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BULLETIN 161

PETROLOGY AND STRUCTURE OF NAKUSP MAP-AREA, BRITISH COLUMBIA

D. W. Hyndman

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By
D. W. Hyndman

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PREFACE

That there is a relationship between granitic and metamorphic rocks and mineral deposits has long been recognized, and information on the origin of the two rock groups is therefore of practical as well as scientific importance. Despite this the processes by which these rocks developed are far from perfectly understood.

The study on which this report is based was carried out in an area in which granitic and metamorphic rocks are sufficiently varied and well exposed to suggest that a detailed investigation would be rewarding. And indeed it has produced considerable information on the structural history of the layered rocks and the metamorphic processes to which they have been subjected. The place of the granitic rocks in the sequence of events was established, as well as their role in the metamorphic history.

Y. O. FORTIER,
Director, Geological Survey of Canada

OTTAWA, 15 April, 1965

БЮЛЛЕТЕНЬ 161 — Петрология и структура Наксупского планшета, Британская Колумбия.

Д. В. Хайндман

BULLETIN 161 — Die Petrographie und Struktur des Kartenblatts Nakusp (Britisch-Kolumbien)

Von D. W. Hyndman

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PETROLOGY AND STRUCTURE OF NAKUSP MAP-AREA, BRITISH COLUMBIA

Abstract

The area studied lies along the Columbia River in the Selkirk Mountains of southeastern British Columbia. Most of the area is underlain by sedimentary and volcanic rocks of Early Jurassic, Triassic, and late Palaeozoic ages that have undergone regional metamorphism ranging in grade from the chlorite to the sillimanite zone. The highest grade zones form part of the Shuswap Complex, the metamorphism considered by some to be pre-late Palaeozoic in age. However, the culminating regional metamorphism in the area mapped affects rocks of Triassic and Lower Jurassic age, but does not affect granitic plutons from which Lower to Upper Cretaceous potassium-argon ages have been determined by the Geological Survey of Canada. Adjacent to these granitic stocks, contact metamorphism and recrystallization have been superimposed on the regional metamorphism.

The most prominent structures in the high-grade rocks are a strong, gently plunging east-west mineral and wrinkle lineation and a gently dipping schistosity. These were formed during the regional metamorphism, along with small recumbent isoclinal folds that have axes and axial planes parallel with the associated penetrative lineation and foliation, respectively. A second phase of deformation has produced strain-slip crenulations in the schistosity in the lower metamorphic grade rocks, and some associated macroscopic folds. Such crenulations may not have appeared in the coarser grained, high metamorphic grade rocks, or may have been parallel with the east-west lineation. Superimposed on these in turn are small folds of a third generation, whose axes within a single structural domain plot in a plane on an equal area net. The regional schistosity is thereby folded and the earlier lineations are deformed so as to lie on acute cones. This third phase may be connected with intrusion of the granitic stocks. Contact metamorphism related to the stocks has been superimposed on wrinkles of the second phase.

The granitic plutons, individually ranging in exposed area from a square mile to 22 square miles, have sharp contacts, are largely concordant, and tend to be elongate in an east-west direction, parallel with the regional structure. In composition they range from quartz diorite and granodiorite to granite and syenite. Biotite–hornblende quartz monzonite is most common. A major post-granite north-south fault, extending south from Upper Arrow Lake, has brought low metamorphic rocks against rocks of higher metamorphic grade.

Résumé

La région à l'étude longe le fleuve Columbia dans les monts Selkirk au sud-est de la Colombie-Britannique. La majeure partie de la région repose sur des roches sédimentaires et volcaniques du Jurassique inférieur, du Trias et du Paléozoïque supérieur qui ont subi un métamorphisme s'échelonnant de zones à chlorite à zones à sillimanite. Les zones de métamorphisme les plus intenses font partie du complexe Shuswap et certains auteurs considèrent que ce métamorphisme appartient au Paléozoïque présupérieur. Cependant le métamorphisme régional le plus intense a touché les roches du Trias et du Jurassique inférieur, mais a laissé intacts les plutons

granitiques dont la Commission géologique du Canada s'est servi pour déterminer au potassium-argon les âges s'échelonnant du Crétacé inférieur au supérieur. Dans le voisinage de ces massifs granitiques, un métamorphisme de contact et une recristallisation se sont ajoutés au métamorphisme régional.

