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PRECAMBRIAN GEOLOGY OF THE JASPER REGION, ALBERTA

by

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Precambrian Geology of the Jasper Region, Alberta

ABSTRACT

The Precambrian Miette Group of the Jasper region conformably underlies the Lower Cambrian Gog Group. In ascending order the group consists of conglomerates, sandstones, siltstones and slates (Meadow Creek Formation) of which only 130 feet are exposed, some 1000 feet of slates, siltstones, limestone breccias and limestones (Old Fort Point Formation), and about 4000 feet of conglomerates, sandstones, siltstones, and slates (Wynd Formation). Two thousand feet of conglomerates and sandstones (Jasper Formation) and 900 feet of quartzites (unit A) make up the lower part of the Gog Group. All these rocks were derived from a dominantly metamorphic and igneous source, which lay to the northeast, and were deposited under deltaic conditions or in shallow seas.

During the Rocky Mountain orogeny, Miette strata were tightly folded and faulted. The folds, which are associated with various types of axial-plane cleavage, appear to die out in the upper part of the Wynd Formation, because those in the Gog Group are generally much more open and widely spaced. The bulk of the Miette Group belongs to the quartz-albite-chlorite-muscovite subfacies of the greenschist metamorphic facies. The major metamorphic reactions were the conversion of illite to muscovite, chlorite, and quartz, and the breakdown of potassic and calcic feldspars into albite. The upper part of the Miette Group and the whole of the Gog Group show fewer metamorphic effects. Quartz-calcite-chlorite veins are common in the Miette Group. Radiometric potassium-argon ages range between 1770 and 69 million years and are intermediate between the age of the source rocks and the age of orogenesis.

INTRODUCTION

The central part of the Canadian Rocky Mountains between latitudes 51 and 54 degrees north may be divided into the Main Ranges, Eastern (Front) Ranges, and Foothills. Whereas the Eastern Ranges and Foothills expose Paleozoic and Mesozoic strata, rocks ranging in age from Late Precambrian to Mississippian crop out within the Main Ranges.

The senior author and a number of former graduate students at the University of Alberta, Edmonton, studied the stratigraphy, lithology, and structure of the Precambrian metasedimentary rocks near the eastern boundary of the Main Ranges, in the immediate vicinity of Jasper, Alberta, where exposures are relatively good and readily accessible. The investigation centred on a 50 square-mile area, which was mapped with the use of Alberta Department of Lands and Forests aerial photographs on base maps prepared from the National Topographic 1:50,000 series. The maps, on a scale of 4 inches to 1 mile, are contained in the pocket of the report.

The map-area is located near the resort town of Jasper, Alberta, about 200 miles west of Edmonton (Fig. 1). It is irregularly shaped and situated in the valleys of the Athabasca and Miette Rivers. Local relief near Jasper (elevation: 3400 ft. above sea level) is about 6000 feet, although the relief within the map-area itself is less than 2000 feet. Fresh, glacially scoured bedrock surfaces are abundant, but geologic relationships commonly are obscured by surficial deposits.

Previous Work

Rocks at Jasper now assigned to the Precambrian were first described by McEvoy (1901, p. 31D). Subsequent investigations were carried out by Walcott (1913, p. 340) and by Allan *et al.* (1932, p. 247). Publications concerning certain aspects of the present study include those by Charlesworth and Remington (1960), Charlesworth *et al.* (1961), Charlesworth and Evans (1962), Evans *et al.* (1964), Charlesworth *et al.* (1963), and Bielenstein and Charlesworth (1965). Unpublished theses have been written by Remington (1960), Evans (1961), Stauffer (1961), Griffiths (1962), Steiner (1962), Akehurst (1964), Bielenstein (1964), and Weiner (1966).

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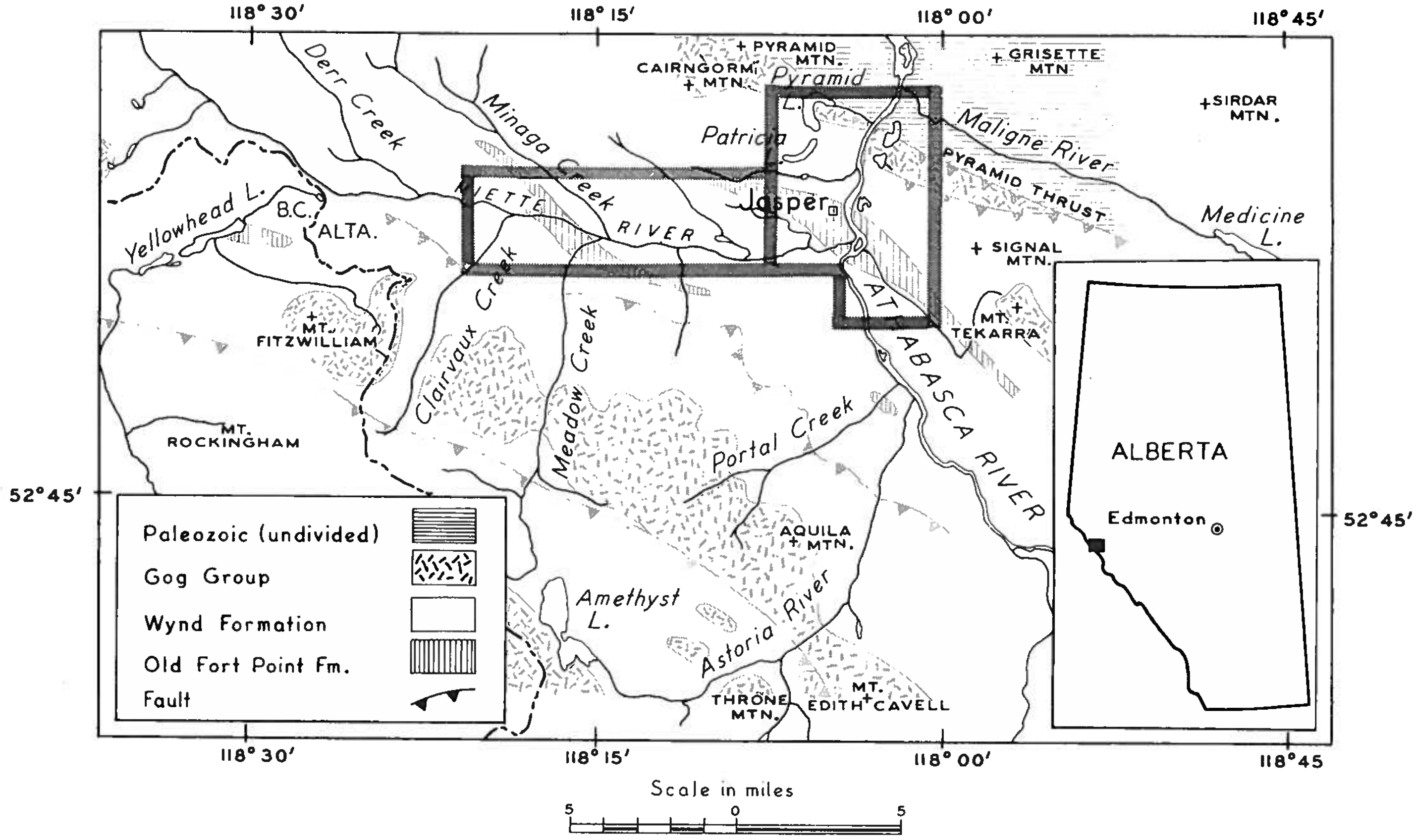

FIGURE 1. *Index map of the Jasper region showing the location of the Jasper (Map 30) and Geikie (Map 31) map-areas.*

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STRATIGRAPHY

The Precambrian rocks at Jasper belong to the lower clastic succession, which, together with the middle carbonate and upper clastic successions, makes up the sedimentary column in the Canadian Rocky Mountains between latitudes 51 and 57 degrees north. The respective ages of the three successions are Late Precambrian to Early Cambrian, Middle Cambrian to Permian, and Triassic to Paleocene. Although information concerning their source is far from complete, the lower clastic rocks and such clastics as are found in the carbonate succession appear to have been derived from the craton to the east, whereas the main source of the upper clastic rocks was the rising cordillera to the west.

The nature of the basement on which this sedimentary succession rests is not known with any degree of certainty. Under the Interior Plains the basement is a westerly extension of the Canadian Shield and belongs to the 1600 to 1900 million year-old Churchill Province (Burwash *et al.*, 1964). Seismic evidence suggests that the same basement extends westwards under the Rocky Mountains (Bally *et al.*, 1966); at Jasper it is probably at a depth of 25,000 feet below sea level.

According to McEvoy (1901, p. 31D), the stratigraphic succession in the Main Ranges near Jasper consists of (1) argillites with some calcareous sandstones, (2) interbedded fine-grained conglomerates and slates, and (3) fine-grained conglomerates. Subsequently, Walcott (1913, p. 340) used the term "Miette formation" for the 2000 feet or more of "massive-bedded, gray sandstones with thick bands of gray and greenish siliceous shales" which crop out in the Miette River valley (Fig. 1). Later, Allan *et al.* (1932, p. 247) described a succession of buff-colored quartzites, argillites, sedimentary breccias, slates, and conglomerates from the neighborhood of Jasper which they termed the "Jasper series". They suggested that the "Miette formation" and the "Jasper series" occupy a similar stratigraphic position immediately beneath the Cambrian. Neither they nor Walcott attempted to relate either unit to McEvoy's three divisions.

The present study has revealed that the largely argillaceous and arenaceous rocks which crop out in the Miette River valley, rocks previously referred to as Miette by Walcott, may be divided into the Meadow Creek, Old Fort Point, and Wynd Formations. The authors follow Mountjoy (1962, p. 3) in raising the "Miette formation" of Walcott to group status.

Overlying the recessive Miette Group, and comprising the remainder of the lower clastic succession, is a cliff-forming arenaceous unit to which, where it crops out near the headwaters of the Snake Indian River, 40 miles northwest of Jasper, the name Gog (Deiss, 1940, p. 771) has been applied by Mountjoy (1962, p. 3-5). Although the term Cavell (Raymond, 1930, p. 293) would appear to have priority, it is poorly defined and rejected in favor of the name Gog. The lower part of the Gog Group in the vicinity of

Jasper is clearly divisible into a lower sandstone and conglomerate unit, and an upper quartzite unit. Allan *et al.* (1932, p. 247) probably had the lower unit in mind when they named the "Jasper series", and thus the name Jasper is retained for this unit. The upper unit, referred to here as unit A, lies outside the area mapped and has not been sufficiently studied to be given formational status.

Specimens of *Archaeocyathus* and *Olenellus* have been found in the upper part of the Gog Group north of Jasper (Mountjoy, 1962, p. 7). In the absence of any visible unconformity within the entire lower clastic succession in the Jasper region, the authors follow Okulitch (1956, p. 728-730) and place the Precambrian-Cambrian boundary at the contact between the Miette and Gog Groups.

Meadow Creek Formation

The Meadow Creek Formation is named after Meadow Creek, a northerly flowing tributary of the Miette River (Fig. 1). It is exposed within the area mapped only along the banks of Meadow Creek, 1¼ miles from its mouth. Composed predominantly of arenaceous rocks, it is readily distinguishable by its coarse grain from the conformably overlying Old Fort Point Formation.

An overturned section through the upper 130 feet of the formation on Meadow Creek (Sec. 1, Fig. 2) contains pebble conglomerate (45 per cent), pebbly sandstone and sandstone (40 per cent), and siltstone and slate (15 per cent). The pebble conglomerate units, from 5 to 20 feet thick, are generally grey and weather rusty brown. Beds range from 6 inches to 15 feet thick, averaging 1½ feet. The conglomerates are poorly sorted, although consisting mainly of subrounded to well-rounded pebbles up to 4 cm in diameter. Sixty-five to ninety-five per cent of the pebbles are vein and plutonic quartz. Most of the remaining pebbles are albite, although metamorphic rock fragments are present. The matrix of the conglomerates, which rarely exceeds 15 per cent by volume, is dominantly sand-sized subangular quartz and albite, with subsidiary quantities of finer-grained calcite, siderite, chlorite, muscovite, quartz, and albite.

Bedding thickness in the grey, rusty brown-weathering, poorly sorted sandstones ranges from 3 inches to 6 feet, averaging 1 foot. Eighty-five to ninety-five per cent of the subangular sand grains are quartz, and the remainder albite. The matrix—fine-grained calcite, siderite, muscovite, and chlorite—constitutes about 15 per cent of the sandstones.

The siltstones and slates are poorly exposed and were not examined in detail. The grey siltstones are in beds up to 2 inches thick and weather rusty brown. The slates are bluish-grey, olive grey-weathering, and poorly laminated.

The heavy accessory minerals are zircon, with subsidiary tourmaline and traces of rutile, garnet, sphene, and anatase. Most zircon grains are pale pink to dark purple hyacinths. Unzoned hyacinths are rounded to well rounded, but zoned ones are more euhedral. Overgrowths are extremely rare, and unoriented inclusions common. Most tourmalines are well rounded although some retain their original prismatic outline. According to criteria established by Krynine (1946), most of the tourmaline appears to have been derived from granitic or metamorphic rocks, and a smaller proportion from pegmatites.

Old Fort Point Formation

The Old Fort Point Formation is named after a prominent landmark south of Jasper known as Old Fort Point (Fig. 3), in the vicinity of which excellent and readily accessible exposures are found. It is exposed in the cores of the Jasper, Portal Creek, Muhigan Creek, Meadow Creek, and Yellowhead Lake Anticlinoria (Fig. 1). Consisting mainly of slates and siltstones with subsidiary limestones, limestone breccias, and calcareous sandstones, it is easily distinguishable from the conglomeratic Meadow Creek and Wynd Formations with which it appears to be conformable.

The formation is divisible into four members with a maximum composite thickness of over 1200 feet. In descending order these are:

Member D: 150-275 feet of green and grey silty slates;
Member C: 0-250 feet of dark bluish-grey, rusty brown-weathering slates, containing near the top 0-20 feet of arenaceous limestone breccias, calcareous sandstones, and limestones;
Member B: 480-650 feet of slates with siltstones, limestones, and limestone breccias;
Member A: 90-425 feet of dark bluish-grey slates with interbedded siltstones near the top.

The distribution and variation in thickness of the four members are given in table 1. Owing to the widespread development of cleavage, the measured thicknesses given here may differ considerably from the original thicknesses.

Member A

The type section of member A (Sec. 2, Fig. 2) is along the top of a low bluff on the west bank of Meadow Creek, 1⅛ miles southwest of its confluence with the Miette River. The beds are overturned to the southwest and therefore are considerably attenuated. A readily accessible partial section exposing the full range of lithologies is found immediately upstream from the bridge at Old Fort Point (Fig. 3). The member consists mainly of dark bluish-grey slates. Towards the top, especially in the Jasper Anti-

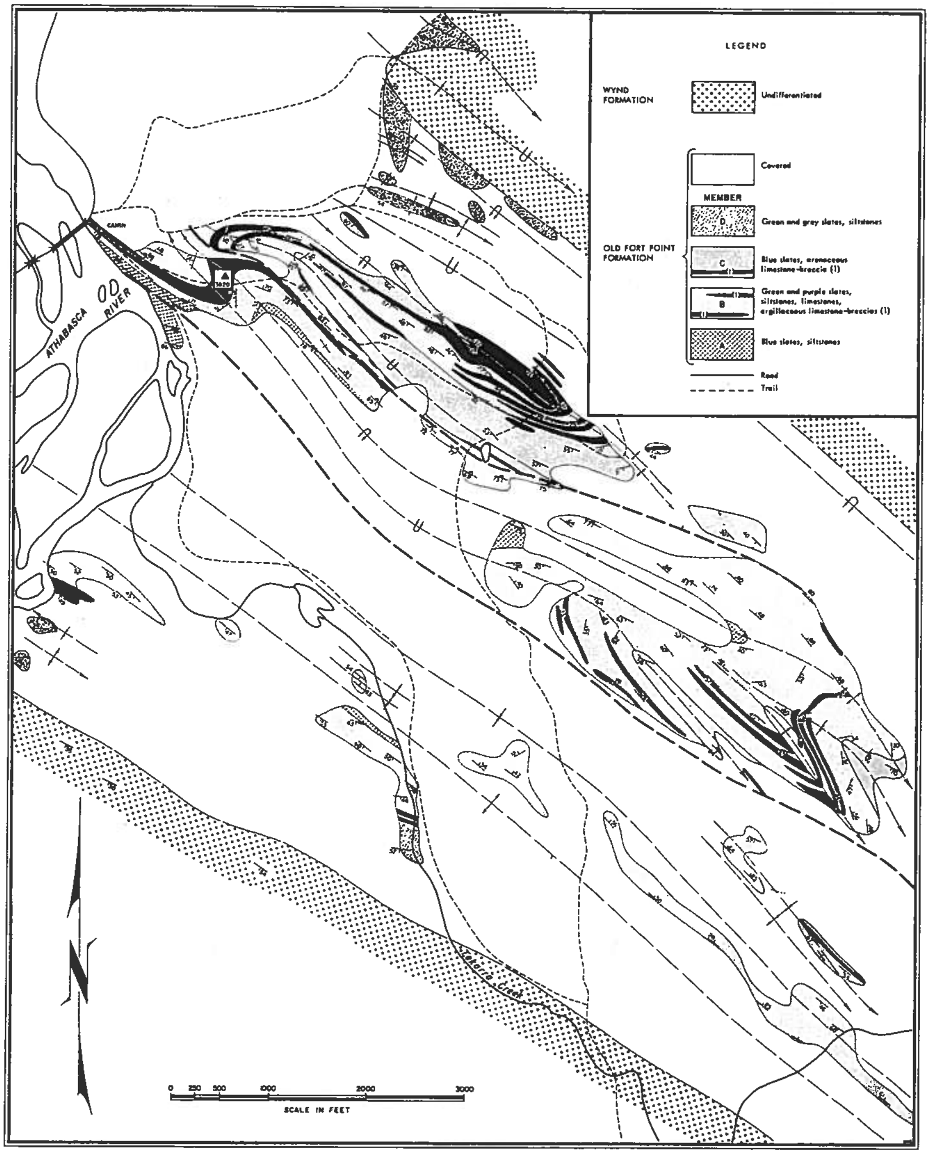

FIGURE 3. *Geologic map of the Old Fort Point area.*

clinorium, the slates become silty and interbedded with greenish-grey, rusty brown-weathering siltstones, the thickness and abundance of which increase upwards.

The slates, thinly laminated and in places banded, are largely muscovite and chlorite in flakes up to 0.03 mm in length. Books of chlorite, in places interleaved with muscovite, up to 0.08 mm in length make up about 3 per cent of the rock. Traces only of quartz, albite, and calcite were observed in the finer-grained rocks, but towards the top, especially in the Jasper Anticlinorium, quartz and albite become abundant. Rusty-weathering siderite rhombs 0.1 mm in diameter are scattered throughout the slates.

The siltstones, in which crosslamination is visible, are present in 0.5- to 6.0-inch beds that are 1 to 18 inches apart. About 60 per cent of the rock is quartz and albite in angular grains up to 0.05 mm in diameter, with rare flakes of altered biotite up to 0.15 mm long and books of chlorite and muscovite (Pl. 1, Fig. 1), and 40 per cent of finely crystalline[1] calcite, and fine-grained muscovite, chlorite, and siderite weathering to limonite. The heavy minerals in this and other members of the Old Fort Point Formation are largely ultrastable zircon and tourmaline, with subsidiary rutile, garnet, ilmenite, and anatase.

Table 1. Thickness Variation within the Old Fort Point Formation of the Jasper (1), Portal Creek (2), Muhigan Creek (3), Meadow Creek (4), and Yellowhead Lake (5) Anticlinoria

Detailed descriptions of the localities are given in Weiner (1966, p. 172-73). Thicknesses are in feet.

Member	Unit	Location					
		1		2	3	4	5
		a[1]	b[1]				
D		150	60[2]	60[2]	160	275	n.e.
C	(2)	10	9-14	20	25	2-9	n.e.
	(1)	250	20	10	0	3-15	n.e.
B	(3)	480[3]	40	26[2]	50[2]	35	n.e.
	(2)		75	n.e.	n.e.	230	100[2]
	(1)		90[2]	n.e.	n.e.	390	250-350
A		350[2]	n.e.	n.e.	n.e.	90	350-425[2]

[1] a, Old Fort Point; b, upper Tekarra Creek.
[2] Partial thickness.
[3] Member B not divisible into units.
n.e. = not exposed.

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[1] Throughout this paper Folk's (1962) classification is used in referring to the size of calcite grains: very coarsely crystalline (1-4 mm), coarsely crystalline (0.25-1.00 mm), medium crystalline (0.062-0.250 mm), finely crystalline (0.016-0.062 mm), very finely crystalline (0.004-0.016 mm), and aphanocrystalline (0.004 mm and less).

Member B

Over most of the Jasper area, member B is developed in what is referred to as the southwestern facies and consists in ascending order of (1) green to greenish-grey slates with some siltstones, (2) purple silty slates and siltstones, and (3) interbedded limestones (purple towards the base and light grey towards the top) and calcareous slates (purple towards the base and green towards the top). However, in the vinicity of Old Fort Point, member B, in the northeastern facies, is composed of greenish-grey slates interbedded with siltstones and limestone breccias. The type section of unit 1 (Sec. 3, Fig. 2) is along the top of a low bluff on the west bank of Meadow Creek, 1⅛ miles from its mouth. The beds are overturned and dip southwest. The type section of unit 2 (Sec. 4, Fig. 2) is along the railway track, about 1⅜ miles west of Geikie Siding (Map 31). The beds are overturned to the southwest. The type section of unit 3 (Sec. 5, Fig. 2) is along the railway track, slightly less than 1¼ miles west of Geikie Siding. The beds are uninverted and dip southwest. The northeastern facies of member B is well exposed along the northern slopes of Old Fort Point (Fig. 3).

Southwestern Facies—Unit 1

Green to greenish-grey slates with minor siltstone interbeds make up unit 1. The gradational color change at the base contrasts with the sharp color break at the top. The slates, commonly laminated, are very fine grained and are largely chlorite and muscovite in flakes 0.1 mm or less in diameter. About 10 per cent of the rock is made up of silt-sized quartz and albite (commonly concentrated in darker-colored laminae 1 mm or less thick), books of chlorite, and finely crystalline calcite and siderite concentrated in the laminae. The few siltstones in this unit consist of angular quartz and albite grains (60 per cent), medium to coarsely crystalline calcite (30 per cent), and books and flakes of chlorite (10 per cent).

Southwestern Facies—Unit 2

Although the basal 10 feet are almost silt-free, the bulk of unit 2 is greyish-purple, silty slate and siltstone. The upper 5 to 15 feet, which are underlain by 30 to 50 feet of laminated silty slates, contain purple limestones. These become more abundant upwards, and in unit 3 comprise 50 per cent or more of the rock.

The slates are laminated and consist of muscovite and chlorite flakes 0.01 mm or less in length (60-80 per cent), finely to coarsely crystalline calcite and rare siderite grains concentrated in light pink laminae (5-20 per cent), silt-sized angular quartz and albite (5-10 per cent), chlorite-muscovite books (5-10 per cent), with 1 to 2 per cent each of large (0.1-0.5 mm) muscovite flakes lying parallel to bedding, and silt-sized magnetite. The reddish rims of hematite on most magnetite grains probably account for the purple color (see Miller and Folk, 1955); in the rare cases where magnetite is absent the beds are green. Slates from the Yellowhead Lake Anticlinorium are finer grained and contain more siderite, in rhombs up to 1 mm in size. The siltstones contain angular quartz and albite (50-60 per cent) and medium crystalline calcite (30-40 per cent) in a fine-grained matrix of muscovite and chlorite (10 per cent).

Southwestern Facies—Unit 3

Limestones (Pl. 1, Fig. 2) in beds up to 6 inches thick and slates up to 3 inches thick make up unit 3. Accounting for about 65 per cent of the unit, the limestones are pink to purple towards the base and light grey towards the top. Except for the upper few feet, where slate predominates over limestone, individual limestone beds are traceable for distances exceeding 100 feet. More than 85 per cent of the limestone is angular, finely crystalline to aphanocrystalline calcite. The remainder is angular silt-sized quartz and albite, with rare books of chlorite interleaved with muscovite, and scattered pyrite cubes up to 7 mm across. Crosslamination is visible on many weathered surfaces. What appear to be asymmetrical ripple marks are common: their steep sides invariably face west. Desiccation cracks and incipient brecciation are present towards the top of the unit near Mina Lake (Map 30), along the Athabasca River southwest of Old Fort Point, and along the upper part of Tekarra Creek.

