliceous sandstones of the Gladstone Formation there is no obvious relationship between the two constituents, feldspars being virtually absent from these rocks.

Montmorillonite. Montmorillonite (*sensu lato*) is common in many of the Blairmore and Mannville sandstones, especially those of the Plains, although mainly in the form of altered volcanic rock fragments of biotite, rather than as an intergranular cement. The distinction between the two modes of emplacement is strictly spatial; the intergranular variety probably formed simultaneously with that replacing altered detritus in those sandstones containing an excess of fluids rich in the necessary chemical constituents. However, in most sandstones the formation of montmorillonite appears to have been localized within individual grains or patches of matrix, the intergranular pores being filled later by other cements, usually kaolinite or chlorite.

Where an intergranular cement, montmorillonite is present as a cryptocrystalline paste or as fibrous or tube-like coatings deposited about the grain walls (Pl. 25, Fig. 2). The color ranges from brown or greenish-brown to nearly colorless, and both the refractive indices and birefringence appear variable. The wide range in pore morphology, color, and optical properties suggest that several types of montmorillonite are present, as might be expected from the susceptibility of this group of minerals to lattice substitution and interlayer cation exchange.

Not all of the cements tentatively identified in thin sections as montmorillonite turn out upon further analysis to contain expandable clay constituents referable to this group of minerals. Among these are various types of filmy, brown to greenish-brown, birefringent, intergranular substances found in some of the volcanic-rich sandstones in the Beaver Mines and Mill Creek Formations of the southern Foothills (Pl. 26, Fig. 2; Pl. 27, Fig. 1). X-ray diffraction patterns and staining tests[1] show that some of these cements do contain montmorillonite as well as chlorite,

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[1] Using a buffered solution of benzidine hydrochloride.

whereas others, seemingly identical in appearance, show none or only trace amounts. Some of this latter material, resembling chloritized biotite, yields X-ray microcamera films that confirm the presence of chlorite and a mica-like mineral (probably illite), but not "mixed layer" clay minerals in the usual sense of the term. In fact, none of the authigenic clay mineral cements identified by X-ray techniques contains mixed layer constituents, although such minerals appear to be present in shales associated with these and other sandstones. A tentative interpretation of the results is that the original cementing agent (probably montmorillonite) has altered through diagenesis to a mixture of chlorite and illite in some sandstones, but in others, particularly those rich in calcite, the transformation has been only partial, yielding mixtures of chlorite and montmorillonite. However, this hypothesis is speculative on the basis of present data.

Montmorillonite is present also in sandstones cemented by other authigenic clay minerals (chlorite or kaolinite) as a cryptocrystalline constituent in altered rock fragments or biotite grains rather than as an intergranular cement. In many of these sandstones, it is distinguishable only by X-ray or staining techniques, being otherwise unrecognizable in thin sections. Because data are scarce, the distribution of montmorillonite in this way is uncertain, although it appears to be erratic and not obviously related to other textural or compositional properties, except in a general way to the distribution of volcanic detritus. However, not all sandstones rich in volcanic detritus contain montmorillonite; additional factors are apparently associated with its genesis.

Illite. Authigenic illite is common in many sandstones from the Beaver Mines Formation in the Foothills but is either absent from or extremely rare in sandstones from other parts of the Blairmore and Mannville Groups.

Two types of illite can be distinguished in thin sections and from X-ray data, although all mixtures of the two "end members" appear to be present. The first type consists of finely crystalline, fibrous aggregates growing out from the pore walls, mixed in some sandstones with tiny subequant quartz crystals (Pl. 27, Fig. 2). This variety has low refractive indices (1.54-1.55) and shows low to moderate birefringence (straw yellow interference colors). The second type consists of densely packed, interlocking, platy crystallites up to 15 or 20 microns in maximum dimension, which, although similar to authigenic kaolinite, are more micaceous in gross aspect (Pl. 28). This variety also has low refractive indices but distinctly higher birefringence (second order red to blue interference colors) than the first.

X-ray microcamera films of both types of illite from various sandstones show consistent differences in diffraction patterns (Carrigy and Mellon, *op. cit.*). The fibrous variety yields patterns that indicate the dominance of the $2M_1$ polymorph, whereas the more coarsely crystalline, micaceous variety yields patterns that indicate the presence of the $1M$ polymorph as well. In fact, both varieties appear to be present in variable amounts in most illite-cemented sandstones, not only on the basis of X-ray data, but also from thin section observations.

Illite is the main or only authigenic clay cement in a few sandstones but is associated in most with authigenic chlorite. In this capacity it fills the residual portions of the pores not cemented by chlorite, in combination with authigenic quartz or alone. Illite also partly replaces feldspars in some sandstones, as small scattered patches probably emplaced at the same time as the intergranular variety associated with chlorite. Few of the sandstones cemented by illite contain montmorillonite as well, although X-ray microcamera data show that illite is intergrown or mixed with authigenic chlorite (or possibly kaolinite) in some samples (see discussion under *Montmorillonite*, above). However, authigenic illite normally appears to be free of other clay impurities, exhibiting sharp intrapore boundaries with chlorite cement lining the pore walls.

Chlorite. Authigenic chlorite is abundant in many of the Blairmore sandstones in the Foothills, especially those from the Beaver Mines Formation south of the Clearwater River, or from the Mountain Park facies of that formation in the north-central Foothills. None has been found in correlative sandstones of the Plains, nor in sandstones from the underlying Gladstone Formation of the Foothills.

Authigenic chlorite is found in thin sections as fibrous, vermiform coatings deposited on grain walls, ranging from a few to 30 microns in thickness. Individual crystallites appear to be a micron or less in thickness and can seldom be distinguished. The mineral is green to bluish-green in transmitted light and black under crossed nicols. It appears homogeneous in most sandstones but shows a gradation from green to bluish-green out from the pore walls in a few cases. The color, high refractive indices, and low anisotropism easily distinguish it from other clay mineral cements.

X-ray diffraction powder patterns of bulk clay mounts from various chlorite-cemented samples show a series of strong basal reflections at 14Å, 7Å, 4.7Å, and 3.5Å, typical of most chlorites. The relative intensities of the peaks, supposedly indicative of the Fe/Mg content, appear relatively constant from sample to sample and indicate a magnesium-rich variety, although, as noted by Brindley (1961), the accuracy associated with determinations of chlorite composition from powder diagrams in the presence of other clay constituents is uncertain. This is especially true in the present case, in which authigenic chlorite in bulk clay residues is invariably mixed with detrital chlorite from rock fragments or matrix of variable origin and composition.

Where present, authigenic chlorite shows evidence of having formed during the early stages of cementation before deposition of other silicate or carbonate cements. In a few of the more tightly packed sandstones, the pores are completely cemented by chlorite (Pl. 26), but in most chlorite cement is present as a pore lining, peripheral to other cements later deposited in the central portions of the pores. In some sandstones the chlorite pore linings have been crumpled or folded, probably during the later stages of compaction but before cementation by other authigenic constituents.

Zeolites

Laumontite. Laumontite, a lime-rich zeolite ($[Ca, Na_2] Al_2 Si_4 O_{12} . 4H_2O$) was observed as a cementing agent in a few of the more feldspathic sandstones in the Beaver Mines Formation of the Foothills.

It is present as colorless intergranular crystals or crystal aggregates or as irregular patches replacing feldspars. It is easily identified in thin sections by the low refractive indices, low birefringence (.010), well-developed undirectional cleavage, and peculiar patchy extinction. Crushed fragments from a laumontite-cemented fracture in one of the sandstones exhibit the following properties when mounted in immersion oils:

(1) length slow;

(2) inclined extinction: 35°-40°;

(3) biaxial negative: $2V > 45°$;

(4) refractive indices (cleavage fragments): $n_1 = 1.514$; $n_2 = 1.504\text{-}1.514$.

The extinction angle and 2V differ slightly for grains mounted in Canada balsam owing to partial dehydration upon heating, but generally agree with published data. X-ray diffraction powder data confirm the identification.

The general habit and distribution of laumontite resemble those of authigenic calcite, although the latter mineral is much more common. In some sandstones laumontite is found filling isolated chlorite-lined pores or clusters of pores, whereas adjacent parts of the same sandstone are cemented by chlorite in combination with calcite or illite. In a few sandstones laumontite not only fills most of the residual intergranular space (Pl. 29) but also partly replaces many of the detrital feldspar grains (both potash- and soda-rich varieties) as irregular streaks and veinlets in optical continuity with larger (in some cases poikilitic) patches filling adjacent pores (Pl. 30, Fig. 1). Partial replacement of feldspars by laumontite or a similar mineral also was observed in one or two other sandstones, but in these the main intergranular cement is calcite.

Hydrocarbon Cements

An intragranular substance tentatively identified as a solid hydrocarbon cement is found in portions of the thick, crossbedded sandstones near the base of the Beaver Mines Formation on Ram River (Fig. 9). Megascopically, the hydrocarbon-bearing rocks are medium- to coarse-grained, dark grey, and emit a strongly fetid smell on a fresh surface, in contrast to the pale grey, nonfetid sandstones (cemented by quartz and illite) with which they are interbedded.

The main intergranular constituent of the fetid sandstones is a dark brown, resinous solid, opaque in transmitted light. The substance, although not analyzed chemically or by X-rays, discolors benzene on standing for several days, which effect suggests an organic composition.

In thin sections the substance is found mainly as a pore-filling, although it has also penetrated scattered feldspar grains or rock fragments along cleavage cracks or micropores, in which case it must have been originally in a fluid state. Patches of authigenic illite also are impregnated to varying degrees, and small specks and blebs of the substance have been engulfed by authigenic quartz overgrowths, forming in a few cases a thin, discontinuous coating that serves to distinguish the detrital grain and its overgrowth (Pl. 30, Fig. 2). Thus, the substance was present in the sandstones before or during the early stages of cementation, probably soon after burial.

The writer's interpretation is that the substance consists of solidified hydrocarbons, probably an asphaltite, which collected initially as oil on the crest and flanks of the growing Ram River structure. Later diagenetic or tectonic modification of the rocks, in part marked by cementation by quartz and illite, at the same time led to transformation of the original petroleum content to an asphaltic cement. In this respect these sandstones may represent a stage of diagenesis beyond that attained by correlative sandstones of the Plains, in which the oil content is still mobile.

Miscellaneous Constituents

This group of constituents includes those difficult to identify or to classify under the categories described above. They fall into two classes on the basis of origin: inorganic and organic, of which the former is the more abundant group. They include:

(1) granular or interstitial iron ores, mainly hematite and pyrite;
(2) leucoxene (altered heavy minerals);
(3) carbonized wood or coal;
(4) spores;
(5) bone fragments.

None of these constituents is volumetrically important.

COMPARATIVE PETROLOGY

Introduction

The sandstones of the Blairmore and Mannville Groups show marked variation in composition among and within the formational units involved. These changes, evident in both the transported and authigenic fractions of the rocks, are geographic as well as stratigraphic, reflecting:

(1) variation in the composition of the original detritus, which in turn is a function of the parent rock composition and the topography and climate prevailing in the source area;

(2) modification of the original detritus during transportation—especially in the basin of deposition—by abrasion and sorting, or by early authigenic processes such as glauconitization;

(3) postdepositional (diagenetic) processes: compaction and cementation.

The main compositional differences involved are those between formations and can be attributed largely to major compositional changes in the parent source rocks, subsequently diluted or masked to varying degrees by the effects of sorting and diagenesis.

Detrital Composition

Gladstone Formation

Sandstones of the Gladstone Formation are medium to dark grey, laminated rocks that grade into sandy conglomerate at the base of the formation or into laminated siltstone and silty shale in the middle and upper parts of the formation. They are hard and well cemented, and tend to be non-fissile owing to abundant quartz cement and to the scarcity of micaceous detritus. Crossbedding is evident at all levels of stratification, ranging in amplitude from several feet to a fraction of an inch, and is emphasized by the presence of light and dark grey color banding that reflects intrastratal variation in composition and texture. Small-scale lamination is most noticeable in the finer-grained sandstones and siltstones, many of which are interbedded on a very fine scale with dark shale, making them difficult to classify or describe precisely in the field.

Most of the modally analyzed Gladstone Formation sandstones come from the lower, more arenaceous part of the succession. They are dominantly siliceous rocks composed of quartz, chert, and finely crystalline sedimentary rock fragments, with variable amounts of transported and authigenic carbonates. Quartz (as overgrowths) and kaolinite are the only common authigenic constituents in addition to calcite and dolomite.

Locally, the sandstones show marked variation in composition, with the result that the precision associated with the estimated mean percentages of constituents for each locality (Fig. 30), based on point counts of only four samples per locality, is undoubtedly low. For example, the high dolomite content of the sandstones from Mill Creek is largely attributable to one sample that contains more than 50 per cent carbonates.

Figure 31 shows the relative proportions of the major noncarbonate detrital constituents of the Gladstone Formation sandstones plotted on a triangular diagram. The main feature of the diagram is the relatively large variation in the amounts of chert and quartz (excluding authigenic overgrowths), compared with that of finely crystalline rock fragments, many of which (shale fragments) are locally derived. The other major detrital or transported constituent, dolomite, is even more erratically distributed, but there is no obvious correlation between total dolomite content and the amounts of other constituents, possibly owing to the fact that some dolomite was redistributed prior to and during diagenesis.

Some of the sample variation in quartz (or chert) content can be correlated with stratigraphic position, the coarser sandstones from the basal member containing less quartz and more chert than sandstones from higher levels at four of the five localities sampled. More likely, however, most of the observed variation in sandstone composition can be attributed to local sorting effects (reflected to some extent in sample grain size differences), rather than to changes in the composition of the source rocks. This is not only evidenced by the marked differences in composition between sandstones from the same bed but also by conspicuous variation in the samples themselves, many of which show well-developed sorting (layering) of light- and dark-colored constituents at the finest levels of stratification. Thus, although the modal analyses tabulated in Appendix B give some idea of the average composition of the coarser-grained Gladstone Formation sandstones, the range in sample variation shows that detection of valid compositional differences among localities or stratigraphic levels would require a much larger number of samples.

The salient compositional features of the Gladstone Formation sandstones are:

(1) the high proportion of siliceous detritus;
(2) the abundance of well-rounded quartz and chert;
(3) the local abundance of transported dolomite;
(4) the scarcity or absence of metamorphic and igneous detritus.

Most of the detritus appears to have come from a sedimentary terrain composed of orthoquartzites, carbonates, and siliceous shales containing abundant chert. It shows little sign of predepositional metamorphism; micaceous slate or phyllite fragments are rare (Fig 20), as are typically

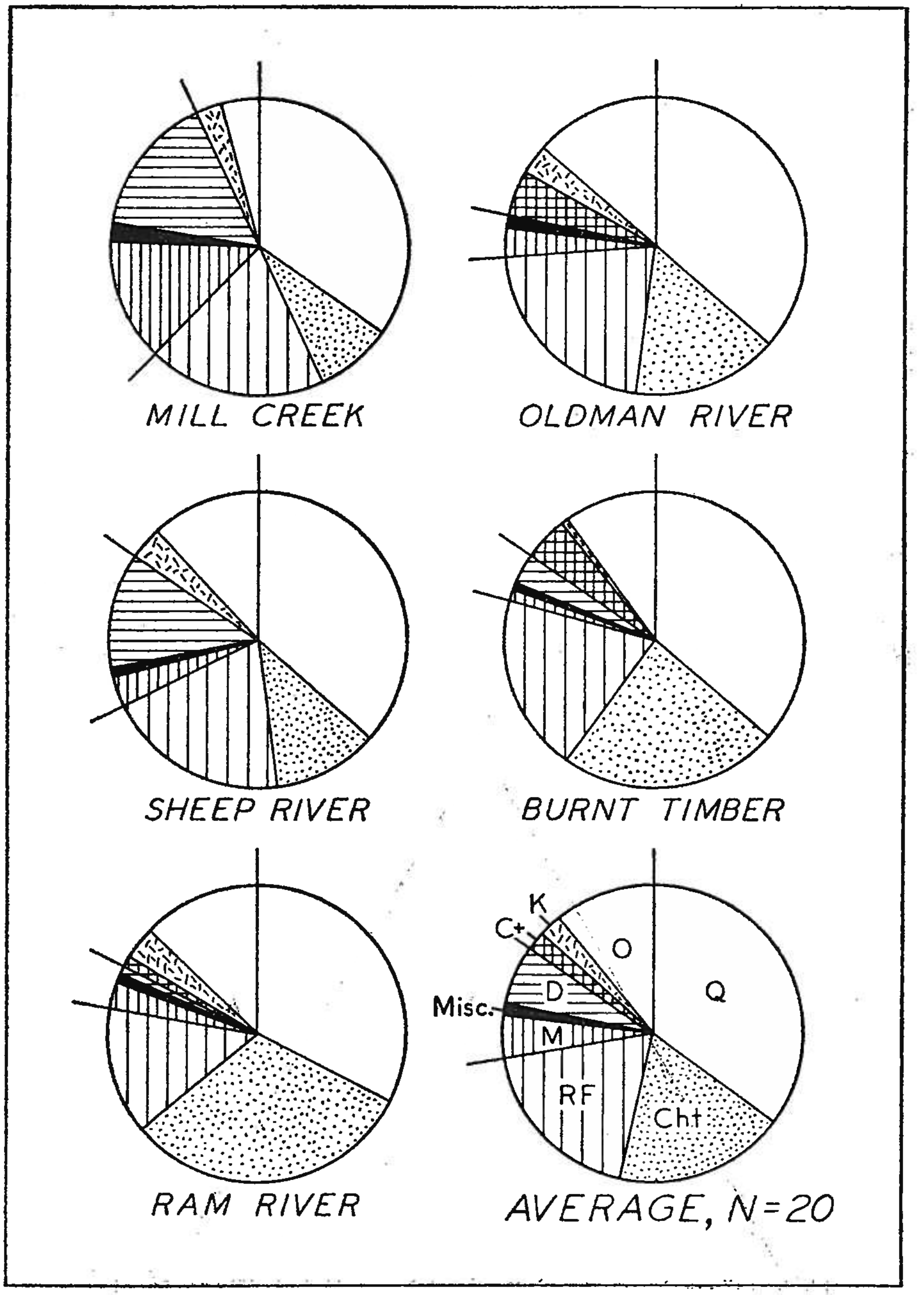

FIGURE 30. *Pie diagrams showing the relative proportions of mineral constituents in modally analysed sandstones from the Gladstone Formation. Key (lower right):* (Q) *detrital quartz,* (Cht) *chert,* (RF) *rock fragments,* (M) *matrix,* (Misc.) *miscellaneous detrital constituents,* (D) *dolomite,* (Ct) *calcite,* (K) *kaolinite,* (O) *authigenic quartz overgrowths.*

metamorphic accessory minerals (micas, garnet, etc.). In this respect the rocks differ basically from Krynine's (1948) "low rank" greywackes (originally "schist arenites" [Krynine, 1940]) of the Appalachian region, which contain abundant micaceous detritus derived from metamorphosed shales and impure quartzites.

Igneous detritus is virtually absent. A few grains of feldspars and accessory minerals (biotite and apatite) of probable pyroclastic origin were observed in two sandstones from Mill Creek, but the total volume is insignificant compared with the amount of volcanic detritus found in the basal sandstone of the overlying Beaver Mines Formation at that locality.

Locally, the Gladstone Formation sandstones resemble the grey, cherty sandstones of the underlying Kootenay Formation, separable from the Gladstone Formation in most of the southern and central Foothills by the presence of the widespread conglomerate bed at the base of the younger formation. However, in detail, the sandstones of the two formations show distinct compositional differences, summarized in figure 32, in which the average composition of four Kootenay Formation sandstones from different parts of the southern Foothills is compared with that of the Gladstone

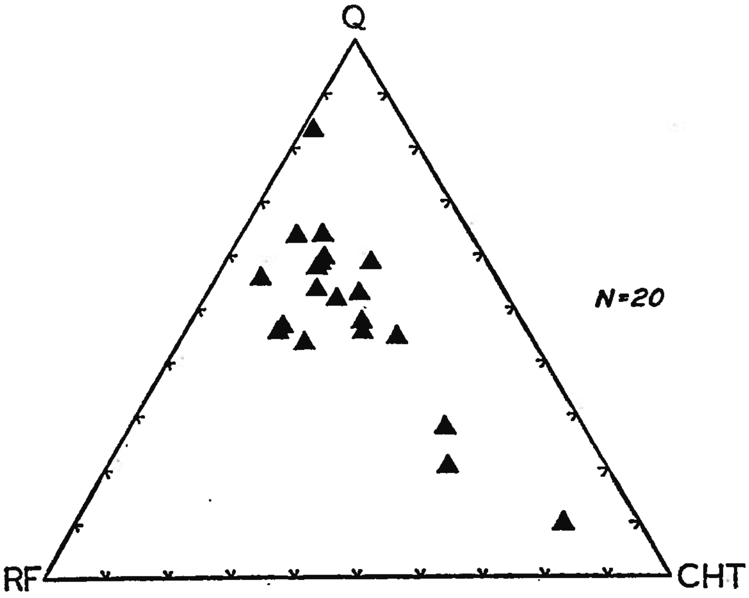

FIGURE 31. Ternary diagram showing the relative proportions of common detrital constituents in modally analysed sandstones from the Gladstone Formation (sampling localities: see figure 30). (Q) quartz, (CHT) chert, (RF) rock fragments.

Formation sandstones described above. The Kootenay Formation sandstones are, like the younger rocks, highly siliceous, consisting mainly of quartz, chert, and finely crystalline sedimentary rock fragments of variable composition and origin (Rapson, 1964). The quartz is well rounded with well-developed overgrowths that have largely obscured the detrital grain boundaries. The rock fragments are largely sedimentary or metasedimentary in origin, consisting of shale, argillite, and slate, siliceous or micaceous in composition (Fig. 20). Trace amounts of plagioclase and volcanic rock fragments are present in two of the sandstones, comprising 1 to 2 per cent of the rocks by volume.

In comparison with the Gladstone Formation rocks, the Kootenay sandstones are distinguished by:

(1) more quartz and less chert (although individual sample percentages are highly variable in both formations);

(2) a higher proportion of finely crystalline micaceous detritus, as rock fragments and derived matrix (Fig. 20);

(3) the absence of dolomite (although carbonates are reported by Newmarch [1953] and Rapson [*op. cit.*] from some of the Kootenay sandstones in the Fernie coal basin of British Columbia);

(4) the presence of trace amounts of volcanic detritus.

However, although the two groups of sandstones can be distinguished on a qualitative basis, particularly with respect to items (2) and (4) above, the reliability of any single compositional criterion is uncertain owing to the wide range in sandstone composition of both formations.

To the east in the Plains, Gladstone strata grade into or interfinger with the quartzose sandstones and siltstones of the McMurray Formation, which, although differing in composition from their Cordilleran counterparts, nevertheless provide a marked contrast to the heterogeneous, feldspathic sandstones of the overlying Fort Augustus Formation. Exactly where and how this lateral change in sandstone composition takes place is uncertain owing to lack of control in the western Plains, but it should provide a basis for future delineation of the areal limits of the two formations.

Described in some detail by Williams (1963, Fig. 9), the McMurray Formation sandstones are friable, porous rocks composed mainly of well-rounded quartz with minor amounts of potash feldspars and rare chert or rock fragments. They grade in the upper part of the unit into matrix-rich, silty sandstones and shales containing trace amounts (in the Fort Augustus No. 1 well) of plagioclase and coarse muscovite, the presence of which heralds the influx of metasedimentary and volcanic detritus in the basal sandstones (Wabiskaw Member) of the overlying Fort Augustus Formation. However, owing to the predominance of shaly beds in the upper part of

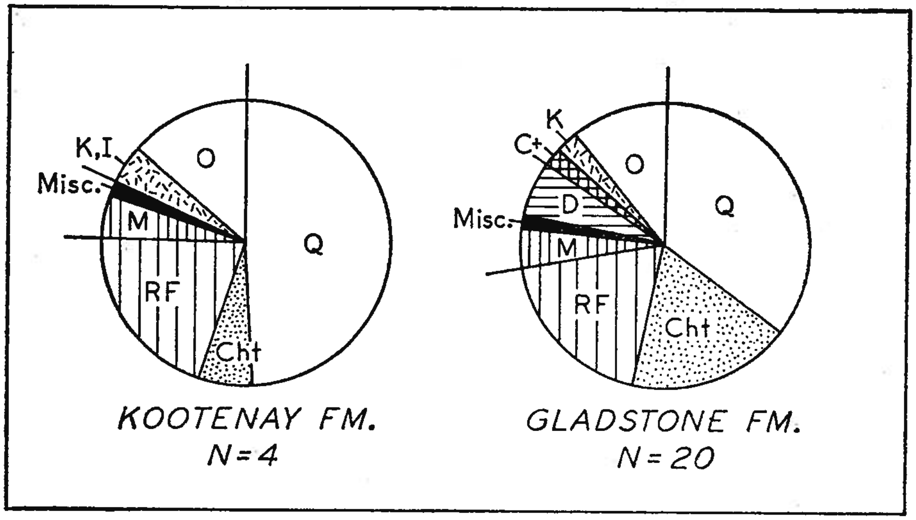

FIGURE 32. *Pie diagrams showing the relative proportions of mineral constituents in modally analysed sandstones from the Gladstone and Kootenay Formations (sampling localities: Gladstone Formation, see figure 30; Kootenay Formation, spot samples from four localities in the southern Foothills).* (Q) *quartz,* (Cht) *chert,* (RF) *rock fragments,* (M) *matrix,* (Misc.) *miscellaneous detrital constituents,* (D) *dolomite,* (Ct) *calcite,* (K) *kaolinite,* (I) *illite,* (O) *authigenic quartz overgrowths.*

the McMurray Formation ("calcareous" member) throughout most of central Alberta, the nature of the petrographic boundary between the two formations—whether sharp or gradational—is uncertain, although the presence of thin quartz sand laminae in the upper part of the McMurray Formation in several wells indicates a relatively abrupt break in sandstone composition at the base of the overlying Wabiskaw Member, similar to that observed in the outcrop region of northeastern Alberta (Carrigy, 1963).

Beaver Mines Formation

Sandstones of the Beaver Mines Formation are largely green or greenish-grey, fine- to medium-grained, well sorted rocks, locally conglomeratic and interbedded with dark green or grey, laminated siltstone and blocky, varicolored shale. Hard and well cemented, many of the sandstones, especially the finer-grained ones, tend to be fissile owing to the concentration of abundant dark brown biotite and carbonized plant debris along certain bedding planes. Although large-scale crossbedding is common in the thicker sandstones, decreasing in amplitude and scale in the more thinly bedded, finer-grained units, the Beaver Mines Formation sandstones on the whole appear to be texturally more homogeneous than those of the underlying Gladstone or Kootenay Formations.

The Beaver Mines Formation sandstones are especially heterogeneous in composition, in gross aspect consisting of angular quartz, feldspars (largely plagioclase), and finely crystalline metasedimentary and volcanic rock fragments, with minor amounts of chert and accessory "heavy" minerals, mainly epidote, biotite, and apatite. In addition, the Luscar-type sandstones, which are present in the lower part of the formation in the central Foothills, contain variable amounts of transported dolomite and minor siderite. The sandstones are cemented by a wide variety of authigenic constituents, including quartz, calcite, clay minerals, and laumontite.

Compared with other sandstones of the Blairmore Group—those of the Gladstone and Mill Creek Formations—the Beaver Mines Formation sandstones show less variation in the distribution of detrital constituents at both the sample and locality levels. Figure 33 shows the relative proportions of noncarbonate detrital constituents for each of three completely sampled sections, based on point counts of 20 sandstones each. The Sheep River sandstones appear to contain slightly more volcanic detritus (feldspars and rock fragments) than the Mill Creek and Ram River sandstones, but this difference may be due to the faulting out of the upper part of the formation on Sheep River (Fig. 6, Sec. 1), which on Mill Creek contains finer-grained, less feldspathic sandstones than the lower and middle parts of the formation. Perhaps the most noteworthy locality difference in detrital composition is the abundance of detrital epidote in sandstones from the two southern localities compared with the absence of this mineral from sandstones north of the Bow River.

The relative amounts of quartz, nonvolcanic rock fragments (including chert), and volcanic detritus (feldspars plus rock fragments) in 60 modally analysed Beaver Mines Formation sandstones have been plotted on a triangular diagram in figure 34. Most of the variation is in the amounts of volcanic detritus and nonvolcanic rock fragments. Quartz, of mixed volcanic and sedimentary origin, is comparatively uniform in distribution, and the amount of chert involved is relatively small. The bulk of the sandstones are clustered in the portion of the diagram rich in volcanic detritus: two thirds of them contain between 50 and 90 per cent volcanic material, whereas only two (basal sandstones on Mill Creek and Ram River) contain less than 20 per cent. Considerable overlap exists between the Mountain Park-type and Luscar-type[1] sandstones, although the latter contain on the average less volcanic detritus and more chert.

Undoubtedly, some of the variation in sandstone composition can be attributed to local compositional variation in the source area, the basal sandstones at each locality tending to contain less volcanic detritus and

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[1] Thirteen grey, kaolinitic sandstones from the lower part of the formation on Ram River.

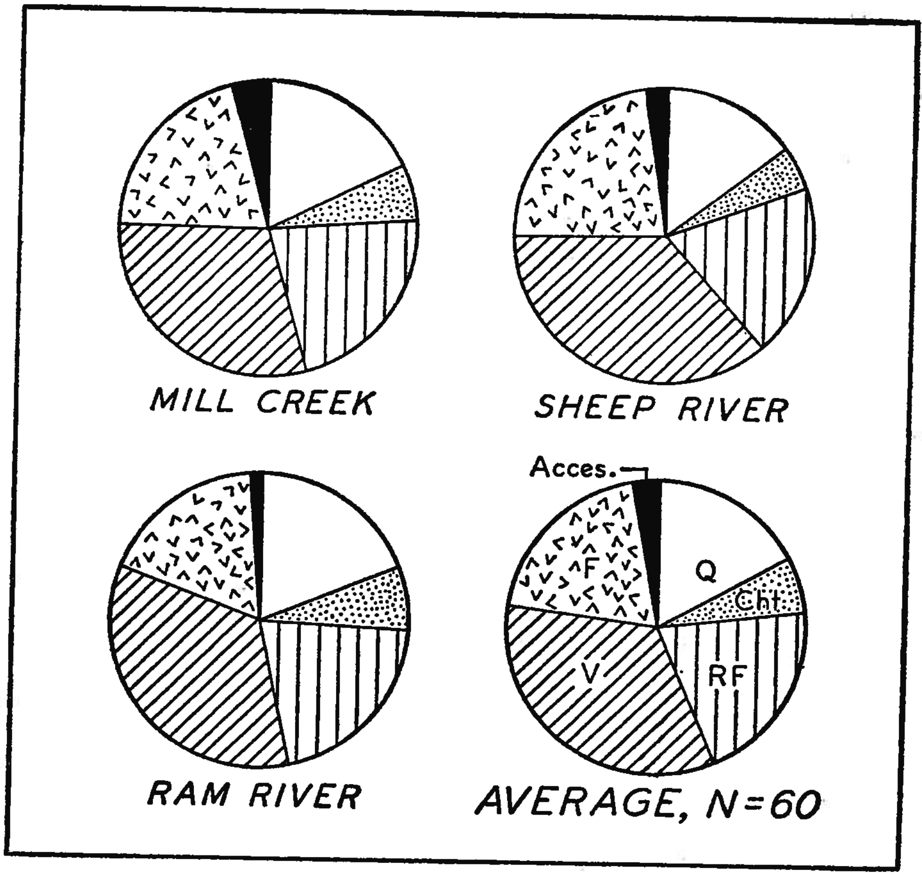

FIGURE 33. Pie diagrams showing the relative proportions of detrital mineral constituents in modally analysed sandstones from the Beaver Mines Formation. Key (lower right): (Q) quartz, (Cht) chert, (RF) nonvolcanic rock fragments, (V) volcanic rock fragments, (F) feldspars, (Acces.) accessory "heavy" minerals.

more chert than the overlying sandstones. Dilution by erratically distributed, locally derived clastic detritus (shale fragments and associated "matrix") also has contributed to sample variation, although to what extent is uncertain, for most of this material has been included with other fine-grained nonvolcanic detritus. However, a general impression is that locally derived detritus is more common in the finer-grained sandstones in the upper part of the formation, at least in the two southern Foothills sections.

Probably more important than either of these factors is the effect of sorting, measured in terms of relationships between composition and grain size. Two such relationships are shown in figure 35, in which feldspar and quartz percentages (calculated as percentages of total sample constituents) for 60 Beaver Mines sandstones are plotted against quartz phi grain size. The correlation is most pronounced for feldspars (significant at the 1 per cent level), the amounts of which increase with grain size. On the other hand, no significant correlation exists between quartz content and grain size; the amount of quartz remains relatively constant within the size range involved, even although feldspars tend to be concentrated in the coarser-grained sandstones.

The reason for the difference in the behaviour of the two constituents is uncertain; possibly the multiple origin—and hence the inherently wider range in grain size—of quartz has some bearing on the problem. On the other hand, most of the feldspars are derived from the phenocryst fraction of volcanic rocks and tend through initial similarity in size and through lack of abrasion to be concentrated in a certain size-fraction of the derived detritus, in this case the medium- to coarse-grained sand-size phases of the formation. However, the roles of the two minerals are reversed in the correlative Mannville sandstones of the Plains. In these, feldspar content bears no relationship to quartz grain size, whereas quartz content

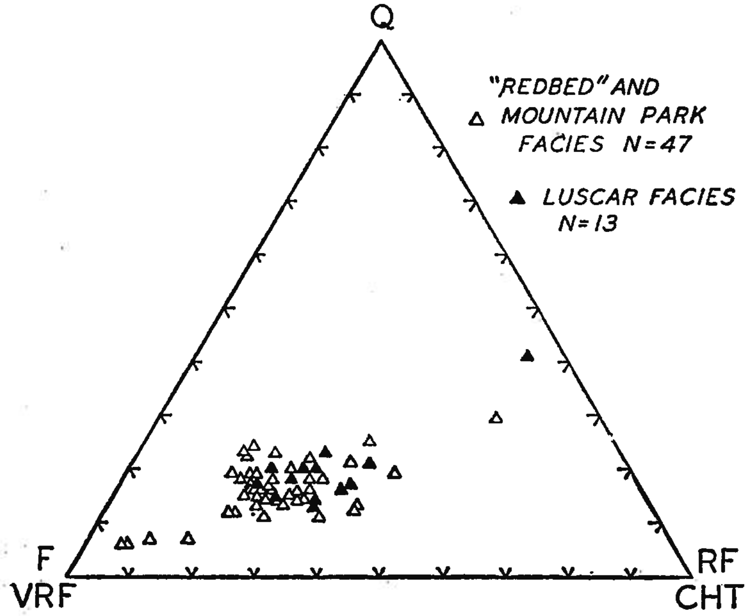

FIGURE 34. Ternary diagram showing the relative proportions of common detrital constituents in modally analysed sandstones from the Beaver Mines Formation (sampling localities: Mill Creek, Sheep River, Ram River). (Q) quartz, (RF) nonvolcanic rock fragments, (CHT) chert, (F) feldspars, (VRF) volcanic rock fragments.

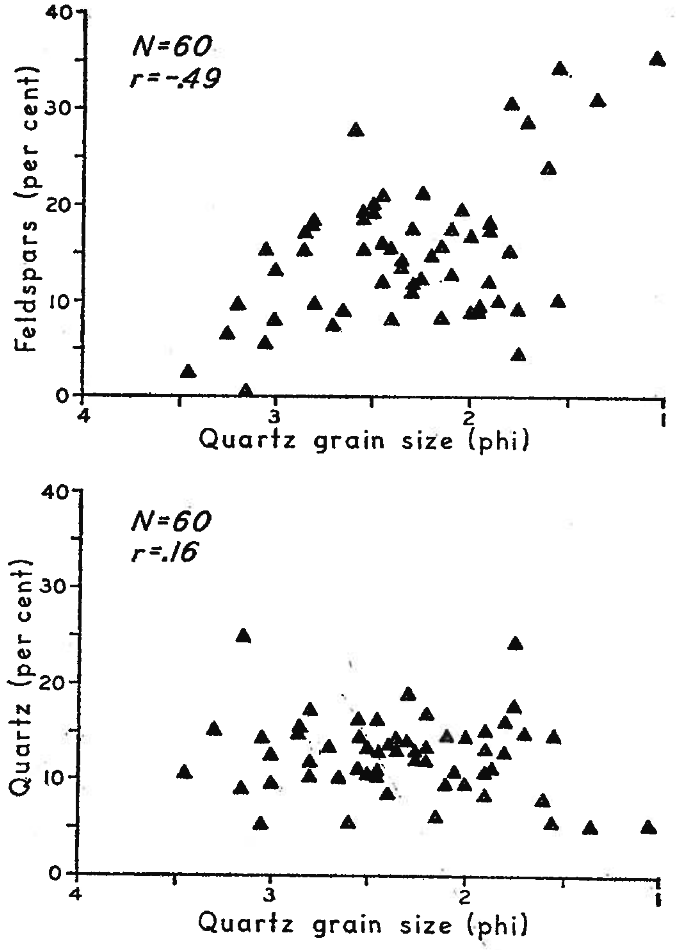

FIGURE 35. Scatter diagrams showing the relationships between feldspar content and quartz grain size and quartz content and quartz grain size in modally analysed sandstones from the Beaver Mines Formation (sampling localities; Mill Creek, Sheep River, Ram River).

decreases noticeably with increasing grain size (Fig. 36). In this instance, the finer-grained sandstones tend to be associated with the shoreline or marine phases of the Fort Augustus Formation, exhibiting more evidence of abrasion and sorting than their nonmarine Plains or Foothills counterparts.

The distinguishing compositional features of the Beaver Mines Formation sandstones are:

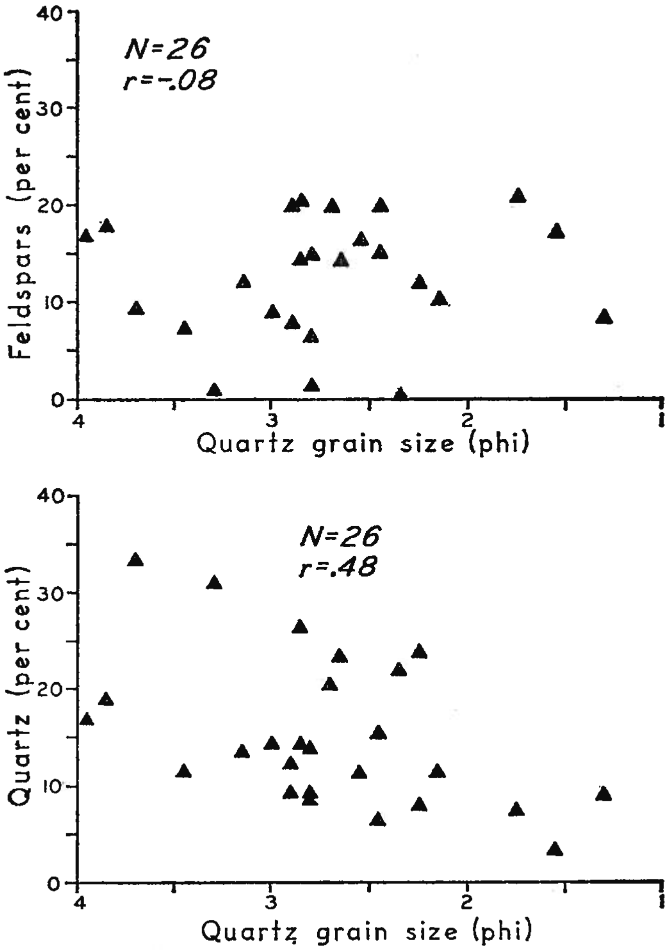

FIGURE 36. Scatter diagrams showing the relationships between feldspar content and quartz grain size and quartz content and quartz grain size in modally analysed sandstones from the Fort Augustus Formation (sampling localities: seven wells listed in table 2).

(1) the high proportion of volcanic detritus—feldspars and rock fragments;

(2) the abundance of plagioclase and chlorite and the scarcity of potash feldspars;

(3) the preponderance of epidote and biotite in the "heavy" mineral fraction, and the absence of pyroxenes and hornblende;

(4) the wide variety of authigenic cements.

The detrital fraction is derived mainly from finely crystalline, porphyritic volcanic rocks interbedded with or extruded among fine-grained, quartzose and argillaceous, low-grade metasedimentary rocks. Of the total amount of transported material (excluding dolomite) in the Beaver Mines Formation sandstones, the proportion of volcanic, including minor intrusive, detritus ranges between 54 and 62 per cent for the three main sampled sections (Fig. 33). These estimates include feldspars, identifiable volcanic rock fragments, and most of the accessory minerals, but exclude an unknown amount of volcanic quartz as well as rock fragments of uncertain origin. If the last two categories are taken into account, then the total amount of volcanic or igneous detritus probably averages between 65 and 75 per cent.

The nonvolcanic portion of the detrital fraction shows a rather marked change from that observed in the underlying Gladstone Formation sandstones. Although essentially unmetamorphosed orthoquartzite pebbles and fragments are present in the conglomeratic or sandy phases of the formation, the associated finely crystalline nonvolcanic fraction shows a much higher proportion of micaceous or chloritic, low-grade metasedimentary detritus in the form of slate or phyllite fragments (Fig. 20).

In the central Foothills north of the Clearwater River, the greenish sandstones in the lower part of the Beaver Mines Formation are replaced by pale grey or greenish-grey, buff-speckled sandstones interbedded with dark grey siltstone and shale containing coal beds of mineable thicknesses. These sandstones have been mapped as part of the Luscar Formation by some investigators, to contrast them with the overlying greenish sandstones of the non-coal-bearing Mountain Park Formation, which forms the upper part of the Blairmore succession at this latitude. The major megascopic distinction between the two types of sandstones, other than color, is the presence of scattered reddish-brown weathering siderite pellets in the grey Luscar-type sandstones, which also tend to be more carbonaceous and friable than the overlying Mountain Park-type sandstones.

In detail, the Luscar-type sandstones contain, in addition to a high proportion of volcanic material in the detrital fraction (Fig. 34), locally abundant amounts of transported dolomite, not present in the green Mountain Park-type sandstones of the southern or central Foothills. The influx of dolomite is accompanied by a slight increase in chert content, as well as by the appearance of siderite pellets noted above (Fig. 37, in pocket). Associated with these regional changes in the transported constituents of the Beaver Mines Formation sandstones are changes in authigenic cements, notably the replacement of chlorite in the sandstones of the southern Foothills by kaolinite or illite in the Luscar-type sandstones.

The appearance of dolomite together with the increase in chert content in the Luscar-type sandstones of the central Foothills apparently heralds the gradual replacement of volcanic detritus in the Beaver Mines

Formation sandstones of the southern Foothills by sedimentary or metasedimentary detritus in a northerly direction. This observation is reflected in the fact that north of Cadomin few attempts have been made to distinguish between the Luscar and Mountain Park "formations" in mapping the Blairmore-equivalent strata of the Alberta Foothills, the term "Luscar Formation" being used for the entire succession. Thus, although no petrographic data are available for the rocks in this region, the failure of field geologists to distinguish between the major stratigraphic units indicates that major compositional differences between Luscar-type and Mountain Park-type sandstones have largely disappeared at this latitude.

More concrete evidence for the northward dilution and ultimate disappearance of volcanic detritus comes from the lower Cretaceous section on Belcourt Ridge, in the Foothills of northeastern British Columbia, a few miles west of the interprovincial boundary, where Blairmore-equivalent beds can be divided into two major units (Mellon *et al.*, 1963): a lower Gething Formation and an upper Commotion Formation with a marine shale member (Moosebar Tongue) at the base (Fig. 15). Cursory examination of conglomerates and sandstones from both formations indicates that they are composed entirely of sedimentary detritus: mainly quartz, chert, clastic carbonates (calcite and dolomite), and siliceous rock fragments (shale, argillite). The petrographic break at the base of the Beaver Mines Formation in the southern and central Alberta Foothills is absent at this latitude, both Gething and Commotion sandstones closely resembling in composition and texture those of the Gladstone Formation to the south.

Fort Augustus Formation

Sandstones from the upper part of the Mannville Group (Fort Augustus Formation) in the central Alberta Plains are similar in appearance to the Luscar-type sandstones of the central Foothills, except that they tend to be more friable and finer-grained on the average than the Foothills rocks (Fig. 17). Typically, they are pale grey, very fine to medium-grained, well-sorted, "salt-and-pepper"-type sandstones, grading into dark greenish-grey, glauconitic sandstones near the base of the formation (Wabiskaw Member). Some are pale to dark brown due to oil staining, and many are buff-speckled owing to concentrations of reddish-brown siderite pellets parallel to the bedding. Most are relatively soft and friable, except those cemented by calcite, tending to split along bedding planes rich in biotite or carbonaceous matter. Small-scale crossbedding is common in the finer-grained sandstones, which tend to be interbedded on a very fine scale with dark grey, carbonaceous siltstone and silty shale, especially in the marine portions of the formation. However, in many of the silty intervals, the bedding has been disturbed or destroyed by burrowing organisms, the primary lamination of the rocks having been replaced by "blebby" or slumped structures.

The Fort Augustus Formation sandstones are similar in composition to the Luscar-type sandstones of the Foothills. Described as "greywackes" or "winnowed greywackes" by Badgley (1952), they are in fact relatively well-sorted sandstones composed of locally derived sedimentary, metasedimentary, and volcanic detritus: mainly quartz, plagioclase and potash feldspars, finely crystalline rock fragments and derived matrix, dolomite, siderite, and accessory detrital minerals (largely biotite, apatite, and zircon). Calcite and kaolinite are the main cementing agents. Montmorillonite is common but difficult to detect in thin sections, and authigenic quartz is relatively scarce.

As a group the Fort Augustus Formation sandstones show more variation in composition than their Foothills counterparts, both at the sample and locality levels. Figure 38 shows the relative amounts of noncarbonate detrital constituents in sandstones from each of the seven wells examined, based on modal analyses of three or four samples per well taken at widely separated stratigraphic intervals (Fig. 39, in pocket). The major compositional difference brought out by the diagrams is in the distribution of volcanic detritus (feldspars plus volcanic rock fragments), most abundant in the two southern wells, Stanmore No. 1 and West Viking No. 1. The amount decreases in the three centrally located wells—Wabamun No. 1, Fort Augustus No. 1, and Elk Point No. 1—which together with the Lyle Lake No. 1 well contain similar amounts of volcanic detritus, ranging between 40 and 50 per cent of the total detrital fraction. The most northerly well, West Wabiskaw No. 1, contains the least amount of volcanic detritus, as well as a noticeably higher proportion of quartz and chert; this is the most marine of the seven subsurface sections sampled, closely resembling the type Clearwater-Grand Rapids succession exposed to the east on the Athabasca River. Other apparent differences in locality composition are less meaningful owing to the small number of samples involved.

Figure 40 shows the relative amounts of quartz, nonvolcanic rock fragments including chert, and volcanic detritus in the 26 modally analysed sandstones, plotted on a triangular diagram. The shaded areas indicate the portions of the same diagram occupied by the bulk of the Beaver Mines Formation sandstones in figure 34 (two aberrant sandstones from the base of the formation on Mill Creek and Ram River are omitted). Although the majority of the Fort Augustus Formation sandstones fall within or close to the area of the diagram occupied by the bulk of the Foothills sandstones, they are on the whole much more variable in composition, especially in the content of quartz and volcanic detritus.