Les structures les plus importantes des roches fortement métamorphisées consistent en rides linéaires minéralisées, à pendage accusé et graduel en direction est-ouest et en strates à pendage peu prononcé. Elles ont pris naissance lors du métamorphisme régional en même temps que de petits plis couchés isoclinaux dont les axes et les plans axiaux sont respectivement parallèles aux rides et aux strates pénétrantes associées. Une deuxième étape de déformation a produit par glissement des crénelures dans les strates faiblement métamorphisées ainsi que quelques plis macroscopiques associés. Il se peut que ces structures crénelées ne se soient pas produites dans les roches fortement métamorphisées et à gros grains où elles peuvent avoir été parallèles aux structures linéaires à direction est-ouest. Superposés à ces structures, on trouve de petits plis d'une autre origine et dont les axes à l'intérieur d'un seul domaine structural se répartissent dans le plan d'un réseau d'une superficie équivalente. La stratification régionale est par conséquent plissée et les structures anciennes sont déformées de façon à reposer sur des cônes aigus. Cette troisième étape peut être reliée à l'intrusion de massifs granitiques. Le métamorphisme de contact associé aux massifs a été superposé aux rides de la deuxième étape.

Les plutons granitiques, dont la répartition dans la région où ils affleurent s'étend sur un à vingt-deux milles carrés, présentent des contacts précis, sont en grande partie concordants et ont des structures allongées en direction est-ouest, parallèles à la structure régionale. Leur composition varie de la diorite à quartz et du granodiorite au granite et à la syénite. La monzonite à biotite-hornblende et à quartz est commune. Une grande faille postgranitique à direction nord-sud qui se trouve au sud du lac Upper Arrow a rapproché des roches peu métamorphisées des roches fortement métamorphisées.

Chapter I

INTRODUCTION

Nakusp map-area lies on the boundary between the Shuswap Complex and the low-grade metamorphic rocks of Mesozoic age to the east. The Shuswap Terrane was first described in 1898 by G. M. Dawson, who considered it to be of Precambrian age. Later work in the thirties, especially by Cairnes, suggested that the metamorphism was Mesozoic, and superimposed on any older rocks. Recently Jones (1959) mapped a large part of the Shuswap Terrane and concluded that the regional metamorphism was pre-Permian and probably Precambrian.

The present more detailed study is an attempt to clarify the relationships between the Shuswap Terrane and the adjacent low metamorphic grade rocks. Its aim is to determine the age of the regional metamorphism of the Shuswap Terrane, to determine the age of the rocks involved in this metamorphism, to correlate the type and sequence of folding in the low-grade rocks with that in the Shuswap Terrane, and to relate time of emplacement of massive granites with metamorphism of the Shuswap. Major conclusions from the present study are that the regional metamorphism is of Jurassic or Early Cretaceous age; that the rocks involved are Lower Jurassic, Triassic, and earlier; and that the phases of deformation affecting the high metamorphic grade rocks also affected the rocks with low grade of regional metamorphism.

Location

Nakusp (82 K/4)[1] map-area is in the Selkirk Mountains of southeastern British Columbia. It lies between latitudes 50°00′N and 50°15′N and between longitudes 117°30′W and 118°00′W, but mapping was extended a few miles to the south, the total area mapped being about 370 square miles. A few towns located in the area, all in the Columbia River valley, are Nakusp, Arrow Park, and Burton.

Access

Provincial Highway No. 6 follows the valley of Bonanza Creek across the northern part of the area to Nakusp and south along the east side of Upper Arrow Lake and the Columbia River. A branch line of the Canadian Pacific Railway

Ms received 17 November, 1964.

[1]Designation of the National Topographic System.

follows the valley of Bonanza Creek as far as Nakusp. Logging roads in various states of repair follow the lower parts of valleys in the western and northern regions of the area. An automobile ferry currently provides daily service on Upper Arrow Lake between Nakusp and Arrowhead. Another supplies continuous service across the Columbia River at Arrow Park. A few trails, kept open by the British Columbia Forest Service, give access to areas beyond the reach of roads.