The interbedded calcareous, silty slates are purple towards the base and green towards the top. They contain approximately equal proportions of medium crystalline calcite, angular silt-sized quartz and albite, and fine-grained muscovite and chlorite, with minor quantities of chlorite books up to 0.36 mm long.

Intraformational limestone-breccias, up to 8 feet long and 1 foot thick, are found throughout the unit but are most abundant towards the top. The angular limestone phenoclasts are embedded in a matrix of calcareous, silty slate. Some breccias are "edgewise", with the imbricate phenoclasts usually inclined toward the east.

One-half mile northwest of Mina Lake, red limestones are interbedded with calcareous siltstones, fine-grained sandstones, and limestone breccias. The well-sorted sandstones and siltstones have matrices of calcite with little or no micaceous material. Calcareous sandstone forms the matrix of the breccias, red limestone the phenoclasts. Small-scale scour channels and crossbedding are common in the sandstones and siltstones.

Northeastern Facies

In the vicinity of Jasper and Old Fort Point, member B consists of greenish-grey laminated slates with interbedded limestone breccias and siltstones (Fig. 3). The slates are composed mainly of very fine grained chlorite and muscovite. Chlorite-muscovite books (5-10 per cent), silt-sized quartz and albite concentrated in brown-weathering laminae (5-10 per cent), with scattered minute crystals of calcite and siderite (1-2 per cent) comprise the remainder. Near the limestone breccias the proportion of calcite is much higher. Pleochroism of the chlorite decreases progressively upwards, as it does in the chlorites of the siltstones and limestone breccias.

Siltstone lenses up to 3 feet thick comprise some 10 per cent of the member. The percentage of quartz and albite, in grains averaging 0.15 mm in diameter, increases from 50 at the base to 90 at the top. Heavy minerals, mainly zircon and ilmenite with some tourmaline and zircon, are especially abundant in the lower siltstones, in which they are concentrated in laminae several millimetres thick, forming 1 per cent of the rock. The matrix of the siltstones is mainly calcite, with very small flakes and larger books of chlorite and muscovite, and minute rhombs of siderite. The matrix becomes progressively less abundant and more calcareous upwards. Scour, slump, pinch-and-swell structures, and cross-stratification are plentiful in the siltstones.

Up to 20 per cent of the member is composed of argillaceous limestone breccias (Pl. 2, Fig. 1), which extend laterally for 200 to 300 times their maximum thickness. The most prominent is 100 feet thick near the bridge at Old Fort Point, where it is associated with considerable basal scour. Angular phenoclasts of pinkish-grey limestone make up from 20 to 60 per cent of the rock. Up to several feet long and 3 inches thick, they are identical petrographically with the limestones in the southwestern facies of member B. In this and higher breccias phenoclast orientation is highly variable: in places the phenoclasts parallel bedding and are arranged in bands, forming a type of sedimentary boudinage, whereas at others they either are randomly oriented or tend to parallel cleavage in the matrix. The matrix of the thick breccia is typically silt-sized quartz and albite, with books of chlorite interleaved with muscovite, in a groundmass of finely crystalline calcite and fine-grained chlorite, muscovite, and siderite. Several thin breccia lenses near the base of member B consist of up to 80 per cent limestone phenoclasts in a limestone matrix. Phenoclasts tend to be smaller (less than 1 foot in length) and the matrix less abundant in the numerous thin breccia lenses in the upper part of member B. The limestone of these phenoclasts is light grey and identical petrographically with the limestones of the southwestern facies. The matrix of these upper breccias has more quartz and albite and less fine-grained chlorite and muscovite, and the calcite is coarser grained.

Correlation of the Two Facies

The presence of pink limestone phenoclasts near the base and light grey phenoclasts near the top of the northeastern facies of member B suggests that most if not all of this facies was deposited during the period of accumulation of unit 3 of the southwestern facies, and therefore that the equivalents of units 1 and 2 are absent in the northeast.

Member C

In ascending order member C consists of (1) dark bluish-grey, rusty-weathering slates commonly interbedded near the top with thinly bedded dark bluish-grey limestone and bluish-grey, coarse-grained, calcareous sandstone, and (2) an arenaceous limestone breccia. The type section of unit 1 (Sec. 6, Fig. 2) is on the northeast bank of Meadow Creek, about ¾ mile from its mouth. Here the beds are overturned to the southwest and presumably are attenuated. The type section of unit 2 (Sec. 7, Fig. 2) is along the railway track just under ¼ mile west of Geikie Siding, where the beds are uninverted and dip gently southwest.

Unit 1

The slates, generally only a few feet thick, total 90 feet just northwest of Jasper and 250 feet southeast of Old Fort Point. They are mainly fine-grained muscovite and chlorite (Pl. 2, Fig. 2). Silt-sized quartz and albite (5-20 per cent) concentrated in laminae, chlorite-muscovite books up to 0.2 mm in length (5-15 per cent), and minute siderite rhombs (0-5 per cent) make up most of the remainder. Altered biotite is present as flakes in the silty laminae and in some chlorite-muscovite books.

The unevenly bedded limestones are usually only a few feet thick but near the headwaters of Tekarra Creek swell to 22 feet. They contain up to 15 per cent silt-sized albite and quartz in a groundmass of aphanocrystalline calcite with subsidiary micaceous material. The albite and quartz, originally well rounded, are now covered by irregular overgrowths. Small grains of siderite 0.02 mm across also may be present.

The sandstones have about 50 per cent sand grains embedded in a matrix of finely to medium crystalline calcite. The round sand grains are mainly single or composite quartz displaying undulose extinction, with minor albite. Common are overgrowths of quartz and replacement of quartz and albite by calcite.

Unit 2

The arenaceous limestone breccia, usually only a few feet thick, is 20 feet thick in the Portal Creek Anticlinorium; near Old Fort Point, it appears to be represented by a 1-inch bed of calcareous sandstone. The angular limestone phenoclasts, which comprise up to 60 per cent of the breccia, are less than 1 foot long and 3 inches wide. The limestone, which is usually dark bluish-grey but in places medium grey in color, is similar to that in unit 1. The phenoclasts are usually randomly oriented (Pl. 3, Fig. 1), but in the steep, northeast limbs of anticlines they have a marked preferred orientation parallel to bedding (Pl. 3, Fig. 2). The matrix of the breccia is similar to the calcareous sandstone of unit 1. In the Muhigan Creek Anticlinorium the breccia grades up into calcareous sandstone.

Member D

Over most of the Jasper area member D consists of laminated silty slates. However, in the Portal Creek Anticlinorium 5 feet of quartz-pebble limestone breccia are found 60 feet above the base. The type section (Sec. 8, Fig. 2) is along the old road north of the Miette River, about ⅝ mile northwest of Geikie Siding, where the beds are overturned to the southwest. Member D becomes coarser grained towards the top in the Jasper Anticlinorium, so that the contact with the overlying Wynd Formation is gradational. Elsewhere, the upper part of the member is much finer grained and the upper contact is sharp (Pl. 4, Fig. 1).

The slates, light green to bluish-grey, contain fine-grained muscovite and chlorite (50 per cent), angular silt-sized quartz and albite (30 per cent), finely crystalline calcite (15 per cent) concentrated in numerous brown-weathering laminae, chlorite-muscovite books and minute siderite rhombs (5 per cent). The proportion of quartz and albite increases upwards. The laminae, largely quartz, albite, and calcite, are commonly arranged in varve-like bands (Pl. 4, Fig. 2). Dark bluish-grey, siliceous nodules up to 25 mm are present near the middle of the member. Interbedded with the slates in the Jasper Anticlinorium are olive-grey siltstones and fine-grained sandstones; detrital biotite is common in the sandstones.

The breccia (Pl. 5, Fig. 1), the contacts of which with the adjacent slates are not exposed, contains phenoclasts (50 per cent) of limestone, sandstone, and limestone breccia in a matrix of calcareous conglomerate. The limestone in angular phenoclasts up to 1 foot long, and the sandstone and arenaceous limestone breccia in angular to subangular, pebble- to boulder-sized phenoclasts, resemble the rock types in member C. The matrix of this member D breccia consists of rounded to subrounded pebbles and sand grains of vein quartz and metaquartzite, in a groundmass of very finely crystalline calcite, with fine-grained muscovite, chlorite, and some albite.

Wynd Formation

The Wynd Formation is named after Wynd Siding (Map 31) on the Canadian National Railway, 2½ miles west of Jasper, near which excellent and readily accessible exposures of the unit may be found. Consisting dominantly of poorly sorted arenaceous and argillaceous sedimentary rocks, it is readily distinguishable from the largely arenaceous Jasper Formation. Although the Precambrian-Cambrian boundary to the west and north has been reported unconformable (Walcott, 1913, p. 340; Slind and Perkins, 1966), the contact between the Wynd and Jasper Formations exposed on Tekarra (Pl. 5, Fig. 2) and Cairngorm Mountains appears conformable. In a railway cut 2½ miles north of Jasper (Map 30), the contact is discordant but faulted. The Wynd Formation may be differentiated from the underlying Old Fort Point Formation by its coarser grain size. The contact between the two formations appears to be conformable; east of Old Fort Point, where it is placed at the base of the lowest pebble conglomerate, the contact is gradational, but in the Meadow Creek Anticlinorium it is sharp (Pl. 4, Fig. 1).

The Wynd Formation is readily divisible into a lower, well exposed, largely arenaceous member, and an upper, poorly exposed, largely argillaceous member. The gradational contact between the two is placed at the top of the highest sandstone bed and beneath the thick, bluish-grey slates of the upper member. The lower member crops out over much of the Miette River valley and on Signal and Whistler's Mountains (Fig. 1), and the upper member on Cairngorm, Whistler's, and Tekarra Mountains, at Saturday Night and Pyramid Lakes, along Minaga Creek, at Dominion Prairie, and among the alpine meadows east of Mount Edith Cavell.

Lithology

Lower Member

The type section of the lower member (Fig. 4), 2400 feet thick, was measured along the Canadian National Railway line, east from Minaga Creek. Because the basal 150 feet of the member are not exposed there, a 700-foot supplementary basal section (Fig. 4) was measured nearby, in the floor of the Miette River valley, east of the mouth of Muhigan Creek. Unfortunately, correlation between the two sections was not achieved. Detailed descriptions of these sections are given in Bielenstein (1964, p. 42-46).

A monotonous succession of interbedded, commonly graded, arenaceous and argillaceous beds (the ratio is 2:1 in the type section) makes up the lower member. The beds may be grouped into ridge-forming, lenticular, arenaceous units, and recessive, argillaceous units, 25 to 500 feet thick (Pl. 6, Fig. 1). The former are dominantly sandstone and conglomerate, and the latter slate and siltstone. An indicator of approximate stratigraphic position is the color of the arenaceous beds: greenish-grey in the lower three-quarters and brownish-grey in the upper quarter (the colors of weathered surfaces are somewhat lighter). Grain-size sorting is generally poor, and the majority of grains in all size ranges are angular to subrounded.

Sandstones and pebble conglomerates are poorly sorted and contain phenoclasts averaging 1 cm across, and sand-, silt-, and clay-sized particles. Their mineral composition is fairly constant, with quartz ranging from 50 to 75 and averaging 60 per cent, detrital and metamorphic mica and chlorite ranging from 15 to 25 and averaging 20 per cent, carbonate and albite each ranging from 0 to 25 and averaging 10 per cent, and accessory minerals making up less than 1 per cent.

Single and composite quartz particles of the vein type predominate, although plutonic and metamorphic types also are present. Not uncommonly, quartz is partially replaced by chlorite, and, to a lesser extent, by muscovite. Albite appears to become less abundant towards the top of this member. Detrital biotite and muscovite flakes, the (001) cleavage of which generally parallels bedding, comprise 1 to 5 per cent of the arenaceous rocks, and are up to 2 cm across. Biotite is commonly partially replaced by interleaved chlorite and muscovite. Carbonate is commonly patchy and is found as fine-grained cement, large twinned grains, and small untwinned crystals replacing feldspar. Calcite is the most abundant carbonate, but siderite and possibly some ankerite are present as small rhombs surrounded by halos of limonite; the average ratio of calcium to iron carbonate is 5:1. Locally, cavernous weathering has developed where carbonate is abundant. Metamorphic chlorite and muscovite make up most of the clay-sized fraction. The characteristic greenish-grey color of much of the lower member is imparted by chlorite; towards the top, it becomes overshadowed by the red color of limonite.

The nonopaque heavy minerals are zircon, tourmaline, rutile, and apatite. Their stratigraphic distribution and that of the varieties of zircon and tourmaline for part of the lower member are shown in figure 5. The opaque minerals are ilmenite, magnetite, and pyrite. The average length and length:width ratio of unbroken zircon crystals (prisms with pyramidal terminations) are 136 microns and slightly less than 2, respectively. Zircons are more rounded than any other mineral, the percentages of well rounded to rounded, subrounded, and subangular to angular being 25, 40, and 35, respectively. Irregular globular inclusions, zoning, rounded overgrowths, and radial fractures are typical features. Tourmaline is present generally as angular to subangular, fracture-terminated prisms with an average width of 85 microns but also is found as irregular flakes. Irregular globular inclusions are common, and dusty inclusions less so. Rutile is present as amber to reddish-brown, angular to subangular grains averaging 100 microns in length. Most grains show longitudinal to oblique striations and some

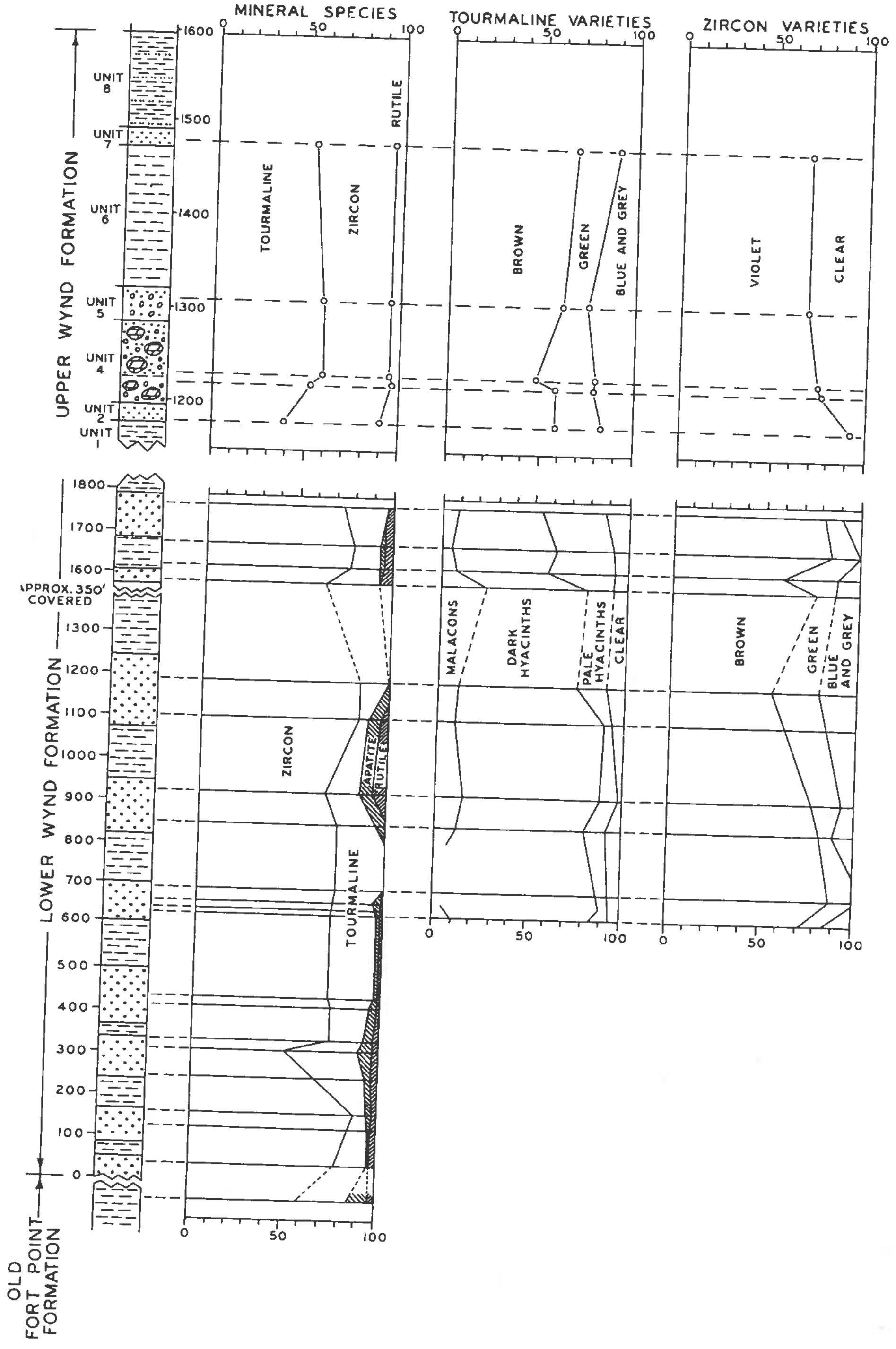

FIGURE 5. *Stratigraphic distribution of nonopaque heavy minerals in part of the lower member of the Wynd Formation, Miette River valley west of Jasper, and in part of the upper member of the Wynd Formation on Tekarra Mountain.*

alteration to leucoxene. Apatite is present as colorless or pale brown, angular grains averaging 95 microns in length. Ilmenite, the most abundant opaque heavy mineral, is observed as subangular grains coated with leucoxene. Magnetite is usually associated with secondary hematite. The pyrite is authigenic and is present as cubes up to 7.5 cm across; grains exposed at the surface are highly weathered and surrounded by limonite-stained "halos", and commonly the crystal has been completely dissolved, leaving a cube-shaped cavity (Pl. 6, Fig. 2). Pyrite crystals are usually surrounded by a rim of recrystallized quartz and, in some cases, by a narrow zone of compaction and wrinkling, the result either of authigenic growth or orogenic stress. Rounded quartz inclusions are common.

Other minor constituents of the arenaceous rocks of the lower member include slate fragments up to 2 feet in diameter and 6 inches thick (Pl. 7, Fig. 1). Conglomerates overlying argillaceous rocks may contain up to 30 per cent slate fragments. Dolomite pebbles, characteristically with rounded structures of possible algal origin, and granite fragments are present locally.

Most conglomerates contain over 50 per cent phenoclasts. However, paraconglomerates (Pettijohn, 1957, p. 261) with only 25 per cent are found within the member (Pl. 7, Fig. 2). Readily accessible outcrops are found at the following localities: (1) in the third argillaceous unit from the base of the member, 1½ miles southeast of Jasper and immediately east of the Athabasca River; (2) one mile northeast of Old Fort Point, immediately southwest of the Jasper Park Lodge reservoir; and (3) in the type section, 750 feet east of the tunnel. The subrounded pebbles in the paraconglomerates are predominantly quartz and argillite. The matrix, except for rare coarse sand grains, consists of unlaminated silty slate.

Siltstone and slate are intimately related and commonly form a gradational series from siltstone, through argillaceous siltstone and silty slate, to slate. The color of fresh surfaces ranges from greenish-grey to grey, with dark grey laminations commonly present in slates. Weathered surfaces are generally light brown on the siltstones and dark rusty brown on the slates. The composition within siltstone-slate series is extremely variable; the major components are quartz, albite, muscovite, chlorite, heavy minerals, and carbonate.

Upper Member

In comparison with the lower member, little is known about the poorly exposed upper member. The type section, 1600 feet thick, was measured on the north slope of Tekarra Mountain (Fig. 4; Pl. 5, Fig. 2). This section, details of which are given in Bielenstein (1964, p. 46-47), has been divided into five units.

Unit 1, about 1175 feet thick, consists of bluish-grey, silty slates and argillites with scattered dark grey laminations and is distinguishable from the argillaceous rocks of the lower member by its color and fine grain size. The unit crops out along Minaga Creek, where it appears to interfinger with sandstones of the lower member, on Whistler's Mountain, at Dominion Prairie, and on Cairngorm Mountain (Fig. 4).

Unit 2, 145 feet thick, is made up largely of dolomite-boulder conglomerates 10-20 feet thick, interbedded with grey to light grey, arkosic pebble conglomerates and sandstones, and slaty argillites. The subrounded dolomite blocks (Pl. 8, Fig. 1A) are grey, weather tan, and range in size from cobbles to boulders 5 feet across (12 feet at Saturday Night Lake). Ovoid particles 0.25-1.00 mm in diameter form about 65 per cent of the dolomite, and silt-sized quartz grains about 10 per cent. The matrix of the dolomite-boulder conglomerates is arkosic pebble conglomerate, with subangular to subrounded quartz pebbles up to 1 cm in diameter. The uppermost 35 feet and the lowermost 20 feet of the unit are free of dolomite boulders. The arenaceous rocks of the unit are rich in feldspar, both as pebbles and as grains, with up to 10 per cent plagioclase and 20 per cent potash feldspar. Slaty argillite fragments are common. The argillites contain up to 15 per cent detrital biotite. Unit 2 crops out at Saturday Night Lake, where 70 feet of dolomite-boulder conglomerate were measured, and on Cairngorm Mountain where the total thickness of the unit is about 150 feet.

Not exposed on Tekarra Mountain, but cropping out immediately below unit 2 at Saturday Night Lake, are 5 to 10 feet of thinly interbedded black argillaceous limestone, calcareous argillite, and calcareous siltstone with angular limestone fragments. Ovoid particles up to 1 mm in diameter are present in the limestone. Similar calcareous rocks crop out by the roadside at Pyramid Lake and Dominion Prairie, near the summit of Whistler's Mountain, and east of Mount Edith Cavell.

Unit 3, 155 feet thick, is made up of grey, silty argillites. Graded bedding, on a scale of ¼-½ inch, is characteristic. Each graded bed ranges from silty argillite to argillite, although siltstone and fine sandstone are present towards the top of the unit. Unit 4, 17 feet thick, is largely thick-bedded, light brown, arkosic sandstone composed of 60 per cent quartz, 15 per cent plagioclase, 10 per cent rock fragments, and 15 per cent matrix. Unit 5, 105 feet thick, consists of graded beds up to 4 feet thick of argillite, siltstone, and, in places, sandstone. Potash feldspar is plentiful in the sand-sized fraction.

In the upper member metamorphic quartz in composite grains is nearly as abundant as the plutonic variety. Potash feldspar (microcline), partially altered to muscovite and chlorite, is in most arenaceous rocks throughout the member. Both plagioclase (An_5-An_{15}) and potash feldspar are corroded by carbonate present as cement. Chlorite and muscovite make up much of the argillites and the matrix of the arenaceous rocks. The heavy minerals are tourmaline, zircon, rutile, ilmenite, magnetite, and pyrite. The distribution of the nonopaque minerals and their varieties is shown in figure 5.

Sedimentary Structures

Bedding in the Wynd Formation is usually poorly defined and uneven, and individual beds, when traced more than 150 feet along strike, lose their identity either by gradational facies change or by abrupt lensing. Bedding thicknesses in arenaceous rocks range from 1 inch to 20 feet but are most commonly between 1 and 2½ feet. In argillaceous rocks they range from 0.1 inch in slate and argillite to 1 inch in siltstone. The division into arenaceous and argillaceous units is a conspicuous feature of the lower member. The contacts between the units are gradational over 2 to 5 feet where the argillaceous unit is the higher, but are much sharper where the arenaceous unit is the higher. The arenaceous units, which interfinger with the argillaceous units, are lenticular and cannot be traced more than 3 miles along strike. The shapes and orientation of these lenses are debatable. However, systematic maximum grain-size distribution and thickness variation suggest that they well may be linear features, trending northwest-southeast in the basal 450 feet and southwest-northeast in the overlying 570 feet (Steiner, 1962).

Graded bedding is conspicuous in the arenaceous units of the lower member, where the gradation is from conglomerate or sandstone at the bottom of a bed to sandstone, siltstone, or slate at the top (Pl. 8, Fig. 2). Although the size of the largest particles decreases upwards, clay-sized particles are present throughout. The graded beds within which lateral variation is rapid, range in thickness from 1 foot to 6 feet but are typically 2½ feet thick. Varve-like graded bedding on a scale of 0.1 inch to 4 inches, from fine-grained sandstone or siltstone to slate, is common within argillaceous beds of the lower member (Pl. 8, Fig. 1B) and in units 3 and 5 of the upper member.

