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GEOLOGY OF THE ROSSLAND-TRAIL MAP-AREA BRITISH COLUMBIA

H.W. LITTLE

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Critical Reader

J.E. Reesor

CONTENTS

Tables

Figures

GEOLOGY OF THE ROSSLAND – TRAIL MAP AREA, BRITISH COLUMBIA

Abstract

Rossland – Trail map area comprises about 1010 km² and includes part of the Rossland and Bonnington ranges, which lie within the Monashee and Selkirk mountains, respectively. The area was entirely covered by the last Pleistocene ice-sheet that flowed southward from the higher mountains to the north.

The low grade metamorphic rocks range in age from probably Carboniferous to Eocene; part of the high grade metamorphic rocks is pre-Pennsylvanian, and may be as old as Aphebian. Three tectonic elements are represented – in the south, a north-directed thrust belt, in the central part a belt with east-directed thrust belt giving way east of the map area to open folding and strike and cross faulting, and in the north, recumbent and open folding of gneisses, giving way north of the map area to diapiric doming in the Shuswap Metamorphic Complex.

Granitic rocks were emplaced in two major episodes. Hornblende and/or biotite granodiorite plutons are probably synorogenic with the Columbian Nelson Intrusions, which are 100 to 171 Ma old. Three radiometric ages of these rocks near Rossland are 50 to 52 Ma, but are believed to be updated by younger intrusions. Soda granite and syenitic to quartz monzonitic plutons are of Tertiary age, the latter being definitely Eocene.

Regional unconformities occur in the Triassic, Cretaceous, and Early Tertiary. Sedimentation was marine until Middle Jurassic time, and was continental in the Upper Cretaceous and Eocene.

Résumé

La région couverte par la carte de Rossland-Trail a environ 1010 km² et comprend une partie des chaînons de Rossland et de Bonnington, qui se trouvent respectivement entre les chaînes Monashee et Selkirk. La région a été entièrement couverte par la dernière calotte glaciaire du Pléistocène qui s'écoulait vers le sud des hautes montagnes situées au nord.

L'âge des roches de degré métamorphique faible varie probablement du Carbonifère à l'Éocène; celui d'une partie des roches de degré métamorphique élevé est pré-Pennsylvanien et peut-être même aussi avancé que l'Aphébien. Trois éléments tectoniques sont représentées: au sud, une zone de poussée orogénique dirigée vers le nord, au centre une autre zone dirigée vers l'est donnant dans la partie est de la carte, des plis ouverts, des couches orientées et des failles perpendiculaires à la direction des couches, et au nord, des plis couchés et ouverts de gneiss qui deviennent au nord de la région couverte par la carte des dômes diapiriques dans le complexe métamorphique du Shuswap.

Les roches granitiques ont été mises en place au cours de deux épisodes principaux. Les plutons de hornblende et (ou) de granodiorite à biotite sont probablement syntectoniques des intrusions Nelson du Colombien qui ont environ 100 à 171 Ma. Trois datations radiométriques pour ces roches près de Rossland ont donné 50 à 52 Ma, mais on pense qu'elles sont antérieures aux intrusions plus récentes. Les plutons de granite alcalin et à syénite ou à monzonite quartzique sont du Tertiaire, les derniers étant sans aucun doute de l'Éocène.

Des discordances régionales se rencontrent dans le Trias, le Crétacé et au début du Tertiaire. La sédimentation a été marine jusqu'au milieu du Jurassique, puis continentale au Crétacé supérieur et à l'Éocène.

INTRODUCTION

Rossland – Trail map area (82 F/4) in southeastern British Columbia encompasses an area of about (1010 km²). It is bounded on the south by the 49th parallel (International Boundary) and on the north by 49°15' north latitude, and on the east and west by 117°30' and 118°00' west longitude, respectively (Fig. 1).

This project is part of a continuing study, based on field work begun by the writer in 1947 and concluded in 1965 (except for short visits in 1977 and 1978) of much of the region between Kootenay and Okanagan lakes.

Location and Accessibility

The city of Trail, on the banks of Columbia River, is about 5 km southeast of the geographic centre of the map area, and is the largest community. The city of Rossland is 11 km by road west-southwest of Trail.

The two cities are served by a branch of the Kettle Valley Railway, which formerly was the southern trans-provincial line of the Canadian Pacific Railway. Rail service is provided via Castlegar to points as far west as Midway, and to Lethbridge, Calgary and all points east. Passenger service is no longer offered and railway freight service on the line between Rossland and Trail has been discontinued. Freight service is also available on the Burlington Northern Railroad which operates between Nelson and Spokane, Washington, and which passes through Waneta, Fruitvale, and Parks.

Many excellent paved highways traverse the area. The southern trans-provincial highway passes from the east edge of the area through Trail and Rossland to the northwest corner. A branch leads from near Parks westward to Champion Lakes park, and a new highway has been constructed from Meadows (in Salmo area) to Castlegar. Another highway links Trail to Castlegar to the north, and to the International Boundary at Waneta. Rossland is also readily accessible from the International Boundary so that

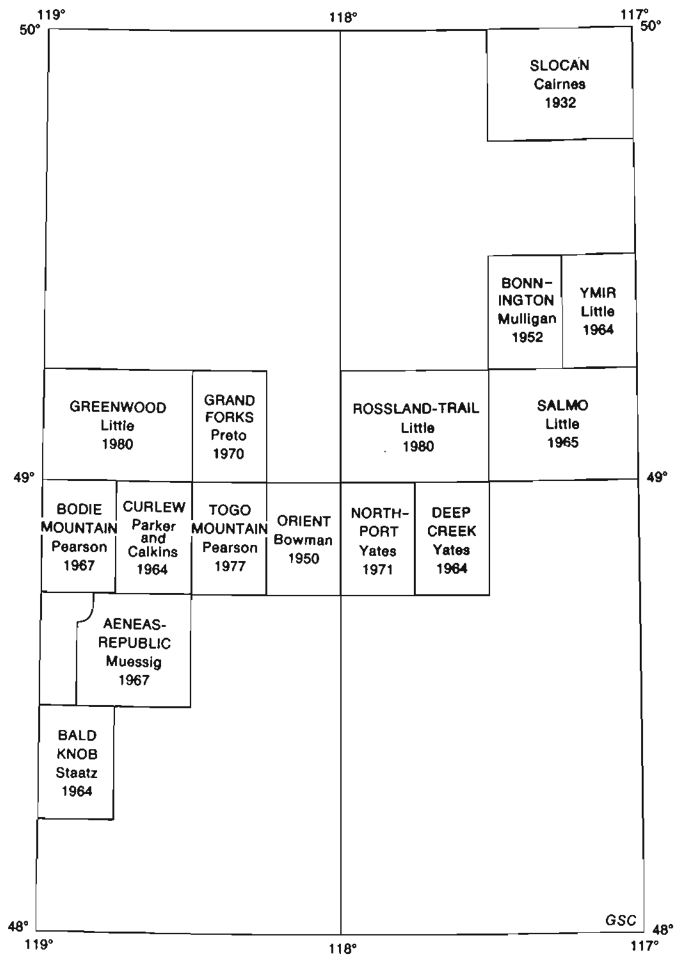

Figure 1. *Index map showing location of Rossland – Trail map area and nearby areas mapped geologically on a scale of 1:62 500 or larger.*

Spokane, Washington, is within two hours driving time. The old "Cascade" highway, a twisting, gravelled road that some years ago was the only link to the west, is maintained only between Rossland and Big Sheep Creek, but provides access to the southwestern part of the area. Several logging roads make the rest of the map area relatively accessible.

History of Mineral Production

The earliest report of mineral discovery was by Hazlitt (1858, p. 128), who reported that placer gold was recovered at the mouth of Pend-d'Oreille River in 1855 by exservants of the Hudson's Bay Company from Fort Colville. This was the first discovery of gold on the mainland of what is now British Columbia. The first claims were staked in 1886. Total production of placer gold from Pend-d'Oreille River is recorded to be 284 ounces (Holland, 1950, p. 14), fineness 815, but only a fraction of this small production came from within the Rossland – Trail map area. The latest recorded placer mining there was in 1940. Placer gold has not been found elsewhere within the map area.

Prospecting for lode deposits began slowly, after discoveries along Kootenay Lake in 1882 and 1883, and near Nelson in 1885. The first lode deposit was discovered on the Dewdney Trail in 1887 and the Lily May claim was located, but allowed to lapse before being restaked in 1889 (Drysdale, 1915a, p. 5). In 1890 two prospectors, Bourgeois and Morris, who had been working in the vicinity, located five claims in one day on Red Mountain. Three of these, the Le Roi, Centre Star, and War Eagle, were to produce 88 per cent of the ore from the Rossland camp, which consisted almost entirely of gold and chalcopyrite (Gilbert, 1948, p. 189). By the spring of 1892, 67 mining claims had been recorded, and production, other than trail shipments, began in 1894 when the Josie shipped 1856 tons of ore, which returned $75 510. By 1895 several companies were paying dividends. In 1896 the B.C. Smelting and Refining Company built a narrow gauge railway between Rossland and Trail to transport ore to its new smelter. In the same year the Columbia and Western Railway constructed a branch line from Robson to Trail. In 1897 the Great Northern Railroad constructed a branch line from Northport to Rossland.

In 1898 the British American Corporation purchased the smelter at Northport and the Le Roi mine. In 1898 also, the Canadian Pacific Railway Company acquired the railway between Rossland and Trail, and the Trail smelter, and immediately reduced smelter charges. Encouraged by these developments, mining activity flourished and production reached a peak in 1903. It declined slightly from then until 1916 and then fell off sharply until the principal mines closed in 1928. A small production since that time has been of ore mined by lessees.

In 1906 the Consolidated Mining and Smelting Company of Canada (now Cominco) had been formed, and in that year acquired the Centre Star and War Eagle mines and the smelter at Trail. In 1911 the Le Roi mine and other claims were added to its holdings, and from that time until 1928 the company was the principal producer of metals. Ninety-eight per cent of metal production of the Rossland camp was won from only four mining claims, the Le Roi, Centre Star, War Eagle, and Josie which produced gold and copper. Only two other properties have had more than minor production. The Velvet mine which is 8 km southwest of Rossland, and operated intermittently between 1901 and 1964, also produced gold and copper. The Coxey (Red Mountain Mines Limited) within the Rossland Camp, produced molybdenum concentrates between 1966 and 1972. About 50 other mines within the map area have each mined between 1 ton and 100 000 tons of ore (Little, 1960).

Previous Geological Work

The earliest geological observations were made along the Columbia Valley at Fort Sheppard and Pend-d'Oreille Valley. These were made by H. Bauerman (1885, p. 24B) who accompanied the International Boundary Commission of 1859 to 1861.

In 1894 R.G. McConnell began mapping the West Kootenay sheet, and his initial work was published at a scale of one inch to one mile (McConnell, 1897b), but because the work was of a reconnaissance nature, publication on such a scale was unjustified. McConnell continued his work on the West Kootenay sheet until 1897, when he was joined by R.W. Brook who completed the project in 1900. The West Kootenay sheets were published under their joint authorships (McConnell and Brock, 1903, 1904). Descriptions of their observations appear in the annual Summary Reports of the Geological Survey for the years 1894 to 1900.

Detailed areal mapping of the Rossland mining camp was carried out by Young in 1906, in conjunction with examinations of the ore deposits there by Brock (1906, 1907). Their reports were subsequently expanded and revised by Drysdale (1915a).

R.A. Daly, as geologist attached to the survey party of the International Boundary Commission from 1901 to 1906, mapped a narrow strip along the International Boundary. His initial descriptions of that part within the Rossland – Trail map area were published in preliminary form (Daly, 1904), and subsequently expanded and incorporated in a memoir with geological maps that covered the entire belt (Daly, 1912).

The present writer spent part of the summer of 1949 within Rossland – Trail area, carrying out reconnaissance mapping that resulted in the publication of a memoir and maps of Nelson map area (west half) (Little, 1960).

In addition to the work of officers of the Geological Survey, detailed studies of the mineral deposits and their environment have been made by geologists of the British Columbia Department of Mines (since 1960 the Department of Mines and Petroleum Resources, and recently changed to the Ministry of Energy, Mines and Petroleum Resources). E.L. Bruce (1917) examined the mineral deposits at Rossland, and J.T. Fyles (Fyles, 1970; 1972; Fyles et al., 1973) made a study of the age of mineralization there. Many other reports on the mineral deposits at Rossland and elsewhere within the map area are contained in Annual Reports of the Minister of Mines (and Petroleum Resources) for the years 1887 to 1975. Very detailed geological studies were done near Trail by Professor Philip Simony and students of the University of Calgary.

Field work on which this report was based was done by the writer in 1961 and 1962, with supplementary examinations in September 1978.

Acknowledgments

Able and enthusiastic assistance in the field was given during the reconnaissance of 1949 by W.H. Dow, E.M. Wilson, L.E. Marjanen and W. Panasiuk. Similar efficient assistance was provided during 1961, when more detailed studies were carried out by J.G. Payne, F.D. Corman, and W.J. McMillan, and in 1962 by R.I. Thorpe and G.O. Raham. The writer is most grateful to P.S. Simony of the University of Calgary who kindly made a trip to Rossland in September 1978 to demonstrate in the field many of the critical outcrops of Trail and Castlegar gneisses, and who provided a copy of his manuscript prior to publication. Simony also provided the writer with a topographical map on which he marked the contacts he had established by detailed mapping of his Trail Gneiss and its mylonite zone, his Castlegar Gneiss, the eastern part of the Mackie Pluton, metamorphic zones in the Mount Roberts Formation and the contacts of the Trail Pluton that were established by C. Moel. Gratitude is expressed to J.T. Fyles of the British Columbia Ministry of Energy, Mines and Petroleum Resources for discussions and the loan of maps and thin sections. Thanks are due also to N.B. Church of the same Ministry who devoted much time to discussions of the Marron lavas and examination of thin sections and hand specimens. His expert knowledge and advice are much appreciated. Also helpful were discussions with J.W.H. Monger of the Geological Survey with regard to correlation with the Marron Formation of Greenwood map area.

The writer acknowledges with pleasure the opportunity provided by the Geological Survey to revisit Rossland – Trail map area and to finalize this geological report and accompanying map.

PHYSIOGRAPHY AND GLACIATION

Rossland – Trail map area lies entirely within the Columbia Mountains (Bostock, 1970) which form a great triangular, highly mountainous area extending from the International Boundary to the bend of the Fraser River near Prince George, and which is bounded on the east by the Rocky Mountain Trench, and on the west by the Interior Plateau. It comprises the Cariboo, Purcell, Selkirk, and Monashee mountains (Holland, 1964). The latter two physiographic divisions are separated by the Columbia River, so that the western part of the map area is within the Monashee Mountains and the eastern part is within the Selkirk Mountains. More specifically, those parts are within the Rossland and Bonnington ranges, respectively.

The dominant physiographic feature of Rossland map area is, of course, the valley of Columbia River, which divides the area unequally in, mainly, a north-south direction. The valley of Pend-d'Oreille River, occupying only the small, southeast corner of the map area, is much less conspicuous; nevertheless, the river is rather large, though smaller than the Columbia. The valley of Beaver Creek to the north is prominent, and that of Big Sheep Creek, in the southwestern part of the area is even more so, being flanked both on the east and west sides by peaks that rise more than 1000 m above the valley floor.

In Rossland Range, the relief is considerable, ranging from the surface of the Columbia River, several metres below the elevation of 1349 feet (411 m) of International Boundary monument near Waneta, to the summit of Old Glory Mountain, at 7795 feet (2376 m). Old Glory, though not as lofty as the mountains of the Norns, Valhalla, and Slocan ranges to the north and northwest (Little, 1960, p. 7), is conspicuous, and is visible from considerable distances away, because it is 135 to 325 m higher than the surrounding peaks. Southeast of Rossland, the peaks of Rossland Range are much lower, ranging from 5424 feet (1653 m) on Lake Mountain to less than 4500 feet (1370 m). Immediately south of the International Boundary, the relief is much less. (Yates, 1964, 1971).

In Bonnington Range, the relief is considerably less than in Rossland Range, from less than 1349 feet (411 m) near Waneta, to more than 4800 feet (1460 m) at the summit of Mount Heinze. The second most prominent peak is Blizzard Mountain at 4608 feet (1404 m). To the east and northeast, however, somewhat higher peaks occur in Bonnington Range.

Lakes within the map area are small and few in number. Nancy Greene Lake (formerly Sheep Lake) is a recreational lake at the junction of highways 3 and 3B, near the headwaters of Blueberry Creek, immediately north of the map area. Another small, swampy lake lies about 3 km west, in the northwest corner of the map area. A group of small lakes, preserved for recreational purpose, lies within Champion Lakes Provincial Park, which is accessible from highway 3, near Parks. Violin Lake, 6.5 km south of Trail, is a water reservoir for that city, and it is not accessible to the public. Unlike the other lakes, which occupy shallow basins in areas of low relief, the western of the three Champion Lakes lies in a fault valley, and Violin Lake lies in a narrow fault valley and owes its existence to damming at both ends by morainal material.

The most conspicuous deposits of glacial origin are exposed along the valley of the Columbia, where exposures of clay, silt, sand, and gravel up to more than 100 m in thickness are visible in terraces along its banks, sand and gravel being the most abundant constituents. Similar deposits occur along the banks of Pend-d'Oreille River, but, as the valley is much more deeply incised, they are not extensive. Furthermore, since the construction of the dam at Waneta, some of the deposits have been flooded, and others have been partially or completely destroyed by wave action in the reservoir that is formed behind the dam. About 0.8 km east-northeast of the mouth of the Pend-d'Oreille, a buried channel, probably of the Pend-d'Oreille (Daly, 1912, p. 589) was outlined by drilling done in connection with dam construction.

Most widespread of the glacial deposits are ground moraines which form, for the most part, a thin mantle of till over much of the map area; consequently, bedrock exposures, except at the highest elevations, are generally not extensive. Deposits characteristic of areas of low relief, such as drumlins, eskers, and kame terraces, were not seen. The movement of the continental ice-sheet has been recorded by many measurements of glacial striae and a few of roches moutonnées (see Fig. 2). In most cases the direction of ice movement could not be detected from glacial striae, but in all cases where it could, and from roches moutonnées, it is

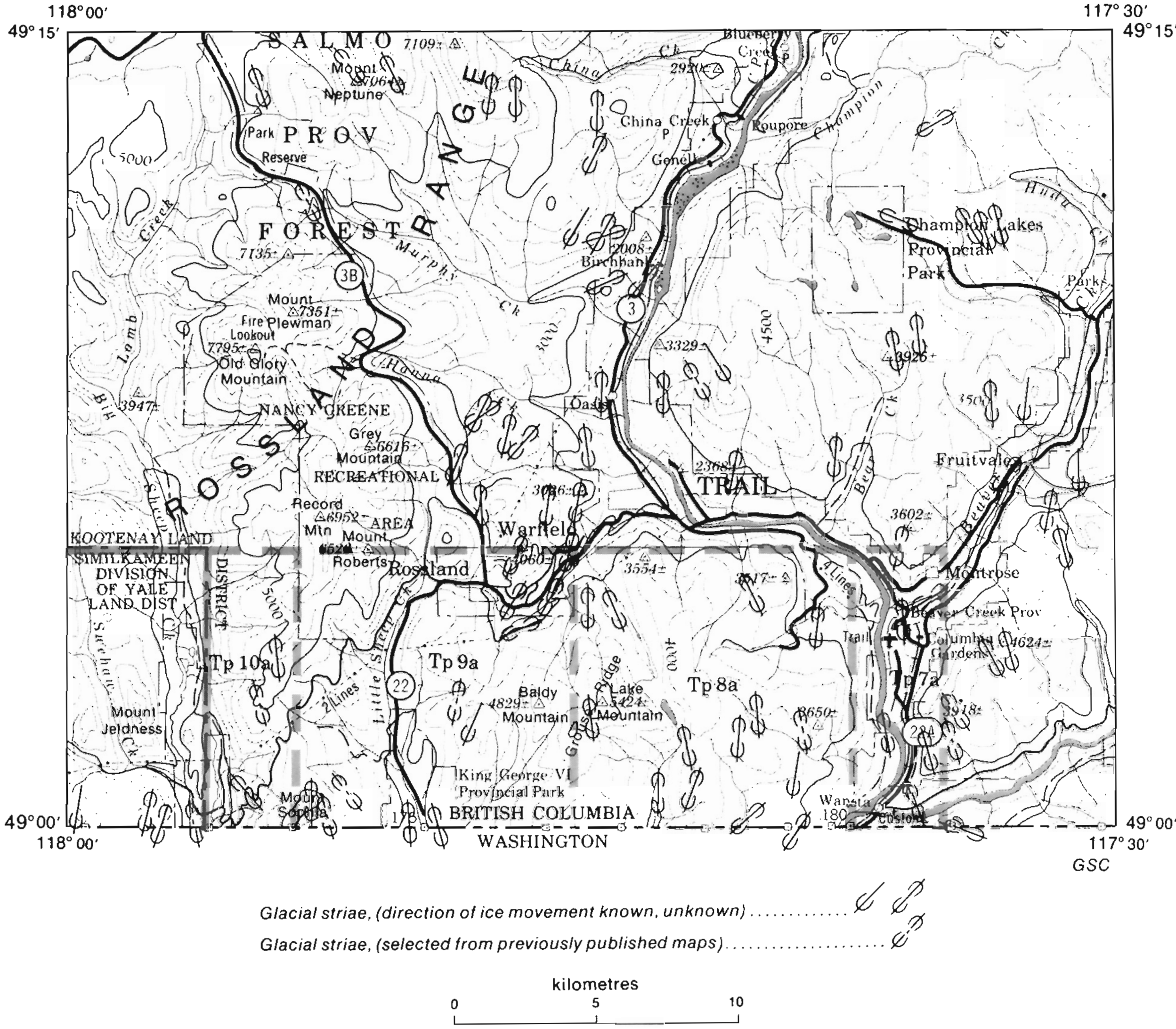

Figure 2. *Map showing glacial straie and roches moutonnées observed in Rossland – Trail map area.*

southerly. The highest glaical striae recorded were obtained at an elevation of about 2050 m on the peak that is about 0.75 km east-northeast of the summit of Mount Neptune. Others have been recorded at nearly that elevation. To the north, in Valkyr and Valhalla ranges, glacial striae have been noted as high as about 2300 m (Little, 1960, Map 1091A). It is probable that the upper surface of the continental ice-sheet reached 2125 m or more in Rossland – Trail map area, but the summit of Old Glory, and perhaps a few other peaks may have escaped continental glaciation. Despite the considerable thickness of the ice-sheet, it is evident that its movement was strongly influenced by the topography, even by smaller valleys such as Beaver and Cambridge creeks.

No alpine glaciers exist within or near the map area, but small cirques on the north sides of Old Glory and Record mountains, and Mounts Plewman and Neptune, are testimony that such at one time existed.

No evidence was seen in the glacial deposits that more than one period of ice advance took place. At two places, however, intersecting sets of glacial striae were recorded. One of these is on the hill 2.5 km north of Rossland, where the Union property occurs. There, striae were measured at 205° and 230°. The other place is 0.75 km northwest of Birchbank, where directions of 210° and 260° were recorded. In neither case could the direction of movement (northerly or southerly) be determined, but in both the higher azimuth represented the earlier movement. Thus, there may have been two advances of the ice-sheet, the earlier being more westerly.

Prest (1970, Fig. XII-15) has indicated that the final retreat of the ice-sheet from this area took place about 10 000 to 12 000 years B.P.

In valleys within the map area and in surrounding areas, white volcanic ash 3 mm to perhaps 5 cm thick lies near the surface of the soil, and is exposed in some stream banks and roadcuts. This material was described in Washington State by Rigg and Gould (1957) as mainly glass shards of acidic composition, and some generally euhedral crystals of andesine, hypersthene, hornblende, magnetite, and augite. ^{14}C age determinations of peat immediately below the ash layer from two localities in Washington yielded averages of 6500 ± 200, and 6950 ± 200 years B.P., respectively. The ash erupted from Glacier Peak, which is west of Lake Chelan, and 3 to 5 km south of the International Boundary, some 253 km west of Rossland.

GENERAL GEOLOGY

Rossland – Trail map area is underlain by rocks that range in age from pre-Pennsylvanian, possibly Aphebian, to Eocene, and surficial deposits of Pleistocene and Recent age. The map area lies between the northwest- to north-directed thrust belt of the southwestern part of the Kootenay Arc composed of Carboniferous(?) rocks that are the youngest in a great miogeosynclinal assemblage, and the high grade metamorphic rocks of the Shuswap Metamorphic Complex. Between these regimes is a fold and easterly-directed thrust belt consisting of eugeosynclinal rocks of Pennsylvanian(?) and Jurassic age. The unconformable contact of these rocks records the widespread Triassic unconformity.

Ultramafic rocks that intrude Jurassic rocks, but may be ophiolites of earlier age, occur in the southwest part of the map area. Probably in the early part of the Columbia Orogeny, Pennsylvanian(?) sediments and minor lava, and some older orthogneiss, were recumbently folded and metamorphosed to granitoid gneiss, and, to the north of the area, domed by diapiric intrusion. In Rossland – Trail map area monzonite and granodiorite plutons were emplaced during the Columbian Orogeny.

