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GEOLOGY OF THE GREENWOOD MAP-AREA BRITISH COLUMBIA

H.W. LITTLE

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J.W.H. Monger

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GREENWOOD MAP AREA, BRITISH COLUMBIA

Abstract

Greenwood map area covers an area of about 1000 km^2, almost totally within the Monashee Mountains of southeastern Mountains British Columbia.

Paragneiss, migmatite, granitoid gneiss, amphibolite and marble, together with lower grade metamorphic rocks such as chlorite and mica schist, greenstone, and hornfels, occur generally in the northern part of the map area, where they are associated with Mesozoic granitic rocks. Chert, greenstone, and amphibolite, associated with fossiliferous limestone and argillite of Permo-Carboniferous age are widespread, as are sharpstone conglomerate, black siltstone, and limestone, with local chert-grain sandstone, green argillite and minor volcanic rocks of Triassic age. Jurassic (?) andesitic to basaltic flow breccia and massive volcanics are in the southeastern part. These rocks are crosscut by ultramafic and intermediate to acidic plutonic rocks of Jura-cretaceous age.

Feldspathic and lithic tuffaceous sandstone and siltstone, and, locally, shale and conglomerate comprise the basal formation of the Middle Eocene succession, which consists mainly of sodic trachyte, andesite, and trachyandesite, minor phonolite and tuff. These rocks are invaded by related hypabyssal and plutonic rocks, mainly syenite, quartz monzonite and pulaskite, but diorite is also present. The youngest rock is an epiclastic breccia (olistostrome) also of Middle Eocene age.

The bases of the Triassic and Jurassic (?) sedimentary and volcanic assemblages appear to be unconformities, and another unconformity is indicated within the Triassic. The angular unconformity at the base of the Middle Eocene is clearly exposed in many places.

Post-Middle Eocene block faulting has left a strong imprint, and obscures earlier structures that were formed by penetrative deformation and metamorphism.

Résumé

La coupure cartographique de Greenwood couvre une superficie d'environ 1 000 km^2 , qui tient presque entièrement dans la chaîne de Monashee dans le sud-est de la Colombie-Britannique.

En général, on trouve du paragneiss, de la migmatite, du gneiss granitoïde, de l'amphibolite et du marbre, ainsi que des roches moins métamorphisées comme de la chlorite et du micaschiste, des roches vertes et des cornéennes dans la partie nord de la région cartographiée, où ils sont associés aux roches granitiques du Mésozoïque. On rencontre également beaucoup de chert, des roches vertes et d'amphibolite associés à du calcaire et à de l'argilite fossilifères du Permo-Carbonifère, de même que des conglomérats à éléments anguleux, des silstones noirs et du calcaire avec, à certains endroits, du grès à grain siliceux, de l'argilite verte et un peu de roches volcaniques du Trias. La partie sud-est contient des roches volcaniques massives et des brèches éruptives jurassiques (?) de composition andésitique à basaltique. Ces roches sont entrecoupées de roches ultrabasiques et de roches plutoniques, neutres à acides, du Jura-Crétacé.

Des silstones et des grès tufacés feldspathiques et à blocs et, par endroits, des schistes argileux et des conglomérats composent la formation basale de la succession de l'Eocène moyen, qui consiste surtout en trachyte sodique, en andésite et en trachyandésite, en un peu de phonolite et en tuf. Ces roches sont envahies de roches plutoniques et hypabyssales parentes, en particulier la syénite, la monzonite quartzifère et la pulaskite, ainsi que la diorite. La roche la plus récente est une brèche épiclastique (olistostrome) qui date également de l'Eocène moyen.

La base des assemblages volcaniques et sédimentaires triasiques et jurassiques(?) semble être discordante. Une autre discordance semble exister dans le Trias. La discordance angulaire à la base de l'Eocène moyen est bien à découvert en beaucoup d'endroits.

Le morcellement par failles survenu après l'Eocène moyen a laissé de profondes empreintes, obscurcissant les structures antérieures créées par déformation pénétrante et métamorphisme.

INTRODUCTION

Greenwood map area encompasses about 100 km^2 in southeastern British Columbia. It is bounded by 49°00' (International Boundary) and 49°15' north latitude and by 118°30' and 119°00' west longitude Fig. 1).

During 1:250 000 scale reconnaissance by the writer and his assistants in 1954-56, it became evident that the complexity of the geology of Greenwood area demanded a more careful study, and the opportunity to do so was gratefully accepted during 1963-65. The results of that work are embodied in this report, and one by Monger (1968).

Location and Accessibility

The city of Greenwood, is 6.5 km east-southeast of the geographic centre of the area, and is the largest community. It is served by the Kettle Valley Railway, the more southerly transprovincial line of the Canadian Pacific Railway, but passenger service is no longer offered. Rail service by the C.P.R. to the mining properties at Deadwood and Phoenix was long ago withdrawn and the lines abandoned, as was done also by the Great Northern Railroad both to Phoenix and to Midway and points along the south side of Kettle River to the west.

Transprovincial Highway 3, a well-engineered paved road, traverses the area from Rock Creek on the west edge of the map-area, through Greenwood to the city of Grand Forks, which is a few miles east of the area. It provides good access to the west, to the Okanagan Valley and Vancouver which is about 480 km distant, and to the cities of the Kootenays and to Calgary, Alberta, which is about 800 km to the east.

Highway 33, also paved, extends up Kettle River from Rock Creek to Westbridge, thence to Beaverdell and Kelowna. Elsewhere good gravel roads are in the valleys of the main streams, and there is an extensive network of secondary logging and mining roads to most parts of the area.

In 1976 Greenwood had a population of 919; Grand Forks, had a population of 3,066. Other communities are Midway (592), Rock Creek (162) and Westbridge (46), the latter two from the 1971 census.

History of Mineral Production

The history of mineral production in the area began with the discovery of placer gold in Rock Creek in 1859 or 1860 (Holland, 1950, p. 36), immediately west of the south-west corner of the map area. Bauerman (1885, p. 36B) reported that in September 1861 about 300 men were at work at Rock Creek, but that a year later the place was deserted. Production continued intermittently until 1941.

Within the map area placer operations began in Boundary Creek in 1862 but there are no records of early production. Recorded production, according to Holland, is 328 ounces valued at $8,277 from Boundary Creek, and 78 ounces valued at $2,346 from May Creek, a tributary of July Creek. He further stated that "no gold production has been recorded from . . . . . Jolly [Jack] Creek, Kettle River, and Norwegian Creek, yet placer activity has been noted on them".

Prospectors began to turn their attention to lode deposits after discoveries along Kootenay Lake in 1882 and 1883 and near Nelson in 1885. The first claims located within the area in 1884 were the Rocky Bar (later the Tunnel), and the Non-such, both near Boundary Falls.

In 1891 prospecting activity accelerated in Greenwood map area and the Mother Lode, Crown Silver, Sunset, Knob Hill, Old Ironsides, Stemwinder, Brooklyn, Idaho, and War Eagle claims were recorded (LeRoy, 1912, p. 14, 15). During the next few years numerous claims were located and by 1900 all the important mines had been developed (McNaughton, 1945, p. 1). Production was stimulated by the completion of branch lines of the Canadian Pacific Railway to Phoenix, Deadwood, and other mining camps in 1898 to 1900, and later by a branch line of the Great Northern Railroad in 1904. The Granby smelter at Grand Forks, which became the largest nonferrous smelter in the British Empire, was "blown in" in August 1900, with self-fluxing ore from Phoenix. In February 1901, the British Columbia Copper Company's smelter at Greenwood began treating ore from the Mother Lode deposit. The Pyrite smelter at Boundary Falls, about 5 km south of Greenwood, was completed in 1901 but remained idle (Brock, 1903, p. 137A), until taken over the following year by the Montreal and Boston Copper Company.

According to McNaughton, "production from the Phoenix district reached a peak in 1913, when 1 250 000 tons of ore were mined and shipped, and slowly decreased thereafter. In 1919, when [known] available ore reserves were approaching exhaustion, labour strikes in the Crowsnest coalfield cut off the supply of coke for the Granby smelter and forced the operators at Phoenix to abandon the mines". Ore production from Boundary district as a whole in 1913 by far exceeded that of any other district in British Columbia, but suffered a parallel decline in production with that of Phoenix.

Development work on the mineral deposits was desultory thereafter for many years. The rise in the price of gold in 1933 resulted in renewed activity on some of the gold and silver deposits. Direct shipping ores were dispatched to the smelters from several of the properties, and small mills were erected at the Providence, Dentonia, and North Star properties from which concentrates were shipped. The renewed activity was, however, comparatively small and decreased early in World War II as a result of shortages of machinery and labour.

Favourable prices for copper in the early 1950's led to further exploration and development in the Greenwood area. Granby Consolidated Mining, Smelting and Power Company (more recently called the Granby Mining Corporation) again acquired the Knob Hill-Old Ironsides property, the Idaho, Brooklyn, and Snowshoe properties, and, lastly, in 1976, the Ore Denoro. These were operated by a subsidiary company, Phoenix Copper Company Limited, and the ore was treated at a mill which commenced operation at Phoenix in 1959, as well as custom ore from the Stemwinder and Rawhide mines. The mill capacity was increased from 900 to 2,750 tons per day in 1972. The ore from all those properties was exhausted in 1976, and since then, only ore from the Morning Star mine, immediately south of the International Boundary in the State of Washington, has been treated.

In 1957, a 1000-ton mill built on the Motherlode property in Deadwood camp was opened, but the owners, Woodgreen Copper Corporation Ltd. were forced to close a few months later, due to falling copper prices and mining problems, which caused bankruptcy. In 1959, the company was reorganized and named Consolidated Woodgreen Mines Limited. The mill was reopened, operating at about half capacity until it was again closed in 1962 and was moved to Mount Washington. The Mother Lode and the adjoining Sunset and Greyhound properties were acquired by Aabro Mining and Oils Limited in 1968, and a new 1500-ton mill was completed early in 1970, which began treating ore from the Greyhound in September. The owner at that time was Greyhound Mines Limited, which went into liquidation in 1971, having ceased operations in January.

Previous Geological Work

The first geological report of that region was that of Bauerman (1885) who accompanied the Boundary Commission Expedition of 1859-61. A geological cross-section adjacent to the Forty-ninth Parallel accompanied the report.

In 1901, Brock (1902), having in 1900 completed field work in the West Kootenay area immediately to the east, began, late in the summer, a reconnaissance of the adjoining Okanagan map-sheet. The following year, despite illness following sunstroke, he (Brock, 1903, 1905a, b) mapped the Boundary Creek sheet, on a topographical base provided by W.H. Miller, on a scale of 1 inch to 1 mile.

A survey of the geology adjacent to, and mainly north of the International Boundary was made in 1901-06 by Daly (1912), who, as Brock's map was already published, confined himself to two rapid traverses across the mountains between Midway and Grand Forks, but did more detailed studies of an 8 km wide belt west of Midway.

In 1908, LeRoy (1912) carried out detailed mapping (1 inch to 400 feet) of the Phoenix mining camp, followed by short visits in 1909 and 1910. In the latter year he (LeRoy, 1913) studied the Deadwood camp, the areal and detailed, geological mapping, being done by C.W. Drysdale. McNaughton (1945) in 1936 extended LeRoy's mapping at Phoenix, especially to the west, and his work was published on a scale of 1 inch to 800 feet.

In 1951 Seraphim (1956), together with the late W.H. White, began a program of geological mapping and exploration for Attwood Copper Mines Limited and published a sketch map on a scale of about 1 inch to 1400 feet of the Phoenix area, in which new interpretations of the geology were presented. He also prepared unpublished maps of the B.C. basin camp to the northeast, and of Deadwood camp. The geology of the adjacent Summit camp was mapped at 1 inch to 1000 feet by the late H.T. Carswell (1957) for Noranda Mines Limited.

Reinsbakken (1970) prepared a geological map at 1 inch to 2000 feet of the Grand Forks-Eholt area, which lies between July Creek and Granby River, between the International Boundary and Brown Creek. This was based on field work done the previous year for Texas Gulf Sulphur Company.

Detailed mapping of small areas adjacent to the major mines has been done over a period of many years by geologists of the British Columbia Ministry of Mines and Petroleum Resources. The largest of the areas thus mapped, the McCarren-Goosmus Creek area, was published by Church (1970).

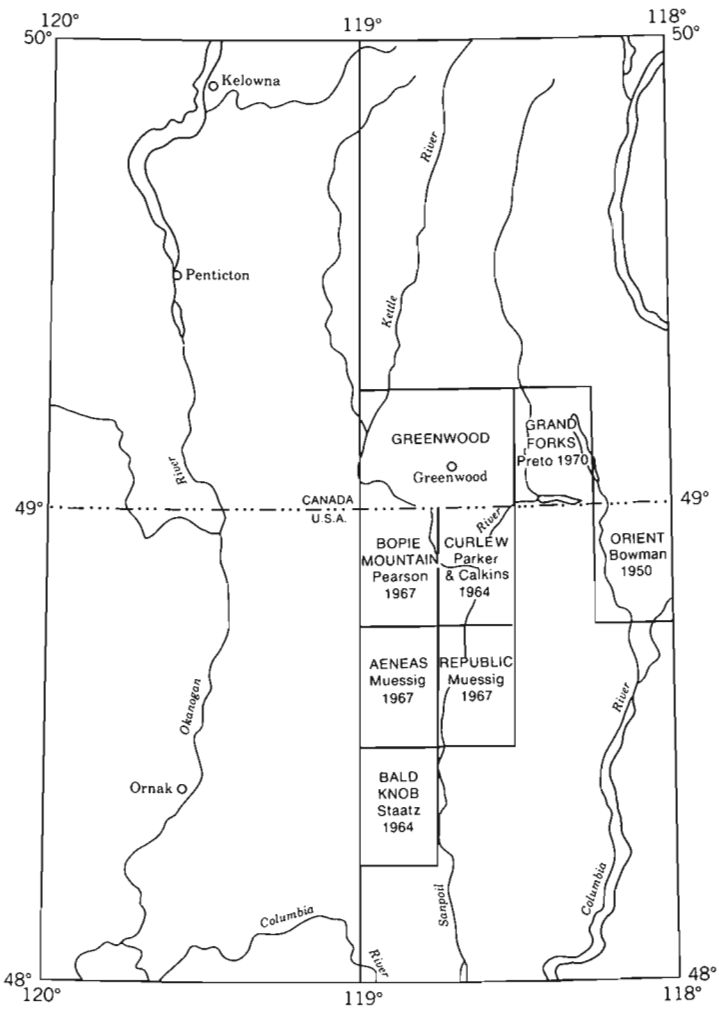

Figure 1. *Index map of Greenwood map area and nearby areas mapped in scales of 1:50 000 or 1:62 500.*

Present Field Work

During 1:250 000 scale reconnaissance mapping of Kettle River area (east half) in 1955, the writer (Little, 1957) made a brief examination of the geology of Greenwood map area, but owing to its extreme complexity and the limited time available, was unable to do more than generalize the geology.

The writer returned to Greenwood area to begin a more detailed study in 1963 with R.I. Thorpe who in that year mapped independently parts of the east half of the area (Little and Thorpe, 1965). The work was continued in 1964 and 1965. In the latter year J.W.H. Monger (Monger, 1968; Little and Monger, 1966) resolved the stratigraphy and structure of the stratified Tertiary rocks which lie mainly in the west half of the map area. The project was completed by the writer under a contract with the Geological Survey of Canada.

Acknowledgments

The many courtesies of the residents of the area are gratefully acknowledged, especially the geological staff of Phoenix Copper Company and J. Paxton in particular. R.H. Seraphim kindly supplied copies of his unpublished maps of B.C. Basin and Deadwood camp. The writer was ably assisted in 1964 by R.I. Thorpe and B.F. Watson, in 1964 by V.A. Preto, and in 1965 by J.W.H. Monger and A.N. LeCheminant, and, during the latter part of the season, R.G. Wilkins. Thorpe and Monger carried out independent mapping, assisted by Watson and LeCheminant, respectively. A re-examination of fossils collected in 1963 and 1964 was made by E.T. Tozer and E.W. Bamber of the Geological Survey, who culled material from the collections for testing for the presence of microfauna. Processing and examination of this and additional material collected in 1977 was done by Joanne Jenkins of the Geological Survey. Unfortunately, no diagnostic microfauna were found.

The writer is most grateful to B. Neil Church, of the British Columbia Ministry of Mines and Petroleum Resources who, in 1976, showed him new data in the field and engaged in many fruitful discussions. Thanks are due also to G.R. Peatfield of Texasgulf Canada Limited who outlined his structural interpretation of the Grand Forks-Eholt area. J.W.H. Monger of the Geological Survey provided constructive criticism and advice.

Physiography and Glaciation

The mountainous terrain east of the Kettle River was named the Midway Mountains by Daly (1912, p. 38, 39), a subdivision of his Columbia "System" which extended eastward to the Columbia River at Trail. The small part of the map area west of the Kettle River, and south of it in the southwest corner of the area, was placed by him in the "Interior Plateaus". Holland (1964) named these parts the Monashee Mountains, a subdivision of the Columbia Mountains (which include the Selkirk and Purcell mountains), and, the less rugged terrain to the west, the Okanagan Highland. The latter name is applied south of the International Boundary to the entire region that stretches from the Okanagan River to the Columbia (Pardee, 1918, p. 14-17). Bostock (1970) uses the term Columbia Mountains and Columbia Highland (rather than Okanagan Highland). The subdivisions of the Columbia Mountains are not given, presumably due to the small scale of the map.

The dominant features of the map area are the valleys of Kettle River and Boundary Creek. Kettle River flows southward near the west edge of the area, thence eastward north of the International Boundary, which it crosses near

Midway. Boundary Creek, its large tributary, flows southward through the city of Greenwood and roughly bisects the map area. These valleys appear to be largely fault-controlled, and have been modified by glaciation. They are characterized by eskers, kame terraces, and kettles. Jewel Lake, which is more than 3 km long, and the only sizeable lake in the area, lies at an elevation of about 840 m, and results from moraines blocking the valley.

The topography is fairly mature, and most peaks are rounded by glacial action. Only one small cirque was observed, on the northeast side of the highest peak, but the alpine glacier that carved it vanished long ago.

The lowest point in the map area, about 530 m above sea level, is in the valley of Kettle River at Carson, in the southeast corner, and the highest point is an unnamed peak, locally known as Nancy, about 6.5 km west of the northeast corner of the area. It is about 6850 ft (2090 m) above sea level. The relief is therefore moderate, a maximum of 1550 m.

During the Pleistocene epoch the Cordilleran ice mass covered even the highest peaks, so that the upper surface reached an elevation of at least 2000 m in the northern part of the map area. This ice mass did not, however, extend more than 110 or 130 km south of the International Boundary.

Numerous glacial striae, occasional roches moutonnees, and two small scale examples of crag and tail provide evidence of continental glaciation. Such features are rare in the west half of the map area where the Tertiary rocks do not appear to lend themselves to the formation of such structures. There, the ice movement was to the south. In the east half of the map area, however, these features are abundant. They indicate that ice flow was strongly influenced by topography, and, although generally southerly ranged from 100° to 235° (see Fig. 2). In three places, striae of two ages were found. On an outcrop 2.4 km at 247° from the Greenwood smelter chimney, early striae strike 185°, whereas later striae strike 205°. About 1.6 km at 291° from the mouth of May Creek, early striae strike 230°, and later striae strike 185°. About 0.8 km at 054° from Boundary Monument 147, early striae strike 140° and later striae strike 105°. The significance of these data is not clear. It is the only evidence suggesting two periods of glaciation in the region and is suspect because in the first example, later movement was more easterly, whereas in the other two examples, later movement was more westerly.

Late, or Classical, Wisconsin glaciation reached its maximum about 20 000 years ago (Prest, 1970, p. 678), but there is no indication when glaciation began in Greenwood map area. Recession of the ice mass began about 11 500 years ago, and the ice front had retreated north of the map area by 10 500 years ago (Prest, 1970, Fig. XII).

Ground moraine, composed almost entirely of till, is widespread throughout the map area, and in places appears to be of considerable thickness, especially in valleys transverse to the ice movement, resulting in generally poor or limited exposures of the bedrock. Deglaciation features are evident in many of the valleys, particularly those of Kettle River and Boundary, Eholt, and July creeks. Most common are kettled hummocky moraines and drumlinoid moraines. Such a moraine led to the formation of Jewel Lake, which is not a deep lake, being 19.5 m deep near the northeast end (Brock, 1903, p. 95A). Kames are also evident in the main valleys, and a few small eskers were noted. Lacustrine sand deposits are well exposed in places along the valley of Kettle River and at Boundary Falls. In the valley of Kettle River, above the main terraces, there are two lateral overflow channels.

In the fresh cuts of roads and streams at lower elevations, a widely distributed layer of white volcanic ash is seen in till just below the soil. This ash is up to 5 cm thick, except in a road cut on the east side of Kettle River at the bend 6.5 km north of the bridge over the Kettle at Rock Creek. There, a pod-like mass of ash 0.6 m or more thick is exposed, probably the result of slumping soon after deposition. A similar white ash in till is described by Rigg and Gould (1957) in the State of Washington. This consists of glass shards of acidic composition and some generally euhedral crystals of andesine, hypersthene, hornblende, magnetite, and augite. It was erupted from Glacier Peak, west of Lake Chelan, and peat immediately below the ash at two localities in Washington yielded ^{14}C ages of 6950 ± 200 and 6500 ± 200 years B.P., respectively.

GENERAL GEOLOGY

Metamorphic, sedimentary, and intrusive and extrusive igneous rock units, ranging in age from possibly late Proterozoic to Middle Eocene are summarized in the Table of Formations. They can be grouped into seven assemblages, separated by intervals of deformation and/or regional metamorphism. The oldest(?) of these is the granitoid gneiss unit Pm[1] of which part may represent the widespread late Proterozoic-early Paleozoic succession of southeastern British Columbia, but some of these gneissic rocks may be as late as Permian, metamorphosed by granitic intrusions of Jura-Cretaceous age.

The relationship of the granitoid gneisses to the amphibolite unit **P**a and the schist unit **P**m is not known. These units differ lithologically and are in general more highly metamorphosed than the Attwood Formation and Knob Hill Group. The metamorphism and deformation of map units Pa and Pm is believed to predate the Attwood and Knob Hill; it is, however, possible that units Pa and Pm, though more highly metamorphosed, are different facies of the Knob Hill Group.

The second assemblage comprises the Attwood Formation and the Knob Hill Group, both of which have yielded fossils of Carboniferous of Permian age. It may contain a disrupted ophiolite suite with which some or all of the ultramafic rocks may be associated. This assemblage was deformed and apparently eroded before deposition of Early Mesozoic rocks.

The third assemblage, the Brooklyn Formation, rests unconformably upon the Knob Hill Group. The lower part consists of the sharpstone and Rawhide members, of Middle, and possibly Lower, Triassic age. The underlying unconformity is widespread in the Western Cordillera.

The fourth assemblage, map unit uTsv, is limited in extent and includes limestone, shale, and some pyroclastic rocks of Upper Triassic age. It is believed to overlie unconformably the Brooklyn Formation.

The fifth assemblage, the volcanic map unit Jv, is correlated lithologically with the Jurassic Rossland Group to the east. It rests upon other units ranging from pre-Permo-Carboniferous (?) to Upper Triassic.

All these assemblages were affected by the widespread Jura-Cretaceous orogeny during which ultramafic, and Nelson and Valhalla intrusions were emplaced. It is possible that the ultramafic bodies were emplaced by a process of cold intrusion.

The sixth assemblage clearly rests unconformably upon Mesozoic and older formations. It consists of the basal Kettle River and the Marron formations of Middle Eocene age. Contemporaneous intrusions include numerous small bodies of syenitic to dioritic composition and plutonic bodies of the Coryell.

[1] Certain symbols used on the map to designate map units are difficult to reproduce in a printed text. These will be referred to by using the closest conventional type.