Cross-stratification of all types described by McKee and Weir (1953) is found in thin-bedded, well-sorted, pebbly, coarse sandstones and conglomerates of the lower member (Pl. 9, Fig. 1). Individual sets are 6 inches to 3 feet thick and 3 to 20 feet long, commonly lying at the base of graded successions. Because they have less matrix than other arenaceous rocks, the crossbeds are in general lighter colored. Figure 6 shows the variation in original dip direction for cross-stratified sandstones and conglomerates of the lower member; the average current direction is S60°W. Crosslamination is common in siltstones of graded successions.

Ripple marks and flute casts are rarely well developed, although certain surface markings on bedding planes resemble them (Pl. 8, Fig. 2).

Load casts are plentiful in arenaceous rocks which overlie argillaceous beds. Casts up to 4 feet across have been observed, although the average width is about 1½ feet. Their relief varies from a few inches to 1 foot. In places the peak of the cast is ruptured, giving rise to a double peak. Down-slope slumping has distorted some load casts to form what Prentice (1960, p. 223) called flow-casts. If the peaks of the flow-casts originally pointed "up-slope", the dip of the depositional surface was southwest. Small-scale load casts are common in graded argillaceous successions within both members.

Both symmetrical and asymmetrical scour-and-fill structures ½ inch to 1 foot deep and 4 inches to 10 feet long are common in the lower member. The scours are generally eroded in slate and filled with pebble conglomerate or coarse sandstone, with the coarsest material in the centre. At one locality between Dorothy and Virl Lakes, one margin of a much larger scour channel is exposed. Four banks belonging to one side of the channel with a total relief of 13 feet are visible (Fig. 7; Pl. 9, Fig. 2). Because the other margin is not exposed the total dimensions of the channel are unknown.

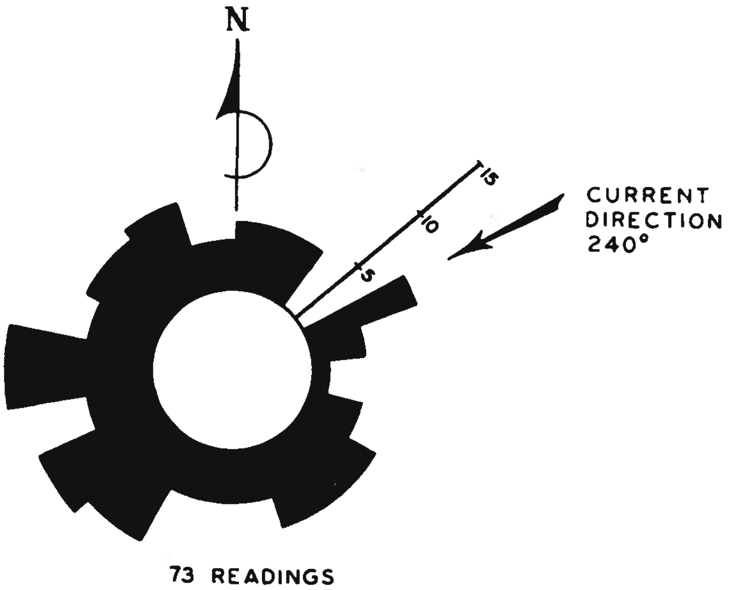

FIGURE 6. Rose diagram showing directions of crossbedding in sandstones and conglomerates of the lower member of the Wynd Formation, Jasper region.

In an outcrop of the lower member between Dorothy and Virl Lakes, 60 feet of laminated slates and siltstones are overlain by over 100 feet of coarse-grained pebbly sandstone. The lower part of this sandstone fills in the scour channel with the four banks mentioned above. From the base of the lowest bank, an essentially concordant sandstone with a maximum thickness of just over 1 foot extends laterally 22 feet into slate (Fig. 7; Pl. 9, Fig. 2). A similar body, 12 feet long, protrudes into slate from the base of the bank immediately above. Three sandstone dykes, a few inches thick and up to 3 feet long, extend upwards from the two concordant sandstones and are almost parallel to cleavage in the slates. The most northerly is disrupted by what appears to be bedding-plane slip associated with folding. Irregular sandstone bodies are associated with the upper concordant sandstone. The two highest banks overhang the channel and protruding sandstone bodies are virtually absent. An explanation of the penecontemporaneously intruded sills and dykes is given in Bielenstein and Charlesworth (1965).

Jasper Formation

The Jasper Formation, some 1500 to 1700 feet thick, consists essentially of brown to light grey, well-sorted, feldspathic, pebbly sandstones and conglomerates, with thin argillaecous siltstones and argillites. It can be distinguished from the overlying unit A by poorer sorting and the absence of quartzites, and from the underlying Wynd Formation by better sorting and the scarcity of argillaceous rocks.

On the southeastern slopes of Pyramid and Kinross Mountains the Jasper Formation is apparently conformable with and grades into unit A and the Wynd Formation. The conformable nature of the Wynd-Jasper contact is further suggested by the widespread presence of argillaceous rocks towards the base of the otherwise largely arenaceous Jasper Formation, and of sandstones towards the top of the largely argillaceous upper member of the Wynd Formation, and also by the presence of plagioclase (common in the Wynd Formation but otherwise absent from the Jasper Formation) in the basal part of the Jasper Formation.

Collet and Paréjas (1932) reported the presence of carbonates on the eastern slopes of Pyramid Mountain, close to the surface trace of the Pyramid thrust fault and at a stratigraphic level somewhere near the contact between the Jasper Formation and unit A. No carbonates have been found by the authors at this horizon on Pyramid Mountain away from the fault; hence the carbonates observed by Collet and Paréjas are probably either in the footwall of the Pyramid thrust or in a fault slice within the fault zone. Beyond the fact that they are apparently younger than the Jasper Formation, nothing is known of their age or stratigraphic position. Conglomeratic sandstones like those of the Jasper Formation, together with cherty quartzites,

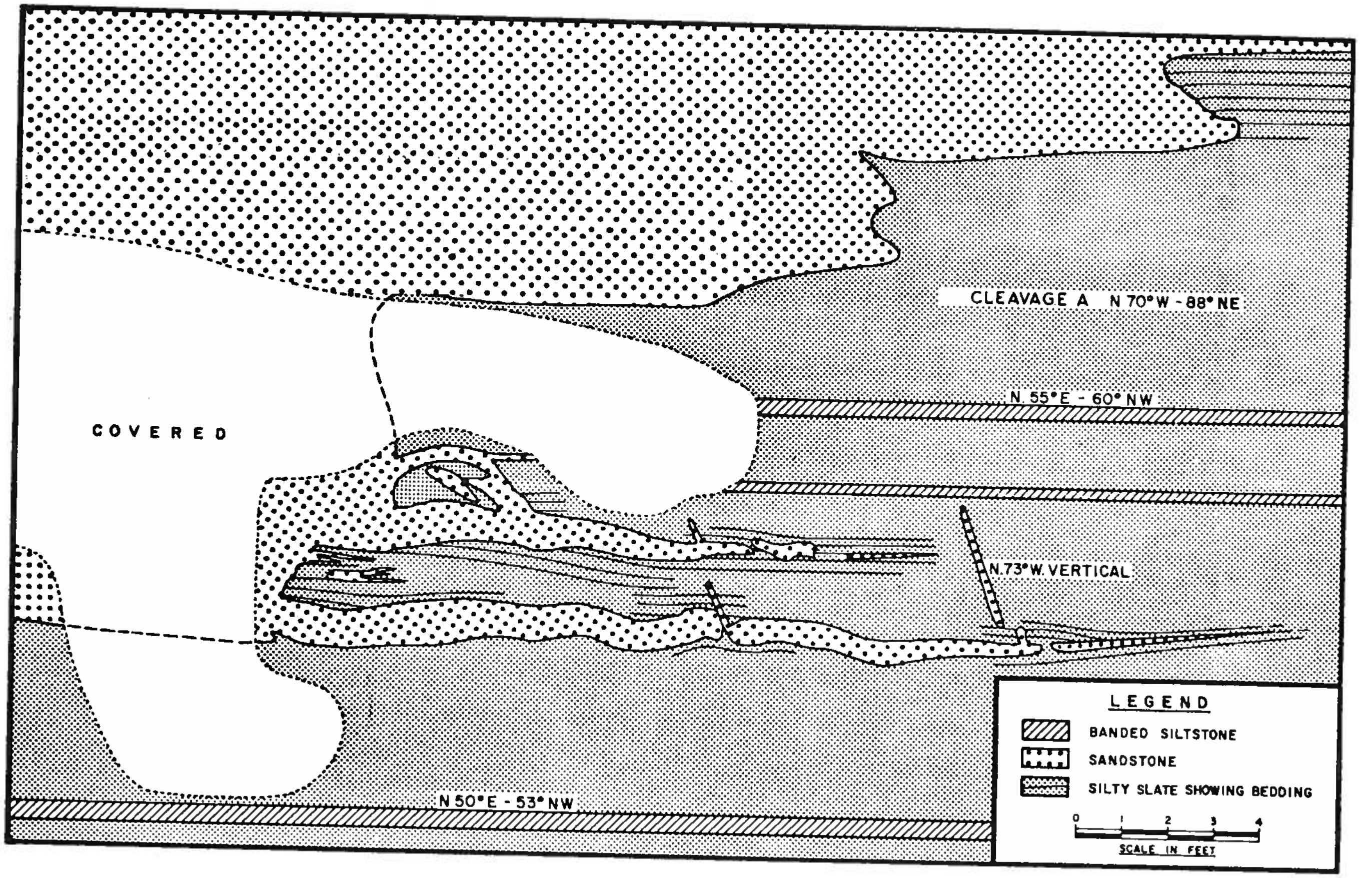

FIGURE 7. Cross section, striking N50°E and dipping 30°SE, through one side of the scour channel between Dorothy and Virl Lakes showing the associated sandstone sills and dykes.

argillites, and algal carbonates, crop out near the base of Signal Mountain across the Athabasca valley to the southeast (Map 30). The stratigraphic position of these rocks also is doubtful for they are bounded by faults.

The Jasper Formation is divisible into a lower member of interbedded sandstones, siltstones, and argillites, and an upper member made up largely of sandstones and pebble and cobble conglomerates.

Lower Member

The composition and thickness of the lower member are variable. The type section was measured on the south slopes of Kinross Mountain (Fig. 4; Pl. 10). A fuller description of this section is given in Akehurst (1964, Table 3 and p. 28-29). The pebbly and feldspathic sandstones are lenticular, and individual beds are 2 to 5 feet thick. They are composed largely of subrounded to subangular granules and pebbles, with scattered rounded pebbles up to 1 cm in diameter. Quartz in single or composite grains accounts for 50 to 85 per cent of the rock volume. Microcline (5-40 per cent) is common, and chlorite, highly altered plagioclase, and epidote grains are present in some samples. The matrix (10 per cent) is formed largely of muscovite and chlorite. The silty nature of the argillites is indicated by their content: about 50 per cent quartz, 10 per cent microcline, and 40 per cent matrix (mostly muscovite and chlorite). The siltstones are intermediate in composition between the sandstones and the argillites.

Most quartz grains exhibit undulose extinction. The dark green chlorite grains are locally abundant in the lower beds; some of the grains are intimately associated with highly altered plagioclase and are presumably an alteration product of the latter. Silica in the form of quartz, which generally forms conspicuous overgrowths, is the principal cementing agent; welded grain contacts are also plentiful. Siderite, in concentrations of up to 5 per cent, usually associated with altered plagioclase, is found in some of the sandstones and siltstones. Argillite phenoclasts are common.

The heavy accessory minerals present in a sample from the basal beds of the lower member near Pyramid Lake are principally tourmaline, including indicolite, and zircon. Granitic and pegmatitic types of tourmaline are dominant (see Akehurst, 1964, Table 4).

Upper Member

The upper member is distinguished from the lower by the relative scarcity of argillaceous rocks, by the presence of cobble conglomerates, and by the absence of chlorite and chloritized feldspar grains from the sandstones. The type section was measured on the south slopes of Pyramid Mountain (Fig. 4; Pl. 10). A more detailed description of this section is given in Akehurst (1964, Table 3 and p. 25-27).

The member can be divided into three units. The conglomeratic and feldspathic sandstones of the upper and lower units are similar in composition, except for the differences mentioned above, to those of the lower member. The most noticeable sedimentary features in these two units are the abundant scour-and-fill structures and the lenticularity of the beds. Graded bedding and small-scale cross-stratification are particularly common in the upper unit.

The middle unit of the upper member consists essentially of pebble conglomerates, cobble conglomerates, and coarse-grained, feldspathic, pebbly sandstones. Lenticular pinch-and-swell structures and cross-stratification are much in evidence. Well-rounded pebbles and cobbles are numerous; those up to 6 cm in diameter are usually quartz or chert, whereas the larger cobbles, locally up to 10 cm in diameter, are quartzite. In thin sections the quartzite exhibits sutured contacts and abundant overgrowths.

In the heavy accessory mineral suite, tourmaline and zircon predominate, although biotite is also abundant. Biotite and muscovite commonly are found as inclusions in quartz pebbles. Metamorphic tourmaline is more abundant than in the lower member, and indicolite is also present (see Akehurst, 1964, Table 4).

Unit A

Unit A was examined only on the south slopes of Pyramid Mountain (Fig. 4; Pl. 10), where it is apparently conformable with the underlying Jasper Formation and with a 200-foot thick argillite unit in the upper Gog Group. The basal beds are mainly light grey, well-sorted, medium-grained, feldspathic quartzites and quartzitic sandstones with rare, thin, pebbly bands. These grade up into light grey, locally red-weathering, dense, relatively pure quartzites containing minor quantities of microcline and fragments of quartzite and chert. The cementing material is quartz, and overgrowths and welded grain contacts are very common. The heavy mineral suite in unit A appears to be similar to that from the upper member of the Jasper Formation, although metamorphic tourmaline is more abundant (see Akehurst, 1964, Table 4).

Provenance

The attitude of cross-stratification throughout the Proterozoic and Lower Cambrian succession at Jasper (e.g., Fig. 7) points to a northeasterly source. This accords with observations by Mountjoy and Aitken (1963), who reported average current directions of S45°W for the upper portion of the Miette Group and S55°W for the lower part of the Gog Group near the headwaters of the Snake Indian River, 40 miles northwest of Jasper. In the Old Fort Point Formation the coarser grain size and the greater amount of brecciation in the northeast both point to a shoreline in that direction.

The composite plutonic and metamorphic quartz particles, abundant feldspar grains, and granite fragments in Wynd Formation strata imply that the source rocks were largely igneous and metamorphic. That the source rocks of the Cambrian strata were largely metamorphic is suggested by the large inclusions of biotite and muscovite in the quartz pebbles, by the schistose rock fragments, by the lack of liquid or other inclusions typical of igneous quartz, and by the abundance of quartzite rock fragments and metamorphic tourmaline. However, almost certainly plutonic rocks were present as evidenced by the indicolite tourmaline.

Carbonate fragments in the Wynd Formation and chert fragments in the Jasper Formation point to the existence of sedimentary rocks in the source area. The abundance of angular coarse-grained material in Meadow Creek Formation, Wynd Formation, and Cambrian strata and the general freshness of the feldspars establish that the major igneous and metamorphic source was not very distant. This source was therefore apparently situated in the adjacent part of the North American craton, namely in the 1600-1900 m.y. Churchill segment (Burwash *et al.*, 1964). This conclusion is supported by the radiometric age studies on the Precambrian rocks themselves (see p. 53).

The absence of potassic and calcic feldspars from the Meadow Creek and Old Fort Point Formations and from most of the Wynd Formation can be attributed either to their destruction during denudation or sedimentation, or to their alteration during metamorphism. The abundance of calcite and muscovite (alteration products of calcic and potassic feldspars) and the complete absence of potassic and calcic feldspars from such a thick succession of beds support the latter interpretation.

Conditions of Deposition

Old Fort Point Formation

A marine origin for the Old Fort Point Formation is implied by the finely laminated nature of many slates, by the vertical and horizontal continuity of many lithologic units, and by the presence of limestones. An alternative view is that the formation was laid down in a large lake. However, in view of the fact that Old Fort Point lithologies can be traced as far as Lake Louise, over 100 miles to the southeast, a lacustrine origin is considered unlikely. The shallowness of the sea is suggested by the breccias, desiccation cracks, crosslaminae, ripple-marks, and scour channels.

Although the fine-grained slates of member A may reflect relatively deep water, the increase in silt towards the top suggests a return to shallower water. This shoaling appears to have continued during the deposition of the southwestern facies of member B, the silt content of which generally increases upwards. The water was probably shallowest during the accumulation of the micritic, crosslaminated limestones and slates of unit 3. The limestones may have originated as micro-crystalline oozes formed by rapid chemical precipitation in sea water (Folk, 1962, p. 66), which then were moved about the bottom by current action.

The equivalents of units 1 and 2 of the southwestern facies are not represented in the northeast; they may be missing through nondeposition or erosion. The northeastern facies appears to have been laid down in shallower water than the finer-grained unit 3 to the southwest, because the argillaceous limestone breccias must have required very shallow water for their formation (see below). The tendency for the siltstones to become better sorted upward may be associated with the sea having become shallower towards the close of member B time. The argillaceous limestone breccias were presumably first laid down as interbedded silts, muds, and micritic oozes. The early lithification of the oozes and the possible thixotropic behaviour of the interbedded clastic material provided a situation where slight movement (perhaps wave-induced) was able to destroy the bedded nature of the deposit and lead to the development of the breccias. That there was some movement during brecciation is suggested by basal scour, but that the movement was not very large is indicated by the angularity of the limestone phenoclasts, the arrangement of phenoclasts in bands, and the fact that the breccia is nowhere seen to rest on undisturbed limestones. The presence of desiccation cracks in many limestone phenoclasts and in the bedded limestones of unit 3 immediately to the southwest suggests that the movements may have been associated with extremely shallow water. The large thickness of the Old Fort Point section (580 feet) as compared with that of its homotaxial equivalent to the southwest (50 feet) may be related to the disappearance of the equivalents of units 1 and 2.

The slates in the lower part of member C indicate a return to deeper water. Their greater thickness in the northeast is possibly attributable to less compaction in member B beds in the northeast (unit 3 equivalents only) compared with that to the southwest (units 1-3) during member C time. In all likelihood, the limestones, sandstones, and breccia in the upper part of member C reflect shallow water, the influx of sand grains at this time resulting from uplift in the source area. The arenaceous limestone breccia probably formed in a manner similar to that of the argillaceous limestone breccias of member B.

Deeper water seemingly returned with the deposition of the fine-grained muds of member D. That shoaling took place later is implied by the upward increase in grain size noticeable in the Old Fort Point area. The restricted distribution of the quartz-pebble limestone breccia is evidence for its being a channel-fill deposit.

In summary, the Old Fort Point Formation probably was laid down in a shallow sea close to a shoreline situated to the northeast. There appear to have been three cycles of deposition, corresponding to members A and B, member C, and member D, each beginning with a marine transgression.

Wynd Formation

The poor sorting in the lower member of the Wynd Formation indicates that the sediments underwent little or no winnowing by wave or current action, and that they were nonmarine. A shallow water or subaerial environment is implied by the cross-stratification in beds up to 3 feet thick, by the scour-and-fill structures, by the undulose and lenticular bedding with abrupt horizontal and vertical variation in grain size, and by the angular fragments of argillaceous rocks. Conversely, the presence of graded bedding is of little help in determining the conditions of deposition, for little is known about the deposition of graded beds in shallow water (Weller, 1960, p. 358). Although detailed comparison with contemporary environments is not possible, the lower member of the Wynd Formation may reasonably be assumed to be deltaic in origin. Should the arenaceous units be linear, the northeasterly trending ones may have accumulated around distributary channels during constructional phases, and the northwesterly trending one as beach ridges or barrier islands during destructional phases (Steiner, 1962). The argillaceous units may represent either lagoonal or mudflat deposits.

The uniformly fine grain of unit 1 of the upper member attests to deposition in a relatively deep sea. The arenaceous rocks of units 2 and 4 probably mark returns to more shallow water. The large dolomite boulders in unit 2 were derived in all likelihood from nearby, penecontemporaneously deposited carbonates. Uppermost Proterozoic carbonates are known from the headwaters of the Snake Indian River, 40 miles north of Jasper (Mountjoy, 1962, p. 4), from Yellowhead and Fitzwilliam Mountains, and from the hills immediately east of Mount Edith Cavell. Equivalent strata once may have covered all or part of the Jasper region, having been lifted above sea level during the shoaling associated with the deposition of unit 2. The carbonate fragments produced by subsequent erosion then may have been laid down more or less *in situ* along with coarse, quartzo-feldspathic material introduced from outside.

Jasper Formation

The relatively well-sorted nature of the sediments in the bulk of the Jasper Formation suggests considerable winnowing by wave and current action, and thus deposition in a shallow sea. This tentative conclusion is supported by the presence of cross-stratified beds up to 1 foot thick, of scour-and-fill structures, and of lenticular bedding. The almost complete absence of plagioclase from the Jasper Formation and from unit A probably resulted not from metamorphism but from destruction during weathering, transportation, or sedimentation.

Meadow Creek Formation and Unit A

The lithological similarity between the Meadow Creek and Wynd Formations suggests that the depositional environments of the two formations resembled one another. Similarly, unit A and the Jasper Formation may have accumulated under the same conditions, although the better sorting of unit A denotes even more winnowing by wave and current action.

Conclusions

The Proterozoic and Lower Cambrian strata of the Jasper region appear to have accumulated under marine or deltaic conditions in a continental shelf-coastal plain setting. The two influxes of coarse sediment, at the beginning of Wynd and Jasper time, were caused probably by either increased precipitation, an uplift of the source area, or a shoaling of the depositional surface. Similarly, the decrease in grain size at the top of the Meadow Creek Formation and the top of the lower member of the Wynd Formation attest to either decreased precipitation, a lowering of the source area, or deepening of the depositional surface.

Correlation

The Old Fort Point Formation resembles lithologically the lower part of the Hector Formation (Walcott, 1910) of the Lake Louise area, which contains green and purple slates, siltstones, limestones, and limestone breccias. This, together with the lithological similarity of the Meadow Creek Formation to the Corral Creek Formation (Walcott, 1910) of the Lake Louise area, suggests that the Meadow Creek and Corral Creek Formations are correlative.

The Jasper Formation is probably equivalent to the lower part of the Gog Group of the Lake Louise area, so that the Wynd Formation is homotaxial with the grey, argillaceous rocks of the upper part of the Hector Formation. The absence of arenaceous rocks from the Lake Louise section shows that, although some erosion undoubtedly took place along the unconformity separating the Hector Formation and the Gog Group, most of the thinning is depositional in origin.

The Meadow Creek, Old Fort Point, and Wynd Formations are probably equivalent to all or part of the Horsethief Creek Formation of the Windermere Group in southeastern British Columbia (Reesor, 1957, p. 160).

STRUCTURE

The Canadian Rocky Mountains are composed essentially of sedimentary rocks disposed in a series of imbricate thrust sheets. The presence of contractional structures within the sedimentary column, the lack of basement participation in such structures, and the fact that to the west the igneous and metamorphic Western Cordillera was already in existence by the time the structures were created, suggest that during orogenesis the sedimentary rocks were separated from the basement and piled up into thrust sheets by relative movement between the Western Cordillera and the cratonic basement. At the latitude of Jasper, separation of the sedimentary column from the basement generally occurred along décollement zones at three stratigraphic levels: Proterozoic under what were to become the Main Ranges, Cambrian under the Eastern (Front) Ranges, and Upper Paleozoic under the Foothills. Whereas many relatively closely spaced thrusts originate within the décollement zones of the Eastern Ranges and Foothills, the thrusts that branch off the Proterozoic zone under the Main Ranges are more widely spaced. A member of this last group of faults, the Pyramid thrust fault, bounds the Main Ranges to the east in the Jasper region. The strata within the various thrust sheets, and in many cases the thrusts themselves, have undergone some degree of folding.