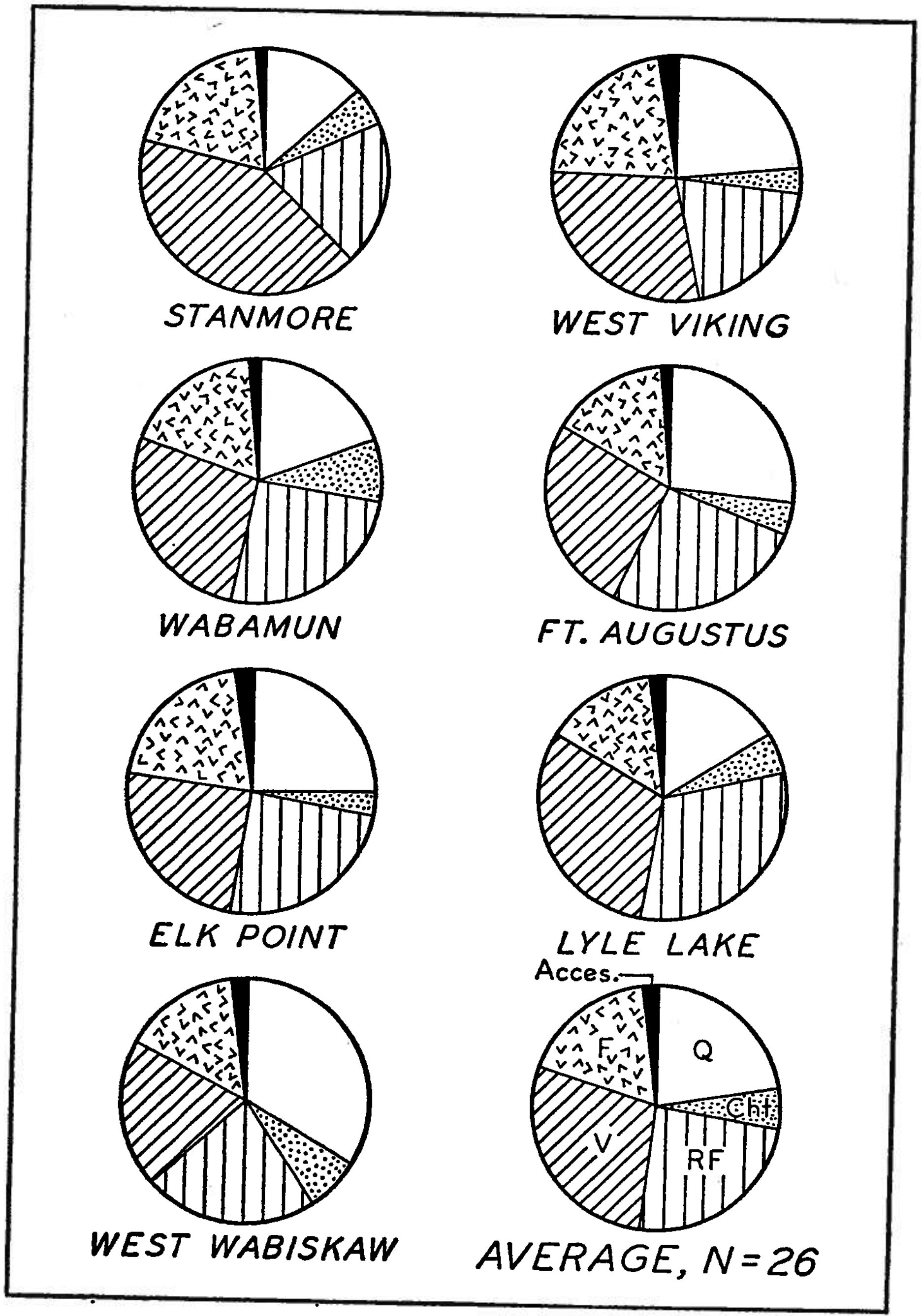

FIGURE 38. *Pie diagrams showing the relative proportions of common detrital constituents in modally analysed sandstones from the Fort Augustus Formation (sampling localities: seven wells listed in table 2). Key (lower right): (Q) quartz, (Cht) chert, (RF) nonvolcanic rock fragments, (V) volcanic rock fragments, (F) feldspars, (Acces.) accessory "heavy" minerals.*

Much of this additional variation in the Plains sandstones is geographic rather than stratigraphic in origin as implied by Williams (1963). This is demonstrated in part in figure 40 by classifyng the sandstones on lithologic and faunal criteria as marine or nonmarine, the first-named category including sandstones from that portion of the formation exhibiting Clearwater or Grand Rapids characteristics, and the second category those sandstones from coal-bearing Luscar-type beds (Figs. 11, 12). These units constitute the three laterally interfingering facies of the Fort Augustus Formation in central and northeastern Alberta, the marine beds gradually displacing the overlying nonmarine Luscar-type beds in a northerly direction. Thus, the ten sandstones classed as Luscar from the five southern wells exhibit a noticeably higher proportion of volcanic detritus than the marine Clearwater or Grand Rapids sandstones, although some overlap exists, in part possibly due to misclassification of samples.

The marine sandstones are more variable in composition than the nonmarine sandstones. This can be partly attributed to the more rigorous

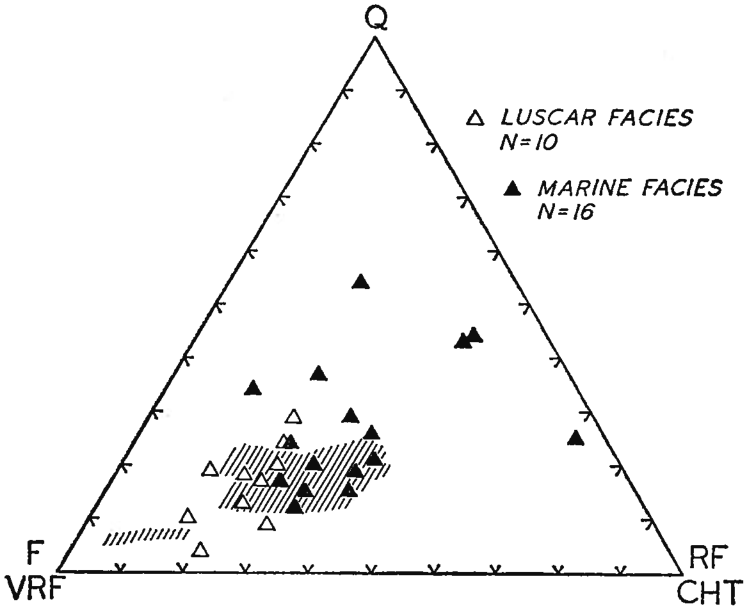

FIGURE 40. Ternary diagram showing the relative proportions of common detrital constituents in modally analysed sandstones from the Fort Augustus Formation (sampling localities: seven wells listed in table 2). Shaded area denotes that portion of the same diagram occupied by correlative Blairmore Group sandstones shown in figure 34. (Q) *quartz,* (RF) *nonvolcanic rock fragments,* (CHT) *chert,* (F) *feldspars,* (VRF) *volcanic rock fragments.*

depositional processes to which some of these sands (largely littoral or bar deposits) were exposed, the result being the breakup of mechanically unstable constituents and the concentration of quartz. Certainly these sandstones show more evidence of grain rounding than the Luscar-type sandstones, many of which contain an abundance of soft, plastic, volcanic rock fragments that would undoubtedly break up if subjected to prolonged reworking along a shoreline. The marine sandstones are also finer-grained than their nonmarine counterparts, the quartz content increasing with decreasing grain size (Fig. 36). This relationship is not unreasonable if both finer grain size and mechanical stability are associated with shoreline or marine conditions of deposition. Feldspar content, on the other hand, shows no obvious relationship to grain size, unlike the relationship observed in the nonmarine sandstones of the Foothills (Fig. 35).

Change in the detrital composition of the Fort Augustus Formation sandstones with time is more difficult to demonstrate than geographic variation, mainly because the boundaries of the facies involved cut across inferred time-datum planes. However, there is some evidence that, at least locally (Wabamun and Ft. Augustus wells), sandstones of the Wabiskaw Member near the base of the formation contain less volcanic and more metasedimentary material than overlying sandstones, as noted by Williams (*op. cit.*). Calculation of the average detrital composition for sandstones grouped according to stratigraphic level (Fig. 41)[1] also suggests an increase in volcanic detritus towards the top of the formation, although there is more overlap in composition among sandstones grouped by stratigraphic level than by facies when individual samples are plotted on a triangular diagram like that in figure 40. Moreover, the grouping in figure 41 is still partly by facies: the lower sandstones are largely marine, the two central groups a mixture of marine and nonmarine, and the upper sandstones mainly nonmarine. In all, the most satisfactory grouping of both the Beaver Mines and Fort Augustus Formations sandstones for comparative purposes is by facies[2], as shown in figure 42, rather than by stratigraphic level.

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[1] Data averaged for the uppermost samples from each of the wells, the next highest, etc. The average sandstone composition of the upper level is based on only five samples owing to the absence of core in the upper part of the formation in the Stanmore No. 1 and Lyle Lake No. 1 wells.

[2] "Redbed" facies includes sandstones from the upper, more shaly part of the Beaver Mines Formation on Mill Creek and Sheep River; Mountain Park facies includes sandstones from the lower part of the formation on Mill Creek and Sheep River, and the upper non-coal-bearing part of the formation on Ram River; Luscar facies (Foothills) includes sandstones from the lower coal-bearing part of the formation on Ram River; Luscar facies (Plains) includes sandstones from the nonmarine portion of the Fort Augustus Formation; marine facies includes sandstones from the Grand Rapids- and Clearwater-type beds of the Fort Augustus Formation.

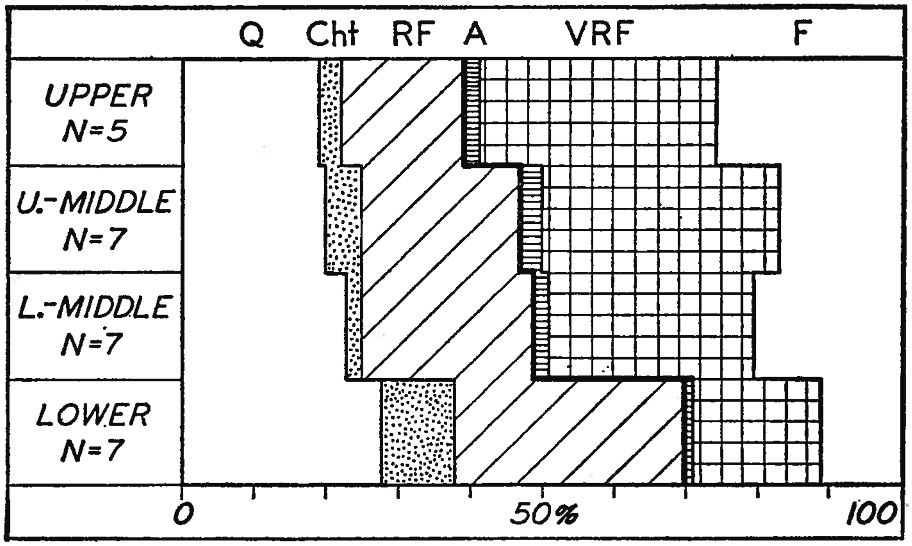

FIGURE 41. Bar diagram showing the relative proportions of detrital constituents in modally analysed sandstones from the Fort Augustus Formation grouped according to stratigraphic level. (Q) *quartz,* (Cht) *chert,* (RF) *nonvolcanic rock fragments,* (A) *accessory "heavy" minerals,* (VRF) *volcanic rock fragments,* (F) *feldspars.*

In summary, the Fort Augustus Formation sandstones, although more variable in composition than the Beaver Mines Formation sandstones, are comparable with the Foothills rocks in:

(1) the high proportion of volcanic detritus—feldspars and rock fragments—especially in the nonmarine Luscar-type sandstones;

(2) the abundance of metasedimentary detritus in the nonvolcanic detrital fraction;

(3) the abundance of biotite and the absence of hornblende and pyroxenes.

The bulk of the noncarbonate detritus in the Fort Augustus Formation appears to have come from the same Cordilleran source as the Foothills sandstones, except possibly for minor dilution by Shield-derived quartzose detritus in the eastern part of the Plains, indicated by the presence of minor metamorphic minerals in "heavy" mineral residues from a few sandtones.[1] However, the Fort Augustus Formation sandstones differ from the bulk of the Foothills sandstones in:

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[1] Cameron (1965) has noted a more striking change in the soda content of the upper Mannville rocks in east-central Alberta near the Saskatchewan border, possibly indicative of a basic change in the source of detritus in that area. He also shows that the potash content of the sandstones, although relatively uniform in the central Alberta Plains, appears to be significantly lower in two Foothills sections, on Mill Creek and Sheep River. This trend accords with the apparent scarcity of potash feldspars in the Foothills sandstones observed in the course of the present study.

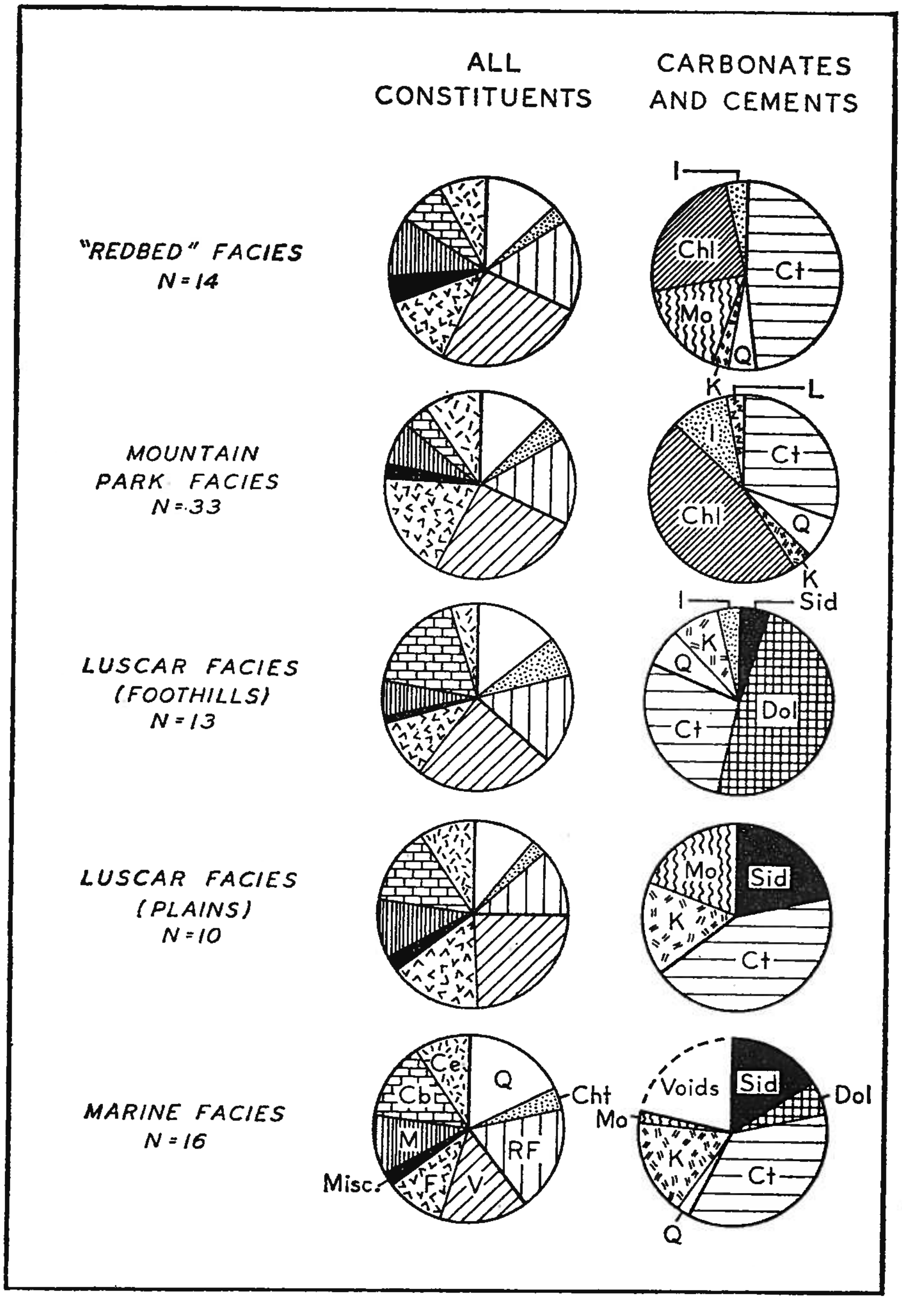

FIGURE 42. Pie diagrams showing the relative proportions of detrital constituents, carbonates, and cements in modally analysed sandstones from the Beaver Mines and Fort Augustus Formations grouped according to facies. (Q) *quartz,* (Cht) *chert,* (RF) *nonvolcanic rock fragments,* (V) *volcanic rock fragments,* (F) *feldspars,* (Misc.) *miscellaneous detrital constituents,* (Cb) *carbonates,* (Ce) *cements,* (Sid) *siderite,* (Dol) *dolomite,* (Ct) *calcite,* (K) *kaolinite,* (Mo) *montmorillonite,* (I) *illite,* (Chl) *chlorite,* (L) *laumontite.*

(1) the much higher potash feldspar content;

(2) the scarcity or absence of detrital and authigenic chlorite;

(3) the widespread distribution of siderite pellets;

(4) the composition and distribution of authigenic cements.

The difference in the composition of the feldspars and volcanic detritus (Fig. 21), abundant in both sets of rocks, can be explained on two grounds, if it is assumed that these constituents come from the same general source. Firstly, the lack of abundant chloritic volcanic fragments in some of the nonmarine Plains sandstones appears to be due to postdepositional alteration of the chloritic groundmass to a mixture of iron oxides and possibly kaolinite or montmorillonite (Pl. 8, Fig. 2), or both. Significantly, the main cementing agent in these sandstones is kaolinite, rather than chlorite, with variable amounts of montmorillonite.

Secondly, the wide discrepancy in the distribution of potash feldspars, both as single grains and as volcanic rock fragments, between the Foothills and Plains sandstones can be attributed to the uneven distribution of "reworked" and pyroclastic volcanic detritus in the basin of deposition during middle Blairmore time. In this light most of the Foothills volcanic detritus, rich in chlorite and albite, is interpreted as having been derived from the erosion of basic to intermediate extrusive rocks in the source area itself, with only minor dilution by erratically distributed pyroclastic detritus of acidic composition: quartz, biotite, and potash feldspars. On the other hand, the Plains rocks, while receiving the same amount of potash-rich pyroclastic detritus, were subjected to a much smaller influx of reworked Cordilleran detritus than their Foothills counterparts, in part owing to the increased distance from the source but, more important, to a much slower rate of deposition in the Plains as evidenced by the marked eastward thinning of the Blairmore-Mannville sediments away from the edge of the outcrop region in the Foothills. The net result is that, although the Beaver Mines and Fort Augustus Formations sandstones both contain a relatively high amount of volcanic detritus, the ratio of "reworked" to pyroclastic material—relatively constant in the Foothills—shows a marked decrease in the Plains.

In carbonate content and in the composition of authigenic cements the Fort Augustus Formation sandstones closely resemble the kaolinitic Luscar-type sandstones of the central Foothills. Reddish-brown siderite pellets are characteristic of both groups of rocks, including both the marine and nonmarine Plains sandstones, although their sample distribution is erratic (Fig. 39). Dolomite is also common in the Luscar-type sandstones of the Foothills, in which it is interpreted as being mainly of detrital origin, although apparently recrystallized in a few sandstones. However, dolomite is present only in minor amounts in the shoreline or marine phases of the correlative Plains sandstones, mainly as abraded or idiomorphic rhombic crystals of local clastic or authigenic origin. The mineral was either not deposited in the Luscar-type sandstones of the Plains, owing to the distance from a potential source area, or, if present initially as transported grains, has been removed subsequently by diagenetic processes. Thus, in most respects, the distribution and texture of dolomite in the Fort Augustus Formation sandstones of the Plains and correlative rocks of the central Foothills follows the scheme described by Sabins (1962).

Mill Creek Formation

Sandstones of the Mill Creek Formation, which comprises the upper part of the Blairmore succession in the southern Foothills, are more variable in megascopic appearance than those from the lower and middle parts of the group. In general, the coarser-grained, thicker-bedded sandstones are hard, pale to dark grey, banded or laminated, well-sorted rocks, invariably crossbedded with locally developed lenses of chert-pebble conglomerate. Superficially, they resemble the hard, siliceous sandstones of the older Gladstone Formation, the sandstones of the two units presenting a marked contrast to the intervening green, biotite-rich sandstones of the Beaver Mines Formation. However, in the southernmost part of the Foothills (Mill Creek, Ma Butte), where the sedimentary rocks that form the lower part of the formation there grade up into or interfinger with the pyroclastic detritus of the Crowsnest Member, the Mill Creek Formation sandstones grade into pale green or bluish-green, biotite-bearing rocks generally similar in appearance to sandstones of the underlying Beaver Mines Formation. North of the Oldman River, about where the volcanic Crowsnest Member disappears as a mappable unit, some of the finer-grained sandstones in the upper part of the formation still retain their greenish cast, although they do not otherwise have a tuffaceous aspect.

The modally analysed sandstones come from four outcrop localities in the southern Foothills and from three subsurface sections near the western margin of the Plains, between Turner Valley and Okotoks. They are mainly fine- to medium-grained, siliceous rocks composed largely of quartz, chert, and finely crystalline sedimentary and metasedimentary rock fragments, with minor amounts of feldspars, volcanic rock fragments, dolomite, and biotite. Quartz and calcite are the most common authigenic constituents, with lesser amounts of kaolinite and chlorite.

The Mill Creek Formation sandstones show wide variation in composition among sampled localities (Fig. 43), partly attributable to compositional differences in stratigraphic level as well. The sandstones from the type section on Mill Creek and from Ma Butte, similar in average composition except for carbonate and matrix content, come from the lower part of the formation, beneath the Crowsnest Member, and are comparable

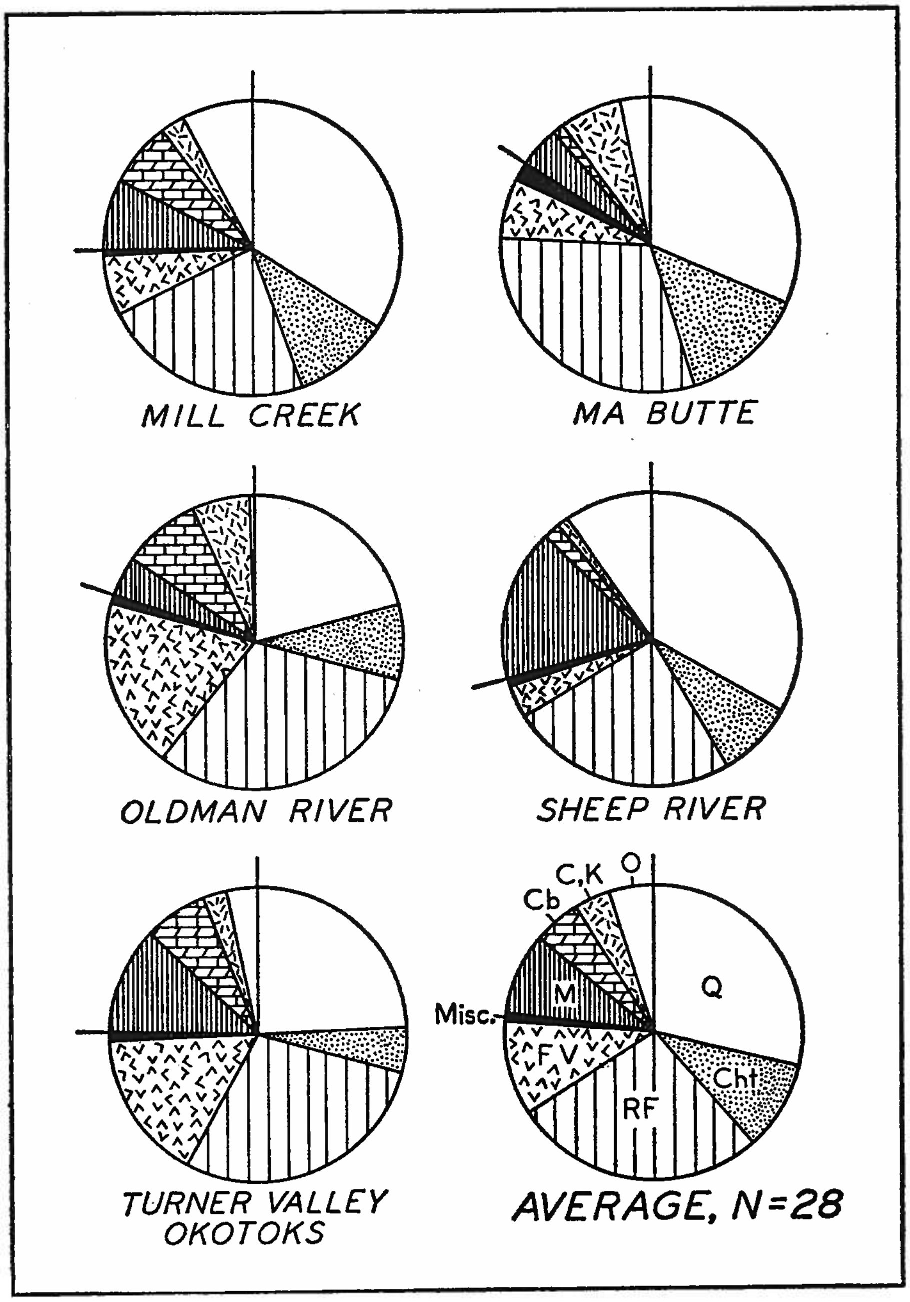

FIGURE 43. *Pie diagrams showing the relative proportions of mineral constituents in modally analysed sandstones from the Mill Creek Formation. Key (lower right):* (Q) *quartz,* (Cht) *chert,* (RF) *nonvolcanic rock fragments,* (FV) *feldspars and volcanic rock fragments,* (Misc.) *miscellaneous detrital constituents,* (M) *matrix,* (Cb) *carbonates,* (C) *chlorite,* (K) *kaolinite,* (O) *quartz overgrowths.*

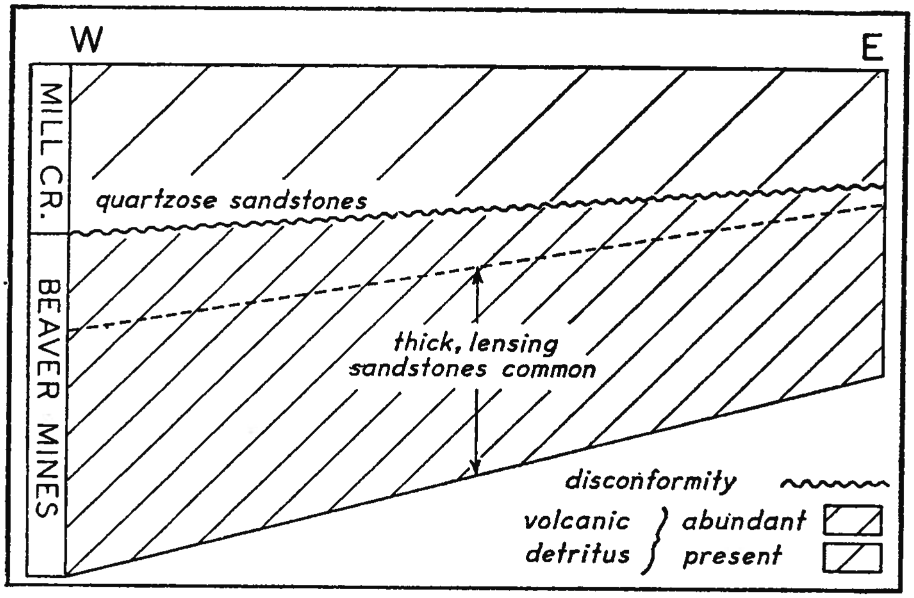

FIGURE 44. Schematic diagram showing the stratigraphic relationship of the basal quartzose sandstones of the Mill Creek Formation on Sheep River to the disconformable lower boundary of the formation. The interpretation is that, following the break in deposition at the end of middle Blairmore (Beaver Mines) time, sedimentation recommenced in the western part of the basin with the deposition of quartzose detritus low in volcanic material, gradually spreading eastward into the Turner Valley-Okotoks region as volcanic detritus became more abundant.

in stratigraphic position (Fig. 37). However, the four samples from Oldman River are from beds a short distance above and below a thin tongue of pyroclastic detritus near the top of the formation and contain relatively abundant amounts of feldspars and volcanic rock fragments. Conversely, four of the six sandstones from the main section on Sheep River are from the basal beds of the formation and contain no identifiable volcanic material, in contrast to the two sandstones from the middle and upper parts of the section at that locality (Fig. 37).

The sandstones from the three wells in the Turner Valley-Okotoks region closely resemble those from Oldman River in average composition, although the subsurface sandstones come from both the lower and upper parts of the Mill Creek-Bow Island succession. There is no apparent trend in the distribution of volcanic detritus in the subsurface sections, which is somewhat anomalous in view of the quartzose composition of the basal sands on Sheep River in the Foothills to the west. One explanation is that the lower quartzose sandstones on Sheep River (also present at the base of the formation on Mill Creek) represent an earlier phase of deposition than the basal beds of the formation in the subsurface to the east, the magnitude of the regional disconformity at the base of the formation increasing towards the Plains (Fig. 44). This hypothesis is not unlikely if it is assumed that deposition, more rapid in the Foothills region than in the Plains, was also more continuous in the west, although the petrographic and floral evidence for a major break in sedimentation at the top of the Beaver Mines Formation in the Foothills at this latitude is still overwhelming.

Variation in the detrital composition of the Mill Creek Formation sandstones is shown in figure 45, a triangular diagram on which the relative amounts of quartz, nonvolcanic rock fragments including chert, and volcanic detritus have been plotted. The shaded areas are those portions of the same diagram occupied by the bulk of the Beaver Mines Formation sandstones in figure 34. The overlap between outcrop and subsurface

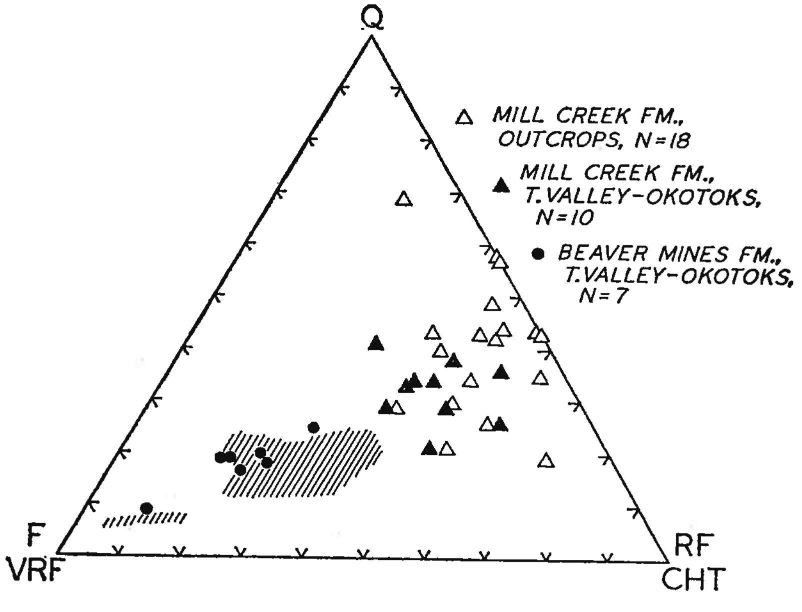

FIGURE 45. Ternary diagram showing the relative proportions of detrital constituents in modally analysed sandstones from the Mill Creek Formation (sampling localities: outcrop and subsurface sections listed in figure 43). Seven subsurface Beaver Mines Formation sandstones from three wells in the Turner Valley-Okotoks region are plotted for comparison. Shaded area denotes that portion of the same diagram occupied by Beaver Mines Formation sandstones in figure 34. (Q) quartz, (RF) nonvolcanic rock fragments, (CHT) chert, (F) feldspars, (VRF) volcanic rock fragments.

sandstones is evident, although the former are more variable in composition, especially in the relative amounts of quartz and chert. None of the Mill Creek Formation sandstones overlaps in composition those from the underlying Beaver Mines Formation, whether from outcrops or from the three wells in the Turner Valley-Okotoks area. In fact, the detrital composition of the subsurface Beaver Mines Formation sandstones is in good agreement with that of correlative outcrop sandstones, the main distinction between them being in the composition of authigenic cements. As noted in discussing the stratigraphy of the rocks, the differentiation of the Beaver Mines from the Mill Creek Formation in the subsurface of the eastern Foothills and adjacent Plains at this latitude depends mainly on recognizing the compositional differences between the sandstones, the gross lithologies (and derived electric log properties) of the two units being closely similar.

In summary, the main compositional features of the Mill Creek sandstones are:

(1) the wide variation in the proportions of different detrital constituents;

(2) the presence of small amounts of volcanic detritus;

(3) the relatively high proportion of metasedimentary micaceous and chloritic rock fragments.

At first sight the Mill Creek Formation sandstones appear to bridge the compositional gulf between the older Gladstone and Beaver Mines Formations sandstones, exhibiting certain of the composition aspects of one or the other sets of older rocks. For example, the detrital quartz in the Mill Creek Formation sandstones, especially in those from the lower part of the formation, is well rounded with abundant interlocking overgrowths and is obviously of second-cycle origin like that in the underlying Gladstone Formation sandstones. This is associated with abundant but highly variable amounts of chert and in samples from Mill Creek and from the subsurface sections east of Turner Valley[1] with variable amounts of transported dolomite. In particular, the quartzose sandstones from the lower part of the formation on Sheep River, devoid of recognizable volcanic detritus, resemble the older siliceous sandstones of the Blairmore Group. However, the finely crystalline nonvolcanic rock fragments in the two groups of sandstones are dissimilar in composition; those in the Mill Creek Formation sandstones include a much higher proportion of micaceous or chloritic metasedimentary rock fragments (Fig. 20), about equal to the same proportion found in the underlying Beaver Mines Formation

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[1] The presence of abundant transported dolomite in the subsurface Mill Creek-equivalent sandstones of the Western Plains coincides with the interfingering of the nonmarine Foothills-type beds there with the marine Bow Island facies. No dolomite was observed in outcrop samples on Sheep River to the west, which strongly suggests that the dolomite in the Bow Island sandstones is of local clastic origin.

sandstones. In this respect the less quartzose or cherty Mill Creek Formation sandstones more closely resemble the classic "low rank" greywackes of Krynine (1948) than do the highly siliceous sandstones of the older Gladstone Formation.

The volcanic detritus in the Mill Creek Formation sandstones, more abundant towards the top of the formation (at least in outcrops), is grossly comparable with that in the older Beaver Mines Formation sandstones, although it is not so abundant that the two groups of rocks overlap in composition (Fig. 45). Plagioclase is the dominant feldspar[1], both as single grains and in volcanic rock fragments, although potash feldspars are abundant in the Crowsnest Member of the southernmost Foothills. A study of outcrop sandstones from both formations indicates a general similarity in the composition of finely crystalline rock fragments, except that the Mill Creek Formation detritus appears less chloritic than the more abundant volcanic material in the Beaver Mines Formation sandstones (Fig. 21). On the other hand, igneous pebbles from local conglomerates in the lower part of the Mill Creek Formation in the Crowsnest Pass region, described by Anderson (1951), appear to be distinctly more granitic in composition and texture than the dominantly dacitic pebbles in the conglomerate on Highwood River (Table 4), although the two sets of pebbles are similar in the scarcity of mafic minerals and the presence of secondary epidote. These data, although not conclusive, suggest at least a moderate change in the composition of the igneous detritus supplied to the Foothills region in late Blairmore time, culminating in the deposition of the alkalic, analcite-bearing pyroclastic rocks of the Crowsnest Member at the close of Blairmore time in the southernmost Foothills.

Source of Sediments

The bulk of the Blairmore and Mannville detritus was derived from highlands situated to the south and west of the present outcrop limits in mid-Cretaceous time. This is evident not only from the composition of the detritus, but also from a general thickening and coarsening of the sediments in a western direction, especially noticeable in the Rocky Mountains and Foothills. However, the exact location and extent of this landmass are conjectural: the western portion of the depositional basin, in the Rocky Mountains and Foothills, has undergone marked foreshortening and partial erosion, and the inferred site of the source region has been subjected to continuing series of orogenic and erosional cycles since mid-Cretaceous time.

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[1] The distribution of potash feldspar is uncertain. Only a few of the outcrop samples were stained for feldspar determinations, and these contain no visible potash feldspars.

The western limit of Blairmore outcrop is situated today within the eastern ranges of the Rocky Mountains in southern Alberta, extending nearly to the western margin of the Rocky Mountains in the Fernie area of southeastern British Columbia. The westernmost exposures are also the thickest sections, such as those in the Elk and Fernie coal basins of British Columbia, where the group attains a maximum thickness of 6500 feet (Price, 1962). Thus, the source of sediments must have been some distance to the west of the present outcrop limits, on the site of what is now the western ranges of the Rocky Mountains, or farther west in the Purcell and Selkirk Mountains (Fig. 46).[1]

The structure of the Rocky and Purcell Mountains of southern Alberta and British Columbia today is such that, in general, successively older beds are exposed in an east to west direction across the strike of the Cordillera. The pre-Jurassic beds now exposed in the eastern ranges of the Rocky Mountains consist of a thick succession of Upper Devonian to Triassic strata, mainly carbonates and calcareous shales (Devonian and Mississippian) with some quartzitic sandstones and siltstones in the upper part (Pennsylvanian-Permian and Triassic). The western ranges of the Rocky Mountains are underlain by a thick succession of Lower Paleozoic carbonates, shales, and quartzites that locally have been subjected to low grade, dynamic metamorphism. Most of the units involved thicken in a westerly direction towards their present outcrop limits, and there can be little doubt from a consideration of lithologies, facies changes, and scattered erosion remnants in and about the margins of the Purcell Mountains to the west that these strata once extended in one form or another over much of southeastern British Columbia, where mainly Precambrian rocks or younger granites are now exposed.

The Purcell Mountains, separated from the Rocky Mountains to the east by the valley of the Rocky Mountain Trench, have the form of a broad, northwest-plunging anticlinorium underlain mainly by metasedimentary rocks of Late Precambrian age (Purcell and Windermere Series). The rocks are of largely detrital origin, with minor carbonates and altered igneous rocks (dioritic sills or flows) that have been subjected to varying intensities of regional metamorphism. They are intruded in places by batholiths or stocks of granitic rocks, marginal to the extensive Nelson batholithic complex to the west.

The simplest procedure for reconstructing the geology of the source region from which the Kootenay and Blairmore sediments were derived

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[1] No allowance has been made here or in the ensuing discussion for the amount of postdepositional structural foreshortening to which the Rocky Mountains and Foothills have been subjected. Presumably, the site of the source area from which the Blairmore sediments were derived, together with the western portion of the depositional basin itself, was compressed and thrust well to the east of its original position during late Cretaceous or early Tertiary time.

involves correlating the detritus in successively younger Mesozoic beds to the east with successively older source rocks in the source region to the west. Such an interpretation assumes, of course, that the Kootenay and Blairmore sediments were derived from the same region in which progressively older beds were being exposed through uplift and erosion.

Figure 47 presents a highly idealized interpretation of the history of sedimentation in southern Alberta and adjacent British Columbia during Blairmore time. The cross sections show a hypothetical landmass which provided the detritus and the depositional basin to the east, extending from a point somewhere on the site of the present-day Purcell Mountains of British Columbia, across the Rocky Mountain Foothills and Plains of southwestern Alberta.

The lowermost section shows Blairmore sedimentation beginning with the deposition of a widespread basal conglomerate that truncates progressively older Kootenay strata towards the east. The underlying Kootenay beds denote the stripping of a large mass of siliceous and shaly detritus from some western source, possibly derived in large part, in accordance with the hypothesis outlined above, from beds correlative with Triassic and early Jurassic strata now exposed in the Rocky Mountains to the east. Partly volcanic equivalents of these beds (Slocan and Ymir Groups) are also exposed to the west of the Purcell ranges, in and about the margins of the Nelson Batholith, which suggests that early Mesozoic strata were much more widely distributed in southeastern British Columbia that at present. The marked break in sedimentation at the top of the Kootenay Formation shows that uplift in the western region during this time was followed also by uplift and partial erosion in the depositional basin to the east, before deposition of the basal Blairmore conglomerate.

The basal Blairmore conglomerate marks a renewal of tectonism in the source region with subsequent erosion of dominantly siliceous and carbonate rocks to form a succession of sediments that becomes progressively finer-grained and more shaly towards the top (Gladstone Formation). The abundance of chert—some with traces of organic remains—detrital dolomite, and well-rounded quartz grains points to widespread exposure of Paleozoic carbonates and orthoquartzites in the source region, with as yet little or no exposure of older metasedimentary rocks. In the Plains to the east, the Cordilleran-derived detritus interfingers with thin quartzose sediments of the McMurray Formation, which from their lack of chert and presence of potash feldspars appear to have been derived from regolithic material developed locally on Paleozoic carbonate rocks, or from a deeply weathered granitic terrain in the Canadian Shield to the northeast (Williams *et al.*, 1962).

Towards the end of early Blairmore time, the source regions, now low or covered, ceased to provide much coarse siliceous detritus, and

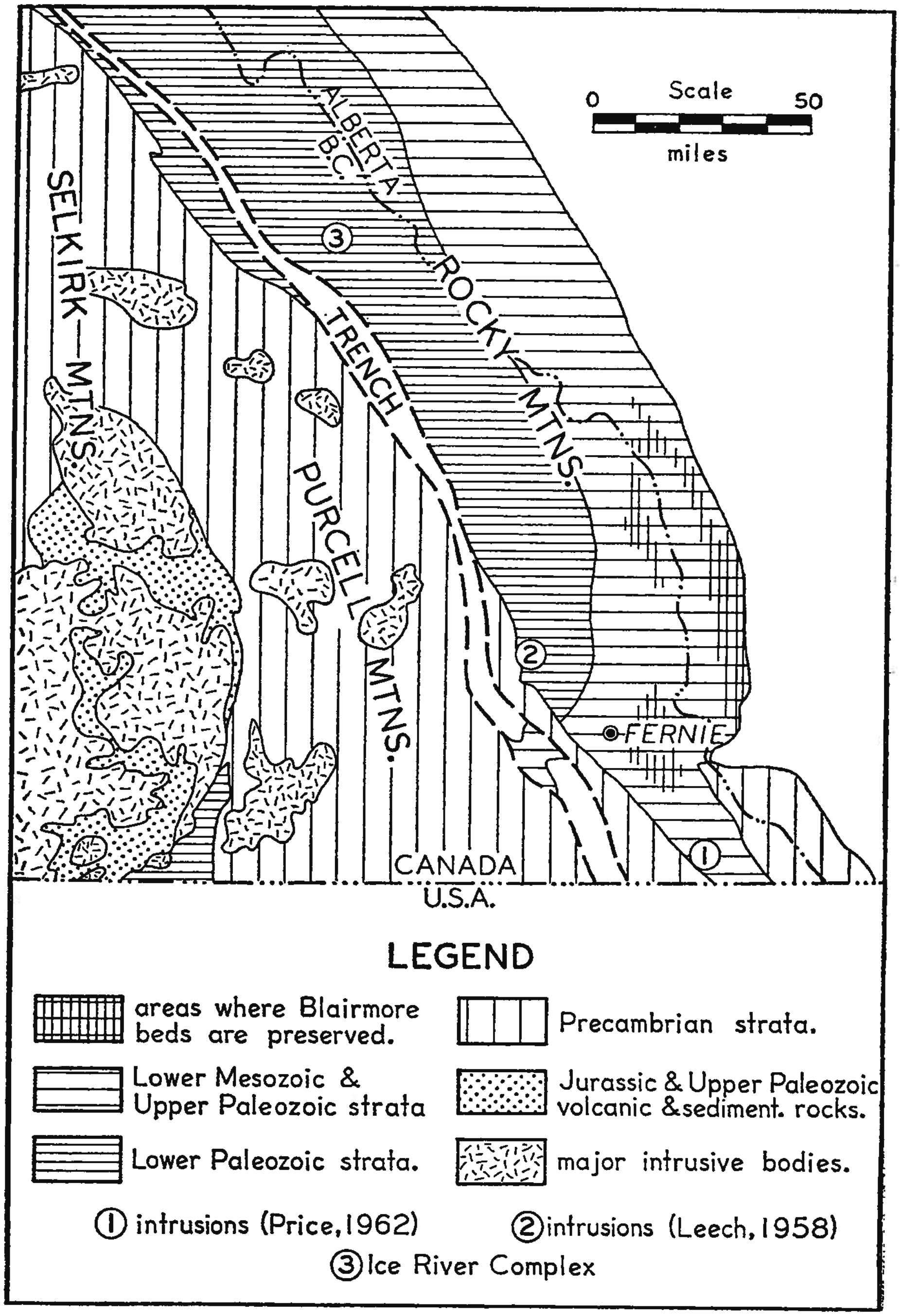

FIGURE 46. Generalized geologic map of the Cordilleran region of southwestern Alberta and adjacent British Columbia.

freshwater shales and marls of the "calcareous" member were deposited over much of the Foothills and Plains.

The advent of middle Blairmore time saw renewed uplift in the highlands to the west, coupled with the transgression of boreal seas over much of the central Alberta Foothills and Plains. Contemporaneous with these events was the outbreak of widespread volcanism in or along the margin of the western highlands, resulting in the deposition of abundant volcanic detritus in the southern and central Alberta Foothills and Plains and extending some distance into western Saskatchewan (Maycock, 1964). The appearance of volcanic material in the Blairmore succession also is associated with a change in the character of the nonvolcanic detritus, from dominantly siliceous, unmetamorphosed sedimentary detritus in the older Gladstone Formation to slightly metamorphosed argillaceous detritus (slate, phyllite) in the younger beds. From this it is evident that renewed uplift in the source area during middle Blairmore time exposed older metasedimentary rocks—lower Paleozoic or Precambrian—in addition to those rock units already contributing to the sedimentary basin (*cf.* Price, 1962, p. 32).

Volcanic detritus predominates throughout the Beaver Mines and Fort Augustus Formations of the southern and central Alberta Foothills and Plains, apparently decreasing in amount towards the northwest, where correlative beds at Belcourt Lake in northeastern British Columbia and in the Peace River district of Alberta are composed largely or entirely of nonvolcanic material. Thus, the locus of volcanic activity lay in the southern part of the Cordillera, from which area pyroclastic and reworked volcanic detritus spread into the basin in a northeasterly direction (Fig. 48). The intensity of and area subjected to volcanism also appear to have increased with time, the upper beds of the succession in both the central Foothills and Plains containing more volcanic detritus than those near the base. However, widespread volcanic activity ceased sometime between the end of middle Blairmore and the beginning of late Blairmore sedimentation, during which period the Foothills and Plains regions were an area of nondeposition, probably subjected in places to local erosion.