Physiography

The Nakusp map-area lies mostly within the Selkirk Mountains subdivision of the Columbia Mountains, that part of the area west of the Columbia River lying in the Monashee Mountains (Bostock, 1948). Upper Arrow Lake and the Columbia River, at an elevation just less than 1,500 feet, represent a through-going drainage to the south. Slocan Lake, lying just to the east of the map-area, also lies in a deep north-south valley. Between these main valleys the tributary drainage is predominantly east-west and the divide lies somewhat east of midpoint between the main valleys. Elevations along the divide range from 2,500 to 8,900 feet. The topography in the southeast is rugged and retains the cirques and related features of former alpine glaciation. In the west, however, the ridges are round topped and a little lower, with abandoned cirques only on north-facing slopes. Plates I and II are typical views of the area.

There are no glaciers in the area and, in fact, few patches of winter snow survive until late August. Continental glaciers covered ridges at least 7,300 feet high, as well-rounded glacial erratics were found at that elevation near the peak of Saddle Mountain. On Scalping Knife Mountain ridge, on a hilltop at an elevation of 7,030 feet a granitic dyke shows glacial polish. Terraces, representing recent renewed downcutting, border all streams in the area.

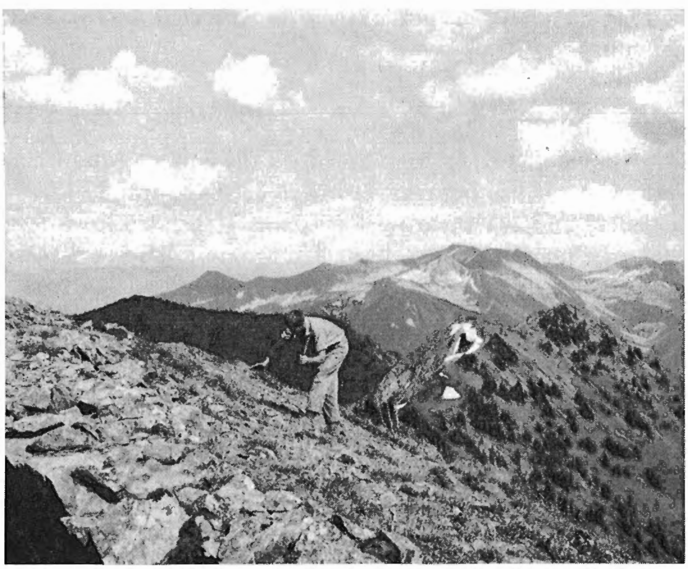

PLATE I.
View due east from Silver Mountain to Mount Vingolf.

116808

PLATE II.
View southeast from Blue Grouse Mountain. Dump of the Millie Mac mine in the foreground.

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Climate, Vegetation, and Fauna

The climate of the Columbia Valley is moderate. Temperatures extend from a mean of 20° in January to 65° in July, with daily ranges of 10° to 30°. There is an annual rainfall of about 25 inches; the maximum rainfall is in December (4 inches), with another peak in June, and minimums are in April and late July ($1\frac{1}{4}$ inches). Rainfall is appreciably higher in the mountains and the temperature is lower.

Evergreens dominate the vegetation, stands of Western red cedar, Engelmann spruce, Western balsam, fir, hemlock, and pine supplying the active logging industry. Of the deciduous vegetation, alder, cottonwood, aspen, maple, and birch are common. Treeline lies between 7,000 and 7,500 feet, higher elevations being confined largely to the southeastern part of the area. Animals most commonly seen are white-tailed deer, black bear, and porcupine.

Earlier Work

The earliest reported geological work done within the map-area was along the Arrow Lakes and Columbia River by G. M. Dawson in 1889 (1890). Later reconnaissance work by R. G. McConnell and R. W. Brock was summarized in 1904 with publication of the West Kootenay sheet. More recently, C. E. Cairnes (1929) mapped the areas bordering the major valleys of the Columbia River and Summit Lake.

Field Work and Acknowledgments

Mapping was undertaken in the summers of 1961 and 1962 as part of a study by the Geological Survey of Canada of the overall geological setting of the plutonic complexes of southern British Columbia. The work was facilitated by the capable

field assistance of P. Roy in 1961, and G. Scott and T. Wedge in 1962. The writer is grateful for aid and hospitality extended by residents of the area, especially J. Raven of the British Columbia Forest Service, Mr. and Mrs. N. Waterfield of Nakusp, and H. Leu of Burton. He wishes also to express his appreciation to Professors F. J. Turner and L. E. Weiss of the University of California for suggestions and constructive criticism during preparation of this report. Discussions with other graduate students, especially S. Blusson, R. Curry, and P. Read, were very helpful.