General Description

The rocks of the Jasper region lie in the hanging wall of the Pyramid thrust fault. This fault strikes N60°W and dips southwest at more than 45° near the Athabasca River (the actual surface is visible in Pyramid Creek, about 500 feet northwest of the railway) but is almost horizontal on the east shoulder of Pyramid Mountain. Although it is approximately parallel to bedding in the Devonian and Mississippian rocks of the footwall, the fault is generally markedly discordant to bedding in the Miette and Gog Groups of the hanging wall. It dies out a few miles north of Pyramid Mountain, to be replaced along strike by the Snaring thrust (Mountjoy, 1961).

The Precambrian rocks within the Pyramid thrust sheet are displayed in a series of tight folds which, within the area mapped (Maps 30 and 31), can be grouped into three anticlinoria and two synclinoria (Fig. 8). Two other major folds, the Dominion Prairie Synclinorium and the Yellowhead Lake Anticlinorium, lie outside the map-area to the west (Fig. 1).

Jasper Anticlinorium

The Jasper Anticlinorium, some 5 miles wide, is outlined mainly by the Old Fort Point and Wynd Formations, although Cambrian beds crop out on the northeast limb. The maximum structural relief is over 6000 feet. The trend of the fold ranges from N50°W in the east to N70°W in the west. To judge from the outcrop width of the Old Fort Point Formation, the fold

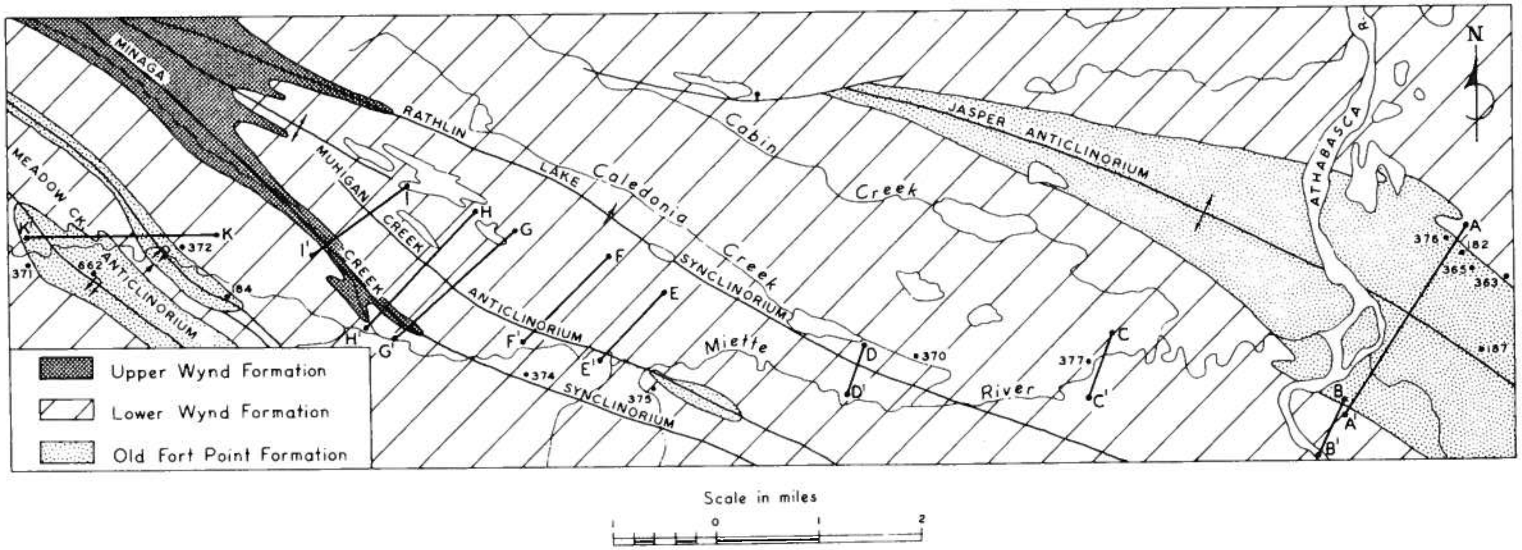

FIGURE 8. Map showing the locations of structural sections on figures 9 and 10, and locations of samples for radiometric dating.

plunges gently northwest west of the Athabasca River and gently southeast east of the river.

The minor folds in the Wynd and Cambrian strata of the northeast limb are too poorly exposed for much of their geometry to be determined. Those in the Old Fort Point Formation (Figs. 3 and 9) are about 400 feet apart and parallel the trend of the anticlinorium. Their plunge is 5-20°NW west of the Athabasca River, 30°NW to 10°SE in the immediate vicinity of Old Fort Point, and 5-25°SE farther southeast. From observations made on vertical faces, the axial surfaces of the folds have a dip of 80°SW. The average dip of bedding in the southwest limbs of anticlines is about 45° SW, whereas in the commonly overturned northeast limbs it is about 70° NE. The sinuous nature of the traces of the axial surfaces, and the failure of bedding poles from areas greater than 10^6 square feet to lie on great circles indicate that these folds, like all other minor folds in the Jasper area, are nonplanar and noncylindrical on scales larger than 1000 feet.

The minor folds in lower Wynd strata of the southwestern limb are well displayed west of the Athabasca River, where the strike of the axial surfaces and the plunge of the hinges, although variable, average about N70°W and 5°NW. Although their average distance apart is about 500 feet, they tend to form anticline-syncline pairs, with each anticline situated immediately southwest of the adjacent syncline (Fig. 9). Dips in the northeast and southwest limbs of anticlines average about 55°NE and 60°SW. The axial surfaces of the folds generally dip steeply northeast.

The structure of the northeast limb of the Jasper Anticlinorium has been modified by faulting (Map 30). West of the Athabasca River steep northeast dips predominate in the Jasper Formation, which is in contact with the Pyramid fault. East of the river the outcrop of this formation, in which bedding dips gently southwest, is separated from the trace of the Pyramid thrust by southwesterly dipping carbonates, argillites, and quartzites of probable Cambrian age. The dissimilarity in structure suggests that a southerly striking wrench fault, possibly continuous with one in the footwall of the Pyramid thrust, underlies the valley (Map 30). Very little is known about the faults in the Jasper Formation northeast of the Athabasca River.

Two longitudinal, high-angle, southwesterly dipping thrusts on the overturned northeast limbs of anticlines cut Old Fort Point strata (Figs. 3 and 9). Displacement along these faults is probably small near the Athabasca River but seems to increase southeastwards bringing to the surface strata that otherwise would be deeply buried because of the steep southeast plunge of minor folds.

The faults in the vicinity of Saturday Night Lake (Map 31) have been mapped to account for the existence of strata belonging to the upper member and the upper part of the lower member of the Wynd Formation in close proximity to Old Fort Point beds.

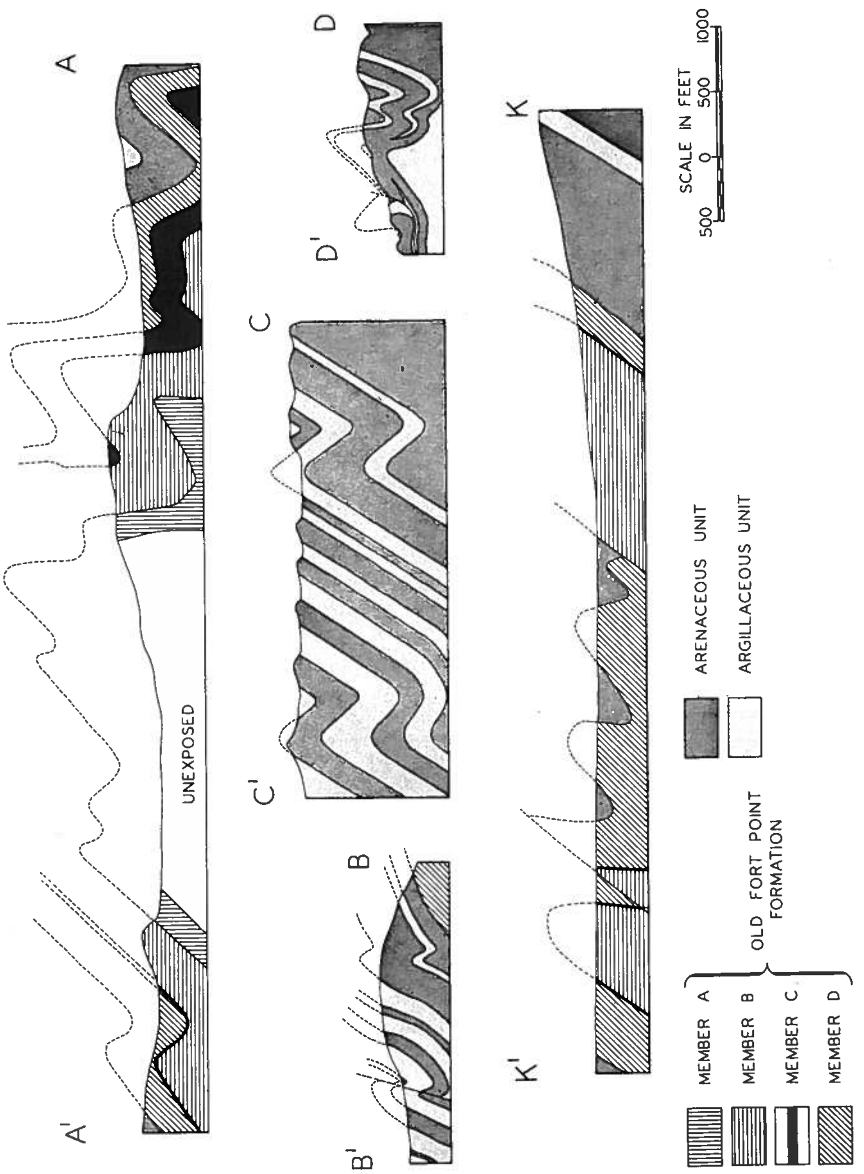

FIGURE 9. Structural cross sections of Precambrian strata, Jasper region (locations shown in figure 8).

Rathlin Lake Synclinorium

The Rathlin Lake Synclinorium contains strata belonging mainly to the lower member of the Wynd Formation. Its trend is sinuous, ranging from N75°W near Wynd Siding, through N55°W near Rathlin Lake, to N75°W north of Christine Lake, where the fold is outlined by a salient of ground underlain by upper Wynd slates (Map 31). If one judges from the appearance of upper Wynd strata northwest of Christine Lake, the fold plunges gently northwest.

Muhigan Creek Anticlinorium

The Muhigan Creek Anticlinorium exposes mainly lower Wynd Formation strata, although a small inlier of the Old Fort Point Formation is situated in the floor of the Miette River valley, and upper Wynd strata make their appearance in the extreme northwest. The wavelength and structural relief decrease northwestwards but average about 6000 and 3000 feet. From southeast to northwest the crest of the anticlinorium migrates from the anticline explosing Old Fort Point beds to the anticline just south of Christine Lake. Thus, whereas the average trend of individual folds is about N65°W, that of the anticlinorium is about N55°W. The anticlinorium, which plunges gently northwest, may be equivalent to the Portal Creek Anticlinorium (Fig. 1).

The northeast and southwest limbs of the anticline in Old Fort Point strata have average dips of 80°SW overturned and 40°SW, and the dip of the axial surface is about 70°SW. The minor folds in lower Wynd strata are the best exposed of their kind in the Jasper region (Map 31 and Fig. 10). The northeast and southwest limbs of anticlines have average dips of about 65° and 60°. The axial surfaces are essentially vertical, and most folds plunge northwest. The spacing of folds varies from about 1000 feet around Iris Lake to about 250 feet around Christine Lake. The structural relief is correspondingly variable. Although many folds die out gradually along strike, others terminate abruptly against folds of markedly different trend (Map 31). From the standpoint of style, the folds have planar limbs and narrow axial regions (Fig. 10). Plunging folds, such as the anticline exposing Old Fort Point strata in its core, which are traceable along strike for considerable distances, can be seen to be approximately similar in style. A profile of the particularly well-exposed anticline running through Iris Lake (Fig. 11) suggests that thickness variation in these similar folds is confined mainly to the argillaceous units: if bedding thickness in the limbs is taken as the basic measure, arenaceous units are 20 per cent thicker and argillaceous units 100 per cent thicker in the axial regions. Thus, although the minor folds in lower Wynd strata tend to be similar, the arenaceous units taken singly form folds that are approximately parallel in style.

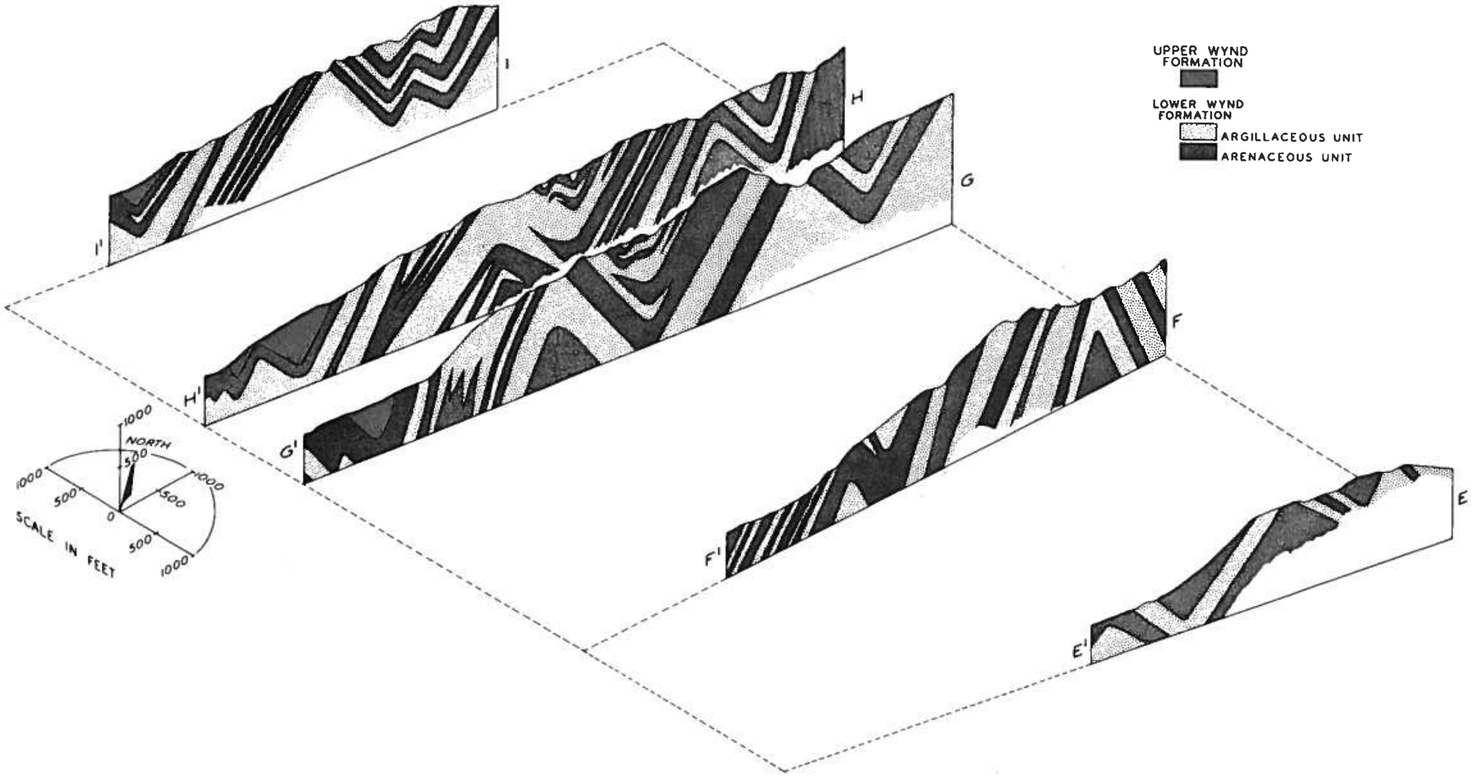

FIGURE 10. Isometric structural cross sections of Precambrian strata, Jasper region (locations shown in figure 8).

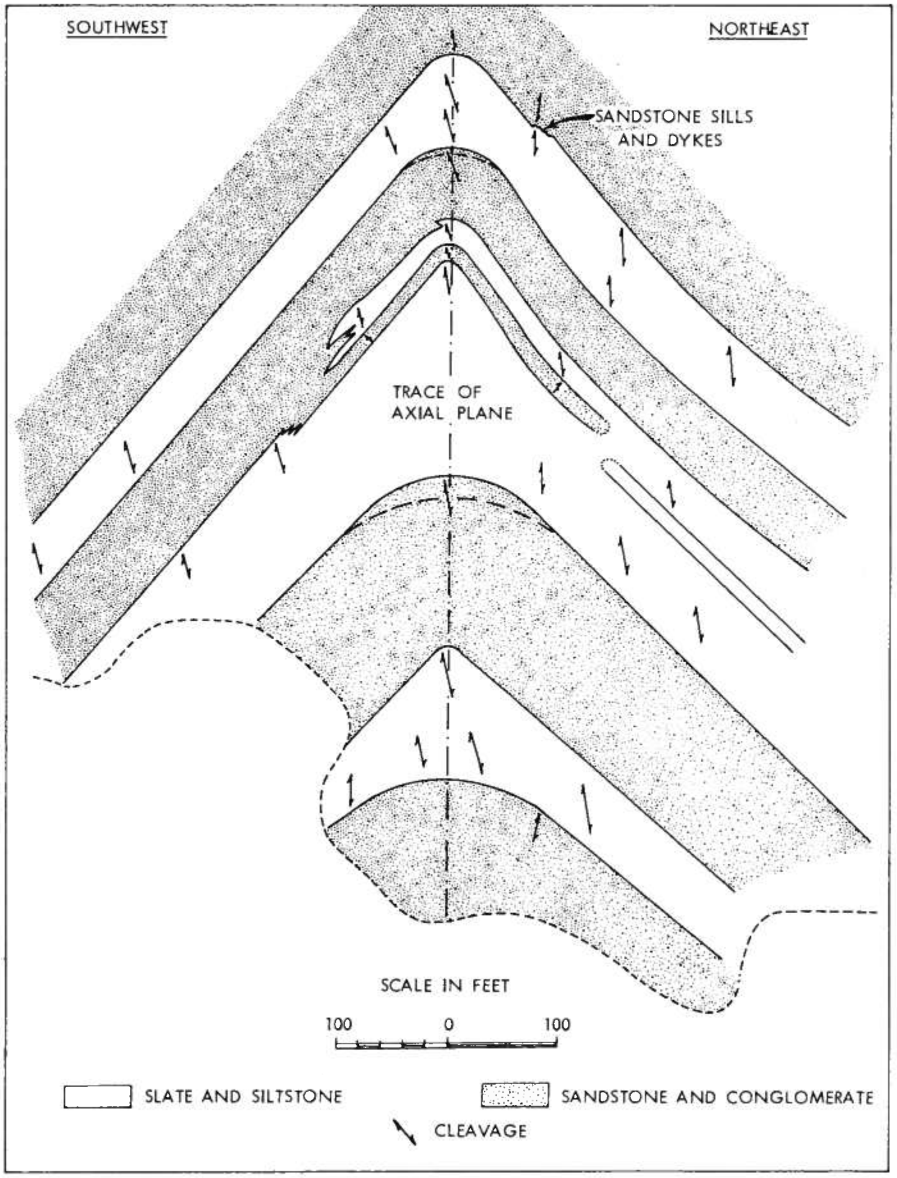

FIGURE 11. Profile of the anticline extending through Iris Lake.

Minaga Creek Synclinorium

The Minaga Creek Synclinorium is developed mainly in lower and upper Wynd strata. The strike of its axial surface ranges from N70°W in the east to N50°W in the west. If one judges from the northwesterly increase in the width of ground underlain by upper Wynd strata, the synclinorium plunges gently northwest. Whereas the axial region of the fold contains many closely spaced tight folds, the structure of the limbs is relatively simple.

Meadow Creek Anticlinorium

The Meadow Creek Anticlinorium is outlined mainly by the Old Fort Point and lower part of Wynd Formations, but the Meadow Creek Formation is exposed in a small inlier along Meadow Creek, and upper Wynd strata appear in Minaga Creek in the northeast limb and at Dominion Prairie and Clairvaux Creek in the southwest limb. Only the northeast limb and axial region were mapped in any detail; the width and structural relief of the northeastern limb both average about 5000 feet. In the axial region the Old Fort Point Formation is exposed in two en echelon anticlinal inliers (Map 31 and Fig. 8). From east to west the crest of the anticlinorium migrates from the southwestern inlier, the trend of which averages about N45°W, to the northeastern inlier, the trend of which ranges from N45°W in the east to N55°W in the west. The anticlinorium as a whole is approximately horizontal.

Minor folding is rare in the lower Wynd strata of the overturned northeast limb, the average dip of which is about 55°SW (Fig. 9). In the Old Fort Point strata of the axial region, the spacing and structural relief of minor folds, although highly variable, average about 150 and 300 feet. The folds, which are generally similar in style (Pl. 13, Fig. 2), parallel the trend of the inliers. In the southwestern inlier the plunge ranges from southeast along Meadow Creek to northwest along the Miette River. In the northeastern inlier the plunge is horizontal to gently southeast. The northeast limbs of anticlines are usually overturned (the average dip is about 60° SW) and have experienced considerable thinning. The southwest limbs and axial surfaces have average dips of about 30°SW and 50°SW.

In the lower Wynd strata of the axial region, the spacing and structural relief of minor folds, although locally variable, average 200 and 400 feet. The approximate average strike and dip of axial surfaces are N50°W and 70°SW, and the plunge is gently northwest.

The southwestern limb of the anticlinorium is essential homoclinal for a distance across strike of some 4000 feet in the northern part of the map-area (the average dip is 50°SW). Minor folds, the axial surfaces of which have an average strike of N70°W and are approximately vertical, are found in the south. Although highly variable, the average spacing and structural relief of these northwesterly plunging folds are both about 300 feet. The limbs both have average dips of about 55°.

A number of normal strike faults intersect both Old Fort Point and Wynd strata in the axial region of the anticlinorium. The faults, which are confined to the overturned northeast limbs of anticlines, dip 50-60°SW—generally slightly less steeply than bedding and cleavage. Bedding in the footwalls of two faults is very tightly and closely folded. Gouge, up to 1½ feet thick and consisting of chlorite, muscovite, quartz, albite, and siderite, is present at a number of localities. Most faults are associated with some brecciation, and with veins 1 to 5 feet thick of quartz with subsidiary calcite, chlorite, siderite, and albite. The pitch of slickensides is about 90°. Asymmetrical steps on slickensided surfaces are such that in footwalls their steep sides face downwards. The displacements along the faults appear to range from 100 to 1000 feet. The presence of upper Wynd slates on Clairvaux Creek, less than one mile southwest of its confluence with the Miette River, suggests that much of the southwest limb of the anticlinorium may be cut out by a longitudinal normal fault. Thrust faults were observed at four localities; their influence on the structure of the anticlinorium is minimal.

Folds

Description

As mentioned above, the Precambrian rocks of the Jasper region lie in a series of tight folds spaced on the average about 400 feet apart. The enveloping surfaces of these folds are themselves folded into major folds (anticlinoria and synclinoria), the limbs of which dip from 25° to 40°.

Folds in Old Fort Point Formation strata are closely spaced (the spacing, although variable, averages about 300 feet) and generally similar in style. The tightness of the folds increases westwards: the apical angle averages about 65° in the Jasper Anticlinorium, 40° in the Muhigan Creek Anticlinorium, and 30° in the Meadow Creek Anticlinorium. The degree of inclination also increases westwards: the northeast and southwest limbs of anticlines and the axial surfaces of the folds have average dips of 70°NE, 45°SW, and 80°SW in the Jasper Anticlinorium; 80°SW overturned, 40°SW, and 70°SW in the Muhigan Creek Anticlinorium; and 60°SW overturned, 30°SW, and 50°SW in the Meadow Creek Anticlinorium. The markedly asymmetrical nature of the folds results from dissimilarity in the lengths of the limbs and from thinning in the steeper limbs.

Folds in lower Wynd beds are on the average about 500 feet apart and thus less closely spaced than in the Old Fort Point Formation. Axial surfaces are generally almost vertical in the Jasper and Muhigan Creek Anticlinoria, where the average dip of the limbs is about 60°. Thicknesses in northeast limbs are about the same as those in southwest limbs, and were it not for the difference in length between the two limbs, the folds would be symmetrical in these anticlinoria. In the axial region of the Meadow Creek Anticlinorium, folds in lower Wynd strata are more closely spaced than those to the east and are overturned to the northeast. These folds are in the basal part of the formation and thus probably transitional between the upright folds typical of Wynd strata and the inclined, more closely spaced folds of the Old Fort Point Formation.