Remnants of Upper Cretaceous continental conglomerate occur in the southwest corner of the area. Farther north, even smaller remnants of Eocene tuffaceous arkose underlie locally the more widespread Eocene volcanics that probably blanketed the entire area. Bodies of soda granite that occur in the southeastern part of the map area are believed to be genetically related to the tuffaceous arkoses. The Coryell Batholith and smaller bodies of syenitic to quartz monzonitic composition outcrop mainly in the western part of the map area, and are genetically related to the Eocene lavas, which they invade.

Tectonic Setting

The regional setting of the Rossland – Trail map area is depicted diagrammatically in Map 1504A. The dominant regional structure is the Kootenay Arc, a complex belt of folding and faulting that sweeps south-southwestward from the Lardeau District, around the east side of the Nelson Batholith, and thence southwestward into northeast Washington. It is bounded on the east by the Helikian sediments of the Purcell Geanticline. Sedimentary and volcanic rocks of the Kootenay Arc range in age from Hadrynian (Windermere Supergroup) to Pennsylvanian, although some periods are very sparsely represented.

In the southwestern part of the Kootenay Arc, there is a homoclinal belt that dips northwesterly with Hadrynian rocks below and lower Paleozoic rocks to the northwest. This is succeeded by an outer fold belt composed of lower Paleozoic sediments forming anticlines and synclines, overturned in the northern part of the belt; strike faults and cross faults occur in the belt. These lower Paleozoic rocks are thrust northwestward to northward upon lower and upper Paleozoic rocks of the thrust belt in which further thrusting and some cross faulting occurs. This belt is exposed along the southern edge of the east half of Rossland – Trail map area.

The thrust belt is in turn thrust over an inner fold belt composed of Jurassic and Pennsylvanian(?) sediments and lavas in the northeastern part of which open folding and strike and cross faults are characteristic. In the western part, in Rossland – Trail and western Salmo map areas, three panels that were overthrust from the west have been identified. It is not known whether the eastward-directed thrust plates predate or postdate those directed from the south and southeast. Steep northeast and east trending faults displace the north striking thrust faults. West of Rossland – Trail map area, Jurassic volcanics occupy most of the terrain between the Coryell Batholith and the International Boundary. As only reconnaissance mapping was done there (Little, 1957), little is known of the structure of these rocks, but to the south Bowman (1950) has delineated fault blocks within which a westerly trending anticline occurs near the International Boundary. These rocks terminate against the Kettle River Fault which marks the eastern boundary of a horst of Shuswap Metamorphic Complex beyond which lies the Republic Graben.

In the northern part of the Rossland – Trail map area, north of the Trail Pluton and west of the Champion Lake Fault, the Trail Gneiss is warped into a gently dipping antiform. This marks the southern end of the Shuswap Metamorphic Complex, identified as such by Reesor (1965) in the Valhalla Range. Simony (1979) postulated that the Trail Gneiss is Precambrian (Hudsonian) basement that was detached and brought into its present position by a deep-seated thrust fault that dips west followed by 5 km of movement on the Champion Lake normal fault. It is definitely pre-Mount Roberts and Simony argued that because it is an orthogneiss it could hardly have been derived from any of the Paleozoic, Hadrynian, or Helikian successions known in the region. This writer cannot agree with the 5 km of normal faulting (proposed by Simony) because the movement ends abruptly at the Trail Pluton, from which it cannot be traced farther in any direction.

Layered Rocks

Trail Gneiss

In the Columbia Valley, north of the Trail Pluton, McConnell and Brock (1904) mapped a body of gneiss, which they tentatively assigned to the 'Shuswap series', comprising "gray gneisses, micaschists, crystalline limestone and dolomites with intercalated crushed and altered granites and diorites." The age was said to be Archean, although some of these gneisses were thought possibly to be metamorphosed Paleozoic rocks. Daly (1912, p. 349) mapped a smaller body of similar rocks on the south side of the Trail Pluton, and defined these rocks as a "shatter-belt" caused by mechanical emplacement of the pluton, for he recognized that such rocks were not the products of simple contact metamorphism. During geological reconnaissance in 1948-1950, the writer (Little, 1960) thought that these rocks were metamorphosed equivalents of Late Paleozoic and Early Mesozoic rocks of, mainly, sedimentary origin. In carrying out more detailed mapping in Trail map area, Little (1962, p. 1) expressed the opinion that the gneisses were products of metamorphism of, possibly, the Sinemurian Archibald Formation, but later (Little, 1963, p. 1) was able to trace the more westerly exposures of gneiss into less metamorphosed Pennsylvanian(?) Mount Roberts Formation. More recently, Moel, and Simony, (1976; 1979) examined the gneisses in more detail than had previous workers. Moel suggested that the gneiss south of the Trail Pluton may have been a fragment of Precambrian basement emplaced during injection of the magma. Simony examined the gneisses north of the Trail Pluton and agreed with the present writer that some of the gneiss is, indeed, metamorphosed Mount Roberts Formation. However, he was able to distinguish a separate gneiss unit which he named the Trail Gneiss.

Distribution and thickness

The Trail Gneiss is exposed north of the Trail Pluton on both sides of the Columbia Valley as far north as Genelle, beyond which it is only on the east side of the valley, to and beyond the north edge of the map area. A comparatively small amount of the gneiss is exposed on both sides of the Columbia River, near the southern border of the Trail Pluton, where it is apparently surrounded by granodiorite. The east boundary of the main mass of gneiss is the Champion Lake Fault, east of which the pre-Nelson rocks are Archibald Formation and Rossland Group. The west side is marked by a zone of ultramylonite along the lower slopes north and south of Sullivan Creek.

Table 1. Table of Formations

ERA	PERIOD OR EPOCH	GROUP OR FORMATION		MAP SYMBOL	LITHOLOGY	THICKNESS (metres)
CENOZOIC	QUATERNARY				Till, sand, gravel, silt	
	EOCENE Middle	Coryell Intrusions		Ec	Syenite, quartz monzonite; minor granite, palaskite, and biotite-augite monzonite	
		INTRUSIVE CONTACT				
		Marron Formation		Emv	Augite and/or hornblende and/or biotite andesite; trachyandesite	900+
		RELATIONSHIP UNKNOWN, BUT MAY BE FEEDER TO MARRON ANDESITE FLOWS				
		Map-unit Ti		Ti	Hornblende-feldspar and hornblende porphyrys	
		CONFORMABLE(?) CONTACT WITH MARRON FORMATION				
		Kettle River Formation		Ekrs	Tuffaceous arkose	100+
MESOZOIC	CRETACEOUS Upper	RELATIONSHIP UNKNOWN; UNCONFORMABLE ON HALL FORMATION				
		Sophie Mountain Formation		uKsms	Coarse conglomerate with minor interbeds of siltstone and arenaceous argillite	100+
	JURASSIC AND/ OR CRETACEOUS	RELATIONSHIP UNKNOWN; UNCONFORMABLE ON ELISE FORMATION				
		Map-unit Kqp		Kqp	Quartz-feldspar porphyry	
		RELATIONSHIP UNKNOWN; INTRUSIVE INTO ULTRAMAFIC INTRUSIONS				
		Nelson Intrusions		JKgd	Granodiorite; minor quartz diorite, and diorite	
		RELATIONSHIP CONTRADICTORY; SEEMS TO BE INTRUSIVE				
		Rossland Monzonite		JKrm	Biotite-hornblende-augite monzonite; mainly medium grained	
	JURASSIC Lower and Middle	INTRUSIVE RELATIONSHIP				
		Rossland Group	Hall Formation	lmJhs	Black, soft carbonaceous shale, buff to brown argillaceous sandstone; some siltstone and minor greywacke	300+
			CONFORMABLE(?) CONTACT			
			Elise Formation	lJev	Flow breccia, massive andesites and basalts, agglomerate, tuff, breccia; black, laminated siltstone (lJes); augite porphyry (lJei)	2,150-3,000
			CONFORMABLE(?) AND INTERDIGITATED CONTACT; UNCONFORMABLE ON MOUNT ROBERTS FORMATION			
			Archibald Formation	lJas	Black, hard, brittle, laminated siltstone, commonly tuffaceous, and arenaceous argillite	900
PALEOZOIC	PENNSYLVANIAN(?)	INTRUSIVE RELATIONSHIP WITH ROSSLAND GROUP, BUT MAY BE COLD INTRUSION				
		Ultramafic Intrusions		P?um	Serpentinite; some dunite	
		INTRUSIVE CONTACT				
		Mount Roberts Formation		Pmr	Black siltstone and argillaceous quartzite, slate, greywacke, chert, pebble conglomerate, lava flows; limestone (Pmrl); paragneiss (Pmrgn)	1,200-1,500
	CARBONIFEROUS(?)	RELATIONSHIP UNKNOWN				
		Map unit Cs		Cs	Black argillite, slate, phyllite, minor chert and greenstone; grey to black limestone (Csl)	2,100
	AGE UNKNOWN	RELATIONSHIP UNKNOWN				
		Gneiss in Bonnington Pluton		gn	Layered granitoid gneiss and amphibolite	
		RELATIONSHIP UNKNOWN				
		Porphyritic leucogranitic rocks		g	Porphyritic leucogranite	
		RELATIONSHIP UNKNOWN				
		Castlegar Gneiss		cgn	Augen gneiss	
		GRADATIONAL CONTACT				
		Trail Gneiss		pCtgn	Amphibolite and grey biotite gneiss, hornblende gneiss, mica schist, aplite, and pegmatite; mylonitized gneiss (pCtgnm)	1,200

BASE NOT EXPOSED

If the thickness of the Trail Gneiss is defined as being perpendicular to the gneissic layering, a rough estimate of the maximum thickness exposed is about 1200 m.

Lithology

The lithology of the Trail Gneiss is best described by Simony (1979) and the following is quoted from his paper: "It is heterogeneous and includes layered hornblende gneiss, biotite granodioritic gneiss, biotite-hornblende quartz diorite gneiss, foliated aplite and pegmatite, massive pegmatite, quartzo-feldspathic mica schist and amphibolite and minor garnet-mica schist and marble. Each rock type is variable in composition, gradations occur from one to another and several rock types are commonly associated in one outcrop.

"The oldest and least common rocks are layered, amphibolite and grey biotite gneiss, laced with foliated pegmatite. These rocks are most abundant on the lower slopes of the west side of the Columbia Valley and are exposed in a large road cut along the highway north of Trail near a golf course. All other gneissic units cross-cut the layered amphibolite complex and layered amphibolite occurs as slabs, schlieren and sharply defined inclusions throughout the younger rocks of the Trail Gneiss.

"The bulk of the Trail Gneiss consists of light and dark grey, intensely foliated and lineated biotite-hornblende quartz diorite gneiss with poorly defined lighter and darker layers and local pods of coarser, more massive material. Some of these lenses resemble metagabbro with a texture of relict pyroxene in hornblende clusters and zoned and twinned calcic andesine. Pods, probably boudins, about 1 m in length, of hornblendite and pyroxenite are also present. Dikes of more leucocratic gneiss cut darker gneiss and vice versa. Because of these ambiguous age relationships all the relatively coarse and homogenous orthogneissic rocks are grouped together. Lineation, resulting from the preferred orientation of hornblende and other acicular minerals, of elongate quartz grains and of spindles constituted of several quartz and feldspar grains, is prominent, locally more so than foliation.

"Rocks clearly of metasedimentary origin are limited to thin layers and lenses of calcium-silicate rock, marble, garnet-mica schist and kyanite-garnet-mica schist. Many of these are near the upper contact of the Trail Gneiss and might therefore represent remnants of a younger sedimentary sequence."

The western part of the Trail Gneiss (Simony, 1979) consists of a zone 200 m to 500 m wide of "platy, schistose, dark and streaked fine-grained rocks," in which the original texture has been destroyed. Porphyroblasts of actinolite and albite up to 0.5 mm long are scattered throughout the zone, which Simony terms blastomylonitic. Lineation of acicular crystals and quartz grain spindles is prominent. At its western margin the mylonite zone is in sharp contact with Mount Roberts Formation which has been metamorphosed to garnet grade.

Internal structural relations

According to Simony (1979), the oldest and least common rocks are layered amphibolite and grey, biotite granitoid gneiss, laced with foliated pegmatite. All other units within the Trail Gneiss crosscut this complex, and xenoliths of amphibolite occur in the younger units. Pervasive lineation of acicular minerals, and quartz and feldspar grains plunges westward at shallow to moderate angles. The compositional layering of the Trail Gneiss for the most part dips gently; dips more than 50 degrees are found only adjacent to plutons of Nelson Intrusions. In the eastern part, dips are mainly northeasterly, with a few easterly ones. In the central part, dips are northerly, although some are erratic. West of the Columbia, the dips are northwest to west. Simony has interpreted the structure as anticlinal, beneath which a low-angle thrust fault is postulated. Such an anticline apparently must plunge northward. An alternative interpretation is that the structure is part of the north half of a gneiss dome.

The gneiss exposed near the mouth of Bear Creek dips gently northwest, but steepens near the contact with the Trail Pluton just to the north. It appears to be a gigantic xenolith within the pluton.

External structural relations

The Trail Gneiss is separated from metamorphosed Mount Roberts Mountain on the west by a zone of blastomylonite. On the east it is separated from the Bonnington Pluton and low grade metamorphic rocks of the Archibald Formation and Rossland Group by the Champion Lake Fault, a west-side-down normal fault. Simony (1979) believes the dip slip movement to be about 5000 m based upon the theoretical consideration that 2000 m of gneiss and 3000 m of cover have been removed on the west side of the fault.

North of the map area the Trail Gneiss must pinch out against the Champion Lake Fault, for east of Castlegar airport relict chert pebbles are present in the gneiss there. The main mass of gneiss is terminated on the south by the intrusive rocks of the Trail Pluton.

Simony is of the opinion that the contact between the Trail Gneiss and the Mount Roberts Formation may be an unconformity that was tectonized by décollement of the cover.

Origin

Simony (1979) has emphasized the difference in lithology between the Trail Gneiss and paragneisses of the Mount Roberts Formation; the former contains virtually no metasedimentary material. He doubts that the lithology of any pre-Carboniferous formations to the east, including the Paleozoic, Windermere, and Purcell successions could give rise through metamorphism to the Trail Gneiss. He therefore favours the source being Hudsonian basement that was thrust from depth eastward over the Rossland Group. As supporting evidence, he quoted the Hudsonian date of 1960 Ma obtained by Wanless and Reesor (1975) from gneiss in the core of Thor-Odin dome, some 160 km north of Trail.

Within the Paleozoic and Upper Proterozoic successions of the Kootenay Arc to the east and northeast, there are, however, locally thick volcanic units. The oldest of these is the Irene Volcanic Formation of the Windermere System (Daly, 1912, p. 144-147; Rice, 1941, p. 15-17) and the equivalent 'Leola Volcanics' and 'Huckleberry greenstone' south of the International Boundary (Little, 1960, p. 18). In the Lardeau area (Fyles and Eastwood, 1962, p. 21, 26; Fyles, 1964, p. 27, 31; Read, 1973, p. 8-10), the Jowett Formation and the upper part of the Index Formation comprise volcanic rocks and feldspar-chlorite schist. These formations are within the Lardeau Group, which is of post-Lower Cambrian and pre-Mississippian age. These volcanic rocks could be metamorphosed to amphibolite to form the oldest part of the Trail Gneiss. Similarly, other Upper Proterozoic or Paleozoic volcanic rocks could be buried under the Carboniferous and younger rocks in or near the Rossland – Trail area, and these could be the source of the amphibolites in the Trail Gneiss.

In an effort to resolve the enigma of the age of the original rock that now forms the Trail Gneiss, a large sample of the granitoid gneiss, which is not the youngest component of the Trail Gneiss was collected from the huge highway cut about 0.8 km south of Genelle. It is hoped that sufficient zircons are present to make a U-Pb age determination, but failing that, a whole-rock Rb-Sr age determination should be most helpful.

Age and correlation

For the present, at least, the age of the Trail Gneiss must remain unknown, but at least is almost certainly pre-Carboniferous. Correlation with other formations elsewhere is not possible at this time.

Castlegar Gneiss

The Castlegar Gneiss was named by Simony (1979) and occupies much of the valley of China Creek. It is an augen gneiss that, according to him was formed partly from Trail Gneiss and partly from gneisses of the Mount Roberts Formation. It is described in the section on regional metamorphism.

Layered Granitoid Gneiss in Bonnington Pluton

Within Bonnington Pluton there are a number of small roof pendants that are composed largely of layered granitoid gneiss, but a few are composed of amphibolite. The origin of these high grade metamorphic rocks is unknown, but it is possible that they were originally Elise Formation.

Map Unit Cs

While carrying out detailed mapping from 1951 to 1956, Fyles and Hewlett (1959, p. 37, 38) examined a sequence of argillaceous and carbonate rocks in the lower part of the valley of Pend-d'Oreille River. These had been earlier questionably referred to the Lower Cambrian Laib Group and the Middle Cambrian Nelway Group (Little, 1950, Map 50-19A). Fyles and Hewlett were able to demonstrate that these sedimentary rocks differ appreciably from the Laib and Nelway, but the contact which they traced intermittently for more than 4 km seemed to be conformable. They were unable, therefore, to suggest an age of these rocks.

Distribution and thickness

Map unit Cs is exposed on both sides of Pend-d'Oreille River from the east edge of the map area at Ninemile Creek westward to Lime Creek, from where it is exposed only on the south side of the river, but not beyond the Waneta dam. West of Columbia River similar sedimentary rocks are poorly exposed over a small area 0.8 km west of the river, immediately north of the International Boundary. More extensive exposures are found high on the east side of the valley of Goodeve Creek for 1.5 km north from the International Boundary and eastward from that point for about 2 km to the valley of Moris Creek.

Outcrops of map unit Cs occur about 5 km farther west on Grouse Ridge, 0.75 to 1.5 km north of the International Boundary but have not been recognized west or north of this locality. Distribution of map unit Cs is remarkably limited, both north and south of the International Boundary.

Neither Fyles and Hewlett nor Yates have published estimates or measurements of the thickness of the unit, which Yates (1964, 1971) informally named the Pend-d'Oreille sequence. Fyles and Hewlett (1959, Fig. 3, Sheet A) have recorded many bedding attitudes of the argillite member, and a few in the chert-greenstone and limestone members. The former members occur only in the south and the latter only in the north. No bedding tops could be determined. Dips range from 20° to vertical, but many lie between 45° and 55° S. Cross-sections drawn across the general strike of the strata indicate a minimum apparent thickness of roughly 2100 m, but neither the top nor the base of the formation have been identified.

Lithology

Fyles and Hewlett (1959, p. 38) distinguished three types of lithology in map unit Cs. The most abundant, black argillite, calcareous argillite, slate, phyllite, and grey-weathering black limestone, is designated in this report by the symbol Csa. Somewhat less abundant is a bed of massive light grey limestone (Csl) that is bounded on the north and south by argillite and phyllite. The limestone weathers white or light blue grey and in only two places, both to the east of this map area, was bedding or banding seen. Based on these attitudes and the limestone-argillite contacts, the limestone bed dips about 50° S, and its apparent thickness ranges roughly from 150 m to 600 m. The limestone is a high calcium, low magnesium carbonate. It has been traced from the east edge of the map area to Reith Creek, and is exposed in a small area south of the Waneta Fault between Reith Creek and Waneta dam.

A third type of lithology occurs in Salmo map area in two narrow belts, one of which is in contact with the upper Laib Group, and the other is parallel with the first, and separated from it by black argillite and slate. These members comprise chert, quartzite, and minor greenstone, and appear to be at least 90 m thick. They have not been identified in Rossland – Trail map area, but in the continuation of map unit Cs south of the International Boundary, both chert and greenstone occur in the map unit (Yates, 1964, 1971).

West of Columbia River some outcrops of black schistose argillite with beds of grey limestone 0.6 to 0.9 m thick lie south of the Waneta Fault about 0.8 km from the river. A few small outcrops of crinoidal limestone are also exposed.

Farther west, on the ridge between Moris and Goodeve creeks, black phyllitic argillite is more extensively exposed. The more northerly outcrops, however, are mainly light grey weathering, medium grey limestone, which is locally silicified. A little sheared greenstone was also noted, but as it is near the Waneta Fault, it is uncertain whether this rock is part of map unit Cs, or Rossland Group. No chert was observed.

Three or four kilometres to the south, Yates (1971) described the dominant rock as black, silty argillite of Carboniferous (?) age.

Internal structural relations

In Pend-d'Oreille Valley, Fyles and Hewlett (1959, Fig. 3, Sheet A) showed that, although there are many erratic attitudes of the bedding, and some small folds occur, map unit Cs strikes roughly parallel with the lower Pend-d'Oreille River (roughly 060° to 070°). Dips range from 20° to vertical but mainly are 45° to 55° S. No bedding tops were determined. The chert-greenstone members outcrop only to the south and the limestone member only on the north. The structure there appears therefore to be roughly homoclinal.

West of Columbia River no bedding attitudes were obtained in the few outcrops exposed 0.8 km west of the river. Immediately south, however, Yates (1964) showed that the argillite there strikes northwesterly and dips 25° to 40° southwest. On the ridge west of Moris Creek the structure is very complex; strikes are erratic and dips are steep. In only one place were bedding tops determined, and there the beds were overturned.

On Grouse Ridge, bedding attitudes are mostly easterly, and the dips are steep. Cleavage in the phyllitic rocks also trends easterly and dips steeply. Because of the poor exposures and limited extent of the map unit, nothing more can be stated about the structure.

External structural relations

In the adjacent Salmo map area, Fyles and Hewlett (1959, p. 37, 38) arbitrarily placed the contact between map unit Cs and the Lower Cambrian Laib Formation "at the southeast side of a distinctive quartzitic unit found in the lower part of the valley of Tillicum Creek." As map unit Cs is no older than Devonian, and the thick Middle Cambrian Nelway Formation and Ordovician Active Formation are missing, the contact must be either unconformable or faulted and there can be little doubt that the latter is the case. Unfortunately such a fault has not been detected. Immediately south of the International Boundary the Leadpoint Fault separates the equivalent of map unit Cs from the Ordovician Ledbetter Slate (Yates, 1964), but the continuation of this fault into Salmo map area has not been identified.

West of Columbia River, map unit Cs is the oldest formation and the base is not exposed. Both east and west of the Columbia, the northern boundary of the formation is the Waneta Fault, which dips southward, and along which map unit Cs has been thrust over lavas and minor sediments of the Rossland Group. In summary, the stratigraphic relationships of map unit Cs to older and younger formations before tectonic deformation took place is unknown.

Age and correlation

Two collections of fossils were made from map unit Cs. In 1961 the writer and his assistants discovered brachiopods in tan weathering, black, silty argillite layers in black argillite. The locality is on the old road along Pend-d'Oreille River about 150 m east of the bridge over Sevenmile Creek. D.J. McLaren of the Geological Survey (written communication, October 26, 1961) stated:

".....most of us have examined [the fauna] in turn. The concensus seems to be that they are unlikely to be Lower Paleozoic or Mesozoic; we cannot exclude a Devonian age and they might be Carboniferous or Permian.....the brachiopods are fairly highly developed and unlikely to be much older than Devonian or Upper Silurian at the earliest." In a postscript, he added "Peter [Harker] thinks one of the brachiopods might be **Leiorhynchus carboniferum** and [if so] of Late Mississippian age."

D.C. McGregor of the Geological Survey tested the material for spores, but none were found.

The writer and his assistants returned to the locality in 1962 and additional brachiopods were collected. These were examined by E.W. Bamber of the Geological Survey who on December 18, 1962 reported as follows:

Locality F1 GSC loc. 51072

> Arthropod (?)
>
> **Leiorhynchus** sp. (?)
>
> Age: Leiorhynchid brachiopods range from Devonian to Permian in age. Associated with these brachiopods, but in a different rock type is a Jurassic ammonite....
>
> It is very unlikely that the brachiopods are younger than late Paleozoic.

Some 5 to 7 m southeast of the brachiopod-bearing bed in dark grey argillite, an assistant, G. Raham, discovered ammonites. The material was obtained by pulling downs slabs from the roadcut and splitting them. The writer was suspicious that the slab may have been float from another source and carefully compared it with the outcrop. It was identical in colour, composition, and grain size, so the slab was added to the brachiopod collection. H. Frebold of the Geological Survey reported on December 10, 1962:

Locality F1 GSC loc. 51072

> The few fossils received from the dark argillite are: one very small ammonite, one fragment, and one ammonite with imprint. This ammonite has a diameter of about 17 mm, is rather involute, has S-shaped ribs, some of which bifurcate on the middle of the flank. In part of the ventral region a very fine denticulation is visible that may belong to a ventral keel. If the latter observation is correct – the preservation of the fossil is too poor to make a definite decision – the ammonite would have to be identified as **Cardioceras** or **Amoeboceras.** General shape and type of ribbing would be aggreeable with such identification. If the ammonites belong to the Cardioceratidae a late Oxfordian or early Kimmeridgian age – i.e. Early Upper Jurassic – would be indicated.......
>
> At any rate there is not much doubt that the ammonites are Jurassic in age.....