The final episode of Blairmore sedimentation is reflected in the Mill Creek and Bow Island beds of the southern Foothills and Plains. Following the hiatus in sedimentation at the end of middle Blairmore time, renewed uplift in the western highlands caused deposition of basal quartzose or cherty sandstones that grade up into rocks containing a high proportion of low grade metasedimentary detritus, similar to the nonvolcanic material deposited during middle Blairmore time. The main compositional distinction between middle and upper Blairmore strata is that the younger beds contain much less volcanic detritus, from which it is evident that the large volumes of volcanic material extruded to the

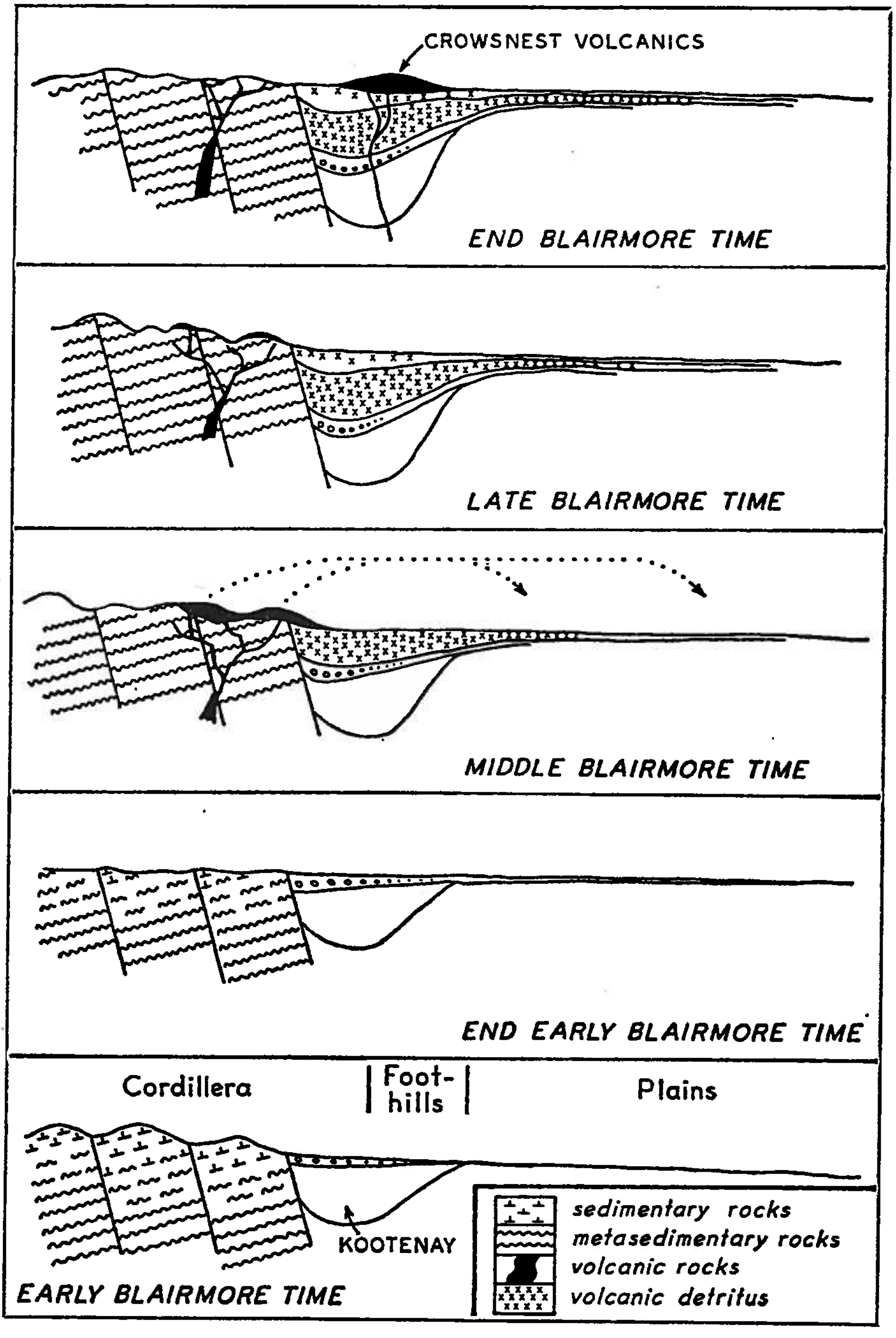

FIGURE 47. *Schematic cross sections showing the evolution of the hypothetical source area and the depositional basin in southwestern Alberta and adjacent British Columbia during Blairmore time.*

west during middle Blairmore time were largely removed by the end of this period or during the hiatus in deposition that followed. However, towards the end of late Blairmore time, a thick wedge of pyroclastic detritus (Crowsnest Member) was deposited at the top of the succession in the southernmost Foothills, having originated locally within the depositional basin itself rather than in highlands to the west.

The source of much of the volcanic detritus in the Blairmore and Mannville Groups (excepting the Crowsnest Member) remains uncertain. The question arises whether this material is:

(1) reworked: from older extrusive rocks;

(2) contemporaneous: from vents in highlands to the west of the depositional basin, possibly associated with the emplacement of large granitic plutons now exposed in the Purcell Mountains and adjacent ranges;

(3) contemporaneous: from vents in or along the western margin of the depositional basin, as in the case of the Crowsnest Member.

The first hypothesis proposes the erosion of older extrusive rocks in the source region to the west. Some minor volcanic rocks, basic sills or flows of Precambrian age, are now exposed in this region (Irene Formation, Moyie Intrusions), but in relation to the amount of metasedimentary detritus with which they are interbedded, their volume is minute. Much thicker bodies of extrusive and pyroclastic rocks (andesites, greenstones) are preserved in younger Carboniferous to Jurassic beds now exposed in central British Columbia, to the west of the Purcell Mountains. The volcanic phases of these units also may have extended farther east in Cretaceous time, interfingering with correlative nonvolcanic beds now exposed in the Rocky Mountains. If such were the case, older volcanic beds could have contributed to sediments in the middle part of the Blairmore Group, although the scarcity or absence of such material in the underlying Kootenay and Gladstone Formations must then be explained.

The alternative to older beds as a source of volcanic detritus is material extruded or ejected contemporaneously[1] within the source region or in the depositional basin itself. The first type of material could have been provided by vents associated with the emplacement of several relatively

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[1] Evidence for the age of the igneous detritus in the Blairmore Group has been published recently by Norris *et al.* (1965), who performed isotopic whole rock age determinations on eight igneous pebbles from conglomerates in the upper part of the group from four widely spaced localities in the southern Foothills. The pebbles appear to come from beds assigned in this report to the Mill Creek Formation, although from different stratigraphic levels within this unit. They yield ages ranging from 113 to 174 million years, which limits coincide closely with an interval of time spanning the entire Jurassic and Lower Cretaceous periods. However, if these ages are correct, the bulk of the pebbles are somewhat older than would be expected from igneous rocks formed contemporaneously with and incorporated into sediments of mid-Cretaceous age.

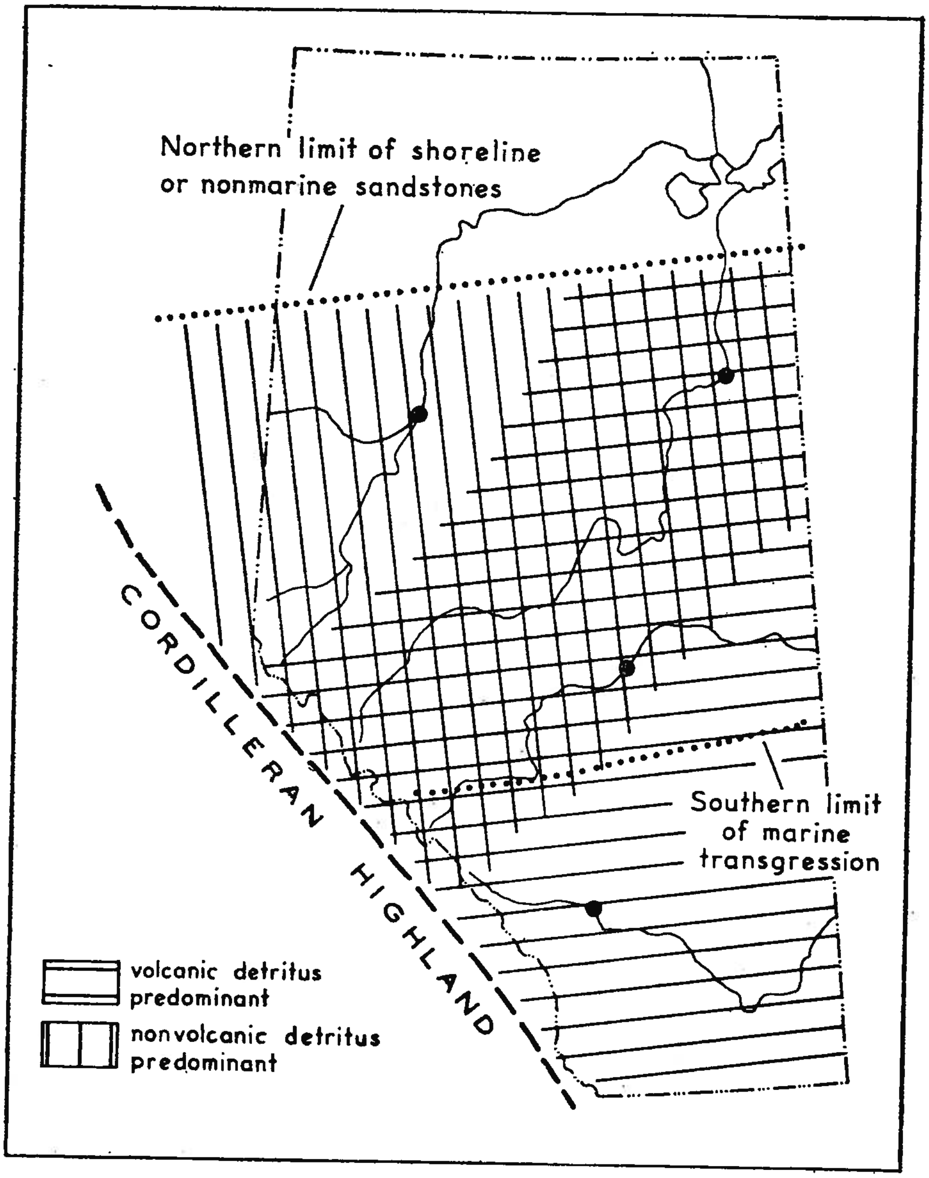

FIGURE 48. Map showing the distribution of volcanic detritus in Alberta during middle Blairmore (late Mannville) time.

large and a number of smaller batholiths or stocks now exposed in the Purcell and northern Selkirk Mountains, in areas presumably well to the west of the depositional basin during mid-Cretaceous time. The plutons range in composition from granodiorite to granite and intrude Precambrian metasedimentary rocks to the east of the more extensive Nelson batholithic complex. Isotopic age determinations of these and the Nelson granites to the west yield ages ranging from late Precambrian to Tertiary (Lowden, 1961; Lowden *et al.*, 1963; Leach *et al.*, 1963; Wanless *et al.*, 1965), the majority falling within age limits generally assigned to the Jurassic and Cretaceous periods. Thus, volcanic activity contemporaneous with the intrusion of certain of these plutons may have contributed some volcanic detritus to the Blairmore sediments, the granites themselves having been unroofed at a later date. However, such a hypothesis is speculative, for there is no evidence from present exposures that the emplacement of these widespread intrusive rocks was accompanied by large-scale volcanic activity.

More likely, the bulk of the Blairmore-Mannville volcanic detritus was derived from vents situated along or within the western margin of the depositional basin, such as those associated with the dominantly pyroclastic Crowsnest Member at the top of the succession. Although not large in comparison with the total volume of upper Blairmore sediments, the Crowsnest Member nevertheless demonstrates that substantial amounts of volcanic detritus can be generated within the basin of deposition without evidence of large scale intrusion. Known sources for this material comprise several small dykes cutting older strata in the Crowsnest Pass region, where the member is thickest (Norris, 1955).

A similar intrabasinal origin is postulated for the much larger volume of volcanic detritus extruded during middle Blairmore time, even though exposures of contemporaneous hypabyssal or plutonic rocks in the Rocky Mountains and Trench are relatively scarce.

One such group of intrusive rocks is present as scattered dykes and stock-like masses of leucocratic alkaline rocks (Howell Creek intrusions), which intrude strata as young as the basal Blairmore conglomerate near the western margin of the Rocky Mountains (Fig. 46), just north of the International Boundary (Price, 1962). The main rock type is a trachyte grossly similar in composition and texture to some of the pebbles found in the conglomerate in the Beaver Mines Formation on Highwood River (Table 4). An isotopic age determination of potash feldspars from a sample of the trachyte yields a date of 126 million years (Leech *et al.*, 1963), compatible with the inferred age of the middle Blairmore-upper Mannville sediments.

A similar group of small stocks and scattered dykes has been described intruding lower (and possibly upper) Paleozoic strata in the western ranges of the Rocky Mountains and adjacent Trench, north and west of Fernie, British Columbia (Leech, 1958). These consist of equigranular to porphyritic rocks ranging in composition from granodiorite to granite or syenite. In addition, Leech describes a succession 1000 to 1500 feet thick of poorly sorted detrital and calcareous rocks interbedded with lenses of tuff, volcanic breccia, and "greenstone" of uncertain age, lying unconformably on the Silurian Brisco Formation in the vicinity of the intrusive rocks described above. Elsewhere in the map area, the Brisco Formation is succeeded by the usual succession of Devonian quartzites and carbonates, and the presence of an exotic, partly volcanic suite of rocks at this stratigraphic level is puzzling.

Both the intrusive and associated bedded rocks are tentatively dated by Leech (*ibid.*) as being possibly as young as Cretaceous, although field evidence for such a designation appears to be lacking. No isotopic age determination of either group of rocks has been published, and their relationships to the volcanic detritus in the Blairmore and Mannville sandstones to the east remain uncertain.

The only other post-Precambrian igneous intrusive rocks in the southern Rocky Mountains that warrant mention are the Ice River intrusions near Field, British Columbia, about 100 miles north of those described above. These consist of syenitic and derived alkalic rocks that intrude Cambro-Ordovician beds in the western ranges of the Rocky Mountains and have long been considered Cretaceous or younger (Allan, 1914). However, if recent isotopic age determinations of these rocks as mid-Paleozoic are correct (Lowden, 1960; Baadsgaard *et al.*, 1961), then the Ice River complex was emplaced long before the advent of Cretaceous sedimentation to the east.

Authigenesis

Mineral Assemblages

The carbonates—calcite, dolomite, and siderite—have erratic sample distributions, which are in large part independent of bulk sandstone composition. This is especially true of calcite, which is common throughout the Blairmore and Mannville Groups as a sandstone cement, although most is concentrated in relatively few sandstones, distributed in apparent random fashion throughout each of the formations sampled.

In contrast, the nature of the silicate cements—quartz, clay minerals, laumontite—in the Blairmore and Mannville sandstones appears to be closely related to the detrital composition of the rocks, although this relationship has been modified to some extent by external factors operating in the unconsolidated or partly cemented sediments during and after deposition.

The relationship between cement and particle composition is especially noticeable in the Foothills (Blairmore) sandstones, as shown schematically in figure 49, in which the distributions of silicate cements are plotted against the volcanic detritus content of the rocks. Considerable overlap exists in the ranges of the cements, which permits the grouping of these constituents into several distinct authigenic mineral assemblages. These are defined, qualitatively at least, by the associations of clay minerals and laumontite, as most of the sandstones contain at least trace amounts of authigenic quartz and calcite. Those assemblages commonly found in the Beaver Mines and Mill Creek Formations in the Foothills are listed in table 7, together with the average percentages of volcanic constituents, silicate cements, and carbonates. The older Gladstone Formation sandstones, not listed in table 7, are composed almost exclusively of nonvolcanic material, quartz and kaolinite being the sole noncarbonate cements.

Laumontite is found in only a few sandstones from the Beaver Mines Formation in the southern Foothills; these contain exceptionally large amounts of volcanic detritus, especially feldspars (Table 7). They also contain abundant chlorite cement, and some contain minor amounts of calcite and quartz or illite and quartz as well, which substitute for laumontite in filling chlorite-lined pores or clusters of pores, as shown in figure 25. The three sandstones with both laumontite and illite cements —all from the thick sandstone unit near the middle of the formation on Mill Creek (Fig. 37)—contain noticeably less volcanic material than the five sandstones containing only laumontite, bridging the compositional gap between the latter and those sandstones cemented by chlorite and illite alone.

The assemblage chlorite-illite is common in many of the Beaver Mines Formation sandstones throughout the formation in the southern and south-central Foothills and in the Mountain Park beds to the north. Chlorite is the main cement in these sandstones, the remaining portions of the rocks being cemented by minor illite and quartz with variable amounts of poikilitic calcite. The fibrous variety of illite is the more common, grading into the micaceous variety in some of the coarser-grained sandstones. A few of these sandstones also contain scattered pockets of kaolinite, although kaolinite and illite are not commonly found together in the presence of chlorite. Such sandstones are included with those containing only chlorite and kaolinite in table 7.

Only a few of the Beaver Mines Formation sandstones contain both chlorite and kaolinite cements, and in these chlorite tends to be less abundant than in laumontite- or illite-bearing sandstones (Table 7). A similar situation prevails in sandstones from the overlying Mill Creek Formation in which kaolinite and quartz are the main silicate cements (Fig. 37),

Table 7. Average Percentages of Feldspars, Volcanic Detritus, Silicate Cements, and Carbonates in Sandstones from the Beaver Mines and Mill Creek Formations Grouped According to Assemblages of Authigenic Silicates

FM.	ASSEMBLAGE	No. OF SAMPLES	AVERAGE PERCENTAGE									
			Detritus[1]		Silicate Cements[1]					Carbonates[1]		
			Fe	TV	Ch	Lau	Ill	Ka	Qtz	Ct	Dol	Sid
Beaver Mines	chlorite, laumontite	5	33.00	65.95	7.40	4.05	—	—	0.10	1.30	—	—
	chlorite, laumon., illite	3	23.17	45.25	11.50	1.25	1.08	—	1.00	—	—	—
	chlorite, illite	28	17.22	44.73	9.47	—	1.63	—	1.30	1.93	—	—
	chlorite[2], kaol., ± illite	15	14.55	38.17	5.35	—	0.40	1.67	0.82	6.05	—	—
	illite ± kaolinite	9	10.89	37.53	—	—	1.31	2.83	1.83	1.61	7.94	1.14
	kaolinite	5	18.30	41.05	—	—	—	6.35	0.25	7.50	0.20	2.45
Mill Creek	chlorite[2], kaolinite	7	5.44	14.46	5.49	—	—	2.94	1.40	2.57	—	—
	kaolinite	15	3.47	8.53	—	—	—	3.39	7.48	2.22	1.83	—

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[1] Fe, feldspars; TV, total volcanic detritus; Ch, chlorite; Lau, laumontite; Ill, illite; Ka, kaolinite; Qtz, quartz; Ct, calcite; Dol, dolomite; Sid, siderite.

[2] includes mixed chlorite-illite cements in some samples.

with rather poorly developed chlorite cement being found in some of the sandstones containing small amounts of volcanic material.

In the lower part of the Beaver Mines Formation in the central Foothills (Luscar beds), sandstones cemented by chlorite in combination with illite or kaolinite—characteristic of the upper part of the formation (Mountain Park beds) there—are replaced by sandstones cemented by kaolinite or illite, or both minerals, together with quartz. In addition, the Luscar-type sandstones contain minor amounts of siderite and abundant but erratically distributed dolomite. Although containing less volcanic detritus on the average than the chlorite-rich Mountain Park-type sandstones, partly due to their high carbonate content, the Luscar-type sandstones show considerable overlap in detrital composition with the younger rocks when individual sandstones are compared (Fig. 34). Moreover, they contain considerably more volcanic material than sandstones from the Mill Creek Formation in the southern Foothills in which chlorite cement is present. Thus, the marked change in authigenic mineral assemblages within sandstones of the Beaver Mines Formation in the central Foothills cannot be explained on the basis of variation in detrital composition alone.

Most of the sandstones from the lower and upper parts of the Blairmore Group in the Foothills, dominantly siliceous in composition, are cemented by quartz and kaolinite associated with variable amounts of calcite and dolomite. Quartz is especially abundant in the quartzose Gladstone Formation sandstones as grain overgrowths on detrital quartz, small patches of kaolinite filling residual intergranular areas. This type of fabric is also common in the more quartzose sandstones of the overlying Mill Creek Formation, although the amount of quartz cement decreases noticeably with increasing amounts of volcanic detritus, its place being taken by chlorite or chlorite-like cement in some sandstones.

Kaolinite is the most abundant cement in the Mannville sandstones of the Plains, in which it is associated at certain stratigraphic levels with variable amounts of glauconite, siderite, and dolomite. Quartz cement is also common in some of the lower Mannville sandstones—the quartzose sandstones of the McMurray Formation and the cherty glauconite sandstones of the overlying Wabiskaw Member—but is rare in or absent from the upper Mannville (Fort Augustus Formation) sandstones, which contain abundant volcanic detritus. In these, some of which are only partly cemented, the main noncarbonate cement is kaolinite, associated in many sandstones with montmorillonite, which, however, is recognizable as an intergranular cement in only a few rocks. A similar assemblage is present in a few of the Foothills sandstones—notably in the upper part of the Beaver Mines Formation on Mill Creek and the upper part of the Mill Creek Formation on Oldman River—although in these sandstones

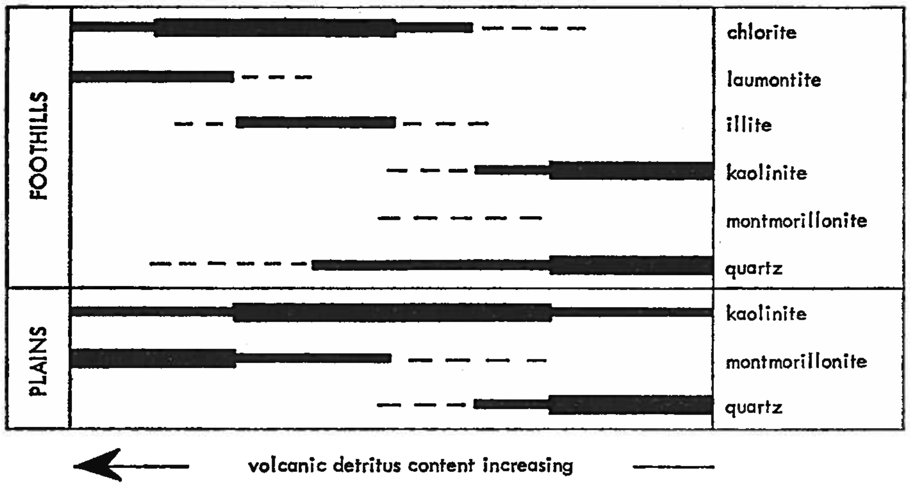

FIGURE 49. Bar diagram showing the distribution of silicate cements in relation to the amount of volcanic detritus in modally analysed sandstones from the Blairmore (Foothills) and Mannville (Plains) Groups.

some or all of what was originally montmorillonite has altered to a greenish-brown, filmy substance composed of chlorite and illite.

Paragenesis

The inferred depositional sequence of the various authigenic constituents discussed above is shown in figure 50. The chart is based largely on the interpretation of intergrowth relationships, although certain minerals (e.g., laumontite and kaolinite) cannot be compared directly because they are not found together in the same sample.

Included in figure 50 are those clastic constituents formed within the basin of deposition by chemical means before compaction and cementation of the wet sediment (halmyrolosis). These constituents are authigenic in a broad sense, although subsequently transported and abraded to some degree before final burial.

Siderite and glauconite are typical examples, being found as abraded grains admixed with other detritus cemented by kaolinite or calcite and quartz. However, neither constituent was observed as a pore filling in the Blairmore or Mannville sandstones, although fibrous illite yielding the same X-ray diffraction pattern as glauconite is a common intergranular cement in the nonmarine Mountain Park-type sandstones of the Foothills.

Much of the dolomite in the rocks also belongs in this category, although some dolomite obviously has been deposited during the later postdepositional stages of cementation as well, as grain overgrowths or metasomatic crystals. However, the paragenetic relationship of much of the recrystallized or authigenic dolomite in the rocks to the associated silicate cements is uncertain.

Postdepositional authigenic constituents (i.e. cements) can be divided into three groups on the basis of their paragenetic relationships:

(1) those deposited during the initial stages of cementation as fibrous coatings on the grain walls;

(2) those deposited subsequently in the residual portions of the intergranular areas;

(3) calcite.

Chlorite and montmorillonite fall in the first group. Where present, chlorite invariably appears to have been the first cement to form, except in one or two sandstones in which a thin layer of laumontite was deposited about the grains before chlorite. Montmorillonite or its altered equivalent is distributed in the same way, although not abundant enough in most sandstones to form an intergranular cement.

The second group of cements includes illite, kaolinite, most laumontite, and quartz. Of these, quartz is the most ubiquitous cement, replacing chlorite or montmorillonite as the earliest constituent in the more siliceous sandstones as overgrowths on detrital grains, followed by deposition of kaolinite or illite in the residual pore spaces. In some of the chlorite-cemented sandstones, quartz is intergrown with illite or kaolinite in such a way to suggest simultaneous deposition, whereas in others it substitutes for these minerals in filling discrete, chlorite-lined pores. In a few chlorite-cemented sandstones quartz has been deposited as grain overgrowths, having ruptured the chlorite pore linings as the overgrowths grew into adjacent cavities.

Calcite forms irregular crystals of variable size that fill scattered chlorite- or quartz-lined pores or clusters of such pores as a late cement. It is only rarely in contact with other silicate cements—kaolinite, illite, laumontite—but where such contacts are observed, the intergrowth relationships suggest that calcite was the last authigenic constituent deposited. For example, in some of the laumontite-bearing sandstones, irregular patches of authigenic calcite cut partially zeolitized feldspars, the inferred sequence of deposition being chlorite, laumontite, and finally calcite. In other sandstones small quartz crystals have grown out from chlorite-lined pores, in some cases filling them completely, in others only partly, with calcite filling the residual, central portions of the pores. These observations show that calcite was the last authigenic mineral to be emplaced, generally in the more loosely packed portions of the sandstones, by depo-

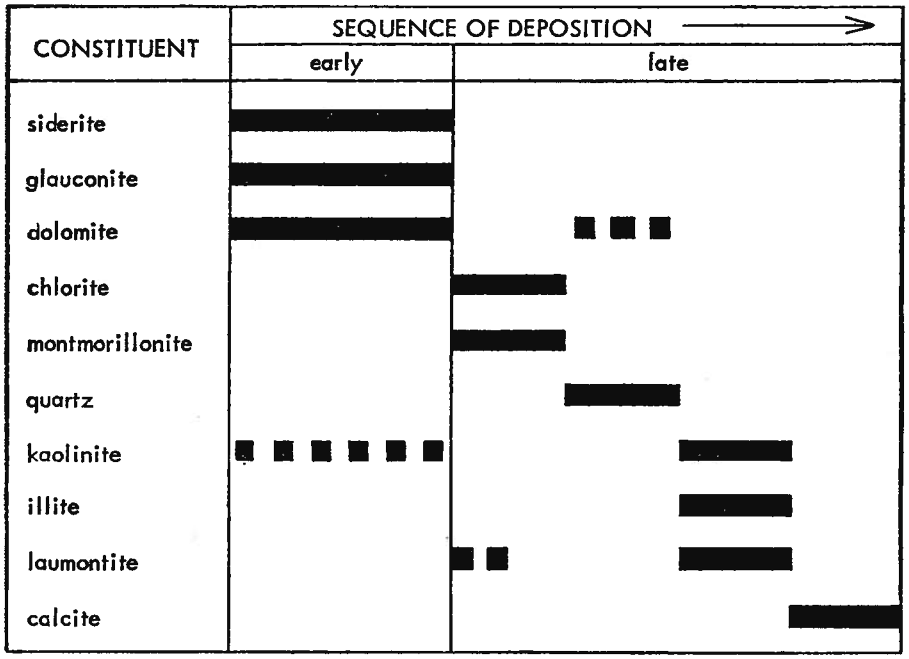

FIGURE 50. Bar diagram showing the paragenetic relationships of authigenic constituents in modally analysed sandstones from the Blairmore and Mannville Groups. "Early" refers to those constituents formed in the basin of deposition during sedimentation; "late" to those constituents formed after deposition and burial of the detrital constituents.

sition from late-forming, carbonate-bearing solutions percolating through pore systems partly cemented by silicates (Mellon, 1964).

The time required for the various stages of cementation go to completion is uncertain. That authigenesis was well underway during deposition is not only demonstrated by the presence of glauconite and abraded reworked (chemiclastic) carbonates in some sandstones, but also by the presence of scattered authigenic kaolinite books in locally derived mudstone pebbles, the kaolinite apparently having grown in soft, partly coherent clays before resedimentation and final burial. Chlorite, or some colloidal precursor, also appears to have been deposited during the early stages of diagenesis, for the chloritic pore linings in some sandstones have been crumpled or ruptured by compactive processes.

The net result of these processes is that the Foothills sandstones are now completely cemented; some microporosity may still be present, especially among the clayey constituents of the rocks, but the visible intergranular spaces have been filled completely, with rare exceptions, by matrix or cements. Cementation was apparently completed by or during the time the rocks were uplifted and folded (during late Cretaceous or early Tertiary time), for in some sandstones tectonic fractures or veinlets filled with later authigenic minerals cut across the depositional fabric of the rocks, replacing grains and primary cements alike. The vein minerals, commonly kaolinite, laumontite, quartz, and calcite, correspond in composition to the earlier-formed cements in the sandstones and are undoubtedly of local origin, formed through selective remobilization and reprecipitation of surrounding materials.

Most of the Plains sandstones examined also give the impression of being completely cemented, although they are much more friable than their Foothills counterparts. In some the clayey cements and matrix are lightly impregnated with heavy oil, the presence of which suggests some permeability even where no porosity is visible in thin sections. In other sandstones, notably from the Lyle Lake and West Wabiskaw No. 1 wells in the northeast, the grains are hardly compacted, and cementation (by kaolinite) is patchy and incomplete. In these sandstones the bulk of the pores are unfilled, and cementation is presumably still taking place.

Distribution and Origin

The distribution of authigenic cements in the Blairmore and Mannville sandstones accords reasonably well with the distribution of volcanic detritus, with the notable exception of calcite, which is present in all phases of the rocks.

The close association of authigenic and detrital silicate constituents in these sandstones strongly suggests that the former were derived locally by means of selective leaching and reprecipitation of the more soluble detritus (grains or matrix) to form intergranular or replacement cements. In other words the availability of key chemical constituents, obtained from the sandstones themselves or present in connate fluids expelled from adjacent shales during compaction, seems to have been the major factor controlling the composition of authigenic cements.

The range of physico-chemical conditions that prevailed in the rocks during cementation is, like the time span involved, discernible in only a general way. However, certain effects of regional differences in these conditions are apparent, the two most noteworthly of these being the contrast between the authigenic mineral assemblages of the Luscar- and Mountain Park-type sandstones in the Foothills, and between the authigenic mineral assemblages of the Foothills and Plains sandstones.

The stratigraphic relationship between the Luscar and overlying Mountain Park beds, which comprise the lower and upper parts of the

Beaver Mines Formation in the central Foothills, is shown in figures 9 and 10. The main lithologic distinction between the two units is the presence of coal in the Luscar beds, and the grey, buff-speckled appearance of the Luscar-type sandstones.

Considerable overlap exists in the detrital composition of the two types of sandstone (Fig. 34), although the Luscar-type sandstones contain on the average less volcanic detritus, as well as abundant dolomite, which is absent from the Mountain Park-type sandstones. However, the difference in cement composition is much more consistent: the abundant chlorite cement of the Mountain Park-type sandstones in the southern and central Foothills is absent from the Luscar-type sandstones, which are cemented by various combinations of kaolinite, illite, quartz, and carbonates (Fig. 37). Also clastic siderite pellets are abundant in the Luscar-type sandstones, accounting for their buff-speckled appearance.

In the central Foothills both types of sandstones have been subjected to the same conditions of burial and folding, so that differences in cements cannot be explained by assuming pressure-temperature differences during diagenesis. Moreover, the compositional distinctions between sandstones of the two facies persist across the strike of the folded belt, from near its eastern edge on Ram River to near the Front Range of the Rocky Mountains on Tershishner Creek, a distance of about 30 miles (no allowance being made for marked foreshortening of beds in this interval). At the three localities examined at this latitude (Fig. 9), the change from grey Luscar-type sandstones to overlying green Mountain Park-type sandstones is pronounced, taking place over a relatively small stratigraphic interval.

The most obvious lithologic change associated with the distribution of cements in the middle part of the Blairmore Group in the central Foothills is the appearance of thick coal beds in the Luscar facies, the thicker, commercial beds being restricted to the lower part of the Beaver Mines Formation. Other organic remains — plant fragments and carbonized wood—are much more common in the Luscar than in the Mountain Park beds, whereas the mottled redbeds and green blocky shales of the southern and south-central Foothills are absent. Undoubtedly, the distribution of these features indicates a regional northward change in the conditions of deposition, including the physico-chemical environment that prevailed in the detritus during sedimentation and early diagenesis.

In particular, the amount of organic matter may have had an important effect on the chemical processes associated with early diagenesis, as suggested by the laboratory experiments of Evans (1964). Preservation of organic matter as plant remains or coal beds normally is associated with a reducing environment during and immediately after deposition, an environment that also would be favourable to the formation of siderite pellets present in the Luscar-type sandstones. In this light the presence of kaolinite and siderite in place of chlorite in the Luscar-type sandstones can be attributed to the physico-chemical conditions present during the early stages of diagenesis ("redoxomorphic stage" of Dapples, 1962), in spite of the abundant volcanic detritus in these as well as the younger Mountain Park beds. Both kaolinite and siderite appear to have been stable over the range of temperatures and pressures that prevailed during the later stages of diagenesis, although some kaolinite cement may have been converted to illite at this time, as authigenic illite has not been found to date in Cretaceous sandstones of the Alberta Plains (Carrigy and Mellon, 1964). Similarly, it should be noted that detrital chlorite is present in the kaolinite- or illite-cemented Luscar-type sandstones of the Foothills and Plains, in which case it may be assumed that the mineral, although not precipitated as an intergranular cement, was at least partly resistant to destruction during the early stages of diagenesis.

The distinction between the authigenic mineral assemblages of the Foothills and Plains sandstones also can be interpreted partly in terms of regional differences in the physico-chemical environment present during the early stages of deposition and cementation, although the Foothills beds undoubtedly were subjected subsequently to more severe pressure-temperature conditions, due to deeper burial and folding, than the Plains beds.

The main difference in cement composition between the sandstones of the two regions is the absence of authigenic chlorite and illite from the Plains sandstones, which contain abundant kaolinite and montmorillonite instead. This rather marked change in cements appears to take place near the eastern edge of the Foothills, as observed in sandstones from outcrops and wells in the Sheep River-Okotoks region of southern Alberta (Fig. 51). Sandstones in the upper part of the Blairmore Group in this region (Mill Creek Formation) are relatively consistent in both authigenic and detrital composition in the several sections examined. Kaolinite and quartz are the main noncarbonate cements, associated in scattered outcrop and subsurface samples with poorly developed chlorite cement. Variable amounts of clastic dolomite are found in sandstones near the western edge of the Plains, where the unit interfingers to the east with the marine Bow Island beds. However, sandstones from the underlying Beaver Mines Formation, although relatively consistent in the amount of volcanic detritus present, show a marked change in cement composition across strike. The abundant chlorite and illite cements of the outcrop sandstones are replaced by kaolinite cement in the subsurface sandstones near Okotoks, although chlorite cement persists to the eastern edge of the folded belt, being found there, together with quartz cement, in sandstones from the Pine Creek No. 1 well.

None of the sandstones from wells in the central Plains contains chlorite cement, and in a few such sandstones from the upper part of the Fort Augustus Formation, cemented by kaolinite and montmorillonite, the chloritic groundmass originally present in volcanic rock fragments has been altered uniformly to dark brown limonite, presumably during the early stages of diagenesis. However, in most of the Mannville sandstones, particularly those of shoreline or marine origin, detrital chlorite, although not abundant, is unaltered, as in the kaolinite- or illite-cemented Luscar-type sandstones of the central Foothills.

In summary, the more feldspathic Blairmore and Mannville sandstones of the Foothills and Plains can be grouped according to chlorite content in the following way:

(1) both authigenic and detrital chlorite abundant: Mountain Park-type sandstones of the southern and central Foothills. Illite and quartz are common accessory cements, with minor laumontite and kaolinite.

(2) authigenic chlorite rare or absent, but detrital (volcanic) chlorite present: Luscar-type sandstones of the central Foothills, subsurface Beaver Mines Formation sandstones of the Okotoks area, and most Fort Augustus Formation sandstones of the Plains. Kaolinite and quartz are the main authigenic cements, with illite common in the Foothills and montmorillonite in the Plains sandstones. Siderite pellets are usually present.

(3) authigenic chlorite absent and detrital chorite altered: some of the nonmarine sandstones in the upper part of the Fort Augustus Formation in the Plains. Kaolinite and montmorillonite are the main cements, and siderite pellets are common.

The change in the Blairmore sandstones from chlorite to kaolinite cement near the eastern edge of the folded belt in the Turner Valley-Okotoks region could be interpreted as an effect of more severe pressure-temperature conditions in the Foothills strata, except that a similar change in sandstone cements is observed along the strike of the folded belt in the central Foothills, in the lower part of the Beaver Mines Formation (Luscar beds). In both areas the change in cement composition is accompanied by changes in gross lithology—replacement of redbeds and green shale by grey carbonaceous shale and development of coal beds—that can be interpreted only in terms of the physico-chemical environment of deposition and early diagenesis (paleoslope, drainage, redox potential), not as a response to later changes in the sediment associated with deep burial or folding. Thus, the restriction of chlorite cement to the Blairmore sandstones of the Foothills[1] and its absence from correlative Plains beds appears coincidental with respect to conditions of burial and folding; rather, the amount of volcanic detritus present, together with the effect of the physico-chemical environment during and immediately after deposition, seems to be the main factor involved in the formation and distribution of chlorite cement.

The main compositional distinction between cementing agents in Lower Cretaceous sandstones of the Plains and Foothills that may be associated with steeper pressure-temperature gradients in the latter region during diagenesis is the widespread presence of authigenic illite in sandstones of the Beaver Mines Formation, including both the Luscar and Mountain Park beds. Illite is found in these sandstones with a wide variety of other cements, and there is some evidence to suggest that it may have formed in some rocks at the expense of previously existing montmorillonite or kaolinite cement to give a brownish, mica-like substance composed of both chlorite and illite, or a finely crystalline mixture of intergrown kaolinite and illite. Mica-like cements, associated with small amounts of kaolinite or montmorillonite, or both, are found in sandstones from both the Beaver Mines and Mill Creek Formations of the southern Foothills, and intergrown kaolinite-illite cements in some of the Luscar-type sandstones on Ram River and at Cadomin.[2] That similar cements or combinations of cements are not found in the Mannville sandstones of the Plains infers that authigenic montmorillonite and kaolinite can be altered under the influence of heat and pressure to illite or illite and chlorite, if the necessary chemical constituents are available. However, this change in cement composition is spotty and in some cases incomplete, as shown by the presence of both kaolinite and montmorillonite in many Foothills sandstones.

Within the folded Foothills belt itself there is no apparent correlation of authigenic mineral assembages with inferred depths of burial, a phenomenon reported by Coombs (1954) and Packham and Crook (1960) as being present in thick successions of volcanic greywackes in New Zealand and New South Wales. In particular, authigenic zeolites in these rocks

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[1] The apparent restriction of chlorite cement to sandstones of the Foothills does not apply to the younger, much thicker series of detrital strata overlying the Blairmore Group and equivalent beds in west-central Alberta. Authigenic chlorite is abundant in some of the nonmarine sandstones of latest Cretaceous or early Tertiary age (Saunders Group) exposed at the top of the bedrock succession in the western part of the Alberta Plains (Carrigy and Mellon, 1964). These beds, which contain moderate amounts of volcanic detritus, have been neither folded nor deeply buried and consequently are more comparable in degree of lithification to the Mannville beds of northeastern Alberta than correlative Blairmore or Mannville strata of the western Plains and Foothills.

[2] Intergrowths of authigenic kaolinite and illite are also present in two of the four Kootenay Formation sandstones examined (Fig. 32) and in the basal sandstones of the Upper Cretaceous Belly River Formation in the southern Foothills. The Belly River material was originally described as "fibrous kaolinite" (Mellon, 1961) but has been since correctly identified from X-ray microcamera films as illite.

have been interpreted as the products of deep burial accompanied by elevated temperatures, although Coombs (1961) later distinguished between zeolites found in essentially flat-lying, shallow sediments ("zeolitites") and those found in deeply buried geosynclinal strata. The latter, confined to certain levels or zones in thick belts of folded strata, such as those now exposed in parts of New Zealand and Australia, have been interpreted as marking the limits of a metamorphic facies (zeolite facies) with mineral assemblages and textures characteristic of the effects of "burial" (as distinct from "regional") metamorphism (Coombs *et al.*, 1959; Coombs, 1961). However, this concept hardly can be applied to the distribution of authigenic zeolites (laumontite) in the Blairmore beds of the Alberta Foothills, which obviously is related to bulk composition of the host sandstones, as are the distributions of other authigenic constituents. Similar compositional control of authigenic mineral assemblages in volcanic greywackes of Oregon has been observed by Brown and Thayer (1963), although they suggest that albitization of the detrital plagioclase is related to depth of burial.

In summary, the Cretaceous strata of the Alberta Foothills appear to be much more variable in composition than the rocks described by Coombs (*op. cit.*) and Packham and Crook (*op. cit.*), exhibiting marked stratigraphic changes in sandstone composition that obviously have played a major role in the formation and distribution of authigenic minerals. Moreover, the Alberta strata have been buried to maximum depths that probably did not exceed 25,000 feet in the thickest parts of the Foothills succession, whereas the New Zealand and Australian rocks seem to have been buried to much greater depths prior to folding, below that level at which the effects of regional metamorphism become apparent. Such indicators of what conventionally are considered metamorphic effects—recrystallization features, albitization of detrital feldspars, development of schistosity or slaty cleavage—are lacking in Cretaceous strata of the Alberta Foothills, and it must be assumed that factors other than those associated with load or regional metamorphism have played a dominant role in the diagenesis of these rocks.

FACIES

Facies in the restricted sense of the word has a geographic connotation, being applicable to regionally distinct lithologic or biologic aspects of the same stratigraphic unit (Moore, 1949). In this sense the facies concept is readily applicable to strata of the Blairmore and Mannville Groups, which can be divided into several laterally interfingering lithofacies that are discordant with and in places cut across formation and time boundaries. The properties involved in distinguishing these units are reviewed below, and the relationships among facies, formations, and time boundaries discussed.

Facies Attributes

Gross Lithology

Basically, two types of cyclically bedded deposits or series are recognizable in strata of the Blairmore and Mannville Groups, in which the depositional or bedding pattern can be described as either of the conventionally graded type (influx type[1]) or the reverse (inverted or fill-in type[1]). These series in turn can be subclassified on the basis of presence or absence of redbeds and coal, yielding an array of rock-type associations distinguishable on the basis of gross lithology alone.

A conventionally graded or influx cycle of deposition is associated with a general decrease in current velocity with time, forming under ideal conditions a series of beds that becomes progressively finer grained towards the top. In the Blairmore Group such a series consists typically of well-sorted, crossbedded sandstone, grading up into thin-bedded siltstone overlain by blocky, silty shale or mudstone. The lower boundaries of the sandstones are sharp and in places uneven, indicating minor scouring or erosion of the shaly beds at the top of the underlying series. The sandstones themselves show considerable variation in vertical grain-size distribution; some appear relatively homogeneous, whereas others show local reversals in the upward trend to finer grain sizes, presumably as a consequence of minor fluctuations in current velocities. However, as a general rule, the coarser detritus (coarse sand or fine gravel) is concentrated at or near the base of the unit, and finer sand and silt in the upper part.

The upper boundaries of these "influx" sandstones are variable, although they tend to be sharp in the thicker units. Overlying beds are microcrossbedded siltstone, grading above into silty shale, which may contain stray thin beds of silty or sandy detritus that reflect minor sedimentary influxes superimposed on the larger cycle. If present, thin ben-

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[1] Krynine's (1959) terminology.

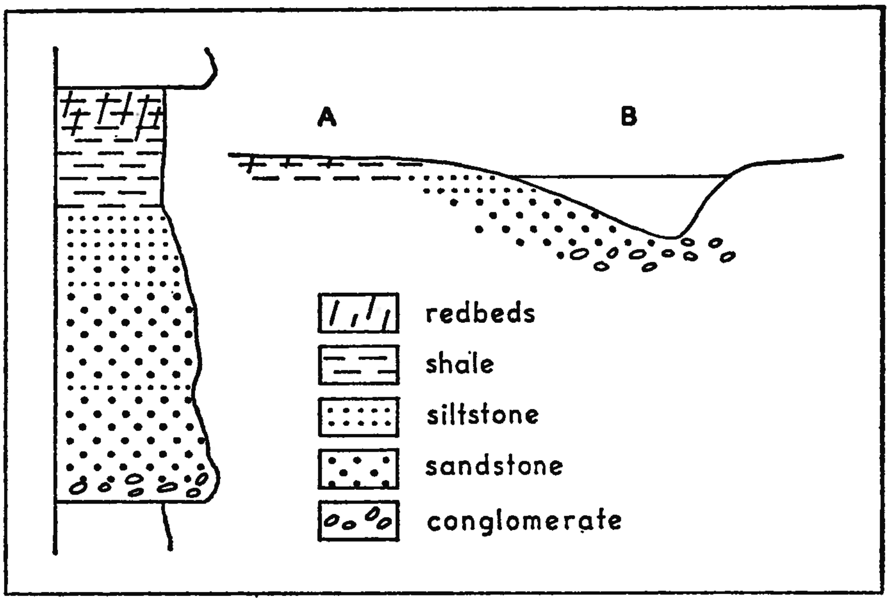

FIGURE 52. Schematic diagram showing a conventionally graded or influx series of sediments characteristic of the nonmarine Blairmore Group of the southern Foothills. Such series are presumed to be of fluviatile origin, being composed of floodplain (A) *and channel* (B) *phases meandering across a gently sloping depositional surface.*

tonite and tuff beds are found generally in the upper part of the shaly succession.

Influx series are typical of the nonmarine portions of the Blairmore and Mannville Groups, deposited in fluviatile channel-floodplain systems like that shown schematically in figure 52. Three lithologic assemblages are recognizable—redbed, intermediate, and coal-bearing—based on the nature of the fine-grained floodplain or interfluve beds.

The redbed type is well developed in the Blairmore Group of southern Alberta. Redbeds themselves are confined with rare exceptions to the shales or mudstones, forming irregularly mottled or crudely banded dark green and red intervals a few inches to several feet thick in the upper part of a series. From its local and regional distribution the red color appears to be postdepositional in origin, that is, developed in subaerially exposed floodplain sediments after deposition but before burial.

In central Alberta redbeds are replaced by dark green and grey shales, transitional to the dark grey, laminated, carbonaceous shales and siltstones associated with the coal beds of the north-central Foothills and Plains. In other respects the pattern of deposition in this intermediate region resembles that associated with the redbed series of southern Alberta and is interpreted in the same channel-floodplain terms.

The coal-bearing beds of the central Foothills and Plains contain good examples of both conventionally and inverted graded deposition. The former type is associated with commercial coal beds in the lower part of the Beaver Mines Formation in the Foothills and the upper part of the Fort Augustus Formation in the Plains. In these beds coal is developed in or replaces the upper, shaly portion of the series, in places directly overlying the adjacent sandstone, as, for example, at Cadomin. The sandstones themselves are similar to those interbedded with red or green, non-coal-bearing shales, and they and the associated shaly and coaly beds are interpreted as the channel and interfluve phases, respectively, of sediments deposited in systems adjacent to the marine or shoreline deposits described below.

Under ideal conditions an inverted or fill-in cycle of sedimentation forms a series of beds that becomes progressively coarser-grained towards the top. Such a series (Fig. 53) in its simplest form consists of dark grey shale at the base, grading up into finely laminated shale and siltstone, overlain by fine- to medium-grained, well-sorted, crossbedded sandstone. Conglomerate, if present, generally is found near the top of the series. Contacts with adjacent beds are generally sharp or gradational over short intervals.

This pattern of sedimentation is characteristic of the marine or shoreline phases of the Blairmore and Mannville Groups, although many local deviations from the ideal succession are present. In central Alberta the beds are associated with carbonaceous shale or coal at the base of a series, which disappears as the succession takes on a more marine aspect. In the northern Plains the arenaceous beds are replaced by dark grey marine shale, in which distinct patterns of cyclic sedimentation are difficult to discern. Good examples of marine or shoreline fill-in deposition are found in the Loon River-Notikewin and Harmon-Cadotte successions exposed along the lower Peace River, and the Wabiskaw Member and overlying Grand Rapids beds in the subsurface of central Alberta.