In the lower part of the upper member of the Wynd Formation, folds are tight and closely spaced. Minor folds in the upper part of the member appear to be absent, so that these strata, like those of the overlying Gog Group, are folded only into open folds on the same scale as the anticlinoria and synclinoria in the underlying strata. Whether or not the anticlinoria and synclinoria in lower Miette beds are continuous with the anticlines and synclines in upper Miette and Gog strata is not known.

Interpretation

The folds in lower Wynd strata are interpreted as buckle folds: folds the periodically varying transverse displacement of which is a secondary effect of compression approximately parallel to layering. The absence of any appreciable variation in thickness of the competent units when traced from the axial regions of folds into the limbs makes this a likely interpretation. The over-all approximately similar style of the lower Wynd folds is attributed to the interaction of the competent arenaceous units during folding (see, for example, Currie *et al.*, 1962, Pl. 2, Fig. 10).

The folds in the relatively incompetent Old Fort Point Formation may have originated as extensions of and developed in a manner similar to those in the lower member of the Wynd Formation. However, the Old Fort Point folds are inclined rather than upright. This difference in attitude may have resulted from a change in the orientation of the maximum principal stress (σ_1) of the orogenic stress-system, from horizontal in the lower Wynd to northeast-plunging in the Old Fort Point Formation. Because σ_1 in the Canadian Rocky Mountains as a whole probably plunged gently northeast (Charlesworth, 1959), it is the stress system in the lower Wynd strata that is anomalous. This anomalous orientation probably resulted from the tendency of σ_1 to be "refracted" towards bedding in the relatively competent lower member of the Wynd Formation.

The apparently unfolded nature of the axial surfaces and the association with axial plane cleavage (see below) makes it likely that the folds discussed above were produced during a single deformational episode.

Cleavage

A number of different types of cleavage, of which five are briefly described below, have been observed in Precambrian rocks at Jasper. To avoid using terms, such as fracture cleavage, which mean different things to different people, the various types are referred to as cleavage A, cleavage B, and so on. Further work needs to be carried out on the nature and origin of these structures, and the following account is by no means complete.

Cleavage A

Description

Cleavage resulting from the preferred orientation of metamorphic muscovite and chlorite (usually called slaty cleavage) is prominent in the argillaceous rocks of the lower part of the Miette Group (Pl. 11, Fig. 1). It is best developed in Old Fort Point Formation slates, but it is also widespread in the lower member of the Wynd Formation. In the upper member of this formation and in Cambrian strata, it tends to be poorly developed, so that argillaceous rocks in this part of the stratigraphic column are generally argillites rather than slates.

The parallel to subparallel arrangement of muscovite and chlorite flakes, which rarely exceed 0.04 mm in length, is apparent in thin section of slates exhibiting cleavage A. In places these minerals are concentrated in tabular layers separated by layers rich in quartz and albite. This layering, presumably metamorphic in origin, parallels cleavage, as commonly does the longest dimension of the quartz and albite grains. Small-scale slickensides normal to the hinges of associated folds have been observed on some cleavage surfaces. In a few thin sections there is evidence of shear along certain cleavage surfaces (Pl. 11, Fig. 2).

Scattered throughout most Old Fort Point Formation slates are books up to 0.4 mm long consisting of chlorite or muscovite, or both, rarely interleaved with biotite. Where cleavage A is well developed, the books are ellipsoidal in shape, with the longest axis parallel to the "c" crystallographic axis and to cleavage. In poorly cleaved rocks, the ellipsoidal or tabular books are parallel to bedding, with the c axis normal to the long dimension of the books (Pl. 1, Fig. 1).

Cleavage A is most commonly approximately parallel to or fans symmetrically about the axial surfaces of folds (Pl. 11, Fig. 1; Pl. 12, Fig. 2). In the Old Fort Point Formation of the Jasper Anticlinorium, cleavage in slates has average dips of 80°SW and 55°SW in the southwest and northeast limbs of anticlines, the average dips of which are 45°SW and 70°NE. A plot of bedding dip against cleavage dip shows that cleavage dip increases at the rate of 2° for every 10° increase in the dip of bedding to the southwest, and that it decreases at the same rate for beds dipping northeast

(Charlesworth and Evans, 1962, p. 358). Slates as devoid as possible of interbedded siltstones and breccias were selected for the above plot, for it was found that the orientation of cleavage is very sensitive to the presence of interbedded siltstones and breccias, as the examples illustrated in figure 12 indicate. In the Old Fort Point Formation of the Meadow Creek Anticlinorium, the average dip of cleavage is about 50° in both limbs of folds, the average dips of which are 30°SW and 60°SW overturned.

In argillaceous strata of the lower part of the Wynd Formation, this type of cleavage is approximately vertical, a finding which is in keeping with the upright nature of the associated folds. In the axial region of the anticline through Iris Lake, the attitude of the cleavage in the slates can be seen to depart slightly from that of the axial surface (Fig. 11).

Interpretation

The axial surface of a buckle fold is approximately normal to σ_1 of the causative stress-system. Its symmetrical distribution about the axial surfaces of folds in the Old Fort Point and Wynd Formations suggests that cleavage A also originated at right angles to σ_1. Moreover, symmetry arguments lead to the conclusion that the curvature of cleavage A around competent inclusions, such as those shown in figure 12, can only be accounted for if the cleavage developed orthogonally to the principal stress-axis trajectories. The rotation of chlorite-muscovite books and cleavage mullions (see p. 46) into the plane of cleavage is further evidence supporting the "flow" nature of cleavage A.

An analysis of the strain associated with the development of cleavage mullions (Charlesworth and Evans, 1962) suggests that although cleavage A originates normal to σ_1, the tendency for the recrystallization associated with it to lag behind the rotation involved in folding results in its becoming oblique to σ_1 and subject to shear. Thus, cleavage A is not entirely a flowage phenomenon. The slickensides observed on certain cleavage surfaces and the shear noticed in certain thin sections support this conclusion.

The slight departure from parallelism of the axial surface and cleavage A in the axial region of the anticline running through Iris Lake is a feature commonly associated with "axial-plane slaty cleavage" (see Talbot, 1965, p. 1031). It probably reflects a slight variation with time in the orientation of the stress system during the time of folding and slaty cleavage development.

The fanning of cleavage A around axial surfaces probably resulted from the tendency demonstrated by Bell and Currie (1964) for σ_1 to be refracted towards bedding. Simple shear in the thin slate bed illustrated in figure 12A, caused by slip between the adjacent competent siltstones, distorted the stress-field in the slate and gave rise to the reversed cleavage fan.

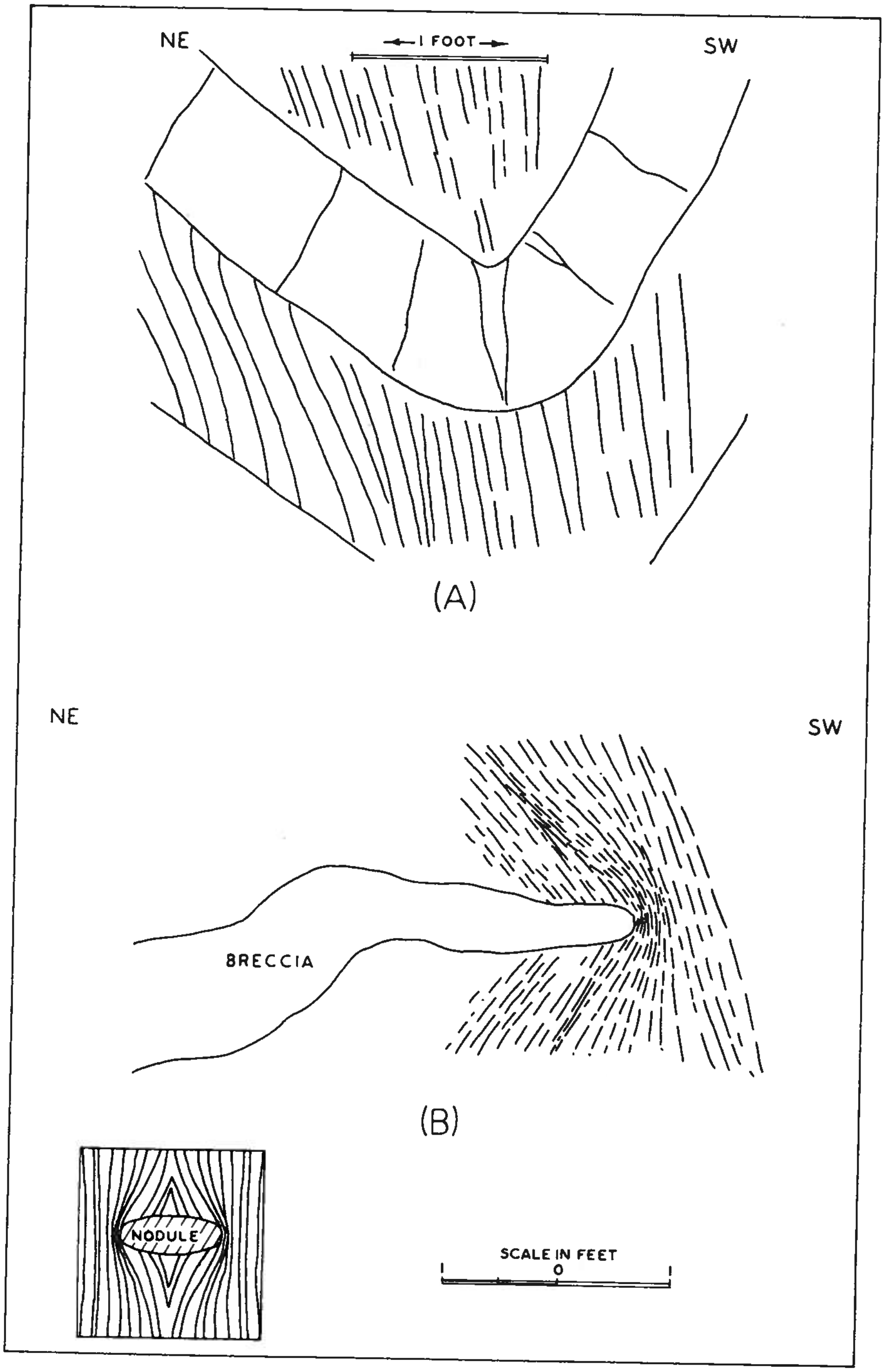

FIGURE 12. (A) Variation in the attitude of cleavage A in slate across a syncline. (B) Cleavage A wrapping around the edge of a breccia lens and around a nodule.

Cleavage B

Where enough preferentially oriented metamorphic muscovite and chlorite is present, cleavage B is found in the poorly sorted arenaceous rocks in the lower member of the Wynd Formation. In these rocks the major cleavage surfaces are somewhat irregular because of their tendency to be deflected around pebbles and large sand grains. The spacing of the surfaces, generally 2 to 10 mm, increases with increasing grain size. Muscovite and chlorite are concentrated along these and more closely spaced irregular surfaces. Because of the preferred orientation of mica, and because many sand grains and pebbles are elongated subparallel to the major surfaces, the cleavage in these arenaceous rocks is similar to cleavage A and is not a fracture cleavage. Cleavage B fans about the axial surfaces of folds in the normal manner but makes a larger angle with bedding than does cleavage A. Within graded beds cleavage A can be seen to grade into cleavage B with a corresponding gradual change in attitude (Pl. 12, Figs. 1 and 2), in contrast to the abrupt change in orientation at the contacts between rocks of markedly different composition.

The similarity of cleavage B to cleavage A, and the symmetrical relationship between cleavage B and the axial surfaces of folds, suggest that cleavage B also originated normal to σ_1. That the σ_1 trajectories were refracted through larger angles in the more competent arenaceous rocks is suggested by the angle of the cleavage fan being larger in these rocks than in the less competent slates.

Cleavage C

Cleavage C, restricted to lower Wynd arenaceous rocks resembles cleavage B in appearance. It differs in being confined to the axial regions of folds, where it parallels the axial surfaces, and in its association with displacement approximately normal to the fold hinge. The sense of displacement is such that the axial region of an anticline has moved upwards, and that of a syncline downwards.

Cleavage D

Cleavage D is found in Old Fort Point Formation limestones. Here, the smooth cleavage surfaces, 5 mm or less apart, are coated with muscovite and chlorite and are commonly associated with shear. The orientation of cleavage D relative to the axial surfaces of folds is identical to that of cleavage B (Pl. 13, Fig. 1A).

Cleavage E

Shear parallel to the cleavage surfaces, accompanied by folds in bedding within the tabular layers between these surfaces, characterizes cleavage E (Pl. 2, Fig. 2; Pl. 13, Figs. 1B, 2). This type of cleavage resembles strain-slip or crenulation cleavage, except that the cleavage is symmetrical about the axial surfaces of folds, and the folds are in bedding and not in an older cleavage.

The best examples of cleavage E are found in tight mesoscopic folds within the interbedded limestones and slates of member B of the Old Fort Point Formation. The sense of shear along the cleavage surfaces which parallel the axial surfaces of folds is such that the axial region of an anticline has moved upwards, and that of a syncline downwards, although in the axial regions themselves the displacement is erratic. Well-developed slickensides along the cleavage surfaces, which are 5 to 15 mm apart, show that shear took place normal to the associated fold hinges. Cleavage E also is found in the siltstones of member B of the Old Fort Point Formation in the Jasper Anticlinorium. Here the attitude of the cleavage appears to be dependent on that of bedding (Fig. 13).

The origin of cleavages C, D, and E is not fully understood.

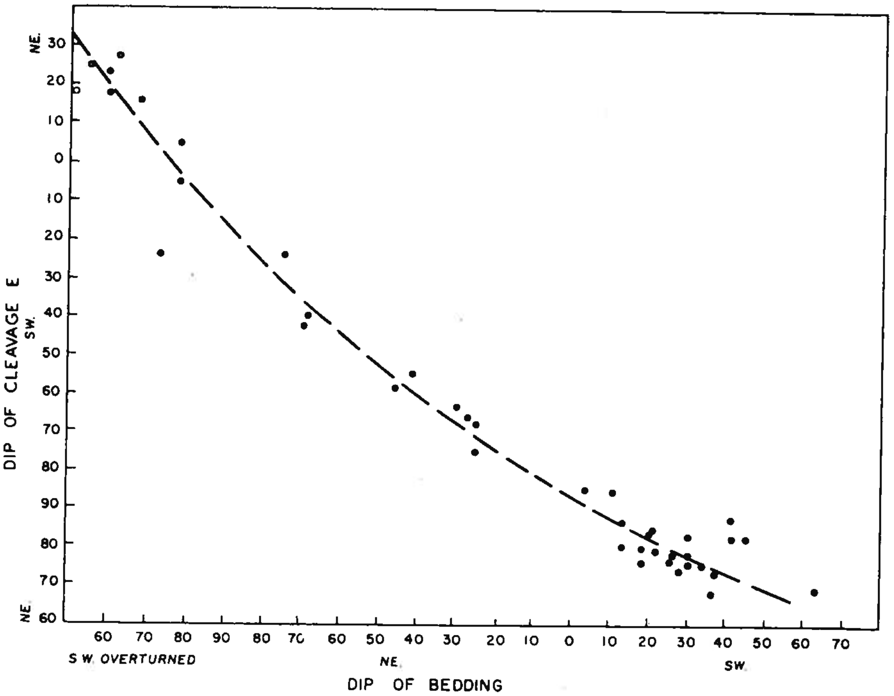

FIGURE 13. Dip of cleavage E in Old Fort Point Formation siltstones from the Jasper Anticlinorium plotted against dip of bedding.

Cleavage Mullions

Cleavage mullions, restricted to thin Old Fort Point Formation siltstones in predominantly slaty surroundings, are commonly present in the northeast limbs of anticlines. Commonly, the mullions have been rotated so that their long axes parallel cleavage A in the enveloping slates. An analysis of the strain involved in the development of the mullions suggests that some shear has occurred parallel to cleavage (Charlesworth and Evans, 1962, p. 359-362).

Age of Cleavage

The approximately symmetrical relationship between the various types of cleavage described above and the axial surfaces of folds, together with the association of cleavage with metamorphic muscovite and chlorite, suggests that the cleavages, which tend to be mutually exclusive, developed during folding.

Kink Folds

Kink folds, restricted almost entirely to the Old Fort Point Formation of the Meadow Creek Anticlinorium, affect slates where the southwest-dipping cleavage A has all but obliterated bedding. They are found in pairs (Pl. 14, Fig. 1), each pair consisting of two parallel surfaces (the axial surfaces of the folds) 3 to 100 mm apart, between which cleavage generally has been rotated 10 to 40 degrees anticlockwise (looking northeast). Only in one outcrop, near a normal fault, is the rotation clockwise.

The attitudes of the axial surfaces vary considerably. Even within a single outcrop, differences in dip of 10° are not unusual, and many kink folds cross one another. The strike ranges from N30°W to N90°W, but the dip is consistently northeast and has an average value of 40°. Veins and evidence of displacement along the axial surfaces are rare. The fold hinges, which parallel the lineation formed by the intersection of cleavage A and the axial surfaces, plunge consistently northwest. The fold pairs, 6 mm to 150 cm apart, can be traced for up to 50 feet, although most die out in shorter distances. Kink folds were observed in siltstones and sandstones, as well as slates, the spacing and distance between the axial surfaces of kink folds increasing with increasing grain size.

Laminar gliding on cleavage surfaces coupled with rotation of the cleavage appears to have been the principal mechanism behind the formation of kink folds. The axial surfaces of the kink folds are thus strain discontinuities that define the limits of gliding.

The kink folds, which are clearly later than the main episode of folding and metamorphism, have been responsible for northeast-southwest horizontal contraction and vertical extension. This suggests that they developed shortly after the main episode of deformation while σ_1 was still approximately horizontal and had a northeast-southwest trend.

Faults

Thrust, normal, and wrench faults cut the Precambrian rocks of the Jasper region. The number of faults in the area mapped is undoubtedly much greater than that shown, especially in ground underlain by the Wynd Formation, where the stratigraphic position of an outcrop is difficult to establish.

Thrusting and wrench faulting probably occurred penecontemporaneously with folding, for all three types of deformation require essentially horizontal compression. Some thrusts, such as the one in section DD′ of figure 9, are probably confined to one limb of a fold and die out downwards into bedding-plane slip associated with buckle folding. The normal faults are not folded and therefore are younger than the main episode of deformation. This conclusion is supported by the presence of calcite in veins parallel to cleavage A in the immediate vicinity of normal faults, and the absence of strained quartz from other veins associated with the faults. Although observational evidence is lacking, normal faulting presumably occurred after kink folding at a time when σ_1 was essentially vertical.

Joints

In the Jasper region joints are common in rocks of all lithologies and at all stratigraphic levels. As might be expected in such a highly deformed terrane, the joint pattern is complex, although commonly approximately symmetrical to the hinges of associated folds. Using *b* parallel to the local orientation of the fold hinge, *a* parallel to bedding and normal to *b*, and *c* normal to bedding, it is generally possible to distinguish an *ac* extension set and two conjugate *hk*O shear sets. In the Wynd Formation the *ac* joints are best developed in the axial regions of folds and in anticlines are associated with thick veins. The *hk*O joints also are veined locally. In view of the complexity of the joint pattern, no conclusions as to the age of jointing are drawn.

METAMORPHISM AND IGNEOUS ACTIVITY

Metamorphism in Lower Miette Rocks

Rocks of the Meadow Creek and Old Fort Point Formations and of the lower member of the Wynd Formation all belong to the quartz-albite-muscovite-chlorite subfacies of the greenschist facies. Two mineral assemblages are present: that of the rocks themselves, and that of the vein material filling many of the joints.

Vein Assemblage

Although some variation in the distribution of vein minerals exists, the over-all compositional differences among joint sets appears to be slight. The average assemblange in veins, which are up to several feet wide, is quartz (79 per cent), chlorite (10 per cent), calcite (10 per cent), and albite (1 per cent), with a trace of siderite. Some veins are monomineralic and are composed of one of the three major constituents. Chlorite and calcite, generally scattered throughout a vein, are found in a few cases in pods, either together or singly.

Quartz is generally elongate, with the c-axis either parallel or normal to the vein walls. There is some suggestion that the c-axis is normal to extension joints and parallel to shear joints. Strained quartz is common, except in veins associated with normal faults, and most grains contain rows of globular and dusty inclusions. Calcite is present as crystals up to 1 inch in diameter. Except in veins associated with normal faults, the crystals are commonly twinned. The results of an X-ray diffraction study (based on a procedure devised by Goldsmith and Graf, 1958, p. 97) indicate 2 per cent mole weight of Mg^{++} in the calcite. The pale green chlorite has a distinct pale blue birefringence, is optically negative, vermicular in habit, and non-pleochroic. The results of an X-ray diffraction study (based on a procedure devised by Shirozu, 1958, p. 223) indicate that the chlorite is monoclinic, with a formula of $(Mg, Fe)_{4.6}(Fe,Al)_{1.4}(Al_{1.4}Si_{2.6})O_{10}(OH)_8$, and a Mg^{++}:Fe^{++} ratio of 3.6:1. Small albite crystals are scattered throughout the veins. The extinction angle of the twin lamellae indicates a composition of $An_{0\text{-}15}$.

The similarity of the vein assemblage to the composition of the country rocks suggests that the vein materials were derived locally and emplaced during orogenesis.

Rock Assemblage

The mineral assemblage in lower Miette strata is quartz, calcite, siderite, albite, chlorite, muscovite, biotite, pyrite, ilmenite, magnetite, zircon, tourmaline, apatite, and rutile. With the exception of biotite, which generally has ill-defined outlines and appears to be partly altered to chlorite in some cases, this assemblage was probably stable during metamorphism. Some minerals, such as quartz, calcite, and biotite, were present before the onset of metamorphism, whereas others, such as chlorite, may have been absent.

Feldspars in silt- to pebble-sized particles are abundant in lower Miette strata. Staining tests (Hayes and Klugman, 1959, p. 227-252) indicate that the only feldspar present is plagioclase. Results obtained from using the Michel-Lévy technique (*in* Rogers and Kerr, 1942, p. 241) suggests a composition of An_{0-15} with an average of An_9, whereas refractive indices (*in* Smith, 1958, p. 1189) suggest An_5. The results of X-ray diffraction studies based on techniques devised by Smith and Yoder (1956, p. 641) and Orville (1958, p. 208) show that the albite is a low-temperature variety, and that two phases are present with Or contents of 6 and 0 mole per cent. Thus, albitization appears to have been an important metamorphic process, for it is reasonable to assume that both potash feldspar and calcic plagioclase were present in the original assemblage, the two phases now present representing their albitized equivalents. The albite is intergrown and apparently replaced, especially along fractures and cleavage planes, commonly by chlorite and muscovite and more rarely by carbonate. This lends support to the hypothesis that it was derived, with loss of potassium and calcium, from potash feldspar and calcic plagioclase.

Whereas most silt- and sand-sized grains are twinned only according to the albite law, the twinning in pebbles (Pl. 14, Fig. 2) is of the chessboard type. Chessboard twinning, according to Starkey (1954), is caused by albitization of potash feldspars and by deformation. He proposed that the chessboard pattern forms in preference to the more normal polysynthetic twinning because the albite has taken over the lattice structure of the potash feldspar. However, this proposal receives no support from the results of the present study. Most commonly, the chessboard effect has been caused by abrupt truncation of the twin lamellae by the (001) cleavage, which is exceptionally well developed in pebble-sized grains. Where not truncated in this manner, the lamellae stop at some irregular fracture or pinch out. There seems to be no relationship between the chessboard pattern and the pericline twin plane, as would be expected if the pattern were inherited from microcline. Furthermore, one grain showing a relict perthite structure in which the two phases, with different crystallographic orientations, are now both albite does not show chessboard twinning.

Chessboard twinning almost certainly developed during metamorphism and deformation of the Precambrian strata at Jasper, for the twinning hardly could have survived the recrystallization that accompanied albitization. The association with the well-developed (001) cleavage in pebbles, which were subject to greater differential stress than smaller particles, suggests a genesis related to orogenic stress. It is postulated first, that in those albite pebbles with (001) planes suitably oriented with respect to the principal stress axes, appreciable displacement occurred along certain (001) planes, and secondly, that variation in the intensity of polysynthetic twinning produced by the resulting variation in elastic strain led to the chessboard effect.