TABLE OF FORMATIONS

ERA	PERIOD OR EPOCH	GROUP OR FORMATION	MAP UNIT SYMBOL	LITHOLOGY	THICKNESS (metres)
CENOZOIC	PLEISTOCENE AND RECENT			Till, sand, gravel, silt	
	EOCENE Middle	Klondike Mountain Formation	Ekm	Heterogeneous epiclastic breccia of pre-Permian to Middle Eocene rocks	900+
		NON-EROSIONAL UNCONFORMITY WITH MARRON FORMATION			
		Coryell Intrusions	Ec	Syenite, quartz monzonite; minor granite and pulaskite	
		Intrusive equivalents of Marron Formation	Emi	Alkaline syenite, syenite, diorite, and diorite porphyry	
		INTRUSIVE CONTACT			
		Marron Formation	Emv	Soda trachyte, andesite, trachyandesite; minor phonolite and tuff	1525±
		Kettle River Formation	Ekrs	Feldspathic volcanic sandstone, lithic volcanic sandstone, shale, conglomerate	90 to 1200
		UNCONFORMITY			
	CRETACEOUS OR TERTIARY	Map-unit KTi	KTi	Quartz-feldspar porphyry, quartz porphyry, felsite	
MESOZOIC		RELATIONSHIP UNKNOWN			
	CRETACEOUS (?)	Valhalla Intrusions	Kvqm	Granite and quartz monzonite, mainly porphyritic; some pegmatite	
		INTRUSIVE CONTACT			
	JURASSIC AND/OR CRETACEOUS	Nelson Intrusions	JKgd	Granodiorite; minor quartz diorite and diorite	
		INTRUSIVE CONTACT (?)			
	JURASSIC (?)	Ultramafic Intrusions	Jum	Peridotite, pyroxenite, dunite, serpentinite	
		INTRUSIVE CONTACT WITH MAP UNIT Jv (?)			
		Map-unit Js	Js	Siltstone; minor phyllite, sandstone, and conglomerate	300–
		Map-unit Jph	Jph	Black phyllite	500–
		Map-unit Jv	Jv	Flow breccia and massive greenstone; basal (?) conglomerate with limestone clasts; flow breccia with minor interbedded limestone	330+
	TRIASSIC Upper	UNCONFORMITY			
		Map-unit uTsv	uTsv	White limestone, black limestone, grey, black, and buff shale, limestone breccia, purple to maroon agglomerate, minor green cherty argillite	330+
		UNCONFORMITY			
	Middle	Brooklyn Formation	mTl	Limestone, containing some chert grains, skarn; minor chert and sharpstone conglomerate, siltstone, and shale	660
	Middle and (?) Lower		mTs	Sharpstone conglomerate with mainly chert clasts; local chert sandstone; minor black argillite and green argillite	760
		INTERBEDDED WITH RAWHIDE FORMATION; UNCONFORMABLE WITH KNOB HILL GROUP			
	Middle	Rawhide Formation	mTr	Black siltstone; minor black argillite and chert sharpstone conglomerate	120–
PALEOZOIC	CARBONIFEROUS OR PERMIAN	Knob Hill Group	CPkh	Massive chert, greenstone, and amphibolite; minor limestone or marble; locally tan or black argillite, fine grained quartzite, conglomerate	?
		Attwood Formation	CPa	Black to grey bedded argillite; locally some grey chert and cherty siltstone; minor chert sharpstone conglomerate; limestone, with some thin chert interbeds	1000+
		UNCONFORMITY (?)			
	PRE-CARBONIFEROUS (?)	Map-unit Pm	Pm	Quartz-chlorite schist, quartz-biotite-muscovite schist, greenstone, bedded chert with argillaceous partings; minor limestone or marble	?
		RELATIONSHIPS UNKNOWN			
		Map-unit Pa	Pa	Amphibolite; minor greenstone, and bedded chert	?
		RELATIONSHIPS UNKNOWN			
PRECAMBRIAN		Map-unit Pm	Pm	Paragneiss, migmatite; some amphibolite with pegmatite or aplite	?

GSC

The youngest assemblage is of limited extent within the map area. It is an epiclastic breccia (recently defined in the literature as an "olistostrome") resulting from a landslide, it rests upon the Marron Formation and is also of Middle Eocene age.

All rocks, Middle Eocene and older, have been affected by block faulting that resulted from crustal tension, and by arching over Middle Eocene intrusive bodies.

Deposits of Pleistocene age consist mainly of till, which is spread widely over the area. In the larger valleys outwash sand, silt, and gravel, and a few kames, eskers, and drumlinoid moraines were noted.

Map Unit Pm

Map unit Pm comprises granitoid gneisses and related metamorphic and intrusive rocks of unknown and possibly various ages that form clusters of outcrops scattered over parts of Greenwood map area.

Map unit Pm1 occurs along the central western margin of the map area north of Ed James Creek in a zone that is a little over 1 km wide 3 km long. Map unit Pm1 consists of layered quartz-biotite-hornblende-feldspar gneiss but in some outcrops the layering becomes less distinct and the rock passes into a foliated biotite-hornblende granodiorite. These rocks are intruded by dykes and somewhat larger bodies of aplite. In the gneiss, folds of a few inches in amplitude trend northeasterly. Within the limited area of rock exposures no minerals indicating the metamorphic grade, other than garnet and hornblende, were seen.

The layering in the gneiss in general strikes northeasterly and dips gently northwest. The gneiss is bounded on the east by Eocene strata from which they are separated by an unnamed, northerly-trending fault that is not exposed. Immediately west of the map area near the north end of the gneiss zone is coarse grained granite, which was previously mapped as Valhalla (Little, 1961). A steep-walled, boulder-filled valley separates the granite outcrops from those of gneiss, and is probably occupied by a fault.

In the area to the west, Cairnes (1940) classified the rocks as "undivided Shuswap [Complex], mainly granite-gneiss, granodiorite-gneiss, pegmatite". There, it is interposed between two extensive areas underlain by a heterogeneous assemblage of schists, argillite, quartzite, conglomerate, limestone, lava, tuff, and basic intrusions that were assumed to be of Carboniferous age. The gneisses were believed to be metamorphosed equivalents of the Carboniferous (?) assemblage, with the metamorphism being related to Mesozoic plutonism (Cairnes, 1939, p. 269, 270). The writer agrees with this interpretation.

Map units Pm2 and Pm3 are exposed in scattered outcrops that extend from the north side of Clement Creek Valley west northwestward along the north side of Windfall Creek to the north side of the upper part of the unnamed valley west of the head of Windfall Creek. They consist of medium- to fine-grained granitoid gneiss and coarse grained amphibolite, respectively. The granitoid gneiss of map unit Pm2 is composed of thin, alternating mafic and felsic layers. Plagioclase (andesine) is most abundant, followed by quartz, orthoclase, hornblende, and biotite. Accessories are apatite and sphene. Almandine is widespread. The amphibolite of map unit Pm3 is coarse grained and contains much hornblende and some plagioclase. It is commonly cut by dykes of aplite and pegmatite that appear to be related to the Valhalla Intrusions.

Map unit Pm4 is exposed in two large outcrops in the southeast corner of the map-area north of highway 3. The dominant rock is medium- to coarse-grained granitoid gneiss in which hornblende needles are abundant and aligned, and plunge gently east-southeasterly and also in the opposite direction. The gneiss is garnetiferous and, locally, somewhat calcareous. These outcrops represent the western extension of Preto's (1970) structural unit V of the metamorphic complex of the Grand Forks Group. He defined this unit as "fine-grained hornblende schist and amphibolite; minor interlayered fine-grained biotite-garnet-quartz schist and staurolite-garnet-quartz schist". The age of this unit is unknown, but Preto correlated it with the "Schist" of Parker and Calkins' (1964, p. 17-19) metamorphic assemblage of Tenas Mary Creek in Curlew quadrangle, to the southwest. To these rocks they assigned a pre-Permian, probably Paleozoic age. The unit is separated from chert and schist of the Knob Hill Group and younger rocks to the west by the Granby River Fault.

Map unit Pm5 comprises a few outcrops that are exposed by highway 3 in the valley of Boundary Creek. One, immediately south of Greenwood, consists of a highly altered, sheared, amphibole-bearing layered gneiss. The others, which are north of Boundary Falls, are layered biotite-hornblende-plagioclase gneiss that is somewhat silicified and veined by quartz. One outcrop consists of dark green gneiss that is graphitic in part. These rocks cannot be traced into adjacent, less metamorphosed Knob Hill cherts and greenstones, or into map unit Pm1. They are believed to be more deeply buried rocks that have been faulted into their present positions. Their age is not known, but is assumed to be Paleozoic(?).

Map Unit Pa

Distribution

This map unit consists almost entirely of amphibolite. It comprises a zone that extends from the Greyhound Creek Fault eastward across the hill north of the Skomac mine to the Haas Creek Fault, which offsets northward the continuation of the zone. The amphibolite then occupies the south side of the valley of Lind Creek for a distance of 4 km east of Boundary Creek, beyond which point glacial drift is very deep for some distance. A small body of similar amphibolite occurs farther to the east near the Athelstan mine. However, there the amphibolite is believed to be part of the Knob Hill Group, although, in this intensely faulted area, it may not be, but may instead be a part of map unit Pa.

Lithology

The amphibolite ranges in grain size from medium to coarse, almost pegmatitic. The coarse grained amphibolite forms patches and irregular dyke-like masses within the medium grained amphibolite. Most of the amphibolite is massive, but locally is gneissic. The amphibolite consists essentially of green hornblende with up to 25 per cent feldspar, mainly plagioclase. Free quartz is rarely visible, but in places the rock is partly silicified. A thin section of a sample of amphibolite taken from a small knob northwest of the Skomac mine reveals aggregates of hornblende in a fine grained, cloudy matrix of epidote, white mica, orthoclase(?), and plagioclase(?), which seem to embay the hornblende. Minute rods of apatite form the only accessory mineral. Another thin section of a sample taken on the south side of Lind Creek consists mainly of pleochroic green and brown hornblende, some plagioclase that is strongly zoned from a core of calcic plagioclase to a rim of albite, a little orthoclase, quartz, and tremolite, minor biotite, chlorite, and opaque minerals, mainly magnetite, and accessory apatite and rutile.

About 0.8 km north of the Skomac mine a bed about 10 m thick of somewhat sheared micaceous quartzite is intercalated with the amphibolite. A little fine grained

greenish quartzite, possibly tuffaceous, occurs nearby. In the valley of lower Lind Creek, some chert beds are associated with the amphibolite, and a little fine grained greenstone is present. Map unit Pa differs from the Knob Hill Group in that it is composed almost entirely of amphibolite. The Knob Hill Group contains abundant chert and greenstone; amphibolite is local and grades into greenstone.

External Structural Relations

Neither the base nor the top of the formation is exposed. Sedimentary interbeds north of the Skomac mine strike N 70°W and dip 40°N; elsewhere, the formation is structureless. The contacts with the argillite unit (CPas) of the Attwood Group on the south and Knob Hill Group (CPkh) on the north are not exposed. Near the Skomac mine a belt of serpentine is intruded along the southern contact, which must be faulted. Church (1977, p. 10) described the formation there as a granodiorite-diorite intrusive complex, and stated that numerous dykes and tongues emanating from it cut the metasedimentary rocks. It is possible that granodiorite has intruded the amphibolite, but the writer suspects that the relations observed by Church result from the mobility of the metamorphic rocks. The formation is interpreted as originally composed of lava with minor sediments and the lava has been converted almost wholly to amphibolite. In view of the high grade of metamorphism relative to the adjacent formations, map unit Pa was probably deeply buried and was faulted into its present position. For lack of more concrete evidence, however, the contacts are now shown as assumed faults. On the other hand, amphibolite fragments occur in green argillite that was included in the Attwood Group on Mount Attwood. Although these fragments are not very rounded, they may indicate pre-Attwood erosion of amphibolite.

Age

The age of the formation is not known, but is believed to be pre-Permian, probably Paleozoic.

Map Unit Pm

This map unit has been divided into units Pm1 and Pm2 which, though similar, are not in contact and therefore may not be correlative. It consists of a heterogeneous assemblage of amphibolite, argillaceous, arenaceous, micaceous and chloritic schists, and minor impure quartzite, limestone, chert, and argillite or phyllite. It differs lithologically from the Knob Hill Group in the abundance of chert with argillaceous partings (in contrast to massive chert of the Knob Hill), in the abundance of argillaceous rocks (now largely micaceous and chloritic schists), and the comparatively minor amount of greenstone and amphibolite.

Map unit Pm comprises a metamorphic assemblage of a variety of rocks of sedimentary and volcanic origin. In this, it is in contrast to the Knob Hill Group which consists almost wholly of massive greenstone and, locally, amphibolite, and massive chert, except in the southwest corner of the map area where some of the chert is bedded, with argillaceous partings. In general, it is more highly metamorphosed than the Knob Hill Group, and is therefore regarded as older. Some of the more highly metamorphosed components of the Knob Hill Group may be included in map unit Pm, especially some greenstones, amphibolite, and chert.

Distribution

Map unit Pm1 occupies the upper plate of the Map Creek Fault north of the International Boundary from the ridge east of July Creek westward to the upper part of McCarren Creek Valley. To the north, in the lower plate, it extends from the east slope of Mount Attwood westward to the Greyhound Creek Fault.

Lithology

South of the May Creek Fault the assemblage consists mainly of amphibolite, some of which is crenulated and contains thin light layers that are in part, chert chlorite schist, and chert with thin argillaceous partings, a rather distinctive rock. There is also minor massive chert, limestone, carbonaceous phyllite and chert with a few, thin interbeds of carbonaceous argillite. On the southern and western slopes of Mount Attwood, the unit consists of fine grained amphibolite and chloritic schists and predominant micaceous arenaceous and argillaceous schists. The compositionally layered schists may be of tuffaceous origin. In some of these incipient gneissosity has developed. Limestone is more abundant, and is mostly light grey and thinly layered, but dark grey and black limestone is also present, the last containing pods of black chert. A bed about (20 to 50 m) thick of grey limestone can be traced almost continuously down the west slope of Mount Attwood, and possibly across Boundary Creek. West of Boundary Creek south of the Skomac mine, argillaceous and arenaceous micaceous schists are common, but limestone and especially chert are more abundant, and some white quartzite, which may be metamorphosed chert, is conspicuous. The thickness of the map unit is unknown, but appears to be considerable. These rocks form the "basement complex" of Church (1970, 1977).

Internal Structural Relations

Little is known of the structure of map unit Pm1; bedding tops were not observed and few bedding attitudes were obtained. Near the International Boundary bedding in the rocks trends northerly with moderate to steep dips. To the northwest, near Mount Wright, bedding appears to trend west northwesterly, but is largely obscured by the schistosity. North of the May Creek Fault, between Mount Attwood and the Greyhound Creek Fault, the beds strike for the most part westerly, but locally northwesterly. Dips are generally steep. On the east side of Mount Attwood, argillite of the Attwood Group, which presumably overlies unconformably the map unit, appears to form a syncline trending west-northwesterly, but the form of older folding is not known.

South of the Skomac mine, the amoeba-like plan of a limestone body indicates complex folding.

External Structural Relations

The base of map unit Pm1 is unknown. It is overlain, presumably unconformably by argillite and limestone of the Attwood Formation, of Carboniferous or Permian age, and by chert sharpstone conglomerate and limestone that has been assigned to the Brooklyn Formation, of Lower(?) and Middle Triassic age. Unless all these contacts are faults, which seems improbable, erosion of map unit Pm1 must have preceded deposition of the later rocks for some time.

Map unit Pm2 is lithologically similar to Pm1 but is more highly metamorphosed.

Distribution

Map unit Pm2 underlies a large area extending from near Boldue Lake north-westward to Jewel Lake, thence more westerly to Boundary Creek Valley and up the valley of Windfall Creek for about 4 km. A number of widely scattered outcrops of similar rocks in the valley of Pass Creek, on the mountain slope to the north, and to the south, east of the B.C. Fault, have been included in the map unit.

Lithology

In the large area mainly to the north of Eholt Valley that is underlain by rocks of map unit Pm2, along the abandoned Canadian Pacific Railway grade for 2.5 km south of Eholt, the rocks consist of fine grained, brown, siliceous siltstone. They were mapped as "undifferentiated greenstone, andesite, basalt, and pyroclastics" of his Eholt Formation by Carswell (1957), but B.N. Church (personal communication, 1977) agreed with this writer that the rocks, though metamorphosed, are sedimentary. They do not resemble other parts of the Eholt Formation, nor do they resemble the Knob Hill Group. To the northwest, towards Boldue Lake, greenstone, chlorite schist, and chert (both bedded and massive) are common. Near Boldue Lake some hornfels is present, but to the west, almost to the ridge south from Mount Pelly, hornfels is the predominant rock. Farther northwest near Jewel Lake and Mount Roderick Dhu, the rocks consist of abundant fine grained quartz-biotite schist, with some hornfels, metamorphosed banded chert, and quartz-biotite-hornblende-plagioclase gneiss, and minor massive white chert and pebble conglomerate in which the pebbles are strongly lineated. Near Clement Creek only quartz-biotite schist and a little medium grained gneiss were seen, but in the valley of lower Windfall Creek there is a greater variety of metamorphic rocks. The most abundant is a fine grained, dark grey, quartz-biotite schist or gneiss, the biotite being in separate layers that are strongly lineated. There can be little doubt that this rock was bedded chert with argillaceous partings that have been converted to biotite through metamorphism. One outcrop each of chert and amphibolite was seen. A little micaceous quartzite and medium grained gneiss are also present. In Windfall Creek, 0.4 km downstream from the mouth of the first tributary flowing from the south, a bed of white, massive, and grey, layered marble apparently at least 30 m thick is exposed. This bed was traced intermittently for more than 0.8 km north-westerly and 0.4 km southeasterly. To the west in Windfall Creek Valley the only metamorphic rocks are those of map units Pm2 and Pm3, these gneisses and amphibolite probably being more highly metamorphosed equivalents of map unit Pm2.

Internal Structural Relations

The thickness and structure of the map-unit are unknown. Throughout the zone just described where beds have been discerned they strike northwesterly and dip rather steeply. Schistosity has roughly the same trends, but lineation plunges gently easterly to east-southeasterly, though in some places in the opposite direction. The rocks are in contact only with younger strata and within the zone just described they form a roof pendant surrounded by granodiorite and related rocks of the Nelson Intrusions. Both these and the metamorphic rocks are cut by dykes and larger bodies of Coryell Intrusions, and by dykes probably related to Marron volcanic rocks. Near Eholt, however, limestone and skarn dubiously referred to the Brooklyn Formation is spatially closely associated with the metamorphic rocks, but although the limestone appears to rest upon them, the contacts are not exposed, and the relationship is not known.

In the valley of Pass Creek, map unit Pm2 is represented mostly by a number of scattered outcrops of quartz-biotite schist and one of each is metamorphosed siltstone and chert, and of fine- to medium-grained quartzose amphibolite. On the mountain slope to the north, fine grained quartz-biotite schist and some medium grained, very quartzose gneiss, are exposed. To the south of Pass Creek, east of the B.C. Fault, the scattered outcrops of map unit Pm2 consist of contorted, layered and massive greenstone and minor amounts of an unidentifiable highly silicified rock and limestone.

The base of this metamorphic succession is not exposed. Within the area described above, these rocks are not in contact with recognizable Attwood or Knob Hill rocks. South of Brown Creek a single outcrop of chert sharpstone conglomerate was encountered, but its relationship to map unit Pm2 is unknown, as the adjacent rocks are Tertiary intrusions.

Age

From the relationships already described with the Attwood Formation on Mount Attwood, the age of the map unit is apparently pre-Permian; a Paleozoic age seems probable, possibly Late Paleozoic.

Attwood Formation

The Attwood 'Series' was defined by Daly (1912, p. 382) from an assemblage of "limestones, argillites, and quartzites" that are exposed on Attwood Mountain, now known as Mount Attwood. Both he and Brock were of the opinion that these rocks resemble the Cache Creek rocks, then believed to be of Carboniferous age. LeRoy (1912, p. 29; 1913, p. 12) incorrectly placed his Brooklyn Formation within the Attwood 'Series', and, although his designation was not followed by McNaughton (1945), it was reintroduced by Seraphim (1956). It is now known that the limestone of the Attwood Formation (CPal) is of Paleozoic age whereas the Brooklyn limestone is Triassic.

It is proposed that the term Attwood Formation be confined to two members – a limestone member and an argillite member – that outcrop on Mount Attwood and elsewhere in the southern part of the map area. The 'quartzites' are part of another map unit that is in general more highly metamorphosed and is believed to be older than the Attwood Formation.

Distribution and Thickness

The limestone member (CPal) is well exposed along the ridge that forms the east end of Mount Attwood from 2.5 to 4.0 km east of the summit, and the slope to the north. The apparent thickness of the unit is nearly 900 m, but, as it has very little lateral extent, there may be considerable tectonic thickening, and the original thickness may be only a few hundred feet. The limestone may be reefoid.

Lithology

The limestone member is mainly white to light grey, fine- to coarse-grained recrystallized limestone or marble. Much of it is massive, but faint banding, which may be bedding, is commonly visible. In some places thin beds of white chert, which may be the result of silicification of limestone, are intercalated. Elsewhere, irregular, sometimes contorted, masses of chert up to 30 cm or more in diameter are seen. Some of the limestone is dark grey or black, and this facies is commonly associated with bands of black tuffaceous(?) argillite, and contains scattered corals and a few brachiopods.

Locally, near the summit of Mount Attwood, the limestone contains fairly abundant chert grains that are up to small pebble size. This chert granule limestone is characteristic of much of the Brooklyn limestone member. There in addition, a 3 m layer of chloritic schist is interbedded. This may be the metamorphic equivalent of green argillite that is also present in the Brooklyn limestone member. However, chert granule limestone (the "peanut brittle" limestone of Seraphim) occurs also at fossil locality F2, so that although it is possible that Brooklyn limestone is faulted into place, or

unconformably overlies the Attwood limestone, the entire succession is regarded as Attwood, and so is Paleozoic, rather than Triassic.

The argillite member of the Attwood Formation is designated by the symbol CPas.

Distribution and Thickness

The type locality of member CPas is on the east side of Mount Attwood where it is exposed on both the north and south sides of the easterly trending ridge, but is more extensive on the north and can be traced intermittently westward for 7 km to the vicinity of the Skomac mine. South of May Creek Fault are two small areas underlain by rocks that have also been correlated with the argillite unit of the Attwood Formation.

The thickness of the argillite member of the Attwood Formation is unknown because it is poorly exposed and few top determinations were possible. It is at least 100 m thick, but it is unlikely that it is more than 300 m thick.

Lithology

On the east side of Mount Attwood the argillite member is composed largely of light to dark grey silty argillite and argillaceous siltstone. A small amount of white siltstone, which is rusty weathering on the fracture surfaces and may be recrystallized chert, is present. From Mount Attwood to Boundary Creek the sequence consists primarily of soft, grey argillite in which bedding from 1 to 2.5 cm thick is distinct. A few thin interbeds of fine- to medium-grained sandstone containing angular lithic and mineral grains are present, and are similar to those south of the May Creek Fault. On the south side of the belt, east of and near Highway No. 3, are outcrops of green chert sharpstone conglomerate that contains interbeds of argillite and hard, silty argillite. The conglomerate contains a few fragments of limestone and resembles that of the Brooklyn Formation but it is clearly a part of the Attwood Formation. An interbed of white siltstone with rusty weathering fractures that is similar to that on Mount Attwood is also exposed.

Farther to the west, the wedge of sediments at the Skomac mine consists mainly of black argillite and has been termed the Skomac Formation by Church (1977, p. 9). The black argillite is distinctly bedded and contains intercalated beds up to 3 m or more thick of dark grey to black bedded siltstone.

South of May Creek fault the more westerly outcrops consist mainly of grey to black argillite associated with some massive, homogeneous medium grey chert and coarser clastic material that ranges from conglomerate to siltstone. The argillite is bedded, the beds being about 2.5 cm in thickness. The beds are thicker in the coarser clastic material in which the grains are composed of angular lithic fragments, mainly of chert and argillite, as well as feldspar and quartz, the coarser grit-sized sediments containing a greater abundance of chert and quartz grains in an argillaceous matrix. The conglomerate contains argillite slabs 5 to 7.5 cm in greater diameter, and somewhat rounded, with subangular to subrounded fragments of chert and a few of other rocks.

The more easterly area is underlain by similar sediments, but there the argillite is more limy, and some tan silty argillite was noted. Pale greenish grey, fine grained, and grey coarse grained limestone at least 15 m thick is present.