Chapter II

METAMORPHIC ROCKS

General Statement

Regional Setting

The plutonic and structural setting of the rocks in Nakusp map-area is shown on Figure 1. The area is bordered on the northeast by the Kuskanax batholith (Cairnes, 1929, pp. 104A–105A), and on the southwest by an extensive mass of porphyritic "Nelson granite" (Little, 1957, 1960; Jones, 1959, p. 51), the adjacent borders of both being within the map-area. Between these batholiths are low-grade metasedimentary and metavolcanic rocks of Mesozoic age, preserved in the Slocan fold or synclinorium. The latter, described by Hedley (1952) for the Slocan area to the southeast, trends east-southeast through the central part of the map-area. The Slocan fold, a recumbent synclinorium open to the southwest, appears to be less pronounced and overturned in the Nakusp area, though the northern limb, along the phyllite belt southeast of Nakusp, is nearly vertical. The Slocan fold is truncated on the west by the north-south Rodd Creek fault which follows the southern part of Upper Arrow Lake. Southward from the Slocan synclinorium, the rocks increase in regional metamorphic grade to very high (sillimanite zone) in the Valhalla dome, a structural complex of Shuswap type (Reesor, *in* Lowdon, 1961, pp. 92–97) immediately south of the area and west of Slocan Lake. Northwest of the map-area, but partly within it is the Monashee Group of the vast, high-grade Shuswap Complex, which extends west to Okanagan Lake and north beyond Shuswap Lake.

Summary of Local Setting

The zones of progressive regional metamorphism as deduced in this study are shown on Figure 14. The Slocan synclinorium trends east to east-southeast in the central part of the map-area, centred just north of Slewiskin Creek. As might be expected, the zone of lowest regional metamorphic grade follows this structural trough. Involved in this low-grade metamorphism (greenschist facies) are volcanic and pelitic sedimentary rocks of Triassic and Lower Jurassic age (*see* Table of Formations). Both the synclinorium and the metamorphic zones are truncated abruptly by the north-south Rodd Creek fault which extends south from Upper Arrow Lake.

North, south, and southwest of this structural and metamorphic low, the grade of regional metamorphism rises to the staurolite zone. Pelitic schist and metavolcanic rocks involved in this zone are older, late Palaeozoic to Triassic. The metamorphic grade is still higher (sillimanite zone) farther south and across the Rodd Creek fault and Upper Arrow Lake to the west, where there are still older (pre-Triassic) pelitic schists, quartzites, calc-silicate, and metavolcanic rocks forming part of the Monashee Group of the Shuswap Complex. The northern edge of the Valhalla Complex of high-grade metamorphic and granitic rocks (equivalent to the Shuswap Complex) lies just beyond the southern edge of the area mapped at Snow