Chlorite is present as minute flakes, generally subparallel to cleavage, and as larger books. It is pale green, generally pleochroic, and optically negative. The results of X-ray diffraction studies based on techniques devised by Warshaw and Roy (1961) and Brindley (1961) suggest that most if not all the chlorite is "normal" 14 Å chlorite, and not septechlorite, which has a 7 Å basal spacing, and that its composition is $(Mg)_{4.07}(Fe,Al)_{0.63}(Al_{0.63}Si_{3.37})O_{10}(OH)_8$, with a Mg^{++}:Fe^{++} ratio of 3.1:1.

Muscovite is present as anhedral minute flakes generally subparallel to cleavage, as larger detrital grains in arenaceous rocks, and interleaved with chlorite in books. X-ray diffraction studies (based on a technique *in* Yoder and Eugster, 1955) suggest that the muscovite present is the 2*M* (two-layer monoclinic) variety. The muscovite and chlorite, along with some quartz, were probably derived from illite in the original sedimentary rock (see Velde, 1964).

Quartz, widespread in silt- to pebble-sized particles, shows little evidence of metamorphic recrystallization. Replacement by calcite is rare. The larger particles generally exhibit undulatory extinction.

Calcite is common, being found in grains of various sizes. The tendency for it to be twinned increases with increasing grain size. X-ray diffraction studies (based on a technique *in* Goldsmith and Graf, 1958, p. 97) indicate 0-3.5 mole per cent of Mg^{++}.

Siderite, present in small amounts only, is present as small anhedral grains or as rhombs up to 2 mm across. Rarely can it be seen to replace calcite. The rhombs commonly contain silt-sized quartz and albite grains. Alteration to hydrous iron oxide is common. Cleavage A surfaces are invariably wrapped around siderite grains, indicating the premetamorphic origin of the latter. Inasmuch as its formation apparently requires an absence of oxygen (Krumbein and Garrels, 1952), its presence in the shallow-water strata of the lower Miette Group suggests a secondary origin.

Metamorphism in Upper Miette and Lower Gog Rocks

Rocks belonging to the upper member of the Wynd Formation, the Jasper Formation, and unit A have been metamorphosed to a lesser degree than lower Miette strata. Veins are rare in upper Wynd rocks and virtually absent from the Gog Group; those that are present generally consist of quartz. The major minerals present in the rocks themselves are quartz, plagioclase, potash feldspar, calcite, chlorite, muscovite, and epidote.

Plagioclase (An_{5-15}) is restricted to the upper part of the Wynd Formation and the basal member of the Jasper Formation. Its virtual absence from Gog strata probably means that it was not present in the original sediments. Potash feldspar (microcline) is found in upper Wynd and Gog strata. Overgrowths on quartz and welded contacts between quartz grains are common in unit A, with the result that arenaceous rocks within this unit are quartzites rather than sandstones. Although metamorphic muscovite and chlorite appear to have replaced the clay minerals of the original sediment, they generally do not have the preferred orientation characteristic of the lower member.

Discussion

No horizontal variation in metamorphic grade of lower Miette rocks was observed within the Jasper region. However, the K/Ar dates show a general westerly decrease (see below), which suggests that the metamorphic grade increases westwards. This possibility is supported by the existence of metamorphic biotite in and the absence of chlorite from upper Precambrian rocks near Mount Robson, 50 miles west of Jasper. The metamorphic grade of the Miette and Gog Groups clearly decreases upwards. The apparent upward increase in degree of induration of arenaceous rocks, from sandstones in the Miette Group, through indurated sandstones in the Jasper Formation, to quartzites in unit A is related to an upward change in composition: in Miette sandstones the sand grains tend to "float" in a micaceous matrix which has prevented welding of grains by pressure-solution effects. However, in unit A the grains are generally in contact and welded together.

During metamorphism, lower Miette strata near Jasper were buried beneath a minimum of 25,000 feet (8 km) of sedimentary rocks. The minerals of the greenschist facies are thought to form at a temperature of about 300°C when subjected to a load pressure of 3000 bars, approximately equivalent to a depth of burial of 8 km (Fyfe, Turner, and Verhoogen, 1958; Velde, 1964). If the effect of orogenic thickening and synorogenic erosion is neglected, these temperatures and pressures suggest that the linear geothermal gradient in the sedimentary column of the Rocky Mountains during orogenesis was less than 35°C/km.

Inasmuch as metamorphic muscovite and chlorite are related to cleavage, which in turn is symmetrical about the axial surfaces of folds, metamorphism and deformation were likely penecontemporaneous.

Igneous Activity

The only igneous rocks cropping out in the Jasper region are in the Meadow Creek Anticlinorium, at a small outcrop on the old Yellowhead road, ⅝ mile northwest of Geikie Siding. At this locality, 10 feet of green, fine-grained igneous rock (probably originally diabase) are intrusive with slight angular discordance into unit 3 of member B of the Old Fort Point Formation. The intrusion, which is highly fractured, veined, and altered, consists of about 40 per cent albite in laths up to 1 mm long, 20 per cent calcite, 20 per cent chlorite, 10 per cent leucoxene, and 10 per cent siderite and pyrite. In view of its altered and deformed nature, the intrusion clearly was emplaced before the onset of orogenesis.

RADIOMETRIC AGE MEASUREMENTS

Potassium-argon (K/Ar) radiometric age measurements were made on a number of whole-rock samples and muscovite separates from Precambrian rocks near Jasper with a view to determining the age of the source terrane of the original sediments and the age of metamorphism. The geographic location, stratigraphic position, and lithology of the samples are listed in table 2. Petrographic descriptions of the samples are given in Weiner (1966, p. 176-177).

The slate samples collected for whole-rock K/Ar measurements were crushed and sieved, and the 0.50-0.85 mm fraction retained. The mesh size of the fraction has no significance, for each particle in the fraction is an aggregate of many smaller grains. The arenaceous rock samples collected for K/Ar measurements on detrital muscovite were crushed and the muscovite recovered from the fractions listed in table 2.

Details of the analytical procedures followed during the measurement of K/Ar radiometric ages can be found in Goldich *et al.* (1961). Potassium determinations were performed by the gravimetric method, in which tetraphenol boron precipitation is used. The K^{40} content was calculated by taking the abundance ratio K^{40}/K to be 0.0118 atomic per cent. Ar^{40} was determined by the isotope dilution method, in which a spike containing a known amount of Ar^{38} is used. Constants used in the calculation of radiometric ages are:

$$\lambda_\epsilon = 0.589 \times 10^{-10}/\text{year}$$
$$\lambda_\beta = 4.760 \times 10^{-10}/\text{year}$$

The measurements of K/Ar radiometric age are given in table 2.

Radiometric Age-Grain Size Relations

The only potassium-bearing mineral in the slates is muscovite. Most of this is metamorphic and parallel to cleavage, but some is detrital. The average grain size of the muscovite in each slate could not be determined, but it presumably is only slightly greater than that of the metamorphic muscovite, which varies from 0.01 to 0.05 mm. The muscovite flakes recovered from the arenaceous rocks are assumed to be all detrital, for in thin sections similar flakes (larger than 0.1 mm in diameter) observed lying parallel to the bedding are considerably larger than those flakes lying parallel to cleavage. Although the ages obtained from the samples range widely, from 1780 to 240 million years (m.y.), the larger values are from the coarser-grained muscovites; hence, there appears to be some relationship between radiometric age and grain size.

The nature of this relationship is further demonstrated in figure 14, in which the cube of the median diameter in phi of detrital muscovite is plotted against radiometric age for samples 363-365, the stratigraphic positions of which are close to the base of the Wynd Formation. A straight-line relationship is found, age decreasing with decreasing grain size. Slate samples 182, 187, 371, 372, 375, 376, which come from horizons within 500 feet of the base of the Wynd Formation, fall on this straight line, if the median diameter of the metamorphic and detrital muscovite in each sample is between 0.050 and 0.055 mm, reasonable values just slightly larger than the diameters of metamorphic muscovite.

The detrital muscovite samples apparently have been updated during metamorphism, such that the coarser the muscovite, the smaller the amount of updating. Thus, the detrital ages are intermediate between the original age of the detrital muscovite (the age of the source rocks) and the age of metamorphism. The whole-rock ages are probably also intermediate between the age of the updated detrital muscovite and that of the metamorphic muscovite (the age of metamorphism).

The linear relationship between radiometric age and the cube of the median diameter should hold only over a limited range of grain sizes. At the lower end the curve should become horizontal at an age equal to the age of metamorphism. Unfortunately, attempts to separate fine-grained metamorphic from detrital muscovite were not successful, so that this hypothesis could not be tested. At the upper end the curve should become horizontal at an age equivalent to the age of the source rocks. Unfortunately, a sufficiently large sample of detrital muscovite coarser than that in sample 363 could not be found.

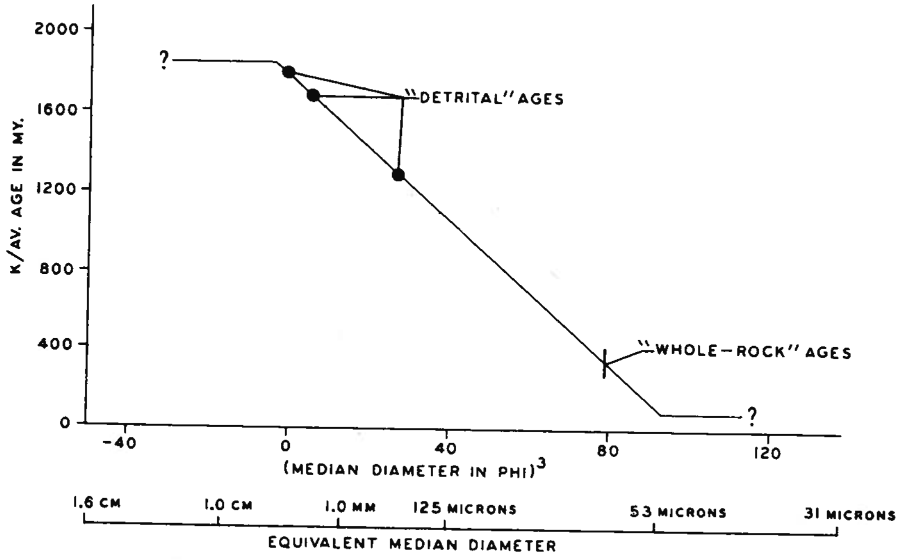

FIGURE 14. Plot of the cube of phi median diameter of detrital and whole-rock muscovite against K/Ar radiometric age for samples collected from near the base of the Wynd Formation.

Radiometric Age-Geographic Location Relations

The radiometric ages of whole-rock samples are plotted against distance west or east of Jasper in figure 15. Although there is a considerable spread of points parallel to the ordinate (caused presumably by such factors as variation in amount of partially updated detrital mica), the data suggest that the radiometric age decreases westwards. This trend possibly reflects a westerly increase in the degree of updating of detrital muscovite in the slates, caused by a westerly increase in metamorphic grade.

Age Determinations on Samples from Near Mount Robson

Some further light on the age of metamorphism of the Precambrian rocks of the Jasper area is given by radiometric age determinations of samples of a biotite-muscovite slate[1] and a quartz-biotite-muscovite schist, from an outcrop 4 miles southwest of Mount Robson Station, B.C., 50 miles west of Jasper. A whole-rock radiometric age was obtained from the slate. The schist was crushed and pulverized, and the 0.177-0.125 mm fraction retained. Muscovite was separated from biotite, and age measurements (Table 2) were made on both minerals.

The 69 m.y. age obtained from the slate upholds the trend for the whole-rock radiometric ages of slates to decrease westwards (Fig. 15). Presumably the 69 m.y. age is closer to the age of metamorphism than the older ages obtained to the east. The 93 and 105 m.y. ages from the muscovite and biotite concentrates suggest that some of the mica in these samples is partially updated detrital mica.

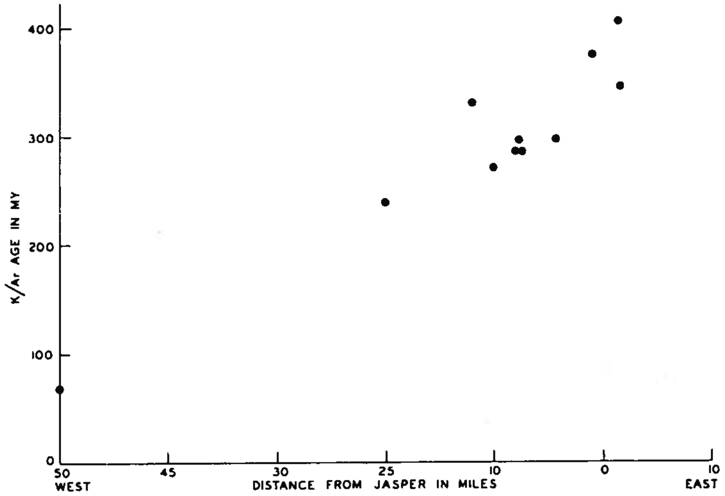

FIGURE 15. Plot of K/Ar radiometric ages of whole-rock samples against distance west or east of Jasper.

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[1] Petrographic descriptions of these rocks are given in Weiner (1966, p. 177).

Table 2. Radiometric Age-Determinations[1]

Sample Number	Rock Type	Stratigraphic Position in Feet Relative to the Base of the Wynd Formation	Distance East or West of Jasper in Miles	Material Dated	% K_2O	$\frac{Ar^{40}}{K^{40}}$	Age in m.y.
363	conglomerate	0	2.0 east	muscovite separate 4.00 - 0.71 mm	8.79	0.1744	1776
364	conglomerate	0	2.0 east	muscovite separate 0.149 - 0.105 mm	6.27	0.1083	1288
365	sandstone	50 below	1.5 east	muscovite separate 0.500 - 0.149 mm	4.67	0.1600	1680
182	slate	300 below	1.5 east	whole rock	3.53	0.0224	346
376	slate	50 below	1.4 east	whole rock	4.60	0.0269	408
377	slate	500 above	1.0 west	whole rock	5.03	0.0246	377
370	slate	2000 above	2.8 west	whole rock	5.14	0.0346	485
375	slate	150 above	4.3 west	whole rock	6.09	0.0192	299
374	slate	1200 above	5.0 west	whole rock	4.99	0.0187	296
372	slate	100 above	7.7 west	whole rock	2.09	0.0188	297
184	slate	200 below	7.7 west	whole rock	4.11	0.0182	286
662	slate	600 below	7.9 west	whole rock	4.95	0.0182	286
371	slate	200 above	10 west	whole rock	5.78	0.0172	271
187	slate	300 below	11 west	whole rock	4.18	0.0213	333
663	slate	600 below	20 west	whole rock	4.57	0.0151	240
661	slate	?	50 west	whole rock	10.58	0.0042	69
659	schist	?	50 west	biotite separate 0.177 - 0.125 mm	8.47	0.0056	93
660	schist	?	50 west	muscovite separate 0.177 - 0.125 mm	10.01	0.0064	105

[1] The assumed deviation in age is ± 5 per cent. The geographic locations of most specimens are shown in figure 8. Specimen 663 comes from the Yellowhead Lake Anticlinorium, and specimens 659-661 from four miles southwest of Mount Robson Station, on Highway 16.

Conclusions

The age of the source rocks is older than 1700 m.y., which lends support to the conclusion drawn in a previous section that the source was part of the 1600-1900 m.y. Churchill segment of the North American craton. The age of metamorphism, and therefore of orogenesis, in the Jasper-Mount Robson region is younger than 75 m.y., which is in agreement with the conclusion drawn by Russell (1954) that the age of orogenesis in the Canadian Rocky Mountains is Late Eocene to Early Oligocene (35 to 40 m.y.).

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Yoder, H. S. and Eugster, H. P. (1955): Synthetic and natural muscovites; Geochim. et Cosmochim. Acta, Vol. 8, No. 5/6, p. 225-80.

PLATE 1.

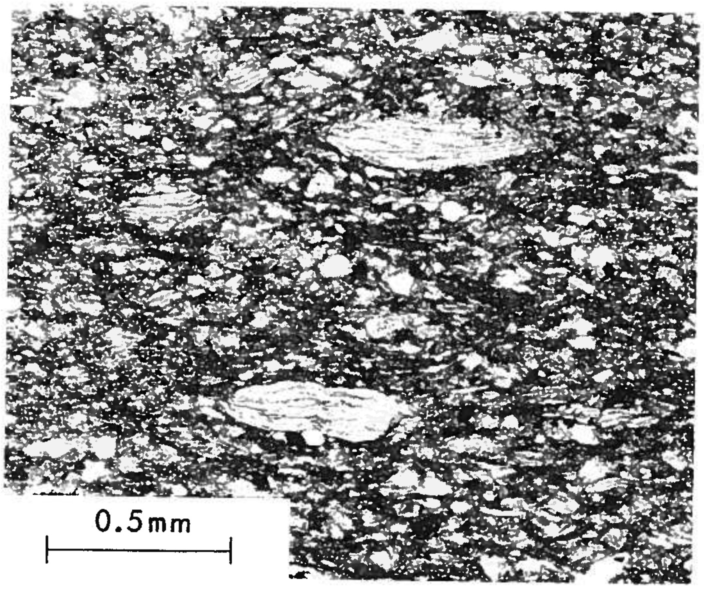


FIGURE 1. Chlorite-muscovite books in uncleaved micaceous siltstone, member A, Old Fort Point Formation, Jasper Anticlinorium. The c-axes of the books are approximately normal to their long axes and to bedding.

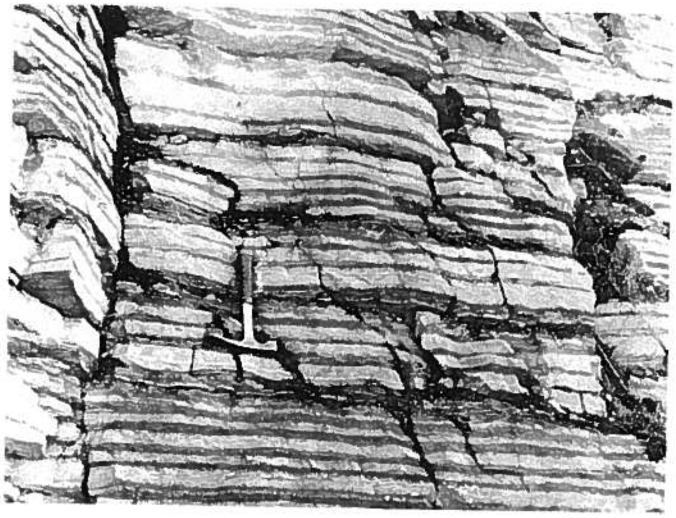


FIGURE 2. Interbedded limestones (light) and slates (dark), unit 3 of member B, Old Fort Point Formation, Meadow Creek Anticlinorium.

PLATE 2.

FIGURE 1. Argillaceous limestone breccia, base of member B, Old Fort Point Formation, Old Fort Point. The breccia, which is overturned, is separated from the underlying laminated siltstones by an erosional surface.

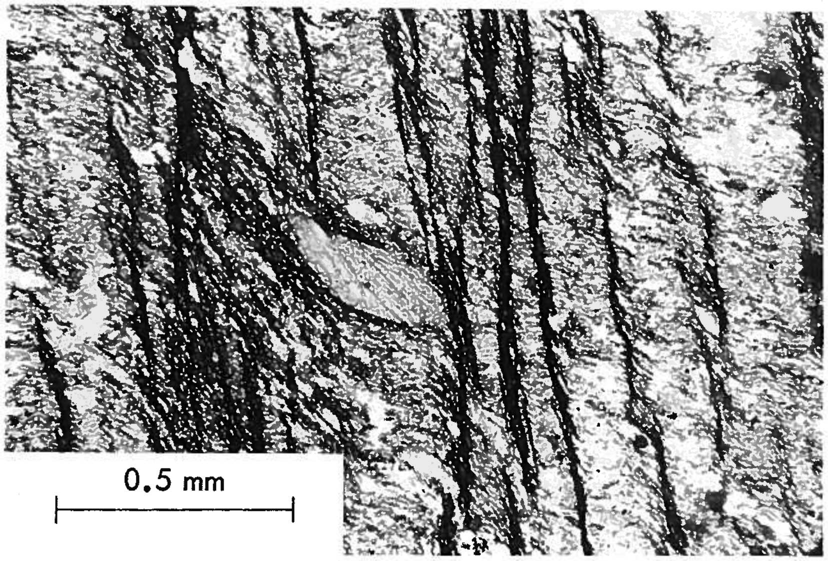


FIGURE 2. Cleavage E (nearly vertical) cutting bedding (dipping at 45° to the right) in slate, unit 1 of member C, Old Fort Point Formation, Meadow Creek Anticlinorium. Note the large chlorite-muscovite book.

PLATE 3.

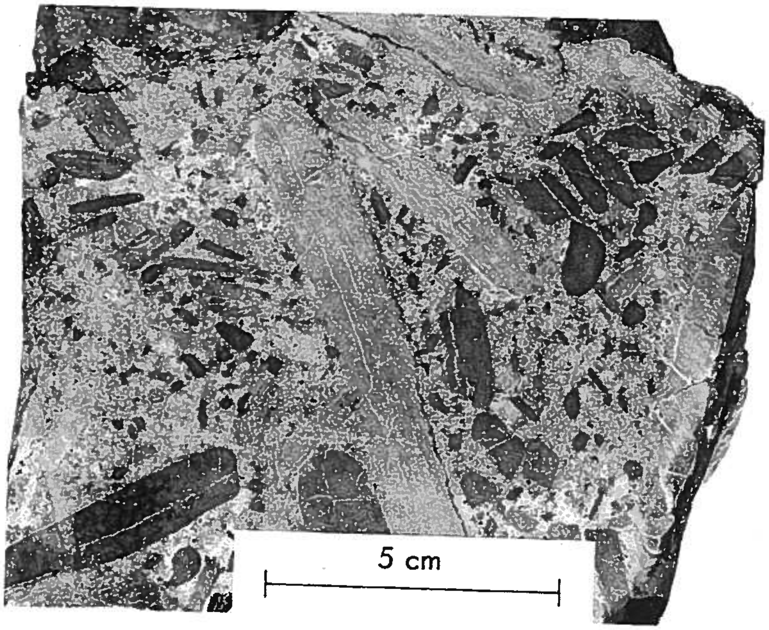


FIGURE 1. *Arenaceous limestone breccia, unit 2 of member C, Old Fort Point Formation, Meadow Creek Anticlinorium. Note random orientation of phenoclasts.*

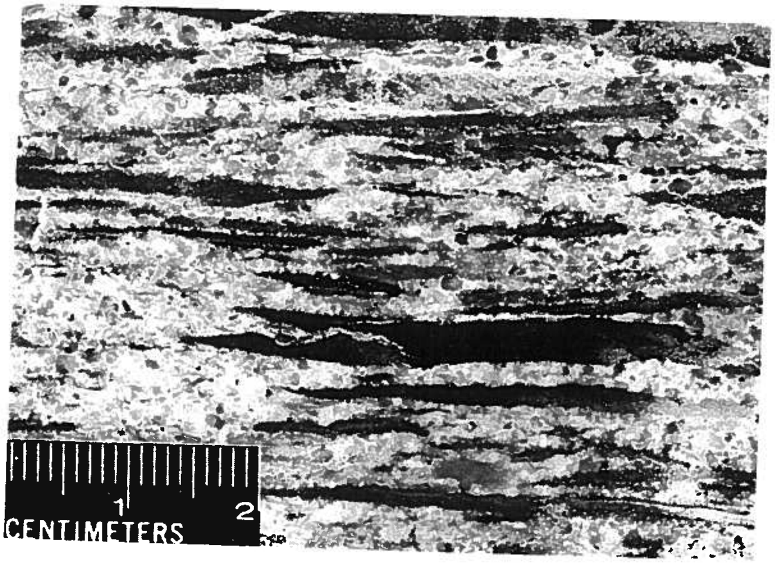


FIGURE 2. *Arenaceous limestone breccia, unit 2 of member C, Old Fort Point Formation, Meadow Creek Anticlinorium. Note preferred orientation of phenoclasts, which have been elongated parallel to bedding.*

PLATE 4.