In June 1963, the writer returned to the locality, accompanied by Dr. Frebold. Between the brachiopod and the ammonite localities there is a fracture that is occupied by a narrow lamprophyre dyke. There is no appreciable change in lithology across the fracture, so that in the writer's opinion, there is little if any displacement along the fracture. Additional brachiopods were collected, but no more ammonites could be found. Because the brachiopods are in place and the slab containing the ammonites could be float, it is concluded that the age of map unit Cs is late Paleozoic (Devonian to Permian), possibly Upper Mississippian.

The formation is correlated with Yates' (1964, 1971) 'Pend-d'Oreille sequence' with which it is for the most part contiguous. Yates assigned a Carboniferous (?) age to the sequence, but gave no reason for doing so.

The Milford Group of Lardeau and Nelson (east half) map areas bears some lithological resemblance to map unit Cs; black slate and argillite, limestone, and chert are mutual constituents. Furthermore, fossils in the limestone of the Milford Group are of Upper Mississippian age (Fyles and Eastwood, 1962, p. 32), an age also indicated for map unit Cs. These fossiliferous beds lie 150 or 160 km northward from Trail, but the group has been traced by Rice (1941, Map 603A) southward to a point about 69 km northeast of Trail where the grade of metamorphism is so high that the strata can no longer be identified.

Near Springdale, Washington, 109 km south of Trail, unnamed carbonate rocks yielded Mississippian fossils (Miller and Clark, 1975, p. 31-33), but Pennsylvanian fossils were collected, and identified, from the same unnamed strata by Enbysk (1954, p. 15).

In Greenwood map area, about 61 to 74 km west of Trail, dark grey silty argillite and argillaceous siltstone, and grey limestone that comprise the Attwood Formation (Little, in press) are to a marked degree similar to members of map unit Cs. Fossils collected from eight localities in the Attwood were insufficiently diagnostic or well preserved to provide a more accurate age than Carboniferous or Permian. It is possible that the Attwood Formation is correlative with map unit Cs.

Mount Roberts Formation

Rocks of the Mount Roberts Formation were first examined and described by McConnell (1897a; 1898, p. 22A), and by Brock (McConnell and Brock, 1904; Brock, 1906, p. 14). They included these rocks, from which they obtained fossils, with their Rossland Volcanic Group. Daly (1912, p. 320, 321) separated some of the rocks near Paterson from McConnell and Brock's Rossland Volcanic Group, and correlated them with his "Pend-d'Oreille Group" (op. cit., Map 81A) of the Selkirk Mountains, which he assumed were also of Carboniferous age (op. cit., p. 322, 323). Other sedimentary rocks at Paterson he further separated based, unfortunately, on incorrect identification of fossil plants. Young, in Drysdale (1915a, p. 38, 39, 193-200) delineated in Rossland Camp sedimentary rocks exposed on the eastern slopes of Mount Roberts that are older than the Rossland Group and named them the Mount Roberts Formation. Bruce (1917, p. 217-219) also examined and described the formation in Rossland Camp. Gilbert (1948, p. 190) stated that it consisted there of "several hundred feet of impure quartzites." The present author, during reconnaissance mapping extended the formation southward to Paterson, northward to Murphy Creek, thence westward to Christina Lake, and correlated similar rocks near Deer Park (Little, 1957; 1960, p. 46, 47). Subsequently, he (Little, 1963), and R.I. Thorpe, made a more detailed study of the formation in Rossland map area. Fyles (1970) remapped Rossland Camp and vicinity on a scale of 1:12 000. The most recent work was by Simony (1979). The writer revisited Rossland Camp briefly in 1978.

Distribution and thickness

In the type area, the Mount Roberts Formation underlies a zone 90 to 400 m wide that extends along the lower slopes of O.K. Mountain, Mount Roberts, and Granite Mountain, a length of nearly 5 km. A smaller area of about 0.5 km^2 southwest of Red Mountain at the headwaters of Little Sheep Creek, is underlain by similar rocks. To the east of this, along the west side of Red Mountain there is a belt of hornfels, locally brecciated on Red Mountain, that extends 0.8 km south of the west end of the city of Rossland, northward to Topping Creek. These rocks were included in the Mount Roberts 'Group' by Young (in Drysdale, 1915a, Map 1004), Gilbert (1948, p. 190), Little (1960, p. 46; 1963, Map 23 – 1963), and Thorpe (1967, Fig. 1). Fyles (1970) classed these rocks as part of the Rossland Group, but subsequently (in a hand-coloured map loaned to the writer, July 1978) has placed some or all of these rocks in the Mount Roberts Formation. Simony (1979, Fig. 2) also assigned these rocks to the Mount Roberts Formation.

Mount Roberts Formation is exposed on both sides of the valley of Little Sheep Creek for a little more than 1.6 km north of the International Boundary. Similar rocks adjacent to the abandoned Great Northern Railway line 3.25 km north of the International Boundary are also correlated with the Mount Roberts quartzites, however, other sediments an additional 3.25 km to the north, originally placed in the Mount Roberts (Little, 1963, Map 23 – 1963), have been classified as Rossland Group by Fyles, and are now correlated with the Elise Formation by the writer. From the International Boundary at and near Paterson, Yates (1971) traced the Mount Roberts Formation westward, south of the Boundary, to the west edge of the Northport quadrangle, beyond which the Churchill Formation of Bowman (1950) extends some 10 km westward to terminate against his Summit Lake Fault. The Churchill Formation is exposed also near Barstow, some 19 km south of this fault. From there, the Churchill Formation was traced farther southward by Kuenzi (1961, 1965).

The Mount Roberts Formation can be traced northward from Red Mountain into the valley of Murphy Creek beyond which it grades into gneisses South of China Creek, argillites, quartzites, limestones, and conglomerates are still identifiable as Mount Roberts Formation within these gneisses. From the upper part of Murphy Creek, these rocks can be traced westward, to Christina Lake except where interrupted by the northern part of the Coryell Batholith beyond the west edge of the map area.

Fyles (1971) estimated the apparent thickness of his eastern unit (the type Mount Roberts Formation), to be about 325 m, but the base is not exposed, being cut off by a fault. Simony (1979, p. 7) gave the approximate thickness of the formation at Murphy Creek as 1200 to 1500 m. The base, however, is marked by mylonitized Trail gneiss, and the top is the unconformity with the Rossland Group. To the west of the headwaters of Murphy Creek, the thickness of the Mount Roberts Formation appears to be great, but as the structure is unknown and the rocks are poorly exposed and are interrupted by intrusions, no estimate of the thickness is possible.

In the valley of Little Sheep Creek near Paterson the structure is unknown. At least three bands of limestone are exposed and range in thickness from 6 m to at least 120 m. The thickness of other members is not known, but is estimated to be at least 600 m and may be as great as 1200 m. No estimate of thickness in Northport quadrangle is given by Yates (1971), but for farther west Bowman (1950) gave a figure of 0 to 120 m.

Lithology

In the type locality the Mount Roberts Formation consists of dark grey to black siltstone and argillaceous quartzite, and black slate. Brock in 1906 also saw a pod of shattered, impure, fossiliferous limestone, and Fyles (1971) noted other pods along the western side of the belt. Fyles (1970; 1971) also placed the adjacent rock unit to the west, which he defined as a breccia, in the Mount Roberts Formation, but the writer and Thorpe (1967, Fig. 1) regard this unit as rather typical of the basal Rossland Group; it does not resemble Mount Roberts rocks elsewhere.

The belt of Mount Roberts Formation to the east that extends across Red Mountain consists of more highly metamorphosed rocks. In the valley at the headwaters of Little Sheep Creek the beds consist of argillaceous quartzite, siltstone, and slate that are similar to those in the type area. Elsewhere in the belt, Thorpe (1967, Fig. 1) described the rocks as "argillaceous quartzite and siltstone, black, slaty argillite, greywacke, and chert." On the north slope of Red Mountain he noted some interbedded volcanics. Fyles (1970) mapped these rocks as banded hornfels which, on the west side of Red Mountain, is highly brecciated. These rocks have been traced, with interruptions, into the valley of Murphy Creek, where Simony (1979, p. 7) described the members exposed there as follows:

Top	Thickness m
Greywacke, laminated siltstone, and pebble conglomerate, and a few thin limestone and lime silicate beds	500
Siltstone, greywacke with much laminated argillite, and slate	200
Siltstone, greywacke, and argillite with lenses and beds of pebble conglomerate	500
Siltstone, mostly massive and pinkish weathering with minor laminated argillite and greywacke. Platy at base	0-300
Schistose and platy Trail Gneiss	

In lower Murphy Creek adjacent to the Trail Pluton and northeastward to the Mackie Pluton, the Mount Roberts beds are transformed into granitoid gneisses that towards the north become garnetiferous. Within the gneiss, however there are masses of low grade metamorphic rocks, some fairly extensive. Along and near the Sullivan Creek road at an elevation of 825 to 850 m, at least 30 m of marble is exposed. Granitoid gneisses north of the Mackie Pluton and exposed along the China Creek watershed are believed to be metamorphosed Mount Roberts Formation. There the gneisses contain large porphyroblasts of potash feldspar. These gneisses Simony (1979, p. 8) correlates with the mixed gneiss of the southwest flank of Passmore Dome of the Valhalla gneissic complex (Reesor, 1965, p. 26-30).

At Strawberry Pass and Mount Crowe, and westward to the west border of the map area, there is much limestone and marble. On a ridge west of Lamb Creek it is estimated to be at least 120 m thick. Siltstone and argillaceous quartzites are, however, the most abundant, and some chert, greenstone, and tuff were observed.

In the valley of Little Sheep Creek near Paterson, limestone is relatively abundant, and much of it contains chert nodules. Some of the limestone contains coarse tuff particles. Argillaceous quartzite, siltstone, argillite, and greywacke are common. Some tuffaceous beds and greenstones were seen. Yates (1971) defines the formation south of the International Boundary as "predominantly fine-grained thin-bedded quartzite and siltite; contains some crystal tuff, chert, and chert conglomerate and a few lava flows, and limestone beds......"

Microscopic examinations were made of some of the sedimentary rock types of the Mount Roberts Formation. A specimen of greywacke contains rounded, 1 mm fragments of siltstone, altered feldspathic rock, and epidote-opaque mineral metamorphic rock in a fine grained matrix of altered feldspars with some subangular quartz. The feldspars are mainly albite and potash feldspar. Much cloudy, argillaceous material and some sericite comprise part of the matrix.

Bedded dark grey siltstone from south of the Sullivan Creek road consists of about 45% quartz, 40% albite, 15% biotite, 1% chlorite, and minor hematite, pyrite, and other opaque minerals. The rock has been somewhat recrystallized so that the quartz and albite form interlocking grains. The albite is slightly saussuritized, and the quartz contains a few minute inclusions.

Two specimens of what in the field was called argillaceous quartzite were examined. One consists of angular grains estimated to comprise 15% quartz, 10% albite, 10% orthoclase, 5% sanidine, and 5% lithic fragments in a very fine grained matrix of quartz, white mica, and, probably, plagioclase. Minor apatite, zircon, and opaque minerals are present. The plagioclase is saussuritized and the quartz is strained, with trains of sparse, very fine grained dark inclusions. It is probably derived largely from a quartz porphyry, and should perhaps be called an arkosic quartzite. The other sample is somewhat metamorphosed, and is a layered rock of fine grained quartzofeldspathic layers with some interstitial biotite and coarser layers with euhedral biotite and minor quartz and feldspar. Inclusion-filled subhedral phlogopite occurs locally. The plagioclase is slightly zoned oligoclase which is more abundant than quartz.

A more highly metamorphosed specimen of impure quartzite is a cordierite hornfels. It consists of about 40% very fine grained quartzfeldspar matrix, 30% medium grained cordierite, 20% reddish brown biotite, 5% epidote, and 5% disseminated, fine grained opaque minerals. The cordierite forms porphyroblasts, a rich zone of which cuts across the thin section.

A specimen of fine chert-pebble conglomerate, somewhat metamorphosed, was examined. It comprises 50% elongate pebbles containing strained quartz and minor very fine grained mica and opaque minerals, in a fine grained matrix of 25% strained quartz, 15% brown biotite, 8% sericite, 2% very fine grained opaque minerals, and minor tourmaline and zircon(?). The sericite appears to be post-tectonic. From elsewhere a boulder of igneous rock in a Mount Roberts conglomerate was examined in thin section to determine its possible source. It is sheared and altered, and comprises approximately 25% plagioclase phenocrysts (oligoclase or andesine), 15% green biotite, and 5% apatite in a very fine grained matrix of quartz, plagioclase, and minor biotite. Minor brown garnet, green chlorite, zircon, and opaque minerals are present.

A coarse grained tuff contains angular to round fragments, 0.1 mm to 2 cm largely of mafic plagioclase porphyry composed of euhedral albite phenocrysts in a very fine grained feldspathic, chloritic matrix. Others are a 5 mm elongate glass fragment with scattered quartz, feldspar, and opaque minerals, and a 5 mm arkosic fragment with medium grained rounded quartz and feldspar grains in a nest of epidote and chlorite.

Internal structural relations

In the type locality, the Mount Roberts Formation appears to be homoclinal, with bedding tops facing steeply west, but, as Fyles (1971) has pointed out, primary structures there indicating stratigraphic tops are few and inconclusive.

In the south end of the belt, where it passes over Red Mountain, the structure is not discernable in the hornfelsic rocks, but bedding is observable in the small area at the head of Little Sheep Creek. Farther north, particularly between Hanna and Murphy creeks, bedding tops were determined at several places and a fold was noted. Simony (1979, Fig. 2, 4) has made a much more detailed examination of the rocks there and has identified a recumbent syncline in the eastern part of the area, and a recumbent anticline to the west, higher in the valleys of Hanna and Murphy creeks. These folds trend northerly but the axes are sinuous, and the axial planes dip moderately to the west.

At Strawberry Pass and Mount Crowe, and to the west, although Mount Roberts rocks are encountered over a large area, outcrops are too scattered and the Mount Roberts is invaded by numerous dykes and larger intrusive bodies, and it is not possible to work out the structure. Similarly, although more detailed mapping of the Mount Roberts beds was done near Paterson some bedding tops were determined from crossbedding and graded beds, but attitudes are for the most part erratic and dips are steep. Three lithological divisions were made there of the Mount Roberts Formation: greywacke with minor greenstone, tuff, argillite, and limestone; limestone with, locally, white chert; argillite and argillaceous quartzite. It is not known which of these divisions is the youngest, or which is the oldest; none can be traced very far. It is concluded that the structure is very complex – it is the product of at least three periods of folding.

External structural relations

The Mount Roberts Formation is in contact with older rocks only in Hanna Creek, and west of Birchbank. At the latter locality the Mount Roberts Formation has been metamorphosed to granitoid gneiss, whereas in Hanna Creek it has suffered only low grade metamorphism. At both localities the older rocks are mylonitized Trial Gneiss. This contact has been studied in detail by Simony (1979, p. 7) who described it as tectonic and either paratochthonous or highly allochthonous. He suggested that the Mount Roberts Formation was laid down unconformably upon the

Hudsonian(?) Trail Gneiss. He noted, however, that northward along the contact, older beds of the Mount Roberts are exposed. This writer, on the other hand, believes that this contact is a fault with great displacement, that pre-dates the Rossland Group.

At the type locality the Mount Roberts Formation is terminated on the east by a west-dipping thrust fault (Little, 1963; Fyles, 1970), part of which is obscured by the intrusion of a large dyke of Coryell alkaline syenite. Beneath the thrust fault are volcanic rocks of the Rossland Group. On the west, the sedimentary rocks are, according to Fyles (1971) gradational into a breccia which he stated is sedimentary in origin and which he assigned to the Mount Roberts Formation, but which the writer believes is basal Rossland Group.

Near Paterson, however, the Mount Roberts Formation is overlain unconformably by volcanic rocks of the Rossland Group. The unconformity is exposed on a small hill that is 670 m northwest of International Boundary monument 175. The regolith consists of what are apparently talus blocks of greywacke, beneath which are greywacke beds that strike northeasterly and dip 70° to 75° southeast. Graded beds give conflicting data, but most seem to indicate that the beds are not overturned. The unconformity is sinuous, and it is apparent that the overlying agglomerate was laid down on a very uneven surface, for the underlying Mount Roberts beds are not similarly contorted. On the east side of the valley the actual unconformity was not observed, but the greywackes, slates, siltstones, minor limestones, and tuffs strike into the overlying agglomerates. At one point near the Mount Roberts – Rossland contact, crossbedding, channel fill, and graded beds in Mount Roberts greywacke all indicate that the beds are overturned – further evidence of unconformity. Finally, basal agglomerate and flow breccia of the Rossland Group rest upon different members of the Mount Roberts Formation. The unconformity is profound, representing all of Permian and Triassic time.

South of the International Boundary Yates (1971) mapped the Mount Roberts – Rossland contact as a fault, but on the north side no evidence of such a fault was seen by the writer.

Origin

Because volcanic rocks are not abundant in the Mount Roberts Formation, the assemblage of greywacke, chert, slate, argillite, siltstone, argillaceous quartzite, and limestone indicates the environment in which they were deposited to be epieugeosynclinal, but there is no evidence that the formation overlies a deformed and intruded eugeosyncline. It appears, therefore, that, despite the paucity of volcanic flows, agglomerates, and tuffs, the assemblage is probably eugeosynclinal; it is not miogeosynclinal.

Age and correlation

Corals were collected by McConnell (1897a) on the west side of Little Sheep Creek near the International Boundary and were identified by Whiteaves as "probably referable to the Carboniferous genus **Lonsdalia.**" Brock in 1906 (in Drysdale, 1915a, p. 199) made a collection of poorly preserved fossils from the eastern slope of O.K. Mountain at an elevation of about 1200 m (Fyles, 1971). These were identified by Ami who stated that they are Upper Carboniferous.

In 1949, the writer and his assistants made fossil collections from seven localities on the west side of Little Sheep Creek, and one on the east side (Little, 1960, p. 48-50). In six of these P. Harker of the Geological Survey of Canada identified a number of fossils, together with three other collections made from fossiliferous limestone fragments found in basal agglomerates and flow breccias, two being nearly 800 m from Paterson and the other on the southeast spur of Granite Mountain, at an elevation of 1700 m. Harker concluded that, despite rather meagre evidence of actual age, the collections are of Pennsylvanian or Permian age, and his opinion was that they are probably Pennsylvanian.

The argillites east of Paterson, from which Daly collected plants identified by Penhallow as Lower Cretaceous were shown to be part of the Mount Roberts Formation, and a **Lepidodendron** collected in 1955 by Harker and identified by W.L. Fry (then of the Geological Survey of Canada) (Little, 1960, p. 51) gave an age "indicative of the Permo-Carboniferous, and possibly of Pennsylvanian age."

In 1961, further collections were made near Paterson, and were studied by Wayne Bamber of the Geological Survey. Of these, only two were sufficiently diagnostic to be of value in confirming or refining earlier reports, and are as follows: (see also Little, 1978, p. 322)

Locality F2 — GSC loc. 51066 (same locality as GSC loc. cat. 17207?)

West side of Little Sheep Creek, 1200 m N 40° W from International Boundary monument 175, elevation 720 m (2400 ft)

Dibunophylloides? sp. - formerly identified by Bamber as **Dibunophyllum** cf. **D. oregonensis** Merriam.

Orygmophyllum sp. - formerly identified by Bamber as **Lithostrotion (siphonodendron)** sp.

Age: **Orygmophyllum** and **Dibunophylloides** are both found in Permian rocks and in equivalents of the North American Pennsylvanian in Russia. Collection LF62-F2 is therefore either Pennsylvanian or Permian age, rather than Mississippian as formerly suggested.

Locality F3 — GSC loc. 51068

East side of Little Sheep Creek, 990 m N 8° W from International Boundary monument 175, elevation 715 m (2350 ft)

Rhipidomella sp.
textularid? foraminifera
crinoid ossicles

Age: **Rhipidomella** ranges from Middle Silurian to Permian. The foraminifera have been referred to T.P. Chamney for further work.

T.P. Chamney of the Geological Survey reported as follows:

Climacammina (4) cf. **cylindrica** Cushman and Waters 1928

Cribrostomum (8) cf. **linum** Cummings 1956

C. (7) n. sp.

Paleotextularia (9) cf. **consobrina** Lipina var. **intermedia** Lipina

Age: Carboniferous, possibly Pennsylvanian (Strawn)

From all the paleontological evidence the age of the Mount Roberts Formation near Paterson and in the type locality is probably Pennsylvanian, although a Permian age cannot be ruled out, and at Locality F3 a Strawn or Allegeny (Middle Pennsylvanian) age is indicated. Indeed, evidence that Permian beds were present or not too distant at the time of eruption of the Rossland volcanics was found in a fossiliferous limestone fragment in basal agglomerate of the Rossland Group. Bamber identified the collection.

GSC loc. 51074

Rossland Group, 630 m N 5° W of International Boundary monument 175, elevation 750 m (2450 ft)

fusulinid foraminifera

Age: These are too poorly preserved for definite identification, but are probably Permian in age.

Permian fusilinids occur in beds similar to those of the Mount Roberts Formation near Barstow, 32 km southwest of Paterson, and in the Colville area, 55 or 65 km south of Paterson. Therefore, it is not unreasonable to assume that Permian beds may exist within the Mount Roberts Formation, particularly in the more highly metamorphosed sediments in which no fossils have been discovered in the northwestern part of Rossland – Trail map area. Indeed, in the southern extension of Bowman's Churchill Formation, Kuenzi (1961, 1965) found Lower Triassic (Scythian, Owenites zone) fossils in platy limestones that appear to form the top of the Permian greywacke-limestone sequence of sedimentation (see also Little, 1978). Until concrete evidence that Permian or Lower Triassic beds are present in the Rossland – Trail map area is obtained, the writer assigns a Pennsylvanian(?) age to the Mount Roberts Formation, as has been done by Yates (1971) and Simony (1979, p. 7).

The Mount Roberts Formation is correlated probably in part with the lithologically similar Churchill Formation of Orient Quadrangle (Bowman, 1950), although one collection of fossils there was dated as Middle or Upper Permian by Henbest, and the other Devonian to Permian, and chert seems to be more abundant there. Mapping by Yates (1971) has linked the two formations, although the fossiliferous part of the Churchill has not been so linked. The Mount Roberts Formation is also correlated with an unnamed formation near Covada, Ferry County, Washington, which is perhaps 65 km south of the Permian near Barstow. Near Covada, Bancroft (1914, p. 14) collected "**Bothrodendron** sp (?) of Carboniferous age, most likely older Pennsylvanian." Near Springdale, Washington, 112 km south of Paterson, unnamed carbonate rocks yielded Pennsylvanian fossils (Enbysk, 1954, p. 15), however, Mississippian fossils were later collected and identified from the same formation (Miller and Clark, 1975, p. 31-35). Farther west, in Curlew (Parker and Calkins, 1964, p. 29) and Republic (Muessig, 1967, p. 21-24) quadrangles, and in the northern Okanogan Valley of Washington (Waters and Krauskopf, 1941; Reinhart and Fox, 1972, p. 7-22; 1976, p. 4), eugeosynclinal assemblages of Permian age are known. In the Okanogan Valley these are named the Anarchist Group.

In Canada, in the Lardeau map area 110 to 150 km north-northeasterly from Rossland, the Milford Group may be in part similar in age to the Mount Roberts Formation, for the basal part is Upper Mississippian (Fyles and Eastwood, 1962, p. 32), and the top is probably Triassic (Little, 1960, p. 53). However, the Milford Group more closely resembles lithologically map unit Cs of Rossland – Trail map area. Parts of the Mount Roberts Formation resemble the Carboniferous or Permian Attwood Group of Greenwood map area (Daly, 1912, p. 382, 383; Little, in press), some 56 km west of Rossland. It does not resemble the adjacent Knob Hill Group of similar, perhaps younger, age. Farther west, the Mount Roberts Formation may be correlated, in part at least, with the eugeosynclinal Pennsylvanian and Permian Cache Creek Group, which extends from the northern Okanagan Valley of British Columbia to northwestern British Columbia (Jones, 1959, p. 43-47; Cockfield, 1948, p. 9; Duffell and McTaggart, 1952, p. 24; Trettin, 1961, p. 17-19; Campbell and Tipper, 1971, p. 22-28; Armstrong, 1949, p. 45-47).

Rossland Group

The Rossland Group was first mapped, and named the "Rossland Volcanic Group", by McConnell and Brock (1904), who included in it the Pennsylvanian(?) Mount Roberts Formation. Also included were the sediments in Archibald Creek (then known as Caribou Creek), which are now the Archibald Formation. Daly (1912, Map 80A), perhaps inadvertently, also included some of the Archibald beds in the Rossland (which he redefined as Rossland Volcanic Formation), but named the sediments at the south end of the belt of type Archibald (Little, 1965) "sediments of the Beaver Mountain Group" (Daly, 1912, p. 352-354). He assigned similar Archibald beds north of Kelly Creek to the Beaver Mountain Group, which he referred to the Mesozoic in his text, but to the Tertiary in his map legend.