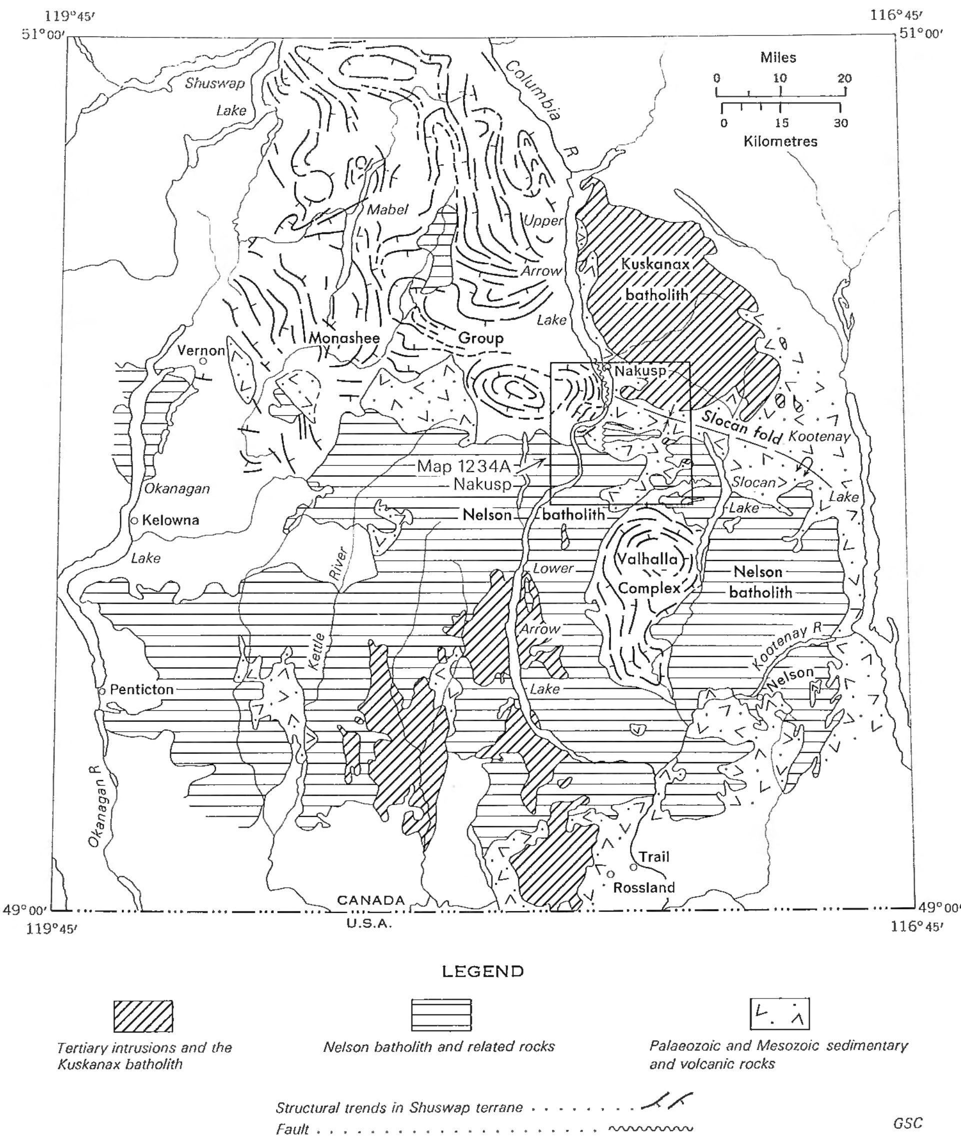

FIGURE 1. Geological setting of Nakusp map-area.

Table of Formations

Era	Period or epoch		Formation and thickness (feet)	Lithology
Cenozoic	Recent and Pleistocene		(highly variable)	Glacial debris, lake silts, and clays, stream gravel, sand, and silt
	Unconformity			
	Tertiary		Lamprophyric dykes	Lamprophyre, basalt, andesite
Mesozoic and/or Cenozoic		Alkalic	Box Mountain pluton?	Syenite
Mesozoic	Cretaceous and/or possibly Jurassic	Calc-alkalic suite	Lower Caribou Creek pluton	Quartz monzonite and granodiorite; minor quartz diorite and granite
		Calc-alkalic suite	Goatcanyon–Halifax Creeks pluton and Snowslide–Wragge Creeks stocks	Quartz monzonite, quartz diorite, diorite, granodiorite
		Calc-alkalic suite	Ruby Range pluton	Quartz monzonite, quartz diorite, diorite
		Calc-alkalic suite	Mountain Meadow and East Caribou plutons	Quartz diorite, diorite, quartz monzonite
		Alkaline suite	Kuskanax batholith	Leucogranite
		Alkaline suite	South Wragge Creek and Shannon Lake stocks	(leuco)quartz monzonite
		Alkaline suite	Lineated leucocratic dykes	(leuco)quartz monzonite
	Intrusive contact			
	Lower Jurassic		Rossland Group (~3,500)	Greenstone, andesite, basalt
	Triassic and Lower Jurassic		Slocan Group (0–2,500)	Unit 11: grey volcanic rocks: andesite, dacite tuffs and flows
			Slocan Group (~4,800)	Unit 10B: non-phyllitic argillaceous rocks: argillite, shale, siltstone, minor volcanic rocks
			Slocan Group (~2,500)	Unit 10A: grey phyllite, slate, siltstone
	Triassic		Kaslo Group (2,400)	Amphibolite (metavolcanic rocks)
	?Pennsylvanian to Triassic		Milford(?) Group (~5,000?)	Calc-silicate metasedimentary rocks, pelitic schist, limestone
Palaeozoic and/or Precambrian	pre-Triassic		(300)	Amphibolite
			Monashee Group (Shuswap Terrane) (1,700)	Pelitic schist
			(2,300)	Diopsidic quartzite
			(>13,000)	Undivided pelitic schist, calc-silicate metasedimentary rocks, amphibolite, marble

Creek. Intruded into the low- to moderate-grade rocks (including staurolite zone) are granitic plutons ranging in composition from quartz diorite to leucogranite and syenite; quartz monzonite is most common. Most are massive, have sharp contacts with the country rocks, and were intruded after regional metamorphism of the country rocks.