Inverted graded deposition also is characteristic of certain intervals in the Gladstone and McMurray Formations in central Alberta, but the fossil assemblages associated with these beds indicate nonmarine conditions of deposition. The best examples were observed in the middle and upper parts of the Gladstone Formation on Ram River (Pl. 4, Fig. 1), in which the base of a series is marked by a thin bed of black, fossiliferous shale that grades up through an interval of finely laminated siltstone and silty shale into grey, fine-grained, usually calcareous sandstone (Fig. 13). In detail the sandy phases consist of beds ranging from 1 to 6 inches thick,

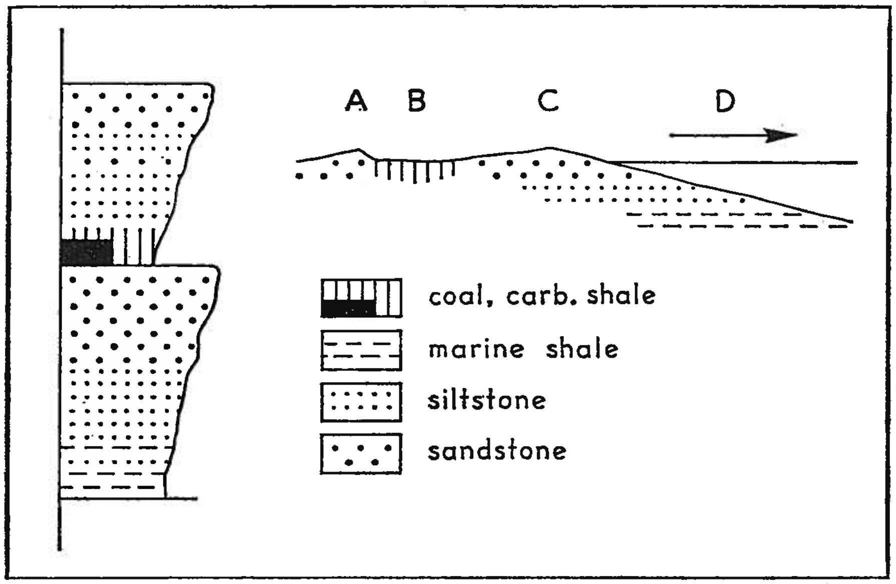

FIGURE 53. Schematic diagram showing an inverted graded or fill-in series of sediments characteristic of the Grand Rapids facies of the Mannville Group in central Alberta. Such series represent a shoreline depositional complex produced by seaward migration (arrow) of (A) a mainland beach, (B) lagoon, (C) spit or bar, and (D) an offshore platform.

silty or shaly at the base, grading up into fine-grained sandstone, the upper surface of which is bounded by symmetrical ripple marks. The abundance of ripple marks and the thin ribbon-like bedding of these rocks presents a marked contrast to the much thicker, more homogeneous sandstones in overlying parts of the Blairmore and Mannville Groups, whether of marine or nonmarine origin. Similar differences in bedding properties were used by Douglas (1956) to distinguish between the lower and upper parts of the coal-bearing Luscar succession in the north-central Foothills.

Sandstone Composition

Although major differences in composition of the Blairmore-Mannville sandstones are associated with formation boundaries, intraformational variation in sandstone composition is sufficiently well developed at certain levels to allow the discrimination of lithofacies on this basis alone.

In some cases such lithofacies coincide with stratigraphic units, such as the volcanic Crowsnest Member, which grades laterally into sedimentary detritus in the upper part of the Blairmore Group in the southern Foothills. Also, the Gladstone and McMurray Formations may be considered lithofacies of the same widespread stratigraphic unit, the heterogeneous cherty Gladstone sandstones of the Foothills grading eastward into the quartzose McMurray sandstones of the Plains.

More complex lateral changes in composition are found in the middle part of the Blairmore Group and correlative Plains strata, involving both the detrital and authigenic constituents of the sandstones. Most noticeable is the marked difference in cements between Foothills and Plains sandstones, chlorite and illite cements of the southern and central Foothills being replaced in the Plains by kaolinite and montmorillonite.

A similar change is observed in the north-central Foothills, where green, chlorite-cemented sandstones in the lower part of the Beaver Mines Formation grade laterally into grey, siderite-bearing Luscar-type sandstones cemented by kaolinite and illite. The change in authigenic composition at this latitude also is accompanied by a gradual change in the detrital composition of the sandstones, from rocks rich in volcanic detritus in the south to those composed mainly or entirely of metasedimentary detritus in the northern Foothills (Fig. 48). A similar trend is evident in correlative Plains sandstones, although masked to some extent by local sorting effects, and possibly by mixing of Shield- and Cordilleran-derived detritus (*cf.* Cameron, 1965).

Fossil Content

Stratigraphic variation in the fossil content of the Blairmore Group and correlative strata has little evolutionary significance, except for the break in the floral succession in the upper part of the Blairmore Group in the southern Foothills, which corresponds to the change in faunal and floral content at the Mannville-Joli Fou boundary in the Plains. Biologic variation within formations or groups can be attributed largely to ecologic factors, reflecting the gradation from nonmarine, largely fluviatile conditions of deposition in the southern Foothills and Plains to marine conditions in the north.

Plant remains are the most common megafossils in the nonmarine parts of the succession, attaining their maximum abundance in the coal-bearing Luscar-type beds of the central Foothills and Plains. In these strata they are associated with nonmarine invertebrates, which, however, are confined mainly to the thin but widespread "calcareous" member in the lower part of the succession, although found locally at higher levels in the southern Foothills where similar calcareous beds are developed. Apparently more susceptible to environmental changes than plants, the fresh-water invertebrate fauna of the southern regions is replaced in central Alberta by brackish-water forms, but data are insufficient to outline the distribution of any given species or assemblage.

In the central Plains, beds containing megafloral remains interfinger in the upper part of the Mannville succession with dark shales containing foraminifera and marine molluscs. Foraminifera are useful mainly in determining the stratigraphic limits of marine transgression[1], although a further distinction can be made between assemblages composed only of agglutinated, shallow-water types and those composed of both agglutinated and deeper-water calcareous forms. The latter are associated with the shaly Clearwater beds at the base of the Fort Augustus Formation, extending progressively higher in section towards the north, where in outcrops along the lower Peace and Athabasca Rivers they are associated with a variety of ammonites and other marine molluscs.

Distribution

The basis for differentiating regionally distinct facies in portions of the Blairmore and Mannville Groups of the Alberta Foothills and Plains is shown schematically in figure 54. The arrangement is such as to show progressive changes in gross lithology, sandstone composition, and fossil content in passing from the nonmarine beds that predominate in the southern Foothills and Plains to the mainly marine beds of the northern Plains (Fig. 55). The scheme is applicable mainly to the middle part of the Blairmore Group in the Foothills and, with some modifications, to correlative Plains strata. However, analogous facies changes can be observed in other portions of the Blairmore and Mannville Groups, although details are less certain owing to lack of control.

In the southern Foothills Blairmore strata appear from their lithology and fossil content to be exclusively nonmarine, forming in the main a succession of cyclic influx-type sandstones, siltstones, and shales deposited in coalescing fluviatile systems of sedimentation. Mottled or banded red intervals are present in many of the shales, extending in the southernmost Foothills from near the base of the group up into the pyroclastic beds of the Crowsnest Member. Postdepositional in origin, the redbeds apparently formed in the higher, better-drained portions of the depositional basin, skirting the hypothetical highland source region in southeastern British Columbia.

Redbeds become progressively less abundant towards the north and east (Fig. 55), being confined in the Plains, according to Glaister (1959), to areas south of township 20. In the Foothills redbeds are restricted to progressively younger strata towards the north, disappearing from the section in the south-central Foothills between the Bow and Red Deer

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[1] Microplankton appear to be even more diagnostic in determining the limits of marine transgression, as, for example, in the Fort Augustus No. 1 well (Singh, 1964). However, knowledge of the distribution of microflora in the Blairmore and Mannville Groups is too sketchy to be of much use in facies studies at present.

Rivers, in which region the Mill Creek Formation also disappears from the upper part of the Blairmore Group (Fig. 55). A similar phenomenon is observed in the northern part of the southern Foothills, in sections paralleling Sheep River, where redbeds in the upper part of the group pass eastward into drab green and grey beds, which in turn interfinger in the upper part of the group with marine beds of the Bow Island Formation in the western Plains (Fig. 55).

Contiguous with the redbed facies of the Blairmore Group in both the Foothills and Plains are strata similar in gross lithology, sandstone composition, and fossil content, except that the shales lack red banding or mottling. In the Beaver Mines Formation of the Foothills, these beds are shown in figure 55 as the Mountain Park facies, after the formation of the same name mapped by MacKay (1929a) in the Cadomin area of the north-central Foothills. At this latitude the Mountain Park facies forms the upper part of the Blairmore Group, being distinguished from the underlying Luscar beds by the lack of coal and the presence of green, chlorite-cemented sandstones. A short distance south of Ram River, the underlying coal-bearing beds apparently grade laterally into Mountain Park-type beds in the lower part of the formation, although exactly where this change takes place is uncertain owing to lack of exposures between the Red Deer and Clearwater Rivers. Nevertheless, in the south-central and southern Foothills the entire Beaver Mines Formation is similar to the Mountain Park facies at Cadomin, except for the development of a redbed subfacies that becomes more prominent southward. Cyclic influx-type deposition prevails, plant remains are common, and sandstone composition is virtually identical in both the detrital and authigenic fractions.

In the northern Foothills, somewhere between Cadomin and Belcourt Lake, British Columbia, Mountain Park-type beds lose their identity as a mappable unit, the entire succession of Blairmore-equivalent strata being mapped as "Luscar Formation" by most investigators in this region. Undoubtedly, the absence of certain features associated with the Mountain Park facies, such as chlorite cement, is connected partly with the change in detrital composition that takes place in the northern Foothills—that is, the gradual dilution and ultimate replacement of volcanic detritus by metasedimentary material in a northerly direction (Fig. 48). However, equally important in this regard is the gradual change in conditions of sedimentation in this direction, from dominantly fluviatile in the southern and central Alberta Foothills to shoreline and marine in the north, authigenic mineral composition depending largely on the physico-chemical aspects of the depositional environment.

In the southern and central Plains the Mountain Park-type beds appear from available evidence to extend no farther than the eastern edge of the folded belt, as in the Turner Valley area, where greenish chlorite- and

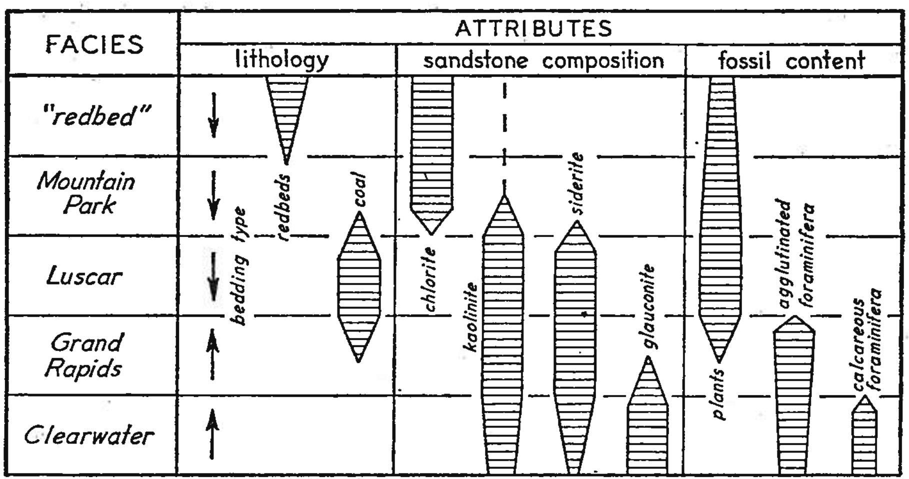

FIGURE 54. Schematic diagram showing the distribution of diagnostic facies attributes of the Beaver Mines and Fort Augustus Formations.

illite-cemented sandstones in the Beaver Mines Formation of the outcrop belt grade laterally in the subsurface into pale grey, kaolinite-cemented sandstones interbedded with drab green and grey shales of the western Plains (Figs. 51 and 55). Comparable in some respects to the Luscar facies of the central Foothills, these beds are apparently contiguous with the redbed facies of the southern Plains, in which the sandstones appear from descriptions to lack the typical chlorite cement found in correlative Foothills sandstones. This is the main distinction between the nonmarine middle Blairmore beds of the Foothills and correlative strata of the southern Plains, although in other respects—mainly lack of both coal and redbeds—a facies analogous to the Mountain Park beds of the Foothills, separating redbeds of southern Alberta from coal measures to the north, should be recognizable in the Plains.

In the central Foothills north of the Clearwater River, the Mountain Park beds in the lower part of the Beaver Mines Formation grade laterally into grey, kaolinitic sandstones, dark silty shales, and coal beds of the Luscar facies. The basis for distinguishing between the two facies has been discussed in some detail in preceding sections of the report: the main differences are the presence of thick coals seams in the Luscar facies and the absence of chlorite cement from the Luscar sandstones (Fig. 37). However, influx-type deposition prevails in both sets of rocks, and the sandstones of both facies contain in the central Foothills abundant volcanic detritus, although the basal Luscar sandstones show some signs of dilution by clastic carbonates and chert, portending a much more complete change in sandstone composition in the northern Foothills (see above).

Similar lithologic changes take place in the underlying Gladstone Formation of the central Foothills, marked by the gradual thinning and disappearance of the "calcareous" member in the south and the presence of thin non-commercial coal beds at various levels in the north. However, sandstone composition does not undergo any obvious change in a northerly direction, and were it not for the presence of a marine shale tongue (Moosebar Tongue) at the base of the overlying Beaver Mines Formation at Cadomin, which presumably extends and thickens in a northerly direction (Fig. 55), it would be difficult to distinguish between the Gething and Commotion Formations of the northern Foothills on the basis of gross lithology or sandstone composition.

In the Plains, Luscar-type beds are recognizable in the upper part of the Fort Augustus Formation in the Mannville Group, contiguous with the Mountain Park facies of the north-central Foothills (Fig. 11). The Luscar sandstones of the central Plains also contain abundant siderite pellets and kaolinite cement like their Foothills counterparts, but with montmorillonite rather than illite as an accessory cement. Thin coal seams and carbonaceous shales carrying plant remains are common at various levels, interfingering at the base and grading laterally to the north with beds containing a marine microfauna. From its position alone, the Luscar facies of the Foothills and Plains probably is a coastal plain or deltaic deposit, intermediate between the continental, fluviatile deposits associated with the Mountain Park and redbed facies to the south and the shoreline and marine deposits to the north.

Marine strata in the middle part of the Blairmore and the upper part of the Mannville Groups are divided in figure 54 into two facies, named after the type Grand Rapids and Clearwater Formations exposed along the lower Athabasca River. In this and most other regions of the northern and central Plains, they lie conformably on quartzose or calcareous sediments of the McMurray Formation, the change in sandstone composition at the top of the McMurray corresponding over much of the area to a relatively abrupt change from nonmarine to marine conditions of deposition at the end of early Mannville time.

The Grand Rapids facies comprises a cyclical succession of thin coal beds, laminated shales and siltstones, and relatively thick sandstones deposited in near-shore and shoreline systems of sedimentation marginal to the boreal Clearwater Sea. Inverted graded bedding predominates, laminated, dark grey shale and siltstone at the base of a series grading upwards into sandstone in sharp contact with the basal shaly beds of the overlying unit. In the absence of other data, the marked change from influx type to fill-in or inverted type deposition is sufficient to distinguish the Grand Rapids facies from the coal-bearing Luscar beds, into which they grade to the south and west.

Each sand-shale series appears to represent a relatively rapid marine transgression, followed by a gradual filling-in, or seaward migration, of progressively coarser-grained arenaceous deposits of bar or beach origin (Fig. 53). Confirmation of the shallow-water marine environment associated with these beds is found in the presence of abundant agglutinated foraminifera in many of the shaly beds (Figs. 11, 12). Higher in section foraminifera decrease in numbers and in species, being associated in the central Plains with plant-bearing carbonaceous shales and thin coal seams. Such beds, also associated with inverted graded sandstones or siltstones, appear to represent lagoonal phases of sedimentation, transitional to typical Luscar sediments, which form the uppermost beds of the Mannville Group in this region.

In composition the Grand Rapids-type sandstones resemble those of the Luscar facies in gross aspect, although they tend to contain more quartz and less volcanic material than the nonmarine rocks (Fig. 40). Also, glauconite and clastic dolomite are present in many of the Grand Rapids sandstones (Fig. 39), especially in the basal Wabiskaw Member, but are absent from the Luscar sandstones of the Plains[1]. However, siderite pellets are common in sandstones of both facies, and in the Plains kaolinite is the main or only sandstone cement.

The southernmost distribution of the Grand Rapids facies in the central Plains is uncertain, although undoubtedly tongues or embayments of the transgressing Clearwater Sea extended for some distance south of Edmonton, probably following low areas in the pre-Cretaceous landscape only partly filled by the older McMurray sediments. In the central Foothills marine or shoreline beds present at Cadomin (Fig. 55) probably extend as far south as the North Saskatchewan River. If this is so, then the thick hydrocarbon-impregnated sandstones at the base of the Beaver Mines Formation on Ram River (Fig. 9) may represent the southernmost edge of the shoreline Grand Rapids facies, although lithologic or faunal evidence is lacking.

In the central Plains the Grand Rapids facies rises northwards from the base of the Fort Augustus Formation to form the upper portions of correlative rock-units exposed along the lower Peace and Athabasca Rivers. In the same manner the Grand Rapids facies is replaced at the base of the Fort Augustus Formation by dark grey, glauconitic and silty shales carrying a calcareous foraminiferal assemblage indicative of a deeper water, offshore facies. Represented only by thin tongues in the north-central Plains (Figs. 11, 12) and in the Foothills to the west, this unit, the Clearwater facies, expands northward at the expense of overlying beds to form the thick Clearwater and Loon River shale units of the northern Plains

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[1] However, dolomite is common in the Luscar facies of the north-central Foothills (Fig. 37).

(Fig. 12). However, among the sections described in preceding sections of the report, the Clearwater facies is well developed only in the West Wabiskaw No. 1 well, although even there beds carrying a Clearwater microfauna (Fig. 12) contain a high proportion of siltstone and fine-grained sandstone. Farther north this interval becomes less arenaceous, and in extreme northwestern Alberta the entire Mannville-equivalent succession, including not only the Grand Rapids beds at the top but also the upper beds of the basal McMurray Formation, is represented by dark grey marine shale containing only stray sandy and silty beds. A detailed discussion of these changes, however, is beyond the scope of this report.

Summary

From an historical point of view the Blairmore Group and correlative Plains strata can be related to two large-scale cycles of sedimentation separated by a widespread break in deposition.

The lower and middle portions of the Blairmore Group in the Foothills and the correlative Mannville Group of the Plains are associated with the transgression of the boreal Clearwater Sea over northern and central Alberta during mid-Cretaceous time and its subsequent withdrawal to the north. During this period sedimentation appears to have remained more or less uninterrupted, except possibly for a minor break in southern Alberta at the end of early Blairmore time, the depositional surface sloping gradually to the north or northeast away from highlands centred in southeastern British Columbia.

During early Blairmore (Gladstone-McMurray) time marine sedimentation was restricted to northernmost Alberta, resulting in the deposition there of shales in the lower part of the Loon River Formation, which interfinger to the southeast with shoreline or nonmarine beds in the upper part of the McMurray Formation. In central and southern Alberta correlative beds are largely or entirely of nonmarine origin, forming in the Foothills redbed, intermediate, and coaly facies corresponding to the redbed, Mountain Park, and Luscar facies of the overlying succession.

The beginning of middle Blairmore (Beaver Mines-Fort Augustus) time saw the southward transgression of the Clearwater Sea into central Alberta, accompanied by the rejuvenation of highlands to the southwest and by the deposition of large amounts of volcanic detritus in the sedimentary basin. The rapidity of this marine transgression in the northeastern Plains and in central Alberta is attested to by the close association between the change in sandstone composition at the top of the McMurray Formation and the appearance of marine beds, in places carrying a deep-water microfauna, at the base of the overlying succession over much of northeastern and central Alberta. Transitional phases are developed in the north, in the West Wabiskaw No. 1 well and in the outcrop region around Fort McMurray, where the "calcareous" member at the top of the McMurray Formation interfingers with or is replaced by shales carrying a shallow-water marine microfauna. However, these beds are separated at both localities from the overlying Clearwater shales by a cherty, glauconitic sandstone unit (Wabiskaw Member), the base of which marks a distinct change in sandstone composition from the underlying quartzose rocks of the McMurray Formation to the heterogeneous sandstones of the overlying Fort Augustus Formation. The change in microfaunal content across the formation boundary can be interpreted only as a response to local environmental changes, and in the absence of other evidence the boundary marking the widespread change in sandstone composition at this level can be treated as a time-datum plane.

Deposition of the overlying middle Blairmore and upper Mannville beds is closely associated with the gradual filling-in and withdrawal of the Clearwater Sea to the north, resulting in the formation of a series of laterally interfingering, diachronous facies, the distribution of which is summarized in figure 56. Thicker and deposited under less rapidly changing conditions than the transgressive beds at the top of the older formations, the younger succession exhibits a more equable transition from marine to nonmarine phases of sedimentation, with the development of a transitional shoreline facies, exemplified by the thick arenaceous Grand Rapids deposits of central and northern Alberta. Similar beds are absent or only poorly developed at the top of the older succession, owing to the rapidity of marine transgression towards the end of early Blairmore (McMurray) time.

By the end of middle Blairmore (late Mannville) time, nonmarine or shoreline sediments were being deposited in most of the Alberta Foothills and Plains regions, the Clearwater Sea having withdrawn to approximately that position it held prior to the transgression at the beginning of the period. The time interval involved in the withdrawal of the sea, although greater than that associated with the earlier transgression, does not appear to have been too great, for the younger succession contains essentially the same long-ranging floral and faunal elements as the older Gladstone and McMurray Formations. Only in northwestern Alberta and adjacent British Columbia does evidence exist in the younger beds of the succession (Cadotte and Commotion Formations) for an evolutionary change in the flora and fauna, which suggests continuity of deposition there for a relatively short time after sedimentation had ceased in more southerly regions of the Foothills and Plains. However, this distinction appears minor in comparison to the marked change in the floral and faunal successions at the top of the middle Blairmore and upper Mannville beds in central and southern Alberta, and it is mainly on this basis, supported by other

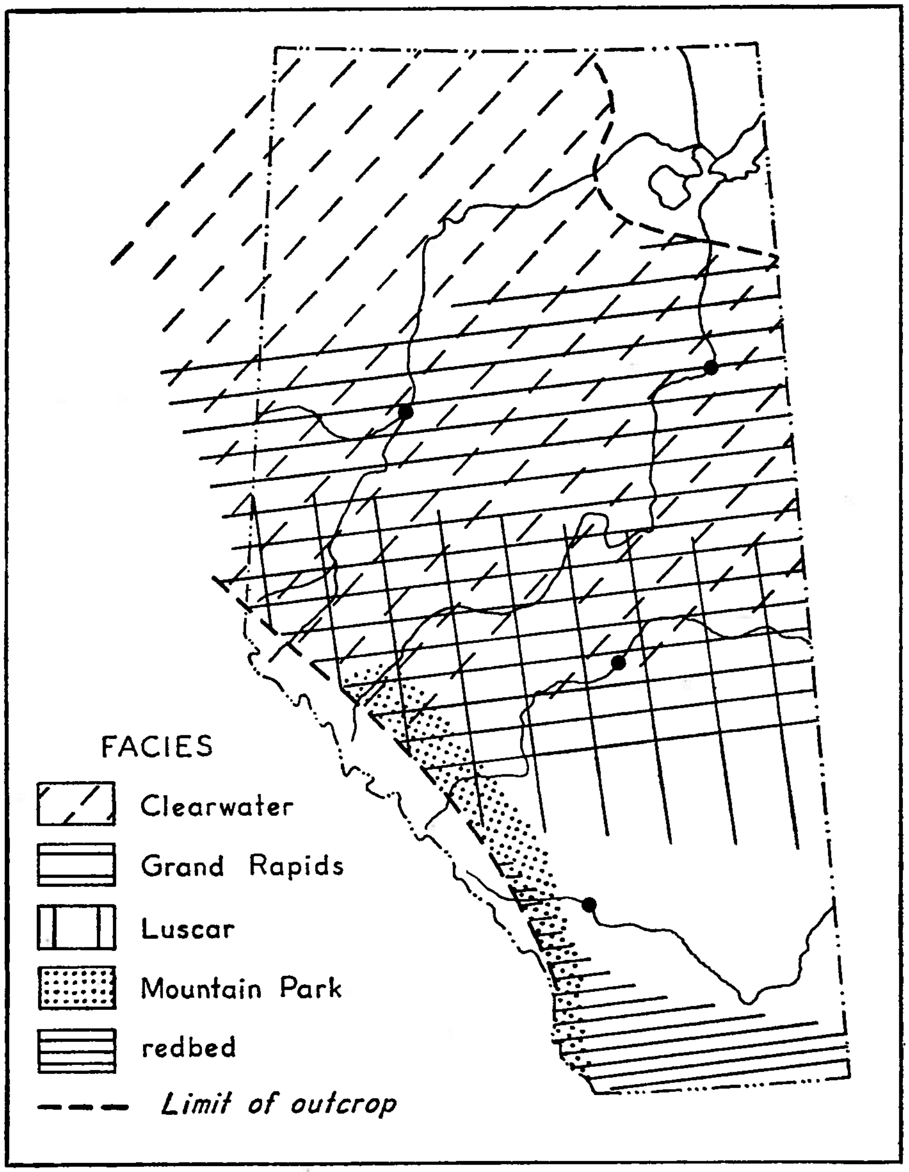

FIGURE 56. Map showing the approximate areal limits of depositional facies in Alberta during middle Blairmore (late Mannville) time.

evidence, that a widespread hiatus in deposition can be postulated at the end of this period.

The upper part of the Blairmore Group in the Foothills and correlative beds of the Plains (Bow Island, Joli Fou-Viking Formations) are separated from older Blairmore and Mannville strata by a regional disconformity that marks a pronounced break in sedimentation at this level in southern and central Alberta. The subsequent history of deposition during late Blairmore time is associated with the northward transgression of the Gulfian Sea over the Plains, followed by its shallowing and partial withdrawal to the south and east. Thus, from a paleogeographic point of view, deposition of the upper Blairmore and correlative Plains beds constitutes an episode of sedimentation quite distinct from that involved earlier with the transgression of the boreal Clearwater Sea.

In the southern Foothills the upper Blairmore Mill Creek Formation appears to be entirely of nonmarine origin, comprising a thick wedge of fluviatile sediments derived from highlands to the west. Redbeds are abundant, and on the basis of lithology alone it would be difficult to distinguish between the younger strata and those of the underlying Beaver Mines Formation, both sets of rocks having been deposited under similar conditions.

Near the eastern edge of the Foothills, upper Blairmore strata interfinger with marine beds which thicken and extend eastward to form the Bow Island Formation of the southern Plains. Thus, in the Sheep River-Okotoks area where this relationship was observed, distinctions are possible among a redbed facies in the outcrop region to the west, an "intermediate" nonmarine facies in the subsurface of the eastern Foothills, and a shoreline facies in the western Plains.

In central Alberta upper Blairmore strata are absent from the Foothills region a short distance north of the Bow River, but whether through nondeposition or erosion is uncertain. However, in the Plains to the east, correlative beds provide a close analogy to the Clearwater-Grand Rapids regression complex of the underlying Mannville Group, comprising a shaly marine facies (Joli Fou) at the base that grades up into a sandy shoreline facies (Viking and Pelican) in sharp contact with overlying marine shales in the lower part of the Colorado Group. The contact of the Joli Fou shales with the underlying nonmarine or shoreline beds of the Mannville Group is also sharp, providing an even greater contrast in lithologies than that at the top of the Viking beds. These relationships, together with the distribution of lithologies and fauna in the Joli Fou-Viking succession itself, all point to a rapid marine transgression at the beginning of this period, followed by a gradual shallowing and possibly partial withdrawal of the sea to the south and east. Certainly, ample evidence exists in the Foothills for a widespread break in deposition at the end of late Blairmore time, progressively younger post-Viking beds of the Alberta Group overlapping disconformably towards the south and west on middle and upper Blairmore strata.

For practical purposes this break can be interpreted as marking a pause between the end of lower Cretaceous sedimentation in Alberta and the beginning of deposition of similar but much thicker upper Cretaceous deposits of the Foothills and Plains.

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APPENDIX A. MEASURED SECTIONS

Section: composite outcrop section of the Blairmore Group (proposed type section).

Location: Mill Creek, Crowsnest Pass region, in Tp. 5, R. 2, W. 5th Mer. (Fig. 4).

Depth[1] (feet)	Thickness (feet)	Lithology
		Section A: Sec. 13, Tp. 5, R. 2, W. 5th Mer.
		BLACKSTONE FORMATION
—	?	hard, platy, greyish-weathering, black shale; *Inoceramus* sp. and *Watinoceras* sp. (Vimy Member).
—	1.0	pale greenish-grey bentonite.
—	50.0	highly contorted, thin-bedded, rusty-weathering shale and siltstone (Sunkay Member).
		MILL CREEK FORMATION (Crowsnest Member)
10.0	10.0	(covered)
13.0	3.0	bluish-green, coarse, even-grained, feldspathic tuff; water-lain in part.
48.0	35.0	(covered)
198.0	150.0	(partly covered) largely hard, massive to rubbly weathering, dark green or greenish-grey, coarse-grained, poorly sorted, feldspathic, lithic and crystal tuff or fine agglomerate, grading at the base into fine tuff interbedded with soft, green, tuffaceous shale; unit is crudely bedded with scattered brown-weathering spheroidal masses of lithic tuff up to 3 feet in diameter in the upper part.
303.0	105.0	soft, massive-weathering, red and green, bentonitic shale, interbedded with scattered thin, hard, cryptocrystalline tuff beds; thin dark grey shale bed with dicotyledon fragments near top of unit.
309.0	6.5	dark green, very fine grained sandstone and siltstone with dicotyledon fragments.
319.5	10.0	(minor fault) interbedded grey, very fine grained tuff and tuffaceous shale; thin red shale bed at top.
324.5	5.0	hard, dark grey, tuffaceous shale with abundant carbonaceous matter.
326.0	1.5	hard, dark greenish-grey, very fine grained tuff.
331.0	5.0	(partly covered) pale green-weathering, tuffaceous shale at base.
345.0	14.0	hard, dark greenish-grey to purplish, cryptocrystalline tuff in beds up to 1¼ feet thick, interbedded with grey, tuffaceous or bentonitic shale in beds up to 3 feet thick.
		base of Crowsnest Member

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[1] Distance below the top of the respective formation.

Depth (feet)	Thickness (feet)	Lithology
347.7	2.7	blocky, red and green mottled shale.
350.2	2.5	dark green siltstone or silty shale.
360.2	10.0	hard, red and green mottled shale.
363.2	3.0	blocky, dark green siltstone and shale.
374.2	11.0	dark grey, very fine grained sandstone and siltstone; sharp lower contact.
381.2	7.0	dark grey siltstone and silty shale; abundant dicotyledon remains (Coll. 55-214C, 55-214E).
381.8	0.6	soft, pale green, bentonitic shale.
422.8	41.0	dark grey or greenish-grey, platy siltstone and dark grey shale in beds 6 inches to 4 feet thick; 4-inch bed of hard, purplish-grey, aphanitic tuff(?) 2 feet above base; scattered plant remains in lower part (Coll. 55-214A, 55-214B).
431.8	9.0	green, fine-grained, laminated sandstone and siltstone.
438.8	7.0	dark grey, fine-grained sandstone with scattered shale pellets.
443.8	5.0	dark greenish-grey siltstone, grading below into fine-grained sandstone.
503.8	60.0	grey, fine- to medium-grained, crossbedded, moderately calcareous, cherty sandstone with scattered silty lenses, becoming finer-grained towards the top; sharp lower contact.
523.8	20.0	dark greenish-grey, crossbedded, calcareous siltstone in beds 3 to 8 inches thick separated by shaly partings.
525.8	2.0	(covered)
528.9	3.1	grey, fine- to medium-grained, cherty sandstone.
529.2	0.3	(covered, shale?)
531.7	2.5	dark grey siltstone.
532.8	1.1	black, fissile shale.
535.3	2.5	dark grey siltstone.
544.8	9.5	poorly exposed black, fissile shale.
546.3	1.5	dark grey, calcareous siltstone.
546.5	0.2	soft, black, silty shale.
549.6	3.1	dark grey, fine-grained, calcareous sandstone; fluted undersurface.
563.1	13.5	hard, whitish to pale grey, fine-grained, crossbedded, quartzose sandstone, grading below into
571.1	8.0	dark grey siltstone; sharp lower contact.
		BEAVER MINES FORMATION
5.5	5.5	soft, green shale, grading below into hard, blocky, green shale.
8.2	2.7	hard, grey, cryptocrystalline tuff(?).
28.7	20.5	hard, blocky, green shale, silty in middle part and at base; sharp lower contact.
29.7	1.0	hard, black, fissile, fossiliferous, calcareous shale.
31.7	2.0	dark grey, fine-grained, shaly limestone; many ostracodes, gastropods, and pelecypods (Coll. 56-149).

base of Section A

Depth (feet)	Thickness (feet)	Lithology
		Section B: Sec. 25, Tp. 5, R. 2, W. 5th Mer.
—	?	dark grey, splintery shale.
—	1.4	hard, dark grey, calcareous siltstone; fluted undersurface forms sharp lower contact.
		base of the Mill Creek Formation
		BEAVER MINES FORMATION
0.2	0.2	soft, black shale; bentonitic at top.
8.2	8.0	soft, dark green, argillaceous sandstone, grading into siltstone in the lower part; dark brown biotite abundant.
12.0	3.8	hard, dark green siltstone and silty shale.
13.7	1.7	blocky, red shale with green patches.
28.1	14.4	interbedded dark green sandstone and siltstone, becoming reddish in the lower 3 feet; thin red shale parting 5 feet below the top.
28.2	0.1	pale grey bentonite.
34.2	6.0	interbedded green, fine-grained sandstone, siltstone, and greenish-grey shale.
38.7	4.5	dark grey, silty shale with coaly streaks and plant fragments.
46.7	8.0	dark green siltstone, grading below into green, fine-grained, argillaceous sandstone; sharp lower contact.
53.7	7.0	greenish-grey, greasy shale, grading below into hard, red and green mottled shale.
58.7	5.0	bluish-green, micaceous siltstone.
61.3	2.6	hard, grey, cryptocrystalline tuff(?); thin grey shale parting near middle.
70.3	9.0	soft, green shale, grading below into hard, green, silty shale and siltstone.
74.3	4.0	red and green mottled shale.
82.2	7.9	thin-bedded, green siltstone, sandy at top, grading into hard, silty shale at base.
87.1	4.9	hard, green shale, grading into red and green mottled shale in the lower 3 feet.
93.5	6.4	dark green, silty shale and siltstone, more silty towards the base.
96.6	3.1	red and green mottled shale.
101.6	5.0	dark green, very fine grained sandstone and siltstone.
104.6	3.0	dark green, silty shale and siltstone.
109.6	5.0	green, very fine grained sandstone, becoming silty at the base.
122.0	12.4	hard, dark grey and green, blocky shale; three bentonitic zones or partings in the middle.
125.7	3.7	green, silty sandstone, grading into hard, silty shale in the lower part.
128.7	3.0	red and green mottled shale; bentonite parting at base.
137.5	8.8	soft, green sandstone, grading below into interbedded hard sandstone and dark grey, carbonaceous siltstone.
142.5	5.0	soft, green, greasy shale.
149.0	6.5	dark grey siltstone; plant fragments in the lower part.

Depth (feet)	Thickness (feet)	Lithology
155.0	6.0	hard, green shale; brown-weathering concretionary bed at base.
158.8	3.8	hard, green, silty shale, grading below into
162.8	4.0	green, fine-grained, biotite-rich sandstone, soft and wet in the upper part.
163.8	1.0	dark red shale.
166.8	3.0	green, fine-grained sandstone.
174.4	7.6	hard, dark greenish-grey shale, waxy and soft at base.
175.6	1.2	hard, pale grey, cryptocrystalline tuff.
178.1	2.5	dark green, sandy siltstone.
190.1	12.0	irregularly banded red and green shale.
192.1	2.0	dark green, sandy siltstone.
197.1	5.0	(covered)
200.7	3.6	banded red and green shale.
202.0	1.3	dark green, sandy siltstone.
204.5	2.5	red and green mottled, silty shale.
208.3	3.8	soft, pale green, very fine grained sandstone with scattered large calcareous concretions.
210.7	2.4	red and green mottled shale.
215.8	5.1	dark greenish-grey, silty shale, grading into dark grey siltstone in the lower 1½ feet; bentonite parting at base.
221.8	6.0	soft, green siltstone, grading below into fine sandstone.
223.8	2.0	red and green mottled shale.
234.3	10.5	dark green and grey, silty shale and laminated, carbonaceous siltstone; bentonite parting at base.
234.8	0.5	black, coaly shale.
236.8	2.0	rusty-weathering, grey siltstone and fine-grained sandstone.
238.8	2.0	hard, dark greenish-grey shale.
240.8	2.0	dark green, greasy, bentonitic(?) shale; large calcareous concretions in the lower part.
243.8	3.0	soft, green sandstone.
252.8	9.0	hard, dark greenish-grey, silty shale, grading below into
258.3	5.5	interbedded dark green siltstone and sandstone, shaly at base; sharp lower contact.
269.3	11.0	friable-weathering, green, fine- to medium-grained sandstone with scattered silty lenses.
273.1	3.8	thin-bedded, dark green siltstone, grading below into dark greenish-grey shale.
280.0	6.9	interbedded dark grey silty shale, siltstone, and green sandstone.
300.2	20.2	green, very fine grained, carbonaceous sandstone; thin dark grey siltstone lens with plant remains 3 feet above base (Coll. 56-132A).
302.2	2.0	(covered)
306.7	4.5	dark green, silty sandstone, grading below into
319.2	12.5	green, fine-grained sandstone; sharp lower contact.
328.4	9.2	interbedded dark grey, silty shale and greenish-grey siltstone.
331.2	2.8	soft, dark green, mottled siltstone; sharp lower contact.
333.2	2.0	hard, blocky, medium grey shale.
336.1	2.9	soft, dark green siltstone; sharp lower contact.
336.9	0.8	soft, grey, bentonitic shale, grading below into
337.8	0.9	soft, waxy, pale green bentonite; sharp lower contact.

Depth (feet)	Thickness (feet)	Lithology
355.8	18.0	interbedded hard, greenish-grey and red and green mottled shale, grading at the base into silty shale.
366.6	10.8	dark green siltstone, grading below into fine-grained sandstone; silty shale partings at base.
367.1	0.5	dark grey shale and bentonite(?).
374.1	7.0	green, fine-grained sandstone; sharp lower contact.
382.6	8.5	dark greenish-grey siltstone, dark grey shaly partings at top; grades below into
391.1	8.5	green, fine-grained sandstone.
402.1	11.0	dark grey siltstone, dark grey shale beds 1 foot thick at top and base.
416.1	14.0	hard, red and green mottled shale.
425.9	9.8	dark green and grey, silty shale with scattered plant fragments; sharp lower contact.
436.4	10.5	interbedded dark green, fine-grained sandstone and siltstone.

base of Section B

Section C: Sec. 26, Tp. 5, R. 2, W. 5th Mer.

BEAVER MINES FORMATION (continued)

Depth (feet)	Thickness (feet)	Lithology
442.9	6.5	dark greenish-grey, silty shale, grading into red mottled shale in the lower 2 feet.
448.4	5.5	dark green siltstone and silty shale.
457.2	8.8	hard, banded red and minor green shale with scattered brown-weathering calcareous concretions in the upper part.
460.2	3.0	soft, green, fine-grained sandstone.
467.3	7.1	hard, red shale with scattered brown-weathering calcareous concretions.
473.0	5.7	dark greenish-grey siltstone, grading into soft, fine-grained sandstone in the upper part.
487.5	14.5	poorly exposed red and green mottled or banded shale.
494.5	7.0	poorly exposed dark green siltstone and silty sandstone; sheared contacts.
501.5	7.0	dark green siltstone.
504.8	3.3	soft, green, fine-grained sandstone; sharp contacts.
516.8	12.0	green, fine-grained sandstone, grading into siltstone in the upper 3 feet.
524.5	7.7	dark greenish-grey, splintery shale, grading into dark grey shale with plant fragments at the base.
554.5	30.0	green, fine- to medium-grained, crossbedded sandstone, becoming finer-grained towards the top.
558.5	4.0	dark grey silty shale, siltstone, and sandstone with scattered plant fragments and coaly streaks.
588.5	30.0	green, fine-grained, crossbedded sandstone, as above.
593.9	5.4	dark greenish-grey siltstone and very fine-grained sandstone.
610.9	17.0	green, fine-grained, crossbedded sandstone, as above; sharp lower contact.

Depth (feet)	Thickness (feet)	Lithology
620.6	9.7	interbedded dark green, silty sandstone, dark greenish-grey siltstone and silty shale.
626.1	5.5	dark greenish-grey siltstone.
634.3	8.2	dark grey, silty shale.
660.3	26.0	(covered)
674.5	14.2	interbedded dark green, very fine grained sandstone and greenish-grey siltstone, becoming more sandy in the upper 8 feet.
695.5	21.0	dark greenish-grey, laminated siltstone, interbedded with scattered dark grey shale partings containing scattered plant fragments.
702.5	7.0	green, fine-grained sandstone, grading up into dark greenish-grey siltstone.
703.0	0.5	hard, black, silty shale with scattered plant fragments.
710.5	7.5	dark greenish-grey, silty sandstone, grading up into siltstone.
717.5	7.0	green, very fine grained sandstone, grading up into siltstone with scattered plant fragments in the upper few inches.
725.4	7.9	dark greenish-grey siltstone, grading into coaly shale in the upper few inches; many well-preserved plant fragments (Coll. 56-73).
730.9	5.5	soft, grey, silty shale, bentonitic(?), grading below into hard, tuffaceous(?) shale.
732.4	1.5	poorly exposed soft, blocky, grey, bentonitic shale.
732.7	0.3	hard, nodular-weathering, dark green, tuffaceous shale.
762.7	30.0	dominantly thin-bedded, dark green to greenish-grey, silty sandstone and siltstone with thin interbeds of dark grey, silty shale up to 6 inches thick.
763.8	0.3	dark grey, silty shale with numerous well-preserved plant remains (Coll. 55-194).
802.0	39.0	green, fine-to medium-grained, crossbedded sandstone, becoming progressively coarser-grained towards the base; sharp lower contact with local channeling of underlying silty beds.
807.0	5.0	dark greenish-grey, thin-bedded siltstone.
832.0	25.0	(covered)
838.0	6.0	dark green, very fine grained sandstone, grading up into dark greenish-grey siltstone.
855.8	17.8	dominantly thin-bedded, dark greenish-grey siltstone with minor dark grey shale partings; large brown-weathering calcareous concretions in the upper 6 feet.
865.1	9.3	interbedded dark greenish-grey, silty sandstone and siltstone; sharp lower contact.
873.9	8.8	dark greenish-grey siltstone, dark red in upper 4 inches, grading below into
875.9	2.0	dark greenish-grey, silty sandstone; sharp lower contact.
888.9	13.0	hard, red and green banded and mottled shale; scattered large, brown-weathering, calcareous concretions 5 feet below the top.
890.9	2.0	(covered)
901.4	10.5	dark green, very fine grained sandstone, becoming silty towards the top.
904.4	3.0	dark green, silty sandstone and dark grey siltstone, grading below into
914.1	9.7	green, fine-grained sandstone, becoming medium-grained in the lower part; sharp lower contact.

Depth (feet)	Thickness (feet)	Lithology
923.6	9.5	greenish-grey, medium- to coarse-grained, pebbly, crossbedded sandstone; pebbles of black, grey, green, and white chert or argillite, quartzite, and minor porphyritic volcanic rocks; sharp contacts.
928.6	5.0	dark greenish-grey, very fine to medium-grained sandstone, grading below into
935.1	6.5	dark greenish-grey, laminated siltstone, grading into hard, dark grey, noncalcareous, silty shale in the lower part; sharp lower contact.

GLADSTONE FORMATION

Depth (feet)	Thickness (feet)	Lithology
2.0	2.0	dark grey, fine-grained, laminated, silty limestone containing thin coquinoid lenses of crushed gastropod shells; grades below into
6.5	4.5	hard, splintery, dark grey, calcareous shale, becoming more fissile towards the base.
8.5	2.0	black, fissile, calcareous shale with numerous crushed shell fragments; sharp contacts.
9.6	1.1	hard, massive-weathering, medium grey, fine-grained limestone.
10.9	1.3	hard, platy-weathering, dark grey, calcareous shale with scattered thin ripple-marked limestone lenses.
13.0	2.1	massive-weathering, grey, fine-grained, laminated, silty limestone.
13.4	0.4	dark grey, calcareous shale.
14.9	1.5	massive-weathering, medium grey, fine-grained limestone; fetid, showing evidence of diagenetic brecciation.
15.6	0.7	dark grey, calcareous shale.
22.6	7.0	massive-weathering, grey, fine-grained, silty limestone in ripple-marked beds 1 to 2 inches thick separated by brown-weathering, calcareous siltstone partings or lenses.
23.5	0.9	black, fissile, calcareous shale.
26.5	3.0	thin-bedded, grey, fine-grained, ripple-marked limestone, with shaly partings; comminuted shell fragments common.
31.1	4.6	hard, platy-weathering, dark grey, calcareous shale.
35.3	4.2	interbedded dark grey, fine-grained, coquinoid limestone and hard, platy weathering, dark grey, calcareous shale; crushed shell remains (pelecypods and gastropods) and ostracodes common in the lower part (Coll. 55-189); sharp lower contact.

base of the "calcareous" member

Depth (feet)	Thickness (feet)	Lithology
40.3	5.0	soft, black, calcareous shale; scattered shell fragments; grades below into
58.3	18.0	hard, dark greenish-grey, blocky shale.
75.3	17.0	dark greenish-grey, blocky, silty shale and siltstone.
82.8	7.5	dark red and greenish-grey mottled shale; silty towards the base.
90.5	7.7	dark grey, mottled shale.
93.5	3.0	dark greenish-grey, calcareous siltstone; disseminated pyrite common.
107.5	14.0	hard, dark red, mottled shale, partly covered.
110.5	3.0	greenish-grey, calcareous siltstone.
113.5	3.0	hard, dark greenish-grey, silty shale; grades below into
118.9	5.4	hard, massive-weathering, grey, calcareous siltstone and fine sandstone.

Depth (feet)	Thickness (feet)	Lithology
126.9	8.0	hard, dark red and greenish-grey mottled shale; irregular concretionary calcareous beds in the upper 2 feet.
129.9	3.0	hard, grey, calcareous sandstone and siltstone; irregular contacts.
130.9	1.0	nodular-weathering, pale grey, aphanitic limestone.
145.9	15.0	hard, blocky, red and minor green mottled, silty shale with scattered lenses or nodules of ironstone up to 1 foot thick.
150.4	4.5	hard, greenish-grey, silty shale, lensing out along strike.
156.9	6.5	grey, fine-grained, calcareous sandstone, grading up into grey siltstone or silty shale; sharp lower contact.
160.8	3.9	dark grey siltstone and silty shale.
161.9	1.1	grey, medium-grained, calcareous sandstone, grading up into siltstone.
162.9	1.0	hard, greenish-grey, calcareous shale.
163.7	0.8	pale greenish-grey, fine-grained, lensing, calcareous sandstone or arenaceous limestone with scattered shell fragments.
167.2	3.5	pale grey, very fine grained, arenaceous limestone, grading up into greenish-grey silty shale in the upper 6 inches.
168.7	1.5	hard, greenish-grey, silty shale.
173.7	5.0	(covered)
183.7	10.0	massive-weathering, greenish-grey siltstone.
213.7	30.0	(covered)
227.7	14.0	dark grey, medium-grained, crossbedded, cherty sandstone; top of the basal sandstone member.
256.7	29.0	sandstone, as above; microcrossbedding prominent with poorly developed ripple marks on some bedding planes; sharp lower contact with minor channeling of underlying black, fissile, coaly shales of the Kootenay Formation.

base of Section C

Section: cored section of the Mannville Group: Fort Augustus Formation (proposed type section) and McMurray Formation.