The "Beaver Mountain Volcanic Group" had been originally separated from the "Rossland Volcanic Group" by McConnell and Brock (1904) who regarded it as younger than the latter and assigned a post-Cretaceous age to it. Daly (1912, p. 353) stated that he had independently come to the conclusion that the lavas and pyroclastic rocks about Beaver Mountain (now known as Mount Kelly) are considerably younger than the Rossland Group. Walker (1934, p. 10-13) was unable to map the two volcanic groups, as separate units and designated them the Beaver Mountain-Rossland Group. He stated, however, that his work corroborated the earlier work, that the Beaver Mountain rocks overlie those of the Rossland, but that there were so many intrusive phases that the relationship could not be truly expressed. In all, greenstone, breccia, banded ash rocks, latite flows, flow breccias, volcanic agglomerates, dykes and sills, and minor limestone were recognized in the complex. The name Beaver Mountain (as a formation) was retained by Little (1950) and Mulligan (1951, 1952) based, in part at least, on early identification of poorly preserved fossils. Subsequently, based upon good fossil evidence, it was shown that the so-called Beaver Mountain rocks are actually Rossland Group (Frebold, 1959; Little, 1960, p. 63, 64; Frebold and Little, 1962; Little, 1965). The name "Beaver Mountain" is therefore both obsolete and incorrect and must be discarded.

On the other hand, some volcanic and sedimentary rocks that were included in the Rossland Group have been removed from the group, and others should probably be removed also. McConnell and Brock (1904) suggested that the andesites of Old Glory and Record mountains are younger than the Rossland Group, but unfortunately suggested that "they may be of the same age as the Beaver Mountain volcanic group." Daly (1912, Map 81A) placed these rocks in the "Rossland volcanic formation." Young (in Drysdale, 1915, p. 201) recognized that the volcanics west of Rossland Camp are younger than the underlying Carboniferous, and assigned them to the Triassic, and so also did not realize they might be much younger. Drysdale himself (op. cit., p. 218) stated that andesites and tuff beds on Mount Roberts "lie at low angles on the steeply dipping older tuffs and agglomerates of Triassic(?) age," but referred them to the Jurassic. Bruce (1917, p. 219) thought that the "beds up to a point about 100 feet (30 m) below the summit of Mount Roberts.........are absolutely conformable on the lower Mount Roberts beds.........but those capping the peak are horizontal, and for this reason have been assigned to a later period." Gilbert (1948, p. 190, Fig. 1) placed the andesite and latite flows west of the Rossland Camp in the Rossland Group, as did Little (1960, Map 1090A), in reconnaissance mapping.

However, in subsequent, more detailed mapping Little (1963), after having seen Daly's Midway volcanics to the west, recognized the similarity of the lavas capping Old Glory Mountain to those west of Granby River but the same

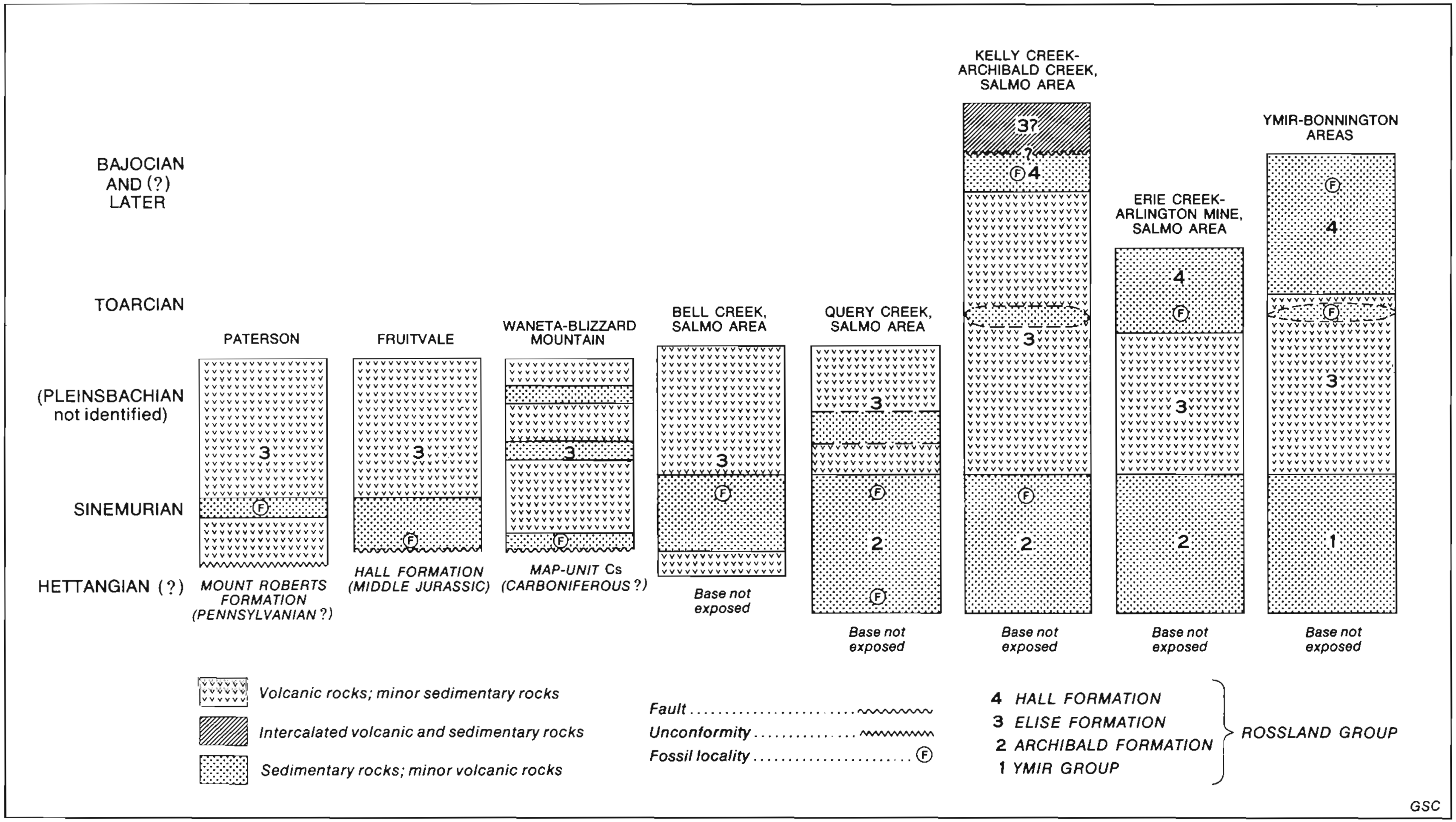

Figure 3. *Correlation of the formations of the Rossland Group in Ymir, Bonnington, Salmo, and Rossland – Trail map areas.*

similarity of the lavas capping Mount Roberts and O.K. Mountain was not recognized. It remained for Fyles (1970) whose much more detailed mapping in the Rossland area revealed the basin-like distribution of the lavas and sediments there and the unconformable nature of the contact with older rocks, to establish the relationship. These rocks are now removed from the Rossland Group, and others may be subsequently shown not to be Rossland, as for example some of the volcanic and sedimentary rocks southeast of Violin Lake. During a check traverse there in September 1978 lavas resembling those on O.K. Mountain were encountered, but the writer did not have the time to determine the extent of these lavas which seem to be interbedded with hard, black, laminated siltstones that resemble those of the Archibald Formation.

Since it was named in 1904, the Rossland Group has been redefined several times, the latest being by Frebold and Little (1962, p. 3) when it was defined to include the Elise and Hall formations and "a considerable thickness of volcanic and sedimentary rocks" that were believed to overlie the Hall Formation in Salmo map area (see also Little, 1965). Subsequent mapping in the adjacent Trail map area revealed that most sedimentary rocks within the panel resemble those of the Archibald Formation. Although no diagnostic fossils were found to confirm this view, it is concluded that the panel represents a fault slice of Elise Formation that has been thrust upon the Hall from the west. Thus, no Jurassic rocks younger than the Hall Formation have as yet been identified.

In the type locality, the Archibald Formation contains only very minor volcanic rocks, though many of the beds are tuffaceous. Farther west, in Rossland – Trail map area, sediments resembling the Archibald and which in places contain Sinemurian fossils, are interbedded with lavas that resemble the Elise, which therefore becomes older to the west (Little, 1962, p. 3, 7). The Archibald-like sedimentary rocks cannot be traced continuously westward from the Salmo map area, due to extensive faulting, and because of drift-filled valleys. It therefore becomes necessary to include such sediments in the Elise Formation (see Fig. 3). It is also necessary to redefine the Rossland Group to include the Archibald Formation, and the Ymir Group of Ymir map area (Little, 1964) as well, for, although the latter has defied all efforts to find fossils within it, there can be little doubt that the upper part at least of the Ymir Group is equivalent to the Archibald (Frebold, 1959, p. 3; Little, 1960, p. 57-59). The Ymir Group in turn is believed to be partly or entirely equivalent to the Slocan Group (Little, 1960, p. 59), but it is not proposed that the Slocan Group be included in the Rossland Group. In summary, then, the Rossland Group is now defined to include the Ymir Group, Archibald Formation, Elise Formation, Hall Formation, and any post-Hall volcanic and/or sedimentary rocks of Jurassic age, should such be identified. The currently known age of the Rossland Group as now defined ranges from Hettangian(?) (lowermost Jurassic) to post-middle Bajocian (early Middle Jurassic).

Archibald Formation

The Archibald Formation is named for Archibald Creek in Salmo map area where it is discontinuously exposed (Frebold and Little (1962, p. 3-5). There, however, the greatest thickness, estimated to be at least 1220 m, is found. The formation was traced westward, though not continuously to the edge of the Salmo map area and beyond to the eastern part of Rossland – Trail map area. Farther west, however, beds that are lithologically similar to the Archibald and are in a few places of considerable thickness, and have in several localities yielded fossils of Sinemurian or probably Sinemurian age, cannot be traced continuously. Furthermore, these beds are underlain by lavas of Elise affinity. In discussion with H. Gabrielse of the Geological Survey it was decided that the principles of stratigraphic nomenclature require that the lowest lavas belong in the Elise Formation and that the interbedded sediments should also be included in the Elise, and they are so shown on Rossland – Trail map.

Distribution and thickness

As a result of the above decision, the distribution of the Archibald Formation is more restricted than as shown on the Trail preliminary map (Little, 1962). Outcrops of Archibald sediments, best exposed in road cuttings along logging roads, occur on the east side of Beaver Creek from near Parks station southward for 4 km. Another area underlain by Archibald Formation is on the northwest side of lower Beaver Creek from Montrose 4 km northeastward. A third locality where there are beds that are strikingly similar to the Archibald is in the northwest part of the map area, about 4 to 5 km southeast of the northwest corner of the map area.

The structure is complex at the last locality, and near Parks, so no reliable estimate of the thicknesses of the formation there, but in each case it must be more than 100 m. Near Montrose, however, exposures are moderately good and the structure appears to be homoclinal. On this basis, the maximum thickness exposed there appears to be about 900 m.

Lithology

The rocks most characteristic of the Archibald Formation are hard, brittle, dark grey to black argillaceous siltstones and arenaceous argillites. Some argillaceous quartzites and greywackes are also present. In Rossland – Trail map area the sediments appear to be more tuffaceous than in Salmo map area. Almost everywhere the beds are distinctly laminated; graded bedding is common, crossbedding is rarely seen and where present is of small amplitude. These features are clearly visible on the light grey weathering surfaces.

Under the microscope the siltstone and arenaceous argillite are shown to comprise plagioclase, calcite, quartz, potash feldspar, chloritized ferromagnesian minerals, magnetite, and hematite in a fine grained matrix of small lithic fragments and unidentified minerals.

Internal structural relations

Along the northwest side of lower Beaver Creek the Archibald Formation forms a homoclinal panel of sedimentary rocks that apparently have been thrust over rocks of the Elise and Hall formations. This homocline dips steeply northwest.

Elsewhere, along the east side of Upper Beaver Creek, although a few bedding tops were determined which indicate an easterly-trending anticline, data are too sparse to put much weight on this interpretation. In the northwestern corner of the map area, no top determinations were possible, and the erratic nature of the bedding attitudes makes structural interpretation impossible.

External structural relations

Nowhere has the base of the Archibald Formation been recognized. In the northwestern part of Rossland – Trail map area, carbonaceous siltstones that have been assigned to the Archibald Formation are bounded on the west by argillaceous quartzites and greywacke that are believed to be Mount Roberts Formation. Rock exposures there, however, are poor, and the contact was not seen. Lavas of the Rossland Group occur within 1.25 km to the southeast, separated by syenite of the Coryell Batholith.

At the upper contact of the Archibald Formation in the Salmo and Bonnington map areas, and in the eastern part of Rossland – Trail map area, sediments give way abruptly to the overlying lava flows, flow breccias and agglomerates of the Elise Formation. But to the west, as can be seen in Figure 3, the upper part of the Archibald Formation grades laterally into lavas and Archibald-like sediments of the Elise Formation.

Origin

The Archibald Formation was deposited in a eugeosynclinal environment. In Salmo and Bonnington map areas debris was deposited in what was probably a rapidly subsiding trough in a tropical or semitropical ocean abounding in ammonites, with, locally, some pelecypods, corals, gastropods and belemnites. The source of the sediments was probably a volcanic chain to the west. Conglomerate is rare and coarse conglomerate lacking, and the sediments are for the most part fine grained; therefore the source area was either low lying or distant. Because Archibald-like sediments form only a minor part of the Sinemurian section in the vicinity of Rossland and lavas are very abundant, it is speculated that the island chain lay not far from that locality. Deposition took place with astonishing rapidity, for on the west side of Archibald Creek, the stratigraphic range of Sinemurian fossils is apparently at least 900 m (Little, 1962, p. 2).

Age and correlation

In Rossland – Trail map area fossils of Sinemurian age were identified by Frebold (1959, p. 4; and unpublished internal report, 1961) from two localities in the Archibald Formation.

Locality F4

East side of Beaver Creek at elevation 825 m (2700 ft) about 3 km north of Fruitvale

Arnioceras sp. indet.

Age: Sinemurian

Locality F5 GSC loc. 45106

West side of Beaver Creek at elevation 750 m (2500 ft) southwest of Fruitvale and just south of Bath Creek

Arniotites sp.

Age: Sinemurian

In Salmo map area to the east, numerous collections of Sinemurian fossils were made from the Archibald Formation (Frebold and Little, 1962), and one that yielded a **Gyrophioceras?** sp. indet., indicating that Hettangian beds may also be present there. In Rossland – Trail map area there is nothing to suggest that the Archibald Formation is anything other than Sinemurian in age.

The Archibald Formation is correlated with the upper part of the unfossiliferous(?) Ymir Group (Frebold and Little, 1962, p. 5) on the basis of similar lithology and stratigraphic position beneath the Elise Formation. The Ymir Group in turn has been correlated, in part at least, with the Slocan Group (Little, 1960, p. 59) in the lower part of which Upper Triassic conodonts have been identified (P.B. Read, pers. comm., quoted in Little, in press).

East of the Kootenay Arc no Sinemurian sediments occur until the Fernie coal basin is encountered, where miogeosynclinal beds of the relatively thin Fernie Group are exposed. Sinemurian fossils were first described there by Warren (1931, p. 105-111). Sinemurian beds are widely distributed throughout the Fernie Group (Frebold, 1957, p. 7-9), which extends throughout much of the eastern Cordillera and into the Interior Plains.

To the west, close correlation with eugeosynclinal deposits is possible where Sinemurian fossils have been identified. These formations are unnamed Lower Jurassic strata of Tyaughton and Taseko Lakes areas, Harbledown Formation of Parson Bay area, and possibly the Bonanza Group of Vancouver Island, and Cultus Formation and possibly Ladner Formation of Hope map area (Monger, 1970, p. 13, 15). In Queen Charlotte Islands, the upper part of the Kunga Formation is Sinemurian (Brown, 1968, p. 61). In northwestern British Columbia, the Hazelton Group as recently redefined (Tipper and Richards, 1976, p. 9-31) is in part Sinemurian, as is the Laberge Group of the Yukon Plateau.

Elise Formation

The Elise Formation was named by Little (1950, p. 25) because it is well exposed on the western slopes of Elise Mountain in the Ymir map area, where, as in the Bonnington and Salmo areas, it consists almost entirely of volcanic rocks and related intrusions. The name was retained by McAllister (1951) and Mulligan (1952), but the unit was temporarily renamed the Rossland Formation (Little, 1960) before being reinstated as the Elise (Frebold and Little, 1962; Little, 1962, 1963). The Elise Formation has been traced from the type locality into the Rossland – Trail map area.

Distribution and thickness

The Elise Formation underlies much of the eastern part of the map area from the Bonnington Pluton south to the south slope of Blizzard Mountain and the lower reaches of Pend-d'Oreille River, extending from the eastern edge of the map area west to the Champion Lake Fault and the Trail Pluton. West of Columbia River it extends from the Trail Pluton south to the International Boundary except where interrupted by bodies of Rossland Monzonite, the Nelson, Sheppard, and Coryell intrusions, and minor Carboniferous(?) sediments and Marron lavas. This broad belt of Elise Formation extends to the southwest corner of the map area. Lavas and minor sediments of the Elise also extend northward from Rossland to the ridges south of Hanna Creek and from the Trail Pluton west to the eastern slopes of the mountains between O.K. Mountain and Mount Kirkup. Somewhat metamorphosed lavas believed to be Elise form two small, and two larger roof pendants in the Coryell Batholith in Lamb Creek Valley.

No accurate measurement of the thickness of the Elise Formation is possible because attitudes are not sufficiently numerous, and there may be hidden faults. Estimates can be made, however. In Ymir and Bonnington map areas, the maximum thicknesses were estimated to be 2750 and 2600 m, respectively (Little, 1960, p. 64). In Salmo map area a figure of slightly more than 3000 m was obtained (Frebold and Little, 1971, p. 7). In Rossland – Trail map area as much as 2450 m of lavas with minor sediments may be present north of Montrose. Northwest of Parks the maximum thickness is estimated to be perhaps 2150 m of which nearly half is sediments. On Ivanhoe Ridge the Elise may be of the order of 3000 m thick. Elsewhere, structural data are too sparse to make meaningful estimates of thicknesses.

Lithology

The lithology of the Elise Formation in Rossland – Trail map area is predominantly volcanic. These rocks consist mainly of flow breccia, massive lava, agglomerate, volcanic breccia, tuff, and related intrusive rocks, most of which are sill-like. The most distinctive rock is a flow breccia and/or agglomerate that contains ellipsoidal fragments of a limestone that is sufficiently fossiliferous to show that it comprises xenoliths of Mount Roberts limestone that have been caught up during volcanic extrusion. This rock type is widespread and wherever the base of the Elise is known, it represents the basal part of the formation. Thin sections of this rock show the matrix, in some places at least, to be tuffaceous, consisting of andesine (An_{38} to An_{43}), quartz, orthoclase, hornblende, and sphene in a fine grained matte of biotite, quartz, feldspar, and hornblende. The coarser crystals are for the most part anhedral. Fyles (1971) stated that in the vicinity of Rossland he could find no flow breccias or agglomerates. He contended that the latter are really volcanic conglomerates, and, presumably, that the former are volcanic breccias.

The flow breccias comprise feldspar porphyries and augite or hornblende porphyries with round or elongate clasts in a groundmass of similar composition. Massive lava flows are also common and are mostly dark green porphyritic aphanites. They are classified as andesites and basalts. The plagioclase is andesine or labradorite, which form the phenocrysts, and is in most thin sections rather saussuritized. Prophylitization of the basic lavas is also common. K-feldspar is probably present in the aphanitic groundmass. Augite, somewhat uralitized, and biotite are common constituents, but hornblende is present in some flows. Epidotization is widespread throughout the Elise lavas.

Volcanic breccias are not abundant but bedded tuffs are common. The latter are usually thin, from 15 cm to perhaps 30 m in thickness. Graded bedding is common in such strata.

Intrusive rocks related to the Elise lavas consist almost entirely of augite porphyries which are mostly peneconcordant with the flows, and are probably sill-like apophyses of feeders to the later flows. They are widespread. The largest such body was mapped by Young (Drysdale, 1915a, p. 202-208) and his description is typical of these intrusions. "The augite porphyrite......is a very dark greyish or greenish black colour and is studded with numerous stout prisms of greenish black pyroxene and hornblende..... [which] are very noticeable and often reach a length of one-quarter of an inch (6 mm), but more commonly are less than half this size....." In thin sections, "the rock is seen to be composed phenocrysts of augite, hornblende and plagioclase......in a fine ground chiefly of plagioclase and hornblende."

Two chemical analyses of Elise volcanic rocks, both by M.F. Connor, have been published. Three others, published by Daly, are now known not to be Elise.

Analyses of Elise igneous rocks

	A	B
SiO_2	50.89	52.17
Al_2O_3	17.00	16.59
Fe_2O_3	0.97	8.32
FeO	7.60	not det.
CaO	9.82	8.25
MgO	5.41	3.87
Na_2O	3.35	3.91
K_2O	1.31	4.00
H_2O+	1.14	1.17
H_2O-	0.06	0.13
TiO_2	0.80	0.80
P_2O_5	0.19	0.24
MnO	0.14	0.11
CO_2	0.28	0.56
S	0.43	1.37
SrO	not det.	0.05
BaO	not det.	0.15
Total	99.39	101.69

A. Augite porphyry (unaltered). 4th level of the War Eagle mine (Drysdale, 1915a, p. 205).

B. Hornblende-augite latite (trachyandesite). Ridge 1.2 km northeast of Columbia Gardens, elevation 3100 feet (Daly, 1912, p. 329).

Sedimentary components of the Elise Formation, other than thin beds of tuff, comprise dark grey to black, hard, brittle, laminated siltstones, somewhat tuffaceous, that closely resemble beds of the Archibald Formation. These are intercalated with the volcanic members of the Elise. Individual intercalations are thickest in the eastern part of the map area where one appears to be about 900 m thick. That south and southeast of Champion Lakes, formerly mapped as Archibald Formation (Little, 1962) may be thicker, but the structure there is complex.

Internal structural relations

Northwest of lower Beaver Creek the structure of the Elise Formation seems to be homoclinal, with lavas and interbedded tuffs dipping and facing steeply northwest. It forms a panel in which it, and the Archibald Formation, have apparently been thrust southwestward. To the north, across Fruitvale Creek the Elise lavas appear to be continuous, but, as the Hall Formation at Fruitvale is abruptly cut off, there must be an undetected east-west fault that forms the contact between that panel and another on the north.

North of the Kelly Creek Fault a panel of Elise Formation has apparently been thrust eastward over Hall Formation in the adjoining Salmo map area where the latter is of Bajocian or later age. The northern part of this panel was subsequently removed by movement on the Query Creek Fault.

West of Beaver Creek and north of Fruitvale Creek, the structure of the Elise Formation appears to be basin-like, the centre of the basin being near the southeast corner of Champion Lakes Park. Dips up to 80° are recorded, however, and bedding top determinations are few, but in none of these is the bedding overturned.

On Blizzard Mountain and in the surrounding area, the structural trend is mainly northeast, and a large number of bedding top determinations were made, all of them showing the beds facing northwest and vertical to overturned. Such a fantastic thickness is indicated that it is concluded that much undetected folding and/or faulting must be present.

West of Columbia River, north of the International Boundary the structural trend is west as far west as the Violin Lake Fault, but the internal structure is vague. Beyond the fault the trend is southwesterly. On Baldy Mountain bedding tops are southeast, whereas on Lake Mountain they are all northwest. This suggests the presence of a large syncline that trends southwesterly with the southeast limb vertical and the northwest limb overturned. West of this locality, in the valley of Little Sheep Creek and especially on Ivanhoe Ridge, the structure appears to be homoclinal, and to face northwest at moderate to steep dips. In the southwest corner of the map area, south of the Coryell Batholith, bedding attitudes are erratic and the structure is evidently complex.

West of Red Mountain, basal Elise limestone-clast bearing agglomerates, or conglomerates(?) trend north and dip steeply west. These have been thrust, together with underlying Mount Roberts Formation, eastward onto Elise lavas which also trend north. East and northeast of Red Mountain the structure of the Elise Formation is rather vague. The structure of the Elise lavas in the valley of Lamb Creek in the northwestern part of the area is unknown.

External structural relations

The Elise Formation rests with apparent conformity upon the Sinemurian and older(?) Archibald Formation except near Paterson where it rests unconformably upon different members of the Pennsylvanian(?) Mount Roberts Formation. This unconformity has been described in the section dealing with the latter formation.

Age and correlation

The Elise Formation is partly younger, and partly contemporaneous with the Archibald Formation (Fig. 3), which is of Sinemurian and(?) Hettangian age. Several fossil collections of Sinemurian, or possibly Sinemurian, age have been made from the Elise Formation in Rossland – Trail map area and were identified by Frebold. The Waneta locality was discovered by him.

Locality F6 GSC loc. 45420

1.5 km due east of Fruitvale, elevation 870 m (2850 ft)

Arniotites sp. indet.