Internal Structural Relations

Little is known of the internal structural relations of the units, particularly of the limestone member, which, from attitudes of interbeds of chert and siltstone, trends northwesterly, parallel to contacts with other units. The argillite member in the type locality appears to be folded into a syncline also trending northwesterly. South of the May Creek fault, in the more easterly exposures, the beds dip steeply northeast with bedding tops in that direction; in the more westerly exposures the beds dip gently southwest and are not overturned. An anticlinal structure may therefore be represented, but, if so, it must be faulted off to the south.

North of Mount Attwood exposures are poor and the structure of the argillite member is unknown, but the trend is west. At the Skomac mine the beds dip north at a moderate angle and the structure appears to homoclinal.

The relationship of the limestone member and the argillite unit to one another is not clear. They are apparently in contact with one another in a few places, but there only thin segments of the units are exposed, and bedding tops are rarely determinable. In general, both units appear to occupy the same stratigraphic position and it is tentatively assumed that they interfinger.

External Structural Relations

The external structural relations are likewise not clear. Both the limestone and the argillite members appear to rest upon the more highly metamorphosed map unit **P**ml. The argillite member in places is succeeded on the north by the amphibolite member **P**a, but this may well be a fault contact, and north of the Skomac mine a narrow belt of serpentine is interposed between the two. North of Mount Attwood the limestone member appears to grade vertically into chert and greenstone of the Knob Hill Group (CPkh), which is assumed to be younger.

Age and Correlation

The age of the Attwood Formation is Carboniferous or Permian. From the limestone member the following collections have been made and were identified by E.W. Bamber of the Geological Survey of Canada.

Locality F1 GSC loc. 62513

South slope of Mount Attwood
49°02.9'N 118°34.9'W

Collected in 1964 by H.W. Little

Echinoderm columnals
Aulophyllid coral

Age: Carboniferous or Permian

Locality F2 GSC loc. 62512

South slope of Mount Attwood about 1.6 km east of summit
49°03.0'N 118°35.1'W

Collected in 1964 by H.W. Little

Unidentified rugose? corals
Echinoderm columnals

Age: Probably Paleozoic

Locality F3 GSC loc. 56900

0.8 km west of where road crosses the east ridge of Mount Attwood
49°03.1'N 118°34.95'E

Collected in 1963 by R.I. Thorpe

Aulacophyllid corals – poorly preserved

Age: Carboniferous or Permian

Locality F3 GSC loc. 56899

Mount Attwood, 85 m N 55° W from loc. 56900
49°03.1'N 118°35.05'E

Collected in 1963 by R.I. Thorpe

Spiriferid brachiopods
Other undeterminable brachiopods
Echinoderm columnals
Trilobite (unidentifiable)
Unidentifiable rugose corals
Fenestrate and ?trepostome bryozoans
Unidentifiable pelecypod

Age: Carboniferous or Permian

Locality F3 GSC loc. 62506

Near locs. 56899 and 56900, or possibly the same as one of them. Elevation 4750'

Collected in 1964 by V.A. Preto

Echinoderm columnals
Unidentifiable horn corals
Linoproductid brachiopods

Age: Carboniferous or Permian

Locality F4 GSC loc. 62505

North side of Mount Attwood. Elevation 4750'
49°03.2'N 118°35.6'W

Collected in 1964 by V.A. Preto

?Linoproductid brachiopods
Aulophyllid coral

Age: Carboniferous or Permian

From the argillite unit, two collections of fossils have been made.

Locality F5 GSC loc. 62509

Ridge north of Mill Creek, 1.25 km west of July Creek.
49°01.1'N 118°34.4'W

Collected in 1964 by H.W. Little and V.A. Preto, identified by E.W. Bamber

Brachiopods indeterminate – poorly preserved
Trepostome bryozoa – too poorly preserved (replaced) for identification

Age: Probably Paleozoic, possibly Early Triassic Trepostome bryozoa are almost entirely restricted to the Paleozoic, except for rare occurrences in the Lower Triassic.

Locality F6 GSC loc. C-65087

180 m due west of adit No. 5, Skomac mine (Church, 1977, Fig. 1)
49°04'N 118°42.5'W.

Collected in 1976 by B.N. Church, B.C. Ministry of Mines and Petroleum Resources, identified by W.W. Nassichuk, Geological Survey of Canada.

cf. ?Warthia sp.
cf. ?Atomadesma sp.
murchisonacean gastropod gen. et. sp. indet.
crinoid stems gen. et. sp. indet.
orthoconic nautiloid gen. et sp. indet.

Age: Carboniferous or Permian

Because of the inexactness of the age, correlation of the Attwood Formation with formations elsewhere can be only approximate and tentative. It is unlikely that Mississippian strata are present, but if they are, there are few reported occurrences elsewhere in this part of the Cordillera. In the Lardeau map area, about 200 km north-northeast of Greenwood, the Milford Group is in part, at least, Upper Mississippian (Fyles and Eastwood, 1962, p. 32). Near Springdale, Washington, about 120 km southeast of Greenwood, in unnamed carbonate rocks a Mississippian age has been established. (Miller and Clark, 1975, p. 31-33).

Pennsylvanian fossils were collected, and identified, from the same unnamed map unit near Springdale by Embysk (1954, p. 15). Plant fossils "of Carboniferous age, most likely older Pennsylvanian" were reported from near Covada, Ferry County, Washington, some 95 to 110 km south of Greenwood (Bancroft, 1914, p. 14). The Mount Roberts Formation, which outcrops in the southwest part of Nelson map area (west half) about 60 km east of Greenwood, has yielded fossils that are Pennsylvanian or Permian in age, the former being favoured (Little, 1960, p. 48-51; Little, 1963, p. 2). Limestone and argillite or slate comprise what is regarded as the lower part of the formation and is comparable lithologically to the Attwood Formation.

For correlations with Permian formations, with which the Attwood Formation also may be compared, the reader is referred to the section on the Knob Hill Group.

Knob Hill Group

The Knob Hill Group (CPkh) was named by LeRoy (1912, p. 26) from Knob Hill, which lies about 1.5 km southwest of the former city of Phoenix, and was defined as "a complex of highly altered rocks of igneous origin with minor developments of sediments". Similar rocks in the Deadwood Camp (LeRoy, 1913) were also assigned to the group. The known extent of these rocks was enlarged subsequently by McNaughton (1945), Seraphim (1956), Little and Thorpe (1965), and Little and Monger (1966), all of whom retained the name "Knob Hill". Reinsbakken (1970), included these rocks in the "Anarchist Group", possibly because Daly's (1912) type Anarchist Group was extended eastward during reconnaissance mapping by Little (1957). The Anarchist Group in Daly's type locality on Anarchist Mountain comprises a heterogeneous, highly metamorphosed assemblage of rocks, chiefly sedimentary in origin. Although the complexity of this unit was recognized, the correlation seemed to be justified when a fossil collected in the Greenwood area was tentatively identified as Permian(?). More detailed mapping has shown that some of this assemblage is probably pre-Permian and may be older than Carboniferous, whereas some

has proven to be Triassic and perhaps even Jurassic. Furthermore, there is strong evidence that unconformities exist within the assemblage.

The Anarchist Group has been redefined by Waters and Krauskopf (1941) as Permian or possibly Carboniferous, and further redefined by Rinehart and Fox (1972, p. 7-22) to include only rocks of Permian age. The present writer does not recommend continuation of the term in Greenwood map area.

Distribution and Thickness

East of July Creek, the Knob Hill Group has been identified in only two small areas near Hardy Mountain, but west of July Creek it occupies a broad belt up to 5 or 6 km wide that extends southward from the Eholt Valley Fault to the valley of Lind Creek. This belt extends westward, though interrupted by the stock of granodiorite at Greenwood, and a zone of overlying Marron volcanics west of the Deadwood Ridge Fault, to the valley of Kettle River.

In the valley of Eholt Creek, north of the Eholt Valley Fault, there is an assemblage of massive chert, some bedded chert with argillaceous partings, massive greenstone, and amphibolite. These rocks are more highly metamorphosed than those south of the Eholt Valley Fault and were earlier interpreted (Little and Thorpe, 1965) as comprising map unit **P**m2. Field investigation in September 1977, however, showed them to be continuous with the rocks mapped as Knob Hill Group east of Glenside Creek, and of Knob Hill rather than map unit **P**m2 lithology.

In the west half of the map area, Knob Hill rocks are exposed in a broad belt extending westward from Wallace Creek to Kettle River Valley, mainly south of Wallace Creek Fault, thence southward to the International Boundary. More limited exposures are in the upper parts of Ingram Creek and its west fork, and in the valley of Bubar Creek.

No accurate nor even approximate thickness of the Knob Hill Group can be measured or calculated. Bedding is rarely found in the chert, and bedding tops are impossible to determine. The other major component, greenstone that here and there is altered to amphibolite, is erratically distributed. Therefore it can only be stated that the thickness of the Knob Hill Group is a minimum of a few thousands of metres.

Lithology

The Knob Hill Group consists principally of massive white to grey chert in which bedding is rarely seen, and greenstone, which is slightly less abundant, and, though commonly much altered, is of andesitic to basaltic composition. In most parts of the map area, chert is more abundant than greenstone, but in some, greenstone and/or amphibolite predominate. Minor argillite or limestone is present here and there in the assemblage.

On the south side of Eholt Creek greenstone and amphibolite predominate, whereas on the north side chert is more abundant. In general, the amphibolite seems to be spatially associated with bodies of Nelson Intrusions, which may have been the source of metasomatic solutions that converted the greenstone into amphibolite.

Knob Hill rocks in the western part of the map area comprise primarily chert, with greenstone, amphibolite, quartzite (which is believed to be formed through the metamorphism of chert), and limestone, all in decreasing order of abundance.

Chert, greenstone, amphibolite, and limestone outcrops in the southwest corner of the map area have been correlated with the Knob Hill Group upon lithological grounds. There, however, limestone is much more abundant than elsewhere, and chert is more commonly bedded, either as 'ribbon' chert or with thin interbeds of black argillite or graphite schist.

Where the Knob Hill Group is in apparent contact with the Attwood Formation on the north slope of Mount Attwood, the former is composed of chert, which is succeeded to the north by greenstone. The oldest part of the group is therefore believed to be chert. Throughout the area no pattern could be discerned to indicate the relationships of the cherts to greenstone. It is probable that the greenstone comprises small intrusive and, more extensively, extrusive bodies respectively cutting, or intercalated with the chert. No volcanic structures or bedding were detected in the greenstone which is for the most part fine grained throughout, but Seraphim (1956, p. 385) commented on streaks having the appearance of flow structure, and structures that may have been bombs. Both Seraphim (1956) and McNaughton (1945) have identified the greenstone as andesite, but the latter states that latite is also present. Both writers have commented upon a cherty phase of the greenstone, McNaughton suggesting it is due to silicification of the flows, but Seraphim contending that it is the result of andesitic tuff being deposited simultaneously with siliceous ooze, or in alternation with it and later flowing into a melange.

The greenstone in most places is of the greenschist facies, but in places it has been metamorphosed and recrystallized into amphibolite, the amphibolite facies being indicated on the Greenwood map.

Limestones are of minor importance in the Knob Hill Group, being restricted in the type area to small pods. In the west half of the map area, however, some limestone bodies are mappable, and in the southwest corner bodies greater than 0.25 km^2 outcrop. The limestone is mainly light grey, contains pods of bedded chert, and is associated with ribbon chert that is commonly limy.

Argillite is rare in the Knob Hill Group and forms thin, widely scattered beds. The only argillite abundant enough to be shown is that mapped by McNaughton (1945) in the valley of Twin Creek, about 1.2 km east of Greenwood. On the ridge south of Skeff Creek, west of July Creek, there are outcrops of tan to green metasiltstone that are associated with chert and greenstone, and so have been assigned to the Knob Hill Group.

Some of the Knob Hill rocks are doubtless included in map units **P**m1 and **P**m2. In those units there are a few massive cherts, and in some places quartzites that may be metamorphosed equivalents of cherts, and also amphibolites, schists, and even gneisses that may be metamorphosed equivalents of greenstones of the Knob Hill Group.

Age and Correlation

The age of the Knob Hill Group has been established at only one locality (F7), about 0.8 km north of the Athelstan mine. The rocks there occur within a fault block and comprise mainly greenstone and amphibolite, but there is some dark grey limy greywacke, black argillite resembling that of the Attwood Group, and minor sharpstone conglomerate with angular to subrounded fragments of mainly black chert, some of white chert, and a few of limestone. In a thin

band of limestone interbedded with the argillite a collection of fossils was made that was examined by E.W. Bamber of the Geological Survey, who reported as follows:

Locality F7 GSC loc. 60956

Abandoned railway grade to Athelstan mine,
Elev. 4000 feet. 49°04.6'N. 118°03.5'W

Collected in 1964 by H.W. Little and V.A. Preto

Aulophyllid corals
Trepostome bryozoa

Age: Carboniferous or Permian

Parts of the Knob Hill Group may be Mississippian or Pennsylvanian, and possible correlatives have been described under the section on the Attwood Formation. As the Knob Hill Group is believed for reasons given in the preceding section, to be younger than the Attwood Formation, possible correlatives with Permian assemblages are listed below. However, as fusilinids have been described from many localities in Permian rocks of the Intermontane Belt in British Columbia and the State of Washington, and none have been reported in the several fossil collections from Greenwood area, some doubt is thrown on the possibility that Permian rocks are exposed in the area.

In the southeastern part of Curlew Quadrangle, Washington, about 32 km southeasterly from Greenwood, Parker and Calkins (1964, p. 29) collected fusilinids of Early Permian, probably Leonard age from a succession of greenstone and limestone with minor black argillite and limestone conglomerate. Unlike the Knob Hill Group, chert occurs only within the limestone. In the Republic quadrangle which adjoins Curlew quadrangle on the south, several collections of Permian, and some of Early Permian (probably Wolfcampian or Leonardian) age were made (Muessig, 1967, p. 21-24). These were in an assemblage comprising mainly greenstone, with argillite, greywacke, limestone, conglomerate, quartzite, and chert, in decreasing order of abundance.

Internal Structural Relations

Because of the scarcity of bedding, except in the southwest corner of the map area, complete lack of criteria for determining bedding tops, and general paucity of outcrops, the internal structural relationships are not known. Between July and Boundary creeks, the general trend of the beds seems to be north to northwest, but west of Boundary Creek it seems to be west to northwest. However, in the vicinity of Phoenix the group was folded, in post-Middle Triassic time, into a syncline, the axis of which strikes north, but the attitudes of earlier structures, before peneplanation, are unknown.

External Structural Relations

The external structural relations of the group with older(?) assemblages, with one possible exception, are obscure. Only on the north slope of Mount Attwood is there an observable relationship. There the cherty limestone of the Attwood Formation seems to grade northeastward into cherts of the Knob Hill Group. Elsewhere the chert and greenstone or amphibolite is either faulted against presumably older map units or may be locally incorporated into them through metamorphism. On the other hand, the assemblage is believed to be overlain unconformably. Earlier writers (Brock, 1903, Daly, 1912, McNaughton, 1945) did not comment on the contact, believing that all the map units were lower Paleozoic. LeRoy (1912, p. 30) believed that no unconformity exists at any contact, but that "the rocks of both (map-units) at the contact have been welded together by silicification".

Seraphim (1956, p. 391) stated that the Knob Hill Group on 'Deadman Ridge', northeast of Phoenix, is overlain by sharpstone conglomerate of the Triassic Brooklyn Formation, and as the contact is exposed within a few inches, the units appear to be conformable. This contact was seen by the writer and, in his opinion, the evidence is not conclusive. Where contacts were observed elsewhere, the sharpstone conglomerate rests upon chert. Re-examination of those contacts has led to the conclusion that the earlier opinion (Little and Thorpe, 1965, p. 56) that massive chert grades upward into fractured chert, thence into disoriented chert fragments and bedded chert sharpstone conglomerate, is not justified in view of the paucity of outcrops and the lichen covering such exposures. However, bedding in the chert strikes at a sharp angle towards the nearby contact. As sharpstone conglomerate rests upon both chert and greenstone of the Knob Hill Group, and some probably older map units, there can be little doubt that the sharpstone unit of the Brooklyn Formation rests unconformably on the Knob Hill and some older(?) assemblages.

At the south border of Orient quadrangle, about 56 km southeast of Greenwood, Bowman (1950), in what he named the Churchill Formation, collected fusilinids of probably Middle, possibly Late Permian age. The assemblage there consists of highly indurated conglomerate, greywacke, and conglomerate, with minor limestone and quartzite, and so is lithologically unlike the Knob Hill Group, but does resemble the Mount Roberts Formation of Rossland map area.

In Bodie Mountain quadrangle, Washington, about 24 km southwest of Greenwood, Pearson (1967, p. 2) reported conglomerate beds in rocks that he correlated lithologically with Upper Triassic rocks of Greenwood map area. Pebbles in the conglomerate contain fusilinids of late Early or early Middle Permian age, proving that rocks of that age existed, and may exist still near that locality.

Farther west, in the northern Okanogan Valley of Washington, Waters and Krauskopf (1941) divided the Anarchist 'Series' into three parts. The lower division consists of black, lustrous phyllite, some chlorite schist, slate, and mica schist, and minor quartzite and conglomerate. The middle division contains quartzite, conglomerate, and limestone, with minor phyllite and greywacke. The upper division is composed mainly of volcanic rocks with interbedded phyllite and fine grained quartzite. Two collections from greywacke of the middle division were regarded as most likely Permian, but possibly Carboniferous.

Rinehart and Fox (1972, p. 7-22, 1976, p. 4) redefined the Anarchist Group to include only Permian (particularly Upper Permian) rocks, and named two formations within it.

West of the Okanagan Valley of southern British Columbia, Bostock (1940) collected from his Blind Creek Formation fossil corals that were identified by Smith (1935) as **Waagenophyllum columbicum** Smith, of Permian age, but later designated by Yabe as the type of **Heritoschoides** (written communication April 20, 1960, Helen Duncan, U.S. Geol. Surv.). Dr. Duncan also favoured a Permian age. Later collections contained fusilinids regarded by W.R. Danner (Univ. B.C., written communication to Dr. Duncan, May 26, 1959) as Late Mississippian to Early Pennsylvanian. In view of the conflicting ages which may be due to structural mixing rocks of different ages in this area, or reworking of older sediments, the age can only be regarded as Carboniferous and/or Permian.

Farther north in the Okanagan Valley, Jones (1959, p. 43-47) listed several collections of fossils obtained from the Cache Creek Group by Cairnes, Rice, and himself. The age of the group is regarded as Permian, possibly Middle Permian, but in some of the collections, a Pennsylvanian age is also indicated. Jones subdivided the group into three parts, a lower division of mainly argillite, a middle division of lava, tuff, argillite, quartzite, and limestone, and an upper division of limestone, quartzite, argillite, and volcanic rock.

In Nicola area, to the west of Vernon map area collections from the Cache Creek rocks made by Cockfield (1948, p. 9) were regarded as Carboniferous in age, but earlier ones (ibid., p. 10) were identified as Upper Pennsylvanian (Gschelian) and Middle Permian (Artinskian).

Still farther west, in the type area of the Cache Creek Group, Duffell and McTaggart (1952, p. 24) concluded that "much of the Cache Creek Group in Ashcroft area is of Middle and possibly Upper Permian age". The Upper Permian age was confirmed by W.R. Danner in samples collected by Trettin (1961, p. 17-19), and Campbell and Tipper (1971, p. 22, 23, 27, 28) report fossils ranging from Early Pennsylvanian (Morrowan) to Late Permian (Guadalupian).

Some evidence that Permian sediments may be present in Greenwood map area has kindly been supplied by P.B. Read, who, with A.V. Okulitch, in 1976 collected limestone samples from outcrops 5.6 km north of Grand Forks, B.C. These lie west of the Granby River Fault and apparently lie within sediments mapped as Middle and (?)Lower Triassic by Preto (1970). Conodonts were identified by B.E.B. Cameron of the Geological Survey as follows:

GSC loc. 93460

East of Granby River, 5.6 km north of Grand Forks, B.C.
49°04.8'N. 118°26.8'W.

Conodonts – completely recrystallized
Neogondolella sp. cf. **N. idahoensis**
(Youngquist et al. – 5 specimens
Ellisonia sp. (fragmentary LA – element?)
– 1 specimen

Age: This material is very poorly preserved. A Permian age is indicated however and more specifically an assignment to the Leonardian appears reasonable.

GSC loc. 93462

East of Granby River, 5.6 km north of Grand Forks, B.C.
49°05'N. 118°26.8'W.

gastropod steinkern
indeterminate skeletal debris
Conodonts – totally recrystallized (recovered from light fraction)
Neogondolella sp. indet.
hindeodellid fragment
Xaniognathus ? sp.

Age: This material is very poorly preserved. I suspect it is probably Permian in age, however.

Brooklyn Formation

The Brooklyn Formation was named by LeRoy (1912, p. 33) after the Brooklyn mine, the deposits of which are hosted by skarn and jasperoid produced by metamorphism of the limestone. LeRoy termed the lower part of the formation 'jasperoid', and the upper part limestone and skarn. In this report, the Brooklyn Formation consists of the lower sharpstone and siltstone (Rawhide) members and upper limestone member, much of the latter, and some of the former, being altered to skarn, and to some extent, jasperoid. A third member, named by LeRoy the Rawhide Formation, is here regarded as a member that is locally interbedded with the sharpstone conglomerate member.

Distribution and Thickness

The Brooklyn Formation is most completely developed within the Phoenix area that was mapped by LeRoy (1912). It is, however, widely distributed throughout the southern half of the map area, especially the chert sharpstone conglomerate member. Because the component members are in many places not found together, the limestone member being eroded, and the Rawhide member being restricted in deposition, the distribution of the formation is described member by member.

The sharpstone conglomerate member was originally regarded by Brock (1903, p. 98A) as silicified limestone and argillite. LeRoy (1912, p. 34-38) termed this rock 'jasperoid', and argued that it was formed "by the replacement of other materials, ordinarily calcite or dolomite". This line of reasoning was accepted by McNaughton (1945, p. 3-5) who asserted that, in addition, the 'jasperoid' below the Rawhide Formation was formed by the silicification of argillites. Seraphim (1956, p. 388, 389), after careful study of the unit concluded that it is a clastic rock, a "sharpstone conglomerate", for the reasons briefly summarized here.

1. The fragments in the sharpstone conglomerate display such a variety of colour, composition, internal variation, orientation, and distribution that the rock could not have resulted from metamorphic processes.
2. The rock is bedded; fine and coarse fragmental beds in which the fragments are rudely aligned contain thin interbeds of shale, siltstone, and impure limestone.
3. Scour and fill structures are not uncommon.
4. The sharpstone conglomerate is better sorted near intercalated shale, siltstone, and limestone.
5. Chert granules in limestone, which LeRoy cited as examples of a transition phase in the alteration of limestone to jasperoid, are well rounded, with frosted surfaces, and are interpreted as windblown sand and pebbles in a limestone matrix.
6. Limestone 'remnants' were said by LeRoy to be numerous in the 'jasperoid' near the contact with limestone. These 'remnants' appear in reality to be pebbles and boulders deposited together with chert fragments, and the rock is regarded as a limestone conglomerate.

Carswell (1957, p. 16, 17) agreed with Seraphim, and added the following observations:

1. Chert pebbles occur in contact with each other without coalescence (in the absence of silica overgrowth).
2. No evidence of silicified zones along fractures was observed.
3. Orientation of flattened pebbles in chert breccia conforms to the bedding of the limestone.
4. Some pebbles have indisputable sedimentary shapes.

Little and Thorpe (1965, p. 56, 57) also agreed with Seraphim that the unit comprises clastic rocks, and commented that several examples of graded beds were observed by them and their assistants.

Distribution and Thickness

The sharpstone conglomerate member is well developed in the vicinity of Phoenix and is exposed in scattered outcrops from there southeastward to Eagle Mountain, eastward to July Creek, and northeastward beyond the Emma mine. Much is exposed in Deadwood Camp and northwest of Skomac mine. It is abundant in an area north of Kettle River, 3 to 6.5 km west-northwest of Midway. Many exposures occur in the upper part of Nicholson Creek Valley, and on the east side of Upper Bubar Creek. It outcrops also 2.5 km south of the village of Rock Creek, and more extensively, west of Kettle River 5 to 6 km north of the village.