Location: Anglo, Home, C. and E. Fort Augustus No. 1 well, about 25 miles northeast of Edmonton in Lsd. 7, Sec. 29, Tp. 55, R. 21, W. 4th Mer. (Figs. 11, 12).

Depth[1] (feet)	Thickness (feet)	Lithology
		JOLI FOU FORMATION
2424	3.0	dark grey, fissile shale with *Inoceramus fragments;* sharp lower contact.
		FORT AUGUSTUS FORMATION
	1.0	hard, pale brownish-grey, carbonaceous siltstone; sharp contacts.
	5.0	soft, white, very fine grained, micaceous, quartzose sandstone; fissile and carbonaceous in the upper part.
2433	8.0	soft, pale grey, laminated, carbonaceous siltstone, slumped at base.
2442	7.5	interbedded dark grey to black shale and grey, fine-grained sandstone; 1-inch bentonite bed at top, 6 inches of coal and coaly shale at base; well-preserved plant remains (Coll. FA-63).
	1.5	soft, pale grey, fine-grained, cherty sandstone; massive with root-like structures.
2451	4.0	poor recovery: sandstone, as above.
	5.0	hard, pale grey, very fine grained, cherty sandstone, intimately mixed with medium grey, silty shale blebs and partings, becoming more silty in the lower part.
2460	0.6	dark grey, laminated siltstone and black, coaly shale.
	3.5	hard, pale grey, massive siltstone and fine-grained sandstone.
	4.3	hard, grey, fine-grained, buff-speckled (sideritic) sandstone; carbonaceous throughout, becoming calcareous in the uppermost foot.
2469	3.0	pale grey, fine-grained, cherty sandstone, as above, grading below into
	5.7	hard, grey, laminated, carbonaceous siltstone, becoming more shaly towards the base; sharp lower contact.
	0.3	hard, medium grey, coaly shale, with fern fragments.
2478	0.5	hard, dark grey siltstone and silty shale; carbonaceous with many burrow structures.
	2.5	soft, black, coaly shale and impure coal; sharp lower contact.
	4.0	hard, pale grey, fine-grained, cherty sandstone, becoming soft and carbonaceous in the lower part.

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[1] Given depth from surface to top of cored interval.

Depth (feet)	Thickness (feet)	Lithology
2487	9.0	soft, buff-speckled sandstone, as above, grading below into pale grey, laminated sandstone and carbonaceous siltstone; 3-inch ironstone bed in middle.
2496	4.3	grey, finely laminated siltstone and minor silty shale, grading below into
	2.2	dark grey, fissile shale, siltstone, and pale grey, fine-grained sandstone; sharp lower contact.
	2.5	hard, dark grey shale, grading into laminated, silty shale and siltstone with abundant carbonaceous matter.
2505	0.5	soft, fissile coal, shaly at base.
	4.6	hard, grey shale and coaly shale with scattered plant fragments.
2514	2.2	soft, blocky to fissile coal, shaly at base.
	4.0	hard, pale to medium grey siltstone and silty shale, becoming more silty towards the base; many plant remains (Coll. FA-72).
	2.8	hard, pale grey, fine-grained, buff-speckled sandstone.
2523	3.7	sandstone, as above, grading below into
	3.3	hard, grey, massive to laminated siltstone and silty shale; grades below into
	2.0	hard, medium grey, laminated, silty shale with scattered plant fragments.
2532	1.0	hard, medium grey shale with abundant plant remains (Coll. FA-75).
2535	1.0	shale, as above, grading below into
	8.0	hard, pale to medium grey, laminated, silty shale and siltstone with scattered conifer fragments in the upper part; more silty in the lower 3 feet.
2544	6.5	laminated, silty shale and siltstone, as above; calcareous in the upper half, grading below into
	2.5	pale grey, laminated, carbonaceous siltstone and silty sandstone with scattered plant remains in the upper 6 inches (Coll. FA-77).
2553	2.0	hard, grey, plant-bearing shale, grading below over a few inches into pale grey, fine-grained, carbonaceous sandstone.
2562	0.5	hard, dark grey, fissile shale; sharp lower contact.
	8.5	hard, grey, massive siltstone and silty shale; poorly laminated with many carbonaceous fragments; poorly preserved gastropods noted.
2571	3.0	hard, pale grey, massive, carbonaceous sandstone, grading below into
	4.2	pale to medium grey, blebby siltstone; grades below into
	1.8	hard, medium grey, carbonaceous shale and ironstone.
2580	2.5	soft to hard, pale grey, laminated, silty sandstone.
	6.5	soft, pale grey, fine- to medium-grained, buff-speckled, cherty sandstone; calcareous between 2584-86 feet, becoming silty towards the base.
2589	6.0	fine-grained, laminated sandstone, as above.
	0.5	hard, massive, silty ironstone.
	2.5	pale grey, laminated, carbonaceous siltstone, grading into laminated silty shale in the lower 6 inches.
2598	3.1	hard, grey, laminated siltstone and silty shale; more massive in the lower part with a 2-inch thick sandstone bed at the base.
	0.7	hard, medium grey, fissile shale; contains agglutinated foraminifera; sharp contacts.

Depth (feet)	Thickness (feet)	Lithology
	0.5	pale grey, laminated siltstone; sharp lower contact.
	2.7	dark grey, fissile, pyritic shale; contains abundant agglutinated foraminifera; sharp lower contact.
	2.0	hard, pale greenish-grey, massive siltstone, grading below into pale greenish-grey shale with scattered plant remains (Coll. FA-89).
2607	1.8	black, coaly shale and impure coal; sharp lower contact.
	0.8	blocky, greenish-grey shale.
	1.5	hard, pale grey, massive, carbonaceous siltstone.
	0.2	black, coaly shale.
	1.0	hard, grey shale, grading below into soft, pale grey, massive siltstone; many plant remains (Coll. FA-90).
	0.7	pale grey, waxy, carbonaceous shale.
	3.0	hard, pale grey, massive siltstone and silty sandstone; much carbonaceous matter.
2616	4.5	hard, pale to medium grey, buff-speckled, silty sandstone and siltstone.
2625	6.0	hard, grey, massive siltstone with scattered ironstone partings.
2634	0.8	hard, pale brownish-grey ironstone, grading below into
	1.5	hard, pale grey, blocky shale with plant remains (Coll. FA-92).
	3.8	hard, pale grey, massive, silty sandstone; laminated with scattered shaly partings in the lower 3 feet; grades below into
	2.0	hard, grey, massive siltstone, grading below into
	1.0	hard, pale grey, silty shale with ironstone partings.
2643	2.0	hard, grey, silty shale with scattered ironstone partings and plant fragments.
2648	6.0	hard, medium grey to black, silty and coaly shale; more silty in the lower 6 inches.
	3.0	soft, pale grey, fine-grained, buff-speckled sandstone.
2657	5.0	sandstone, as above, grading in the lower 4 feet into hard, pale grey, medium- to coarse-grained, calcareous sandstone; siderite pellets and carbonaceous matter abundant.
2662	4.0	hard, pale grey, laminated siltstone with minor silty shale and fine-grained sandstone.
	3.0	hard, grey, laminated, calcareous siltstone and sandstone with brownish ironstone partings in the lower foot.
	1.0	grey, laminated siltstone.
2671	9.0	poor recovery: mainly comminuted grey, silty shale.
2680	7.5	pale grey to brownish, fine- to medium-grained, glauconitic, cherty sandstone; hard and calcareous in the uppermost 2 feet, soft and brownish due to light oil stain in lower part.
2689	1.5	hard, medium grey, massive shale; contains small pelecypod shells and abundant agglutinated foraminifera; grades below into
	4.5	hard, grey, massive, silty shale with scattered thin beds of ironstone and calcareous siltstone; grades below into
	3.0	hard, pale grey, laminated siltstone and silty shale.
2699	7.0	laminated siltstone and silty shale, as above, grading below into
	1.5	hard, medium grey, massive, silty shale; sharp lower contact.
	0.5	hard, grey, laminated siltstone.
2708	9.0	hard, medium grey, laminated, silty shale with scattered pale grey silty laminae or zones and several inch-thick ironstone partings; *Lingula* sp. noted.

Depth (feet)	Thickness (feet)	Lithology
2717	2.2	silty shale, as above.
	1.8	hard, medium grey shale, grading below into
	4.5	hard, dark grey shale; sandy in the uppermost 6 inches and lowermost 2 inches; glauconitic at base with a few small pelecypod shells and agglutinated foraminifera; sharp lower contact.
	0.5	soft, pale brown, fine- to medium-grained, cherty sandstone.
2725	9.0	sandstone, as above, with faint oil stain.
2734	1.5	soft, pale brownish-grey, silty sandstone with scattered dark grey shale partings; hard and calcareous in the uppermost 4 inches; grades below into
	4.5	dark grey, semi-fissile, slightly silty shale; contains rare agglutinated foraminifera; grades below into
	3.0	soft, pale grey, laminated siltstone and white, fine-grained sandstone with scattered shaly partings; several ironstone partings in the lowermost 6 inches.
2743	2.0	hard, brownish-grey, massive, silty ironstone; sharp lower contact.
	6.0	soft, pale grey to brown, medium-grained, cherty sandstone with scattered hard calcareous intervals; some faint irregular oil stain.
2752	7.0	fine- to medium-grained sandstone, as above.
2761	9.0	fine- to very fine grained sandstone, as above; many buff siderite pellets.
2770	7.0	sandstone, as above, with scattered shaly partings.
	1.5	hard, pale grey, fine-grained, calcareous sandstone with scattered glauconite pellets.
2779	1.5	calcareous, glauconitic sandstone, as above.
	7.5	soft, pale brown, fine, even-grained sandstone; siderite pellets and glauconite common; shows faint oil stain.
2788	9.0	soft, pale brown, very fine grained sandstone with scattered silty partings.
2797	1.0	hard, dark brown, medium-grained, oil-stained sandstone.
2798	2.0	hard, pale grey, fine-grained, orange-speckled, calcareous sandstone.
2808	3.0	hard, pale brown, fine-grained, laminated sandstone, grading below into
	4.0	pale brown, fissile, silty sandstone with silty shale partings in the lower 18 inches.
2815	1.0	hard, pale brown to grey, fissile, laminated siltstone and silty shale, grading below into
	1.5	hard, medium-grey, semi-fissile, waxy shale with scattered silty laminae; ironstone partings in the uppermost 6 inches; agglutinated foraminifera common.
	6.5	hard, grey, laminated to blebby siltstone and silty shale, grading into soft, white, silty sandstone in the lowermost 2 feet.
2824	9.0	hard, pale grey, laminated, carbonaceous sandstone and siltstone with darker shaly partings in the lower half.
2833	3.5	hard, grey, laminated siltstone and silty shale.
	3.0	pale grey, fine-grained, silty sandstone; hard and calcareous in lower 2 feet; sharp lower contact.
	2.5	hard, grey, laminated siltstone and silty shale.
2842	9.0	laminated siltstone and shale, as above, becoming more shaly in the lower 3 feet.

Depth (feet)	Thickness (feet)	Lithology
2851	9.0	laminated siltstone and silty shale, as above, with scattered pale grey, silty sandstone beds up to 2 inches thick in the upper 6 feet, the proportion of dark grey, silty shale increasing below.
2860	6.6	hard, medium to dark grey, semifissile, silty shale, becoming more silty towards the base; agglutinated and calcareous foraminifera present; sharp lower contact.
	2.4	hard, pale grey, laminated, silty, glauconitic sandstone with scattered dark grey, silty shale partings in the lower foot.
2869	8.5	soft, black, fissile shale with scattered silty laminae; calcareous foraminifera common; sharp lower contact.
	0.5	hard, green, fine-grained, glauconitic sandstone mixed with grey, carbonaceous sandstone.
2878	9.0	dark green to greenish-grey, fine-grained, glauconitic, cherty, calcareous sandstone with rare dark grey shale blebs; faint oil stain.
2887	7.5	dark green, glauconitic sandstone, as above; moderately calcareous in the upper part with abundant hard, dark grey, silty shale partings in the lowermost 18 inches.
2896	4.0	soft, silty, glauconitic, calcareous sandstone with numerous dark grey, silty shale partings; sharp lower contact marks the base of the Fort Augustus Formation.

McMURRAY FORMATION

Depth (feet)	Thickness (feet)	Lithology
	5.0	hard, dark brownish-grey, silty shale with numerous crumpled silty laminae becoming more common towards the base; siltstone is whitish to pale brown, micaceous-quartzose, and shows faint irregular oil stain.
2905	9.0	hard to soft, white, quartzose siltstone and dark grey, silty shale; massive to blebby with burrow structures common.
2914	9.0	siltstone and shale, as above, with scattered pockets or laminae of fine-grained, quartzose sandstone.
2923	9.0	siltstone and shale, as above, with a few harder claystone-like partings.
2932	4.0	siltstone and shale, as above, harder and siliceous(?).
	2.0	white, laminated, carbonaceous siltstone and dark grey shale; similar to above except for the presence of well-preserved bedding.
2938	6.0	hard, laminated, quartzose siltstone and black shale, as above, becoming moderately calcareous and fossiliferous (pelecypods, ostracodes) in the lower 4 feet; few thin beds of white, porous sand in the upper part with many silty lenses showing faint oil stain; marks the top of the "calcareous" member.
2947	0.5	hard, black, laminated, silty shale with scattered ostracodes.
	2.0	hard and soft, pale grey, slumped, silty sandstone.
	7.0	hard, pale grey, finely laminated siltstone, sandstone, and dark grey shale; calcareous in part with some slumping.
2956	9.0	hard, laminated siltstone and silty shale, as above; partly calcareous with scattered pelecypods and ostracodes, becoming more shaly towards the base.

Depth (feet)	Thickness (feet)	Lithology
2965	9.0	hard, black, calcareous shale with scattered silty beds becoming less common in the basal foot; many ostracodes.
2974	8.7	hard, black, calcareous, silty shale with abundant pelecypods, ostracodes, and rare gastropods; sharp lower contact marks base of "calcareous" member.
	0.3	hard, pale brown, fine-grained, calcareous sandstone.
2983	6.0	hard, pale grey to brown siltstone, intimately mixed with thin partings and blebs of dark grey silty shale.
	2.0	soft, pale brown, very fine grained sandstone.
	1.0	hard, grey, massive, silty shale with pale brown silt blebs.
2992	1.6	hard, grey, blebby siltstone and silty shale.
	2.5	hard, pale grey, massive siltstone, grading below into soft, pale brown, fine-grained sandstone.
3001	7.0	interbedded pale brown, silty, carbonaceous sandstone, minor siltstone and dark grey silty shale.
3010	3.6	interbedded pale brown, very fine grained, massive sandstone and blebby siltstone; sharp lower contact.
	0.7	hard, dark brownish-grey, massive, silty shale and siltstone.
	4.7	soft, pale brown, silty sandstone with hard silty intervals in the upper part.
3019	9.0	hard to soft, pale brown to grey, massive to blebby, silty sandstone and siltstone with scattered dark grey shale blebs.
3028	0.2	pale brown ironstone.
	2.8	hard, dark grey, semifissile, silty shale, grading below into pale grey, massive to blebby siltstone.
3037	1.5	hard, pale grey, blebby siltstone and dark grey, silty shale with scattered beds of soft, pale brown, silty sandstone.
	4.5	soft, pale brown, silty sandstone with scattered hard silty beds.
3046	6.0	sandstone, as above, with rare dark shale partings.
3054	7.0	soft, pale brown, fine-grained, quartzose sandstone, mixed with hard, dark grey, silty shale in uppermost foot.
3062	4.0	sandstone, as above, with several inch-thick beds of siltstone and silty shale.
3066	8.0	sandstone, as above, with scattered shaly partings; 2-inch bed of brownish-grey, silty ironstone at base.
3075	2.9	soft, pale brown, fine- to coarse-grained, quartzose sandstone with scattered shaly partings.
	0.2	hard, sandy ironstone.
	3.3	interbedded grey siltstone, silty shale, and sandstone; massive to blebby; sharp lower contact.
	0.9	hard, dark grey, waxy shale.
	0.7	soft, brown and white, fine-grained sandstone.
3084	3.3	sandstone, as above.
	4.7	interbedded hard, grey, silty shale, siltstone, and white, quartzose sandstone; laminated to massive.
3093	4.5	pale brown to grey, soft, silty sandstone and hard siltstone; sharp lower contact.
	4.5	interbedded hard, dark brownish-grey, silty shale and pale grey, laminated to massive, carbonaceous siltstone.

Depth (feet)	Thickness (feet)	Lithology
3102	1.0	hard, whitish, massive siltstone.
3111	9.0	soft, pale brown to grey, very fine grained, quartzose sandstone with scattered thin beds of hard, grey, laminated siltstone and silty shale.
3129	9.0	soft, pale brown, fine-grained, quartzose sandstone.
3138	9.0	sandstone, as above.
3147	8.0	sandstone, as above, becoming medium to coarse grained in the lower 5 feet; slightly calcareous in the basal 2 feet.
3156	3.3	hard, dark grey, massive, silty shale; 2-inch ironstone bed at top; sharp lower contact.
	5.7	hard, grey to brown, carbonaceous siltstone with numerous dark grey, silty shale and whitish sandstone partings; small pelecypod shell noted.
3165	1.2	hard, dark brownish-grey, calcareous siltstone, grading below into
	3.0	pale brown to grey, silty to medium-grained, calcareous, "salt-and-pepper" sandstone; sharp lower contact.
	2.7	hard, brownish-grey, laminated, calcareous siltstone, grading below into hard, dark brown, calcareous, silty shale.
3174	3.0	shale, as above, grading below into
	2.0	hard, black, waxy shale with scattered fish scales; 3-inch ironstone bed at base.
3179	4.0	shale, as above; sharp lower contact.
	2.0	soft, white, massive, clayey siltstone.
3188	1.5	siltstone, as above, grading below into
	1.5	brownish-grey siltstone; grades below into
	2.5	hard, dark brownish-grey, massive shale.
3197	2.0	shale, as above, grading below into black, fissile shale; sharp lower contact.
	2.0	hard, dark brown, massive siltstone, grading below into soft, pale brown sandstone.
	1.5	soft, pale grey sandstone, grading below into hard, dark brown, massive siltstone and silty shale.
3204	1.2	dark brown, silty shale, becoming sandy at the base.
	4.8	soft, white, fine-grained, quartzose sandstone.
3213	3.5	hard, brownish-grey, waxy shale, becoming sandy in the basal 6 inches; grades below into
	1.0	white, massive, clayey siltstone; sharp lower contact.
	2.5	brownish-grey, massive, waxy shale.
3222	7.0	hard, dark brown, waxy shale, becoming silty and carbonaceous in the lower part.
	2.0	soft, white, clayey siltstone.
3231	0.5	hard, brown, massive siltstone.
	2.0	soft, white, clayey siltstone and sandstone; sharp lower contact.
	1.5	hard, dark brown, massive shale, becoming silty towards the base.
3240	0.5	hard, pale grey, blebby siltstone; sharp lower contact.
	3.0	hard, brownish-grey, blocky shale.
	3.0	hard, brown, massive siltstone, grading below into
	2.0	soft, white, clayey siltstone and fine-grained sandstone.
3249	5.0	pale grey to white, quartzose siltstone with scattered dark shale partings; sandy towards the base.

Depth (feet)	Thickness (feet)	Lithology
3257	9.0	interbedded white, quartzose siltstone and fine-grained sandstone with many carbonaceous and coaly partings.
3266	9.0	hard, pale green to bluish-green, massive, silty shale; 4 inches of fine-grained, calcareous, quartzose sandstone at the base.
3275	6.0	shale, as above; sharp lower contact with brown, finely crystalline dolomite (Devonian).

base of measured section

APPENDIX B. TABLES 8-14

LOCATIONS, GRAIN SIZES, AND MODAL ANALYSES OF PETROGRAPHICALLY ANALYSED BLAIRMORE AND MANNVILLE GROUP SANDSTONES

Key to table headings:

Spl: sample number.

Fm (Tables 11, 12), formation: BM, Beaver Mines; MC, Mill Creek; FS, "Fish-scale" sand; bC, basal Blacktone (post-"Fish-scale" sand); MP, Mountain Park; Lu, Luscar; FA, Fort Augustus; Mc, McMurray.

Dep: feet below top or above base of formation.

Size: mean quartz grain size in millimeters.

Q: quartz, quartzite.

Ch: chert.

F: feldspars.

RF: nonvolcanic rock fragments.

VR: volcanic rock fragments.

Mi: micas.

H: accessory "heavy" minerals.

Ma: matrix.

Ct: calcite.

Do: dolomite.

Si: siderite.

Qz: quartz cement.

Cl: chlorite cement.

K: kaolinite cement.

I: illite cement.

Mo: montmorillonite cement.

L: laumontite cement.

H: hydrocarbon cement.

Ot: other cementing agents.

V: uncemented pore spaces.

Ms: miscellaneous constituents.

Table 8. Locations, Grain Sizes, and Modal Analyses of Gladstone Formation Sandstones, Alberta Foothills

Spl	Location	Position	Size	Q	Ch	F	RF	Mi	H	Ma	Ct	Do	Qz	K	Ms
57-25	Mill Creek	basal member[1]	.258	40.00	10.25	-	16.50	-	-	5.00	-	12.75	8.25	4.25	3.00
57-26	Mill Creek	basal member	.184	29.50	9.50	-	23.25	-	-	25.25	-	2.25	3.75	4.75	1.75
56-26	Mill Creek	50 ft. above b. mbr.	.152	26.75	3.50	0.50	18.00	-	-	3.25	0.75	47.00	tr	-	0.25
56-27	Mill Creek	50 ft. above b. mbr.	.222	42.75	10.50	0.25	18.75	-	-	20.50	-	-	4.50	2.00	0.75
57-17	Oldman R.	basal member	.289	33.00	20.75	-	20.25	-	-	-	-	tr	19.50	6.00	0.50
57-18	Oldman R.	basal member	.456	32.00	24.00	-	15.50	-	0.25	0.25	-	0.25	22.75	2.75	2.25
57-19	Oldman R.	25 ft. above b. mbr.	.260	40.25	13.00	-	34.75	-	-	0.75	-	0.75	6.00	3.75	0.75
57-20	Oldman R.	25 ft. above b. mbr.	.112	40.00	5.50	-	17.00	-	0.25	11.25	19.50	-	6.25	-	0.25
57-44	Sheep River	basal member	.307	35.00	16.00	-	28.50	-	-	-	-	10.25	8.25	1.25	0.75
57-45	Sheep River	basal member	.216	38.75	10.00	-	17.50	-	-	-	-	7.25	20.25	4.75	1.50
56-413	Sheep River	85 ft. above b. mbr.	.110	33.50	6.75	-	12.50	-	-	11.00	tr	18.25	17.75	tr	0.25
56-414	Sheep River	90 ft. above b. mbr.	.196	37.75	15.00	-	20.25	-	-	1.75	tr	16.25	7.50	1.00	0.50
57-58	B. Timber Cr.	10 ft. above b. mbr.	.408	49.25	19.00	-	15.50	-	-	-	-	1.00	13.75	1.00	0.50
57-59	B. Timber Cr.	10 ft. above b. mbr.	.331	42.00	24.00	-	22.00	-	-	-	-	-	10.50	1.00	0.50
57-60	B. Timber Cr.	75 ft. above b. mbr.	.191	15.50	40.50	-	19.00	-	-	2.00	7.50	10.50	3.50	-	1.50
57-61	B. Timber Cr.	75 ft. above b. mbr.	.266	38.25	12.00	-	20.50	-	-	3.00	11.00	2.00	12.75	-	0.50
57-121	Ram River	basal member	.451	9.00	69.50	-	11.00	-	-	0.50	-	-	4.00	6.00	-
57-122	Ram River	basal member	.317	21.00	37.50	-	17.00	-	-	1.00	-	-	16.00	7.50	-
57-114	Ram River	130 ft. above b. mbr.	.176	39.00	18.00	-	16.50	-	-	5.50	1.50	4.00	13.00	1.50	1.00
57-103	Ram River	350 ft. above b. mbr.	.043	60.50	1.00	-	11.00	1.50	0.50	4.50	2.50	-	18.00	-	0.50

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[1] equivalent to the Cadomin Conglomerate in most parts of the Foothills.

Table 9. Grain Sizes and Modal Analyses of Beaver Mines Formation Sandstones, Mill Creek, Type Section

Spl	Dep[1]	Size	Q	Ch	F	RF	VR	Mi	H	Ma	Ct	Qz	Cl	CM[2]	K	I	L	Ms
56-105	70	.204	14.00	1.00	11.00	20.25	22.25	2.50	-	9.50	10.00	-	-	7.00	2.00	-	-	0.50
56-104	70	.250	9.75	2.25	8.75	17.00	20.50	2.50	0.50	5.00	27.00	-	-	6.50	tr	-	-	0.25
56-108	120	.195	14.50	2.75	14.25	23.75	23.75	2.25	0.50	6.50	6.75	-	*	4.25	0.25	-	-	0.50
56-111	155	.139	15.75	2.00	15.25	10.25	20.00	1.50	1.75	12.50	0.50	-	*	18.75	1.00	-	-	0.75
57-27	205	.091	10.50	2.00	2.50	16.00	18.00	2.50	0.75	11.50	35.00	-	-	tr	-	-	-	1.25
56-128	255	.281	11.00	6.50	10.00	12.50	32.25	1.50	3.50	4.50	-	-	16.75[3]	**	-	0.50	-	1.00
56-130	260	.142	10.50	4.00	18.00	15.00	25.75	2.00	5.00	3.75	14.00	-	1.75[3]	**	-	-	-	0.25
56-132	285	.141	15.00	3.00	17.00	17.00	19.00	4.00	1.50	12.00	-	2.50	7.50	-	-	tr	-	1.50
56-145	365	.180	13.00	2.25	16.00	17.00	31.50	2.75	2.75	3.75	-	1.00	8.75	-	-	1.00	-	0.25
57-28	430	.142	17.50	1.00	18.50	13.50	24.75	1.00	2.75	13.25	0.50	1.25	1.75	-	2.00	2.00	-	0.25
56-86	525	.307	15.00	3.25	28.50	14.75	22.25	2.25	1.25	3.50	-	0.75	6.50	-	-	1.00	0.75	0.25
56-85	530	.287	16.25	4.75	30.25	9.75	23.50	0.50	2.00	1.50	4.00	0.25	6.25	-	-	-	0.25	0.75
56-82	565	.184	11.00	4.25	21.00	20.50	20.00	1.50	0.50	3.75	-	2.00	11.25	-	-	0.75	2.75	0.75
56-79	595	.174	10.50	2.50	20.00	19.50	24.00	1.00	0.75	1.75	-	0.25	16.75	-	-	1.50	0.25	1.25
57-29	625	.238	11.00	7.75	19.50	16.25	24.00	0.25	1.25	1.25	9.50	0.25	8.25	-	-	-	-	0.75
56-65	765	.235	9.50	10.75	17.50	19.50	28.25	-	0.50	1.25	1.00	1.75	9.75	-	-	0.25	-	-
56-63	780	.221	12.00	4.50	14.75	12.75	29.50	0.25	2.25	1.75	0.50	1.25	18.50	-	-	1.25	-	0.75
56-61	800	.250	14.50	5.75	16.75	16.50	24.50	1.50	2.50	2.75	-	1.25	12.00	-	-	1.75	-	0.25
56-50	875	.103	15.25	4.25	6.50	18.25	12.25	3.75	1.50	24.50	-	-	-	-	-	12.00	-	1.75
56-41	920	.301	24.50	16.25	4.50	29.00	9.00	0.50	-	3.75	-	2.00	4.25	-	1.75	2.75	-	1.75

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[1] feet below top of formation. [2] mixed chlorite-montmorillonite cement. [3] includes some montmorillonite.

* included with chlorite-montmorillonite cement. ** included with chlorite.

Table 10. Grain Sizes and Modal Analyses of Beaver Mines Formation Sandstones, Sheep River, Western Section

Spl	Dep[1]	Size	Q	Ch	F	RF	VR	Mi	H	Ma	Ct	Qz	Cl	K	I	L	Ms
57-35	55	.283	13.00	5.25	15.25	18.25	30.75	1.25	0.50	7.75	0.75	3.75	3.50	-	tr	-	-
57-37	130	.142	12.00	2.75	9.75	10.50	24.50	1.75	0.75	24.75	1.75	0.50	8.75	1.00	1.00	-	0.25
57-38	170	.187	13.75	2.00	8.25	16.50	34.25	1.50	2.00	4.25	11.50	1.00	2.25	-	2.75	-	-
57-39	170	.107	9.00	0.50	9.75	17.50	27.25	0.75	1.50	26.00	0.75	0.50	4.50	-	1.75	-	0.25
56-316	215	.163	5.75	1.50	27.75	11.00	32.00	0.50	1.00	10.00	0.50	tr	7.25	-	1.75	-	1.00
56-320	235	.183	11.50	1.25	21.00	15.00	27.75	0.50	0.75	9.25	1.75	tr	8.00	-	3.25	-	-
56-338	375	.398	5.25	0.50	31.00	4.25	40.50	-	0.25	4.00	1.75	0.25	6.50	-	-	5.75	-
56-342	390	.346	5.75	0.50	34.50	7.25	30.50	0.50	0.75	4.75	0.50	-	12.50	-	-	2.50	-
56-347	420	.486	5.25	0.25	35.25	5.75	39.25	0.25	1.00	3.25	0.25	-	6.25	-	-	3.25	-
57-40	445	.271	15.25	3.00	17.25	12.50	32.50	1.25	1.50	5.25	-	7.50	3.50	-	0.50	-	-
57-41	505	.124	12.75	2.00	8.00	19.25	23.50	3.75	1.00	17.75	2.25	-	3.50	-	5.50	-	0.75
57-42	590	.184	16.50	5.75	12.00	15.75	23.00	1.25	1.50	6.75	2.75	2.50	11.25	-	0.25	-	0.75
57-43	600	.172	16.50	2.25	15.50	13.50	22.25	0.25	1.50	14.00	0.25	2.50	9.25	-	0.75	-	1.50
56-364	650	.173	11.25	4.50	18.50	20.50	25.25	0.50	1.75	2.75	1.75	3.25	9.00	-	0.75	-	0.25
56-362	675	.216	13.50	4.50	15.75	12.75	35.75	-	2.00	2.50	0.25	2.00	8.50	-	2.25	-	0.25
56-368	725	.176	13.50	3.00	19.25	20.75	24.00	0.50	1.75	4.50	-	1.50	7.50	-	3.00	-	0.75
56-370	745	.192	8.75	5.00	15.50	15.25	30.25	0.25	2.00	2.50	8.00	0.50	10.25	-	1.25	-	0.50
56-372	765	.271	11.00	9.75	12.00	23.25	24.75	0.75	1.00	4.75	2.00	2.75	6.50	-	1.50	-	-
56-374	785	.228	6.25	9.25	8.25	12.75	16.00	1.75	0.25	0.50	44.75	-	-	-	-	-	0.25
56-377	830	.153	13.50	8.75	7.50	22.50	16.75	3.00	0.75	19.00	2.00	-	0.50	-	5.25	-	0.50

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[1] feet below top of formation.

Table 11. Grain Sizes and Modal Analyses of Beaver Mines Formation Sandstones, Ram River

Spl	Dep[2]	Size	Q	Ch	F	RF	VR	Mi	H	Ma	Ct	Do	Si	Qz	Cl	K	I	Hy	Ms
57-128[1]	18	.210	13.00	5.00	21.25	13.75	29.75	1.25	-	4.00	4.00	-	-	-	2.25	5.75	-	-	-
57-129[1]	25	.334	8.00	4.25	23.75	10.00	23.50	0.50	-	-	29.75	-	-	-	-	-	-	-	0.25
57-74	140	.120	14.50	0.50	15.50	10.00	17.00	2.00	-	27.00	0.50	-	-	3.00	8.00	1.50	?	-	0.50
57-75	150	.198	13.00	4.00	13.50	16.25	33.25	1.25	0.25	6.50	7.50	-	-	0.50	1.25	1.00	-	-	1.75
57-76	195	.168	14.75	4.00	19.25	12.00	27.00	1.25	-	3.50	12.50	-	-	0.50	2.00	2.25	-	-	1.00
57-81	215	.203	13.75	2.00	17.50	17.00	28.50	1.75	0.25	11.75	2.50	-	-	1.25	2.25	1.25	-	-	0.25
57-82	230	.188	8.50	1.75	15.25	12.75	29.50	0.75	0.50	23.75	1.75	-	-	0.25	3.25	1.25	0.25	-	0.50
57-78	260	.208	12.25	4.25	12.25	13.75	18.00	0.50	-	19.00	20.00	-	tr	-	tr	-	-	-	-
57-85	375	.218	16.25	5.00	14.00	17.75	29.00	0.50	-	6.25	0.50	0.25	3.25	1.25	-	4.00	1.75	-	0.25
57-86	390	.204	17.75	2.25	11.25	21.25	27.25	-	-	7.75	-	-	3.00	1.25	-	7.50	0.75	-	-
57-89	430	.126	9.75	2.50	13.25	10.50	22.25	0.75	-	7.25	5.00	24.50	0.75	-	-	2.00	1.50	-	-
57-90	450	.158	11.00	1.00	8.25	11.75	21.00	1.00	0.25	2.00	8.25	28.75	3.50	0.25	-	2.25	0.25	-	0.50
57-94	495	.230	14.50	4.25	12.50	17.50	31.75	0.50	-	9.25	-	1.00	0.75	0.75	-	7.25	-	-	-
57-95	505	.120	5.00	1.75	5.75	11.00	10.75	0.25	-	3.50	21.50	39.25	1.25	-	-	-	-	-	-
57-96	555	.262	8.50	9.50	8.75	9.75	21.50	1.00	0.50	2.00	25.00	13.00	0.25	-	-	-	-	-	0.25
57-97	570	.341	14.75	14.25	10.00	18.25	29.75	0.75	-	4.25	0.50	0.75	-	4.75	-	-	0.50	1.25	0.25
57-98	610	.293	17.75	17.50	9.00	15.00	25.00	0.50	0.50	4.25	tr	1.00	-	2.25	-	-	1.75	5.25	0.25
57-99	635	.271	13.00	6.50	17.50	16.25	33.50	0.75	-	5.25	0.25	1.00	1.25	2.25	-	-	0.75	1.75	-
57-100	665	.264	10.75	11.25	9.50	16.25	36.00	0.25	-	7.50	-	1.50	-	2.75	-	-	4.00	0.25	-
57-101	710	.111	25.00	5.25	0.25	26.50	3.00	0.50	-	3.50	-	33.00	-	3.00	-	-	-	-	-

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[1] from North Ram River, on strike with the main Ram River section. [2] feet below top of formation.

Table 12. Locations, Grain Sizes, and Modal Analyses of Miscellaneous Alberta and Blairmore Group Sandstones, Alberta Foothills and Southern Plains

Spl	Location	Fm	Dep[3]	Dep[4]	Size	Q	Ch	F	RF	VR	Mi	H	Ma	Ct	Do	Si	Qz	Cl	K	I	Ot	Ms
56-211	Ma Butte	BM	20	?	-	16.00	3.00	16.00	21.00	19.00	2.00	2.00	3.00	11.00	-	-	-	1.00	4.00	-	-	2.00
56-464	Sheep River[1]	MC	70	?	-	23.00	14.00	3.00	37.00	8.00	-	-	1.00	1.00	-	-	1.00	11.00[5]	1.00	*	-	-
56-468	Sheep River[1]	BM	?	760	-	9.50	2.00	25.50	5.00	31.00	2.00	2.50	2.00	2.00	-	-	-	14.00	-	4.00	-	0.50
56-474	Sheep River[1]	BM	?	415	-	7.00	2.50	34.00	7.00	31.00	1.50	2.00	1.00	-	-	-	-	5.50	-	-	8.50[6]	-
PC8120	Pine Creek No. 1	BM	50	450	.163	13.33	2.00	26.00	15.33	21.33	2.67	-	6.00	4.67	-	-	0.67	8.00	-	-	-	-
PC8240	Pine Creek No. 1	BM	170	330	.206	14.67	-	22.00	14.67	26.00	1.33	-	17.33	-	-	-	0.67	3.33	-	-	-	-
CM6790	Okotoks 10-23	BM	35	460	.197	7.00	1.00	32.00	7.00	29.00	2.00	-	10.00	3.00	-	-	-	tr	8.00	-	-	1.00
CM6840	Okotoks 10-23	BM	90	405	.152	14.00	1.00	22.00	15.00	14.00	3.00	-	22.00	9.00	-	-	-	**	**	-	-	-
CM7030	Okotoks 10-23	BM	275	220	.091	15.00	4.00	16.00	13.00	11.00	-	-	21.00	11.00	-	8.00	tr	-	tr	-	-	1.00
CM7150	Okotoks 10-23	BM	395	100	.219	14.00	1.00	17.00	11.00	29.00	-	-	4.00	16.00	-	2.00	-	-	6.00	-	-	-
RB 6250	Ranchmen's 1	FS	-	-	.192	48.67	2.67	-	13.33	1.33	-	-	3.33	-	-	-	14.00	10.00	5.33	-	-	1.33
RB 6668	Ranchmen's 1	BM	110	395	.150	12.00	1.33	20.00	15.33	16.66	0.67	-	7.33	24.00	-	2.66	-	-	tr	-	-	-
57-52	B. Timber Cr.[2]	bC	-	-	-	60.00	11.00	-	17.50	-	-	-	1.50	-	-	-	***	2.00[7]	1.00	-	6.50[8]	0.50
57-54	B. Timber Cr.[2]	BM	10	860	-	16.50	8.50	18.00	11.50	25.50	0.50	-	3.00	4.50	-	-	-	9.00	3.00	-	-	-
60-116	B. Timber Cr.[2]	BM	360	510	-	15.00	-	26.50	6.00	33.50	-	-	1.50	2.00	-	-	-	15.00	-	tr	-	0.50
60-36	Tershishner Cr.	MP	?	?	-	11.00	4.50	28.50	12.00	24.50	-	-	-	-	-	-	-	18.50	-	1.00	-	-
60-37	Tershishner Cr.	MP	?	?	-	17.00	4.00	24.50	10.00	21.50	1.00	-	1.50	4.50	-	-	-	14.50	-	1.00	-	0.50
60-41	Tershisher Cr.	Lu	?	?	-	18.50	5.00	14.00	23.50	13.00	1.50	-	4.00	7.50	-	1.50	0.50	-	10.50	-	-	0.50
57-12	Cadomin	MP	130	?	.212	10.75	2.50	24.50	14.25	28.25	0.50	-	5.75	4.50	-	-	0.25	5.50	-	3.25	-	-
57-11	Cadomin	MP	160	?	.346	11.00	6.75	13.25	12.75	34.75	1.25	-	5.50	4.50	-	-	0.75	9.50	-	-	-	-
57-10	Cadomin	MP	190	?	.240	12.25	3.50	17.50	12.50	31.50	0.25	-	4.75	4.25	-	-	1.50	11.75	-	-	-	0.25
57-9	Cadomin	MP	230	?	.196	12.50	2.00	20.00	12.75	30.75	0.75	0.50	5.50	0.25	-	-	0.25	14.00	-	0.50	-	0.25
57-8	Cadomin	MP	260	?	.173	13.25	3.25	17.50	14.50	25.75	0.50	-	4.00	4.75	-	-	0.50	15.25	-	0.75	-	-
57-5	Cadomin	Lu	?	?	.139	20.25	8.50	5.25	23.25	16.00	0.25	-	8.50	-	5.75	-	1.75	-	9.75	0.50	-	0.25

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[1] section 2, figure 6. [2] section east of Forestry Trunk Road bridge. [3] feet below top of formation. [4] feet above base of formation.

[5] mixed chlorite-illite cement. [6] laumontite. [7] identification uncertain. [8] empty pore space.

* included with chlorite. ** indistinguishable from clastic "matrix". *** included with detrital quartz.

Table 13. Locations, Grain Sizes, and Modal Analyses of Mannville Group Sandstones, Alberta Plains

Spl	Location	Fm	Dep[1]	Size	Q	Ch	F	RF	VR	Mi	H	Ma	Ct	Do	Si	Qz	K	Mo	V	Ms
BS-17	Stanmore No. 1	FA	115	.411	8.5	4.5	8.5	11.5	34.5		0.5	3.5	1.5	-	2.0	-	4.5	19.0	-	1.5
BS-24	Stanmore No. 1	FA	199	.141	14.5	2.0	20.5	15.0	27.5	2.5	-	8.5	-	-	-	-	9.0	-	-	0.5
BS-34	Stanmore No. 1	FA	300	.184	6.5	3.0	13.5	16.0	25.0	0.5	-	10.0	0.5	-	5.5	-	8.5	11.0	-	-
WV-31	W. Viking No. 1	FA	5	.063	17.0	1.0	16.5	12.5	8.5	2.0	1.0	37.0	-	tr	2.5	tr	1.5	-	-	0.5
WV-37	W. Viking No. 1	FA	79	.224	11.5	2.5	10.5	6.5	29.5	1.0	-	30.0	-	-	-	tr	7.0	-	-	1.5
WV-42	W. Viking No. 1	FA	170	.212	8.0	1.0	11.5	9.5	14.5	0.5	-	-	50.5	-	3.0	-	-	-	-	1.5
WV-53	W. Viking No. 1	FA	299	.211	24.0	4.0	12.0	23.0	18.0	1.0	2.0	1.0	-	-	-	tr	14.0	-	-	1.0
AW-127	Wabamun No. 1	FA	56	.292	7.0	3.0	19.0	9.5	33.0	-	1.0	3.5	16.5	-	7.0	-	-	tr	-	0.5
AW-161	Wabamun No. 1	FA	168	.156	20.5	4.5	19.5	15.5	21.0	1.5	-	4.0	-	tr	3.5	tr	10.0	-	-	-
AW-177	Wabamun No. 1	FA	311	.183	14.5	2.5	20.0	20.5	28.0	0.5	0.5	3.0	-	-	4.0	tr	6.0	-	-	0.5
AW-206	Wabamun No. 1	FA	474	.270	22.0	18.0	0.5	42.5	4.0	-	-	2.0	-	0.5	-	8.5	2.0	-	-	-
FA-66	Ft. Augustus No. 1	FA	38	.135	11.5	2,5	18.5	13.0	13.5	-	0.5	-	35.0	-	4.5	-	-	-	-	1.0
FA-83	Ft. Augustus No. 1	FA	159	.092	9.5	2.0	4.5	12.5	13.0	2.0	-	8.5	20.0	-	25.0	-	3.0	-	-	-
FA-109	Ft. Augustus No. 1	FA	339	.097	19.0	0.5	18.0	19.0	24.0	-	-	8.0	-	2.0	-	tr	6.0	-	3.5	-
FA-123	Ft. Augustus No. 1	FA	465	.141	30.5	5.5	1.0	25.5	9.5	-	-	13.5	-	8.0	0.5	tr	1.0	-	3.5	1.5
FA-143	Ft. Augustus No. 1	Mc	643	.282	68.0	1.0	1.0	-	-	-	-	-	30.0	-	tr	tr	-	-	-	-
FA-147	Ft. Augustus No. 1	Mc	723	.503	64.0	-	1.0	3.0	-	-	-	4.0	2.0	-	-	2.0	2.0	-	22.0	-
EP-45	Elk Point No. 1	FA	75	.343	3.0	1.0	14.5	12.5	30.5	1.5	-	0.5	-	-	23.5	-	0.5	12.5	-	-
EP-48	Elk Point No. 1	FA	112	.169	11.5	3.5	16.5	21.5	20.0	2.5	1.5	3.0	-	tr	tr	-	19.5	*	-	0.5
EP-59	Elk Point No. 1	FA	264	.077	26.0	1.0	8.0	10.0	3.5	1.0	-	9.0	21.0	-	18.0	-	-	-	-	2.5
EP-67	Elk Point No. 1	FA	380	.114	13.0	3.0	12.0	16.5	7.0	0.5	-	-	47.0	-	0.5	-	-	-	-	0.5
LL-5	Lyle Lake No. 1	FA	214	.134	9.0	4.0	7.5	18.5	18.0	1.5	-	-	36.5	-	4.0	-	-	-	-	1.0
LL-13	Lyle Lake No. 1	FA	312	.144	9.5	2.5	15.0	23.5	31.5	-	-	-	-	0.5	-	-	0.5	0.5	16.5	-
LL-22	Lyle Lake No. 1	FA	443	.124	14.0	3.5	9.0	23.5	16.5	2.0	-	4.5	-	6.5	1.0	-	5.0	-	13.0	1.5
WW-11	W. Wabiskaw No. 1	FA	42	.160	23.5	2.0	14.5	8.0	20.5	-	1.0	-	-	2.5	0.5	-	3.0	5.0	19.5	-
WW-24	W. Wabiskaw No. 1	FA	194	.137	26.5	2.5	14.5	14.0	13.5	-	0.5	-	-	2.0	-	-	1.0	tr	25.0	0.5
WW-45	W. Wabiskaw No. 1	FA	410	.143	8.5	1.0	6.0	15.5	9.5	3.0	-	48.5	0.5	0.5	4.0	-	-	-	-	3.0
WW-77	W. Wabiskaw No. 1	FA	696	.146	14.0	6.5	1.5	7.5	2.5	-	-	65.5	-	-	-	-	1.0	-	1.0	0.5

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[1] depth below top of the Mannville Group. *included with kaolinite.