Age: Sinemurian

Locality F7 GSC loc. 45104

West side of Beaver Creek, 3.25 km north-northeast of Fruitvale, elevation 750 m (2500 ft)

Poorly preserved ammonites, possibly **Arniotites**

Age: Possibly Sinemurian

Locality F8 GSC loc. 45110

At switchback on logging road on the south side of Marsh Creek, west 2.25 km of Beaver Creek, elevation 870 m (2850 ft)

Arniotites sp.

Age: Sinemurian

Locality F9 GSC loc. 45418

At north end of Waneta dam

Arniotites sp.

Age: Sinemurian

Locality F10 GSC loc. 51062

On nose between Grouse Ridge and Malde Creek, 1.85 km due north of International Boundary, elevation 1145 m (3750 ft)

Arnioceras sp.

Age: Sinemurian

Locality F11 GSC loc. 51605

On east side of Malde Creek, 1.85 km due north of International Boundary, elevation 945 m (3100 ft)

Poorly preserved pelecypod (deformed Pectonid ?)

Age: Probably Sinemurian

Locality F12 GSC loc. 51064

On Ivanhoe Ridge, 2.1 km northwest of the mouth of Sophia Creek

Small ammonites, possibly Arnioceratids

Age: Probably Sinemurian

The age of the Elise Formation is Sinemurian. Because a Hettangian(?) age is indicated for some beds in the Archibald Formation (Frebold and Little, 1962, p. 14, 15). It is also possible the basal part of the Elise Formation may be pre-Jurassic. In marine beds near the top of the type Elise Formation in Ymir map area fossils of Lower Toarcian age occur (op. cit., p. 24; Frebold, 1959, p. 4). No Toarcian fossils have been found in the Elise Formation in Rossland – Trail map area, but some occur in the overlying Hall Formation and the top of the Elise may be Lower Toarcian there as well.

Volcanic rocks of Lower Jurassic age occur in map unit 16 of Bonaparte Lake map area (Campbell and Tipper, 1971, p. 44), the Bonanza Group of Vancouver Island and the Hazelton Group of northwestern British Columbia. Correlations with sedimentary units of Sinemurian and Toarcian age are given in the sections on the Archibald and Hall formations, respectively.

Hall Formation

The Hall Formation was named the Hall 'series' and described by Drysdale (1917, p. 27-29) from its type locality on Hall Creek in Bonnington map area. It is renamed Hall Group by Little (1950, p. 26) and has subsequently been referred to as the Hall Formation by Mulligan (1952) and all subsequent writers. The Hall Formation was included in the Rossland Group by Drysdale.

Distribution and thickness

The Hall Formation in Rossland – Trail map area has been identified at only two localities. It occupies a triangular area, largely drift-covered, in the valley of lower Beaver Creek, extending southwesterly from Fruitvale for about 5 km. The other locality is 4.5 km west of Mount Plewman, where a small area on a spur is underlain by shales of the Hall Formation.

It is impossible to estimate the thickness of the Hall Formation near Fruitvale because outcrops are not abundant and bedding top determinations are insufficient. However, it is probable that more than 300 m of beds are present. On the spur west of Mount Plewman only a single outcrop was seen, and the thickness there cannot be more than 30 m.

Lithology

Sediments of the Hall Formation can usually be distinguished from those of the Archibald and Elise formations by their relative softness and fissility. They comprise for the most part black, carbonaceous shales and buff to brown argillaceous sandstone. Some siltstone and minor greywacke are also present, but conglomerates are fairly abundant in the type locality (Mulligan, 1952, p. 6-8; Little, 1960, p. 69), although not present in Rossland – Trail map area. Flows or sills were noted in a few places. On the spur west of Mount Plewman, only fissile black shale was seen.

Internal structural relations

Exposures of Hall Formation in Rossland – Trail map area are too scattered to assess the structure. In Beaver Creek Valley, of the few bedding top determinations that could be made, none were overturned although dips up to 70° were recorded.

External structural relations

The base of the Hall Formation lies near Fruitvale but there the actual contact has not been seen, due to poor rock exposures. The Hall Formation appears to rest upon lavas of the Elise Formation, a relationship that has been established in Bonnington and Salmo map areas. In Salmo map area the contact appears to be conformable (Little, 1960, p. 70), but in Bonnington map area, Mulligan (1952, p. 6) stated that there is locally a suggestion of erosional unconformity between the two formations.

On the west side of lower Beaver Creek the Hall Formation is in contact with the Archibald Formation which, together with the Elise Formation which rests upon it, has apparently been thrust over the Hall.

On the spur west of Mount Plewman, the Hall Formation is either part of a roof pendant within the Coryell Batholith or it is in faulted relationship with the Coryell. In view of the low grade metamorphism of the soft shales which contain identifiable ammonites, the contact is probably a fault, which forms the western contact with syenite. The shales are overlain on the east by arkose of the Kettle River Formation which is in turn succeeded by Marron lava.

Origin

Mulligan (1952, p. 7) pointed out that the decrease in conglomerate roundstones and the increase in quartz content in the sediments in a southward direction from the type area suggest a change from littoral to offshore conditions. This holds true in Rossland – Trail map area where the sediments are for the most part pelitic. The source of the sediments must be to the north or northeast.

Age and correlation

The age of the Hall Formation has been established in Salmo and Bonnington map areas as lower Toarcian to middle Bajocian, but one fossil collection is younger than middle Bajocian (Frebold and Little, 1962, p. 20-24). Lower Toarcian fossils were collected in beds a short distance below the top of the Elise Formation (Frebold, 1959, p. 4). The lower age limit of the Hall Formation is thus established as late Lower Jurassic, and the upper age limit is probably Middle Jurassic but may be later.

Within Rossland – Trail map area only fossils of Toarcian age have been found; these were identified by H. Frebold.

Locality F13 GSC loc. 45111

On Bath Creek road 1.3 km southwest of Fruitvale, elevation 720 m (2400 ft)

Dactylioceras sp. indet.
Pelecypods (undescribed)

Age: Toarcian

Locality F13 GSC loc. 45112

On Bath Creek road, 30 m southwest of GSC loc. 45111

Pelecypods (undescribed)

Age: Toarcian

Locality F14 GSC loc. 51063

On spur 4.5 km west of Mount Plewman, elevation 1500 m (5000 ft)

Harpoceratids, poorly preserved. Gen. et sp. indet.

Age: Toarcian

The Hall Formation may be correlated with the miogeosynclinal sediments of the Fernie Group which lies east of the Rocky Mountain Trench. Beds of Toarcian and Bajocian age have been identified in the Fernie (Frebold, 1957, p. 9-18; 1963, p. 27) as well as post-Bajocian strata.

To the west, sediments of Toarcian and Bajocian age are eugiosynclinal. In Manning Park (Coates, 1974, p. 12-23), the Ladner Group, which comprises volcanic sandstone, argillite conglomerate, tuff, breccia, and lavas, has yielded a varied fauna of Toarcian and Bajocian age. In the Hope map area the upper part of the Cultus Formation is in part Bajocian (Monger, 1970, p. 12), so that Toarcian beds may also be present. On Vancouver Island in the upper part of the Bonanza Group, Toarcian beds have been identified, and Bajocian may be present. On Queen Charlotte Islands, the Maude Formation is Pliensbachian and Toarcian (Brown, 1968, p. 65).

In western British Columbia Bajocian sediments occur in an unnamed map unit in Mount Waddington area (Tipper, 1969, p. 29, 30). Farther north, the extensive Hazelton Group contains Pliensbachian to Callovian beds (Tipper and Richards, 1976). The Laberge Group in the Yukon Plateau is in part Toarcian.

Sophie Mountain Formation

Conglomerate of this formation was first encountered on Grouse Ridge, 1.6 to 3.2 km south-southwest of the summit of Lake Mountain, by McConnell (1897b) who did not describe it but showed it on his Trail Creek map. McConnell and Brock (1904) mapped more extensive exposures of the formation on Mount Sophia, formerly known as Sophie Mountain. In the descriptive notes on their "West Kootenay sheet", they described it as red weathering conglomerate and correlated it with the conglomerates of Franklin Camp to the northwest, now known to be Kettle River Formation. Brock (1903a, p. 67A) enlarged a little upon this description of the map unit.

Daly (1912, p. 350-352) found small outliers of the formation 8 and 16 km west of Mount Sophia at Boundary monuments 172 and 169, and described the rocks in some detail. The formation was named "Sophie Mountain conglomerate" by Bruce (1917, p. 223, 224). He also described the formation, but it is not clear whether he observed the rocks or quoted other authors, for his work was apparently confined to the vicinity of the Rossland Camp. Little (1960, p. 73) referred to the map unit as the Sophie Mountain Formation.

Distribution and thickness

The largest area underlain by the Sophie Mountain Formation is that capping Mount Sophie. This area is 2.23 km^2 north of the International Boundary, and more than 5 km^2 south of the Boundary (Yates, 1971). Another small area north of the International Boundary west of that on Mount Sophia and separated from it by Coryell Intrusions is contiguous with the Sophie Mountain Formation south of the International Boundary.

On Grouse Ridge, the area underlain by Sophie Mountain conglomerate is 1.14 km^2. Only in the vicinity of Boundary monument 172 in the southwest corner of the map area was more Sophie Mountain Formation encountered. At the monument, and for 200 m westward, only Coryell intrusions are exposed. Beyond that point, conglomerate outcrops for about 100 m. To the north for about 300 m the conglomerate forms isolated outcrops between which are outcrops of Coryell intrusions that have invaded the Sophie Mountain Formation.

To the west, the formation has been identified only at Boundary monument 169, some 8 km distant.

In the Northport quadrangle, Yates (1971) mapped an area about 3 km wide and extending southward 2 km in which outcrops of Sophie Mountain Formation contiguous with those in the type locality are abundant. About 5 km to the east, on the east side of Little Sheep Creek Valley, an area of about 2.5 km^2 is underlain by the formation which extends to the International Boundary, but not north of it. A third extensive area containing outcrops of Sophie Mountain Formation is south of the southwest part of the Rossland – Trail map area, and is about 3 km wide and extends about 1.5 km south of the border. The western part adjoins the conglomerate in Rossland – Trail map area. Yates' map, however, shows the formation extending along the International Boundary from 1.1 km to 2.25 km east of monument 172. One of the writer's assistants, in 1962, interpreted these rocks as agglomerate, augite porphyry, and a flow of the Rossland Group; however, in one outcrop white chert fragments appeared in the agglomerate, which has rarely been reported elsewhere in the Rossland. It is possible that these rocks are indeed Sophie Mountain Formation, but if so they cannot extend more than a short distance north of the International Boundary. Sophie Mountain Formation was mapped by Yates (1971) within five smaller areas that extend as much as 8 km south of the last two described. No Sophie Mountain rocks were identified by Bowman (1950) in the Orient quadrangle to the west.

Except for the tiny outlier at Boundary monument 169, exposures of Sophie Mountain Formation are confined to an area that is 17.5 km east to west, and 13 km north to south, but was probably more extensive in Cretaceous time.

Bedding attitudes can be obtained only from interbeds of grit, siltstone, and argillite, and such interbeds are few in number. In the type locality six attitudes were measured; the dips range from 5° to 75° and the strikes are erratic. Such interbeds may have had a moderate initial dip. Only at one place could bedding tops be determined, and these beds dip 75° east. It can only be stated that probably the maximum thickness is more than 100 m. On Grouse Ridge dips of bedding range from 20° to vertical in three determinations. The structure there is also complex. The formation seems to form a thin covering on the ridge. The thickness there, and near monument 172, is indeterminate.

Lithology

In the type area on Mount Sophia, the Sophie Mountain Formation consists almost entirely of conglomerate; thin intercalations of arenaceous argillite and grit are not common. The roundstones in the conglomerate range in size from 2.5 to 5 cm in some places, to more than 60 cm in the most westerly part. Most are well rounded, and consist predominantly of purplish red quartzite, but a few of black chert, argillite, vein quartz, greenstone and fine grained granite were noted. In some places, white quartz roundstones are almost as abundant as quartzite, and are more conspicuous. Brock (1903a, p. 67A) observed also roundstones of serpentine and older conglomerate, and a few of sandstone and jasper. Bruce (1917, p. 223) added that pebbles of gneiss and limestone are present, but whether this was observed on Grouse Ridge, or Mount Sophia, or both, was not specified.

On Grouse Ridge, conglomerate is also the predominant facies. It is poorly sorted and the roundstones range in size from 6 mm to about 20 cm, but on the eastern side, some 60 to 90 cm in diameter were noted. The degree of rounding ranges from almost spherical to somewhat angular, especially in the largest masses. The roundstones are predominantly of sedimentary origin, purplish red to brownish red quartzite being the most common. Some are of grey quartzite or of arkosic sandstone. Chert, vein quartz, and argillite were also noted. A few interbeds of black arenaceous argillite and grit are present. The matrix of the conglomerate is arenaceous.

In the southwest corner of the map area, near Boundary monument 172 roundstones up to more than 30 cm in diameter were recorded, but some finer facies with pebbles up to only a little more than 2.5 cm were seen. The roundstones consist mostly of quartzite, white quartz, granitic rocks, and porphyritic hypabassal rocks; a few of greywacke, grey argillaceous siltstone, and chert are present. One roundstone resembles Nelson granodiorite. A thin section showed it to be composed of 33.0% plagioclase, zoned, An_{20} to An_{40}, 21.5% quartz, 21.25% orthoclase, 16.0% chlorite, 6.25% biotite, 0.5% carbonate, 1.5% opaque minerals, and minor apatite, zircon, sericite, and rutile. There can be little doubt that this is Nelson granodiorite, which therefore was unroofed by Late Cretaceous time. Daly (1912, p. 352) also found pebbles of equigranular biotite granite. The matrix of the conglomerate is arenaceous. A few interbeds of grit were encountered.

Yates (1971) described the Sophie Mountain Formation in the Northport quadrangle as coarse conglomerate with boulders as large as 1.2 m long, with quartz cement. The large clasts in some areas are predominantly coarse grained quartzite; elsewhere they are greenstone or quartz-feldspar porphyries.

Internal structural relations

On Mount Sophia near Boundary monument 174, according to Daly (1912, p. 351), the conglomerate dips 31° northwest; however, in 1949, dips of 10° to 20° northwest were recorded in that vicinity, but on the east side the dip is 35° west, and near the most westerly exposures the beds strike north 20° east and dip 70° southwest. Newer determinations of dips between monument 174 and the western limits were 25° south-southwest and 70° east, the latter beds are with tops to the east. With such scanty data little can be said of the structure except that it appears to be complex. To the south, Yates has recorded three attitudes; all are erratic as to both strike and dip.

On Grouse Ridge, Daly (1912, p. 350) stated that the conglomerate dips northeast at an average angle of 20°. Attitudes recorded by the writer and his assistants were 60° northwest, 20° northeast, 25° south and vertical, with a north strike. There, also, the structure is apparently not simple. Near monument 172, Daly found the conglomerate striking north 30° west and dipping 28° northeast. More recent measurements of dips are 65° northeast and 75° east-northeast.

External structural relations

The basal contact of the Sophie Mountain Formation has not been seen, but there can be no doubt that the relationship with Rossland and older rocks is unconformable. Other contacts with dykes and larger bodies of Coryell and Sheppard rocks are intrusive. The top of the formation has been removed by erosion, so that the relationship to younger sedimentary and volcanic rocks is unknown.

Origin

Daly (1912, p. 350) suggested that the deposits represent river gravels, and that the roundstones were derived from Paleozoic and Precambrian terranes of the Selkirk Mountains, some 40 km to the east. The purplish red quartzites so abundant in the roundstones in the more easterly areas have not been reported to outcrop anywhere within 160 km. In view of the large size of some of the roundstones, they cannot have been transported more than a short distance. The source beds must either have been removed by erosion, buried under younger rocks, or replaced by granitic intrusions; or else the source area has been greatly transported tectonically since the Cretaceous.

Yates' (1971) observation of the variation of composition of roundstones from place to place suggests the sources were local. It seems probable that the conglomerate, with minor grit and sandy argillite beds was deposited in a lake basin by streams of high gradient from surrounding mountains.

Age and correlation

Fossil leaves that were collected by Daly (1912, p. 351) near Boundary monument 174 on Mount Sophia were assigned a Tertiary, possibly Miocene age by Penhallow. In 1949, the writer and his assistants made two collections, 90 m north 20° east of monument 174, and an additional 200 m north of that point, respectively. W.A. Bell of the Geological Survey concluded the age is probably Upper Cretaceous, although a Tertiary age was not ruled out (Little, 1960, p. 74).

In 1962 a new locality was discovered between the other two, and large slabs of material were collected. The collection was examined in March 1964 by Dr. Bell, whose report follows:

Locality F15 GSC loc. No. 6430

Mount Sophia, 220 m N 9° E of International Boundary monument No. 174, at elevation about 1585 m (5200 ft)

Florule: **Menispermites** sp. cf. **heteroides** Hollick
Castaliites sp. cf. **cordatus** Hollick
Rhamnites eminens? (Dawson) Bell
Zizyphus cf. **cretaceus** (Dawson) Bell
Dicotylophyllum cf. **Ficus fontainii** Berry
Dicotylophyllum sp.

Remarks: Angiosperms are represented by many parts of leaves, whereas ferns, cycadophytes, and conifers are lacking. The fragmentary nature as well as their preservation preclude reliable generic and specific identifications, because marginal features, apices and bases of leaves, and much of the venation pattern, so necessary for taxonomic identification are missing. None the less, the aggregate assemblage of forms is considered by the writer to be Upper Cretaceous, and falling most probably in the time interval Cenomanian-Campanian, with some preference to the latter.

The nearest continental beds of Cretaceous age are found in Princeton map area (Rice, 1947, p. 19-25) where the Pasayten, Spence Bridge, and Kingsvale groups have yielded fossil plants of Aptian (late Lower Cretaceous) age. These groups are not only probably older than the Sophie Mountain Formation, but differ completely in that they are predominantly volcanic. Farther west, on Vancouver Island, part of the Nanaimo Group is of similar age to the Sophie Mountain Formation (Bell, 1957, p. 9-13). There, however, the environment is completely different, for much of the group is marine.

Similarly, to the east the nearest nonmarine beds of Upper Cretaceous age are found only east of the Rocky Mountains, and again in a different environment, where they are not rudites, but pelites and arenites, and are underlain by, and partly interbedded with, marine sediments.

Kettle River Formation

The Kettle River Formation was named by Daly (1912, p. 394-396) from Kettle River, along the valley of which it is exposed intermittently, between the villages of Rock Creek and Midway, as well as elsewhere. There it was most recently studied by Monger (1968, p.4-11) who described it as consisting of discontinuous basal conglomerate succeeded by feldspathic and lithic volcanic sandstone and siltstone, acidic pyroclastic rock, acidic lava, shale, and relatively minor conglomerate. The formation rests unconformably on pre-Tertiary rocks and is overlain by the volcanic Marron Formation, with which it is locally gradational, lavas and flow breccias interfingering with tuffaceous sediments.

Distribution and thickness

Sedimentary rocks that are correlated with the Kettle River Formation were encountered at two localities in the Rossland – Trail map area, one north and the other northwest of Old Glory Mountain. The larger of these remnants is 5.25 km northwest of the summit of Mount Plewman, at an elevation of about 1615 to 1645 m, and is exposed across a slope distance of some 120 m. The attitude of the beds could not be determined. The belt of arkose extends 1.25 km north to the south side of the valley of a small tributary of Lamb Creek, elevation about 1430 to 1460 m, where it is exposed across a slope distance of roughly 275 m. There, also, the bedding planes are indistinct.

Because the structure is unknown, the thickness of the beds could not be determined; the maximum thickness exposed may be a hundred metres and is probably at least 30 m.

The small remnant lies at an elevation of 1500 m on a ridge 1.6 km west of the south end of the larger one an outcrop of hard, tough arkose is exposed, and the minimum thickness (i.e. width of outcrop) is not recorded.

Lithology

At the south end of the larger remnant the sandstone has an arkosic aspect. Quartz grains were estimated to comprise 5 per cent of the rock, the remainder being white feldspar. A few fragments of a syenitic rock somewhat resembling certain phases of Coryell Intrusions were noted, and one or two of mafic material. At the northern end the beds are better exposed, and are composed of massive, well indurated sandstone of uniform grain size. Quartz grains are readily visible. Pebbles are few in number and are widely scattered. Their composition was not noted.

In the smaller remnant the arkose has been baked to a high degree of induration by the underlying Coryell Batholith, a dyke from which cuts the beds. A thin section shows that it contains abundant plagioclase and quartz, some chert, some microcline, and a little biotite. Some of the quartz and feldspar seem to have been derived by erosion from a granitic source. Some of the quartz grains are embayed, which N.B. Church (pers. comm.) states is common in the Kettle River arkoses, even where no rhyolite is near.

Internal and external structural relations

In the larger remnant, no bedding planes could be seen, but the trend of the formation is north. The arkose rests, no doubt unconformably, upon Elise lavas at the north end, but at the south end, the base is in intrusive contact with the Coryell Batholith. The contact with the overlying Marron agglomerates and lavas was not seen.

In the smaller remnant to the west, the base is not exposed, but to the west the arkose rests, also no doubt unconformably, upon dark grey, slaty, fossiliferous sediments of the Hall Formation. On the east side, the arkose is overlain by laminated tuff and flows of the Marron Formation which dip 60° and face easterly. Rocks of these formations are surrounded by porphyritic and nonporphyritic syenitic phases of the Coryell Batholith.

Origin

The lithic volcanic sandstones of the Kettle River Formation was widespread, but intermittently exposed, throughout a large area of south-central British Columbia and northeastern Washington. The volcanic sources proposed by Pearson and Obradovich (1977, p. 14, 15) are the Shingle Creek porphyry and similar porphyries near Beaverdell, and dykes and intrusive bodies of unknown shape south of Republic. Other erosional ingredients of the strata have been derived from local sources, but in Rossland – Trail map area these appear to be minor. Kettle River sediments were deposited entirely in a continental environment, on a peneplain that has since been disrupted by largely normal faulting.

Age and correlation

No fossils have been seen in the beds in Rossland – Trail map area that have been correlated with the Kettle River Formation. Correlation is based upon lithology and the apparently basal relationship with volcanic rocks that are lithologically comparable with the Marron Formation. The age of the Kettle River Formation has been established elsewhere as Middle Eocene (Monger, 1968, p. 11; Little, in press; Pearson and Obradovich, 1977, p. 13) both on palynological and K-Ar isotope age dating.

Precise correlations of the Kettle River Formation with other continental assemblages are not possible. However, close analogies both in lithology and age are probable. In British Columbia, the Coldwater 'Group' (Dawson, 1895, p. 68B-71B; Cockfield, 1948, p. 31-34; Duffell and McTaggart, 1952, p. 64-66), unnamed Eocene rocks of Siwhe Creek (Duffell and McTaggart, 1952, p. 61-64), Springbrook Formation (Bostock, H.S., 1940, 1941a; 1941b; Little, 1961; Bostock, H.H., 1966, p. 7-12; Church, 1973, p. 27-32, and the Curry Creek 'Series' (Reinecke, 1915, p. 53-56) are correlated mainly on lithology and stratigraphic position, but partly upon paleobotany. Correlation with at least part of the Princeton Group (Rice, 1947, p. 27-31) is certain because, in 1935 Russell (1935) identified a mammal tooth as **Trogosus minor**, of Middle Eocene age.

The Kettle River Formation is also correlated with considerable precision with the O'Brien Creek Formation of Washington (Muessig, 1962; 1967, p. 45-50; Parker and Calkins, 1964, p. 46-48; Pearson, 1967), with which it is locally contiguous. Pearson and Obradovich (1977, p. 6-11) have correlated the O'Brien Creek with the basal member of the First Thought Formation of the Orient quadrangle (Bowman, 1950), and approximately with other Early Tertiary sedimentary rocks in northeastern Washington, extending from Pend Oreille valley to Okanogan Valley.

Only four K-Ar radiometric age for the Kettle River and O'Brien Creek formations have been published. The first, by Mathews (1964, p. 4) on biotite from dacitic tuff collected about 64 km north of Rock Creek is 46 ± 2 Ma, corrected to 47 ± 2 Ma. Two others, from the Williams Lake area some 32 km south of Rossland, also on biotite from tuff, are 41.4 ± 1.2, and 40.2 ± 1.3 (42.5 ± 1.2 and 41.3 ± 1.3), and are obviously too young (Yates and Engels, 1968, p. D246). That on biotite from bedded tuff in the Pend Oreille valley of Washington, perhaps 60 km southeast of Trail yielded an age of 53.1 ± 1.5 Ma (54.3 ± 1.5) which is reasonable in view of the ages, 50 to 51 Ma (which, when corrected are 51 to 52 Ma) obtained on lavas of the overlying Sanpoil Volcanics (Pearson and Obradovich, 1977, p. 66).

Marron Formation

The Marron Formation was named by Bostock (1940; 1941a, b) from Marron River in Okanagan Falls map area, where it was subsequently studied with great care by Church (1973). Church subdivided it into five members, and removed from Bostock's Marron rhyodacitic and rhyolitic rocks that he found are unconformably overlying the Marron as now defined, and these he named the Marama Formation.