Beyond the map area to the east, the sharpstone member outcrops extensively on the west side of Granby Valley along the Canadian Pacific Railway line, intermittently for 5.5 km south from the Hummingbird mine. Preto (1970) has mapped it on the east side of the valley for 6.5 to 18 km north of Grand Forks. Similar rocks were noted by the writer in earlier reconnaissance traverses west of Rock Creek.

The thickness of the sharpstone member is not known accurately, but was estimated by Seraphim (1956) to be about 750 m.

Lithology

The greater part of the sharpstone conglomerate member consists of bedded, angular fragments of, largely, white to grey or pale green chert, with minor amounts of jasper, limestone and greenstone in a matrix of fine chert grains, calcite, and chlorite. In most places the chlorite, which may be the alteration product of volcanic ash contributed to the sediments, or the erosion product of greenstone, imparts an overall green colour to the formation. Locally, rocks of the sharpstone unit are grey or buff.

In the Mother lode – Old Ironsides pit at Phoenix there is a bed about 9 m thick of green argillite that is interbedded with the conglomerate and can be traced for some distance. Soft green argillite and black argillite may be more widespread in the unit than at present realized, as these rocks, being readily eroded, are rarely well exposed.

Between the Greyhound Creek and Deadwood Ridge Faults, on the hill west of the Skomac mine, the sharpstone member is mostly pale buff, and consists mainly of massive chert sandstone, with interbeds of chert grit and a few of chert sharpstone conglomerate. A lenticular interbed of black argillite at least 9 m thick is exposed in a roadcut. Soft bright green argillite, estimated to be about 250 m thick near the Deadwood Ridge Fault (provided there is no repetition of the beds), tapers out eastward, or is faulted off, within 450 m. The green argillite is bedded, and near the contact with chert sandstone contains interbeds of chert sandstone and some chert sharpstone conglomerate.

Internal Structural Relations

The internal structural relationships of the sharpstone member are known only at two localities, and only imperfectly at one of them. At Phoenix the Brooklyn Formation is folded into a syncline, with moderate to steep dips, that appears to plunge gently north. The east limb is interrupted by a normal fault that strikes northerly, dips west, and brings Eocene stratified and minor intrusive rocks into contact with the Brooklyn Formation on the east. At Phoenix the syncline is offset to the left by the Twin Creek Fault, which is not exposed. The syncline terminates against the Eholt Valley Fault, beyond which regionally metamorphosed rocks of the Knob Hill Group are exposed in the valley of Eholt Creek.

Seraphim (1956) interpreted the sharpstone conglomerate at the Stemwinder property as being younger than the limestone member. The present writer regards it as the east limb of the Phoenix syncline, north of the Twin Creek Fault, and, therefore, older than the limestone.

West of the Deadwood Ridge Fault, on the hill northwest of Skomac mine, the structure appears to be a recumbent syncline, the axial plane dipping 35° to 40° north, but as no reliable determinations of bedding tops could be made, this interpretation could not be confirmed. It is based upon the fact that green argillite and buff chert sandstone are 'overlain' by massive chert of the older Knob Hill Group occurring to the North. Similar massive chert apparently underlies the chert sandstone and grit, and minor chert sharpstone conglomerate in the more southerly exposures.

External Structural Relations

Northwest of Phoenix the sharpstone member does not reveal a basal roundstone conglomerate that clearly indicates unconformable relationships with older formations. The basal part of the member consists of sharpstone chert conglomerate or breccia with little matrix, which grades upward into bedded sharpstone conglomerate. Near the contact with chert of the underlying Knob Hill Group, bedding in the chert strikes toward the nearby contact, indicating that the chert was tilted and eroded before deposition of the sharpstone member.

Elsewhere, the sharpstone member seems to form erosional remnants that rest unconformably upon, mainly, the Knob Hill Group. On Mount Attwood sharpstone conglomerate and associated limestone mapped as Brooklyn Formation rests upon rocks of map unit Pml, which may contain some Knob Hill rocks, but the contacts are partly, and perhaps entirely, faulted. Farther west, between Boundary Falls and lower McCarren Creek, small patches of chert sharpstone conglomerate rest upon map unit Pml, except near the Ruby mine, where a larger block is exposed, but nearby outcrops there are of younger age and mainly intrusive.

The sharpstone member is overlain, with apparent conformity, by the limestone unit in the vicinity of Phoenix where the contact is in places well exposed. Elsewhere, the contact has not been seen, but is believed to be similar. In a few places in the southeastern part of the map area, the sharpstone conglomerate member is overlain, apparently unconformably, by flow breccia and greenstone of map unit Jv.

The limestone member of the Brooklyn Formation is not as widely distributed as the chert sharpstone member. This is probably because it was more extensively eroded as it is the upper member of the Brooklyn Formation.

Distribution and Thickness

The limestone member, being intimately associated with the sharpstone conglomerate member, has to some degree, a similar distribution, but is more abundant in the area between Wilgress Lake and Fisherman Creek, in the vicinity of Hardy Mountain, and west of July Creek between Skeff and May creeks. Numerous outcrops of the limestone are exposed in Deadwood Camp, at the head of Motherlode Creek, and in the valley of Kettle River 3 to 6.5 km west of Midway. A little of the limestone is exposed on Mount Attwood and east of Boundary Falls at the Ruby mine. None is known west of the Ingram Creek Fault, although in places there is much chert sharpstone conglomerate. Small exposures of limestone and skarn near Eholt have been doubtfully referred to the Brooklyn Formation although sharpstone conglomerate is lacking and the associated rocks

are placed in the Paleozoic(?) map unit Pm2. Some limestone on the south slope of Mount Attwood resembles Brooklyn limestone.

Lithology

The limestone member of the Brooklyn Formation consists largely of massive, white to grey limestone. Characteristic of the limestone, especially the lower part, are sparse to moderately abundant rounded grains of chert. Most of these are of sand size, but range locally up to pebble size. Chert granule limestone, containing an abundance of rounded, frosted white to grey chert ovoids, 3 to 6 mm in diameter, and termed "peanut-brittle limestone" by Seraphim (1956, p. 389) comprises a few beds. He also mentioned minor shale and siltstone. In the upper part of the limestone occupying the core of the syncline north of Phoenix, a limestone breccia or conglomerate is exposed north of Providence Lake. This 'conglomerate' contains angular to rounded masses of limestone from 6 mm to 30 cm in diameter, and a few of chert up to about 25 mm in a calcareous matrix. Limestone 'conglomerate' at the Stemwinder mine, which is to a degree similar, appears to be interbedded in the chert sharpstone member and if so, must be Middle, or possibly Lower, Triassic, and the erosional source rock would be Attwood limestone.

Internal Structural Relations

The internal structural relations, as mentioned in descriptions of the sharpstone member, are established in the vicinity of Phoenix to be a north-trending syncline, possibly plunging gently north, offset to the left by the Twin Creek Fault and terminated on the north by the Eholt Valley Fault. East of Phoenix in the upper valley of Fisherman Creek, there appears to be a synclinorium trending north, the trough of which is occupied by younger (Upper Triassic) rocks. The west limb is crumpled into small folds that result in alternate exposures of limestone and sharpstone conglomerate being exposed across the strike. The east limb is almost entirely covered by volcanic rocks of Jurassic(?) age. The synclinorium terminates against the Eagle Mountain Fault on the south, and the B.C. Fault on the northeast. Elsewhere, the internal structural relations of the limestone member are unclear except that in most places the trend is northerly.

External Structural Relations

The Brooklyn limestone member rests, where observed, conformably on the sharpstone conglomerate member, except northeast of Deadwood, east of the Greyhound Creek Fault, against which it appears to be faulted, and at the head of Motherlode Creek where the sharpstone member is only locally exposed and the limestone, which in the more northerly exposures has been altered to skarn, seems to be in direct contact with greenstone and chert of the Knob Hill Group. Near Eholt, as mentioned previously, limestone and skarn doubtfully referred to the Brooklyn Formation are most closely associated with rocks of map unit Pm2.

The Brooklyn limestone member is overlain unconformably by Jurassic(?) volcanic rocks of map unit Jv in the southeast part of the map area, and at Phoenix also by the Eocene Kettle River Formation.

Age and Correlation

Brock (1902, 1903, 1905), Daly (1912), LeRoy (1912, 1913), McNaughton (1945), and Seraphim (1956) all correlated the rocks now known as the Brooklyn Formation with the Cache Creek Group, and regarded them as of Carboniferous, or at least of Late Paleozoic age. The first fossils reported from the Brooklyn Formation were collected by R.H. Seraphim in 1952, from a limestone outcrop that is 100 m east of a farm about 3.2 km east of the former city of Phoenix (Locality F8). The late F.H. McLearn reported as follows:

> "This collection comprises specimens of "**Spirifer**" (Spiriferina?) "Terebratula"? and some pelecypods. The material is not very diagnostic and no exact correlation is made. A late Paleozoic or Triassic age is proposed. The spiriferoid does not appear to be punctate, but the preservation of the shell does not permit an exact determination of this character; if it were punctate a Triassic age would be indicated".

Additional fossil collections were made in 1954 and 1956 by the writer, who, in the latter year, was guided by Seraphim to his locality, and who was joined by P. Harker of the Geological Survey in further search for fossils. Due to the poor state of preservation of the fossils, paleontological reports on these collections did not resolve the Late Paleozoic-Triassic dilemma, P. Harker and T.E. Bolton of the Geological Survey of Canada favouring a Permian age, and F.K. Stehle, to whom the brachiopods were submitted, a Triassic age. Consequently, (Little, 1957), the entire assemblage was put into a 'wastebasket' Anarchist Group and assigned a Permian(?) age. Subsequently, (December, 1957) a Norian (mid-Upper Triassic) age was established by D.F. Squires of the American Museum of Natural History at Locality F15. More detailed mapping in the present project has resolved at least part of the problem.

From the Brooklyn Formation, and the interbedded(?) Rawhide Member the following collections have been identified by E.T. Tozer of the Geological Survey, except locality F11.

Brooklyn Formation, limestone member

Locality F9 GSC loc. 56910

Phoenix camp, upper abandoned G.N.R. railroad grade, about 580 m west of the Brooklyn mine shaft.
49°06.2'N. 118° 36.25 W.

Collected in 1963 by R.I. Thorpe and H.W. Little

Small, moderately globose ammonite with ceratitic suture line.
Daonella sp.

Age: Middle Triassic

Locality F9 GSC loc. 56905

Phoenix Camp, 240 feet N 39°E from loc. 56910
49° 06.26'N 118° 36.2'W

Collected in 1963 by B.F. Watson

Small, moderately globose ammonite with ceratitic suture line.
Daonella sp.
"**Penetacrinus**" columnals

Age: Middle Triassic

Tozer (1967, p. 83) subsequently stated that

"Middle Triassic Daonellas that resemble **Daonella degeeri** Boehm and are probably of Lower Ladinian age, are now known from three widely scattered areas of the Western Cordillera. They are . . . [and] from map-unit 9 (Little and Thorpe, 1965) near Phoenix in Penticton area, British Columbia (56910, 56905)."

Locality F9 GSC loc. 56915

Phoenix Camp, portal of adit on G.N.R. railroad grade, 30 m east of loc. 56910. Horizon about 7 m from that of loc. 56910.

Collected in 1963 by R.I. Thorpe.

Daonella? sp.
Ammonite impression, **Longobardites**-Like?

Age: Triassic, probably Middle Triassic

(Note: GSC locs. 56910 and 56915 were destroyed by road-widening activities).

Locality F10 GSC loc. 56907

North of Phoenix, 30 m north of Providence Lake
49°06.5'N, 118°06.9'W

Collected in 1963 by B.F. Watson.

Daonella? sp.

Age: Triassic, probably Middle Triassic.

Locality F11 GSC loc. 62510

About 915 m west of the south end of Crook Lake
49° 03.8'N 118° 32.6'W

Collected in 1964 by V.A. Preto
(Identified by E.W. Bamber)

Poorly preserved, unidentifiable rhynchonelloid, ?spiriferoid, and ?productoid brachiopods
horn coral – unidentifiable
echinoderm columnals

Age: The presence of a ?productoid brachiopod suggests a Carboniferous or Permian age for this collection. The specimen is very poorly preserved, however, and its identification is tentative. A Mesozoic age cannot be eliminated on the basis of this identification.

Locality F12 GSC loc. 56912

1460 m 188° from junction of Skeff Creek with July Creek
49° 02.5'N 118°33.0'W

Collected in 1963 by R.I. Thorpe

Moderately involute ammonite, round venter, apparently ceratitic suture line.

Age: Probably Triassic.

Locality F13 GSC loc. 56909

730 m south of where the C.P.R. line crosses the east edge of the map-area, and 240 m east.
49° 08.8'N 118°29.8'W

Collected in 1963 by R.I. Thorpe

Small (d 2mm) ammonite with ceratitic suture line

Age: Probably Triassic.

Reinsbakken's Locality (in Grand Forks map-area)

About 2.7 km east of Hardy Mountain
49° 04.0'N 118° 29.1'W

(In rocks he mapped as Brooklyn Formation about 1050 m east of the east edge of Greenwood map-area)

Reinsbakken (1970, p. 111) states there are "very small, generally from 1 to 5 mm, typically subglobose, involute, low arched venter, smooth, exhibit ceratitic sutures with large number of elements, approximately six in mature specimens. The ammonoid has been tentatively identified as possibly genus Megaphyllites or maybe Parapopanoceras by E.T. Tozer (personal communication, 1970)."

Age: Anisian (lowest Middle Triassic) to Norian (mid-Upper Triassic).

The age of the Brooklyn limestone member is Middle Triassic, and, in part at least, probably lower Ladinian. The age of the underlying Brooklyn sharpstone conglomerate member is also largely Middle Triassic, for fossils identified as "probably Middle or Upper Triassic" were collected from the Rawhide member which is believed to be interbedded with the conglomerate but, according to Seraphim, is at the base of it. It is possible, therefore, that the lower part of the sharpstone member is Lower Triassic.

Formations that may be correlated with the Brooklyn Formation are not widespread in the Intermontane Belt and its equivalent south of the International Boundary. At Kelly Hill, Washington, about 55 km southeast of Greenwood, Kuenzi (1961, 1965) has reported fossils of the Smithian stage of the Lower Triassic (Scythian). Although the lower part of the Brooklyn Formation may be as old as this, the succession is different, for the Scythian of Kelly Hill is a shaly limestone that represents the top of a greywacke assemblage of the Churchill Formation, in which limestone pods yielded fusilinids of probable Middle Permian age (Bowman, 1950).

The Kobau Formation in Loomis quadrangle, Washington (Rinehart and Fox 1972, p. 7-22), about 64 km southwest of Greenwood, overlies unconformably the Anarchist Group, the upper part of which contains fossils of Permian, possibly Early Permian age, and is cut by the Loomis pluton of Late Triassic age. The Kobau Formation "consists of a thick sequence of unfossiliferous greyish-green phyllite, greenstone, and massive metachert", and may be least partly equivalent in age to the Brooklyn Formation. On the other hand, in the type area, where the base of the Kobau Group is not exposed, Okulitch (1973), after a meticulous study of polyphase deformation, believes the age to be pre-Pennsylvanian.

The Milford Group in Lardeau map-area (Fyles and Eastwood, 1962, p. 30-32) about 160 km northeast of Greenwood, consists of slate, argillite, chert, limestone, and pebble conglomerate. The lower part of the group is Upper Mississippian, but the upper part contains belemnites of probably Triassic age (Cairnes, 1934, p. 43; Little, 1960, p. 53). This may therefore be equivalent in age, or partly so to the Brooklyn Formation, as may be also the overlying Kaslo Group, which consists of volcanic rocks. Read and Okulitch (1977, p. 628), however place the upper part of the Milford Group in Lower Permian, and the Kaslo also in the Permian. Parts of the Slocan Group, which also yielded belemnites of probably Triassic age (Cairnes, 1934, p. 60; Little, 1960, p. 57) may be correlative to the Brooklyn Formation.

Near Lillooet, about 290 km northwest of Greenwood, Trettin (1961, p. 20-34) has described the Pavillion Group as consisting largely of chert and argillite in the lower part, and of volcanic rocks and sandstones in the upper part, which contains a fossil hexacoral of Triassic age. The Pavillion Group may be equivalent in part to the Brooklyn Formation. About 24 km farther west, the Fergusson Group (Cameron and Monger, 1971) comprises thin bedded chert, pelite, cherty argillite, volcanic rocks, and minor pods of carbonate. A single collection of conodonts has been identified as Middle Triassic, and a Ladinian age is indicated. However, recently (Monger, pers. comm. 1978) possible Upper Triassic and lower Middle Jurassic radiolaria have also been identified.

Rawhide Member

The Rawhide 'Formation' (mTr) was named by LeRoy (1912, p. 40) from the Rawhide property on which the formation is exposed southeast of the mine workings. The rocks were described as "dark grey to black slightly carbonaceous argillites in beds varying from 3 to 18 inches in thickness. A fine lamination parallel to the bedding planes occurs in some beds, the laminae being alternately light and dark grey". McNaughton (1945) also described the rock as argillite, but Seraphim (1956) called it "shale, with intercalated lenses of sandstone and conglomerate with smoky grey chert and sparse jasper pebbles".

LeRoy (1912, p. 40) believed that the Rawhide 'Formation' overlies the Brooklyn Formation conformably. McNaughton (1945, p. 3) stated that, because the 'jasperoids' associated with the Rawhide 'Formation' were formed by silicification of the argillites themselves, this did not indicate that the argillites are younger than the Brooklyn Formation, but he did not know the relationship. Seraphim (1956, p. 385, 386) thought that the Rawhide is older than, and transitional into, the Brooklyn Formation. Little and Thorpe (1965, p. 57) were convinced that the Rawhide 'Formation' is underlain and overlain by chert-pebble sharpstone conglomerate of the Brooklyn Formation, and therefore represents a local facies (member) of the lower Brooklyn Formation. A similar, local, thinner, argillaceous facies occurs within chert sandstone and minor sharpstone conglomerate that is correlated with the lower Brooklyn Formation and is exposed west of Greyhound Creek Fault.

Distribution and Thickness

The Rawhide Member is confined to an area of about 1900 m^3 in the vicinity of the Rawhide property, and a much smaller area along the old CPR railway grade about 600 m to the east. Poorly exposed black argillite (mTs4) that is probably not more than 15 m thick, and lies within what is correlated with the sharpstone member northwest of Skomac mine may be Rawhide.

In the type locality the apparent thickness is nearly 120 m, but if, as suggested in the following paragraph, recumbent folding is present, the thickness might be only half that figure.

Lithology

Little and Thorpe (1965, p. 58) defined the formation as "black siltstone; minor argillite and chert sharpstone conglomerate". The greater part of the formation is laminated, hard, brittle, fine grained siltstone that bears a striking lithological resemblance to the Archibald Formation (Little, 1962, p. 2; 1963, p. 3; Frebold and Little, 1962, p. 3-5) of Rossland, Trail, and Salmo map areas to the east, but which is Jurassic, rather than Triassic. The hardness and brittleness of the Rawhide 'argillite' was believed by McNaughton (1945, p. 3) to be due to silicification that produced his adjacent 'jasperoids'. The present writer believes it is due to induration such as occurred in the widespread Archibald Formation.

Internal Structural Relations

The internal structural relations are obscure. In the northwestern part the bedding dips 40° northwest, parallel to that in the sharpstone conglomerate unit above. In the old railway cut near the old mine buildings it dips about 10° northwest, and Seraphim (1956, p. 385) determined that, in one outcrop, these beds are not overturned. It may be that the entire sequence is not overturned, but an alternative suggestion is proposed. As shown in cross-section E-F, (Map 1500A) the Rawhide Member may form a recumbent syncline and superimposed anticline whose axial planes dip gently southeast. This would account for the presence of what has been mapped as Rawhide Member adjacent to the Eagle Mountain Fault, to the east of the type locality.

External Structural Relations

The Rawhide Member appears to be gradational laterally into the sharpstone member.

Age and Correlation

McNaughton (1945, p. 5) reported a possible fossil plant, and Seraphim (1956, p. 385) reported plant fossils or possibly graptolites from the Rawhide Member. A more diagnostic collection was made subsequently and was examined by E.T. Tozer of the Geological Survey.

Locality F14 GSC loc. 56911

In old rock-cut on abandoned C.P. railway grade southwest of Rawhide mine. (Locality now destroyed by widening of cut for a new road).
49° 05.4'N 118°05.0'W

Collected in 1963 by R.I. Thorpe and H.W. Little

Small fragmentary pelecypods, probably halobiids. Plant fragments.

Age: Probably Middle or Upper Triassic.

Because the Rawhide Member is overlain by chert sharpstone conglomerate, which is succeeded above by limestone of probable lower Ladinian age, the Rawhide Member is Middle Triassic, and at least as old as lower Ladinian, and therefore may be of Anisian age.

For possible correlatives of the Rawhide Member, the reader is referred to the section on the Brooklyn Formation.

Map Unit uTsv

These rocks, which differ lithologically from others of Triassic age, are shown as a separate map unit.

Distribution and Thickness

Rocks of map unit uTsv have been identified in two parts of the map area, one adjacent to Highway 3 for about 1.5 km north and south of Fisherman Creek, the other at and east of Highway 3 in lower July Creek. The thicknesses of the component members are estimated at 120 m, 30 m, and more than 1000 m, but the aggregate thickness may be less than the total of the three members, as there may be interfingering of the strata.

Lithology

In lower July Creek and on the uplands to the east the map unit comprises mainly white, massive limestone that lacks the chert granules that are typical of the Brooklyn limestone. In road cuts along Highway 3, however, the rocks exposed are incompetent light grey and black shale, and thin, massive, black limestone. Near Fisherman Creek the more easterly exposures are of white to medium grey massive limestone, several outcrops of which contain poorly preserved fragments of brachiopods and crinoid stems. On the highway about a mile north of its junction with the road to Phoenix, there is a large road-cut on Highway 3 that exposes limestone conglomerate or breccia, some clasts of which contain poorly preserved fossils; others contain fine chert granules. The clasts range in size from 2.5 cm to perhaps 30 cm by 60 cm. This may represent a basal conglomerate, but, in the writer's opinion is more likely an off-reef facies, or reef talus because many of the clasts are angular and are fossiliferous. Similar material occurs in the core of the Phoenix anticline north of Providence Lake, and may be of the same age. The more westerly exposures, well observed in highway road-cuts, are of distinctive rock with angular to round light grey limestone clasts, ranging from less than 2.5 cm to 12.5 cm in diameter, though locally a few are as much as 1.5 m in length in a purple to maroon tuffaceous matrix. Near the contact with massive limestone, this is interbedded with thin beds of red, shaly tuff, minor pale green slaty argillite, and thin beds of white to grey limestone. At the southern end of this area, a short distance north of Hardy Mountain, some outcrops of green cherty argillite, like some nearby limestone, have been referred to map unit uTsv. The lower(?) agglomeratic member south of Fisherman Creek may be as much as 120 m thick. The lower(?) shale member in July Creek may not be greater than 30 m thick. The upper(?) limestone member has an apparent thickness of greater than 1000 m, but the structure is not known. On the other hand, the top may have been eroded before the deposition of map unit Jv.

Internal Structural Relations

The rocks of map unit uTsv seem to have been gently folded, and tilted to the east. If this be so, at Fisherman Creek the maroon agglomerates represent the lower member of the map unit, whereas in lower July Creek the grey and black shales represent the lower member. At both localities, therefore, massive grey limestone forms the upper member.

External Structural Relations

The base of map unit uTsv is not exposed. The agglomerate members appears to rest upon the chert sharpstone conglomerate member of the Brooklyn Formation which is exposed nearby. If so, this marks an unconformity in which the limestone member of the Brooklyn Formation has been removed by erosion. It is possible, however, that the contact is a fault. In lower July Creek deep drift separates the basal(?) shale member from outcrops of Brooklyn limestone and Knob Hill chert.

The upper contact of the limestone member of map unit uTsv is also not exposed. However, to the east the limestone dips under volcanic rocks of map unit Jv. The limestone is also succeeded on the north by volcanic rocks of the same Jurassic(?) formation, which elsewhere rests upon rock units of different ages. It is probable, therefore, that map unit uTsv is overlain unconformably by volcanic rocks of Jurassic(?) age.

Age and Correlation

Several collections of fossils have been made from map-unit uTsv, in 1954, 1956, 1963 and 1964. The most diagnostic was made initially in 1954 from a large outcrop west of Highway 3 about 90 m north of the intersection of Highway 3 with the road to Phoenix (as both roads existed at that time). P. Harker of the Geological Survey examined the collection.