Table 14. Locations, Grain Sizes, and Modal Analyses of Mill Creek Formation Sandstones, Southern Alberta Foothills and Plains

Spl	Location	Dep[1]	Dep[2]	Size	Q	Ch	F	RF	VR	Mi	H	Ma	Ct	Do	Qz	Cl	K	Ms
56-177	Mill Creek	370	210	.039	23.50	4.00	5.50	30.00	5.00	0.50	-	11.50	11.00	9.00	tr	-	tr	-
57-21	Mill Creek	450	130	.336	34.75	14.25	1.50	24.75	3.25	0.50	-	4.25	3.00	3.50	7.25	-	2.50	0.50
57-22	Mill Creek	490	90	.371	27.50	19.75	0.75	28.00	2.75	-	-	3.50	1.50	-	12.25	-	3.75	0.25
55-218	Mill Creek	560	20	.077	49.50	4.50	4.00	10.50	3.50	-	-	12.00	-	-	12.00	-	3.50	0.50
56-199	Ma Butte	?	255	.257	34.00	13.00	1.50	28.00	5.00	0.50	-	6.50	0.50	-	1.50	-	8.00	1.50
56-202	Ma Butte	?	240	.281	40.50	14.00	3.00	23.50	1.00	0.50	-	3.00	-	-	8.50	-	3.50	2.50
56-207	Ma Butte	?	30	.140	33.50	6.50	2.00	29.50	5.00	0.50	0.50	7.00	0.50	-	1.50	8.50	4.00	1.00
56-209	Ma Butte	?	10	.582	17.50	22.00	2.50	41.00	7.00	0.50	-	1.50	2.50	-	2.00	-	3.00	0.50
56-183	Oldman R.	60	?	.336	21.00	11.50	2.75	34.25	11.00	-	-	2.00	0.25	-	tr	10.50[3]	6.75	-
56-184	Oldman R.	60	?	.341	23.50	5.25	7.00	33.25	8.00	1.75	-	11.25	2.25	-	tr	3.25[3]	4.50	-
56-189	Oldman R.	145	?	.273	24.00	8.50	9.50	25.50	15.50	1.00	-	4.00	9.00	-	2.00	1.00[3]	?	-
56-190	Oldman R.	155	?	.222	16.25	7.00	4.75	34.00	15.75	-	-	-	22.00	-	-	-	-	0.25
56-215	Sheep R.	70	330	.129	27.50	2.50	4.50	22.50	5.00	1.50	-	33.50	2.50	-	-	*	-	0.50
56-244	Sheep R.	150	250	.127	29.00	9.50	4.50	21.00	7.00	1.00	0.50	17.50	5.00	-	tr	1.50	3.00	0.50
57-30	Sheep R.	270	130	.192	45.25	6.75	-	25.75	-	-	-	2.50	2.25	-	16.75	-	0.75	-
57-31	Sheep R.	270	130	.199	33.25	8.00	-	34.75	-	-	-	10.00	0.50	-	12.50	-	1.00	-
57-32	Sheep R.	370	30	.215	41.00	7.50	-	23.25	-	-	0.25	3.50	-	-	23.50	-	0.50	0.50
57-33	Sheep R.	370	30	.118	26.50	12.00	-	22.25	-	-	0.50	33.75	-	-	5.00	*	-	-
PC7850	Pine Creek No. 1	80	220	.287	28.00	10.00	9.33	26.67	8.67	-	-	7.33	-	-	5.33	2.67	1.33	0.66
PC8000	Pine Creek No. 1	230	70	.111	26.00	5.33	7.33	26.00	4.67	-	-	8.00	?	20.67	1.33	-	-	0.66
CM6530	Okotoks 10-23	80	220	.281	27.00	14.00	2.67	26.00	4.67	-	-	9.33	2.00	2.00	6.33	-	3.33	2.67
CM6600	Okotoks 10-23	150	150	.253	18.00	7.00	14.00	17.00	6.00	-	-	32.00	1.00	-	5.00	*	-	-
CM6670	Okotoks 10-23	220	80	.155	21.00	11.33	7.33	37.33	5.33	-	-	8.67	-	2.67	1.67	-	4.67	-
CM6690	Okotoks 10-23	240	60	.071	19.66	3.33	10.67	20.67	5.33	-	-	23.33	?	12.00	3.67	-	-	1.33
RB6316	Ranchmen's No. 1	51	244	.158	24.66	4.00	4.00	26.00	12.67	1.33	-	13.33	1.00	5.67	2.67	-	4.67	-
RB6360	Ranchmen's No. 1	95	200	.280	31.67	6.00	9.33	18.00	12.67	-	-	2.67	9.00	3.67	2.33	-	4.67	-
RB6485	Ranchmen's No. 1	220	75	.233	18.00	10.00	10.00	32.00	13.00	1.00	-	5.00	-	1.00	3.00	-	7.00	-
RB6520	Ranchmen's No. 1	255	40	.184	23.00	4.00	9.33	34.67	8.67	-	-	18.00	-	-	2.33	*	-	-

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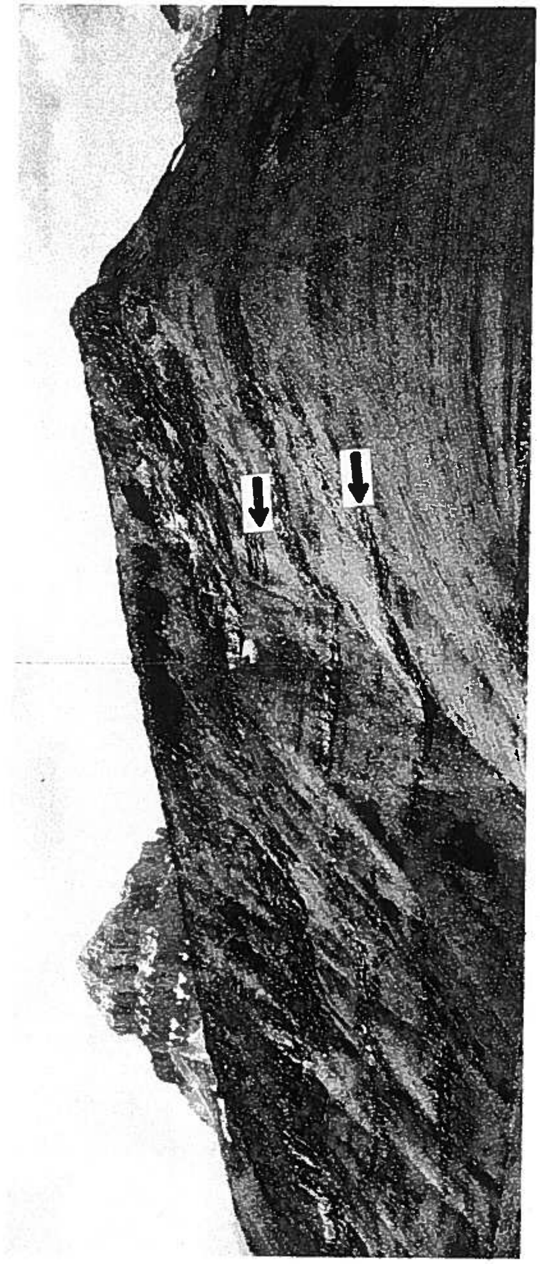
[1] feet below top of formation. [2] feet above base of formation. [3] includes some montmorillonite or illite.

* indistinguishable from clastic "matrix".

PLATES 1-30

PLATE 1



Upper beds of the Blairmore Group, Ma Butte, Crowsnest Pass area. Lower arrow marks the disconformable contact between the Beaver Mines and overlying Mill Creek Formations, at the base of a thick, laterally persistent sandstone containing lenses of chert pebble conglomerate (Fig. 5). Upper arrow marks the transition of soft tuffaceous shale to more resistant tuffs and agglomerates of the Crowsnest Member, which form the cliffs along the crest of the butte.

PLATE 2

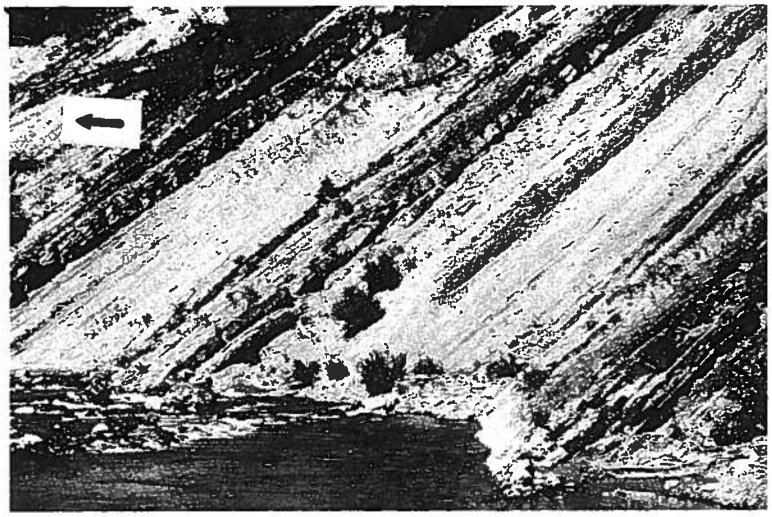


FIGURE 1. *Thin-bedded varicolored shales and silty sandstones of the Mill Creek Formation, type section, Mill Creek (Fig. 4). Sandstones contain abundant dicotyledons and ginkgos, grading over an interval of a few feet* (arrow, *upper left*) *into thin tuffs and tuffaceous shales of the Crowsnest Member.*

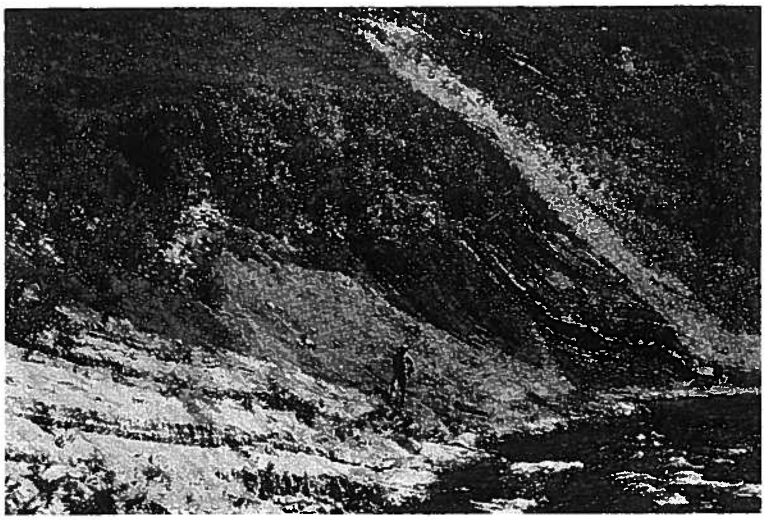


FIGURE 2. *Contact between light-colored finely crystalline tuffs and tuffaceous shales of the Crowsnest Member and overlying dark grey silty shales (Sunkay Member) of the Blackstone Formation, Mill Creek, downstream from the type section (Fig. 4). An exceptionally well-preserved dicotyledonous flora was collected from just below the contact, which, athough seemingly conformable, marks a significant hiatus in deposition at this locality.*

PLATE 3

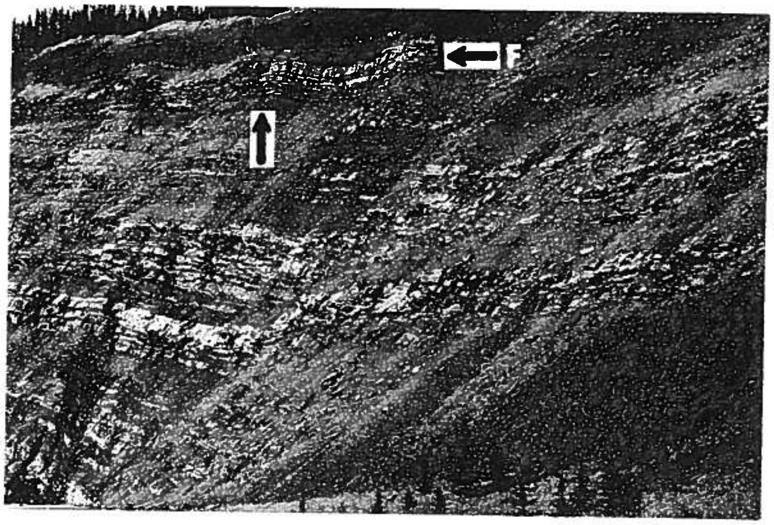


FIGURE 1. Upper beds of the Blairmore Group, Ram River. Vertical arrow marks the contact with the Blackstone Formation, which is about 20 feet below the base of a persistent quartzose sandstone (F) *correlative with the "Fish-scale" marker bed of the Plains (Figs. 9, 11). The greenish shales and sandstones of the Blairmore Group contain a non-dicotyledonous flora, correlating with the Beaver Mines Formation of the southern Foothills; however, beds correlative with the Mill Creek Formation of the southern Foothills are absent through nondeposition or erosion.*

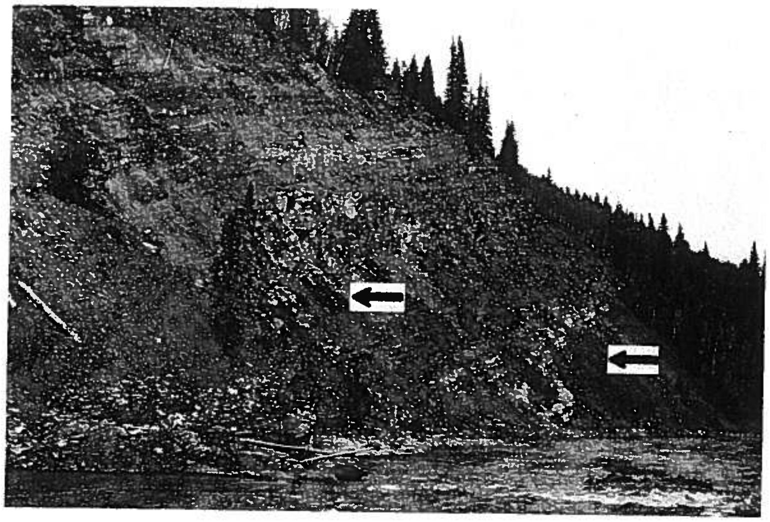


FIGURE 2. Coal-bearing (Luscar facies) beds of the Beaver Mines Formation, Ram River. The two thick coal seams in the section (Fig. 9) are indicated by arrows, beneath thick, grey, kaolinitic sandstones, the lower of which appears to lens out along the face of the outcrop. Towards the top of the section the beds grade into the greenish chloritic beds (Mountain Park facies) of the formation, shown in figure 1, above.

PLATE 4

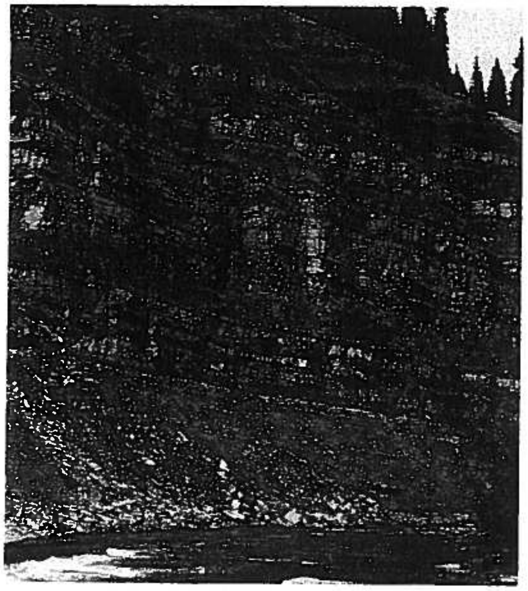


FIGURE 1. Upper beds of the Gladstone Formation, Ram River. Thin-bedded fossiliferous dark grey shale, laminated siltstone and sandstone contrast markedly in bedding and cyclicity with the overlying coal-bearing strata of the Beaver Mines Formation, although the distinctive "calcareous" member at the top of the formation in the southern Foothills is not present at this latitude (Figs. 9, 13).

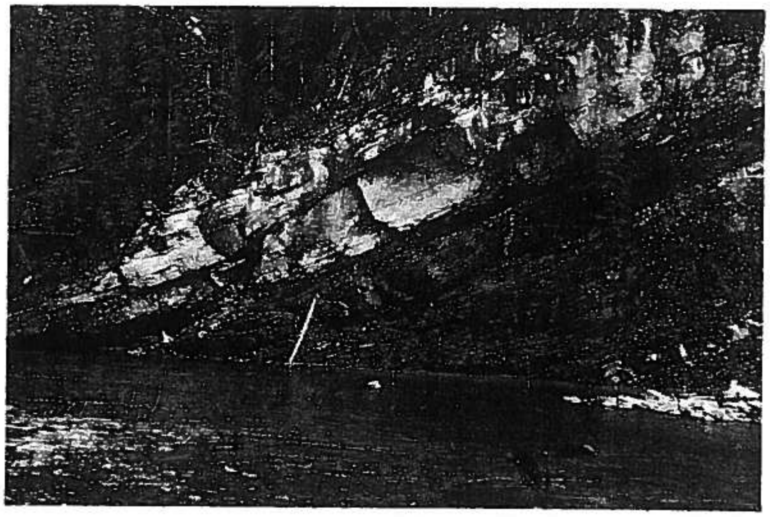


FIGURE 2. Contact between thin-bedded siltstones of the Nikinassin Formation and overlying quartzose conglomeratic sandstone (Cadomin Member) of the Blairmore Group. The contact is disconformable with a relief of several feet prevailing in channels developed in the upper surface of the Nikanassin beds (upper right).

PLATE 5

FIGURE 1. Contact (arrow) *between nonmarine plant-bearing siltstones and shales of the Beaver Mines Formation (Mountain Park facies) and overlying marine silty shales of the Blackstone Formation, Cadomin. Shales just above the contact at left contain a post-Viking microfauna, whereas Mountain Park-type beds about 15 feet below the contact contain a pre-Joli Fou non-dicotyledonous "lower Blairmore" flora (Fig. 10).*

FIGURE 2. Marine tongue (arrow) *at the base of the Beaver Mines Formation, Cadomin. The unit, which contains a microfauna correlative with that found in the Moosebar Shale of the northern Foothills, is about 15 feet thick, resting sharply but conformably on thin-bedded silty shales and siliceous sandstones of the Gladstone Formation containing ostracodes and non-dicotyledonous plant remains (Fig. 10).*

PLATE 6

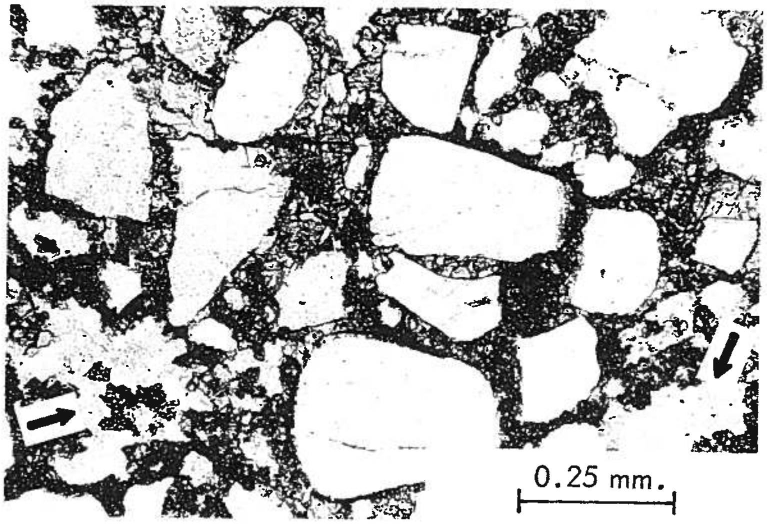


FIGURE 1. *Mixture of rounded and broken angular quartz grains and scattered shale fragments "floating" in granular dolomite. Patches of silty clay matrix* (arrows) *suggest that the dolomite is largely authigenic, having replaced most of the original clay matrix after deposition. Gladstone Formation, Mill Creek (sample 56-26).*

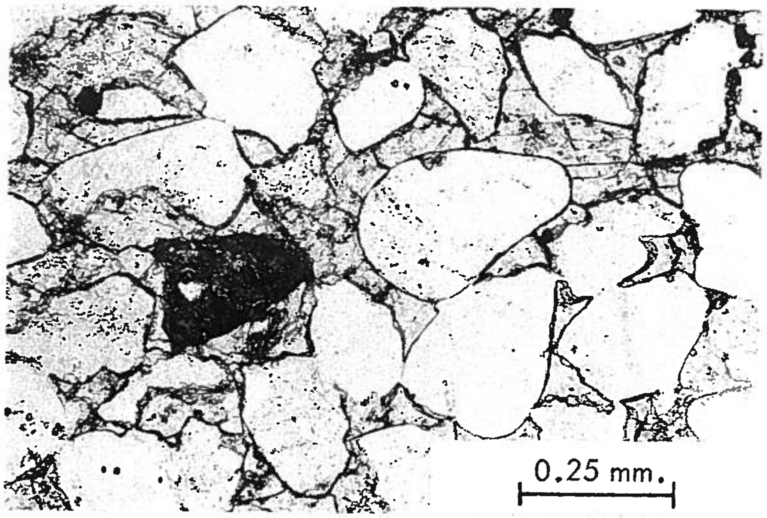


FIGURE 2. *Loosely packed, well-rounded quartz grains cemented by poikilitic (optically continuous) calcite. The apparent angularity of some quartz grains is due to incipient development of authigenic overgrowths rather than replacement ("etching") by calcite. Rare chert grains (dark) and potash feldspar grains constitute the remainder of the detritus. McMurray Formation (Ellerslie Member), Fort Augustus No. 1 well (sample FA-143).*

PLATE 7

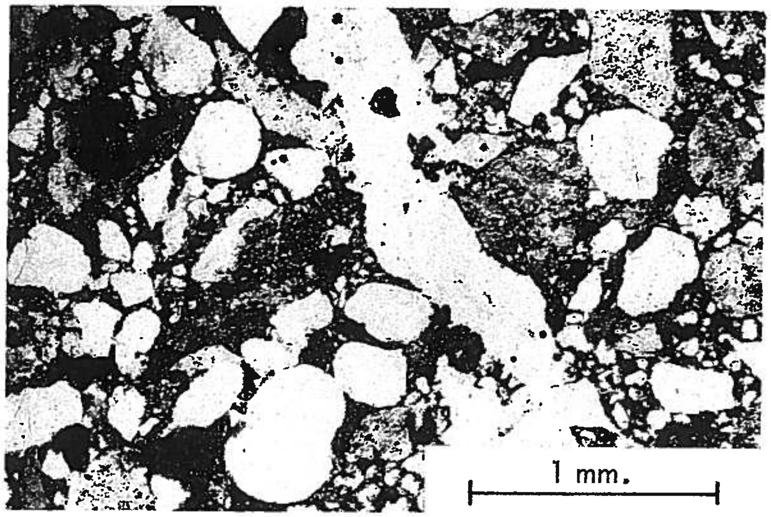


FIGURE 1. *Rounded quartz grains and siliceous rock fragments (chert, argillite) in a dark green chloritic matrix derived from the breakup of admixed clastic siltstone fragments. The transverse veinlet, cemented by clear microquartz, is of late tectonic origin. Mill Creek Formation (basal portion), Sheep River (sample 57-33).*

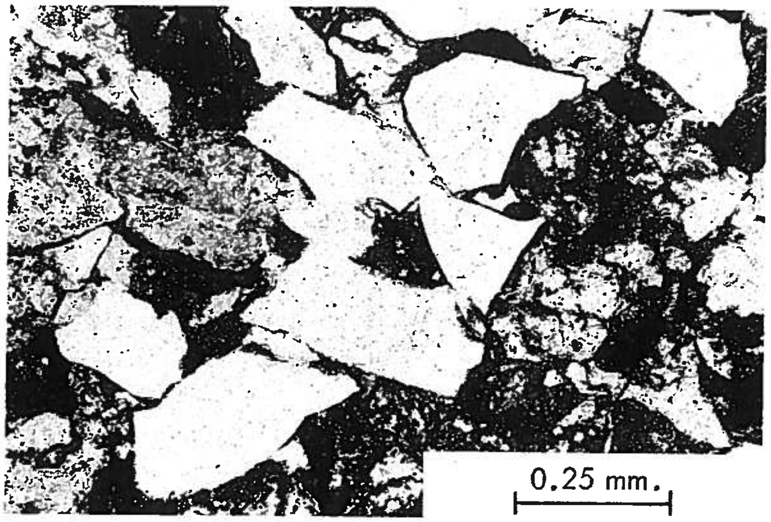


FIGURE 2. *Angular shard-like quartz (clear) and plagioclase (cloudy) in a groundmass composed mainly of crushed volcanic rock fragments and chlorite. This type of quartz is typical of most phases of the Beaver Mines and Fort Augustus Formations and is probably of volcanic (possibly pyroclastic) origin. Beaver Mines Formation, Mill Creek.*

PLATE 8

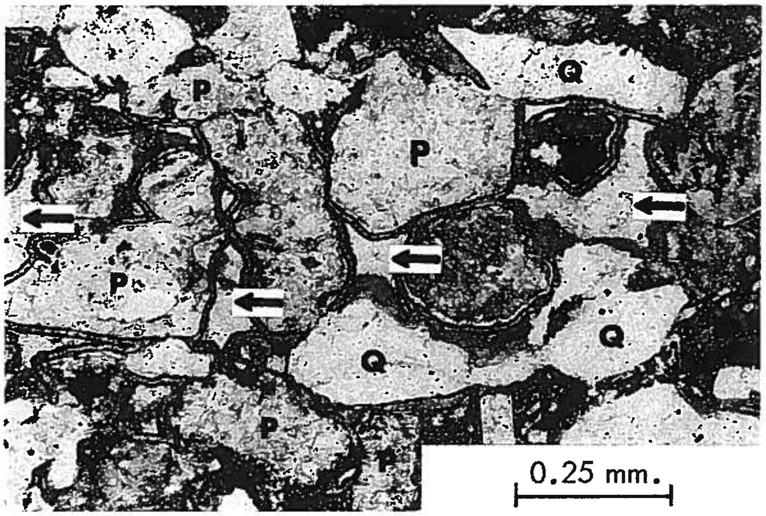


FIGURE 1. Typical Blairmore volcanic arenite composed of quartz (Q), *plagioclase* (P), *and volcanic rock fragments cemented by chlorite (as a coating on the grains) and laumontite* (arrows). *Most of the detritus is of volcanic origin, either reworked or pyroclastic, and shows only slight to moderate amounts of rounding due to abrasion. Beaver Mines Formation, Sheep River (sample 56-342).*

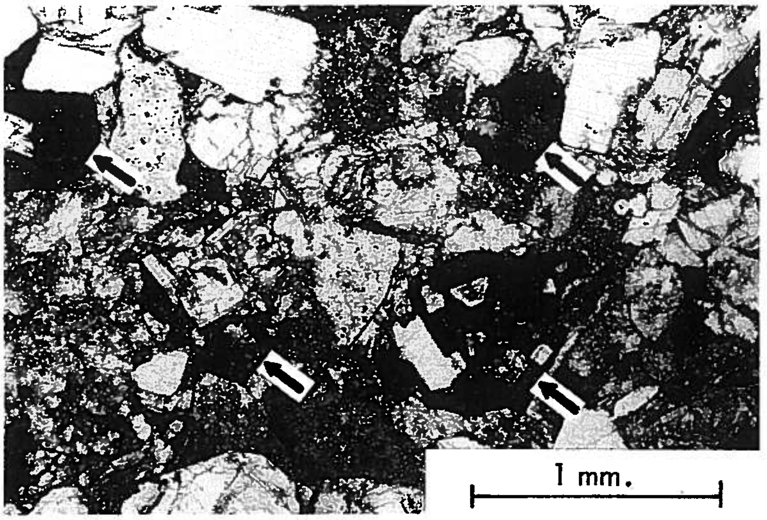


FIGURE 2. Volcanic arenite typical of the coarser-grained nonmarine phases in the upper part of the Mannville Group. Detritus consists largely of euhedral feldspars (showing prominent cleavage), crushed volcanic rock fragments (arrows), *minor clastic or metasedimentary detritus, and quartz cemented by granular calcite. Most of the volcanic fragments are composed of euhedral plagioclase in a dark brown groundmass of cryptocrystalline iron oxides, probably derived from the oxidation of chlorite. Biotite is the only common mafic constituent in these sandstones. Fort Augustus Formation, Wabamun No. 1 well (sample AW-127).*

PLATE 12

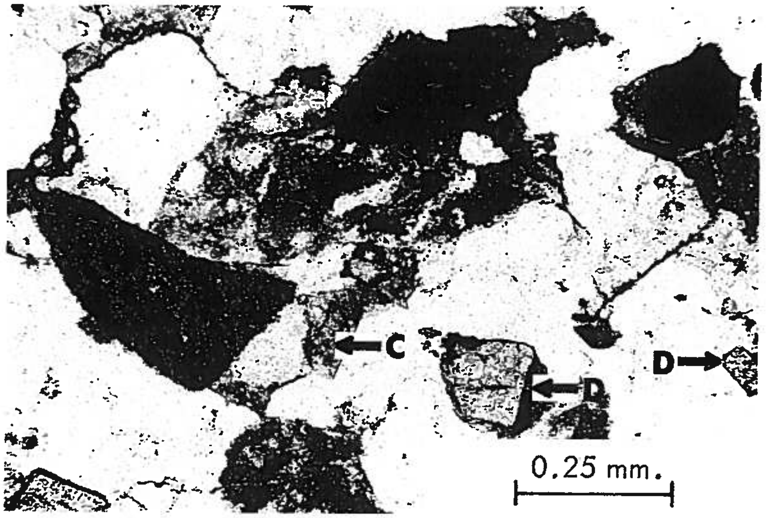


FIGURE 1. Protoquartzite composed of quartz, chert, sedimentary rock fragments, and clastic dolomite (D) *cemented by quartz (as grain overgrowths) and calcite* (C). *The rock fragments are mainly finely crystalline siliceous types (impure chert grading into argillite) that, apart from their apparently hard, indurated nature, show little evidence of metamorphic effects. Gladstone Formation, Ram River (sample 57-114).*

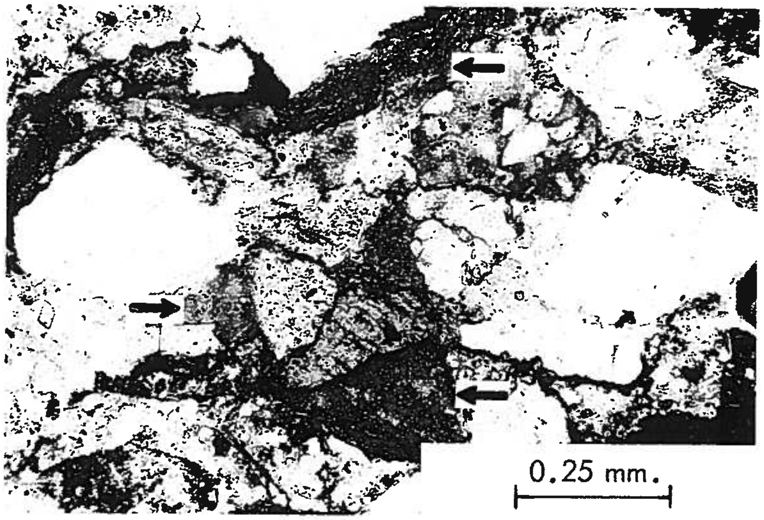


FIGURE 2. Lithic arenite composed of quartz and various types of sedimentary and metasedimentary rock fragments (silty shale, chert, argillite, slate). Many of the micromicaceous rock fragments (arrows) *exhibit all degrees of replacement by glauconite, grading from unaltered shale or slate into bright green homogeneous glauconite pellets, such as those in plate 11, figure 2. Glauconite formation apparently occurred before or during deposition, certainly prior to cementation, the main post-depositional cements in this and other Mannville glauconitic sandstones being kaolinite and quartz. Fort Augustus Formation (Wabiskaw Member), Wabamun No. 1 well (sample AW-206).*

PLATE 10

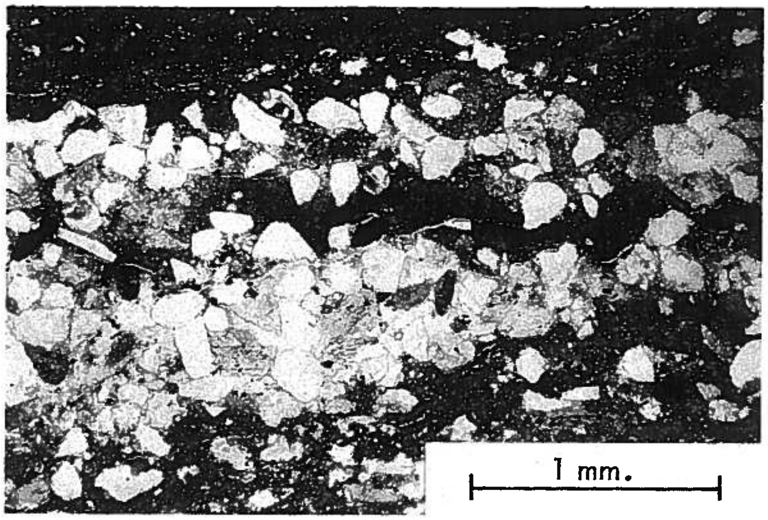


FIGURE 1. *Laminated sandstone and silty shale, typical of the finer-grained marine phases of the Mannville Group. The two lenses of fine-grained, loosely packed sandstone are partly cemented by authigenic kaolinite, grading into sand admixed with clayey matrix near the boundaries with the shaly laminae. Porosity appears to be confined to the partly cemented sand lenses which exhibit light oil staining in hand specimen. Fort Augustus Formation (type Wabiskaw Member), West Wabiskaw No. 1 well (sample WW-77).*

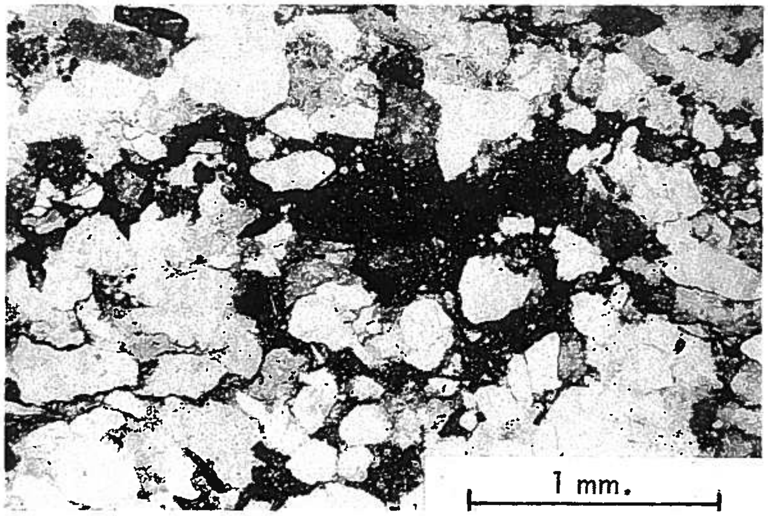


FIGURE 2. *Large clastic shale fragment in quartzose Blairmore sandstone; fragment is derived from the breakup of partly lithified shaly beds, such as those in figure 1, above. Such fragments were relatively plastic at the time of deposition, compacting and flowing to form irregular patches of porosity-destroying clayey matrix after burial. Gladstone Formation, Mill Creek (sample 57-25).*

PLATE 11

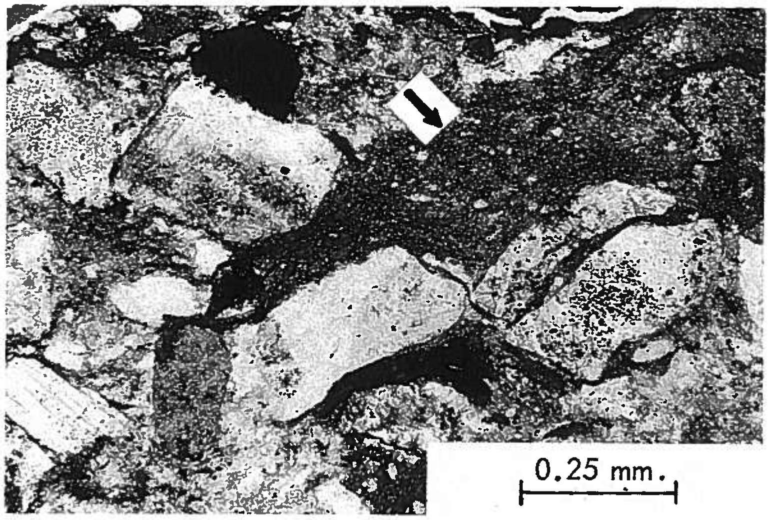


FIGURE 1. Detrital grains (mainly feldspars and finely crystalline volcanic and sedimentary rock fragments) "floating" in a cryptocrystalline clayey matrix. The latter is derived from the breakup in situ *of soft clastic shale fragments* (arrow) *during compaction, thus inhibiting the formation of authigenic cements. Fort Augustus Formation, West Viking No. 1 well (sample* WV-37).

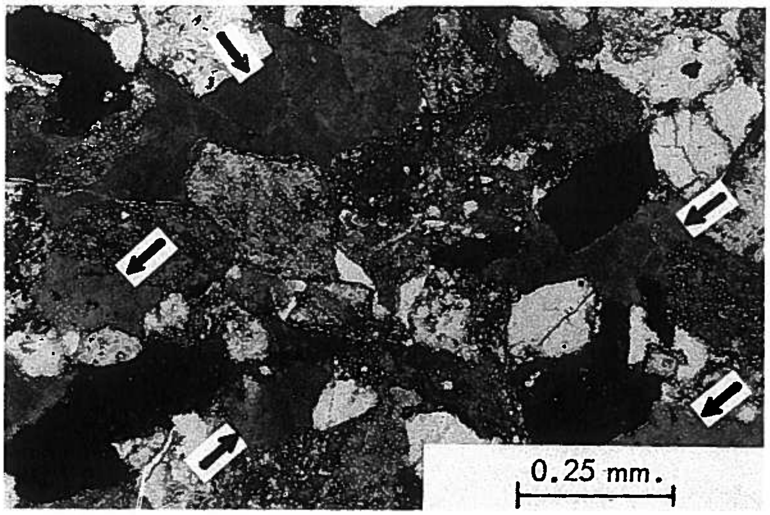


FIGURE 2. Lithic arenite composed of finely crystalline clastic and metasedimentary rock fragments, glauconite, quartz, and minor feldspars. Glauconite grains (arrows) *have been compacted and squeezed among the more rigid grains, destroying much of the original porosity of the rock. Fort Augustus Formation, Fort Augustus No. 1 well (sample FA-123).*

PLATE 9

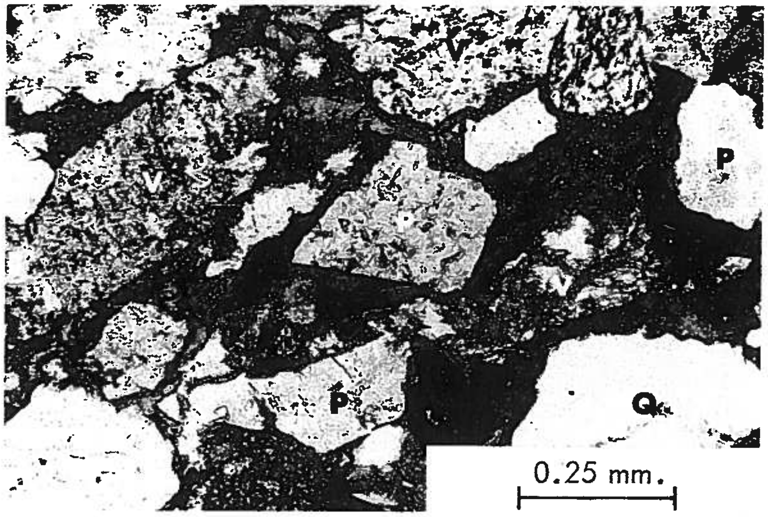


FIGURE 1. *Quartz* (Q), *subhedral plagioclase* (P), *and volcanic rock fragments* (V) *with abundant intergranular cement composed of crumpled layers of chlorite mixed with montmorillonite*(?) *and rare illite* (*cf. Pl. 26, Fig. 2*). *Volcanic fragments are largely basic or intermediate varieties composed of chorite and felsite* (*quartz and plagioclase*). *The sample is noteworthy for its high content of detrital and authigenic chlorite. Beaver Mines Formation, Mill Creek* (*sample 56-128*).

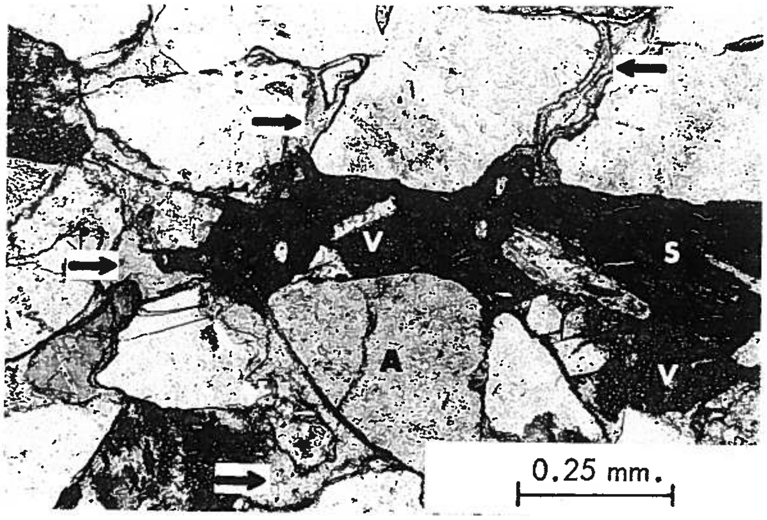


FIGURE 2. *Largely plagioclase and different kinds of rock fragments* (*volcanic,* V; *graphitic slate,* S; *argillite,* A) *cemented by chlorite and minor illite. Chlorite cement* (arrows) *is confined mainly to the interstices between the more rigid grains; any porosity originally present adjacent to the more flexible rock fragments has been largely destroyed by compaction, as, for example, in the vicinity of the crushed chloritic fragment* (*spilite*?) *in the centre of the figure. Beaver Mines Formation, Burnt Timber Creek* (*sample 60-116*).

PLATE 13

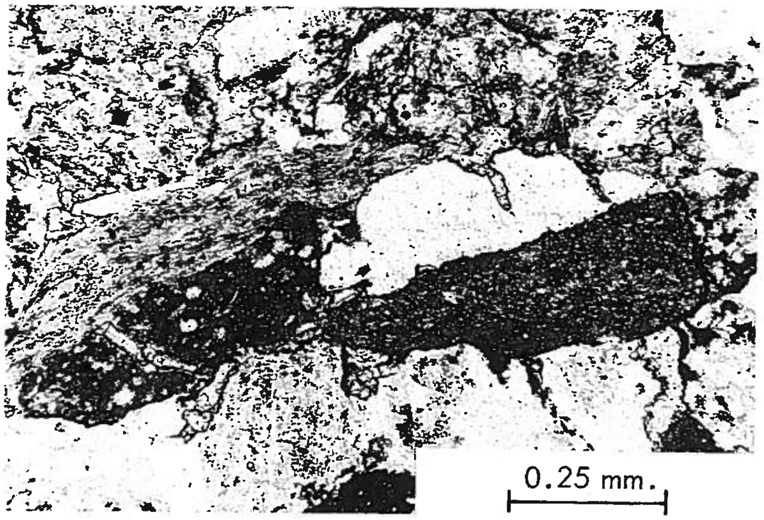


FIGURE 1. Upper Blairmore lithic arenite composed mainly of tightly packed micaceous slate and phyllite fragments, chert, quartz, and minor volcanic detritus cemented by sparry calcite. These sandstones contain a relatively high proportion of low grade metamorphic detritus in contrast to sandstones in the lower part of the group (Gladstone Formation). Mill Creek Formation (upper part), Oldman River (sample 56-189).