In Greenwood map area, Monger (1968) showed that the stratigraphy of Daly's (1912, p. 398-400, p. 411-420) Midway Volcanic Group is remarkably similar to that of the Marron Formation. He renamed those rocks Marron; although the name Midway has priority over Marron, the former had been used prior to Daly's usage, and so had to be abandoned.

In Rossland – Trail map area, it was stated in marginal notes by McConnell and Brock (1904) that the "andesite masses of Old Glory and Record Mountains......are undoubtedly younger than augite-porphyrite and tuffs," but these rocks were shown as Rossland on their map. They were also mapped as Rossland by Daly (1912), Gilbert (1948), and Little (1960). Little (1963) subsequently recognized that the rocks on Old Glory Mountain and northward are Marron, but did not think that the rocks on Record Ridge, Mount Roberts, and O.K. Mountain were similar (Thorpe and Little, 1973). Fyles et al. (1973, p. 28) did, however, state they are closely similar and they felt that a K-Ar age determination on a sample confirmed the correlation. The sample could, however, have been updated by Coryell Intrusions. There can now be no doubt that most, if not all these volcanic rocks, are Marron.

Distribution and thickness

The Marron Formation in Rossland – Trail map area forms the upper part of Old Glory Mountain and a belt that extends from the peak of Old Glory northward for 5 km. Three small roof pendants were traversed 0.8 to 1.6 km west of the above belt, northwest of Old Glory Mountain, and another lies 0.8 km east of that peak. From the northern and eastern slopes of Mount Kirkup a second belt extends southward to the southern slope of O.K. Mountain, thence westward to Record Ridge and Record Mountain, interrupted only by a wide, dyke-like intrusion of Coryell syenite. This is the largest area in Rossland – Trail map area that is underlain by Marron Formation. A small mass of Marron rocks underlies the south end of Record Ridge.

On the ridge east of Goodeve Creek and south to southeast of Violin Lake, feldspar lath porphyry lavas and minor tuff were encountered on a traverse made by the writer in September, 1978. These are virtually identical to those of Record Ridge and so are classified as Marron Formation. Time did not permit the determination in the field of the extent of these rocks, but review of the field notes of 1961 allowed the writer to establish the probable boundaries, except on the east, where the contact with Rossland volcanics is vague. The total area that is underlain by Marron rocks is probably about 1.25 km^2.

No other localities where Marron Formation occurs are known within the map area, but some may exist where Marron has been confused with Rossland as has occurred in the past.

The thickest section of Marron Formation is probably that exposed on Mount Roberts and on its eastern slope. From Fyles' (1970) detailed mapping, and the few bedding attitudes obtained, a thickness of more than 900 m is indicated. Farther west, on the east side of Record Ridge, Fyles et al. (1973, p. 28) collected a sample of Marron lava that they estimated to be at least 600 m above the base of the lava pile. In the light of present information, no accurate figures for the thickness can be given. The base of the Marron is not everywhere exposed, nor has the top been seen, although the youngest member of the formation has been identified petrographically.

Lithology

Although equivalents of lavas in two of the members of the type Marron Formation, the Kitley Lake and Park Rill, are now recognized in Rossland – Trail map area, traverses by the writer and his assistants were too widely spaced to delimit the members there. In the parts mapped in detail by Fyles (1970) this should be possible, and in thin sections of his samples that he loaned me, and which were examined by Church, three samples each of Kitley Lake and Park Rill members were recognized. Elsewhere, beyond the detailed mapping of Fyles, the Marron would have to be retraversed, applying a knowledge of the Marron succession that did not exist in 1962 and earlier.

Church (1973, p. 26) summarized the stratigraphy of the Marron Formation in the White Lake Basin as follows:

Marron Formation	Thickness metres
Park Rill Member Mainly merocrystalline and glassy andesite lava	60-450
Nimpit Lake Member Mainly trachyte and trachyandesite lava	120-300
Kearns Lake Member Mainly pyroxene-rich vesicular basaltic andesite lava	0-120
Kitley Lake Member Mainly trachyte and trachyandesite lava	300
Yellow Lake Member Mainly anorthoclase lava, augite porphyry lavas (phonolites), and pyroclastic rocks	150-550

Equivalents of the Yellow Lake Member occur extensively in Greenwood map area, (Monger, 1968, p. 14-17) which lies between White Lake Basin and Rossland – Trail map area, where it was called Division 4A, the lower division. Lavas of this division extend only a short distance southward into the State of Washington where they are very limited in distribution. Equivalents of the Yellow Lake Member have not been seen in Rossland – Trail map area, and most probably are not present.

The Kitley Lake Member was recognized from specimens collected in 1962 and 1978 on a hill 0.8 km east of the peak of Old Glory Mountain, 75 m west of the forestry lookout, and on the old Cascade highway southeast of the peak of O.K. Mountain. According to Church (pers. comm., 1979) the latter two are typical lavas of the Kitley Lake Member. They are dark green aphanitic rocks with numerous small phenocrysts of white feldspar. Thin sections reveal that the phenocrysts are zoned plagioclase ranging in composition from An_{55} to An_{65}, biotite, and pseudomorphs of clinopyroxene in a cloudy, feldspathic matrix that is partly glass and contains plagioclase microlites. They could be classified as basalts, but as the matrix probably contains some K-feldspar, they are most likely clinopyroxene-biotite andesites. The other lava is buff with a pinkish cast, is coarser in grain size, and contains glomerophenocrysts 2 to 8 mm long of glassy feldspar and small phenocrysts of pyroxene, the clot porphyry of Church (1973, p. 98). In a thin section the phenocrysts were identified as sanidine and oligoclase. One oligoclase crystal is jacketed by sanidine, which Church informed me is characteristic of Kitley Lake trachyandesites. Clinopyroxene and biotite are the ferromagnesian minerals. The groundmass is composed of felted feldspar microlites with interstitial biotite and magnetite.

The four samples collected by Fyles that have the characteristics of Kitley Lake lavas are from the eastern slopes of Mount Roberts and O.K. Mountain and the eastern slope of Record Ridge, but the localities are not accurately described. These are clot prophyries which in two cases are so altered as to leave some doubt as to their correlation to the Kitley Lake Member. One is a biotite trachyte, two are biotite-pyroxene trachytes, and the last is a biotite-pyroxene trachyandesite.

Two other samples that may represent the Kitley Lake Member were collected in 1962 from an outcrop a short distance northwest of the summit of O.K. Mountain and on a nose a short distance southwest of the Snowdrop mine. The former is a pyroxene-plagioclase andesite that, aside from a little chloritization is quite fresh. The latter is a porphyritic clinopyroxene-biotite andesite, with a few phenocrysts of plagioclase and a number of plagioclase microlites, and also is little altered.

In summary, equivalents of the Kitley Lake Member occur near and probably at the base of the formation southwest of O.K. Mountain, and perhaps northwest of the summit, on the eastern slopes of O.K. Mountain and Mount Roberts, on the upper slopes on the east side of Record Ridge, and a short distance west of the summit of Old Glory Mountain. Some confirmation that at the last locality the lowest part of the Marron Formation is present is obtained from a sample of rhyolite collected nearby. This lava contains phenocrysts of sanidine in a fine grained matrix with sinuous flow layers. No glass is present, but that may be due to recrystallization during thermal metamorphism. Such rhyolite has been reported in a few places in the Kettle River Formation.

Equivalents of the Kearns Lake and Nimpit Lake members have not been identified. However, many of the aphanitic or highly altered lavas could be and probably are equivalent. These, for the most part, consist of dark green aphanitic feldspar-lath porphyries, but some altered varieties may be trachytes and trachyandesites. Their composition is usually in the andesitic to basaltic range and they are abundant on the south slope of O.K. Mountain, the summit of Mount Roberts, on Record Ridge, and southeast of Violin Lake. A few flows are amygdaloidal, the amygdales consisting mainly of calcite and quartz. One sample that was collected on the ridge northwest of Old Glory Mountain was thought in the field to be augite porphyry, but the supposed phenocrysts were seen under the microscope to be calcite, quartz and abundant green chlorite which was formed through thermal metamorphism by the underlying Coryell Batholith. Most of the lavas examined showed such thermal effects as chloritization and epidotization, but a few are quite fresh.

Tuff beds were encountered at several localities and probably occur throughout the Marron section. Those that were examined in thin sections are of andesitic composition and contain much magnetite and chloritized biotite or hornblende. Some agglomerate is present, mainly on and near Old Glory Mountain.

Lavas that closely resemble those of the Park Rill Member occur on the ridge 650 m south of the summit of O.K. Mountain, where in hand specimens they are seen to be dark green aphanitic rocks with numerous small phenocrysts of white feldspar. The phenocrysts are zoned andesine, and some clinopyroxene is present in a glassy matrix. Another, identified by means of a thin section loaned by J.T. Fyles is from the Delaware adit and is a pyroxene andesite with some glass present in the matrix.

Three other samples, also identified in thin sections, are more altered and so correlation with the Park Rill Member is less certain. One specimen is from Mount Roberts and is a hornblende andesite. The hornblende forms needles up to 3 mm long and some glass is present. Another specimen is from the east slope of Grey Mountain and is a pyroxene-hornblende andesite. The matrix is aphanitic. The third specimen was collected west of Sophia Creek, north of the large serpentine body.

Two other samples were collected in 1962 on the ridge west-northwest of Mount Plewman, 1.6 and 2 km respectively from that peak. The one nearer to Mount Plewman is a dark green aphanitic, amygdaloidal rock with phenocrysts of white feldspar that are mostly minute. In thin section the rock is seen to be an andesite, but seems to be pyroclastic. Some epidote and quartz have been introduced. The more westerly specimen is also dark green and aphanitic with dark green minerals that, superficially resemble pyroxene. As in another specimen, the dark green mineral turned out to be chloritic amygdales. The rock is identified as probably andesite, but alteration is intense. Neither of these rocks can be placed in the Park Rill with any certainty, but that correlation is tentatively suggested.

Two samples collected by Daly (1912, p. 325-327) from what he thought were Rossland lavas, but are almost undoubtedly Marron, were chemically analyzed by M.F. Connor.

Analyses of Marron lavas

	A	B
SiO_2	54.54	59.06
Al_2O_3	18.10	16.24
Fe_2O_3	1.14	0.43
FeO	4.63	4.88
CaO	5.85	5.59
MgO	4.56	3.51
Na_2O	3.38	2.84
K_2O	5.44	3.95
H_2O	0.50	0.19
H_2O	0.10	0.21
TiO_2	0.96	1.08
P_2O_5	0.46	0.21
MnO	0.10	0.20
SrO	0.15	0.12
BaO	0.21	0.11
Totals	100.12	99.32

A. Augite latite (trachyandesite). At elevation 1500 m (6000 ft) on the east side of Grey Mountain.

B. Augite-biotite latite (trachyandesite). On crest of Record Ridge about 4 km, at elevation about 1740 m (5700 ft).

Tentative correlation of the Marron Formation in Rossland map area with areas to the west is given in the table below.

Internal structural relations

Fyles' (1970) detailed mapping showed that within the largest area that is underlain by Marron Formation the lavas form a basin with steeply dipping margins. Rough confirmation of this is obtained by the distribution of lavas that have been correlated with the members of the type Marron Formation, except for the andesite at the Delaware adit that is correlated with the Park Rill Member. The roof pendant that extends northward from Old Glory Mountain also appears to be basin-like, although structural data are sparse. Elsewhere, in the small roof pendants, the structure is unknown, as is true also in the Marron rocks that are exposed southeast of Violin Lake.

External structural relations

The large basin of Marron rocks west of Rossland rests unconformably upon Mount Roberts Formation, serpentine, and Elise Formation. This unconformity was seen and described by Drysdale (1915a, p. 218) who stated that the andesite flows and tuff beds "lie at low angles on the steeply dipping older tuffs and agglomerates........" On the western and northern extremities of the basin, however, the Marron rocks have been invaded and digested by syenitic rocks of the Coryell Batholith.

Elsewhere, from the large roof pendant that extends northward from Old Glory Mountain to the small ones to the west and east of it, the relationships of the Marron to the underlying Coryell are intrusive. Only in the northwestern part of this roof pendant, and in a smaller one to the west, do the Marron lavas rest upon tuffaceous arkose of the Kettle River Formation. This contact is not well exposed, so the detailed relationships are not known, but in Greenwood map area there is some intercalation of the two formations (Monger, 1968, p. 24). The small mass of Marron lava in the southern part of Record Ridge probably rests unconformably upon Archibald-like sediments of the Elise Formation in the southwestern edge, but rock exposures there are poor. The remainder of the mass appears to rest upon serpentine on the east, and is in intrusive relationship with the Coryell Batholith on the west.

Southeast of Violin Lake the contacts of Marron Formation, if that unit was correctly identified, with other formations were not seen except to the west where the

Correlation of Marron Formation

White Lake Basin (Church, 1973)	Greenwood map area (Monger, 1968)	Rossland-Trail map area
Park Rill Member andesite	Upper Division (4C) andesite	andesite
Nimpit Lake Member trachyte		
Kearns Lake Member andesite	Middle Division (4B) trachyandesite andesite	andesite, basalt?
Kitley Lake Member trachyandesite		trachyandesite
Yellow Lake Member phonolite	Lower Division (4A) sodic trachyte, minor phonolite	not present

Violin Lake Fault downfaults them against lavas of the Elise Formation. On the south they must rest upon argillite and limestone of map unit Cs, and probably also upon Sheppard Intrusions. On the north they must rest upon sediments of the Elise Formation, and on the east on Elise lavas.

Age and correlation

The Marron Formation in Greenwood map area locally rests upon the Kettle River Formation, the age of which has elsewhere been established as Middle Eocene (Rouse and Mathews, 1961). In the Republic quadrangle, Washington (Muessig, 1967) the Sanpoil Volcanics, which are equivalent in major part to the Marron Formation, are overlain unconformably by the Klondike Mountain Formation. Lake beds within the latter contain fossil fish that have been identified as Middle Eocene (Wilson, 1978). The Marron Formation is therefore of Middle Eocene age.

Fyles et al. (1973, p. 26, 28) obtained a whole rock K-Ar age determination on a sample collected on the east slope of Record Ridge. The age obtained was 51.6 ± 1.7 Ma, which, corrected to the new decay constants (Steiger and Jäger, 1977) is 52.8 ± 1.7 Ma.

Seventy-two kilometres to the west in Greenwood map area, Mathews (1963, p. 4, 8) obtained ages of 49 ± 2 Ma (50.2 ± 2) on a tuff bed underlying trachyandesite of the Middle Division (4B) and 48 ± 2 Ma (49.2 ± 2) on a syenite porphyry sill intrusive into Kettle River beds. On Belshazzar Mountain 18 km south-southwest of Record Ridge, Yates and Engels (1968) obtained K-Ar ages of 50.4 ± 1.5 Ma (51.6 ± 1.5) and 50.5 ± 1.5 Ma (51.7 ± 1.5) on lavas.

Pearson and Obradovich (1977), from 13 samples of Sanpoil volcanic rocks, obtained K-Ar ages averaging 50-51 Ma (51-52) and 8 K-Ar ages obtained from biotite and hornblende in 3 samples of the overlying Klondike Mountain Formation, which range from 41.3 to 49.1 Ma (42.4 to 50.3). By eliminating extreme values in considering data from all sources, the most likely age for Marron and Sanpoil volcanics, corrected to the new decay constants is 51 ± 1.5 Ma.

The Marron Formation of Rossland – Trail map area is correlated with considerable certainty with the Kitley Lake and Park Rill members of the type Marron of White Lake Basin, and with less certainty with the Kearns Lake and Nimpit Lake members. Similar correlations are made with the middle and upper divisions of the Marron Formation in Greenwood map area.

Tentative agreement is made with Drysdale's correlation of "Midway Volcanic Group" of Franklin Mining Camp (Drysdale, 1915b, p. 85-91), where the lower, phonolitic facies may be present (op. cit., p. 126, 127). Correlation with the Kamloops Group of the Nicola map area (Cockfield, 1948, p. 37-40), and to the lava division of the Princeton Group of Nicola map area (Rice, 1947, p. 29) is more uncertain because no careful study of these volcanic rocks has been made.

South of Rossland map area, in Northport quadrangle (Yates, 1971), biotite-bearing basalt or andesite flows and tuffs exposed east of Little Sheep Creek, on Belshazzar Mountain, two hills to the south, and another to the west, seem, from the petrographic description and the radiometric age, to be correlative with part of the Marron Formation that appears to lie above the rocks correlated with the Kitley Lake Member. The most southerly exposures are underlain unconformably according to Yates and Engels (1968) by rhyodacites of the Sanpoil Volcanics. The Sanpoil, as mapped in Togo Mountain (Pearson, 1977), Curlew (Parker and Calkins, 1964), Republic (Muessig, 1967), and Bald Knob (Staatz, 1964) quadrangles seems to include most equivalents of the Marron Formation except the Yellow Lake, or lowest, member. Pearson and Obradovich (1977, p. 10, 11), however, indicated that almost everywhere the Sanpoil Volcanics are equivalent only to the Park Rill Member.

Intrusive Rocks

Ultramafic Intrusions

Distribution

Ultramafic intrusions occur only in the southwest part of Rossland – Trail map area where they occupy a narrow, discontinuous belt trending southwesterly from a point near Rossland to the west side of Big Sheep Creek Valley; another small body occupies the southwest corner of the area. The most easterly body is roughly rhomb-shaped in plan and occupies both sides of part of the valley of Little Sheep Creek, an area of about 1 km. A small area on the west side of the valley, underlain by serpentine and separated from the larger mass by a body of syenite, is shown by Fyles (1970) and doubtless was the southern tip of the larger body, before intrusion of the syenite. Young (in Drysdale, 1915a, p. 212) found a small body of pyroxenite in augite porphyry along the Great Northern Railroad line, now abandoned, on the west side of the creek, a short distance from the larger body of serpentine. This body was not seen by Daly, nor by subsequent workers.

The largest body of ultramafic rock extends from Ivanhoe Ridge southwestward to the southern part of Record Ridge, an area of about 6.2 km^2. Two small bodies were seen southwest of this area, one being in the vicinity of the Velvet mine and the other farther south, on the western slope of Mount Sophia. Both these bodies lie between a large body of quartz-feldspar porphyry and Coryell Intrusions, and probably represent pendants of the larger serpentinite stock.

Part of a body of serpentinite is exposed in the extreme southwest corner of the map area, underlying an area of 0.4 km^2; the remainder of the body lies in the adjacent Kettle River map area, and the Orient and Northport quadrangles, which are south of the International Boundary.

Beyond the map area to the west, large serpentinite bodies occur about 1.5 km west of the last-named body, and some 11 km farther west, near the point where the Kettle River turns southward to cross the International Boundary (Little, 1957). From there to Granby River, no ultramafites occur in the metamorphic complex (Preto, 1970).

South of the International Boundary in Deep Creek and Northport quadrangles (Yates, 1964; 1971), the only ultramafic body is that contiguous with the one that lies in the southwest corner of Rossland map area. To the west, in Orient quadrangle (Bowman, 1950), four bodies of serpentinite and two of pyroxenite were mapped.

Lithology

McConnell and Brock (1904), Young (in Drysdale, 1915a, p. 211), and Fyles (1970) termed these rocks serpentine; apparently no relicts of mafic minerals were seen. Daly (1912, p. 334, 335) described the ultramafites on Record Ridge as "dunite", now partly serpentinized." That in Little Sheep Creek valley was described as similar, but no other workers, including the writer, have identified olivine, or other mafic minerals there. The body in the southwest corner of the map area is entirely serpentinite.

The serpentinite is most commonly a dense, dark green, massive rock that is in places not easy to distinguish from some of the basic volcanic rocks (see Daly, 1912, p. 335). In a few localities, particularly near Coryell Intrusions, the serpentinite may be a chocolate brown colour. Where the serpentinite has been sheared it may assume a light and dark green mottled appearance, possibly due to introduction of carbonate. In no place was the quartz-carbonate-talc rock, a common alteration of serpentinite elsewhere, observed within the map area.

Four thin sections of serpentinite from specimens collected in 1962 were examined. One, collected where the gas pipeline crosses Ivanhoe Ridge, consists of fine grained antigorite and very fine grained opaque minerals in a mat of serpophite. Carbonate comprises about 30 per cent of the rock, and the balance is composed of a little chlorite and opaque minerals. A second specimen, from above (elevation about 1400 m) the old Cascade highway near where it crosses the tributary of Sophia Creek about 1.6 km southwest of the bridge over the main creek, is the only one in which a femic mineral was identified. The rock consists mainly of antigorite, but relict crystals of olivine, largely serpentinized, are readily identified. The rock was therefore a dunite. A small amount of magnetite or spinel is also present. A third sample, from the saddle between Record Ridge and Mount Sophia about 0.8 km south of the old Cascade highway, is of the chocolate brown variety of serpentinite. About half the rock is dusky carbonate and about 20 per cent opaque minerals, possibly including chromite. The balance of the rock is serpophite and antigorite.

The fourth specimen is from the extreme southwest corner of the map area, and comprises matted antigorite blades with very fine grained interstitial antigorite, and a small amount of chrysotile. About 5 per cent of the rock is carbonate which forms diffuse patches straddling the antigorite. A small amount of opaque minerals is present, some of which form small, anhedral crystals.

Internal structural relations

Because serpentinization is almost complete in the ultramafites, and only dunite has been identified, it is not possible to establish the relationships between dunite, peridotite, and pyroxenite (if the latter two existed) within the serpentinite bodies.

External structural relations

The ultramafic bodies were injected into rocks ranging in age from Pennsylvanian (?) to Upper Cretaceous. The oldest rocks invaded are those of the Mount Roberts Formation, but larger and more abundant intrusions are found in the Lower and Middle Jurassic Rossland Group. The only younger rocks invaded are those of the Cenomanian to Campanian Sophie Mountain Formation, in the Douglas mine, in the main shear zone, along a contact between conglomerate and hypabyssal syenite, masses of serpentine, most of them small but one at least 30 feet (9 m) in diameter, occur in that formation (Little, 1960, p. 125). It was concluded that these were emplaced as 'cold' intrusions, during faulting, probably from an underlying mass of serpentinite, some of which is exposed in the vicinity.

The larger bodies of serpentinite do not appear to be related to faults except that in Little Sheep Creek where J.T. Fyles mapped the eastern contact as a fault and regards the rhombic plan of the body as indicating fault control during emplacement (Fyles, pers. comm., 1978).

The ultramafic rocks are cut by dykes that are believed to be related to Nelson Intrusions, and are definitely intruded by the body of quartz-feldspar porphyry (map unit Kqp) and by Coryell Intrusions.

Origin

The serpentinite bodies are spatially associated with the Mount Roberts Formation only in upper Little Sheep Creek. They are intrusive into volcanic rocks of the Rossland Group, particularly southwest of Rossland, where the group is probably underlain by Mount Roberts Formation. There are no serpentinite bodies to the east where the Rossland Group is underlain by the largely sedimentary Archibald Formation, map unit Cs, or, to the northeast of the map area, the Ymir Group.

To the west, in the southeast part of Kettle River map area, ultramafites intrude only the Rossland Group (Little, 1957). To the southwest, in Orient quadrangle (Bowman, 1950) three bodies of serpentinite cut the Rossland Group, and one the Permian Churchill Formation, where the ultramafic rocks are in contact with gabbro, but the relationship is now known. The two bodies of pyroxenite are surrounded by gabbro which intrudes Rossland volcanics, but these intrusions are probably unrelated to the serpentinites, both in Orient quadrangle and in Rossland – Trail area.

The ultramafic intrusions in Rossland – Trail map area do not show any signs of differentiation; they are in most places completely serpentinized and only dunite has been positively identified. Such ultramafites are typical of an ophiolite, rather than an alpine suite, but the formation with which they are most likely to be associated is the Mount Roberts, which comprises marine greywacke, slate, argillite, limestone, tuffs, and minor greenstone and lacks the sheeted dykes, gabbro, and pillow basalts normally associated with ophiolites. Nevertheless, the relatively close association spatially of the serpentinites with the Mount Roberts Formation suggests a chronological, if not a genetic, relationship. Also, as pointed out in the following section, serpentine fragments are reported in Rossland agglomerates in areas to the west and southwest, indicating a pre-Jurassic age for the serpentinites. It is possible that the Mount Roberts Formation is underlain locally by ophiolites. If this is so, then invasion of the Rossland Group was by 'cold' intrusion.

No significant accumulations of chromite have been discovered within the map area, but from the Mastodon group, staked upon similar serpentinite about 11 km west of the area, 670 tons (608 tonnes) of chromite grading 38.5 per cent Cr_2O_3 were shipped in 1918 (Minister of Mines, B.C., Ann. Rept. 1918, p. 205). In recent years, some showings of nickel in the largest body west of Ivanhoe Ridge have been reported.