Locality F15 GSC loc. 24704

40° 06.3'N 118° 31.7'W.

Collected by H.W. Little in 1954.

Spiriferina sp.
Terabratula sp.

Age: Several large pieces (of silicified brachiopod fragments) were dissolved, of which two species are represented. One is a coarsely plicate spiriferoid which has a well developed median septum and all the other features of the genus **Spiriferina.** The other species is a smooth shelled terabratuloid with a long internal brachial loop. It is almost impossible to distinguish between the late Paleozoic and Mesozoic forms of the Spiriferina group and it would be of little use to attempt to date this species in a fauna consisting of only two species. Dr. F.H. McLearn states that the association of coarse spiriferoids and smooth terebratulas is a feature of some Triassic beds, however, there was a fragment which might possibly have been a productoid, which suggests a Paleozoic age.

An additional collection was made from the same locality by P. Harker and the writer in 1956. Harker commented:

GSC loc. 25603

"Colonial corals
Spiriferoid fragments
Terebratuloids
Pelecypods

"The brachiopods were examined by
Dr. F.K. Stehli who stated that
they could be Permian but a Triassic
age was perhaps more likely."

The corals were submitted to Donald F. Squires, of the American Museum of Natural History who, December 16, 1957 reported:

"There is little doubt in my mind but what they represent the Norian species **Thecosmilia suttonensis** which was described by Clapp and Shimer from the Norian of Cowichan Island. I also found what I believe to be the same species in the Idaho material I described in 1956. As you know, that fauna is associated with Spondylospira."

Locality F16 GSC loc. 56906

580 m north along the first G.N.R. railway grade crossing the road to Phoenix, west of Highway 3.
49° 06.3'N 118° 32.1'W

Collected by R.I. Thorpe in 1963

Examined by E.T. Tozer

Ammonite fragments
"**Pentacrinus**" columnals

Age: Probably Middle or Upper Triassic

Locality F17 GSC loc. 56904

70 m north of Fisherman Creek road, 0.4 km east of Highway 3.
49° 06.35'N 118° 31.4'W

Collected by B.F. Watson in 1963

Examined by E.T. Tozer

Spiriferina sp. (silicified)
Halobiid pelecypod fragments

Age: Middle or Upper Triassic

In 1957, J.A. Calkins and S. Muessig of the U.S. Geological Survey, while travelling along Highway 3, were struck by the similarity of beds exposed in rock cuts in lower July Creek to those about 7 km to the south in Curlew quadrangle, from which Parker and Calkins (1964, p. 31) had collected **Halobia** of early or medial Late Triassic (Karnian or early Norian) age. They obtained some fragments of ribbed pelecypods which Calkins kindly sent to the writer.

Locality F18 GSC loc. 32343

Highway 3, 6 km (by road) west of the junction with Highway 21.
49° 02.0'N 118° 32.25'W

Examined by E.T. Tozer, November 15, 1957

The collection contains fragmentary individuals of a pelecypod referable to either Halobia or Daonella. The anterior part of the shell is not preserved so that the distinction between **Daonella** and **Halobia** cannot be made. The shell has the flexuous ribs commonly found in Halobia.

Age: Triassic, probably Upper Triassic

Attempts by the writer and his assistants in 1963 and 1964 to collect more diagnostic material from the locality were unsuccessful, but, in view of the lithological similarity to the **Halobia**-bearing locality to the south, it seems probable that the shells are **Halobia** and the age of the beds Karnian or early Norian.

Map-unit uTsv is correlated with the upper part of the "Permian and Triassic rocks" of Parker and Calkins (1964, p. 27-35), which consist of greenstone, limestone, chert, argillite, greywacke, and conglomerate, and therefore include several of map-units of Greenwood map area. A second fossil collection, 3 km south-southwest of their **Halobia** locality, contained **Spondylospira,** also of Late Triassic age. No rocks of Triassic age were found to the south in the adjoining Republic and Aeneas quadrangles (Muessig, 1967).

In Slocan area, about 145 km northeast of Greenwood, the Kaslo Group (Cairnes, 1934, p. 43-49; Little, 1960, p. 52, 53), composed of volcanic breccia and tuff at the base and flows and intrusives above, has been placed in the Triassic because of Triassic belemnites near the top of the underlying Milford Group. The Kaslo may therefore be equivalent in age to map unit uTsv. Read and Okulitch (1977, p. 628), however, place the Kaslo in the Permian, due, apparently, to the unconformity with the overlying Slocan Group. The Slocan Group is, in part at least, equivalent to map unit uTsv. It consists of predominantly argillaceous rocks, some fine-grained quartzite and limestone, and minor tuff and conglomerate. The thickness was estimated by Cairnes to be 2000 m, but Hedley (1952, p. 23), as a result of detailed mapping, suggested it might be several times that figure. Belemnites, collected by Cairnes, were identified by Jeletzky as "most probably Triassic" (Little, 1960, p. 53). Recently conodonts collected from the lower part (as interpreted by Hedley) of the Slocan Group by P.B. Read and A.V. Okulitch (Read, pers. comm., April 1977) were identified by B.E.B. Cameron of the Geological Survey as "Late Triassic, latest Karnian to early Norian".

In the Intermontane Belt, the nearest rocks of similar age are those of the widespread Nicola Group, which consist largely of volcanic rocks, between Okanagan and Fraser Valleys, from near the International Boundary north to the fifty-first parallel (Rice, 1947; Cockfield, 1948; Little, 1961; Okulitch and Cameron, 1976), 100 km to 260 km west and northwest of Greenwood. The abundant lavas consist mostly of andesite and basalt, and the marine sediments of small patches of bedded tuff, tuffaceous argillite, limestone, and conglomerate. The Nicola rocks are therefore not lithologically similar to map unit uTsv. Numerous collections of fossils, however, are of Karnian and Norian (Upper Triassic) age.

In the Intermontane Belt of north-central British Columbia the Takla Group, as now defined, resembles the Nicola Group lithologically and is correlated with it. It contains fossils of Late Triassic (Late Karnian to Middle Norian, possibly Late Norian) age, (Tipper and Richards, 1976, p. 5). It is therefore equivalent in age to map unit uTsv, but not in lithology.

Map Unit Jv

Volcanic rocks of this map unit were included by Brock (1903, p. 97; 1905) in his Paleozoic assemblage and were correlated with greenstones of the Cache Creek 'series', but shown as being much more widespread than they are. Daly (1912, p. 383-385) recognized them as a separate, younger formation and correlated them with the Rossland Group to the east which he correctly placed in the Mesozoic. He named this volcanic unit the Phoenix Volcanic Group from "a small mass of volcanic rock" at the town of Phoenix which

R.W. Brock had interpreted as a volcanic neck. LeRoy (1912), however, in detailed mapping, did not identify this rock. Little (1957), in an attempt to find a substitute name for Daly's Midway Volcanic Group, because the name Midway had been used previously elsewhere, erroneously applied the name Phoenix to these Tertiary rocks which are exposed at Phoenix. This unfortunate error, although subsequently corrected (Little, 1961) has been perpetuated because the earlier publication remains in print. The name "Phoenix" has therefore been abandoned in this publication, and the map unit is unnamed.

McNaughton (1945) in the Greenwood-Phoenix area identified several bodies of "diorite, gabbro, and pyroxenite" beyond the boundaries of LeRoy's map area, which he thought might be slightly older than the granodiorite, but genetically connected with it. Seraphim (1956) recognized that the bodies mapped by McNaughton near Providence Lake are volcanic in origin, and were included by him in the upper part of the Brooklyn Formation. Like Daly, Little and Thorpe (1965) were impressed by the resemblance of these volcanic rocks particularly the flow breccias and augite porphyries to those of the Rossland Group.

Distribution and Thickness

The volcanic rocks of map unit Jv occur only in the southeast quarter of the map area. They are most extensively exposed in the valleys of May and July creeks, and on the uplands east of July Creek from the International Boundary north to the B.C. Fault. A large mass is exposed from lower Hippolite Creek to upper Gidon Creek, and some east of Mount Wright. Relatively small exposures occur between Lind Creek and the Eholt Valley Fault. East of the map area, in the valley of Granby River east to the Granby River Fault these volcanic rocks are exposed as far north as Hornet Creek, about 18 km from Grand Forks.

As the rocks of map unit Jv are almost entirely massive lavas, flow breccias, nothing is known of the structure, so that no meaningful cross-sections can be drawn. The thickness appears to be at least 330 m.

Lithology

The most common rock is flow breccia that is extremely well exposed in rock-cuts along Highway 3 in the valley of July Creek. South of Eagle Mountain and eastward beyond the edge of the map area these flows contain thin pods of interbedded limestone, and Seraphim (1956) mentioned also shale.

In Hippolite and Gidon creeks, however, the rock is a massive, structureless, fine grained greenstone, which in fresher samples is an augite porphyry containing, in addition to augite, plagioclase, tremolite, epidote, and minor interstitial quartz, apatite, chlorite, zircon(?), rutile(?), and opaque minerals. More altered specimens consist mainly of actinolite, with epidote, chlorite, albite, lesser quartz, and minor leucoxene, sphene, and opaques, mainly magnetite.

In May Creek the rocks are propylitized, consisting of albite, actinolite(?), and epidote in a fine grained matrix made up of plagioclase with epidote, chlorite, biotite, and minor opaque minerals. Near Phoenix the rocks have been identified as andesite and basalt.

Some of the smaller exposures are probably volcanic necks, and a few of these are medium grained diorites or gabbros.

Internal Structural Relations

The internal structural relations of the map unit are not known. Although it must have been involved in the Jura-Cretaceous orogeny, this does not seem to have affected the structure except locally. The unit rests upon various older map units but there is little evidence of subsequent folding. In the vicinity of Mount McLaren and Rusty Mountain, however, the rocks form a thrust plate in which, in the upper part of the section, strong lineations plunging gently eastward are evident.

External Structural Relations

The contact of map unit Jv with older rocks has not been observed, except possibly north of the head of McCarren Creek. There, Church (1970, p. 416) has found a conglomerate intercalated between his "basement complex" (map unit **P**m1) and the basic lavas of map unit Jv. This conglomerate, which consists of distorted boulders of carbonate in a schistose matrix of greywacke, he regards as basal. Elsewhere, flows of map unit Jv rest with apparent unconformity upon map unit **P**m1 north of May Creek, but elsewhere upon the Knob Hill Group, the Brooklyn Formation, and the Upper Triassic map unit uTsv.

Age and Correlation

The age of map unit Jv is not accurately known, but as it overlies the Upper Triassic and older formations, it is no older than Upper Triassic. It is overlain unconformably by the Middle Eocene Kettle River Formation. A single collection of poorly preserved fossils was obtained from a limestone bed about 9 m thick that is interbedded with flow breccia. E.W. Bamber of the Geological Survey examined the collection.

Locality F19 GSC loc. 62511

On slope, 2.7 km N 19° W from Boundary Monument 154 at Carson.
49° 01.4'N 118° 30.9'W

Collected in 1964 by H.W. Little and V.A. Preto

Immature, unidentifiable gastropods
Foraminifera, possibly fusilinids
?Brachiopod fragments – poorly preserved

Age: Insufficient material in macrofauna for age determination.

T.P. Chamney of the Geological Survey examined the material and reported that he "was able to distinguish two very indistinct, re-crystallized Foraminiferida". The material was tested for conodonts in 1977 by Joanne Jenkins of the Geological Survey, but without success. Although no diagnostic fauna have been found in this limestone, further collections are recommended.

The formation is correlated on lithological grounds with the Rossland Group and the age is taken to be Jurassic(?).

The Rossland Group in the Salmo map area is underlain by the marine sedimentary Archibald Formation of early Early Jurassic (Sinemurian and (?)Hettangian) age (Frebold and Little, 1962). The lowest unit there of the Rossland Group is the Elise Formation comprising volcanic rocks only. Above this is the marine sedimentary Hall Formation, of late Early and early Middle Jurassic (Toarcian and Bajocian) age. Farther west, in Trail and Rossland map area (Little, 1962, 1963) the Archibald Formation is missing and the volcanic rocks of the Rossland Group rest unconformably upon Paleozoic beds. Thin beds of tough, brittle, black siltstones that resemble the Archibald Formation are interbedded with the lavas up to some thousands of feet above the base and yield ammonites of early Early Jurassic (Sinemurian) age.

At one locality in each of the Trail and Rossland map areas, ammonites of late Early Jurassic (Toarcian) age were collected from thin black shaly beds high in the Rossland Group.

Rocks of the Rossland Group have been traced as far west as Christina Lake (Little, 1961). South of Trail map area, they do not extend more than about 100 m south of the International Boundary at Columbia River (Yates, 1964), where they terminate against the Waneta thrust fault. South of Rossland map area, they have been traced intermittently some 13 km south of the Boundary (Yates, 1971). To the west, they have been mapped by Bowman (1950) and extend some 19 km south of the International Boundary, and west to the Kettle River.

The Nicola Group, described previously under map unit uTsv, although of similar lithology to map unit Jv, is regarded as Late Triassic (Karnian and Norian) age, but one collection by Dawson (1896, p. 57B, 112B) was said to be Lower Jurassic. However, Duffell and McTaggart (1952, p. 31) discounted this possibility. Map unit Jv may be, in part, equivalent to the Nicola Group, either because Lower Jurassic beds may be present in the Nicola, or because map unit Jv may be Upper Triassic.

A little farther west of the Nicola Group, the Ladner Group, comprising volcanic sandstone, argillite, conglomerate, tuff, breccia, and lava flows is of Toarcian to Bajocian age (Coates, 1974) and so is nearly equivalent in age to the Rossland Group, and therefore is thought to be equivalent to map unit Jv.

In the Intermontane Belt in north-central British Columbia the widespread Hazelton Group (as defined by Tipper and Richards, 1976, p. 5, 6) consists of basaltic to rhyolitic volcanic rocks and marine sedimentary and tuffaceous rocks. The age of these rocks is Sinemurian to Early Callovian (Early and Middle Jurassic), and so is closely equivalent to the Rossland Group, and therefore possibly to map unit Jv.

Map Unit Jph

Map unit Jph is the northward extension of a phyllite map unit that was defined by Parker and Calkins (1964) in Curlew quadrangle, Washington.

Distribution and Thickness

Map unit Jph occupies an arcuate belt that extends from the International Boundary east of Mount McLaren northwesterly to Rusty Mountain, thence west-southwest to the Boundary again south of the upper part of Norwegian Creek. These rocks outcrop more extensively to the south, in Curlew quadrangle. The apparent thickness of the map unit is about 500 m, but, as the strata are intensely crumpled and folded, the true thickness is probably considerably less.

Lithology

Map unit Jph consists primarily of lustrous, carbonaceous phyllite, but near its lower contact at the head of Bubar Creek, there is much chlorite schist which is interpreted to be intercalated lava that has been converted to schist through dynamic metamorphism. A few beds of greenish grey argillite, and dark grey greywacke were noted in the middle part of the formation. In the upper part, thin intercalations of greywacke and siltstone mark the transition into the overlying siltstone and fine-pebble conglomerate of map unit Js. In most exposures, bedding in the phyllite is not visible, or is faint, but in some, bedding is distinct, and in two outcrops, fine crossbeds were seen. The bedding is produced by laminae of lighter grey silty argillite that are commonly very thin.

Throughout, the phyllite is strongly foliated, the sheen being imparted by very fine flakes of sericite that are oriented parallel to the foliation, which is invariably at an angle to the bedding. In most outcrops the phyllite is strongly lineated due to small crenulations and pencil structures, which plunge from 0° to 15° in a direction of 110° to 120°.

In thin sections the phyllite is seen to consist of a very fine grained laminated aggregate of quartz, sericite, some biotite, and minor limonite. Some of the phyllite is knotted, containing porphyroblasts that consist almost entirely of white mica. Parker and Calkins (1964, p. 21) believed these to be poikoblastic cordierite, but in a sample collected in the valley of Norwegian Creek, the shape of the crystals is more like chloritoid (ottrelite).

Internal Structural Relations

From its distribution and its relationships to adjacent map units, the phyllite appears to form an open syncline that plunges gently south-southwest. However, bedding attitudes do not conform very closely to this concept, and dips for the most part are steep. Furthermore, strong lineations and minor folds are never parallel to the axis of such a syncline, but plunge 0° to 15° in a direction 110° to 120°. It seems probable that the rocks were folded gently into a syncline and then thrust north-northeastward, along with the underlying and overlying formations, at which time the strong lineations were imparted, and the rocks north of Rusty Mountain intensely sheared.

External Structural Relations

Map unit Jph is believed to rest conformably and gradationally on the volcanic flows of map unit Jv. It is overlain conformably by map unit Js.

Age and Correlation

Little and Thorpe (1965, p. 56) were uncertain of the relationship of the phyllite to other units, and they accepted Parker and Calkins' (1964, p. 20, 23) conclusion that the rocks are pre-Permian. Church (1970), as a result of more detailed mapping, concluded that the phyllite is younger than the lavas. The writer, accompanied by Church, re-examined the phyllite and overlying map unit in 1976 and agrees with him that they are indeed younger. In three outcrops bedding tops face south, which would be contrary to the conclusions of Parker and Calkins. They (op cit p. 23) described greenstone of Permian and Triassic age overlying the phyllite 1.6 km north of the International Boundary. From the geological map, this could only be greenstone of map unit Jv, believed to be of Jurassic age and to underlie the phyllite. Parker and Calkins' phyllite map unit contains some greenstone, which may be the equivalent of the Jurassic (?) volcanics. If so, the major part of the volcanics south of the International Boundary have been cut out by faults that terminate the phyllite unit on the east and west. One would have to assume a third fault on the south, and the higher grade of metamorphism in the adjoining schist to the south is suggestive of a faulted contact.

As the phyllite is believed to younger than map unit Jv, and only slightly so, the age is taken to be Jurassic(?). As the age is not known with certainty, no correlations with other formations are possible.

Map Unit Js

Map unit Js was first distinguished by Church (1970) who noted the slightly coarser grain of the sediments above the phyllite on Mount McLaren, and was able to map them as

a separate unit. The writer confirmed this in the field in 1976 and from earlier field notes, and therfore agrees with Church.

Distribution and Thickness

Map unit Js has been identified only on the summit and upper part of Mount McLaren. It is exposed over an area of only about 1.3 km^2 but much Tertiary diorite is also exposed within the same area. No accurate figure for the thickness can be given, but it is somewhat less than 300 m.

Lithology

The unit consists of fine grained dark grey siltstone (described as quartz wacke by Church) and minor fine-pebble conglomerate.

Internal Structural Relations

Bedding consists mainly of fine laminae that are discernable in most outcrops. In two places, fine cross-bedding was noted. The attitudes of the beds are mostly westerly, but some are northwesterly. Dips range from moderate to steep. Like the underlying map unit, the rocks are strongly lineated in about the same direction, and are probably identically deformed.

External Structural Relations and Age

As map unit Js overlies conformably map unit Jph and has undergone the same deformation, the age is also assumed to be Jurassic(?). The top of the formation has been eroded, and it is not overlain by any other map unit.

Ultramafic Intrusions

Ultramafic intrusions that are most commonly associated with rocks of map unit Pml and the Knob Hill Group are scattered throughout the southern part of the map area. The largest bodies occur in the valley of Goosmus Creek, on the ridge north of Gidon Creek, the north and east slopes of Mount Wright, north of Skeff Creek, at the head of July Creek, and 3 km north-northeast of Rock Creek. Smaller bodies occur in the southeast corner of the map area, east of Hardy Mountain, in the block bounded by the May Creek and the Fisherman Creek and Twin Creek faults, also extending as far west as the Greyhound Creek Fault, in the hills northwest of Midway, in the valley of the Kettle 6.5 km east of Rock Creek, and in the fault block that is underlain by Knob Hill Group, extending on the east side of Kettle River from the vicinity of Rock Creek to the bend of the Kettle 6.5 km north.

The ultramafic intrusions were described by Brock (1903, p. 98A, 99A) as serpentine. Daly (1912, p. 393) stated that serpentine exposed 1.5 km north of Rock Creek, but west of Kettle River and therefore just outside the map area, is dunite, and consists solely of olivine and chromite. McNaughton (1945, p. 7) also recognized a few relict grains of olivine in serpentinite, but the locality was not stated. Church (1970, p. 416, 417) in the McCarren Creek-Goosmus Creek area found relicts of pyroxene in most thin sections, and in a few, of both olivine and pyroxene.

A dozen thin sections were examined by the writer; all were somewhat altered to atigorite, and some contained much carbonate, but no talc was identified in them. Of the dozen examined, two were identified as pyroxenite, one as dunite, three as peridotite, and the remaining six were completely altered to serpentinite.

The largest body of pyroxenite is exposed along Highway 3 about 1.5 km south of the junction of the road to Phoenix, and on the abandoned Great Northern Railroad right-of-way a short distance to the west. In thin section it is seen to be largely antigorite containing remnants of clinopyroxene (of which the optic sign could not be determined with confidence). The pyroxene is traversed by minute veinlets of chrysotile. A few grains of chromite or chrome spinel, and minute crystals of magnetite are fairly abundant along fractures in the pseudomorphs. This pyroxenite, which is mostly coarse grained does not extend far from the highway. An outcrop on the highway southwest of the pyroxenite is of peridotite in which round pseudomorphs, now consisting of felted antigorite, were almost certainly olivine, the remainder of the rock consisting of clino-pyroxene, almost entirely altered to antigorite, and minor chromite and magnetite.

A small body of pyroxenite was also identified nearly 1.5 km northeast of Crook Lake. Abundant carbonate has been introduced into the rock.

The serpentinite on the ridge north of Gidon Creek consists entirely of antigorite, carbonate, and magnetite; no pseudomorphs are visible. Farther east, in the valley of Goosmus Creek the serpentinite is intensely sheared, has a smooth, greasy appearance and mottled dark and light green colour, and is locally altered to talc. Still farther east, south of Gibbs Creek, the ultramafic rock is locally altered to talc. On the ridge east of the City of Paris mine, it contains tiny veinlets of chrysotile and some clusters of bladed crystals of brucite.

South of Gibbs Creek the ultramafic rock is relatively fresh, but contains a little carbonate. The rock is composed of 25 to 35 per cent olivine. The clinopyroxene has a 2V of about 90° and so could be either enstatite or hypersthene.

The body extending north from Mount Wright is serpentinite, containing a few tiny veinlets of chrysotile and a little carbonate. A body on the northwest slope of Mount Attwood, which was thought in the field to be a massive ultramafic rock, turned out to consist of antigorite with some carbonate and a little magnetite; no pseudomorphs were visible in thin section. In another body that is about 0.8 km east-northeast of Mount Attwood, the serpentinite has been thermally metamorphosed, and fibrous masses of tremolite have been developed.

Finally, a sample from an outcrop of ultramafic rock on the Lind Creek road 2.2 km from Greenwood, though consisting largely of antigorite, with much magnetite, some carbonate, and minor hematite, chromite, and chrysotile, is believed to be dunite because some olivine remains, but no pyroxene, which is less readily serpentinized.

The age of the ultramafic intrusions is difficult to establish because, like evaporites, ultramafic rocks, especially when serpentinized, are easily subject to plastic deformation at low temperatures, and form diapiric intrusions. This is readily apparent in Greenwood map area where small pods of serpentine occur in one or two places in faults that displace Marron volcanic rocks (Little and Monger, 1966, p. 67), which are of Early Tertiary age.

Brock (1903, p. 99A, 100A) believed that the serpentine is of two ages, because he found serpentine boulders "in the green volcanic conglomerates", which must be Triassic or at latest, Jurassic in age, and he noted that some serpentine "seems to be intrusive into green porphyrite which is a little later age than these volcanic conglomerates". The present writer is not aware of such boulders and so has no evidence for more than one age of primary intrusion.

The ultramafic rocks definitely form intrusive bodies in the Knob Hill Group, and so are of Carboniferous or later age. Rocks as young as map unit Jv, of Jurassic(?) age, appear to be intruded by bodies of serpentine, and between Rusty Mountain and Mount Wright, map unit Jph is interrupted as well by the elongate mass of serpentine there. These examples could result from cold intrusion, but the writer does not think so except possibly in the last case, where the serpentine is intensely sheared, whereas the larger bodies are in general not.