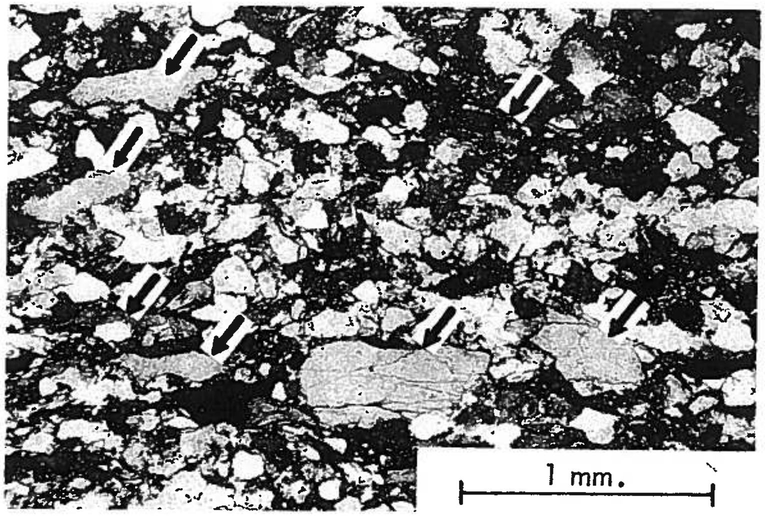


FIGURE 2. Fine-grained volcanic arenite showing laminae rich in "placers" of greenish biotite (arrows) *and carbonized wood fragments (dark), which form numerous fissile bedding planes in the finer-grained phases of many Blairmore sandstones. Note the relatively large size of the biotite flakes, many of which appear partly altered (degraded) to chlorite(?). Beaver Mines Formation, Mill Creek (sample 56-132).*

PLATE 14

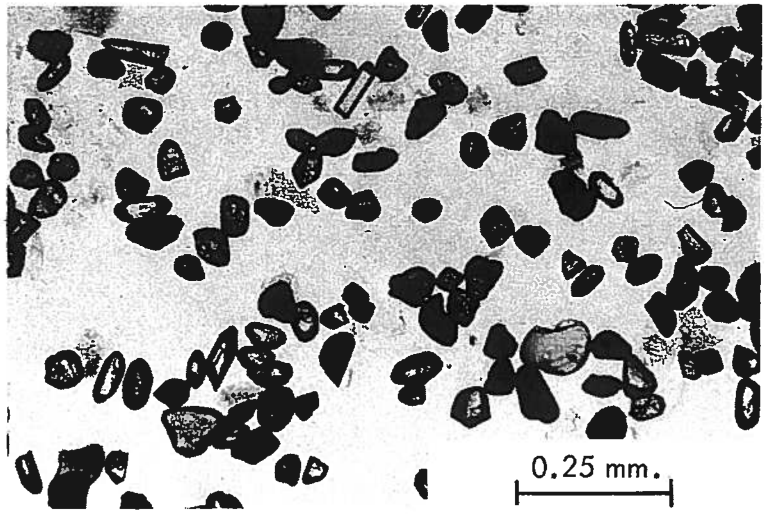


FIGURE 1. *Typical stable heavy mineral assemblage composed mainly of colorless zircon with lesser amounts of varicolored tourmaline and brownish-yellow rutile (colorless grains with very low relief are quartz). The grains tend to be well rounded although some are fractured. Gladstone Formation, Sheep River.*

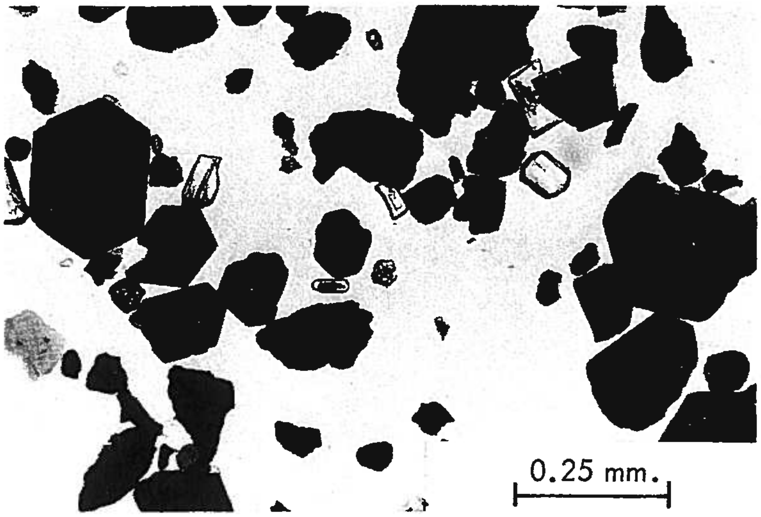


FIGURE 2. *Idiomórphic biotite and apatite (colorless) of probable pyroclastic origin. The two minerals tend to be distributed together in "floods" in certain of the Blairmore and Mannville sandstones rich in volcanic detritus, whereas adjacent sandstones of similar composition contain only trace amounts. Smaller opaque grains of irregular shape are .pyrite. Fort Augustus Formation, Elk Point No. 1 well.*

PLATE 15

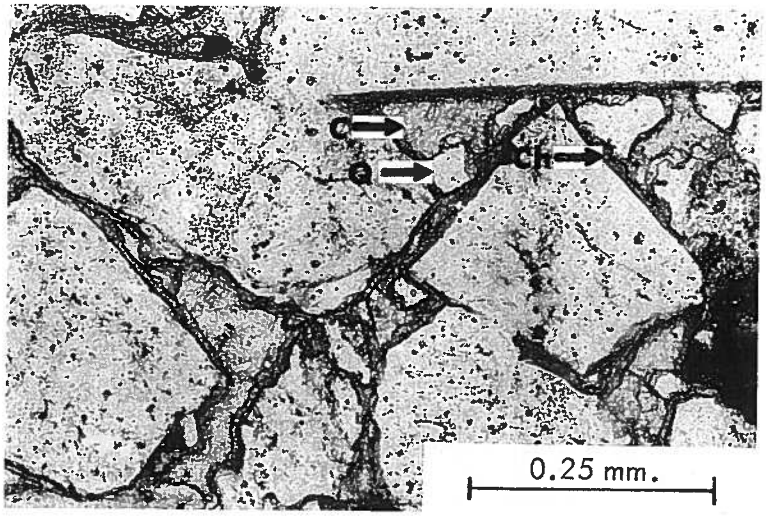


FIGURE 1. *Angular quartz cemented by chlorite (Ch), quartz (Q), and calcite (C), in that order of deposition. Chlorite is present as a fibrous layer 5 to 15 microns thick coating the pore walls, the remaining intergranular space being filled by small anhedral quartz crystals intergrown with large patches of optically continuous calcite. Beaver Mines Formation, Mill Creek.*

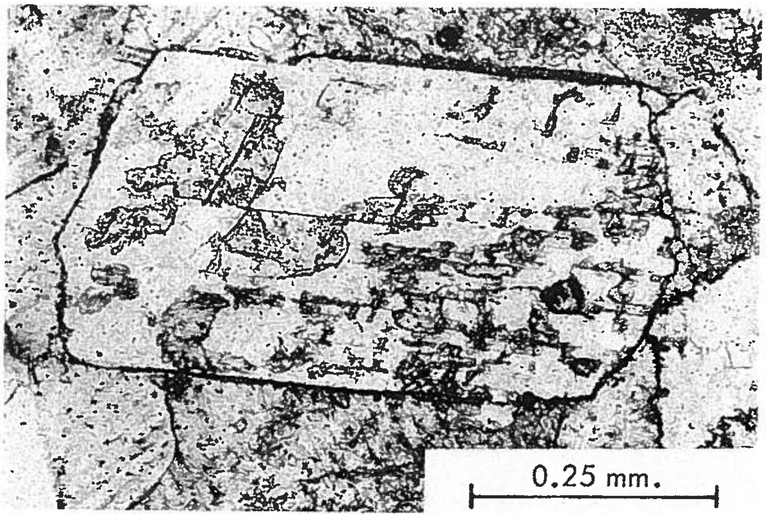


FIGURE 2. *Euhedral plagioclase grain partly replaced by authigenic calcite, also abundant as an intergranular cement. Note how the calcite parallels the cleavage planes, which have provided paths along which carbonate-bearing solutions penetrated during authigenesis. Possibly for this reason feldspars are more susceptible to replacement than quartz. Beaver Mines Formation (Mountain Park facies), North Ram River (sample 57-129).*

PLATE 16

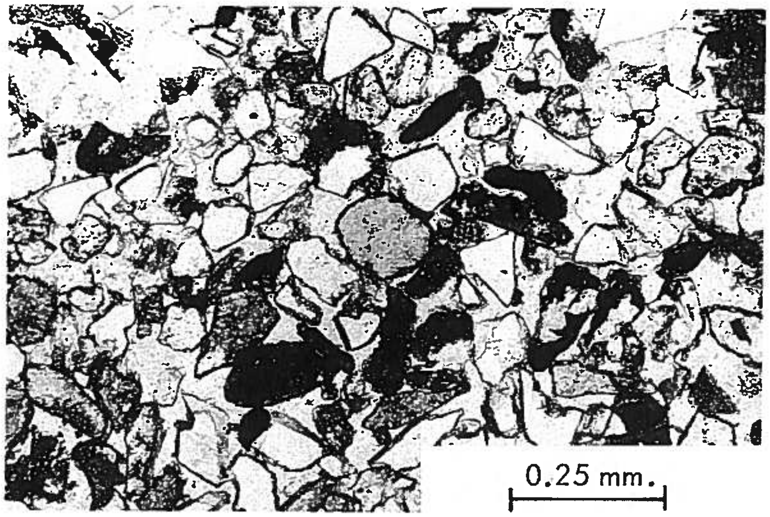


FIGURE 1. *Loosely packed detrital grains (quartz, feldspars, and various types of rock fragments) cemented by large poikilitic patches of sparry calcite. Only minor replacement of detrital constituents by calcite is evident, the "etching" effect observed about the edges of some grains being due to overlapping (slanted) calcite-grain boundaries. Fort Augustus Formation, Elk Point No. 1 well (sample EP-67).*

FIGURE 2. *Figure 1, above, crossed nicols. Diagram illustrates the large size of the irregularly shaped poikilitic calcite patches, the bifurcating one in the centre (light area) separating three similar patches (dark areas) about the periphery of the field.*

PLATE 17

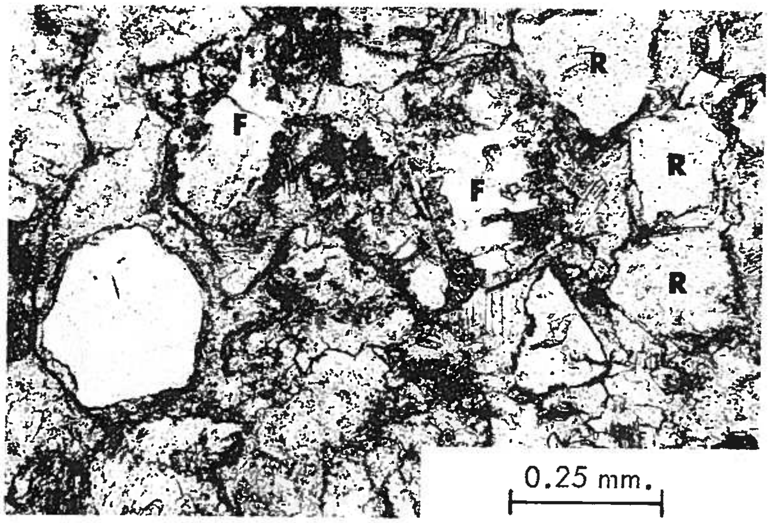


FIGURE 1. Volcanic arenite showing detrital constituents "floating" in a groundmass of anhedral equigranular calcite, grading in adjacent parts of the thin section into a bladed or fibrous variety with a spherulitic habit. Many of the feldspars (F) *and rock fragments* (R) *have been partly or completely replaced, and the original depositional fabric of the rock has been largely destroyed. Beaver Mines Formation* (*Mountain Park facies*)*, Ram River.*

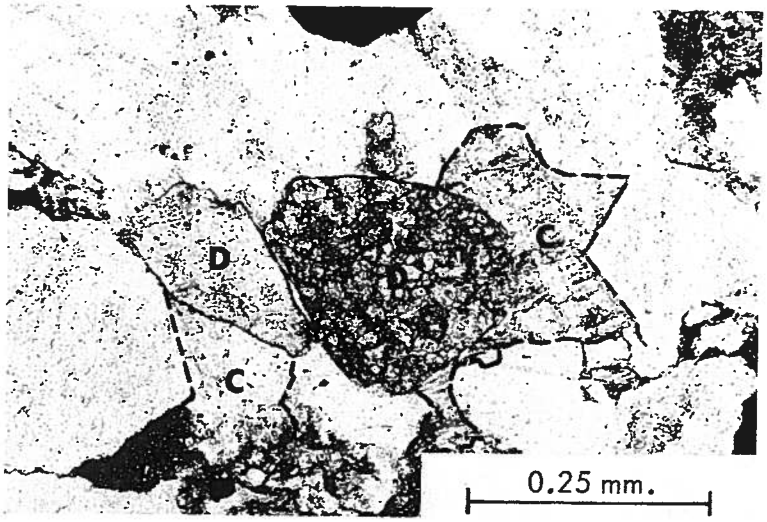


FIGURE 2. Transported dolomite grains (D)*, quartz, and siliceous rock fragments cemented by calcite* (C) *and quartz overgrowths. Polycrystalline dolomite grain* (*right*) *is of detrital or clastic origin; smaller grain* (*left*) *is an abraded rhombic crystal of local* (*clastic*) *origin. The two grains are partly enclosed by authigenic calcite* (*boundaries retouched*)*, a not uncommon feature in some sandstones. Gladstone Formation, Burnt Timber Creek* (*sample 57-61*).

PLATE 18

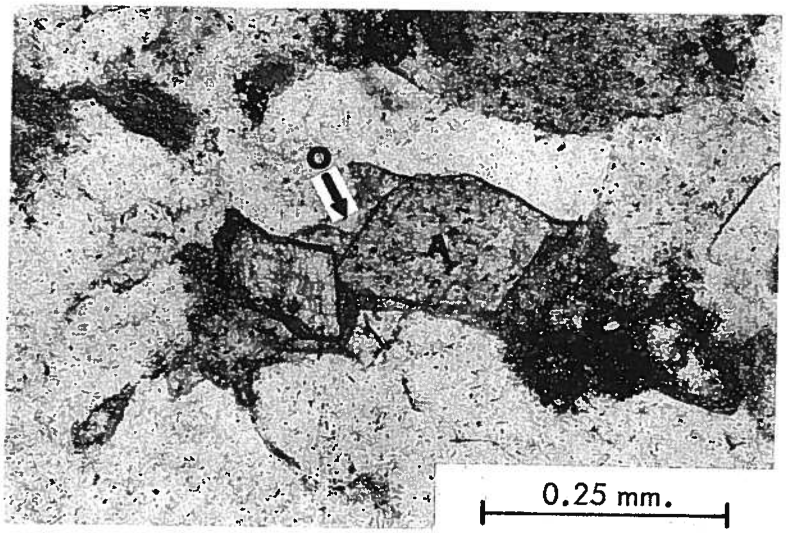


FIGURE 1. Abraded dolomite rhomb (A) in optical continuity with overgrowth (O) in quartzose sandstone. The abraded nucleus is slightly darker than the overgrowth, which partly encloses an angular rhombic grain on the left with a different optical orientation. Gladstone Formation, Mill Creek (sample 57-25).

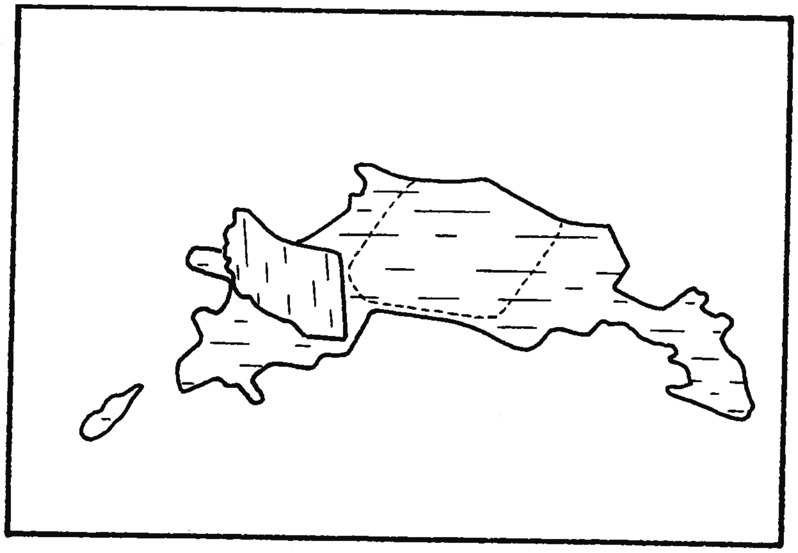


FIGURE 2. Sketch of dolomite complex in figure 1, above, showing the relative orientation of the two rhombic grains and the overgrowth.

PLATE 19

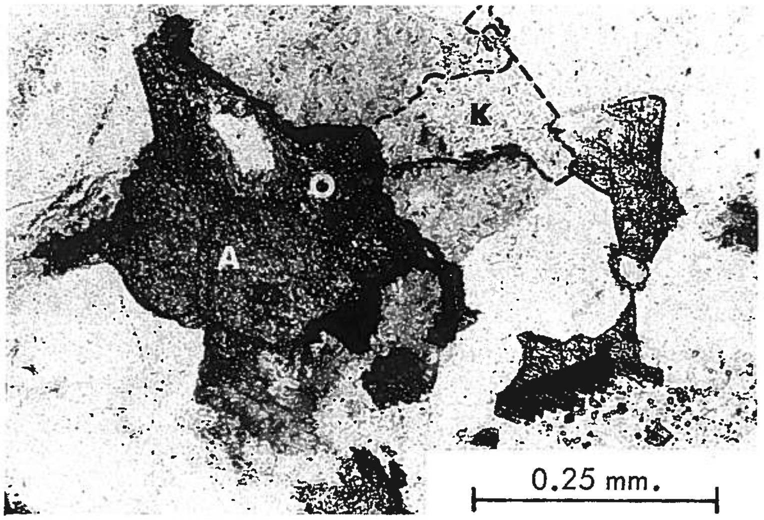


FIGURE 1. Abraded dolomite crystal (A) *and authigenic overgrowth* (O); *smaller patches of sparry dolomite to the right* (*high relief*) *are in optical continuity with the larger grain and overgrowth. Other constituents are quartz and siliceous rock fragments, quartz overgrowths, and a patch of authigenic kaolinite* (K, *retouched borders*) *in upper right of diagram. The kaolinite is in contact with both authigenic quartz and dolomite overgrowths, but the paragenesis of the three constituents is uncertain. Gladstone Formation, Mill Creek* (*sample 57-25*).

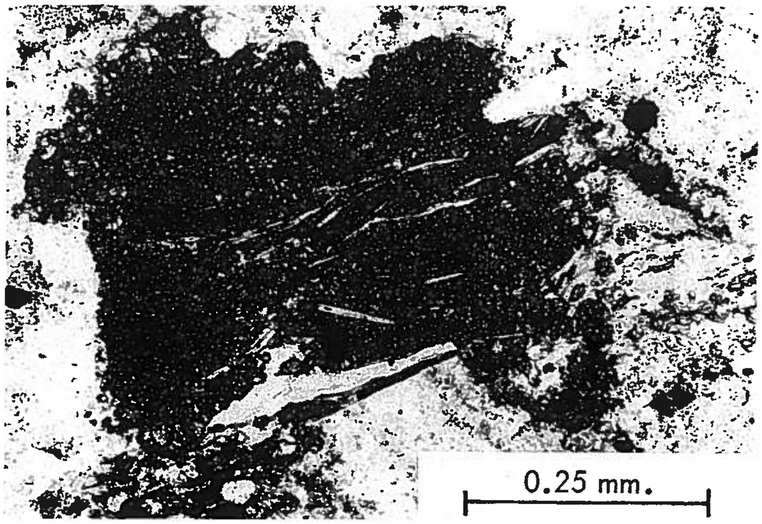


FIGURE 2. Large pellet composed of granular siderite engulfing shred-like fragments of a large chlorite flake. The pellet apparently grew through expansion and replacement of the chlorite, before compaction and cementation. Fort Augustus Formation, Elk Point No. 1 well (*sample EP-45*).

PLATE 20

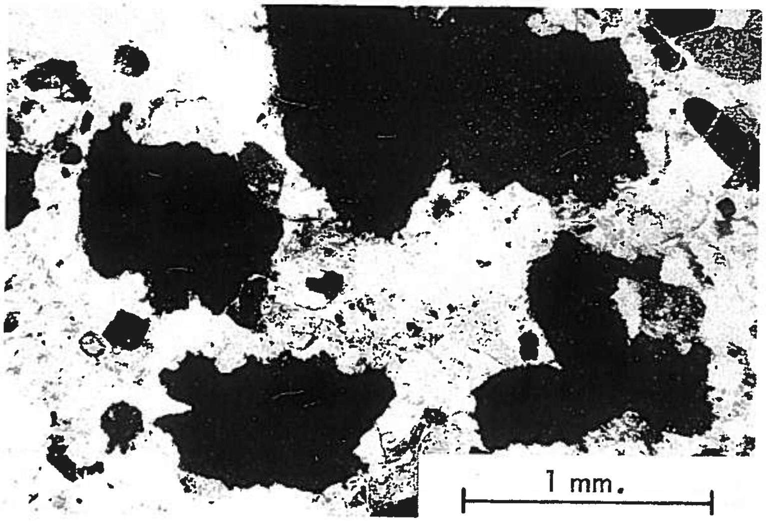


FIGURE 1. Dark brown, partly oxidized siderite pellets in volcanic arenite. Note the elongation of some pellets perpendicular to the bedding which contrasts with the seemingly compacted and flattened shapes of others. Fort Augustus Formation, Elk Point No. 1 well (sample EP-45).

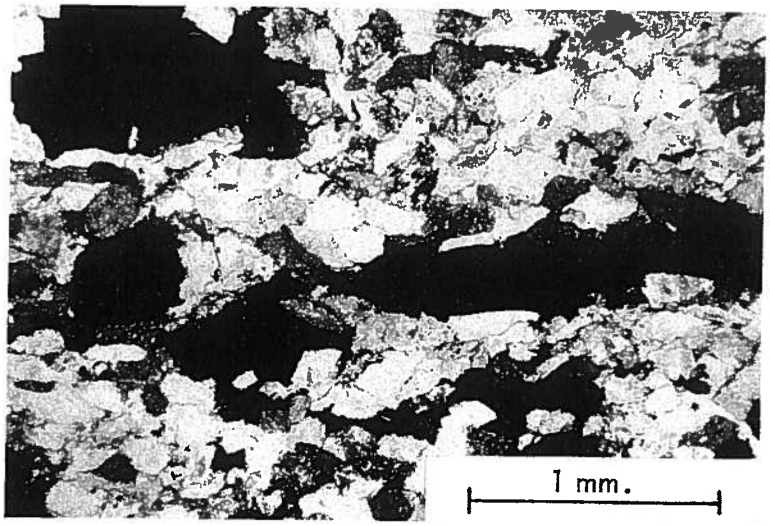


FIGURE 2. Compacted and crushed oxidized siderite pellets in sandstones from the coal-bearing Luscar facies of the Foothills. Appearance of these pellets in the succession of the central Foothills coincides with the replacement of chlorite cement by kaolinite or illite, although the detrital composition of the sandstones remains relatively constant. Beaver Mines Formation, Ram River (sample 57-85).

PLATE 21

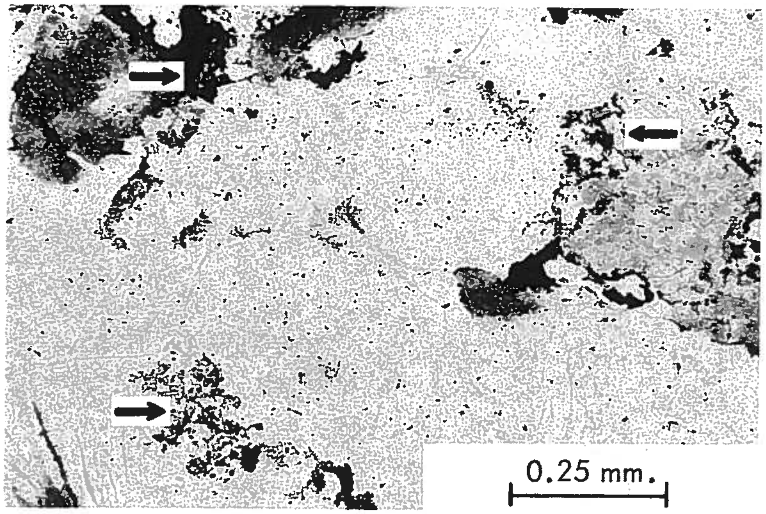


FIGURE 1. *Siliceous sandstone (protoquartzite) composed of well-rounded quartz grains, chert, and cryptocrystalline rock fragments cemented by authigenic quartz overgrowths and scattered patches of kaolinite* (arrows). *Kaolinite is mixed with black patches of abrasive powder, having been partly removed during grinding of the thin section. Gladstone Formation, Sheep River (sample 57-18).*

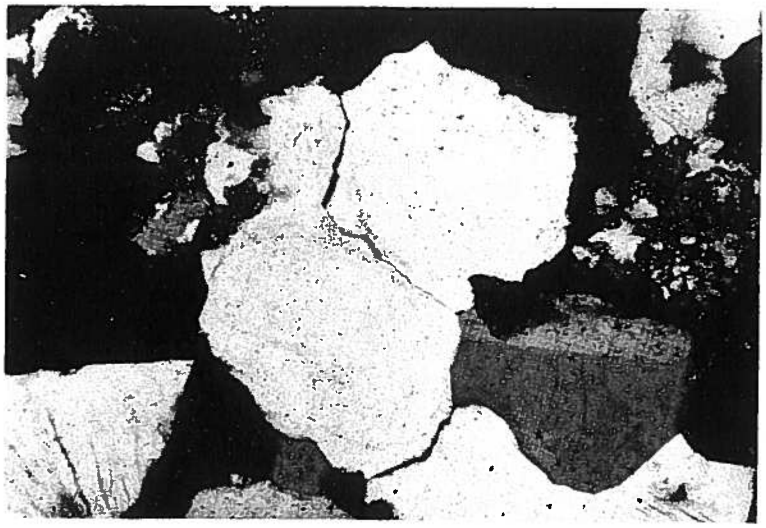


FIGURE 2. *Figure 1, above, crossed nicols, showing the irregular, interlocking overgrowth contacts, which impart a markedly angular appearance to the well-rounded detrital grains.*

PLATE 22

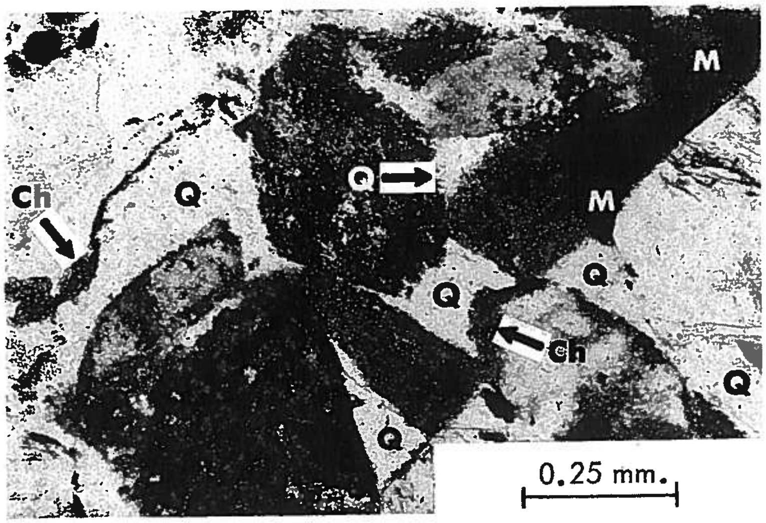


FIGURE 1. *Loosely packed quartz, chert, feldspars, and rock fragments cemented by cherty quartz* (Q) *and minor chlorite* (Ch). *The latter is present as a thin discontinuous coating on the pore walls, difficult to distinguish in places from interstitial chlorite matrix* (M) *derived from crushed rock fragments. Mill Creek Formation, Pine Creek No. 1 well* (*sample PC-7850*).

FIGURE 2. *Figure 1, above, crossed nicols, showing the anhedral cherty texture of the intergranular quartz. Chert cement is rare in most phases of the Blairmore and Mannville sandstones.*

PLATE 23

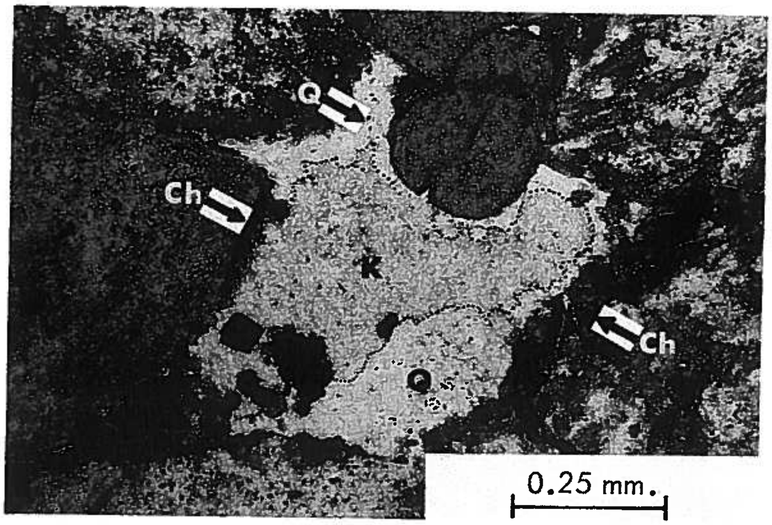


FIGURE 1. Large pore in chert arenite cemented by a thin patchy film of chlorite (Ch) on the pore walls, with a peripheral layer of cherty microquartz (Q), and finely crystalline kaolinite (K, contact retouched), in that order of deposition. Small, dark, euhedral crystals of pyrite in the lower left corner of the pore cut across the boundaries of the other constituents, being the last authigenic mineral to form. Mill Creek Formation (basal bed), Ma Butte.

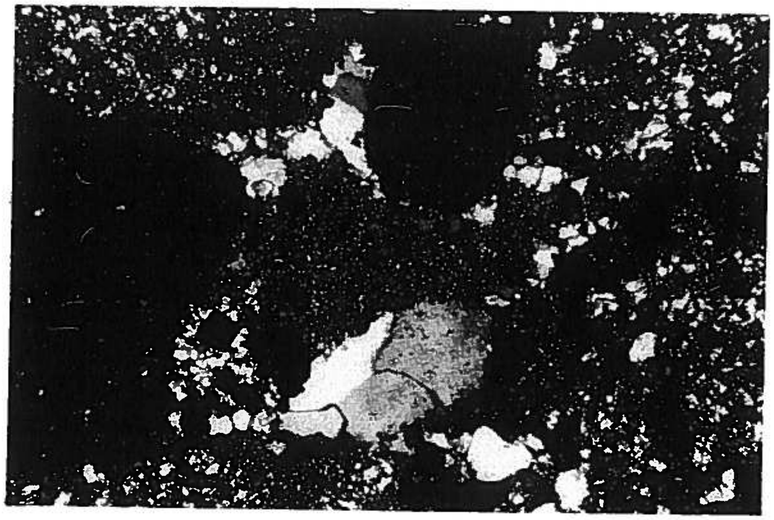


FIGURE 2. Figure 1, above, crossed nicols, showing the anhedral, interlocking texture of the quartz cement and the finely crystalline nature of the kaolinite.

PLATE 24

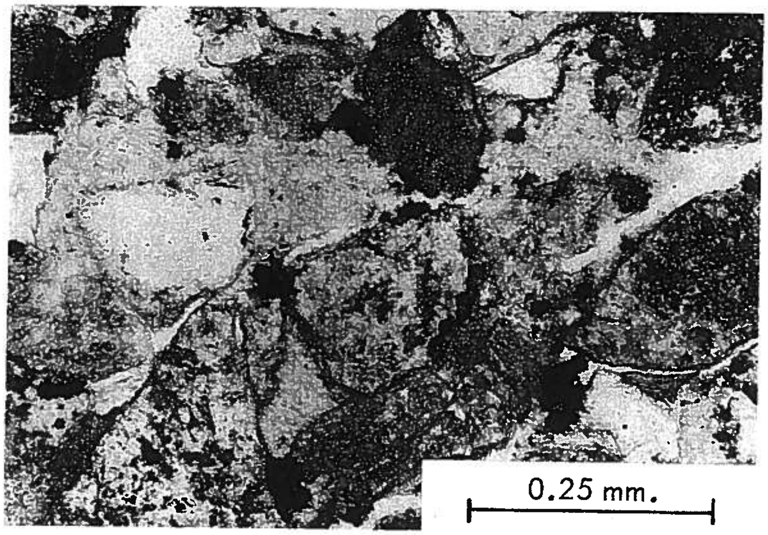


FIGURE 1. Loosely packed quartz, feldspars, and volcanic rock fragments cemented by large patches of finely crystalline kaolinite and minor pyrite (small black patches). Cracks and small holes in the silde are caused by separation of the grains during mounting: the rock appears completely cemented with no evidence of indigenous intergranular voids. Kaolinite is slightly brownish in transmitted light owing to light oil staining. Fort Augustus Formation, West Viking No. 1 well (sample WV-53).

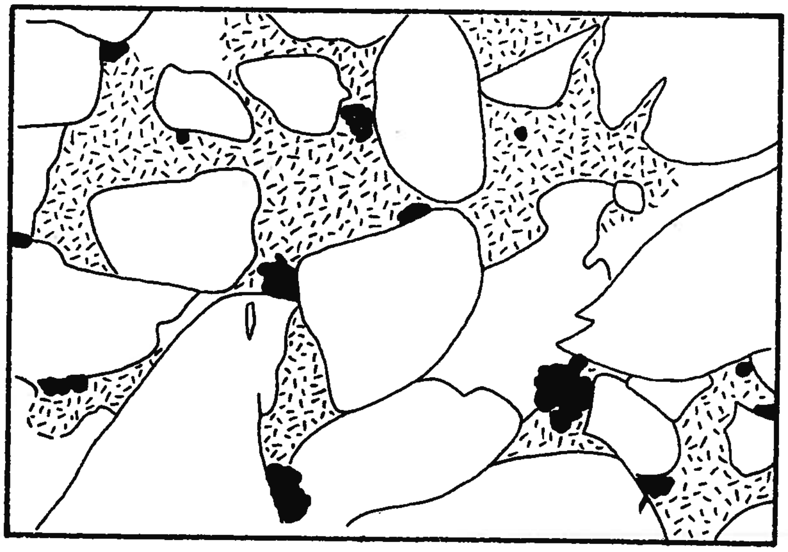


FIGURE 2. Sketch of figure 1, above, showing the distribution of kaolinite (stippled) and pyrite (black) relative to the granular framework of the sandstone.

PLATE 25

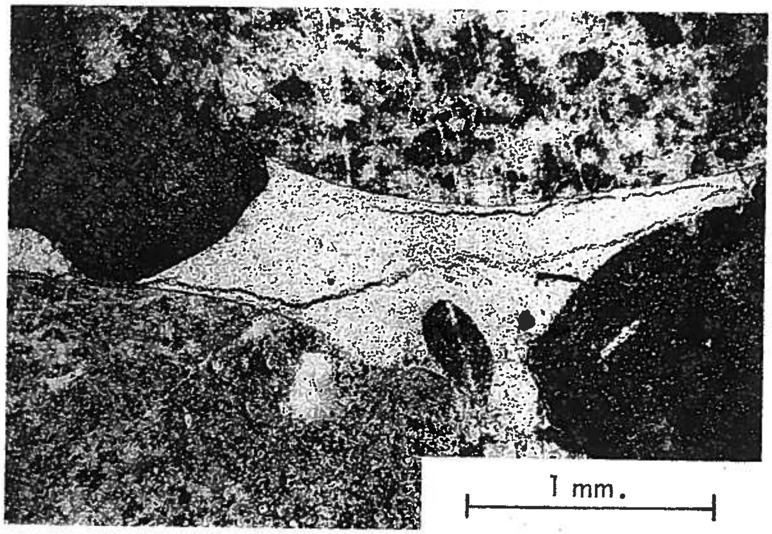


FIGURE 1. Large kaolinite-cemented pore in chert-pebble conglomerate. Gladstone Formation (basal conglomerate), Grassy Mountain, near Blairmore.

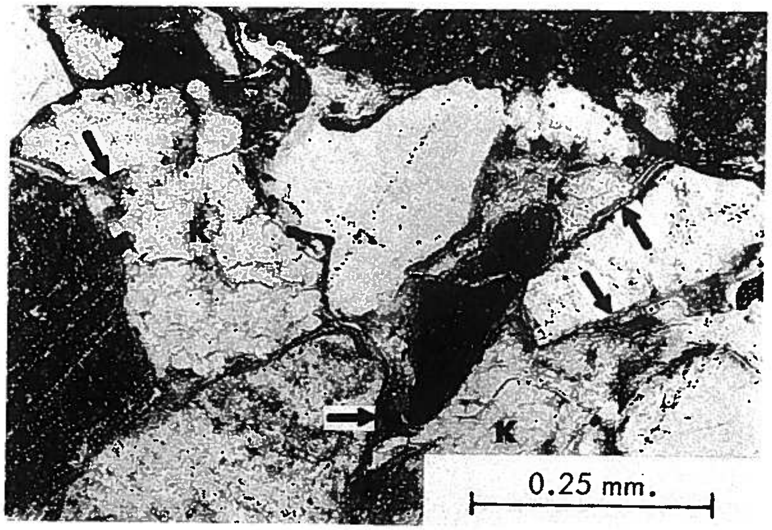


FIGURE 2. Quartz, feldspars, and volcanic rock fragments cemented by montmorillonite and coarsely crystalline kaolinite (K). Montmorillonite is abundant in altered volcanic rock fragments and also as a thin vermiform coating about the pore walls (M), its presence causing the sandstone to disintegrate within a few minutes of being immersed in water. Kaolinite fills many of the pore centres, varying widely in crystal size: note the finely crystalline texture of that in the small pore in the upper right compared with the coarsely crystalline material in the two larger pores. Fort Augustus Formation, Stanmore No. 1 well (sample BS-17).

PLATE 26

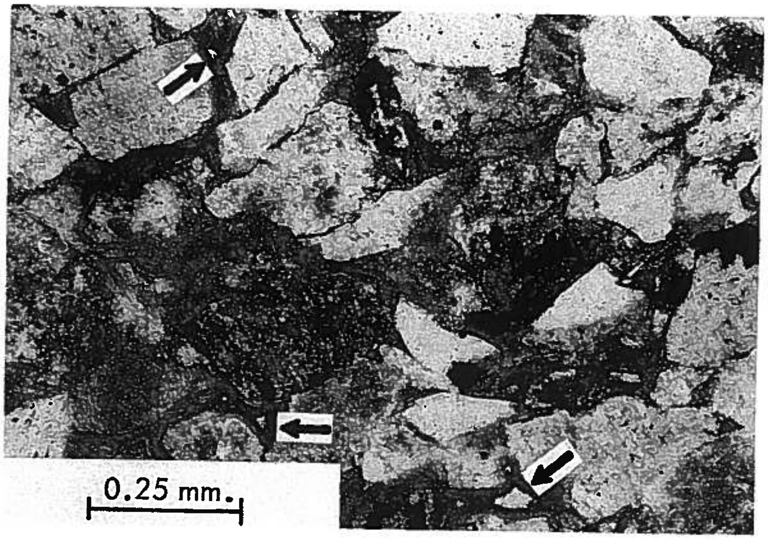


FIGURE 1. Largely plagioclase and volcanic rock fragments with minor quartz cemented by green fibrous chlorite and rare illite. The central portions of a few pores are uncemented (arrows), *a rare phenomenon in Blairmore sandstones of the Foothills. Beaver Mines Formation, Burnt Timber Creek (sample 60-116).*

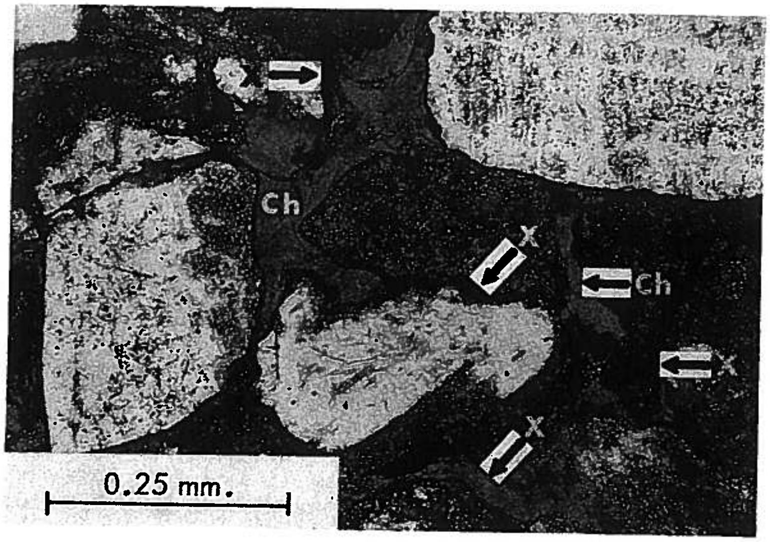


FIGURE 2. Plagioclase and chloritic volcanic fragments cemented by crumpled layers of dark green chlorite (Ch) *associated about the grain boundaries with thin streaks and patches of a dark brown felty substance* (X), *probably montmorillonite as shown by staining tests. Beaver Mines Formation, Mill Creek (sample 56-128).*

PLATE 27

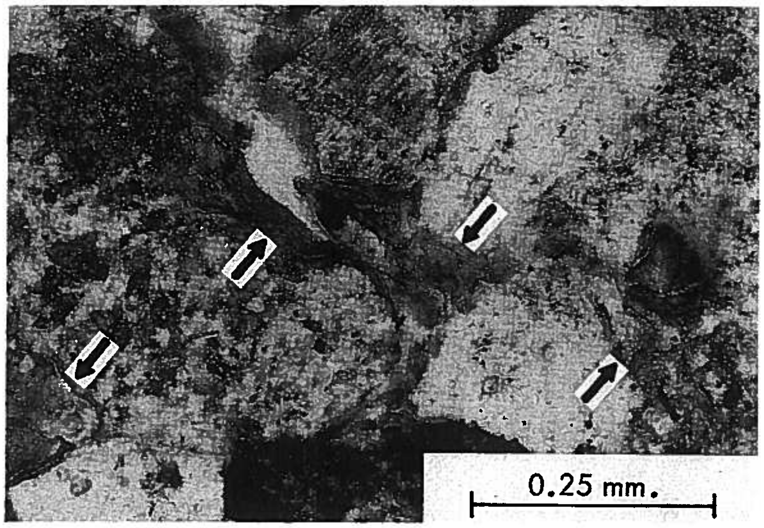


FIGURE 1. *Quartz, feldspars, and metasedimentary rock fragments cemented by by crumpled patches of a greenish-brown, anisotropic, mica-like substance* (arrows) *that from X-ray microcamera data appears to be a mixture of chlorite and illite. The central portions of some pores in other parts of the sandstone (not shown) are filled by kaolinite. Mill Creek Formation (upper part), Sheep River (sample 56-464).*

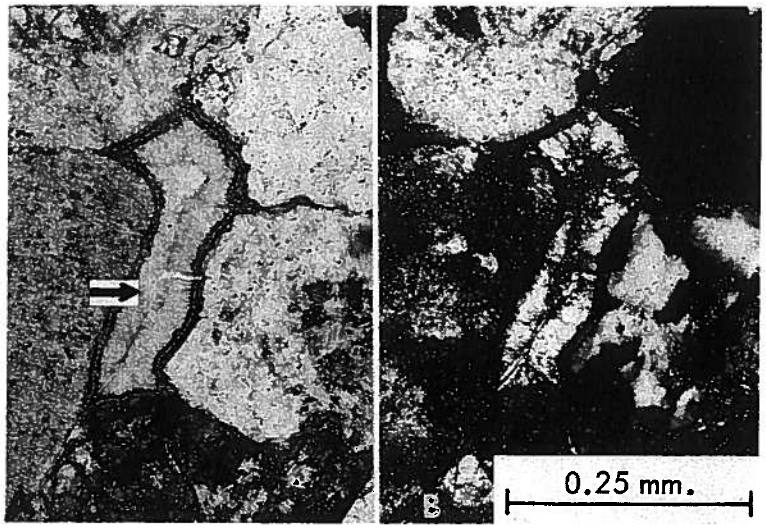


FIGURE 2. *Large pore in volcanic arenite cemented by a thin coating of chlorite and colorless fibrous illite* (arrow), *plane-polarized light* (A) *and crossed nicols* (B). *Illite has grown in from the pore walls as a fibrous lining, meeting in the centre of the pore to form a sinuous furrowed contact. Note the sharp boundary between the two cements and the contrasting high birefringence of the illite. Beaver Mines Formation, Sheep River (sample 56-468).*

PLATE 28

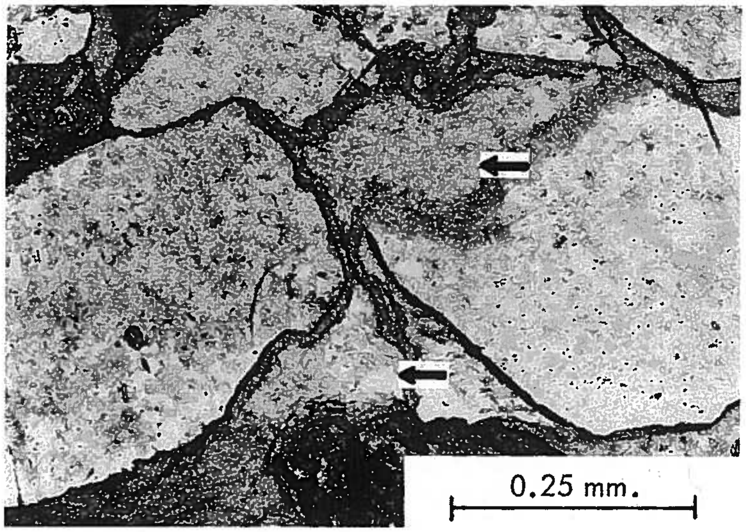


FIGURE 1. Quartz, plagioclase, and rock fragments cemented by fribrous green chlorite and colorless illite (arrows). *Illite is composed of tighty packed book-shaped particles with a micaceous appearance, in contrast to the fibrous variety shown in plate 27, figure 2. X-ray diffraction patterns of the two illite varieties also exhibit differences in the intensities of certain reflections. Beaver Mines Formation, Tershishner Creek (sample 60-36).*

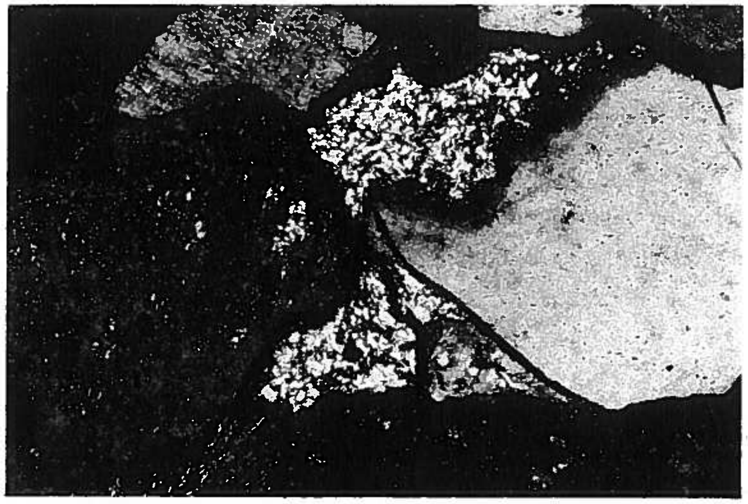


FIGURE 2. Figure 1, above, crossed nicols. Note the small patches of authigenic illite in plagioclase grain to the left.

PLATE 29

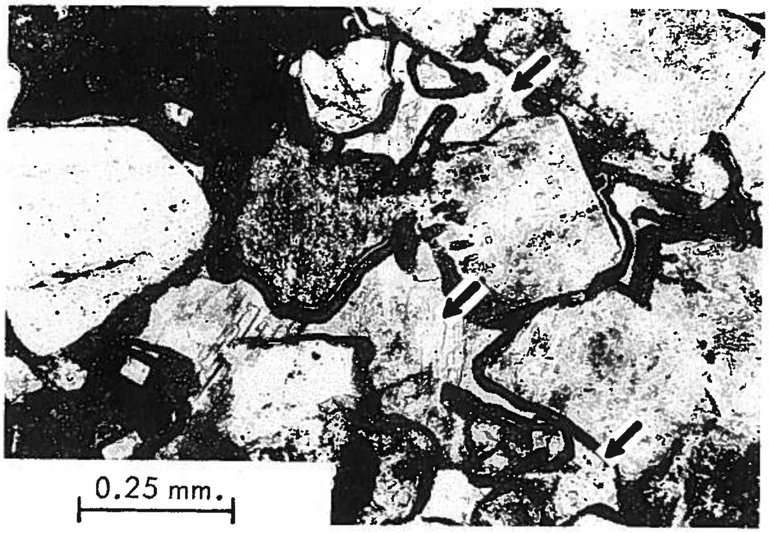


FIGURE 1. *Loosely packed plagioclase, quartz, and volcanic rock fragments cemented by dark green chlorite and the zeolite, laumontite* (arrows). *Chlorite rims are detached from the pore walls in a few places, being separated from the adjacent grains by a thin layer of laumontite. Beaver Mines Formation, Sheep River (sample 56-341).*

FIGURE 2. *Figure 1, above, crossed nicols. Laumontite-cemented areas are filled by two distinct crystallographic units: the large bright poikilitic patch filling the cluster of pores on the right (see arrows in figure 1, above), and the smaller dark patch filling the lefthand portion of the large dumbell-shaped pore in the centre* (arrow).

PLATE 30

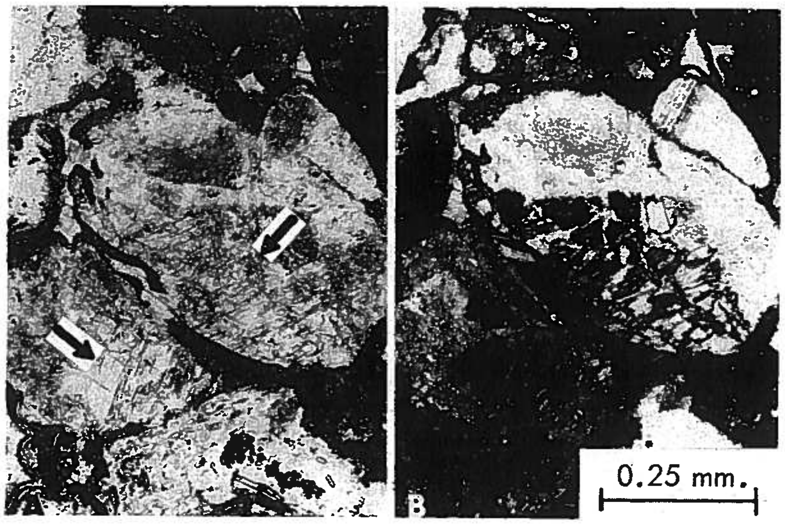


FIGURE 1. Feldspar grains partly replaced by authigenic laumontite (arrows, A), *plane polarized light* (A) *and crossed nicols* (B). *Note the sieve-like appearance of the laumontite patches, which in many grains are in optical continuity with large laumontite crystals filling adjacent pore spaces. Beaver Mines Formation, Sheep River* (*sample 56-341*).

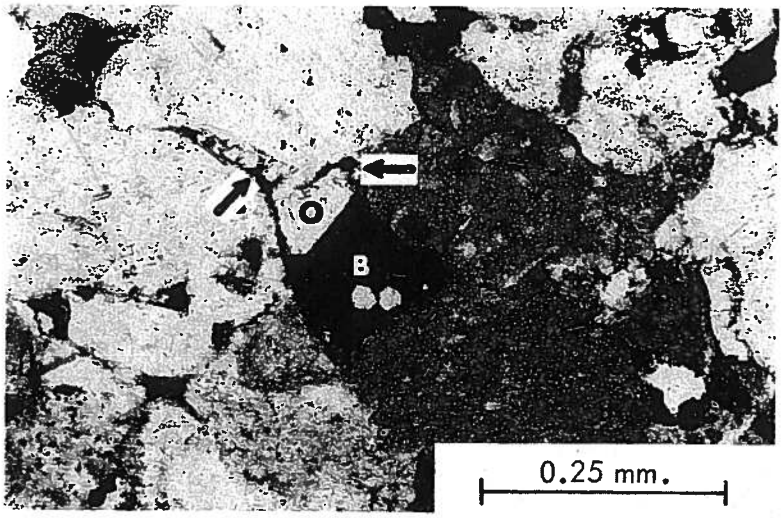


FIGURE 2. Quartz, plagioclase, and volcanic rock fragments cemented by quartz overgrowths and a black solid bituminous(?) substance (*dark intergranular patches*). *Note the large bitumen-cemented pore in the centre* (B) *enclosing two small euhedral quartz crystals, adjacent to a large quartz overgrowth* (O) *which has engulfed or is intergrown with inclusions of bituminous cement* (arrows). *Beaver Mines Formation* (*Luscar facies, lower part*), *Ram River* (*sample 57-98*).