Age and correlation

McConnell and Brock (1904) assigned a Paleozoic age to the serpentines because "they have not been observed to cut any formations younger than......Shuswap." Daly (1912, p. 334) stated that the ultramafites cut the Rossland volcanics, and in his legend placed them in the Mesozoic. Young (in Drysdale, 1915a, p. 212) assigned a Mesozoic or younger age, but on his map legend, they are classified as Mesozoic, post-Jurassic(?). Little (1960, p. 109) suggested that the age is latest Jurassic or Cretaceous, because the ultramafic bodies cut Lower and Middle Jurassic Rossland volcanics and are cut by dykes believed to be intrusions related to Nelson. Furthermore, he believed they represented the earliest intrusions related to the orogeny that resulted in supplying coarse grained sediments to the Kootenay Formation to the east, the basal part of which is Portlandian. To the south Yates (1971) referred his ultramafic body to the Jurassic. Bowman (1950) in Orient quadrangle, placed the ultramafites dubiously in the Upper Jurassic-Lower Cretaceous, but pointed out, as did Brock (1903b, p. 99A, 100A) in the Boundary Creek district, that some serpentine fragments occur in Rossland agglomerates, and both suggested that the ultramafites are of two ages, pre- and post-Rossland.

This problem is resolved if one assumes that all ultramafites were associated with the Pennsylvanian(?) Mount Roberts Formation and/or the Permian Churchill Formation (of Orient quadrangle). If this were so, the ultramafites may have been remobilized during the local (?) orogeny that affected the Mount Roberts Formation prior to deposition of the basal Rossland agglomerates and flows. However, the main intrusion occurred during the Columbian Orogeny, whether by 'cold' intrusion (remobilization) or magmatic injection. 'Cold' intrusion into a shear in the Sophie Mountain Formation at the Douglas mine must have occurred in Upper Cretaceous or Tertiary time, but is minor in comparison with that of the Columbian Orogeny.

Based upon the above premise, the age of the ultramafic intrusions is therefore assumed to be Pennsylvanian(?).

The small pyroxenite body described by Young on the west side of Little Sheep Creek is "enclosed" in augite porphyry of the Rossland Group. It contains no orthorhombic pyroxene and is therefore undoubtedly not related to the other ultramafites, but is probably a differentiate of the Jurassic augite porphyry.

The ultramafic intrusions of Rossland – Trail map area are correlated with those of southeastern Kettle River area and with those of Orient quadrangle, Washington which are not intimately associated with gabbro. Correlation with ultramafites that are more distant is not possible at this time.

Rossland Monzonite

The Rossland monzonite was first recognized by McConnell (1897b) and Brock (McConnell and Brock, 1904) and subsequently described by Young (in Drysdale, 1915a, p. 219-227), by Daly (1912, p. 337-344), and by Bruce (1917, p. 222, 223). It was named "Rossland Monzonite" by Daly (1912, p. 337) and, although the name Rossland had previously been applied to the Rossland Volcanic Group, it has been retained by Little (1960, p. 77; 1963, p. 4), Fyles (1970) and Fyles et al. (1973), and seems not to present a conflict of understanding with the name Rossland Group. Indeed, it is well exposed at Rossland whereas the Rossland Group is better exposed and less structurally complex elsewhere.

Distribution

McConnell and Brock (1904) were of the opinion that the Rossland monzonite was widely distributed, and showed bodies of that intrusion in the northwest part of Rossland – Trail map area, along the east shore of Christina Lake, and in Franklin mining camp. Later, more detailed studies by Drysdale (1915b, Map 97A) did not confirm its presence in Franklin camp, and Daly described the rock east of Christina Lake as gabbro which he did not relate to the Rossland monzonite. However, confirmation of the presence of Rossland monzonite in the northwest and northeast part of Rossland – Trail map area was obtained in the more detailed examinations of 1961 and 1962 by Little, although not in the same localities that were designated by McConnell and Brock (1904).

The main body of monzonite extends eastward from Rossland and is 0.75 to 3.25 km wide and 8 km long. Southeast of Trail another body 0.4 to 2 km wide and 4 km long lies between the Trail pluton and schists of the Rossland Group to the south. Two small bodies of the monzonite were encountered south of Champion Creek in the northeast part of the map area. A small body, cut by granodiorite was shown by Fyles (1970) 0.8 km northwest of Red Mountain. Seven small bodies of the monzonite occur on Mount Neptune and northwest of it, and one in the northwest corner of the map area.

Lithology

The monzonite is a green rock, and is for the most part a medium grained, inequigranular aggregate of white feldspar and pyroxene, hornblende, and biotite. In the mass at and near Rossland however, it shows wide variations in colour and texture. The colour ranges from light grey to dark green and the grain size from fine to coarse, the fine grained facies superficially resembling andesite of the Rossland Group.

In thin sections the rock commonly consists of oligoclase, orthoclase, small stout prisms of augite, hornblende, and biotite which in the coarser phases is poikilitic. Some facies contain andesine rather than oligoclase; others contain only small amounts or traces of hornblende and pyroxene. Magnetite and apatite, and locally sphene, are present as accessories. A chemical analysis of fresh monzonite from the 700-foot level of Le Roi mine that was collected by Young and analyzed by M.F. Connor (in Drysdale, 1915a, p. 223; Daly, 1912, p. 343), is reprinted below.

Analysis of Rossland monzonite

	Per cent
SiO_2	54.49
TiO_2	0.70
Al_2O_3	16.51
Fe_2O_3	2.79
FeO	5.20
MnO	0.10
MgO	3.55
CaO	7.06
Na_2O	3.50
K_2O	4.36
H_2O at 110°C	0.07
H_2O above 110°C	1.18
P_2O_5	0.20
CO_2	0.10
S	0.23
Cu	none
	100.04

External structural relations

The Rossland monzonite intrudes the Rossland Group and the older Mount Roberts Formation. It was not observed to intrude serpentine. The relationship of the main mass of Rossland monzonite to the Nelson Intrusions, more specifically the Trail Pluton, was not described by the early workers, though McConnell and Young indicated on their legends that the monzonite is older, but in the legend of McConnell and Brock (1904) a younger age is implied. Bruce (1917, p. 222, 223) was unable to confirm that dykes of Nelson granodiorite cut the monzonite. Gilbert (1948, p. 189), however, stated that the monzonite is the older, although he gave no supporting evidence. Fyles et al. (1973, p. 24) found the contact of the monzonite with the Rainy Day stock, which all have regarded as an offshoot of the Trail Pluton, is not well exposed but indicates the monzonite is older. On highway 3A just west of Warfield similar relationships also indicated to them that the monzonite is older than the Trail Pluton. On the other hand, the writer's field assistants reported (Little, 1963, p. 4) that rocks correlated with the Rossland monzonite cut the Trail Pluton southeast of Trail, and intrude rocks believed to be Nelson Intrusions on Mount Neptune.

Origin

All writers agree that the monzonite is intrusive, although Little (1960, p. 77, 80) did suggest that a metasomatic origin was possible, but after more detailed study, he retracted this Little (1963, p. 4). Fyles et al. (1973, p. 24) mapped an aureole of thermal metamorphism surrounding the main body that is 150 m to 1600 m or more wide.

McConnell and Drysdale believed that the Rossland monzonite body is genetically related to latites of the Rossland Group and is indeed a volcanic neck. Drysdale (1915a, p. 246) also thought that it is genetically associated with the Trail Pluton, as did Young, and Daly (Map 81A), who regarded it as an early phase, whereas Bruce (1917, p. 223) and Thorpe (1967, p. 4) regarded it as a late phase. The conflicting data as to whether the Rossland monzonite is earlier or later than the Trail and correlated granodiorite is strong evidence of their genetic relationship.

Age and correlation

The age of the Rossland monzonite has been regarded by all writers except Fyles et al. as Jurassic, probably Lower Cretaceous. Fyles et al. (1973, p. 23, 26), from analysis of three samples for K-Ar dates, found widely divergent ages, which suggests updating by younger intrusions. The oldest date is 90 Ma, and they concluded that that is a minimum age for the body. To this writer, a Late Jurassic or Early Cretaceous age seems most probable.

Because it is concluded that the Rossland monzonite is a distinct and important phase of Nelson Intrusions, the same correlations indicated for the latter apply.

Nelson Intrusions

Granitic rocks of Mesozoic age in the West Kootenay district were first described by Dawson (1890, p. 32B, 33B) and subsequently mapped by McConnell and Brock who named them the "Nelson granite". They were renamed "Nelson plutonic rocks" in Nelson map area, west half by Little (1960, p. 81) because rocks of metasomatic and some of metamorphic origin were included. In Rossland – Trail map area rocks of the Nelson suite are clearly intrusive and so are here defined as Nelson Intrusions.

Distribution

The largest body within the map area is what Daly (1912, p. 346-349) called the Trail Batholith, recently referred to as the Trail Pluton by Simony (1979), a name that is retained in this report. The Trail Pluton is about 106 km^2 and straddles Columbia River. The city of Trail is built upon the south-central part of the pluton.

A larger body, called the Bonnington Pluton by Simony (op. cit.) and not to be confused with the Bonnington Complex of Mulligan (1952, p. 10-13; Little, 1960, p. 80, 81), lies mainly northeast of the map area, so that only a portion of it, some 54 km^2 underlies the northeastern part of the map area. A third pluton, named the Mackie Pluton by Simony, extends 17 km from the headwaters of Lamb Creek eastward almost to Columbia River near Genelle. It ranges in width from 1.5 km to 5 km. The most northerly part of the pluton lies a short distance north of the northern edge of the map area. Bodies of granodiorite and diorite west of Lamb Creek may represent roof pendants of the Mackie Pluton within the Coryell Batholith.

Other bodies, ranging in size from perhaps 2.5 km^2 down to dykes occur mainly near the plutons, but a few lie farther away, particularly in the northwestern corner of the map area.

Lithology

The main granitic component of the Trail Pluton is granodiorite, but locally some quartz diorite and diorite are present, the latter occurring as a border phase, and in peripheral dykes. The grandiorite is a greenish grey, coarse- to medium-grained, hypidiomorphic rock that contains macroscopically visible quartz, feldspar, hornblende, and biotite. In thin sections, the plagioclase is identified as andesine and exceeds both orthoclase and microcline in amount. Hornblende usually exceeds biotite. Accessory minerals are apatite, sphene, and magnetite. Minor amounts of chlorite and epidote are not uncommon.

A sample was collected by Daly (1912, p. 347) from a railway cutting two miles west of Trail, and was chemically analyzed by M.F. Connor.

Analysis of Trail granodiorite

	Per cent
SiO_2	62.08
Al_2O_3	16.61
Fe_2O_3	1.53
FeO	3.72
CaO	5.20
MgO	2.44
Na_2O	3.18
K_2O	3.29
H_2O+	1.00
H_2O-	0.16
TiO_2	0.73
P_2O_5	0.30
MnO	0.11
SrO	0.03
BaO	0.09
	100.47

Daly stated that the granodiorite passes gradually into biotite granite or hornblende granite, but these phases have not been noted by other writers, and to this writer, such gradations seemed to be into more basic phases.

Little (1963) showed two bodies of granodiorite west of the Trail Pluton that were believed to be cupolas. Fyles et al. (1973) correlated the more northerly one with the Trail granodiorite. The more southerly they named the Rainy Day Stock, which although it is quartz diorite in composition, they believed to be, together with two large dykes of similar composition, probable offshoots of the Trail Pluton.

Along the southern edge of the Bonnington Pluton the rock is mainly hornblende granodiorite, grading in places to diorite. Towards the north edge of the map area biotite gradually increases in content until, in some outcrops, hornblende is completely lacking. Within the Bonnington Pluton there are some small pendants of granitoid gneiss that more closely resemble Simony's (1979) Castlegar Gneiss than his Trail Gneiss. Some amphibolite is also present, however. In this writer's opinion the granitoid gneiss east of the Champion Lake Fault is the result of granitization of beds of the Rossland Group, and the amphibolite the metamorphic product of Rossland lavas. Simony has pointed out that the Bonnington Pluton is more strongly lineated than the Trail Pluton.

The Mackie Pluton is also mainly biotite-hornblende granodiorite; no phases where biotite exceeded hornblende were seen. The eastern end of the pluton is much more strongly foliated than the western, where few attitudes could be obtained. The smaller bodies of Nelson Intrusions are also of biotite-hornblende granodiorite, with the smallest trending towards diorite.

Origin

The lithological and compositional similarity of the bodies mapped as Nelson Intrusions within Nelson map area have led past workers to believe them to be consanguineous and probably of closely similar age. In recent years radiometric dating has indicated a much more complex history for the Nelson Intrusions. The suite should be defined as being associated with the Late Jurassic-Early Cretaceous Columbian Orogeny, and bodies that are indisputably shown to be markedly older or younger should not be included with the Nelson Intrusions. Those mapped as such in Rossland – Trail map area are believed to have been emplaced during the Columbian Orogeny, but some radiometric dates have thrown some doubt on this.

Age and correlation

The Nelson Intrusions cut formations of Middle Jurassic age and older. Some roundstones in the Sophie Mountain Formation resemble Nelson rocks, indicating that the Nelson Batholith and/or its satellites had been unroofed by Campanian time. Indeed, indications that it was unroofed by Albian (Late Lower Cretaceous) time were provided by Beveridge and Folinsbee (1956, p. 41), who found that a heavy mineral suite that is identical to that of the Nelson is present in igneous pebbles from the McDougall-Segur conglomerate of the Blairmore Formation of Alberta.

K-Ar ages up to 171 Ma have been recorded on biotite in granitic rocks from the Nelson Batholith (Reesor, 1965, p. 51, 52) but some are as young as 60 Ma were obtained. More recent K-Ar ages from samples collected from the northern part of the Nelson Batholith range from 120 ± 5 Ma to 169 ± 6 Ma (Nguyen et al., 1968), and further work by Reesor (Gabrielse and Reesor, 1974) has established the age as Middle and Upper Jurassic. To this writer, it is surprising that the earliest emplacement of the Nelson Batholith should have taken place during deposition of the Hall Formation, and that such orogeny is not reflected in the sedimentation of the Hall.

Fyles et al. (1973) made K-Ar age determinations on biotite from two samples of Trail granodiorite and one of Rainy Day quartz diorite. From those of Trail granodiorite ages of 50.5 ± 1.5 Ma and 49.5 ± 1.4 Ma were obtained, and from Rainy Day quartz diorite 48.7 ± 1.5 Ma. Recalculation to new standards of decay constants and isotope abundances that were recommended by the IUGS Subcommission on Geochronology (Steiger and Jager, 1977) increases each of the ages by about 1.2 Ma. Fyles et al. (op. cit.) concluded that because of the Tertiary radiometric ages obtained "the Trail batholith can no longer be regarded as part of the Nelson plutonic suite". Thorpe and Little (1973) objected to a Tertiary date for the Trail Pluton on the grounds that the sampled area is adjacent to the Coryell Batholith, and that numerous small intrusions of associated phases suggest that the area around Rossland is underlain at no great depth by the batholith. Examples were given where radiometric dates had been reset as much as 2 km from intrusions of much smaller size than the Coryell Batholith. It was argued that the rocks around Rossland had been subjected to an over-printing in the Tertiary. In September 1978 the writer attempted to obtain samples of Trail granodiorite from the summit of Mount Heinze, well away from Coryell Intrusions, but poor weather had made the Bear Creek road impassible. It is hoped that such samples can be obtained in the future.

Bodies of granodiorite, quartz monzonite, and quartz diorite similar to those of the Nelson Intrusions of Nelson map area have been mapped as Nelson as far west as Okanagan Lake (Little, 1957, 1961). They are correlated in large part with the Okanagan Intrusives of Cairnes (1940), and with intrusive rocks of similar age and composition that are widespread throughout southern British Columbia (Little, 1962b) and eastern Washington (Huntting et al., 1961; Yates and Engels, 1968, p. D243-D245).

Porphyritic Leucogranitic Rocks

North of the upper part of China Creek a small area is underlain by massive porphyritic biotite leucoquartz monzonite which is foliated, but has no compositional layering. The rock contains abundant quartz, which is smoky grey in colour, and numerous phenocrysts or metacrysts of euhedral potash feldspar. It is for the most part coarse grained, but some medium grained facies were noted. The rock resembles the porphyritic Valhalla Intrusions of Kettle River (East Half) map area (Little, 1957), which intrude the Nelson granitic rocks. The relationship to the Nelson was not observed in Rossland – Trail map area.

Similar, but nonporphyritic rocks were mapped and named by McConnell and Brock (1904) as "Valhalla Granite" in the Valhalla Range, and were also mapped as "Valhalla plutonic rocks" (Little, 1960, p. 87-90) and were noted to be intrusive into Nelson in some places, and gradational in others. Reesor (1965, p. 27) as a result of very detailed studies classified the rock unit as "leucocratic gneiss and leucogranite" consisting of an interlayered and interdigitating assemblage of fine- to medium-grained, faintly gneissic rock of granodioritic composition and a medium- to coarse-grained very leucocratic granitic rock. This unit he included with his "mixed gneiss." It is possible, therefore, that the porphyritic leucogranitic rocks of upper China Creek may be meta-somatic rather than intrusive, and may overlie the Castlegar Gneiss of Simony (1979).

Quartz-Feldspar-Porphyry

On the east side of the valley of Big Sheep Creek about 1.5 to 2.5 km north of the International Boundary there is an intrusive body, about 1.3 km^2 in area, of quartz-feldspar porphyry. Megascopically it is a mottled light greyish green rock with phenocrysts of white feldspar and characteristic round phenocrysts or "eyes" of clear quartz. The mafic mineral is chloritized hornblende. Thin sections show that the rock is highly altered, the feldspars consisting almost entirely of saussurite and sericite. Quartz is more abundant in the groundmass than as phenocrysts. In one thin section green, pleochroic biotite is relatively abundant, but no other mafic minerals were identified due to chloritization. Epidote is present, and a little scapolite was identified.

Some dykes surrounding this intrusion were seen. A dyke of similar rock was collected from diamond-drill core that was obtained by Cominco a short distance east of Rossland, but this distinctive rock was seen nowhere else in the map area.

The age of this intrusion is unknown. It intrudes the Elise Formation, and serpentinite in the Velvet mine, but has not been observed to intrude the nearby Sophie Mountain Formation. For this reason, and because it is highly altered, it is assumed to be Cretaceous(?). The closest petrographic affinity is to the Sheppard Intrusions, but the abundance of mafic minerals indicates that it is not related to the Sheppard.

Sheppard Intrusions

Granite bodies in Columbia and Pend-d'Oreille valleys were first mapped by McConnell and Brock (1904) as "Rossland alkali granite and syenite" who recognized their Tertiary age. More detailed studies of these rocks were made by Daly (1912, p. 354-356) who distinguished them from the Coryell, and named them the Sheppard granite, from Sheppard Creek, a western tributary to Columbia River. Walker (1934, Map 299A) referred these rocks to the "Nelson batholith" of Mesozoic age, but Little (1950, p. 31; 1960, p. 94, 95) and Fyles and Hewlett (1959, p. 42) considered the age to be Tertiary. South of the International Boundary these granites were mapped by Yates and Robertson (1958) who also found that they do not occur far from the Boundary, and their westward distribution across Columbia Valley was delineated by Little (1962, 1963) and Yates (1964, 1971).

Distribution

The Sheppard Intrusions occur on both sides of Pend-d'Oreille River extending from a short distance east of the eastern border of Rossland – Trail map area westward to about 13 km from the mouth of Pend-d'Oreille River, and are not exposed more than 8 km north, and 7 km south of the International Boundary. Thus, these intrusions are limited to an area of 15 by 22 km.

Lithology

Daly (1912, p. 355) described the Sheppard granite as "a pinkish, medium- to fine-grained, aplitic aggregate of quartz, microperthite, orthoclase, and oligoclase, near Ab_8 An_1, and a very little generally chloritized biotite; in the granite of the stock on the Pend-d'Oreille, biotite is replaced by diopsidic augite which is hardly more than accessory. A little magnetite and well crystallized titanite, with a few minute zircons, are always present. Apatite seems to fail. The structure is the eugranitic, tending to the panidiomorphic." Fyles and Hewlett (1959, p. 43) described the bodies along lower Pend-d'Oreille River as "mainly light-coloured medium-grained granite and syenite. The rocks are highly fractured, and weathered surfaces are white or rust stained but fresh surfaces are light grey........ Specimens studied in thin section contain mainly albite and microcline-microperthite with minor amounts of quartz and rare pyroxene or hornblende." Yates (1971) in his legend called the rock "leucocratic microcline-albite granite; locally a cataclasite."

In Rossland – Trail map area, Sheppard Intrusions range in composition from granite to syenite, in grain size from fine- to medium-grained, and in colour from white or grey to pink. Some phases of the Sheppard, in particular in the Casino Creek basin, closely resemble certain phases of the Coryell Intrusions. Near the International Boundary, however, some of the granitic bodies are intensely sheared to form cataclasites, and there mafic minerals are generally lacking, apparently completely replaced by specular hematite.

On the ridge north of Sheppard Creek, from the locality where Daly collected his sample of type Sheppard granite, R.G. Yates and the writer collected a large chip sample, which was divided and submitted to our respective chemical laboratories for analysis. Table 2 shows the analyses of this material, and that collected by Daly.

A rapid rock analysis of the sample submitted by Yates to the US Geological Survey laboratories gave results that were very close to those from the GSC laboratories.

A Rosiwal analysis of a thin section of the sample of Sheppard granite that was chemically analyzed in the GSC laboratories follows.

Rosiwal analyses of Sheppard granite

Sample LF 62 – A1

	Per cent
Myrmekite	49.0
Perthitic K-feldspar	21.0
Albite (An_0-An_8)	13.75
Quartz	9.0
Green chlorite	5.0
Biotite	2.0
Opaque minerals	0.25
	100.00

Sample LF 62 – A1 is from Daly's type locality of Sheppard granite.

In the roadcut on highway 3B, Sheppard granite is exposed 0.25 km west of the railway crossing at the western limits of Warfield. A thin section of the granite contains the following minerals, the relative contents being approximate: Strongly altered albite (An_0-An_{10}) 20%, diffuse anhedral potassium feldspar 20%, fine grained quartz-feldspar matrix 35%, perthitic orthoclase 5%, epidote 5%, quartz 1%, biotite 1%, green chlorite 15%.

Age and correlation

Sheppard Intrusions cut the Trail granodiorite and older rocks, and, according to Daly, the Upper Cretaceous Sophie Mountain Formation on Lake Mountain. Granite porphyry dykes in the Rossland mining camp that cut Coryell pulaskite were correlated with Sheppard Intrusions by Drysdale (1915a, p. 240) but Gilbert (1948, p. 149) thought that the granite porphyry might be a younger phase of the Coryell. Yates (1971) implied in his legend that the Sheppard is older than Coryell. Drysdale (1915b, p. 74) suggested that the source of rhyolite in the Kettle River Formation of Franklin Mining Camp is Valhalla granite. The Valhalla, however, is overlain unconformably by Kettle River Formation (Little, 1957; 1961; in press). Pearson and Obradovich (1977, p. 15) favoured the Sheppard as a possible source of Kettle River flows and tuffs because "it has appropriate composition and is the oldest Tertiary rock in the area where it occurs." If this correlation be valid, then the age of the Sheppard Intrusions is Middle Eocene.

The Sheppard Intrusions may be correlated on a chemical basis with the rhyolite flows and the widespread tuffs of the Middle Eocene Kettle River Formation. They may also be correlative with the Shingle Creek porphyry (Bostock, 1966) a short distance west of Penticton, which cuts part of the Springbrook Formation, believed to be mainly correlative with the Kettle River Formation, and which probably supplied volcanic ash to the tuffaceous beds of these formations. A body of similar porphyry containing large, euhedral phenocrysts of potassium feldspar was seen by the writer in the lower part of Tuzo Creek, about 6 km south of the town of Beaverdell, (Little, 1961), and this may also be correlative.

Coryell Intrusions

These distinctive rocks were first noted along the shores of Lower Arrow Lake by Dawson (1890, p. 33B) who referred to them as "younger red granites." Their distribution was later shown on the West Kootenay sheet by McConnell and Brock (1904) who named them "Rossland alkali granite and syenite", in which they included the Sheppard Intrusions. Daly (1912, p. 358-362) separated the syenitic rocks from the grouping and applied the name "Coryell syenite" to them, from Coryell railway station on

Table 2. Analyses of Sheppard granite

	Daly (1912, p. 355)*	GSC lab.**	
SiO_2	77.09	73.50	73.40
Al_2O_3	13.04	14.04	14.18
Fe_2O_3	0.82	0.90	0.91
FeO	0.26	1.28	1.30
CaO	0.63	0.30	0.30
MgO	0.12	0.32†	0.33†
Na_2O	3.11	3.51	3.44
K_2O	4.50	4.61	4.61
H_2O+	0.07	0.90	0.92
H_2O-	0.03	0.08	0.10
TiO_2	0.05	0.19	0.19
P_2O_5	0.10	0.03	0.04
MnO	tr.	0.09	0.04
CO_2	-	-	-
Total	99.82	99.69	99.76

* Analyst M.F. Connor
** Analyst G.Bender
† MgO determined colorimetrically

Note: Two separate analyses were made of the material by the GSC laboratories.