About 19 km east of Grand Forks, and east of the Kettle River Fault (Preto, 1970), a large body of serpentinite cuts the Rossland Group, of Lower and Middle Jurassic age, and the same relationship obtains in other places farther east of that locality (Little, 1957, 1960). If the ultramafic rocks there are the same age as those of Greenwood map area, then the latter are also Middle Jurassic or later.

In Greenwood area the serpentinites are cut by dykes of Tertiary age and some believed to be related to the Nelson Intrusions. Most previous authors (Brock, 1905a; Daly, 1912; McNaughton, 1945) agree that the ultramafic intrusions are pre-Nelson, and McNaughton stated that they are cut by granodiorite. Church (1970, p. 416), however, stated that the quartz-feldspar porphyry, quartz porphyry, and felsite, which he regarded as of Early Mesozoic(?) age, are cut by the serpentine which he assigned to the Cretaceous(?). A Jurassic(?) age would not be out of keeping with these facts, but even if the acid intrusions are later than Jurassic, cold intrusion of the serpentine would be most likely in the zone of intense shearing. Reinsbakken (1970, Table 1) assigned a Late Cretaceous or Early Tertiary age to the ultramafic rocks, but did not offer any supporting evidence in the text for this conclusion. The age of these intrusions is therefore taken to be Jurassic(?).

The ultramafic rocks may be part of a disrupted ophiolite that formed the floor of the Knob Hill Group, (Okulitch and Peatfield, 1977; Monger, personal communication, 1978) as this association with greenstone, chert, and limestone is characteristic of the Cache Creek, Bridge River, Fergusson, Hozameen, and Sylvester groups that appear to have ophiolite affinities. The ultramafic rocks were subsequently squeezed into rocks as young as Eocene. Zoning of some of the ultramafic bodies, particularly that in upper July Creek which was emplaced in Jurassic(?) rocks, suggests to the writer that these bodies in Greenwood map area are not Late Paleozoic intrusive bodies that were later emplaced by cold intrusion. The possibility that they are ophiolite fragments is not entirely discounted, however, and perhaps there are two ages (and types) of ultramafic intrusions as Brock suggested, but if so, it is not possible to separate them.

The Ultramafic Intrusions are tentatively correlated with those elsewhere in Kettle River (east and west halves) and Nelson map areas (Little, 1957, 1960, 1961), and Curlew (Parker and Calkins, 1964) and Orient (Bowman, 1950) quadrangles. Ultramafic rocks elsewhere in southern British Columbia appear to be a little earlier. Jones (1959, p. 35) "provisionally considered such rocks to be pre-Permian". However, as they cut the Mount Ida Group, subsequently shown to be Late Triassic (Okulitch and Cameron, 1976, p. 49), they are Late Triassic or later. Leech (1953, p. 39), in Shulaps Range (west of Fraser River) thought the age of the Shulaps ultramafic intrusions are Late Triassic or Early Jurassic, for they intrude Upper Triassic beds, and Lower(?) Jurassic strata contain chromite. They may be as late as Upper Jurassic, however, as the Jurassic(?) strata are now known to be Lower Cretaceous (Tipper, H.W., personal communication, 1979). In the Intermontane Belt of north-central British Columbia, Armstrong (1949, p. 91, 92) established the age of the Trembleur Intrusions as Triassic, as they cut Permian strata, and Upper Triassic conglomerate contains boulders of serpentine and grains of chromite.

Nelson Intrusions

The Nelson Intrusions (JKgd) consist of stocks and smaller bodies that are composed mainly of granodiorite. Much of the north part of the map area as far west as the Fiva Creek and Louise Lake faults at one time must have been underlain by these rocks, but subsequently some of the Nelson rocks were intruded by smaller bodies of Coryell Intrusions (Ec), particularly in the northeastern part. In the southern part, bodies of Nelson Intrusions are smaller and more scattered, the largest being the stock that is centered at Greenwood.

Megascopically, the Nelson Intrusions are easily recognizable. They consist largely of medium- to coarse-grained grey biotite hornblende granodiorite. The texture is hypidiomorphic. Locally, the rock is more melanocratic and no quartz is visible. This dioritic facies is most commonly seen near the borders of the intrusive bodies.

The Greenwood stock was described as being of granodiorite by Brock (1905a) and McNaughton (1945), and LeRoy (1913, p. 20-24) has described in great detail the small satellite bodies of granodiorite in Deadwood camp, just west of the Greenwood stock. Seraphim (1956, p. 390), however, described the Greenwood stock as being of quartz diorite, although he stated that the larger body to the north, which he defined as a batholith, is of granodiorite. The small, elongate body of diorite that lies a short distance northeast of the Greenwood stock differs from the other bodies mapped as diorite by McNaughton. It most closely resembles Nelson rocks and is therefore so classified on the geological map of Greenwood area.

The "Rock Creek Plutonic Rocks" that form a large stock in the southwest corner of the map area, south of Rock Creek, were described by Daly (1912, p. 392, 393). They are coarse grained and consist of basic andesine, with some orthoclase, microperthite, quartz, biotite, and hornblende. "Epidote, calcite, and kaolin are very abundant secondary constituents". The contact phases consist of quartz diorite. South of the International Boundary, Pearson (1967, p. 2) also identified the rock as granodiorite, but stated that it "varies widely in composition and grain size, and is extensively altered to saussurite, epidote, greenish-brown biotite, sericite, and chlorite".

Small bodies of Nelson Intrusions west and northwest of the Oro Denoro and Emma mines, named the Lion Creek and Emma intrusives by Carswell (1957) are composed of granodiorite, which was confirmed by N.B. Church (personal communication, 1977).

The large bodies of Nelson Intrusions in the north half of the map area appear to be uniform in composition. Thin sections of specimens show that the rock is composed mainly of andesine (An_{34-40}), slightly zoned, and slightly saussuritized, with lesser orthoclase and perthite, which are partly sericitized, and quartz, which forms round interstitial clusters, and small, round crystals within the plagioclase. Myrmekite occurs at the borders of the plagioclase and orthoclase. The mafic minerals are hornblende and biotite, the latter altered in part to chlorite. Disoriented clusters of fine grained corroded biotite contain small crystals of amphibole. Biotite is commonly interstitial to quartz. Epidote, sericite, and opaque minerals are scattered in the rock. Accessory minerals are sphene, and minor zircon and apatite.

Rosiwal analyses of three specimens are presented below:

Specimen No.	LF64-13L	LF64-18P	LF64-39P
Andesine	43.3	42.8	40.9
K-feldspar	1.5	15.4	1.4
Quartz	34.3	21.3	5.1
Hornblende	6.0	5.1	14.7
Biotite	12.7	9.7	10.7
Pyroxene			21.4
Epidote	1.4	3.7	0.9
Chlorite	0.2	n.d.	-
Sericite	0.3	n.d.	-
Sphene	n.d.	0.9	-
Opaques	0.3	1.0	4.9
	100.0	100.0	100.0

LF64-13L - north side of Wallace Creek near 188° 45'W.

LF64-18P - 4 km N 60°W from the mouth of Henderson Creek.

LF64-30P - 0.4 km west of Boundary Creek, 0.8 km south of north edge of the map area.

In a number of places primary foliation of the granodiorite has been recorded, and mostly has a westerly trend with dips steeply north to vertical. Locally, however, there are northwesterly or northeasterly, and a few northerly, trends. These data indicate that the foliation that was produced is mostly parallel to the southern border of the batholith of Nelson Intrusions that was emplaced in the northern part of the map area and farther to the north.

Radiometric ages of the Nelson Intrusions are variable. In the Nelson batholith K-Ar ages range from 60 to 171 Ma (Reesor, 1965, p. 51, 52) and in the Valhalla Complex adjoining it to the west are as young as 11 Ma. It can be argued that the younger ages obtained in the Nelson batholith and the Valhalla Complex have resulted from the adjacent younger metamorphic event. However, it is evident from field data that the evolution of the Nelson batholith was probably long and complex. The earliest ages indicate, rather surprisingly, that parts of the batholith were emplaced in early Middle Jurassic time when sediments of the fossiliferous Hall Formation were being deposited. Such deposition appears to have continued for some time afterward, contemporaneously with emplacement of the Nelson batholith, but the resulting rocks contain no record of such an amount.

Few radiometric ages have been obtained for Nelson Intrusions west of the Nelson batholith. One of these is a specimen of granodiorite collected by Church and Winsby (1974, p. 58) from the Dentonia mine near Jewel Lake that yielded a K-Ar age of 125 ± 5 Ma. Another sample, collected by Church from the Lion Creek granodiorite stock was dated at 140 ± 5 Ma. (Church, personal communication, 1977). These dates may, however, have been updated by subsequent events. Two suites of granitic rocks that are lithologically distinct exist in the northwestern part of the map area. The earlier, the Nelson, is invaded by the Valhalla suite, which is older than the Middle Eocene Kettle River Formation, in which boulders of both Nelson and Valhalla rocks are present.

Granodiorite is typical of those bodies that extend southward and westward from the type 'Nelson batholith', in which the dominant rock is porphyritic granite or quartz monzonite (Little, 1960, p. 80-85; 1957, 1961; Reesor, 1965, p. 34-38). The "Okanagan Intrusives" of Cairnes (1940) in the Kettle River (west half) map area are, in part at least, equivalent in age and composition, to the Nelson Intrusions. Intrusive rocks of similar age and composition are widespread throughout southern British Columbia (Little, 1962b) and eastern Washington (Huntting, et al., 1961).

Valhalla Intrusions

The Valhalla Intrusions (Kvqm) were first recognized by Brock (McConnell and Brock, 1904) who observed that they cut the Nelson Intrusions and had a much fresher appearance than the latter. In consequence, he regarded them as "post-Cretaceous" which turned out to be in part correct in the type locality of the Valhalla Mountains (Reesor, 1965, p. 38, 52). There, however, the Valhalla is in places gradational into rocks regarded by Brock (op cit.) and Little (1960, p. 87) as Nelson plutonic rocks, but shown later by Reesor to be largely or wholly part of the Valhalla gneiss complex. These same relationships exist farther west in Inonoaklin Valley (Little, 1957), but farther west, and southwest, Valhalla rocks only intrude the Nelson, and this is true in the north-central part of Greenwood map area.

The Valhalla Intrusions are exposed in an area of about 15 km^2 in the upper part of Boundary Creek Valley and the most northerly tributary from the east, and an area of about 4 km^2 along the north edge of the map area about 0.75 to 3.0 km west of upper Henderson Creek.

For the most part, the Valhalla Intrusions consist of extensive masses of leucocratic pegmatite in which white to pink feldspar and smoky quartz are abundant, and a small amount (usually less than 5 per cent) of coarse biotite occurs, commonly in clusters. Pegmatite also forms dykes that cut gneiss, amphibolite, and Nelson granodiorite.

Coarse grained granite and possibly quartz monzonite, in a few places medium grained, make up most of the balance of the suite. In many outcrops these rocks are faintly gneissic, or have secondary foliation. Microscopic examination of this facies reveals that it is composed mainly of potash feldspar and quartz, with some calcic oligoclase (Ab_{71}), and a little biotite. The minerals are little altered. The potash feldspar is usually pink in colour and forms somewhat euhedral phenocrysts (metacrysts?) that are normally about 2.5 cm, but not uncommonly 5 to 7.5 cm long. In many places the phenocrysts have been crushed into augen. Accessory minerals are sphene, which forms relatively large prisms, and magnetite, allanite, and apatite, which form relatively small anhedral crystals.

Alpite is a minor facies that intrudes pegmatite, granite, gneiss, and amphibolite in narrow dykes, indicative of rapid crystallization in the late stages of intrusion, due to release of pressure.

The erratic grain size of components of the map unit and its association, although only to a small extent, with migmatites suggests that it is probably a part of a metamorphic complex. These rocks extend northward from Greenwood map-area for a considerable distance, at least to the 50th parallel of latitude (Little, 1957).

The Valhalla Intrusions, as mentioned, cut migmatites and Nelson Intrusions. North of the map area and elsewhere they are in turn cut by Coryell Intrusions, of Eocene age, and by other hypabyssal rocks of Tertiary age. Boulders resembling Valhalla granite and quartz monzonite occur in conglomerate of the Kettle River Formation, which, beyond the map area, rests upon Valhalla rocks. In view of the fact that unmetamorphosed Kettle River sediments rest upon Valhalla rocks in Kettle River area and dykes cutting these sediments, which yield Middle Eocene plant spores, and are cut by dykes yielding radiometric ages of 46 Ma to 49 Ma, it is unlikely that the Valhalla rocks in Greenwood map area are

less than 60 Ma. Indeed, to allow for denudation of the metamorphic rocks, a minimum age of 65 Ma to 70 Ma (Latest Cretaceous), and a maximum age of 120 Ma (Early Cretaceous) seem most probable. The age is therefore taken to be Cretaceous(?).

Map Unit KTi

In a few places, widely scattered in the map area, a suite of acidic intrusions that is characterized by round phenocrysts of quartz (eyes) was encountered that do not seem to be related to either Nelson and Valhalla intrusions or to intrusive rocks of Eocene age. They may be unrelated to one another, but, except where sheared, are for the most part fresher than Nelson rocks. In no place were they seen in contact with Kettle River or Marron formations, and only west of Midway are they cut by intrusions of established Eocene age. Their age is therefore assumed to be Cretaceous or earliest Tertiary.

A large body of quartz-feldspar porphyry extends along the valley of Gidon Creek and the lower part of the ridge between Gidon and McCarren creeks, thence southwestward to the lower part of Hippolite Creek. Dykes of similar rock are seen near the International Boundary from upper Norwegian Creek eastward almost to Mount McLaren. A thin section of this rock shows it to be cataclastic, with round to subhedral quartz, plagioclase and perthite in a fine grained matrix of sutured quartz and plagioclase. Zoned plagioclase porphyroclasts make up about half of the rock, perthite porphyroclasts about 10%, and quartz porphyroclasts about 10%. The groundmass consists of quartz (15%), plagioclase (5%), epidote (5%), hornblende (1%), biotite (1%) and less than 1% each of apatite, zircon, chlorite, limonite, and an opaque mineral, probable magnetite. This is fairly close to a modal analysis of four samples published by Church (1970, p. 416).

In the valley of Goosmus Creek, Church (op cit.) mapped also a body of quartz porphyry which he described as displaying "a number of facies, including a fine-grained chilled selvage and a fine-grained phase resulting from cataclasis. The typical porphyry phase contains subhedral quartz phenocrysts and composite quartz eyes 2 to 7 mm in diameter set in a matrix of small, rectangular plagioclase crystals 1 to 2 mm in diameter, chloritized biotite, and interstitial fin-grained quartz and feldspar. Quartz phenocrysts rarely exceed 10 per cent of the rock, however, according to calculations based on chemical analysis, normative quartz is about 35 per cent, presumably about 25 per cent is in the matrix. Potassium feldspar is scarce and occurs as thin mantles on plagioclase grains or discrete grains in the matrix".

Four small bodies of quartz porphyry were seen in the valley of Boundary Creek south of the mouth of Windfall Creek and are tentatively correlated with those in the south part of the map area.

On the hills north of Kettle River, 3.25 to 6.5 km west of Midway there are melanocratic intrusive bodies which seem to vary greatly in appearance from place to place. The most common facies is a fine to medium-grained dark green rock that resembles the Scatter Creek rhyodacite exposed in Bodie Mountain quadrangle (Pearson, 1967) to the south, and quartz eyes were seen in very few places. One sample contains round, coalescing quartz phenocrysts, less than 5 mm in diameter, and euhedral phenocrysts about 5 mm in diameter of complexly twinned, zoned, and altered plagioclase, some with albite rims. Subhedral pseudomorphs, less than 3 mm across of potassium feldspar(?) now consist of chlorite, epidote, quartz, plagioclase, apatite, and opaques. The matrix is granular and composed of plagioclase, quartz, white mica, epidote, albite, carbonate, and opaques. The rock may have been rhyodacite, but the variation in facies is unlike the Scatter Creek Formation. It is cut by diorite believed to be related to the upper division of the Marron Formation.

Another large body of quartz-feldspar porphyry outcrops 2.25 km northeast of Rock Creek. It is a medium grained, porphyritic rock, with round phenocrysts of quartz and prismatic phenocrysts of pale red feldspar. Biotite and hornblende are somewhat chloritzed so that the rock has a somewhat green cast.

A thin section reveals that the rock is a porphyritic quartz diorite, unlike any other rock seen in the area. The phenocrysts, in decreasing order of abundance, are andesine (An_{32}), which is highly saussuritized, hornblende, which is largely chloritized, quartz grains, which are round and unstrained though some are fractured, brown biotite, much chloritized, and a little potassium feldspar(?), which is almost completely sericitized. The groundmass, which is very fine-grained, consists of albitized plagioclase, quartz, carbonate, and chlorite. Accessorites are magnetite and apatite.

Kettle River Formation

A study of the Early Tertiary stratified rocks of Greenwood map area was published by Monger (1968); parts of this and the two following sections are paraphrased from this work to which the reader is referred for more details concerning these rocks.

The rocks were first mapped and briefly described by Brock (1902, p. 56A; 1903, p. 97A, 102A; 1905). Brock examined the rocks in the eastern part of Greenwood map area, whereas Daly's (1912, p. 394-423) more detailed study was in the southwest part. LeRoy (1912, p. 42-44) described the small volume of basal Tertiary sediments at and near Phoenix, which he correlated with Daly's Kettle River Formation, and with the Coldwater beds near Kamloops.

Distribution and Thickness

The largest areas where Kettle River rocks are exposed are from Windfall Creek southwest to the head of Fiva Creek, on the ridge east of Kettle River from lower Fiva Creek southward to the Wallace Creek Fault, in Nicholson Creek Valley, and the valley of the west fork of Ingram Creek. Smaller but excellent exposures occur on the ridge between Pass and South Pass creeks, on Baker Ridge and on the north side of Fisherman Creek, at Phoenix, near the headwaters of Motherlode Creek and northeastward for 3 km, on the ridges north and south of Myers Creek, south of Kettle Valley and on the hill 2 km south of Rock Creek. Several smaller exposures of Kettle River rocks are scattered throughout much of the map area. The Kettle River Formation must underlie, in places at considerable depth, all or nearly all outcrops of Marron volcanics.

According to Monger (1968, p. 5), the thickness of the Kettle River Formation ranges from 80 m at Phoenix where it was measured by LeRoy (1912, p. 42) to 1,200 m or more in the northeastern part of the map area, where the base was not seen. To the south, on the divide between Nicholson Creek and Kettle River the thickness is probably just over 600 m, and farther south, on the north side of the west end of Myers Creek canyon it is also about 600 m but the base is an intrusive contact of rhomb porphyry. At Fisherman Creek, at the east edge of the map area, the formation is about 350 m thick.

Lithology

The most abundant rock is a characteristically white cream, pale grey, or buff feldspathic volcanic sandstone composed of clastic grains of feldspar and visible quartz, with subordinate muscovite, lithic volcanic fragments, and

rare fragments of granitic rock, chert, shale, and carbonaceous matter. Plagioclase is generally two or three times as abundant as orthoclase. Many quartz grains are embayed, indicating a volcanic origin (Folk, 1961, p. 69). Locally, the sandstone grades into arkose on the one hand, or into acidic tuff on the other. Bedding is rarely seen.

In the western part of the map area, south of Westbridge, lithic volcanic sandsotnes occur in the upper part of the section and are as much as 500 m thick where the formation is thickest. These rocks are grey-green and generally finer grained than the feldspathic volcanic sandstone. Some interbeds of shale and siltstone are present, but the beds in the lithic volcanic sandstone are for the most part massive. The detrital grains, of andesitic composition, contain many microlites; others are of altered chloritic material that may have been volcanic glass. Feldspar, mainly sodic plagioclase, forms up to 20 per cent of the rock; quartz is usually less than 5 per cent. The rock grades upward into andesitic tuff and local agglomerate just beneath the basal Marron flows.

Conglomerate occurs at all stratigraphic levels, but the basal conglomerates are the thickest, and south of Rock Creek the conglomerate is at least 100 m thick. Clasts in the basal conglomerate in a few places exceed 1 m in diameter. They are usually composed of local basement rocks – granodiorite, porphyritic quartz monzonite, chert, and greenstone. Breccias composed of angular clasts of quartz – feldspar porphyry and dacitic tuff in a feldspathic matrix occur locally and grade into feldspathic volcanic sandstones.

Volcanic rocks are present but only in minor amount in the formation. White to pink porphyritic dacite containing phenocrysts of andesine or oligoclase and minor orthoclase, with round phenocrysts of quartz, in a greenish aphamitic matrix of minute crystals and mica and devitrified glass has been identified in and south of lower Fiva Creek, and along Kettle River 3 km south of Westbridge. One to two metres of tuff composed largely of lithic fragments with others of clinopyroxene, feldspar euhedra, and rare quartz, commonly occurs at the contact of the Kettle River and Marron formations.

Internal Structural Relations

Almost everywhere throughout the map area the Kettle River strata are eastward-dipping, in fault blocks that are eastward-tilted between steeply-dipping normal faults, but in a few places the dips of the faults may be 30° or less. In a few localities, however, except for local crumples adjacent to faults, anticlines have been determined by mapping. These are broad, open folds the largest of which occurs on the ridge east of Kettle River, a few kilometres east of Westbridge. There, the axial trace trends north-northeast, and the dips are gentle (maximum 40°). Eight kilometres to the south, in lower Nicholson Creek Valley, a similar anticline, much faulted, occurs. A third such anticline lies 5 km north of the bridge.

External Structural Relations

The Kettle River Formation rests with marked unconformity upon basement rocks that range in age from Carboniferous and/or Permian and(?) older to the Jurassic and/or Cretaceous Nelson Intrusions.

It is overlain by and is partially transitional into basal lavas of the Marron Formation. It is intruded by small bodies of Coryell Intrusions, which have been correlated by Monger (1968, p. 30) to the trachyandesites of the uppper part of the middle division of the Marron Formation.

Origin

The Kettle River Formation was laid down upon a peneplain that resulted from erosion following the Columbian Orogeny. Widespread acidic to intermediate volcanism contributed tuffaceous material to the debris that was deposited in numerous large lakes that existed in Middle Eocene time throughout south-central British Columbia and northeastern Washington. Local relief must have been considerable in view of the coarseness of some of the conglomerates.

Age and Correlation

Prior to 1964, the ages assigned to plant fossils collected from the Kettle River Formation ranged from Paleocene to Oligocene. Plant spores collected in 1956 from the slopes west of the lower part of Nicholson Creek were identified by Rouse as being of Middle Eocene age (Rouse and Mathews, 1961). In 1958, megafossil plants were collected some 60 km north of the northwest corner of the map area, from exposures of Kettle River feldspathic volcanic sandstones. The fossils were identified by D.C. McGregor of the Geological Survey.

GSC loc. cat. no. 5147

About 1.6 km north of the summit of the Beaverdell-Kelowna highway, 3 km east of McCullogh.

Metasequoia occidentalis (Newb.) Chaney
Pinus sp. (leaves)
cf. Betula sp.

These range in age from Paleocene to mid-Miocene, but in 1959 a collection of carbonaceous material from a road cutting 5 km farther north on the same highway was made (GSC loc. 5501). This was sent to G.E. Rouse of the University of British Columbia, who in November 1961 reported microflora of Eocene, probably Middle Eocene age.

Only one K-Ar radiometric age for the Kettle River Formation has been obtained from biotite in dacite collected some 60 km north of Greenwood map area, and was 46 ± 2 Ma (Mathews, 1963, p. 9). The dacite was assigned to the Kettle River Formation by Little (1961). Yates and Engel (1968, p. D243) obtained K-Ar ages of 41.6 ± 1.2, 41.1 ± 1.2, and 40.2 ± 1.3 Ma from biotite in tuffaceous sandstone of the O'Brien Creek Formation. All these dates are obviously much too low. Pearson and Obradovich (1977, p. 13) determined a K-Ar age of 53.1 ± 1.5 Ma on biotite from bedded tuff in Pend Oreille River area, and this age seems reasonable in view of the several ages obtained from the overlying Sanpoil Volcanics.