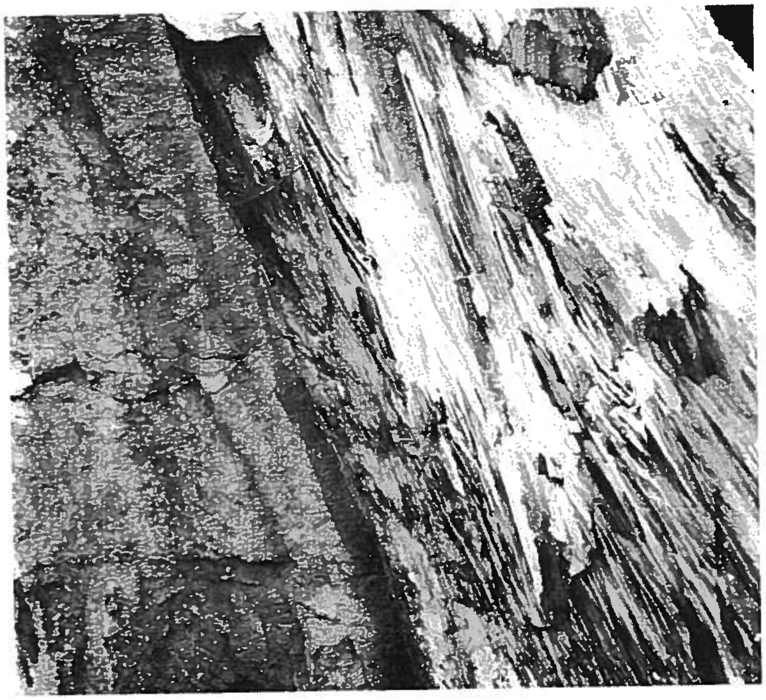


FIGURE 1. Concordant contact between slates belonging to member D of the Old Fort Point Formation and sandstones and conglomerates of the Wynd Formation, Meadow Creek Anticlinorium. The strata are overturned.

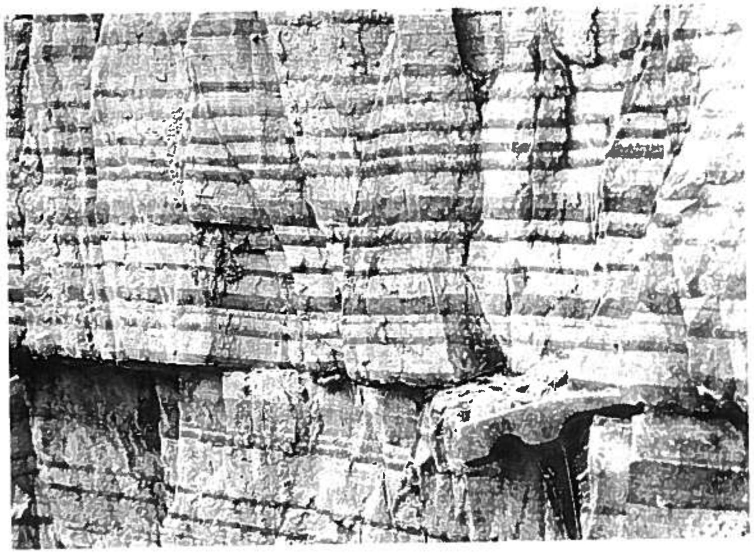


FIGURE 2. Interbedded slates (dark) and silty slates (light), member D, Old Fort Point Formation, Muhigan Creek Anticlinorium.

PLATE 5.

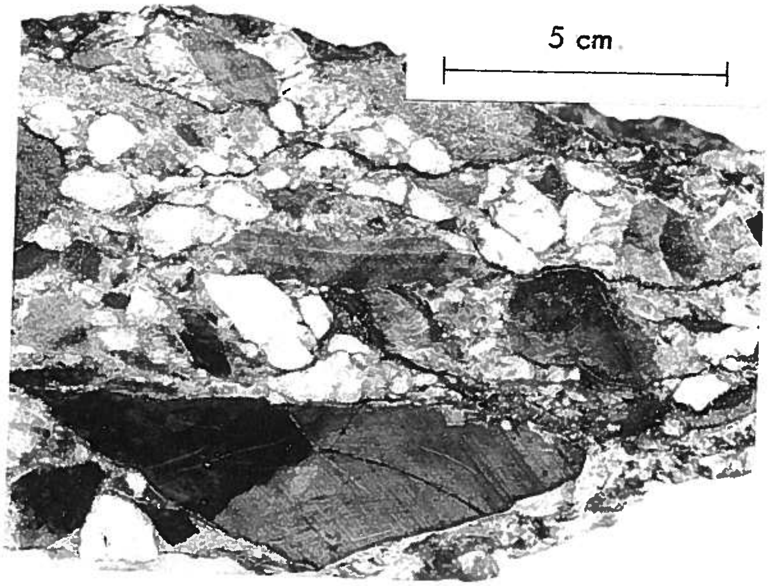


FIGURE 1. Quartz-pebble limestone breccia, member D, Old Fort Point Formation, Portal Creek Anticlinorium. The phenoclasts are limestone and calcareous sandstone. Prominent in the conglomerate matrix are pebbles of vein quartz.

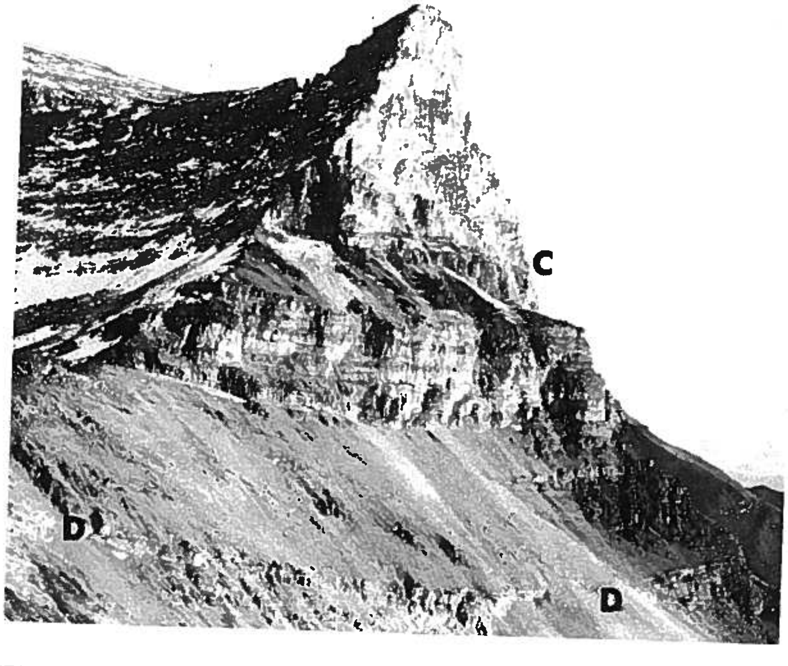


FIGURE 2. North slope of Tekarra Mountain. (C) contact between the Miette and Gog Groups, (D) dolomite boulder conglomerate.

PLATE 6.

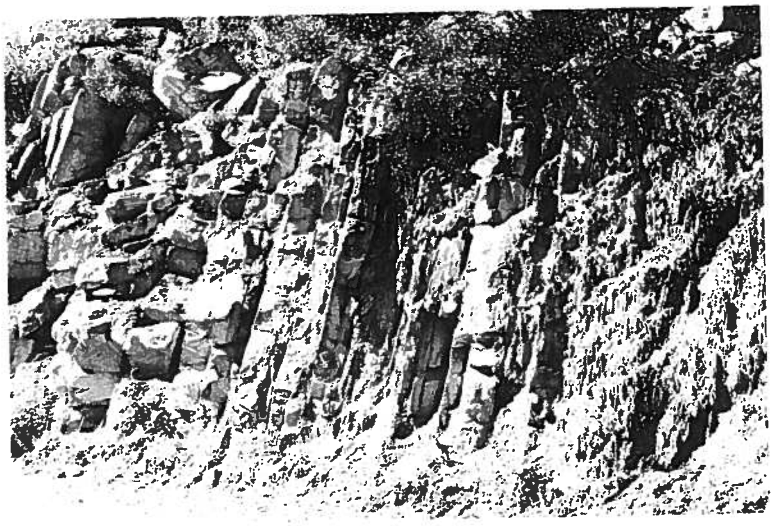


FIGURE 1. Contact between an arenaceous unit (left) and an argillaceous unit (right), lower member of the Wynd Formation, southwest limb of the Jasper Anticlinorium. The exposure is about 6 feet high.

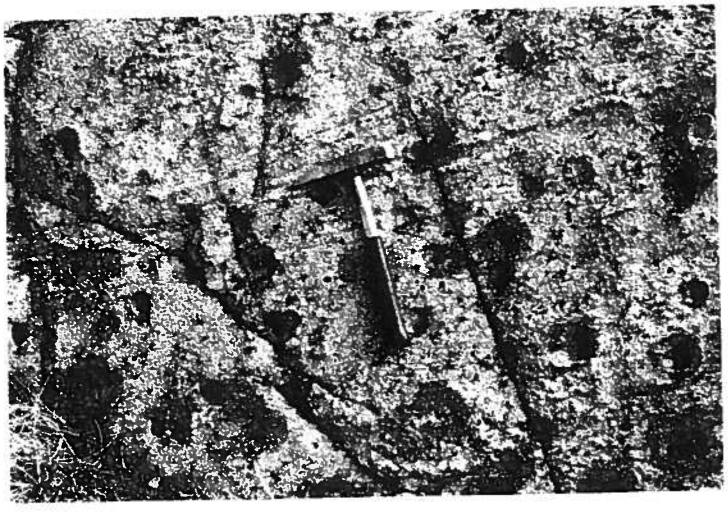


FIGURE 2. Iron-stained cavities, originally pyrite cubes, in coarse-grained, pebbly sandstone, lower member of the Wynd Formation, southwest limb of the Muhigan Creek Anticlinorium.

PLATE 7.

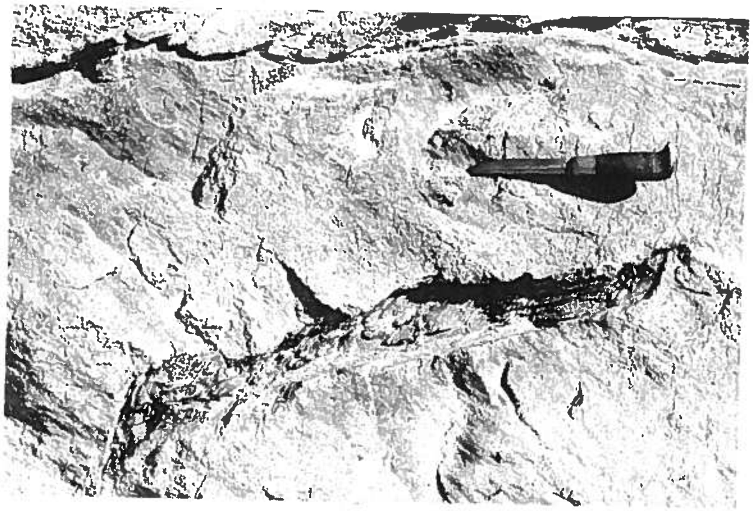


FIGURE 1. Slate phenoclast in coarse-grained sandstone, lower member of the Wynd Formation, southwest limb of the Muhigan Creek Anticlinorium.

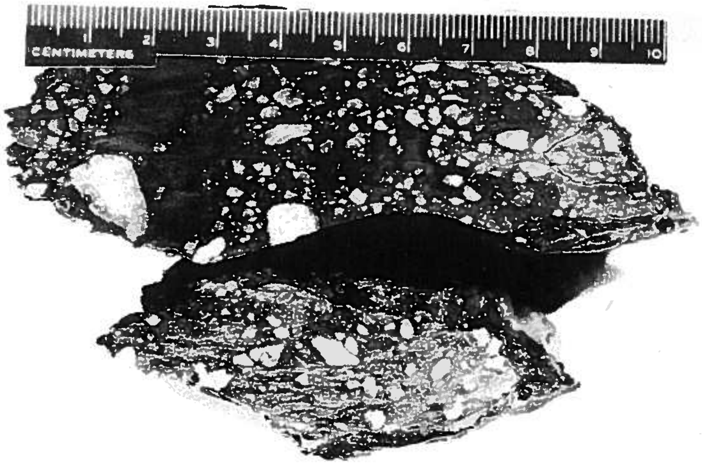


FIGURE 2. Paraconglomerate, lower member of the Wynd Formation, southwest limb of the Muhigan Creek Anticlinorium.

PLATE 8.

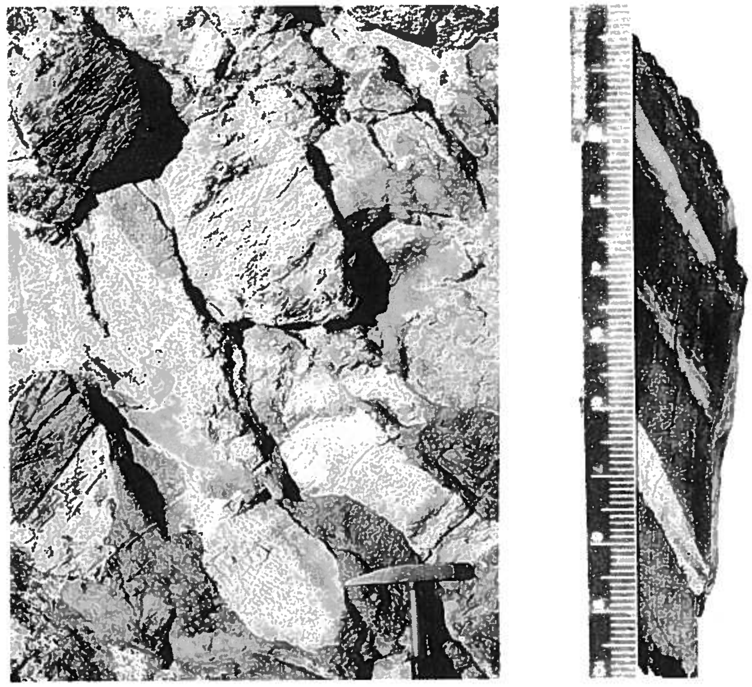


FIGURE 1. *(A) Dolomite-boulder conglomerate, upper member of the Wynd Formation, Tekarra Mountain. (B) Interbedded siltstone (light) and slate (dark), lower member of the Wynd Formation, crest of Muhigan Creek Anticlinorium. Cleavage is "refracted" at each siltstone-slate interface.*

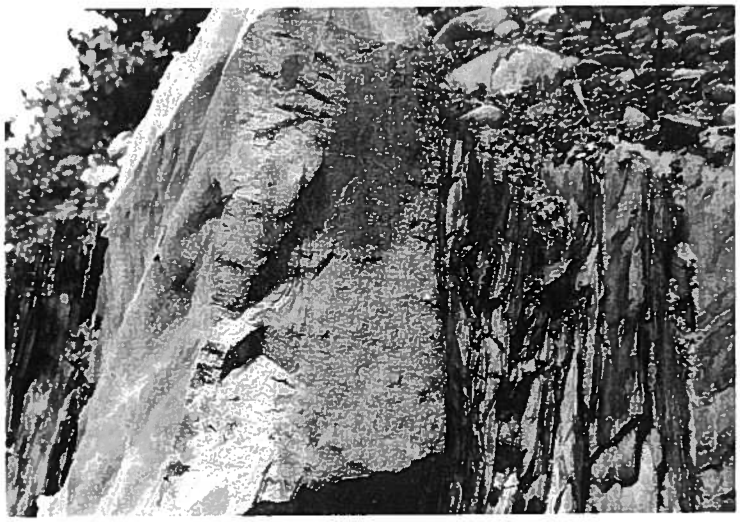


FIGURE 2. *Pebble conglomerate grading up (to the left) into sandstone. The upper surface of the graded bed, which is intercalated between argillaceous rocks, shows interference ripple marks. Lower member of the Wynd Formation, southwest limb of the Jasper Anticlinorium.*

PLATE 9.

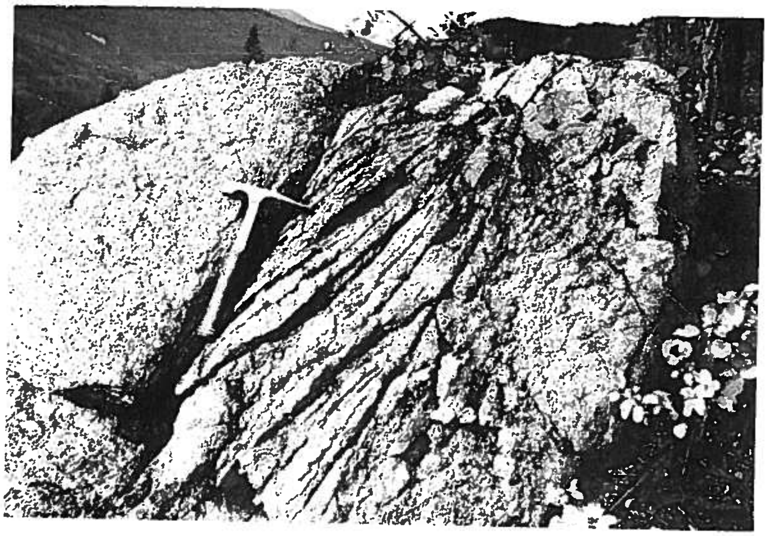


FIGURE 1. Cross-stratification in pebble conglomerate, lower member of the Wynd Formation, southwest limb of the Jasper Anticlinorium.

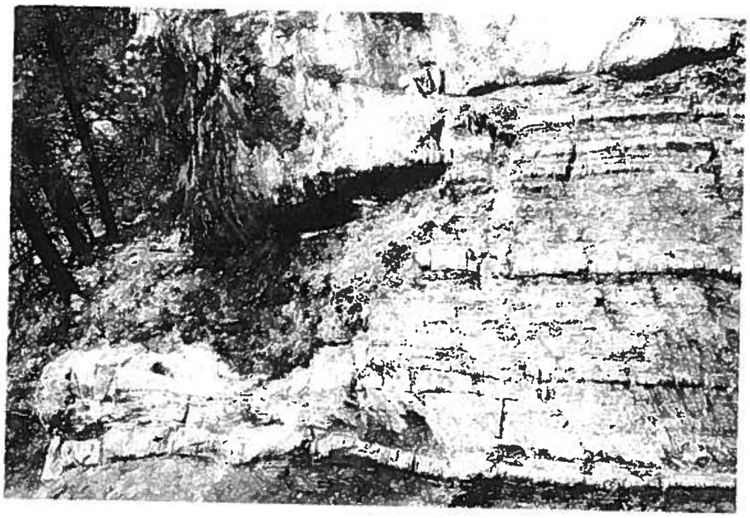
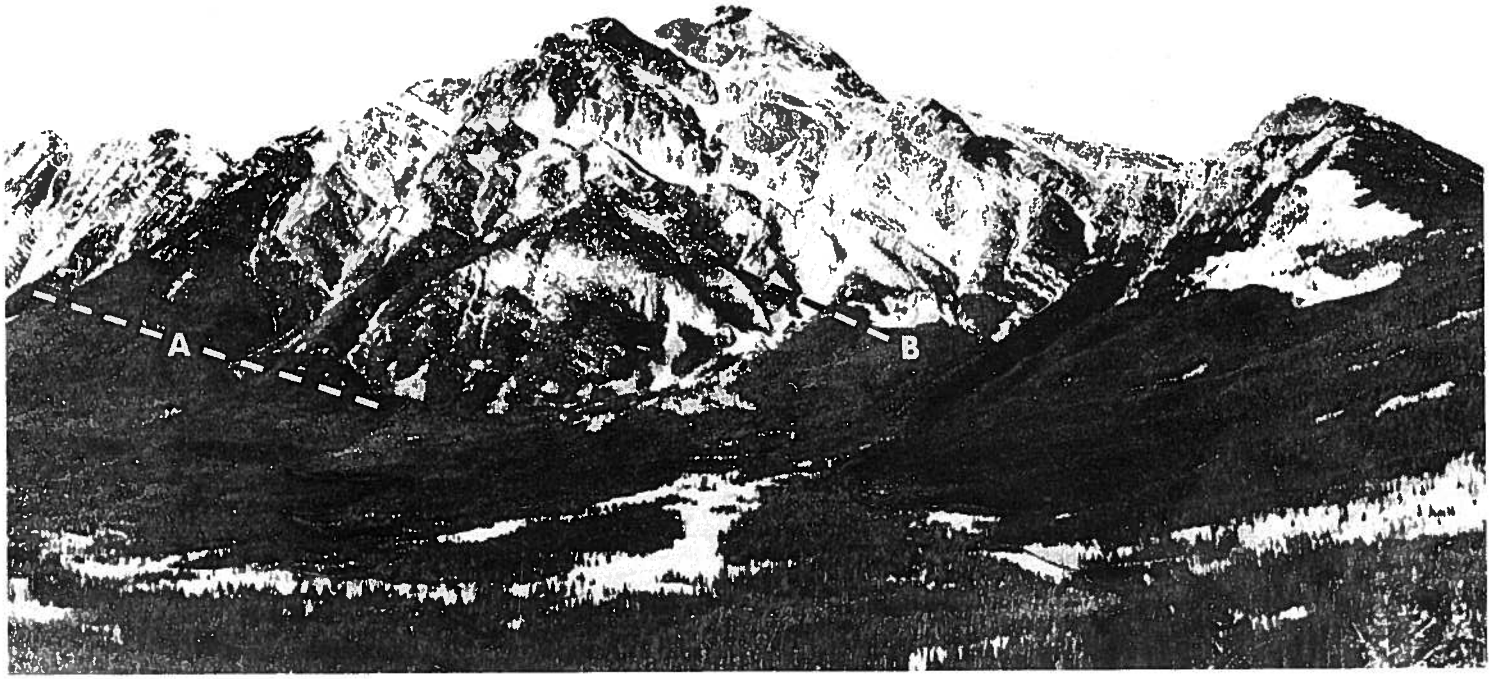


FIGURE 2. Part of an infilled scour channel (top left) eroded into interbedded slates and siltstones (bottom right), lower member of the Wynd Formation, between Virl and Dorothy Lakes. Note the sandstone sills (S) and dyke (D).

PLATE 10.



Pyramid (central peak) and Kinross (left peak) Mountains, locations of the type section of the Jasper Formation, showing the approximate contacts between the Miette Group and the overlying Jasper Formation (A), and the Jasper Formation and overlying unit A (B).

PLATE 11.

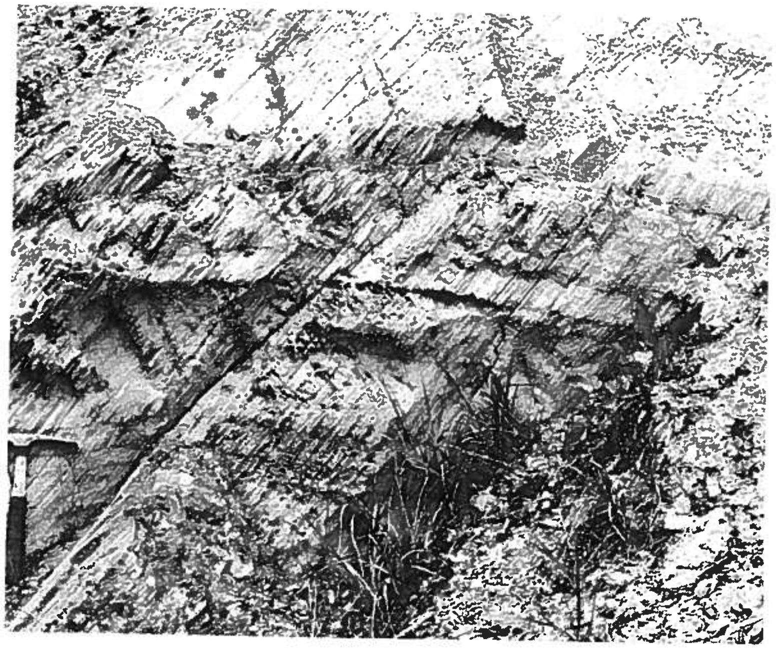


FIGURE 1. Cleavage A (dipping steeply to the left) in the axial region of an anticline, member D of the Old Fort Point Formation, Meadow Creek Anticlinorium.