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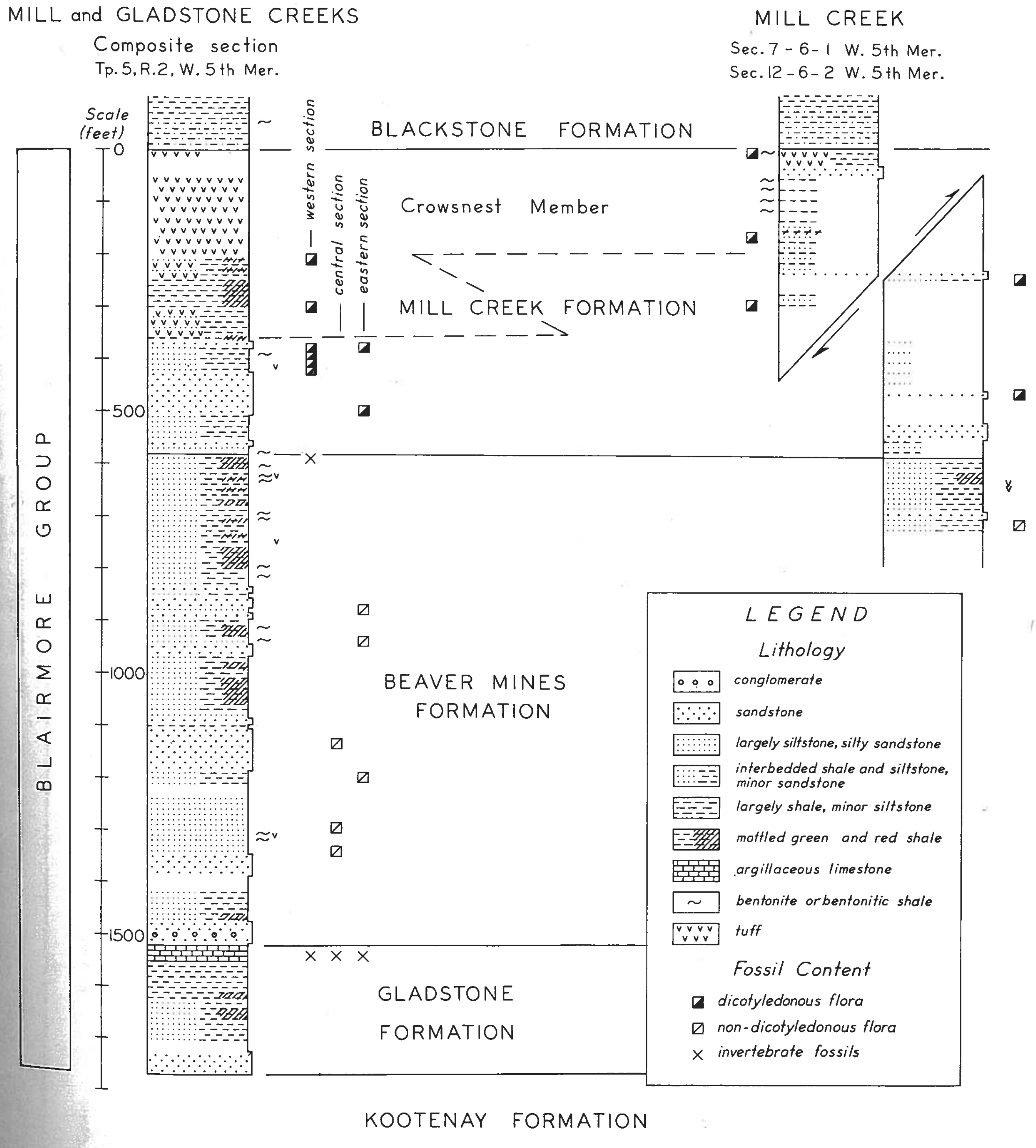


FIGURE 4. Columnar sections showing the lithology and fossil content of the Blairmore Group, Mill Creek and tributaries, southern Alberta Foothills (datum: base of the Blackstone Formation).

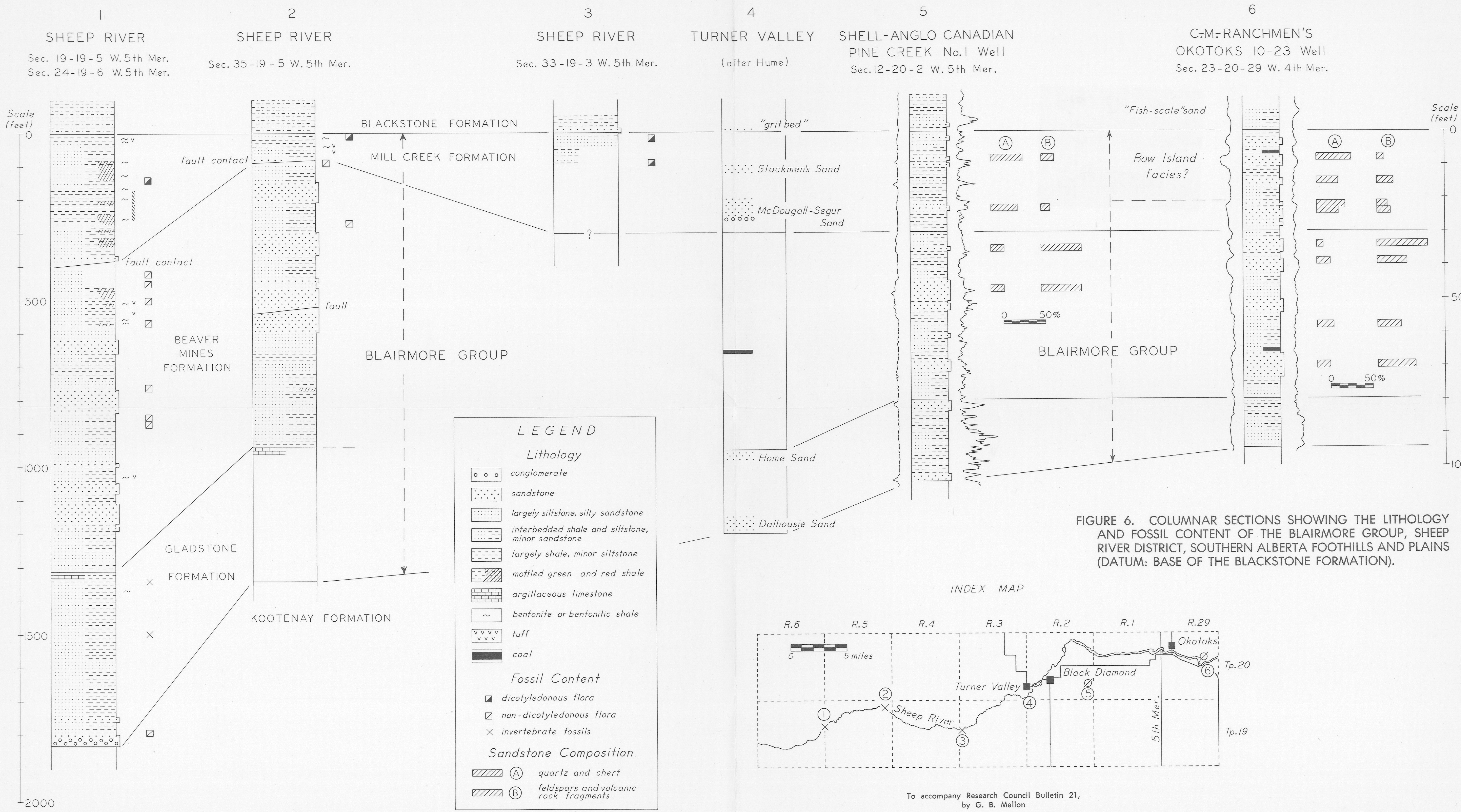
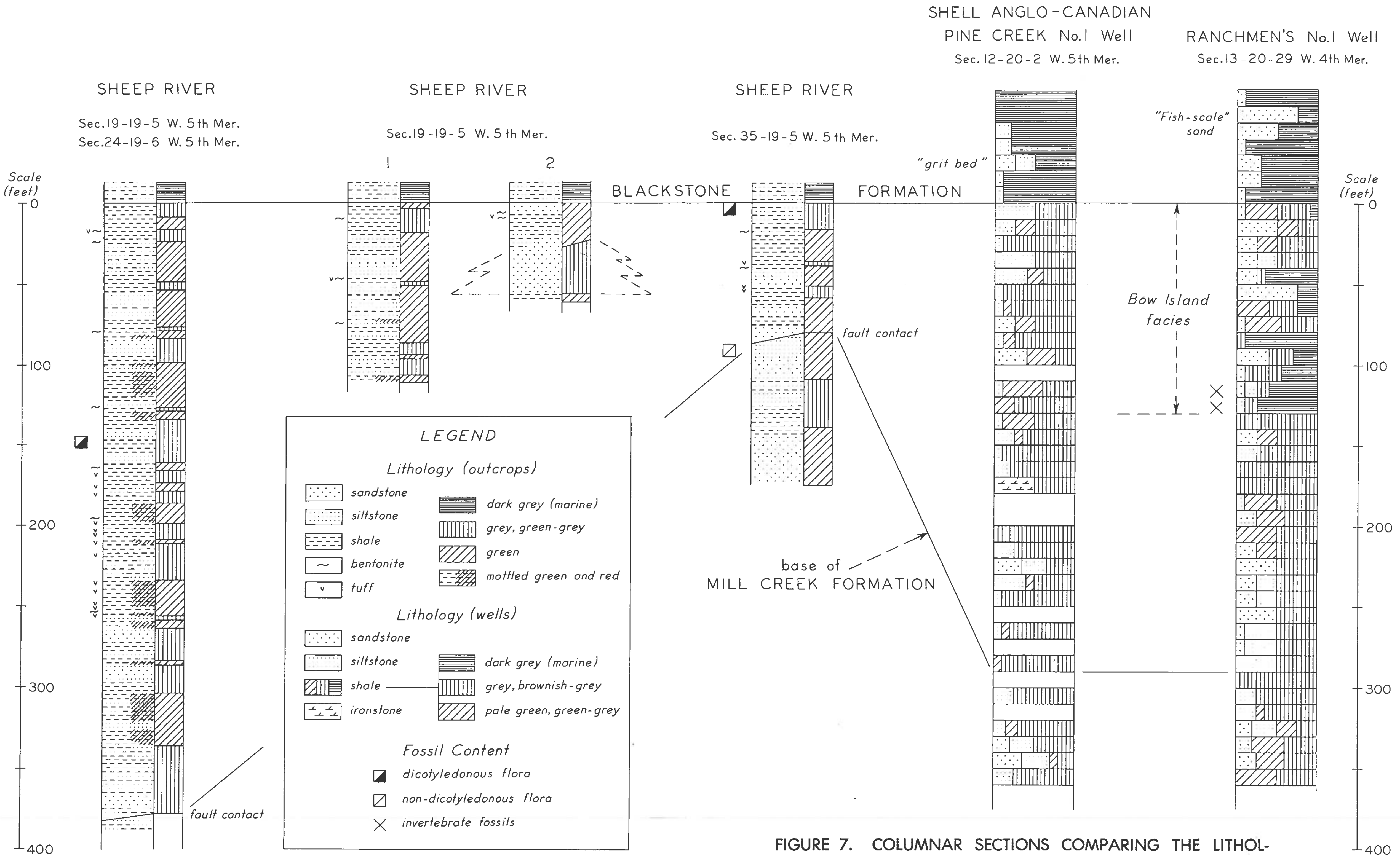


FIGURE 6. COLUMNAR SECTIONS SHOWING THE LITHOLOGY AND FOSSIL CONTENT OF THE BLAIRMORE GROUP, SHEEP RIVER DISTRICT, SOUTHERN ALBERTA FOOTHILLS AND PLAINS (DATUM: BASE OF THE BLACKSTONE FORMATION).

To accompany Research Council Bulletin 21,
by G. B. Mellon



To accompany Research Council Bulletin 21, by G. B. Mellon

FIGURE 7. COLUMNAR SECTIONS COMPARING THE LITHOLOGY OF THE MILL CREEK FORMATION IN OUTCROP SECTIONS ON SHEEP RIVER WITH THE LITHOLOGY OF CORRELATIVE BEDS IN THE SUBSURFACE TO THE EAST, SOUTHERN ALBERTA FOOTHILLS AND PLAINS (DATUM: BASE OF THE BLACKSTONE FORMATION).

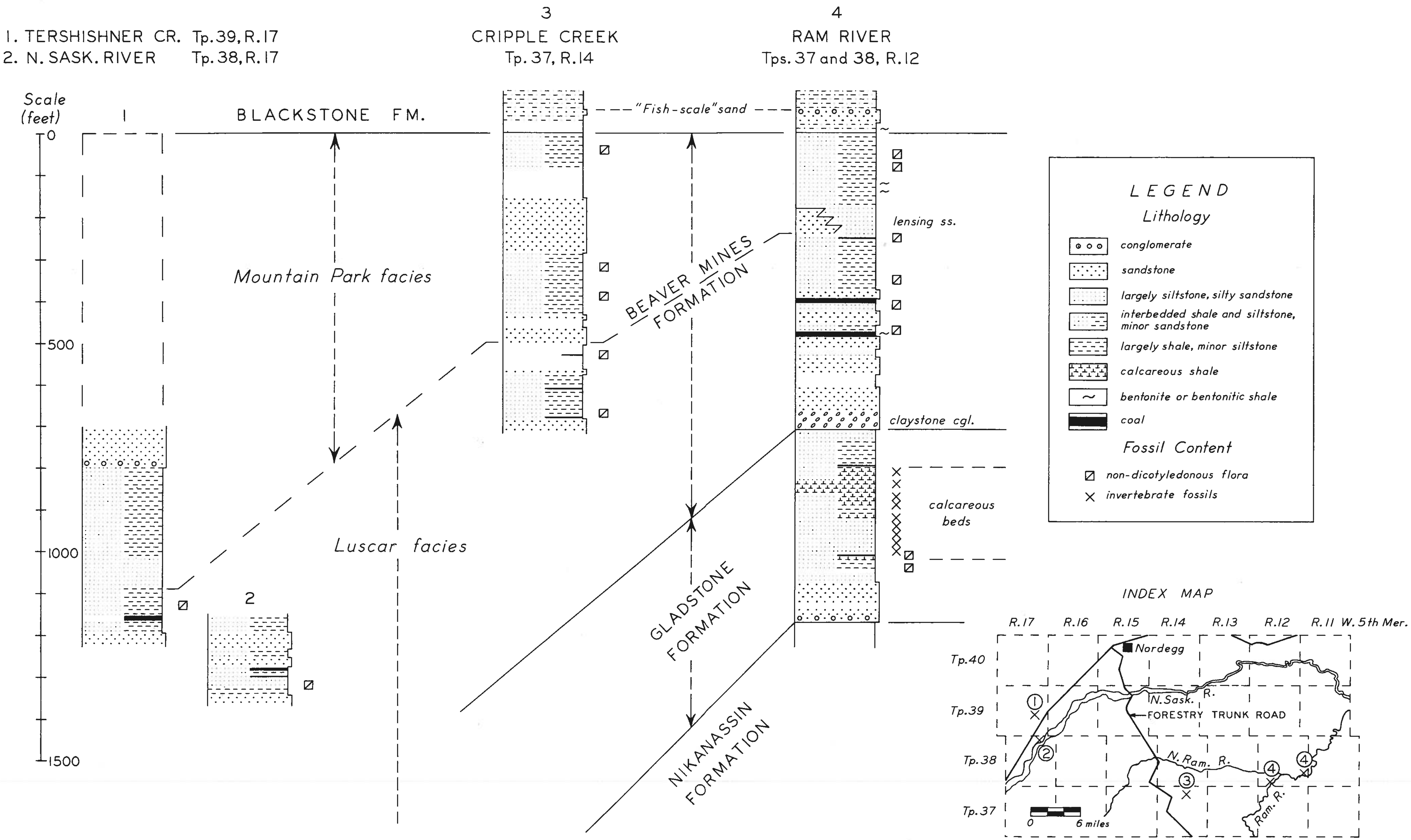


FIGURE 9. COLUMNAR SECTIONS SHOWING THE LITHOLOGY AND FOSSIL CONTENT OF THE BLAIRMORE GROUP, NORTH SASKATCHEWAN AND RAM RIVERS AND TRIBUTARIES, CENTRAL ALBERTA FOOTHILLS (DATUM: BASE OF THE BLACKSTONE FORMATION).

To accompany Research Council Bulletin 21,
by G. B. Mellon

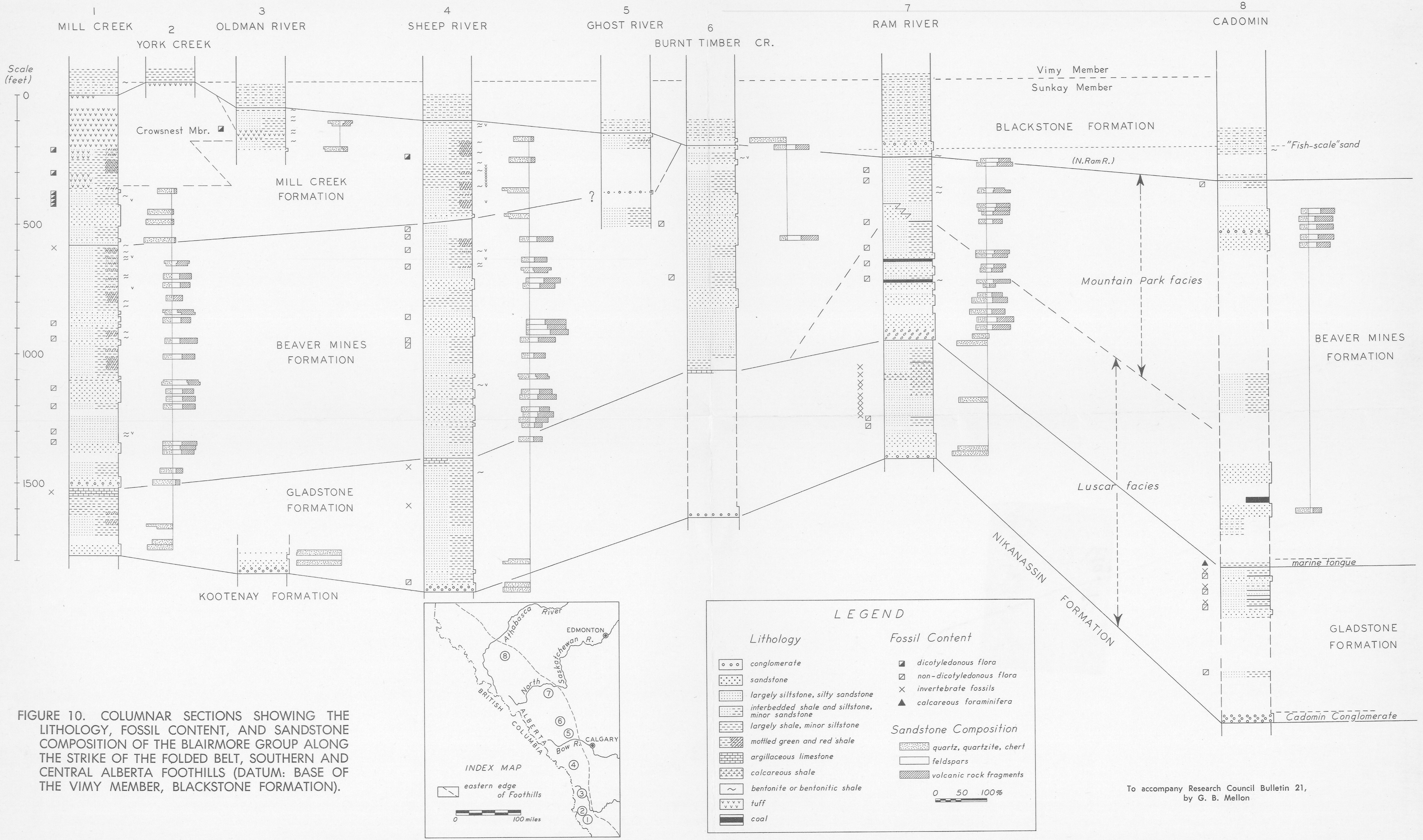
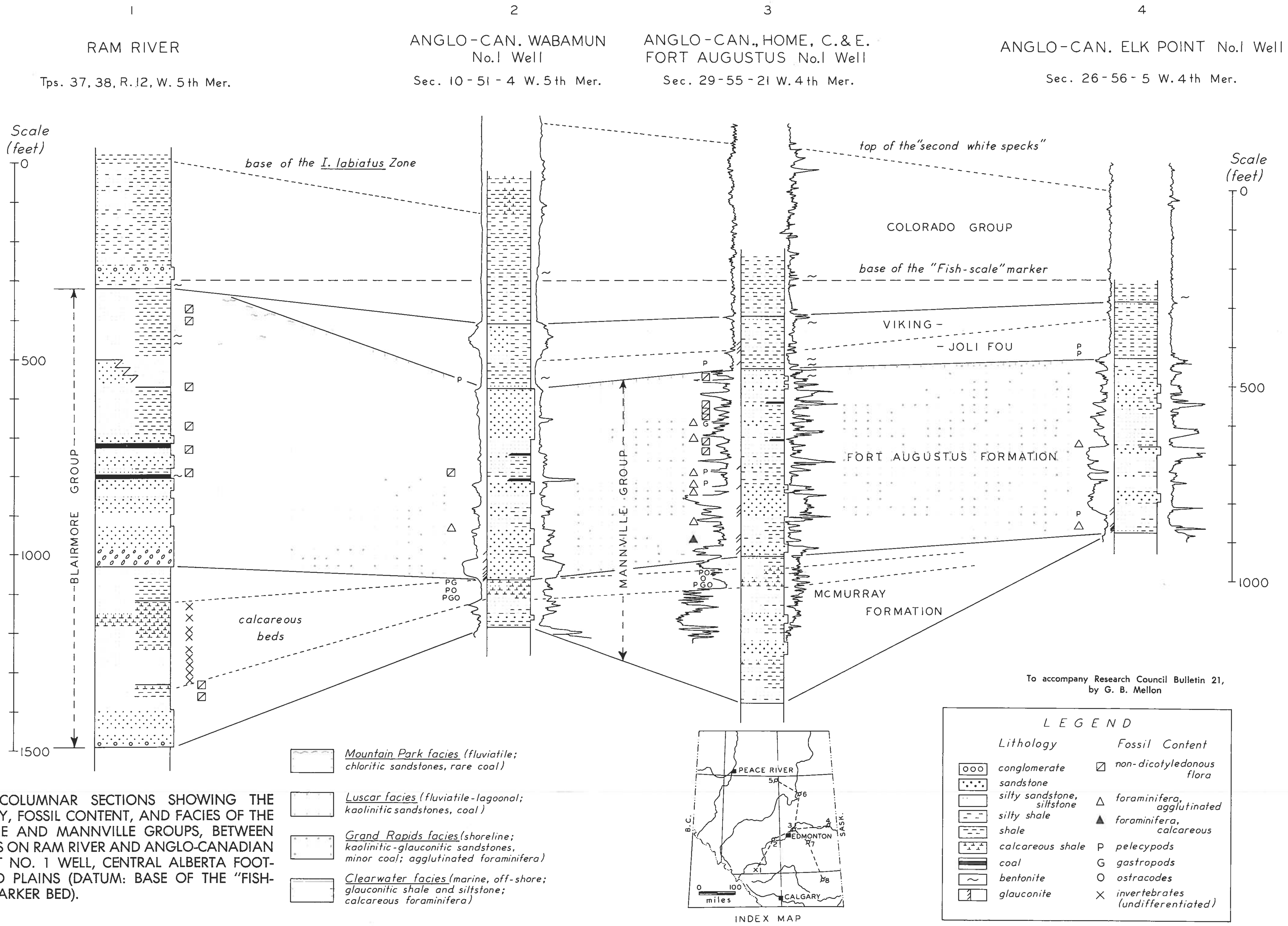


FIGURE 10. COLUMNAR SECTIONS SHOWING THE LITHOLOGY, FOSSIL CONTENT, AND SANDSTONE COMPOSITION OF THE BLAIRMORE GROUP ALONG THE STRIKE OF THE FOLDED BELT, SOUTHERN AND CENTRAL ALBERTA FOOTHILLS (DATUM: BASE OF THE VIMY MEMBER, BLACKSTONE FORMATION).

To accompany Research Council Bulletin 21,
by G. B. Mellon



To accompany Research Council Bulletin 21, by G. B. Mellon

FIGURE 11. COLUMNAR SECTIONS SHOWING THE LITHOLOGY, FOSSIL CONTENT, AND FACIES OF THE BLAIRMORE AND MANNVILLE GROUPS, BETWEEN OUTCROPS ON RAM RIVER AND ANGLO-CANADIAN ELK POINT NO. 1 WELL, CENTRAL ALBERTA FOOTHILLS AND PLAINS (DATUM: BASE OF THE "FISH-SCALE" MARKER BED).

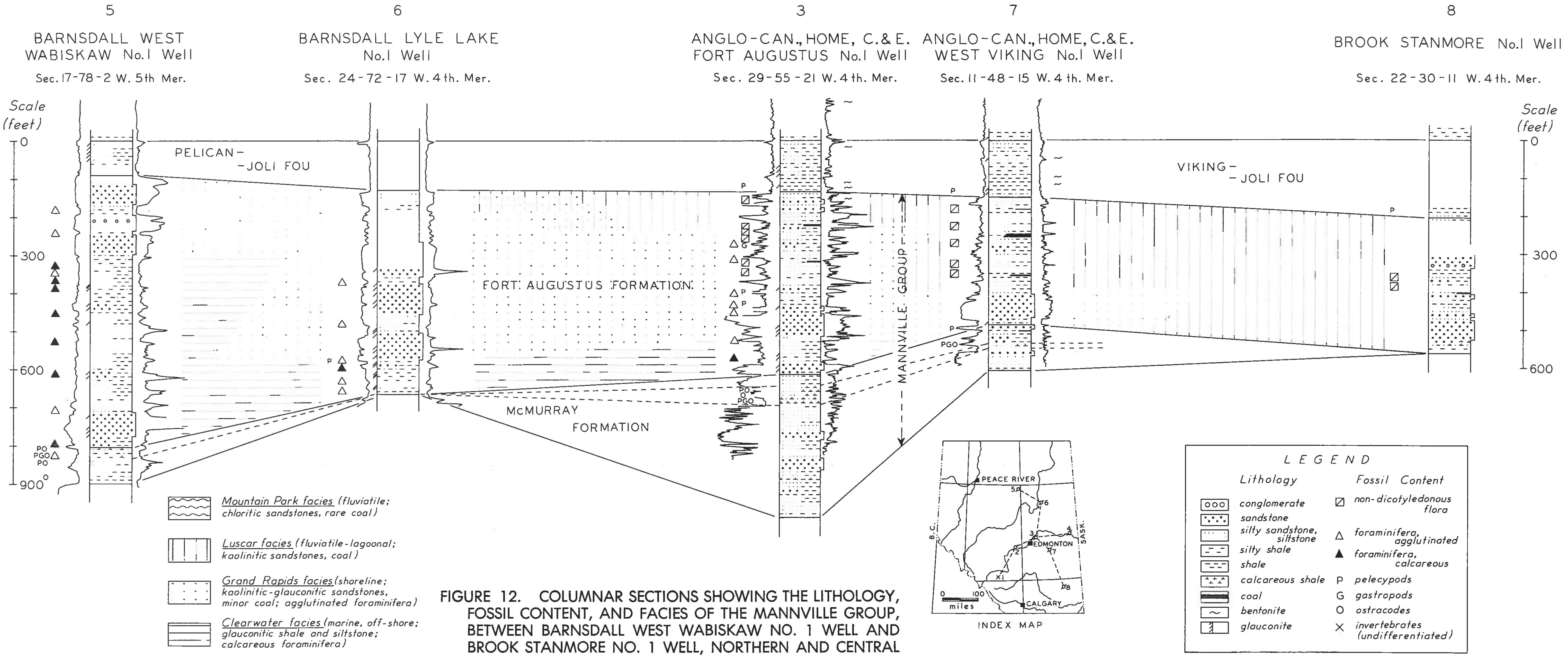


FIGURE 12. COLUMNAR SECTIONS SHOWING THE LITHOLOGY, FOSSIL CONTENT, AND FACIES OF THE MANNVILLE GROUP, BETWEEN BARNSDALL WEST WABISKAW NO. 1 WELL AND BROOK STANMORE NO. 1 WELL, NORTHERN AND CENTRAL ALBERTA PLAINS (DATUM: TOP OF THE VIKING SANDSTONE).

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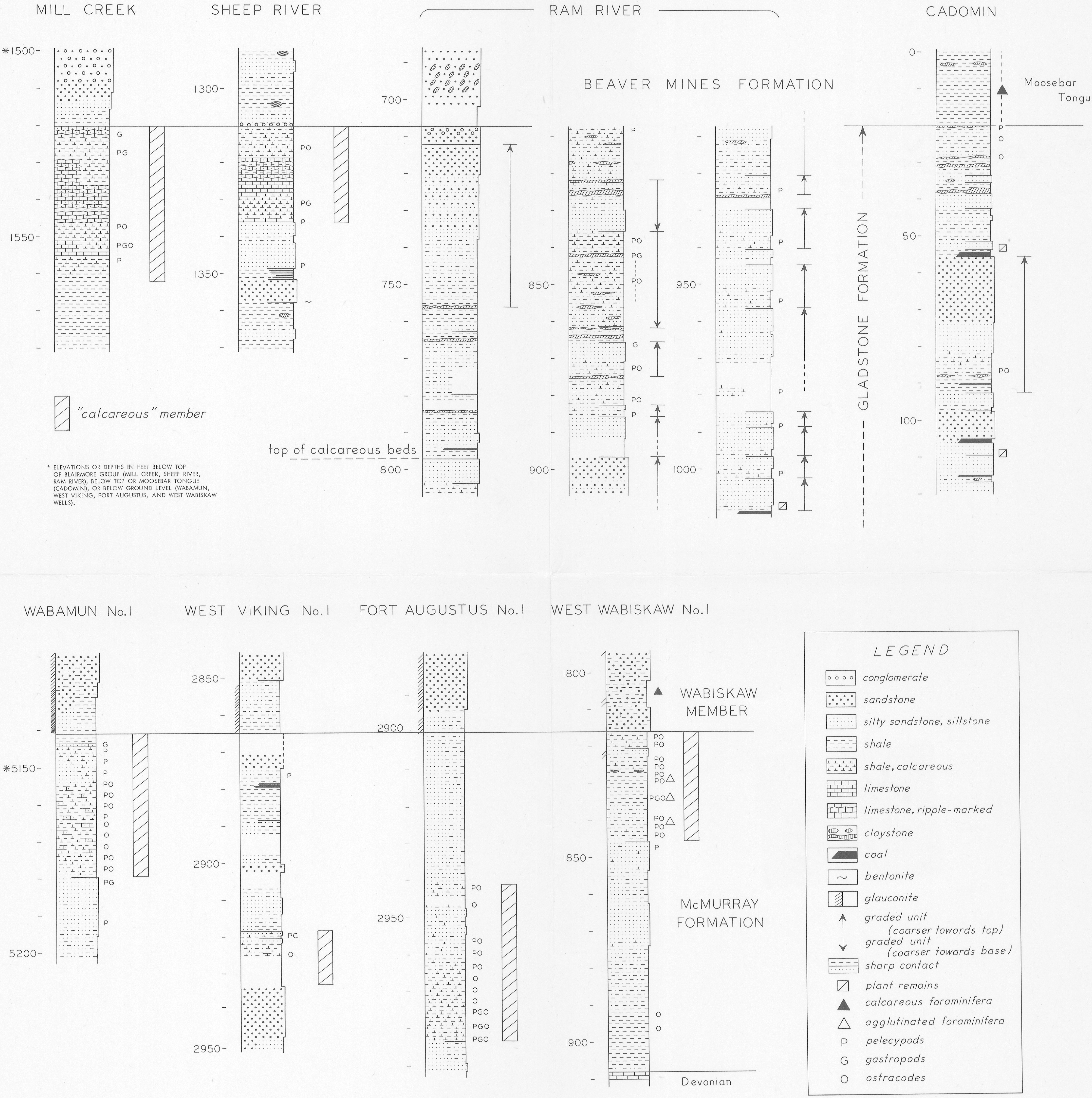

* ELEVATIONS OR DEPTHS IN FEET BELOW TOP OF BLAIRMORE GROUP (MILL CREEK, SHEEP RIVER, RAM RIVER), BELOW TOP OR MOOSEBAR TONGUE (CADOMIN), OR BELOW GROUND LEVEL (WABAMUN, WEST VIKING, FORT AUGUSTUS, AND WEST WABISKAW WELLS).

FIGURE 13. COLUMNAR SECTIONS SHOWING THE LITHOLOGY AND FOSSIL CONTENT OF THE "CALCAREOUS" MEMBER AND ADJACENT BEDS, OUTCROP AND SUBSURFACE SECTIONS, ALBERTA FOOTHILLS AND PLAINS.

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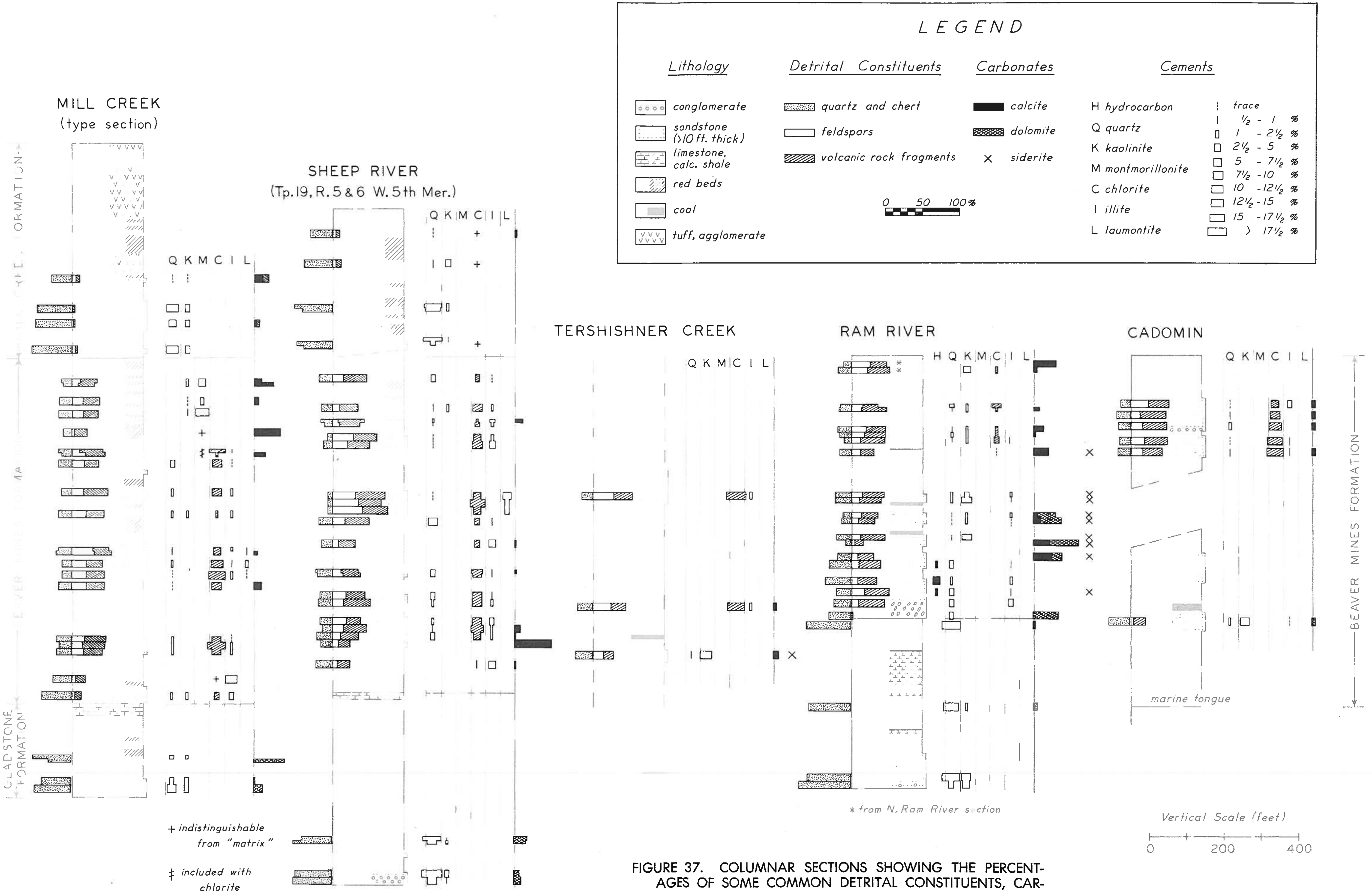

FIGURE 37. COLUMNAR SECTIONS SHOWING THE PERCENTAGES OF SOME COMMON DETRITAL CONSTITUENTS, CARBONATES, AND SILICATE AND HYDROCARBON CEMENTS IN MODALLY ANALYSED BLAIRMORE GROUP SANDSTONES FROM FIVE LOCALITIES IN THE ALBERTA FOOTHILLS (SEE

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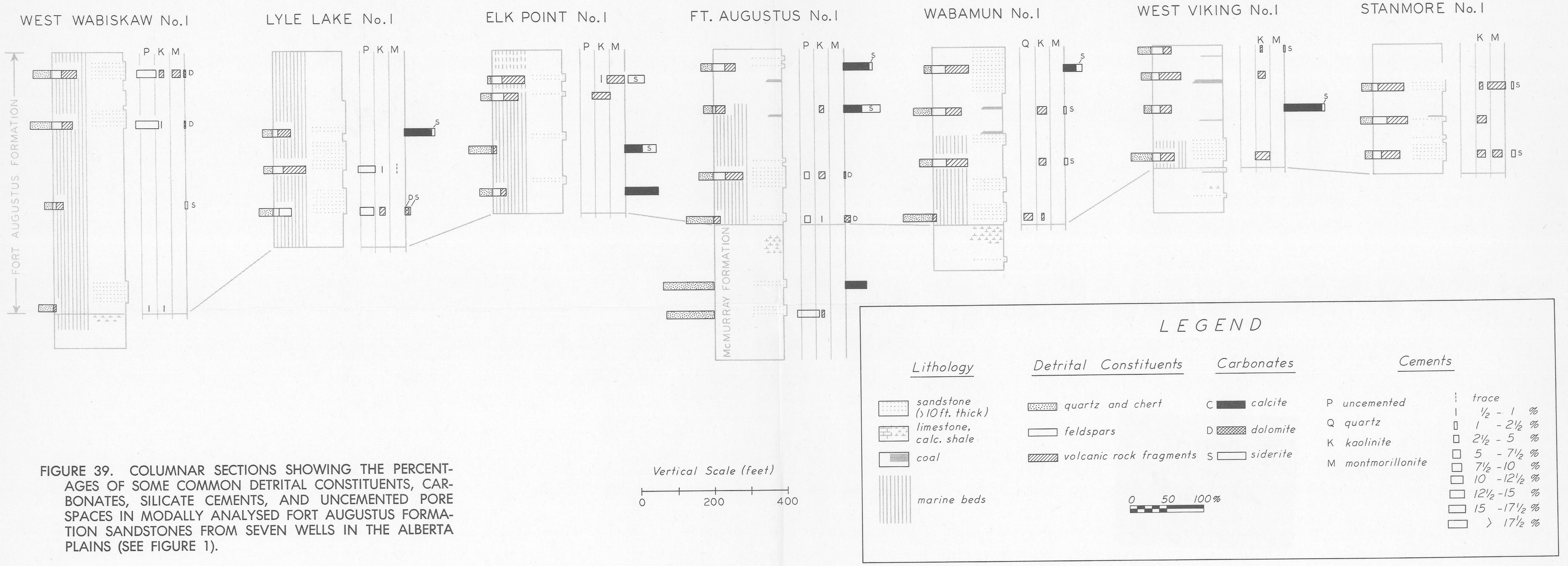

FIGURE 39. COLUMNAR SECTIONS SHOWING THE PERCENTAGES OF SOME COMMON DETRITAL CONSTITUENTS, CARBONATES, SILICATE CEMENTS, AND UNCEMENTED PORE SPACES IN MODALLY ANALYSED FORT AUGUSTUS FORMATION SANDSTONES FROM SEVEN WELLS IN THE ALBERTA PLAINS (SEE FIGURE 1).

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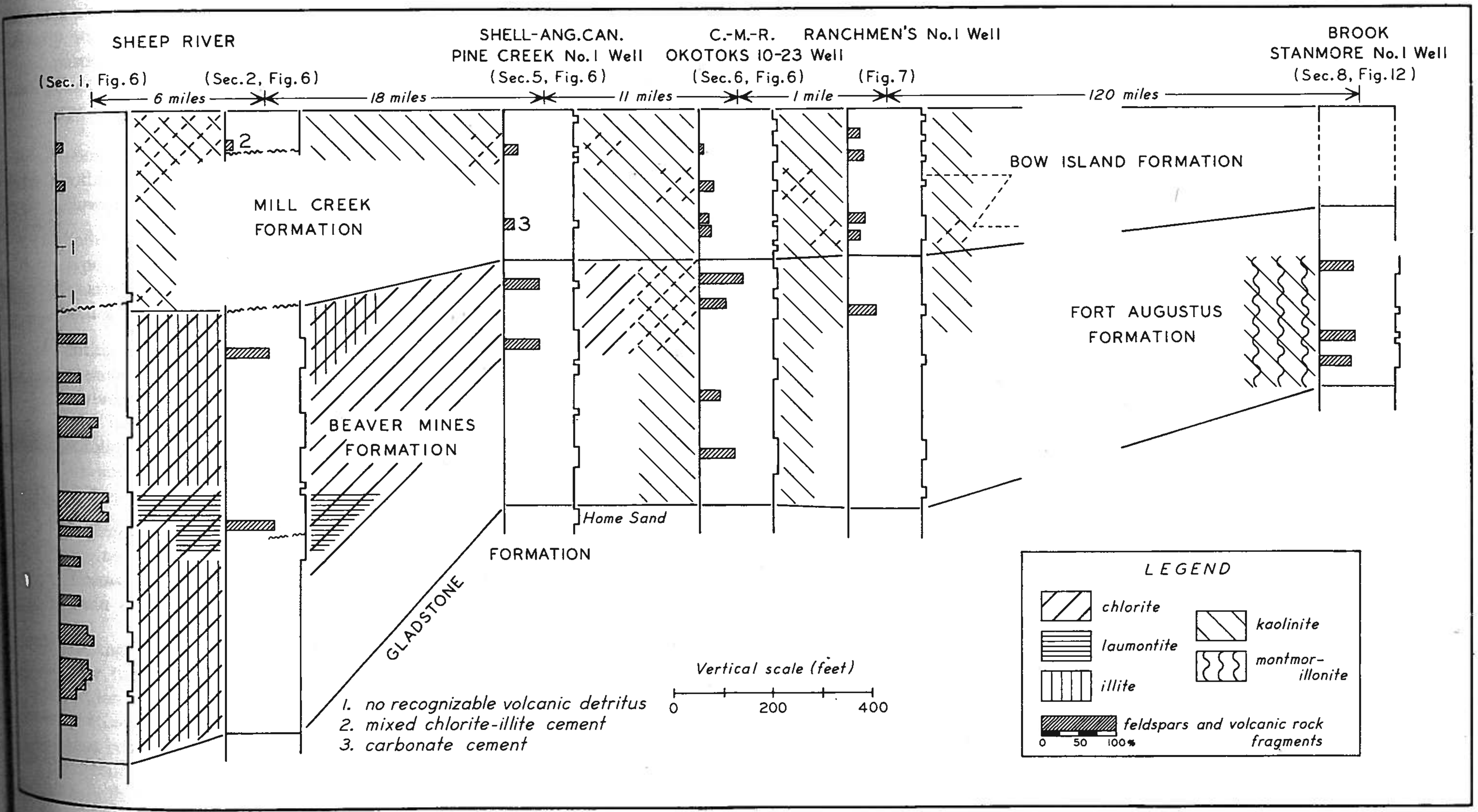

FIGURE 51. *Columnar sections showing the percentages of volcanic detritus and the generalized distribution of silicate cements in modally analysed sandstones from the middle and upper parts of the Blairmore Group and correlative Plains strata across the strike of the southern Alberta Foothills and adjacent Plains (see figure 1 for locations of sections).*

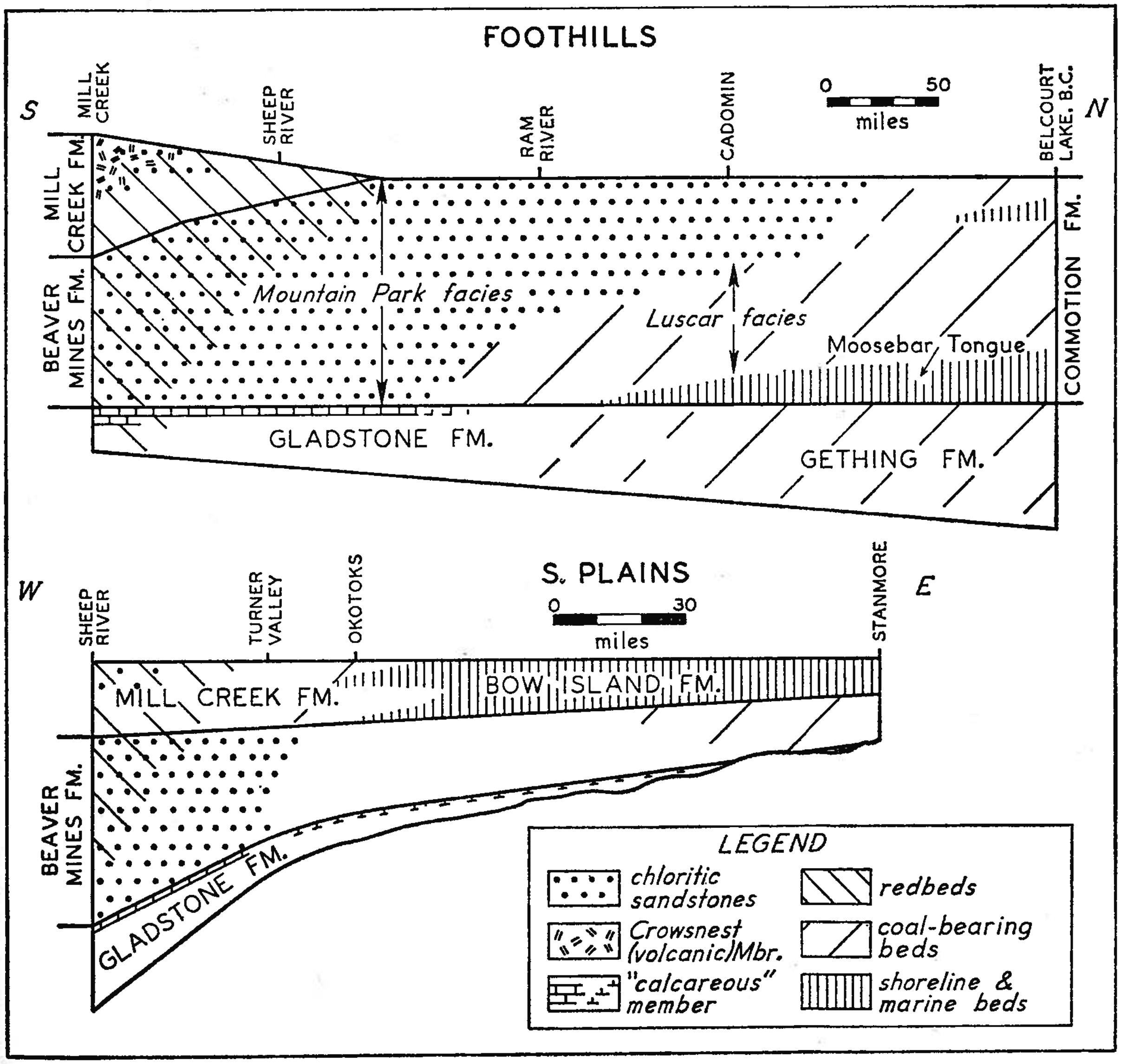

FIGURE 55. *Schematic cross sections through the Blairmore Group of the Alberta Foothills and the Blairmore and Mannville Groups of the southern Alberta Foothills and Plains showing the relationship of gross facies attributes to formations.*