Monger (1968, Fig. 1) has shown the distribution of early Tertiary sedimentary rocks in south-central British Columbia and northeastern Washington. Pearson and Obradovich (1977) have made a thorough study of these rocks. They correlate the Kettle River Formation with the contiguous O'Brien Creek Formation of northeastern Washington (Muessig, 1967, p. 45-50; Yates and Engels, 1968; Parker and Calkins, 1964, p. 46-48; Staatz, 1964, p. 32-35; Yates, 1971). The O'Brien Creek Formation then in turn correlate with the lower member of the First Thought Formation (Bowman, 1950) and basal Tertiary conglomerates in the Kettle Falls and Enterprise Valley areas.

In Canada, the Kettle River Formation is correlated with the Springbrook Formation of Bostock (1940, 1941; Church, 1973, p. 27-32) which occurs on the west side of the Okanagan Valley, and with the Curry Creek 'Series' of Beaverdell area (Reinecke, 1915), which was previously acknowledged by Little (1957, 1961). Correlation

with at least part of the Princeton Group (Rice, 1947, p. 27-31) is certain because in 1935 L.S. Russell identified a mammal tooth obtained from sediments of that group as being of Middle Eocene age.

Marron Formation

The Marron Formation (Emv) comprises the rocks originally named "Midway Volcanic Group" by Daly (1912, p. 398) where they are exposed along the valley of Kettle River between Nicholson Creek and the lower part of Norwegian Creek. Little (1957) on the grounds of priority erroneously renamed these rocks "Phoenix Volcanic Group", a term which should be discarded. Monger (1968, p. 12) proposed that they be designated Marron Formation, because of the close similarity with the type Marron. The Marron Formation was applied by Bostock (1941) to Early Tertiary volcanic rocks outcropping in the vicinity of Marron River on the west side of Okanagan Valley, about 80 km west-northwest of Greenwood. These rocks have recently been restudied in great detail by Church (1973), who has defined five members within the formation. He removed from the original Marron Formation rhyolite and dacite flows up to about 330 m thick that unconformably overlie the Marron. To this unit, Church gave the name Marama Formation, which has not been identified in Greenwood map area. As neither rhyolite nor dacite have been described in the Sanpoil Volcanics of Bodie Mountain (Pearson, 1967), Curlew (Parker and Calkins, 1964), Republic (Muessig, 1967) or Bald Knob (Staatz, 1964) quadrangles, Marama rocks are either not present or escaped detection to the south of Greenwood map area.

Distribution and Thickness

Lavas of the Marron Formation are extensively distributed west of the Louise Lake and Fiva Creek faults in the northwest part of the map area, and south of the Wallace Creek Fault in the southwest part. Small areas are underlain by Marron rocks near Phoenix, in Fisherman Creek Valley, and from Brown Creek to Pass Creek.

At Phoenix and in Fisherman Creek only about 90 m of lavas are exposed, but in the western part of the map area the total thickness of the formation ranges from 900 m to 1800 m, but the maximum thickness is not known because with one exception the upper limit is either an erosion surface or a fault plane.

Lithology

In Greenwood map area the Marron Formation has been subdivided into three members. The lower division (Emv1) is composed predominantly of soda trachyte, in part under-saturated and tending towards phonolite. The middle division (Emv2) is pyroxene andesite and trachyandesite. The upper division (Emv3) comprises biotite-pyroxene andesite, pyroxene andesite, and hornblende andesite. Certain distinctive textures of the lavas serve very well to identify the three divisions in the field. The lower division contains soda trachytes in which the anorthoclase phenocrysts are commonly rhomb-shaped, particularly in intrusive phases. In the lower part of the middle division, glomeroporphyritic flows (or 'clob' porphyries) are distinctive, and some flows higher in the division can be recognized as both porphyries. The upper division contains flows that are massive and merocrystalline, containing small crystals of feldspar and pyroxene in a glassy matrix.

Internal Structural Relations

In most parts of the map area the Marron lavas are eastward-dipping, lying within tilted fault blocks that are separated by mainly steep-dipping normal faults. North of Wallace Creek Fault, east of Kettle River, the lavas dip both eastward and westward, away from an anticlinal core of Kettle River Formation.

External Structural Relations

Lavas and pyroclastics of the lower division of the Marron Formation rest upon sedimentary beds of the Kettle River Formation with apparent conformity. In some places, however, there is interdigitation of the pyroclastics with the uppermost beds of the Kettle River Formation.

The upper division of the Marron Formation is overlain unconformably on the hills south of Norwegian Creek by an epiclastic breccia (olistostrome) that forms the basal part of the Klondike Mountain Formation.

Age and Correlation

The age of the Marron Formation is Middle Eocene. It is underlain by the Kettle River Formation containing pollen of Middle Eocene age and is overlain by the Klondike Mountain Formation which yielded fish that are also Middle Eocene.

Mathews (1963, p. 4, 8) obtained a radiometric age of 49 ± 2 Ma on a tuff bed that Monger (1968, p. 24) stated underlies trachyandesite of the middle division west of lower Nicholson Creek. Church (1973, p. 39) dated biotite from trachyte of the Kitley Lake Member at 51.6 ± 1.8 Ma by the K-Ar method. Pearson and Obradovich (1977, p. 22, 23, 40) from K-Ar analyses of biotite, hornblende, and plagioclase in seven samples of Sanpoil rocks obtained 13 dates that range from 48.4 ± 3.0 Ma to 53.4 ± 2.0 Ma, and they concluded the most probable age is 50-51 Ma.

The type Marron Formation in White Lake Basin has been subdivided by Church (1973, p. 26) into the following members:

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

In Greenwood map area the lower division is correlated with Church's Yellow Lake Member, the middle division is correlated with the Kitley Lake, Kearns Creek and Nimpit Lake members, and the upper division with the Park Rill Member. To the east, in Rossland-Trail map area Church (personal communication, 1979) has recognized lavas closely similar to those of the Kitley Lake and Park Rill members, and somewhat altered equivalents of the Kearns Creek and Nimpit Lake members may be present. However, none of the soda trachytes or phonolites of the Yellow Lake Member were encountered.

South of the International Boundary in northeastern Washington, Pearson and Obradovich 91977, p. 15-24) have discussed at length the widespread Eocene Sanpoil Volcanics, and have correlated with them volcanic rocks of the Orient, Kettle Falls, and other areas. Except in the northern part of the Bodie Mountain quadrangle (Pearson, 1967) where the equivalent of Yellow Lake lavas extends a short distance south of the International Boundary, these lavas are not found in the Sanpoil Volcanics, which nearly everywhere seems to consist mainly of lavas that are equivalent to those of the Park Rill Member, and the upper division of Greenwood area (Pearson and Obradovich, 1977, p. 10, 11).

Intrusive Equivalents of the Marron Formation

Probable intrusive equivalents (Emi) of rocks comprising the Marron Formation were classified by Monger by lithological similarity to members of the Marron Formation and from crosscutting relationships. Some intrusions which were not thus classified by Monger have been by the writer. Furthermore, rocks of his map unit 5d, which he described as being "of Coryell type (in part, possibly equivalent to lavas of division 4B)" have been mapped as a separate map unit in view of the widespread occurrence of this suite in southern British Columbia and the historical and current use of the name "Coryell".

The oldest intrusive, feldspar-rhomb syenite (Emi1) is the intrusive equivalent of unit Emv1 and forms dykes and also large, irregularly shaped sill-like bodies that intrude or are in contact with the Kettle River Formation. The rocks are distinguished from their extrusive equivalents by their crosscutting relationships, ratio of phenocrysts to matrix which is much higher in the intrusives, and by the groundmass which is finely crystalline and contains patches of nonporphyritic, fresh biotite.

Two principal lithologies characterize the rocks equivalent to Division Emv2. These are syenite and diorite. Like unit Emi1 they range in size from dykes to bodies up to 5 km^2.

Intrusive rocks (Emi3) which appear related to extrusive rocks of division Emv3 are common in the south-central part of the map area. They are two varieties – one characterized by hornblende phenocrysts is the equivalent of the rocks that form the lower part of division Emv3, the other and more common variety contains biotite and altered pyroxene phenocrysts and is the equivalent of the upper part of division Emv3.

Coryell Intrusions

The Coryell Intrusions (Ec) were first observed by Dawson (1890, p. 33B) along the shores of Lower Arrow Lake, and described as "younger red granites". Their distribution as far west as meridian 118°30'W was later demonstrated by McConnell and Brock (1904) who called them "Rossland alkali granite and syenite". Daly (1912, p. 358-362) applied the name "Coryell syenite" to these rocks, the type locality being at Coryell station, some 43 km east of Greenwood, on the Canadian Pacific Railway. These rocks have been traced as far west as Mount Christie (Little, 1961) about 30 km northwest of Greenwood map area, and probably even occur west of Okanagan Lake (Jones, 1959, map 1059A). To the east and north of Greenwood map area the Coryell rocks form a few batholiths (Little, 1962b), numerous smaller bodies, and a host of dykes.

In the larger bodies, the rock is medium- to coarse-grained, inequigranular, red or pink to pale buff, the latter being more common, and is mainly syenite, grading into granite on the one hand, and into monzonite and quartz monzonite on the other. In some places the rock is porphyritic.

In Greenwood map area, however, the coarse, plutonic facies is rather limited in distribution, being present only here and there in the northeast corner of the area, where it comprises the southernmost end of a batholith (Little, 1957). There, the coarse facies is composed mainly of pink feldspar with minor amounts of biotite or white mica. Hornblende and pyroxene are rare.

In many, but not a majority, of specimens, a little free quartz is visible. Thin sections of two typical examples of this facies were examined.

One, from near the north edge of the map-area about 0.8 km west of the head of the west branch of Rock Candy Creek, contains euhedral to anhedral crystals of altered perthitic potassium feldspar and altered plagioclase (An_{37}). The feldspar crystals are less than 10 mm long and comprise about 85 per cent of the rock. The ratio of potassium feldspar to plagioclase is about 2:1. Small, graphic or equant crystals of quartz, less than 1 mm across, form about 10 per cent of the rock and contain minute euhedral crystals of apatite and calcic plagioclase. Biotite crystals, less than 1 mm long, occurring interstitially, and comprising about 1 per cent of the rock, are associated with opaque minerals, limonite, apatite, and zircon. This rock is granite.

The other sample, a medium grained porphyritic granite was collected from Windfall Creek. The phenocrysts consist of plagioclase (oligoclase), 15 per cent, which is somewhat albitized, with sanidine, 5 per cent, quartz, 6 per cent, white mica, 2 per cent, and a pseudomorphic melange of carbonate and white mica, 1 per cent. The groundmass comprises 60 per cent albite, which is highly saussuritized, 10 per cent quartz, and 2 per cent opaque minerals.

The plutonic rocks are cut by a host of dyke rocks; indeed, most of the outcrops of Coryell Intrusions are hypabyssal in the northeast corner of the map area, and elsewhere all are hypabyssal. These exhibit a great variety of colours, ranging through red, pink, buff, grey, and green, and a variety of textures. Most are porphyritic, feldspar being the most common phenocryst, but biotite and hornblende are not uncommon.

Where they have been seen in contact, the green porphyritic dykes are later than the red to grey varieties. Some red to pink dykes have been termed pulaskite or pulaskite porphyry by the earlier geologists (Brock, 1905a; Daly, 1912, p. 417, 418), Daly's petrographic description did not, however, include nepheline, sodalite, or noselite, which are generally considered to be essential constituents; indeed, Daly found a little interstitial quartz present. Carswell (1957), however, identified pulaskite, as did Reinsbakken (1970, p. 67, 69), in which nepheline occurs as inclusions in early minerals. These dykes are probably feeders to division Emv 2 of the Marron Formation.

Of sixteen thin sections of these hypabyssal rocks that were examined by the writer, none contained nepheline. It is therefore concluded that pulaskite, although present, is not as abundant as was formerly believed. The red to pink dykes contain phenocrysts of grey feldspar that make up 5 to nearly 30 per cent of the rock. In some, the phenocrysts are albite or oligoclase (An_{91} to An_{69}) which are much sericitized, but in others they are anorthoclase, also sericitized, in one case with a little sanidine. The groundmass is largely potassium feldspar with 5 to 10 per cent quartz. Up to 10 per cent biotite is present; in some samples about half the biotite forms phenocrysts. Apatite is the accessory mineral common to all samples, and magnetite and zircon were noted in one sample. The rock is described as a porphyritic trachyte or microsyenite.

Another variety of dyke rock is medium grained, dark grey with a faint dark purple cast. The rock is commonly porphyritic, with small crystals of feldspar, and in some

samples, small phenocrysts of hornblende and/or biotite are present. The feldspar phenocrysts are oligoclase (An_{15}), which is somewhat altered to albite and saussurite. Interstitial clusters of biotite and hornblende are common, and a little clinopyroxene is usually present. The matrix is largely altered potassium feldspar and minor quartz. Accessory minerals are apatite, zircon, and sphene. The rock is a porphyritic syenite. These dykes are probably feeders to division Emv3 of the Marron Formation.

Medium to light grey porphyritic microsyenites or trachytes are probably the most common dyke rock. The phenocrysts are mostly orthoclase, with either some microcline or sanidine. A few phenocrysts are of oligoclase. Biotite is present both as phenocrysts or in the groundmass, where minor clinopyroxene is sometimes present. Quartz is interstitial and rarely exceeds 5 per cent. In a few specimens, some hornblende is present.

The age of the Coryell Intrusions is known with greater accuracy than those of the other plutonic rocks in the region, but their precise relationship to the Marron Formation is not known. Daly (1912, p. 419) correlated 'pulaskite porphyry' that cuts the Kettle River Formation some 9.5 km west of Midway with the type Coryell rocks to the east, on the basis of chemical resemblance, and both being the youngest or nearly youngest intrusions in the respective localities. In Rossland area (Little, 1963), Old Glory Mountain is capped by agglomerate and flows resembling the andesitic and trachyandesitic middle and upper divisions of the Marron Formation of Greenwood area. These lavas are underlain at one point by white tuffaceous arkose resembling Kettle River Formation, and elsewhere by the Coryell Batholith from which dykes intrude into the overlying Marron lavas. Buff and pink weathering syenites believed to be Coryell Intrusions cut lavas of the lower division of the Marron Formation in the northeast part of Greenwood map-area. Thus, the Coryell is definitely younger than the lower part of the Marron, but the relationships to the middle and upper divisions are not known. Monger (1968) has suggested that a correlation with the middle division, based on chemical and mineralogical similarity, is possible.

Monger (1968, p. 32) goes on to say:

> "Similarly, no conclusions can be reached from available radiometric dates. Ages of early Tertiary lavas in south-central British Columbia range from 45 to 53 million years (Rouse and Mathews, 1961; Mathews, 1963) and, with rapid cooling of lavas these ages appear to represent accurately their time of extrusion. Ages of Coryell plutonic rocks are 27, 32, 53, 54, 56, 58 and 60 million years (Baadsgaard, et al., 1961, p. 697, Lowdon, 1961, pp. 12-13, 1962, pp. 10-11) and are probably minimum ages, representing the time at which these rocks had cooled sufficiently to prevent free diffusion of argon, and not necessarily the time at which these rocks were emplaced. The ages of 56 and 60 million years are from the type Coryell batholith, and thus at least part of this particular intrusion appears to have been emplaced earlier than rocks related to the Marron Formation".

The Coryell Intrusions are probably correlative with map units 9 and 10 in the Valhalla Gneiss Complex (Reesor, 1965, p. 38-41). They are also probably correlative 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" of Republic quadrangle (Muessig, 1967, p. 62-68). These rocks are younger than the Scatter Creek rhyodacite, of Middle Eocene age, and older than the Klondike Mountain Formation, also of Middle Eocene age.

Klondike Mountain Formation

The Klondike Moutnain Formation (Ekm) was named by Muessig (1967, p. 70) in Republic quadrangle, Washington, where pyroclastics, lavas, and "lake beds" overlie unconformably the Sanpoin Volcanics, which are equivalent to the Marron Formation of Greenwood map-area. The Klondike Mountain Formation occurs also to the north in Curlew quadrangle (Parker and Calkins, 1964, p. 62-64), where the lower part of the formation is composed of clastic and pyroclastic material and minor flows, and the upper part of dark glassy flows containing minor clastic and pyroclastic material. South of the east half of Greenwood map-area, in Bodie Mountain quadrangle. Pearson (1967), in addition to the above rocks, recognized "epiclastic nonvolcanic breccias and conglomerate, and tuffaceous sandstone and shale" which forms the basal part of the formation. There, "the breccias consist of two distinctive types of quartz monzonite and various low grade metamorphic rocks typical of Permian and Triassic rocks in nearby areas".

This lower part of the Klondike Mountain Formation is exposed in only one segment of Greenwood map area; the upper parts are not. On the 1130 m high hill south of Norwegian Creek, the outcrops consist of greenstone and arenaceous micaceous schist or impure quartzite, and metamorphosed bedded chert. They strike rather consistently northeast and dip steeply northwest. These rocks appear to be correlative with map unit Pml, but, though locally massive, pass into fractured rocks and thence to brecciated rocks which, as Pearson (1967, p. 2) has described, in places show considerable rotation of the fragments. Where brecciation is strong, alteration is also intense. To the south of the hill, Scatter Creek rhyodacite is more common, and diorite and serpentine are also present. These rocks also range from unbrecciated through fractured to brecciated.

North of the hill, near Norwegian Creek, isolated exposures of buff palagonite tuff interbedded with the breccia, are included in the formation. These locally strike northeast and dip steeply northwest, but in most places bedding is not visible. The rock consists of generally broken crystals from 0.01 mm to 3 mm diameter, of partly altered plagioclase of various compositions but most near An_{34}, some glassy crystals of sanidine, somewhat altered, and minor brown glass and clear glass shards, minute rods of apatite, limonite, opaque minerals, and epidote(?). These are embedded in a nearly opaque, green isotropic, palagonite.

These breccias are interpreted by Pearson as "lenses or sheets of pre-Tertiary rock debris that slid off a highland to the east"[1]. The writer accepts this interpretation as the most probable hypothesis to account for the origin of this peculiar formation. That the Early Tertiary Scatter Creek Formation should also be involved as to be expected. The eastern and southern margins of the Klondike Mountain Formation are faulted, as indicated on the map. On the western boundary, Marron lava adjacent to the contact is sheared, but otherwise the relationships are as one might expect.

Within the limited area of exposure the thickness and structure of the Klondike Mountain Formation are not known; the apparent thickness of the breccia unit is at least 900 m. It is bounded by faults on the east and south sides. On the west, Marron lava within 0.3 m of the contact is strongly sheared, so that this contact may also be faulted. On the north the breccia and tuff disappear under deep drift.

The age of the Klondike Mountain Formation was reported to be Oligocene, from plant fossils in lake beds in Republic (Muessig, 1967, p. 74, 75), Curlew (Parker and Calkins, 1964, p. 66), and Bodie Mountain (Pearson, 1967, p. 2) quadrangles. Recently, however, Wilson (1977, p. 681) has identified fish (**Eohidon woodruffi**) of Middle Eocene age

[1] Such deposits have been named olistostromes by Carter et al. (1976).

from shales of the Tom Thumb member of the Klondike Mountain Formation. Wilson also stated that recent radiometric dating by the United States Geological Survey established the age of the Klondike Mountain lavas as close to 46 Ma and the underlying Sanpoil Volcanics as about 50 Ma. Details concerning these K-Ar ages were subsequently published by Pearson and Obradovich (1977, p. 29, 41). Thus the Klondike Mountain Formation is only slightly younger than the Marron Formation, and both are Middle Eocene.

The Klondike Mountain olistostrome in Greenwood map area may be correlated with breccias of the Skaha Formation of the White Lake Basin 72 to 80 km west of Greenwood. A basal breccia that ranges in thickness from zero to about 90 m is composed of fragments of the pre-Tertiary Shoemaker, Old Tom, and Vaseaux formations. It rests unconformably upon older Tertiary and pre-Tertiary rocks, and is interpreted by Church (1973, p. 51-57) as a slide breccia. This is succeeded locally by augite porphyry lava (tephrite) and by a granite breccia facies, which consists of large blocks of granite surrounded by autobreccia and frictional breccia. This unit is from zero to 90 m thick, and also in interpreted as a slide phenomenon, modified by stream action, or fanglomerate. The similarity to the lower part of the Klondike Mountain Formation, as Church has pointed out, is striking, both in origin and time.

STRUCTURAL GEOLOGY

Regional Structural Pattern

Certain areas within the region of south-central British Columbia and north-central Washington that surrounds Greenwood map area are underlain by rocks of great structural complexity. These comprise the Shuswap Metamorphic Complex and related terranes, such as the Grand Forks Group, which have been correlated by Reesor and Moore (1971, Fig. 1). They have summarized and discussed at length (op. cit., p. 107-117) the origin, ages of the component rocks, and time of metamorphism of the Complex. A characteristic feature of the Complex is the development of mantled gneiss domes, and attendant recumbent folding in the cover rocks. In the Purcell and Selkirk mountains, the rocks involved, based on lithological correlations, range in age from Purcell, through Windermere-lower Paleozoic and upper Paleozoic, to Triassic. In the adjoining Grand Forks map area (Preto, 1970, p. 33), only representatives of Windermere and lower Paleozoic successions have been recognized.

The time of metamorphism, as discussed by Reesor and Moore (1971, p. 116) may range from 250 Ma to 100 Ma ago, although in the Valhalla complex ages as young as 66 Ma to 11 Ma were obtained by the potassium-argon method on biotite (Reesor, 1965, p. 51). An age of 36 Ma was obtained on biotite from granodiorite gneiss in the Grand Forks Group, but Preto (1970, p. 74) considered this to be anomalous.

Recumbent folding directed northward in the Grand Forks Group indicates that these are mantling rocks and that a gneiss dome should exist south of the International Boundary. In the Shuswap Metamorphic Complex such domes are commonly paired. One such pair occurs south of Kelowna, where Dawson (1879, p. 101, 102) discovered the smaller of the two on Okanagan Mountain, and the larger was discovered by Brock (1934) on Little White Mountain.

Within Greenwood map area Shuswap rocks have been positively identified only in the extreme southeast corner, but may occur in the extreme west-central part, and the Valhalla Intrusions may represent a late, mobile phase of Shuswap metamorphism. If this be so, then the latest phase of such deformation is post-Nelson, but must be pre-Kettle River Formation.

The structure of the other pre-Permian (pre-Carboniferous?) map-units Pa and Pm is not known, but they apparently were deformed and eroded before deposition of the Attwood Group, and suffered further deformation in Permian, Triassic, Jura-Cretaceous and post-Eocene time.

The northwesterly trending folding in the Attwood Group apparently predated the deposition of the Triassic rocks in which folding that is believed to be related to the orogeny associated with the Nelson Intrusions trends northerly. Faulting related to this orogeny has not been definitely identified. It is probable that some of the post-Middle Eocene faults were initiated before the Tertiary, and possible that some are of Nelson age. The Twin Creek Fault is pre-Middle Eocene, and the Eholt Valley Fault and May Creek Thrust Fault appear to be also.

The dominant structural feature south of the map-area is the Republic Graben. However, as Parker and Calkins (1964, p. 70) have pointed out, north of the International Boundary the graben loses its identity, for the bounding faults on the west side of the graben could not be traced into Canada. G.R. Peatfield (pers. comm. 1976), however, by continuing the pattern of post-Eocene normal faulting from the west side of Greenwood map area to the east side and reversing the displacement of the faults, derived a pattern which indicated that the faults of the Republic Graben do indeed continue north of the International Boundary. The dominant structural features of Greenwood map area are the north-northeast trending normal faults of Tertiary age between which blocks are tilted eastward. These have been described by Monger (1968, p. 33-37).

Faults

Granby River Fault

The most prominent fault in the region is the Granby River Fault, named by Preto (1970). It has been traced more than 64 km north of the International Boundary (Little, 1957) and it separates the Shuswap-like metamorphic complex of the Grand Forks Group from younger rocks to the west. It enters Greenwood map area about 1.5 km north of the intersection of highways 3 and 41. It strikes 020° and dips steeply west. Within a short distance it disappears under surficial deposits, where it may be offset by the May Creek Thrust Fault. Deeply buried metamorphic rocks have moved upward relative to the rocks on the west; the lateral displacement is unknown. The time of earliest movement is likewise unknown, but as Eocene rocks are displaced, the latest movement is Eocene or later.