Table 3. Chemical analyses of Coryell rocks

Chemical	A	B	C	D
SiO_2	62.59	64.58	60.51	52.38
Al_2O_3	17.23	16.31	16.71	15.29
Fe_2O_3	1.51	1.38	1.72	2.99
FeO	2.02	1.90	3.34	5.53
CaO	1.99	2.05	3.62	7.30
MgO	1.30	1.26	2.53	5.84
Na_2O	5.50	4.77	4.64	3.68
K_2O	6.74	5.69	5.20	3.84
H_2O+	0.30	0.61	0.27	0.63
H_2O-		0.17	0.03	0.21
TiO_2	0.54	0.44	0.60	1.10
P_2O_5	0.11	0.22	0.16	0.75
MnO	tr	0.07	0.10	0.10
CO_2	tr	0.51	not det.	not det.
BaO	not det.	not det.	0.12	0.25
S	tr	not det.	not det.	not det.
SrO	not det.	not det.	0.10	0.15
Totals	99.83	99.96	99.65	100.04
Analysts	M. Dittrich	G. Bender	M.F. Connor	M.F. Connor

A. Syenite. From a point north of Record Mountain. (Daly, 1912, p. 359)

B. Syenite. Composite sample of specimens collected in Nelson map area, west half. (Little, 1960, p. 91)

C. Porphyritic syenite. From the crest of the ridge south of Santa Rosa Creek, near International Boundary monument 172. (Daly, 1912, p. 364)

D. Monzonite. From railway cutting about 3.2 km southwest of Coryell. (Daly, 1912, p. 361)

McRae Creek to the east of Rossland map area. The name "Coryell" has been retained because the name "Rossland", although it has priority, was also applied by McConnell and Brock to an assemblage of volcanic and sedimentary rocks and that usage has been retained by all subsequent writers, although in a more restricted sense than the original.

Distribution

Within the map area the main mass of Coryell Intrusions is the Coryell Batholith which extends more or less from the International Boundary northward to the northern edge of the map area, and from the crest of Record Ridge and the contiguous mountains northward nearly to Strawberry Pass and the headwaters of Lamb Creek, westward to the western border of the map area. Small bodies of syenitic rock that may be cupolas lie within a few miles of the batholith, except near Violin Lake, where a large body may lie at no great depth. Numerous dykes of syenitic rocks occur in the western part of the map area but only some of the larger ones are shown on the map.

Small bodies and dykes of porphyritic augite-biotite monzonite are believed to be genetically related to the Coryell Intrusions and have been mapped as such. They are best known in the Rossland camp, but four or five bodies occur in the valley of lower Hanna Creek. A dyke of this monzonite is exposed in a rock cutting on highway 3B between Hanna Creek and the south branch of Murphy Creek, where it cuts the Coryell syenite.

This distinctive rock has been seen in many localities between Ymir and Christina Lake.

Lithology

Coryell plutonic rocks that are exposed in several batholiths and smaller bodies in south-central British Columbia are coarse grained syenites, granites, quartz monzonites, and monzonites, the quartz monzonite being the most widespread. In the Coryell Batholith the coarse grained phase is not as abundant as elsewhere, and is in most places syenite, a mainly coarse grained inequigranular, locally porphyritic, and for the most part red to pink in colour, but grading into pale buff. However, in many places, quartz becomes sufficiently abundant to be a granite. Daly (1912, p. 359) regards the coarse grained phase as the dominant one in the Coryell Batholith; this writer does not agree and was impressed by the variety of phases, mostly hypabyssal, that are encountered in traversing the batholith.

Thin sections of the coarse grained phase usually contain little quartz, but this increases locally to more than 10 per cent. Microperthite and orthoclase are the most abundant constituents; some plagioclase is usually present. Biotite and hornblende are conspicuous and in some samples a little pyroxene is present. Accessory minerals are apatite, sphene, zircon, magnetite, and sometimes allanite. A sample of this phase was collected by Brock at a point north of Record Mountain (Daly, 1912, p. 359). A composite sample of the most typical Coryell rocks from specimens collected in Nelson map area, west half in 1949, 1950, and 1952 by the writer and his parties was submitted for analysis (Little, 1960, p. 91). In addition Daly collected a monzonite which he regarded as a basic contact phase of the Coryell and a porphyritic phase, for which he also presented analyses (Daly, 1912, p. 361, 364).

Hypabyssal phases of the Coryell are numerous. Most are medium-grained, porphyritic, with phenocrysts of white to pink feldspar. Most of the rocks are pink to red, but many are white or green, the latter being due to chloritization of abundant mafic minerals.

Several specimens of the porphyritic hypabyssal Coryell rocks were examined in thin sections. A sample collected on the ridge 0.75 km east of Old Glory Mountain contains estimated percentages of the following minerals:

	Per cent
Perthitic orthoclase	50
Oligoclase (An_{20})	30
Hornblende	5
Clinopyroxene	5
Biotite	1
Quartz	5
Opaque minerals	2
Undetermined mineral	1
Accessories Apatite, zircon, and sphene	

Another specimen of aplite that cuts coarse grained syenite 3 km southwest of Old Glory Mountain contains:

	Per cent
Perthitic K-feldspar	80
Quartz	10
Opaque minerals	5
Sphene	2
Hornblende	2
Apatite	1
Minor biotite, epidote, and zircon	

A sample of porphyritic syenite from the southwest corner of the map area contains, by Rosiwal analysis:

	Per cent
fine grained feldspathic matrix	45.75
Albite	27.75
Orthoclase	23.00
Carbonate	1.25
Quartz	1.00
Biotite	0.50
Chlorite	0.50
Opaque minerals	0.25

A dyke that intrudes Trail granodiorite near Warfield contains:

	Per cent
very fine grained dark matrix	24.25
Albite(?), highly sericitized	24.75
Orthoclase	12.50
Yellow chlorite	27.25
Sericite	7.50
Green chlorite	0.75
Quartz	2.75
Opaque minerals	0.25

The porphyritic monzonite phase that is believed to be genetically related to the main Coryell intrusions is in hand specimen of medium grey colour, coarse grained, and stout prisms of pyroxene are conspicuous phenocrysts. White feldspar and small hexagonal flakes of biotite make up the balance of the rock. In thin sections the feldspar is seen to consist mainly of microperthite and orthoclase, and some andesine. The pyroxene phenocrysts are light green augite; the other mafic minerals being dark green hornblende, and pleochroic brown biotite.

An interesting variation of the porphyritic augite-biotite monzonite phase is a distinctive rock in which thin biotite lamellae have grown along small joint planes, giving freshly-broken rock a distinctive facetted appearance. This rock is more basic than the normal porphyritic syenite, and contains olivine. A dyke-like body of this rock, which intrudes Coryell syenite, is exposed in a road cutting on highway 3B. A Rosiwal analysis of the rock gave:

	Per cent
Orthoclase	11.50
Andesine (An_{32} to An_{40})	18.33
Biotite	34.00
Clinopyroxene	24.50
Olivine	9.67
Chlorite	0.33
White mica	0.50
Phlogopite	0.17
Sphene	0.50
Opaque minerals	0.33
Apatite	0.17

Origin

The Coryell Intrusions are genetically related to the widespread Marron lavas which Monger (1968) in Greenwood map area divided into three divisions. He correlated those believed to represent Coryell Intrusions with his middle division of the Marron Formation. In Rossland – Trail map area, the lower part of the Marron Formation is invaded by apophyses of the Coryell Batholith. This relationship is clearly shown on Old Glory Mountain where a large roof pendant of Marron Formation is well exposed and rests upon the batholith. The epizonal plutonic rocks have burst through and partly digested or stoped the penecontemporaneous volcanic rocks. The magma chambers that supplied the material for both extrusive and intrusive rocks must have been very extensive.

Age and correlation

The age of the Marron Formation is Middle Eocene, so the age of the Coryell Intrusions, which are intimately related, is also Middle Eocene.

Early radiometric determinations of the age of the Coryell Intrusions, from samples taken from the Coryell Batholith, are 54 and 58 Ma. (Baadsgaard et al., 1961, p. 697). In the light of current information, these figures are rather high. Mathews (1963) obtained a K-Ar age of 48 ± 2 Ma (increased by 1.2 Ma using the new constants) on biotite from a syenite porphyry that cuts the Kettle River Formation in Greenwood map area. Yates and Engels (1968) sampled satellite syenitic dykes south of the Coryell Batholith, from which K-Ar ages on biotite of 50.7 ± 1.5 Ma (51.9 ± 1.5) and 50.4 ± 1.5 Ma (51.6 ± 1.5) were obtained. Pearson and Obradovich (1977, p. 40) obtained a K-Ar age of 51.7 ± 1.6 Ma (52.9 ± 1.6) from biotite in a specimen of quartz monzonite of Long Alec Creek. From unnamed quartz monzonites, ages of 51.1 ± 1.6 Ma (52.3 ± 1.6) and 52.2 ± 1.7 Ma (53.4 ± 1.7) from biotite, and 53.7 ± 2.7 Ma (54.9 ± 2.7). These ages are virtually identical to those of the Sanpoil and Marron formations and confirm the genetic relationship between the two.

The Coryell Intrusions are correlated with the "quartz monzonite of Long Alec Creek" in Curlew quadrangle (Parker and Calkins, 1964, p. 54-60) and "quartz monzonite east of Sherman Fault" in Republic quadrangle (Muessig, 1967, p. 62-68). They are also correlated with map units 9 and 10 in the Valhalla Gneiss Complex (Reesor, 1965, p. 38-41).

Minor Intrusions

Many varieties of minor intrusions form small bodies and dykes throughout the map area, dykes being extremely numerous and, according to Daly, numbering in the thousands. No attempt to map all or most of the dykes was made; only some of the largest, or those of special petrographic interest, have been plotted. In some localities, as for example in the Trial Pluton north of East Trail, dyke swarms are conspicuous.

Minor intrusions that form the largest bodies in the map area are those that are clustered on and around Blizzard Mountain. They consist of two phases that are apparently intimately associated. The more abundant is a greyish green feldspar porphyry with abundant phenocrysts of white feldspar, and a few of hornblende, in a fine grained matrix. In thin section the feldspar phenocrysts, some of which are almost completely saussuritized, were determined to be andesine (An_{35}), and some chloritization of the hornblende phenocrysts was seen. The groundmass consists of microlites of andesine and some orthoclase. Small amounts of carbonate, sphene, and hematite are present. Tiny veinlets of quartz traverse the rock. The feldspar porphyry is similar in composition but not texture to the andesites of the Marron Formation. The other, less abundant phase, is a dark green aphanitic rock with acicular phenocrysts of hornblende. This rock closely resembles a hornblende andesite that was collected by Fyles from Mount Roberts. These bodies may be volcanic necks that were feeders to the Marron flows. If so, they would be Eocene, but in any case they are almost certainly Tertiary.

Feldspar porphyry, superficially similar to that on Blizzard Mountain, forms a small body on the east side of Mount Sophia. In thin sections, however, it is seen that the plagioclase is more calcic, labradorite to sodic bytownite (An_{55} to An_{73}), but such calcic plagioclases are not uncommon in Marron andesites. Amphibole is largely altered to chlorite. Orthoclase is about half as abundant as plagioclase. Quartz, biotite apatite, and opaque grains comprise not more than 1 per cent of the rock, and there is minor tourmaline and carbonate present.

A short distance west of Paterson there is a small body of augite diorite that intrudes Mount Roberts Formation. It consists of 54% zoned plagioclase (An_{10} to An_{45}), 28% actinolite, 11% augite, and chlorite, opaque minerals, and epidote. This intrusion might also be a feeder to augite andesite flows of the Marron Formation.

It is not possible to comment on the numerous dykes, except that Daly (1912, p. 351) remarked that near International Boundary monument 174 several dykes of augite-biotite monzonite porphyry cutting the Sophie Mountain Formation are similar to latite on Record Ridge. These could be feeders to Marron flows.

STRUCTURE

The structure of Rossland – Trail map area is complex and is difficult to solve due to the general paucity of continuous rock outcrops, particularly in critical places. The area lies between the southwestern part of the Thrust Belt of the Kootenay Arc and the diapiric environment of the Valhalla and Passmore gneiss domes and the southern extension of the Shuswap Complex (Map 1504A, insert).

Faults

The most prominant thrust fault in the map area is the Waneta Fault which was discovered by Fyles and Hewlett (1959, p. 55, 56) and was traced by them intermittently from Waneta northeastward almost to Salmo. It was subsequently traced west of the Columbia River by the writer (Little, 1962) to Moris Creek where it seems to pass underneath Marron lavas before terminating against the Violin Lake Fault. In the northeastern part of the fault, Lower Cambrian sediments of the Laib Formation are thrust over lavas of the Rossland Group, but west of Limpid Creek the overthrust rocks are the Carboniferous(?) sediments of map unit B of Salmo map area (Little, 1965) which is map unit Cs of this report. The same relationship persists to the western termination of the fault. The trace of the fault is sinuous due to its gentle dip, to changes in its strike, and the irregularity of the topography. Fyles and Hewlett (op. cit.) estimate the dip to be 20° to 35° south. They observed the fault some 1825 m east of Waneta dam and described it as a zone 9 to 12 m thick of black, fine grained mylonite containing rounded and eye-shaped fragments ranging in size from a fraction of an inch to a few feet across. This locality is now under water. Near Seven Mile Creek and Ruth Creek, the Waneta Fault has been displaced southward on the west side of north-striking steep faults. The direction of movement on these faults is unknown. Scarcity of outcrops has made it impossible to trace these faults either northward or southward.

Another important thrust fault is the Beaver Creek Fault which is not exposed, but its presence was detected when the Archibald Formation was found to be in contact with the Hall Formation near Bath Creek. The fault strikes southerly near Bath Creek but near Montrose curves to a southwesterly strike, and apparently terminates against a body of Nelson Intrusions that is exposed on the west side of Columbia River. The northern end terminates against the Kelly Creek Fault, which has not been observed, but must exist because Hall Formation is brought into contact with Elise Formation in the lower part of Kelly Creek. The Kelly Creek Fault probably has great right hand displacement, for probably the Elise Formation north of Kelly Creek, which was formerly interpreted in the adjacent Salmo area as being younger than the Hall Formation (Frebold and Little, 1962, p. 9; Little, 1965), has apparently been thrust eastward over the Hall Formation. As this is the same relationship that exists just west of Fruitvale, it appears likely that the contact between Elise and Hall north of Kelly Creek in Salmo map area is the northward continuation of the Beaver Creek Fault. Furthermore, the presence of the Kelly Creek Fault would explain the difficulties encountered in Salmo map area in tracing the Archibald, Elise, and Hall formations southward from Kelly Creek and the high ridges east of that creek. In Salmo map area the overthrust panel of Elise Formation just described dips westerly at moderate angles, as does that on the south side of the Kelly Creek Fault west of Fruitvale. In Salmo area this panel is terminated on the north by the Doubtful Creek Fault, which trends northeast, apparently dips steeply, and is of large displacement. It has not been possible to trace this fault accurately into Rossland – Trail map area, but it lies approximately 2.5 km north of Kelly Creek. To the west, across Beaver Creek Valley it could not be detected, but it may coalesce with the Kelly Creek Fault.

West of Red Mountain a thrust fault, which is unnamed, was suspected (Little, 1962), and Fyles (1970) agreed with this interpretation. The strike is northerly and the dip must be west. It has carried a panel of Mount Roberts Formation and overlying basal Elise Formation eastward over Elise lavas. The central part of the fault has been cut off by a steeply dipping, north-striking fault, along the east side of which a wide dyke of alkali syenite has been intruded. The thrust fault terminates on the south against a body of serpentinite and disappears under Marron lavas to the north. The steeply dipping fault has been traced by Fyles (1970) from a point about 1.5 km south of Hanna Creek southward to the south slope of Deer Park Hill.

The Violin Lake Fault has been traced from the International Boundary northward to Violin Lake where its strike changes to north-northwesterly. The main fault is believed to follow Cambridge Creek, but a branch to the east seems to displace the contact between Rossland Monzonite and the Trail Pluton. It has been seen near Hanna Creek where, both north and south of the creek, porphyritic augite monzonite is in faulted contact with granodiorite of the Trail

Pluton. Where observed, the dips are vertical, or nearly so. The direction and amount of displacement on the Violin Lake Fault is not known.

The Champion Lake Fault strikes north and dips steeply. It extends from the north edge of the Trail Pluton to the north border of the map area, and has been traced by Simony (1979, Fig. 2) northward beyond Castlegar. It brings the Bonnington Pluton and Elise Formation on the east side into contact with Trail Gneiss on the west. Based on his model of the structure and the conjectured age of the Trail Gneiss, Simony deduced that the Champion Lake Fault is a west-side-down normal fault with about 5000 m dip slip. Furthermore, he concluded that the fault movement occurred before emplacement of the Trail Pluton which is displaced little if at all, and after emplacement of the Bonnington Pluton which is clearly faulted at the west end. The writer can see no way in which 5 km of dip slip can be absorbed without similarly disrupting formations of the Rossland Group to the east, south, or southwest, or the Mount Roberts Formation to the west, and there is no such disruption. It is concluded that the Champion Lake Fault is a hinge fault and that the maximum displacement cannot be so great.

Folds

Attitudes of the compositional layering in the Trail Gneiss indicate the structure to be a broad antiform that plunges gently north, the east limb being cut by the Champion Lake Fault. Simony (1979, Fig. 2, 4) confirms this and has traced the antiform northerly across the Columbia River into Castlegar Gneiss and for several kilometres to the mountains northwest of Castlegar.

Simony (op. cit., Fig. 2) by detailed study of the Mount Roberts Formation north of Red Mountain, identified an anticline, overturned to the east, which he traced northward to the Mackie Pluton. He also identified a matching, sub-parallel syncline, also overturned 1.5 to 3 km to the east.

Elsewhere in the map area few folds have been identified. In the Elise Formation, a syncline trending northeast with a vertical southeast limb and an overturned northwest limb is indicated by bedding attitudes and top determinations on Baldy and Lake mountains. A basin-like open synclinal structure with the centre near the southeast corner of Champion Lakes Park is indicated by bedding attitudes and distribution of sedimentary members of the Elise Formation.

The structure of the main mass of Marron lavas from Record Ridge to Mount Kirkup is also basin-like particularly on the eastern and southern sides.

REGIONAL METAMORPHISM

The Trail Gneiss of Simony (1979), which he regarded as basement of Hudsonian age, and which is certainly pre-Pennsylvanian, is everywhere of amphibolite metamorphic grade, which may be retrograde. Garnets are ubiquitous in aplitic and pegmatitic phases of the gneiss.

Small masses of granitic gneiss and amphibolite encased in granodiorite occur within the Bonnington Pluton and the eastern part of the Trail Pluton as well as in the central part of the Mackie Pluton. They would appear also to be of amphibolite grade, but their origin is unclear.

Metamorphic zoning is, however, evident in the Mount Roberts Formation, as described by Simony (1979), and further data have been provided to the writer by him. South of Rossland, the metamorphic grade is greenschist facies, passing into the biotite facies at Rossland, then into the garnet facies on the ridge north of Hanna Creek and the lower slopes on the north side of lower Murphy Creek. North of a line extending from the mouth of Elgood Creek to the mylonitic Trail Gneiss 1.6 km west of the mouth of Sullivan Creek, the Mount Roberts Formation changes from low grade metasediments to gneisses in which conglomerate beds can still be discerned. These rocks are exposed north of the Mackie Pluton, and south of China Creek Simony discovered sillimanite in pelite on the north side of the 5100-foot high hill that is 3.25 km west of the bridge where highway 3 crosses China Creek. From a little north of that point to the north edge of the map area the gneissic Mount Roberts loses its identity and passes into granitoid augen gneiss that Simony (1979, p. 7) has named the Castlegar Gneiss. He gave evidence also that some of the Trail Gneiss is incorporated into the Castlegar Gneiss, which he described as follows:

"The most important rock types.....are biotite gneiss and hornblende-biotite gneiss with 5-30% potash feldspar porphyroblasts. One to two percent garnet in grains up to 2 mm in diameter are irregularly scattered through the gneisses. The feldspar megacrysts are ovoid and locally have an envelope of small quartz and plagioclase grains and biotite flakes that contribute to the augen texture. The augen are not relicts in mylonitized rock. Potash feldspar replaced adjacent grains and plagioclase in contact with it has myrmekite 'cauliflowers' facing the potash feldspar. Such replacement textures and the presence of potash feldspar megacrysts scattered through a variety of rock types suggest that a potash feldspar blastesis event took place in a previously tectonized gneiss complex."

Elsewhere in the map area, the regional metamorphism is represented almost everywhere by the greenschist facies.

CONTACT METAMORPHISM

Thermal effects related to the intrusion of the Rossland Monzonite were studies by Fyles (1971) who noted that extensive secondary biotite was generated in siltstones invaded by the monzonite. On the southern and northern sides of the pluton the aureole is less than 450 m wide, but on the west side it is much wider. Fyles suggested that the contacts of the pluton probably dip steeply on the north and south, and gently to the west. On the south side of the smaller pluton that is southeast of Trail, the Elise Formation is highly schistose, and much biotite has been formed.

Contact metamorphism surrounding the Nelson Intrusions is less evident and, as Fyles remarked, the aureoles are not as wide as with the Rossland Monzonite. In some places the thermal effects are evident, however, such as along and near the northeast contact of the Trail Pluton, where siltstones have been metamorphosed to hornfels. Similar hornfels was noted in places along the south edge of the Bonnington Pluton. Around the Mackie Pluton contact metamorphism is masked by regional metamorphism.

Sheppard Intrusions are shallow and show little if any effect upon the intruded rocks. Similarly the Coryell Intrusions are epizonal and Fyles has remarked that the metamorphic aureole is narrow, despite the large mass of the batholith. Even where limestone beds are invaded, as in the valley of Lamb Creek, the limestone is virtually unaffected.

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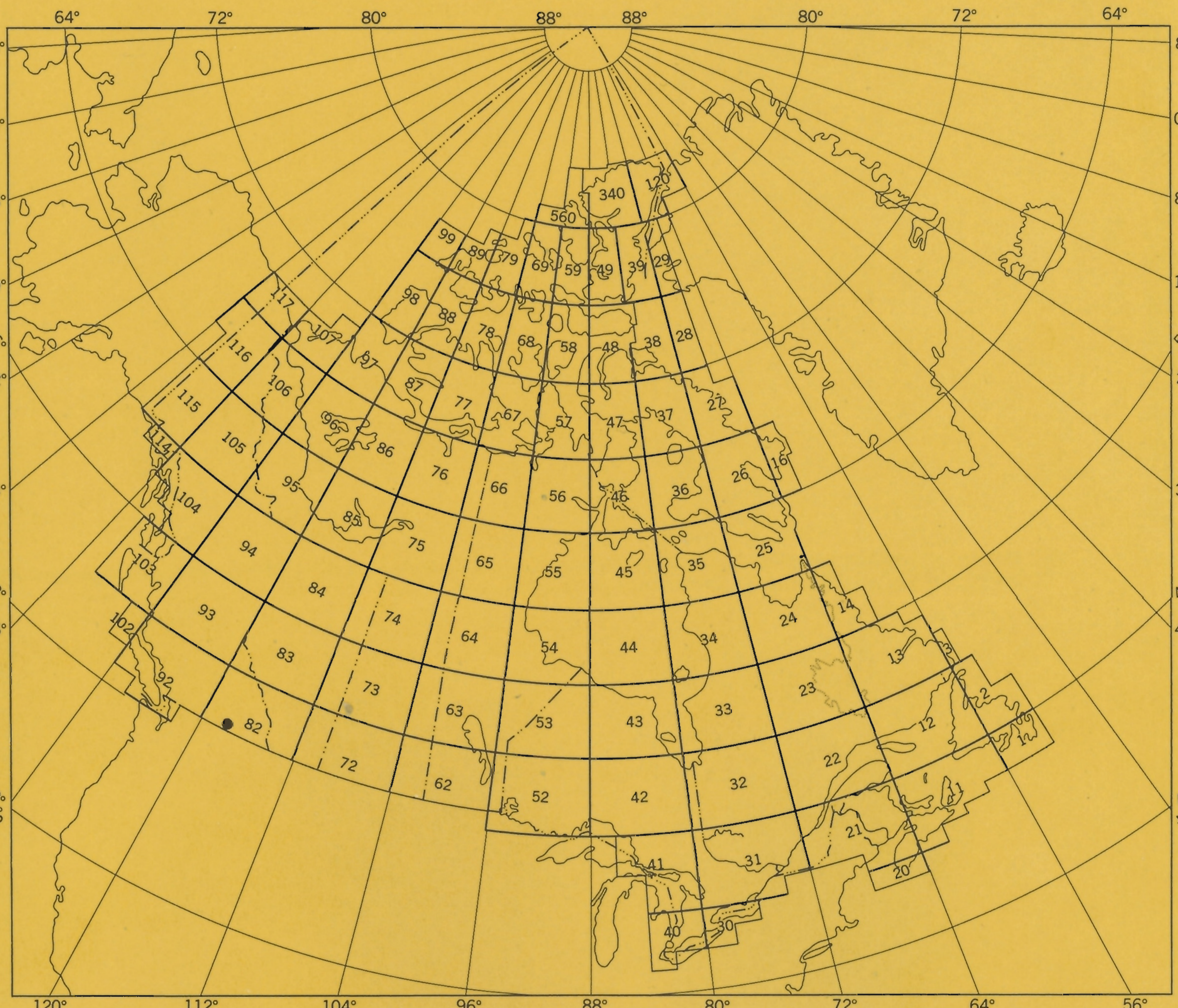

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