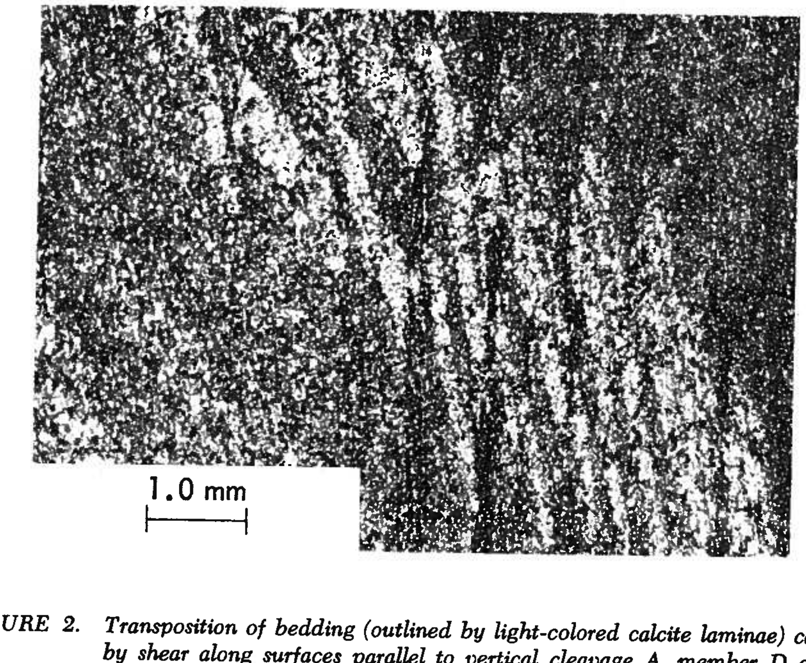


FIGURE 2. Transposition of bedding (outlined by light-colored calcite laminae) caused by shear along surfaces parallel to vertical cleavage A, member D of the Old Fort Point Formation, Meadow Creek Anticlinorium. Crossed nicols.

PLATE 12.

FIGURE 1. A graded sandstone bed with cleavage B overlying slate with cleavage A, lower member of the Wynd Formation, southwest limb of the Muhigan Creek Anticlinorium. Note the sharp break between the two cleavages at the base of the graded bed and the gradual steepening of cleavage B towards the top of the graded bed where it merges with cleavage A in slate.

FIGURE 2. Transition of cleavage B (almost vertical) in sandstone to cleavage A (dipping to the right) in overlying slate, basal beds of the Wynd Formation, axial region of the Meadow Creek Anticlinorium. Note the parallelism between cleavage A and the axial plane of the syncline.

PLATE 13.

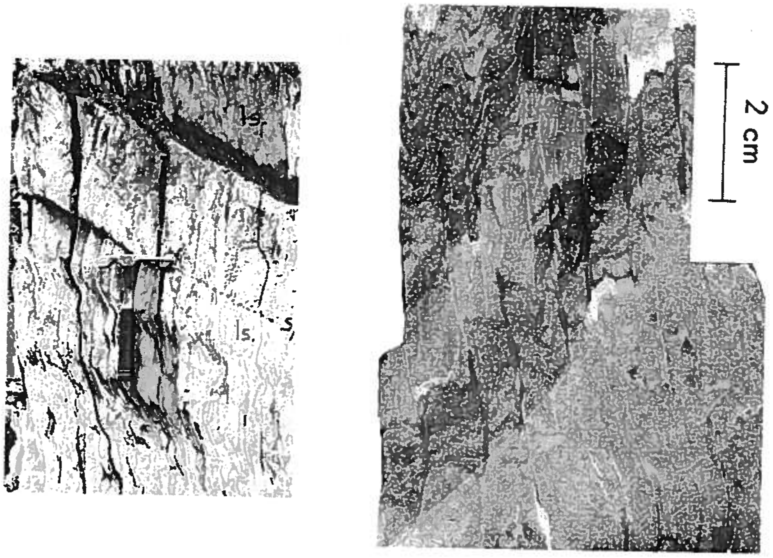


FIGURE 1. (A) *Interbedded limestone with cleavage D (steeply dipping to the left) and slate with cleavage A (steeply dipping to the right), member B of the Old Fort Point Formation, Muhigan Creek Anticlinorium.* (B) *Cleavage E (almost vertical) in interbedded limestone (light) and slates (dark), member B of the Old Fort Point Formation, Meadow Creek Anticlinorium. Note the crumpled bedding in the slates and the anticlockwise shear along cleavage surfaces in the limestone.*

FIGURE 2. *Anticline in interbedded limestone (light) and slate (dark), member B of the Old Fort Point Formation, Meadow Creek Anticlinorium. Note the similar style of the fold and the axial-plane nature of the associated cleavage E.*

PLATE 14.

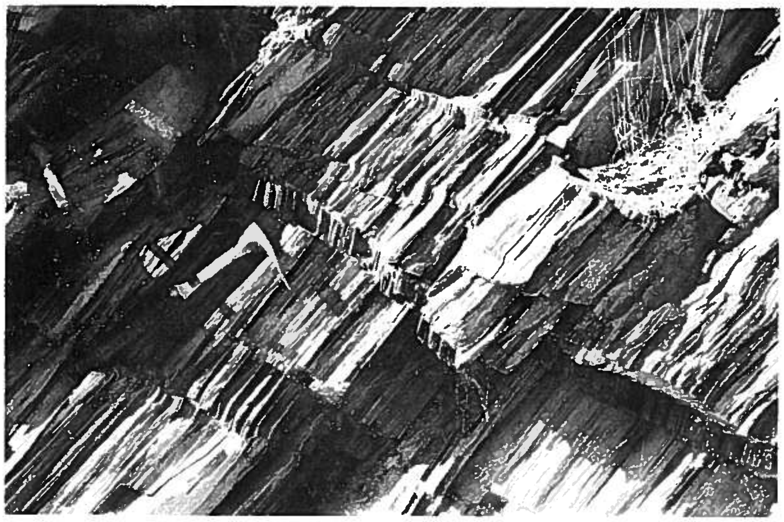


FIGURE 1. Kink folds in slates belonging to unit 2 of member B, Old Fort Point Formation, Meadow Creek Anticlinorium.

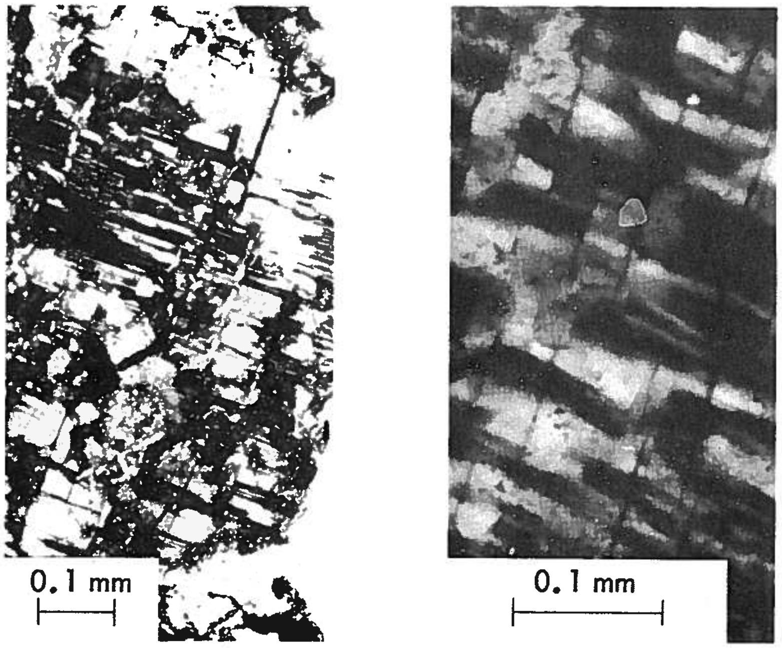


FIGURE 2. Chessboard twinning in an albite pebble, lower member of the Wynd Formation, southwest limb of the Jasper Anticlinorium. The (001) cleavage, which dips steeply to the left, can be seen to truncate the twin lamellae. Crossed nicols.

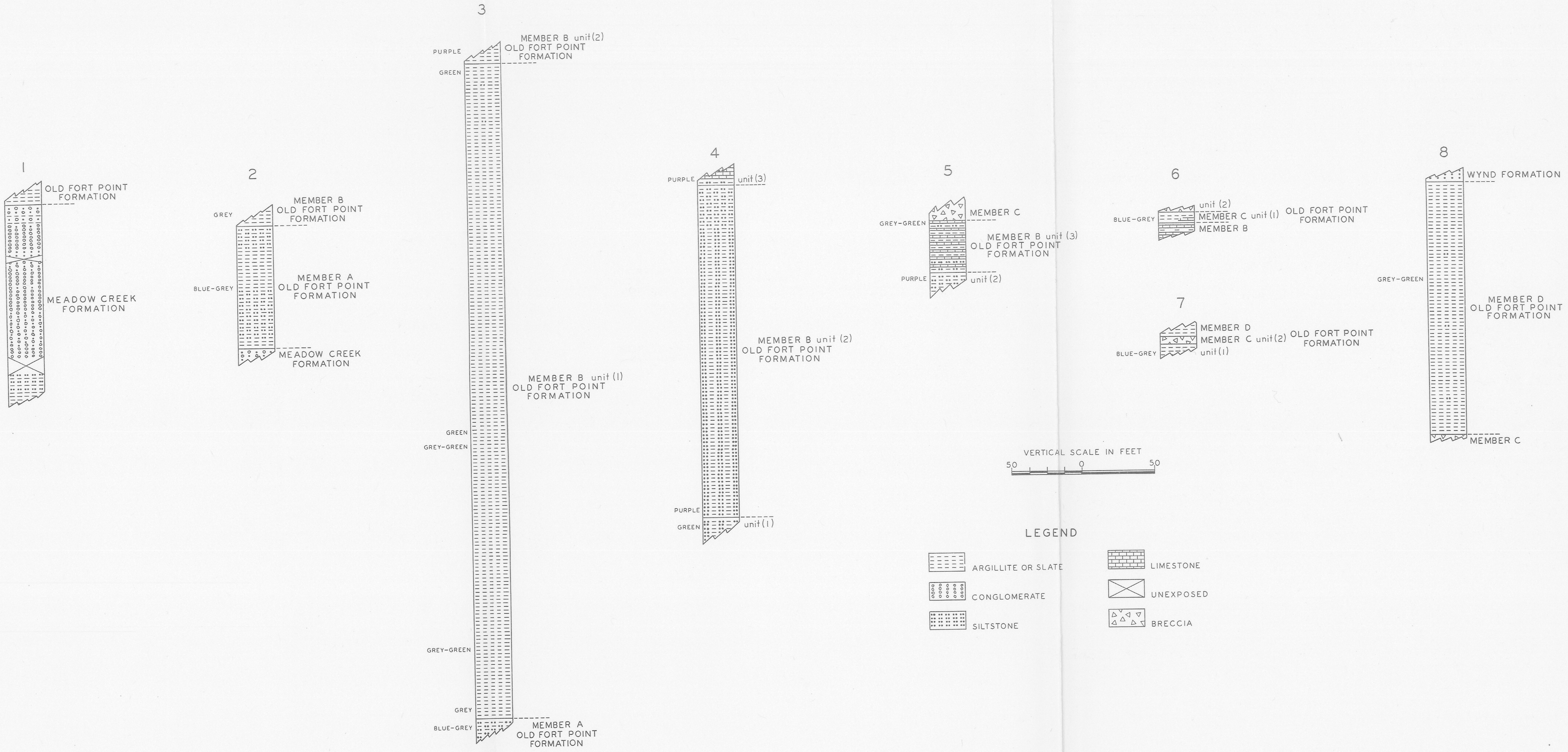


FIGURE 2. *Columnar sections of the Meadow Creek and Old Fort Point Formations (locations of sections given in text).*

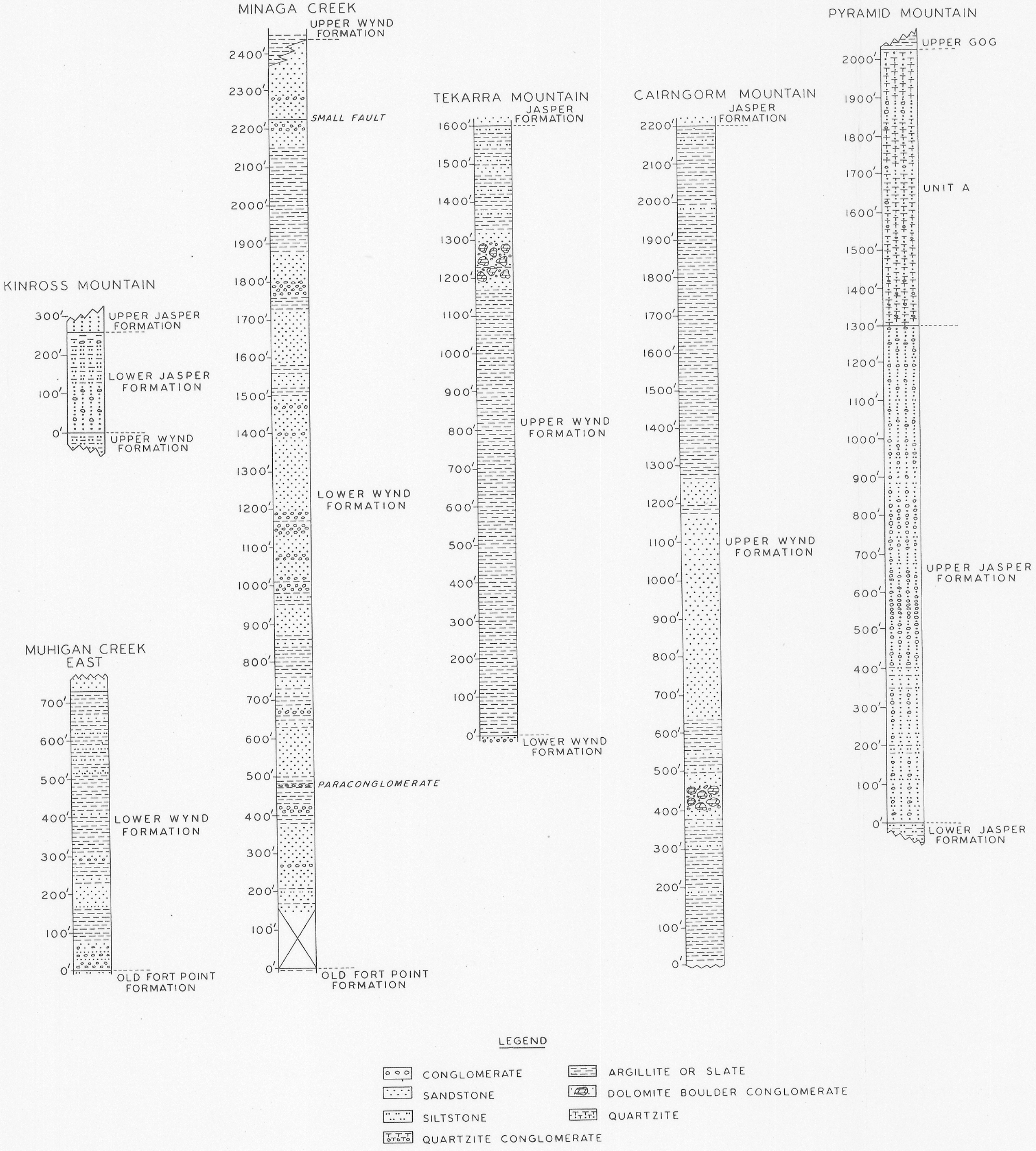


FIGURE 4. Columnar sections of the Wynd Formation, Jasper Formation, and unit A.

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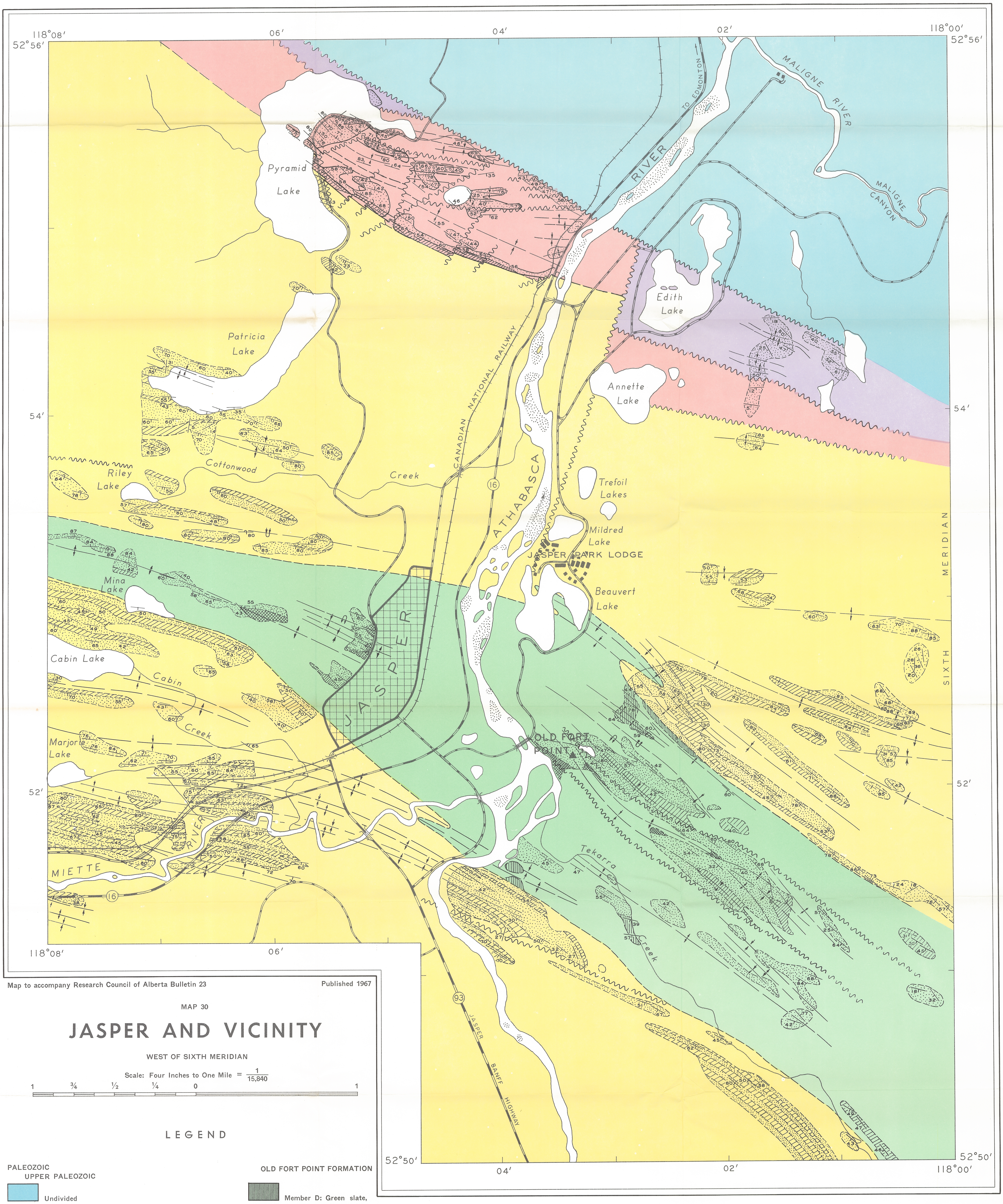


Map to accompany Research Council of Alberta Bulletin 23

Published 1967

MAP 30

JASPER AND VICINITY

WEST OF SIXTH MERIDIAN

Scale: Four Inches to One Mile = $\frac{1}{15,840}$

1 ¾ ½ ¼ 0 1

LEGEND

PALEOZOIC

UPPER PALEOZOIC

- 🟦 Undivided

LOWER CAMBRIAN

- 🟪 Quartzite, carbonate, argillite

JASPER FORMATION

- 🟥 Cobble conglomerate
- 🟥 Sandstone, pebble conglomerate
- 🟥 Interbedded sandstone and argillite
- 🟥 Unexposed

PRECAMBRIAN

WYND FORMATION

- 🟨 Interbedded sandstone and minor slate
- 🟨 Interbedded slate and minor sandstone
- 🟨 Unexposed

OLD FORT POINT FORMATION

- ▥ Member D: Green slate, siltstone
- ▨ Member C: Blue slate, arenaceous limestone breccia
- 🟩 Member B: Green and purple slate, siltstone, limestone, limestone breccia
- ▩ Member A: Blue slate, siltstone
- 🟩 Unexposed

Geological boundary (formation, member) . . . .

Bedding, tops known (inclined, vertical, overturned) . . 48 80

Bedding, tops unknown, direction of dip known 60

Fault (approximate, assumed) . . . .

Anticline (defined) . . . .

Syncline (defined) . . . .

Anticline and syncline (overturned) . . . .

Anticline or syncline (arrow indicates plunge) . . . . .

Geology by H. A. K. Charlesworth *et al.*

Highway 16

Improved road . . . .

Railway . . . . SIDING

Bridge (road, railway overpass) . . . .

Townsite, building, or lodge . . . .

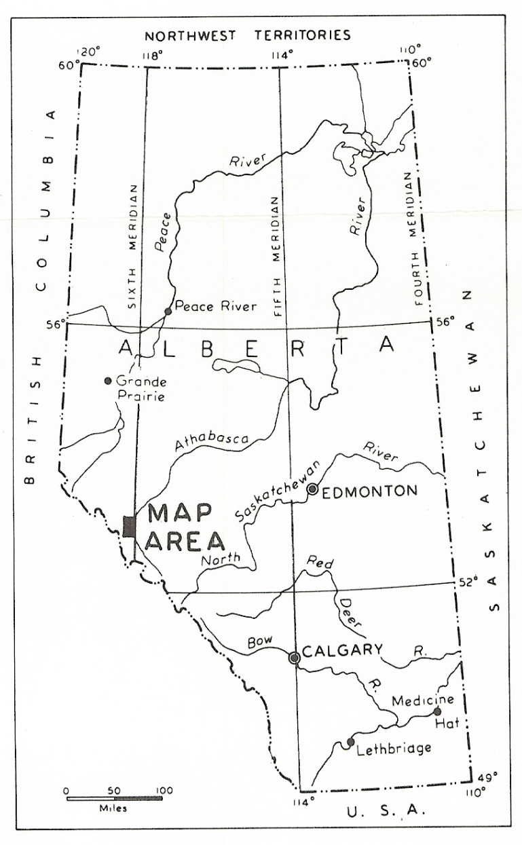
River and stream . . . .

Sand and gravel . . . .

Base map compiled from National Topographic Series, part of Sheet 83 $\frac{D}{16}$ East half, 1953.

Air photographs covering this area are obtainable from Department of Lands and Forests, Government of Alberta, Edmonton, and National Air Photographic Library, Topographical Survey, Ottawa.

INDEX MAP



RESEARCH COUNCIL OF ALBERTA

Map to accompany Research Council of Alberta Bulletin 23

Published 1967

LEGEND

PRECAMBRIAN

WYND FORMATION

- ▨ Interbedded sandstone and minor slate
- ▨ Interbedded slate and minor sandstone
- 🟨 Unexposed

OLD FORT POINT FORMATION

- ▨ Member D: Green slate, siltstone
- ▨ Member C: Blue slate, arenaceous limestone breccia
- ▨ Member B: Green and purple slate, siltstone, limestone, limestone breccia
- ▨ Member A: Blue slate, siltstone
- 🟩 Unexposed

MEADOW CREEK FORMATION

- 🟥 Interbedded sandstone, pebble conglomerate, slate

Geological boundary (formation, member) . . . .

Bedding, tops known (inclined, vertical, overturned) 48 80

Bedding, tops unknown, direction of dip known 60

Fault (approximate, assumed) . . . .

Anticline (defined) . . . .

Syncline (defined) . . . .

Anticline and syncline (overturned) . . . .

Geology by H. A. K. Charlesworth *et al.*

MAP 31

GEIKIE SIDING

WEST OF SIXTH MERIDIAN

Scale: Four Inches to One Mile = $\frac{1}{15,840}$

1 ¼ ½ ¾ 0 1

Highway 16

Improved road . . . .

Railway . . . . Tunnel SIDING

Bridge (road, railway overpass) . . . .

River and stream . . . .

Base map compiled from National Topographic Series, part of Sheet 83 $\frac{D}{16}$ East and West half, 1953.

Air photographs covering this area are obtainable from Department of Lands and Forests, Government of Alberta, Edmonton, and National Air Photographic Library, Topographical Survey, Ottawa.

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