May Creek Thrust Fault

Along the south side of the valley of May Creek, and across the south end of the ridge east of July Creek, rocks of map unit Pml and some overlying rocks of Jurassic(?) age have been thrust northwards over the lavas of map unit Jv. The fault itself is not exposed, but the adjacent rocks both above and below it are strongly schistose, the schistosity striking 110° and dipping 35°S. To the east, the fault disappears under deep drift of the Kettle River Valley, where it may terminate against the Granby River Fault. To the west, it either joins the McCarren Creek Fault or disappears under it. The age of the fault is unknown, except that it is post-Jurassic.

McCarren Creek Fault

Along the valley of McCarren Creek, exposures of serpentinite are intensely sheared, and north of Rusty Mountain, greenstones of Jurassic(?) age (map unit Jv) are abruptly terminated against the older rocks of map unit Pml. To the west, what is believed to be the continuation of

the McCarren Creek Fault curves southwestward where, in the valley of Norwegian Creek it forms the contact between the intrusive rocks of map unit KTi and sedimentary and volcanic rocks of Jurassic(?) age on the east, and Tertiary rocks of upper Marron and lower Klondike Mountain Formations. The sense of movement – vertical or horizontal – on this fault is not known, but the western part indicates upward displacement on the east side, and the latest movement is post-Middle Eocene, because Klondike Mountain rocks are displaced.

Eagle Mountain Fault

The Eagle Mountain Fault is identified by strong shearing of serpentinite, greenstone, and limestone, and the abrupt termination of Tertiary dykes on the east side of July Creek, and strong shearing in amphibolite and mylonite separating the Brooklyn and Rawhide Formations from Knob Hill greenstones on the west side of July Creek. The strike is sinuous, and trends northwesterly, with steep dips east of July Creek, and the mylonite west of July Creek dips 45°NE. The southeast part of the fault disappears under deep drift, and the western end under the Gold Drop Fault. The Twin Creek Fault may be its continuation. Lateral displacement has offset dykes along the fault, but the direction is not known. The latest movement was post-Middle Eocene.

B.C. Fault

About 460 m northeast of the B.C. mine, there is a broad zone of intensely brecciated chert and syenitic rock that trends northwesterly. Shearing in mainly Tertiary rocks that is roughly aligned with the breccia zone, is exposed at intervals between Brown and Pass Creeks, and is assumed to be parts of the same fault. Little is known of the movement along this fault. The latest movement was post-Middle Eocene.

Twin Creek Fault

The Twin Creek Fault, which occupies the upper part of the valley of Twin Creek is not exposed. Its presence was deduced from the left hand offset of the axis of the Phoenix Anticline, a distance of some 600 m. The strike is probably west and the dip steep. It does not appear to have offset the Tertiary rocks and so is pre-Middle Eocene.

Gold Drop Fault

This fault is named from the Gold Drop claim where it is well exposed in the glory hole. There it strikes 015° and dips 30°W. The major movement is normal faulting, the Kettle River and lower Marron rocks being tilted east, and dropped on the west side of the fault. Beyond the outcrops of Tertiary rocks, it cannot be traced. It is typical of the north-northeasterly trending faults so evident in the west half of the map area, as also is the smaller fault near the east edge of the area, just north of Fisherman Creek.

Eholt Valley Fault

Triassic rocks within the Phoenix syncline are terminated against rocks of the Knob Hill Group, high on the south side of Eholt Valley. This contact is the Eholt Valley Fault which has been observed in several places. It strikes west and dips 40° to 50° S, and is slightly undulating. The east end of the fault disappears under the Kettle River and lower Marron formations. The west end appears to be covered by drift and seems to terminate against the Greenwood granodiorite stock. The vertical movement is normal; the lateral movement is unknown. The age is pre-Middle Eocene. Its relationship to the Nelson Intrusions is conflicting; it does not seem to displace the Greenwood stock, but, on the other hand, appears to have truncated the south boundary of the smaller body of granodiorite lying about 2.5 km to the east.

Haas Creek Fault

This fault is exposed just north of Motherlode Creek where it forms a faulted contact between Knob Hill chert and the Greenwood stock. About 1.5 km north of the creek it occupies a small valley that marks the boundary between granodiorite, chert, and limestone on the east, and chert, sharpstone conglomerate, and limestone on the west. To the north, the fault is obscured by drift. The course of the fault south of Motherlode Creek is obscure, but it may link with shearing observed to the south, on the east side of Boundary Creek. Where observed, the fault strikes north and dips vertically. The time of major movement is unknown, but some movement was post-Middle Eocene.

Greyhound Creek Fault

The Greyhound Creek Fault is not exposed, but its position is known in some places with great accuracy. It is one of the north-northeasterly trending normal faults that are so common in the west half of the map area. It has been traced south to the International Boundary, and north to its junction with the Haas Creek Fault, and is of post-Middle Eocene age.

Deadwood Ridge Fault

This fault is best exposed on Deadwood Ridge where it strikes northerly and dips about 25°W. It separates granodiorite, chert, brecciated argillite, sharpstone conglomerate, and a small body of Coryell microsyenite probably coeval with lavas of the middle division of the Marron Formation. The shallow dip of the fault there may be due to subsequent folding, for elsewhere the dip is steep. The fault has been traced northward across Wallace Creek, and it terminates against the Windfall Creek Fault. To the south, between Deadwood and Motherlode creeks, the chert beneath the fault is brecciated. Farther south, its position is identified by the marked change in lithology, and where it curves southeastward to terminate against the Greyhound Creek Fault, its topographic expression is shown by a marked valley that contains a small stream.

Windfall Creek Fault

The Windfall Creek Fault has not been observed, but is inferred from abrupt changes in lithology, particularly along Windfall Creek. The termination of the thick Kettle River Formation there, and, more particularly, the abrupt change from syenite and diorite related to the middle division of the Marron Formation to Coryell Intrusions, indicates faulting of major proportions. However, the final movement on this fault was post-Middle Eocene, and the northeast side moved upward.

Wallace Creek Fault

This fault has been traced from the valley of Kettle River eastward to where it terminates against the Deadwood Ridge Fault. Near the head of Wallace Creek, it has been displaced (a left-hand offset) by a north-trending fault. The strike is westerly, and from the trace across the topography, the dip is steeply south. Monger (1968, p. 35) stated that the south side is upthrown, and lateral displacement was left hand.

Other Faults

Numerous other faults, for the most part north to northeasterly trending, comprise normal post-Eocene faulting as a result of tension. They are poorly exposed and have been located by Monger based upon geological deduction. His summary of these faults, their pattern, and their origin was quoted in a previous section.

Folds

In only a few places are large scale folds in the pre-Tertiary rocks evident. This may be in large part due to extensive post-Marron faulting which is almost impossible to detect, except where the Early Tertiary stratified rocks are present. Monger (1968, p. 33) suggested that such faulting extends over the entire map area, and if so would add greatly to the complexity of the structure. G.R. Peatfield (personal communication, 1977) restudied Reinsbakken's (1970) detailed mapping. He assumed a pattern of Tertiary faulting similar to that established in the west part of Greenwood map area, and attempted to restore the rocks to their pre-tertiary position. He concluded that the Brooklyn Formation and the overlying map unit Jv east of July Creek formed a syncline that plunges gently northeast, and that, towards the northeast the syncline becomes recumbent, with the northwest limb being completely overturned.

Three to six kilometres east of Phoenix, repeated alternations across the strike of the sharpstone unit and the limestone unit of the Brooklyn Formation are evidence that a north-trending synclinorium exists there, which disappears to the east and south under younger Mesozoic rocks. It is possible, however, that the alternation of sharpstone and limestone is due, not to faulting, but to undetected northerly trending block faulting of the Tertiary pattern.

On the northwest flank of Mount Attwood a northwesterly-trending syncline appears to exist where black argillite of the Attwood Group is surrounded by rocks of map unit Pml.

In the Tertiary rocks, however, folds are more evident, though not numerous. They have been described by Monger (1968, p. 35) as follows:

> "The axial trace of the best defined fold is about 1 1/2 miles due east of the confluence of Kettle and West Kettle Rivers and trends roughly north-northeast. Kettle River sandsotne forming the core of the anticline dips away on both sides of the crest at angles up to 40°, and is overlain on both limbs by the Marron Formation. A similar, but much faulted anticline occurs about 5 miles due south in the southernmost part of Nicholson Creek Valley, and a third anticline is located about 3 miles north of the highway bridge over Kettle River, 5 miles west of Midway.
>
> "H.W. Little suggested to the writer that these anticlinal structures were formed by the arching of Kettle River sandstone over intrusive bodies. Such an origin is compatible with the tensional nature of all other structures affecting Tertiary rocks in this area. The anticline due east of the confluence of Kettle and West Kettle Rivers is truncated on the south by a large east-west trending fault (the Wallace Creek Fault in this report). On the southern, upthrown side of this fault, a large, irregular sill-like body of rhomb-porphyry intrudes the basal Kettle River sandstone, and is abruptly cut off on the north by the fault. Allowing for lateral displacement on this fault, the northern extension of this intrusion presumably underlies the Kettle River Formation and thus could well be responsible for the anticline . . . . . In addition, numerous nearly vertical dykes cutting the Kettle River Formation trend roughly parallel to the axial trace of the anticline, and thus appear to have been intruded along extension, "a-b" joints. Other large bodies of rhomb-porphyry intrusive into the Kettle River Formation south of Kettle River, are due south of the axial trace of the faulted anticline at the south end of Nicholson Creek Valley. Possibly all of these rhomb-porphyry bodies originally formed a single elongate intrusion that was emplaced in the Kettle River Formation, and up-arched it into a single north trending anticline. Subsequently, this anticline was segmented and laterally displaced by faulting".

REGIONAL METAMORPHISM

South of the east half of Greenwood map area, in Curlew and Republic quadrangles, the dominant structural element is the Republic graben. It is marked on the east side by parallel, en echelon faults, beyond which, to the east, is a high grade metamorphic complex. North of the International Boundary the bounding fault is the Granby River Fault which traverses the southeasternmost corner of Greenwood map area. East of this fault the Grand Forks Group, a metamorphic complex of the Shuswap type, has been studied in detail by Preto (1970), who designated several grades of metamorphism in pelitic, calcareous, and quartzofeldspathic assemblages. Of the map units that he outlined only his unit V has been identified within Greenwood map area, in the extreme southeast corner. It is a pelitic and quartzofeldspathic assemblage that is characterized by the presence of staurolite, garnet, muscovite, and reddish biotite, and by the absence of orthoclase and sillimanite. Where the unit is exposed in Greenwood map area, however, no staurolite was seen.

High grade metamorphic rocks are exposed elsewhere in Greenwood area, where they have been called map unit Pm, and they form widely scattered clusters of outcrops. All are quartzofeldspathic, with minor pelitic facies. The former form layered gneisses in which red garnet is ubiquitous, and biotite and hornblende are commonly present, along with abundant chlorite and epidote. The pelitic facies unusually rich in biotite and hornblende.

Rocks of the amphibolite facies are present almost universally in map unit Pa. Similar rocks of amphibolite grade occur in many parts of the Knob Hill Group, where fine grained greenstone has apparently been recrystallized to amphibolite. In many places where this has occurred, this facies is to a degree spatially associated with bodies of Nelson granodiorite. In others, such association is not evident, but Nelson rocks may underlie these masses of amphibolite. It is unlikely that the shallow intrusions of the Coryell could induce metamorphism of amphibolite grade. Calcareous rocks in the area have been little affected by regional metamorphism, other than coarse recrystallization.

Rocks of map unit Pm are almost everywhere schistose, with abundant development of muscovite in the pelitic rocks. Locally greenish brown biotite has been produced, and some actinolite.

Rocks of Carboniferous to Jurassic(?) age, have not suffered regional metamorphism above the greenschist facies, with the possible exception of parts of the Knob Hill Group, in which amphibolite has been developed locally, but this is regarded as more likely a contact metamorphism phenomenon.

CONTACT METAMORPHISM

Contact metamorphism related to the deep seated Nelson Intrusions is evident in many parts of Greenwood map area. One of the most conspicuous is on an embayment within the batholith that extends from Eholt Valley

Northward. In psammitic rocks of map unit Pm2 between Jewel Lake and Boldue Lake many outcrops of hornfels occur. A thin section of this rock shows it to be composed of anhedral to subhedral, saussuritized and slightly albitized plagioclase, elongate, subhedral hornblende crystals that are less than 0.2 mm long, and euhedral flakes of biotite 0.1 mm in diameter. These minerals are clouded with numerous minute inclusions of mafic minerals, and fine grained opaque minerals are scattered throughout the rock and are in places associated with epidote. These minerals show an interlocking texture.

In the Knob Hill Group, as described previously, amphibolite that is believed to be generated as a result of metasomatism derived from nearby or underlying Nelson Intrusions is scattered throughout much of the Greenwood map area.

Equally widespread in the region is the local development of skarn which is almost entirely confined to the upper part of the Brooklyn Formation, although some is possibly of the Knob Hill Group or the limestone of map unit uTsv. The skarn consists of garnet, calcite, epidote, quartz, chlorite, actinolite, and lesser amounts of zoisite, tremolite, and minor apatite. The most abundant metallic mineral is magnetite, with some pyrite, pyrrhotite, and specularite. Chalcopyrite is the common ore mineral in orebodies, though in the upper parts secondary carbonates were common. Brock (1903, p. 111A) did not believe that the granodiorite could have been responsible for the formation of the skarn, and that the Tertiary intrusions must have been. LeRoy (1912, p. 67), McNaughton (1945, p. 15), and Seraphim (1956, p. 392) all attribute the formation of the skarn to the Nelson Intrusions. The writer concurs; the shallow Coryell or Midway igneous rocks are unlikely to have produced such widespread contact metamorphism.

GEOLOGICAL HISTORY

The earliest rocks indicated to have been deposited in the region are those of psammitic, pelitic, and calcareous sediments that Preto (1970, p. 32, 69), on lithological grounds, correlated with late Proterozoic and early Paleozoic successions in the Selkirk and Purcell mountains. These were intruded by basic sills, and subsequently by granodiorite gneiss during broad warping of the sedimentary pile. As compression continued, numerous asymmetric folds developed on the broad folds. These subsidiary folds are directed northward. During this deep seated activity, estimated to be 10 to 12 km deep, the rocks were intensely metamorphosed, ranging from amphibolite to sillimanite grade. In Greenwood map area, migmatitic rocks (map unit Pm) are sparsely distributed.

Amphibolite (map unit Pa) is believed to be derived from the metamorphism of volcanic rocks and minor interbedded chert. It seems likely that these rocks were laid down in early Paleozoic time, probably on the rocks that now form map unit Pm. They may have been metamorphosed simultaneously with the formation of the migmatites, and subsequently. Such volcanic rocks may mark a westward transition from miogeosynclinal rocks in the early Paleozoic to eugeosynclinal rocks.

In mid-Paleozoic (but possibly as late as Carboniferous) time arenaceous, pelitic, volcanic, and minor calcareous rocks were deposited in the region. Because the contacts with earlier rocks are not exposed, the relationship is unknown, but the earlier phase of deformation of the Shuswap rocks, which are more intensely deformed and metamorphosed, seems to have predated their deposition. Being more deeply buried than the Permo-Carboniferous rocks which are the oldest to be dated by fossil evidence, they now comprise quartz-chlorite schist, quartz-biotite schist, greenstone, chlorite schist, amphibolite, bedded chert, and marble. The structure of these rocks is imperfectly known, but they may be overlain unconformably by Permo-Carboniferous rocks, and minor folding and erosion may have occurred in mid- to Late Paleozoic time.

Upon the surface of these schists was deposited limestone and argillite of the Attwood Formation, apparently in part contemporaneously of Carboniferous or Permian age. They were laid down in warm, quiescent, shallow seas, as indicated by the presence of corals, brachipods, and gastropods, and the abundance of limestone and fine clastics. These rocks, which are very restricted in distribution, were succeeded, also in Permo-Carboniferous time, by a thick succession of chert and andesitic lavas, with minor limestone, in a eugeosynclinal environment. To the south of the map area, rocks of similar lithology have yielded fusilinids of Early Permian age, so that deposition of this succession probably continued until at least Early Permian time.

Thirty to fifty kilometres to the east, however, and south of in Orient quadrangle, the Permian succession consists of greywacke and some limestone. The uppermost part is thin bedded, shaly limestone which rests on greywacke and contains ammonites of Scythian (Early Triassic) age (Kuenzi, 1961). At that locality Permian sedimentation apparently was extended into Early Triassic time, a condition not observed elsewhere. In Greenwood map area, the Permo-Carboniferous Knob Hill Group and the older(?) map unit Pm was covered in Lower(?) and Middle Triassic time by the chert sharpstone conglomerate member of the Brooklyn Formation. As there is no normal basal conglomerate, the sharpstone conglomerate must have been deposited on the older rocks with great rapidity from adjacent steep topography. West of the Greyhound Creek Fault, relief must have been much lower, as chert sands predominate there. At the Rawhide mine black siltstones were deposited simultaneously with some sharpstone conglomerate, and similarly, west of the Greyhound Creek Fault, black argillite was deposited simultaneously with chert sands. At the Stemwinder mine, limestone conglomerate appears to have been deposited simultaneously with sharpstone conglomerate.

Through Middle Triassic time, the sediments became more calcareous, ending with the deposition of the limestone member of the Brooklyn Formation. The succession apparently reflects a change from nearshore to offshore conditions. The fauna comprised pelecypods and ammonites. At the end of the Middle Triassic, open folding with north trending axes occurred.

After a brief period of erosion, agglomeratic deposits characterized by limestone clasts, with some shale were laid down locally. These were followed by limestone and minor shale containing corals and pelecypods, indicating quiescent, shallow water conditions in Norian and (?) Karnian (Upper Triassic) time.

Gentle warping along north trending axes was followed by a longer period of erosion, after which in the Jurassic period, propylitized basic to intermediate lavas were spread over the region, but are preserved only in the southeastern part of Greenwood area and in Granby Valley to the east.

Ultramafic intrusions were emplaced in the southern part of the map-area where they form part of a zone extending from Baldy Mountain, 16 km west of Greenwood map-area, 105 km eastward to Rossland. These intrusions may, however, be partly or entirely cold intrusions of earlier ophiolitic untramafics. This zone lies mainly north of the International Boundary, and is markedly interrupted by the metamorphic complex between Granby River and Kettle River faults, in which no ultramafic intrusions were emplaced. Where they are not completely altered, peridotite, dunite, and pyroxenite have been identified. The ultramafic intrusions do not seem to be related to any evident tectonic event.

In Late Jurassic and/or Early Cretaceous time, folding about north trending axes and probable faulting affected all of the earlier rocks of Greenwood map area, as well as the Grand Forks Group to the east (Preto, 1970, p. 72, 73). During this orogeny, granodiorite and related rocks of the Nelson Intrusions were emplaced. These were followed by the Valhalla Intrusions which may represent the final stages of the evolution of the Shuswap Metamorphic Complex.

Uplift and erosion occurred from mid-Cretaceous to the Early Eocene, during which the Nelson Intrusions and the Shuswap Metamorphic Complex were exposed throughout the region. During this peneplanation, the topographic relief was greatly moderated. In the Middle Eocene, continental sedimentation was initiated by explosive volcanism resulting in widespread dacitic tuff, which in most places was reworked and deposited along with lithic sandstone, shale, and locally conglomerate of the Kettle River Formation. Before the end of this sedimentation, lavas and intrusions of the Marron Formation began to be extruded or emplaced over a very extensive region. Coryell Intrusions, several of batholithic dimensions, were probably emplaced contemporaneously with some of the Marron lavas, but possibly slightly later.

Minor normal north-northeasterly trending faulting may have occurred shortly after deposition of the Middle Eocene rocks. There must have been a marked uplift of the region to the southeast at that time because from that upland a large heterogeneous mass of rocks ranging in age from pre-Permian to mid-Eocene detached itself and slid northwestward over Marron lavas forming a décollement. This epiclastic mass olistostrome forms the basal member of the Klondike Mountain Formation. Upon this mass were deposited tuffaceous lake beds that contain fossil plants and fish of Middle Eocene age, which were capped by basic lava and volcanic glass. Only the basal member is now exposed north of the International Boundary.

After deposition of the Klondike Mountain Formation, extensive north northeasterly trending normal faulting, with displacements of from a few feet or metres to more than 300 m occurred, and the resulting fault blocks were for the most part tilted eastward at angles up to 30° or so. Some 30 km north of Greenwood map area, Marron lavas are overlain unconformably by flat lying basalts believed to be of Miocene age. Such lavas may have been extruded within the map area, but if so, have since been removed by erosion.

During the Pleistocene epoch the entire area was covered by the Cordilleran ice mass, which receded about 10 500 to 11 500 years ago.

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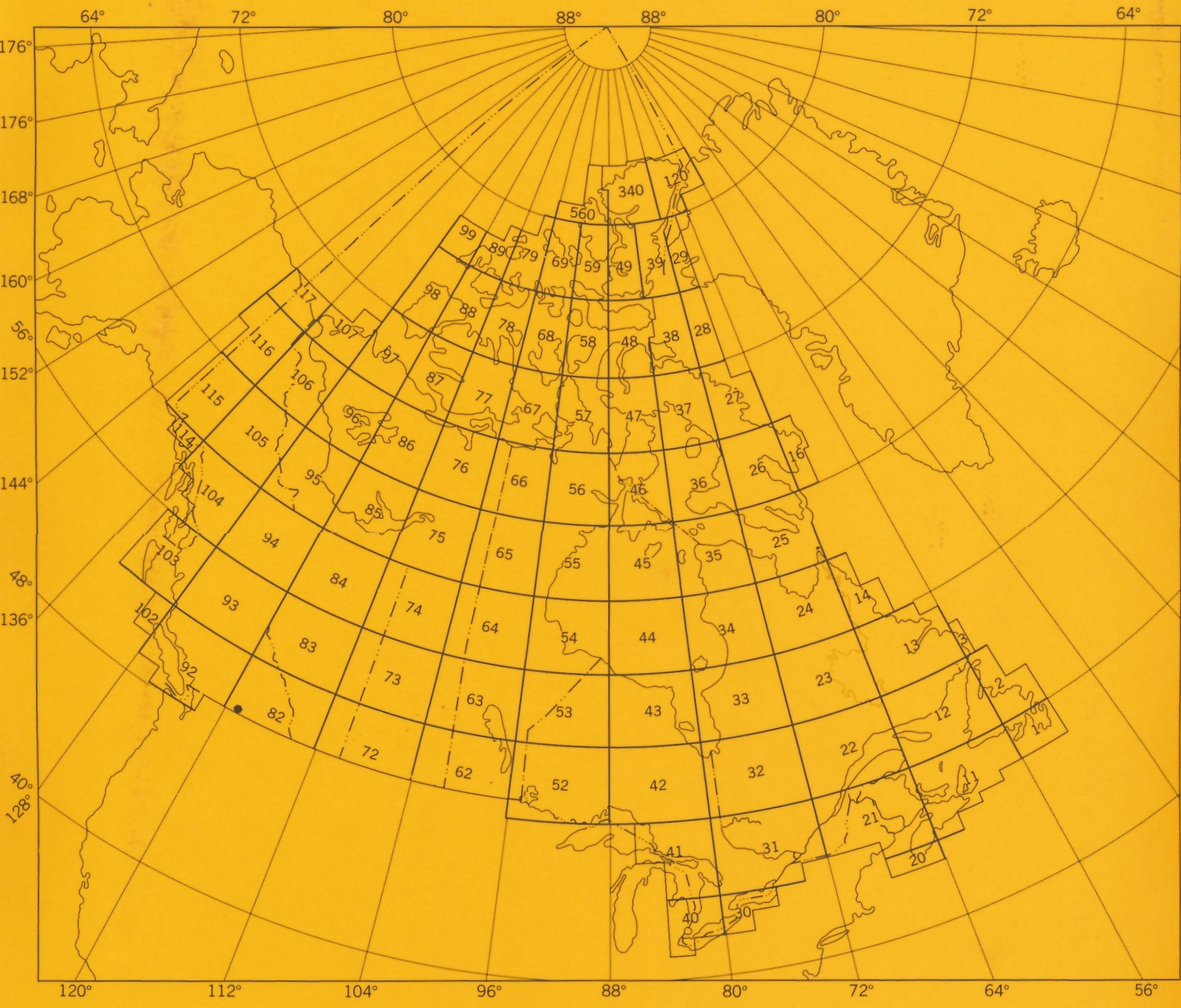

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