High-Grade Metamorphic Rocks

Field Description and Distribution

Rocks belonging to the lower half of the stratigraphic succession in this area (pre-Triassic Monashee Group) are dominantly of pelitic sedimentary origin. As grain-size gradually increases from very fine (argillites) in the low metamorphic grades to medium in the high grades, there is no reason to imply that rocks in the high grades were not also fine grained prior to metamorphism. They could have been, however, predominantly sand-size particles (e.g., greywackes). Intercalated with the metasediments of pelitic origin in the Monashee Group are some rather calcareous beds, perhaps originally calcareous siltstones, and a few layers of metavolcanic rocks, perhaps originally andesitic tuffs.

Overlying the Monashee Group (*see* Table of Formations) are a few hundred feet of metavolcanic rocks, either flows or tuffs, which are also probably pre-Triassic. In turn, above the metavolcanic rocks are a few thousand feet of metasedimentary rocks considered to belong to the Milford Group. These are dominantly calcareous much like their thinner, more highly metamorphosed neighbours in the Monashee Group. They too were probably impure calcareous siltstones. Intercalated with the calcareous rocks of the Milford Group and forming a thick section between its upper and lower dominantly calcareous members is a thick section of pelitic sedimentary rocks, originally shales or fine greywackes. A few thin beds (a few inches to a few feet thick) of limestone occur within the calcareous members. Overlying the Milford Group are two to three thousand feet of metavolcanic rocks (probably flows) of the Kaslo Group of Triassic age.

Metamorphic rocks whose pelitic members have been involved in metamorphism of the almandine–amphibolite facies (as defined by Turner and Verhoogen, 1960, pp. 544–545), corresponding to the staurolite to sillimanite zones of Barrow (1912), are designated here as high-grade rocks. In the Naskusp area, the lower grade limit of these rocks coincides closely with the finer grained, or lower grade, limit of schists in pelites. Individual grains may however be distinguished in hand specimen, which is not true for the low-grade rocks described in the next section. High-grade metamorphic rocks underlie 38 per cent of the area mapped, low-grade rocks 40 per cent, and granitic plutons 22 per cent (*see* Fig. 14).

Pelitic Schists (*1*, *3*, *4*, *6A*, *7*)

Metamorphism of pelitic rocks in the staurolite–almandine subfacies has produced fine to very fine grained schists (unit 6A), many of them appearing somewhat phyllitic in hand specimens but having at least one visible mica. In some schists mica or garnet porphyroblasts as much as a millimetre across pepper the rocks. Commonly, rocks of this subfacies are grey to dark grey but range to pale grey and brownish. Schistosity is poorly developed in some rocks, well developed in others (*see* Pl. III). Lineations are mostly less distinct than in the phyllites of unit 10.

Metamorphism of pelitic rocks in the sillimanite–almandine–muscovite and sillimanite–almandine–orthoclase subfacies (Turner and Verhoogen, 1960, p. 548) has produced schists and paragneisses of medium to moderately coarse grain (units 1 and 3). Prominent in the field and in hand specimens is a well-developed schistosity due to alignment of micas and commonly accentuated by development of quartzo-feldspathic laminae. The schistosity is generally almost planar but becomes wavy to knotty where sillimanite has formed lenticular pods aligned in the schistosity and lineation (*see* Plate IV). A lineation consisting of wrinkled micas or aligned prismatic minerals is generally apparent but not always conspicuous. Such rocks are dark brown to greyish brown, grading to paler colours with a greater proportion of felsic constituents. The prevalent minerals easily visible in hand specimens are biotite, quartz, and plagioclase. Sillimanite is moderately common, appearing generally as quarter-inch- to three-quarter-inch-long disks or streaks of white matted fibres. Muscovite occurs in the sillimanite–almandine–muscovite subfacies as scattered silvery spangles. Garnet is rare in all the pelitic schists.

Pelitic schists are the most voluminous and widespread of the units mapped throughout the area of high-grade metamorphism.

PLATE III.
Well-developed schistosity in fine-grained pelitic schists southeast of Mount Vingolf.

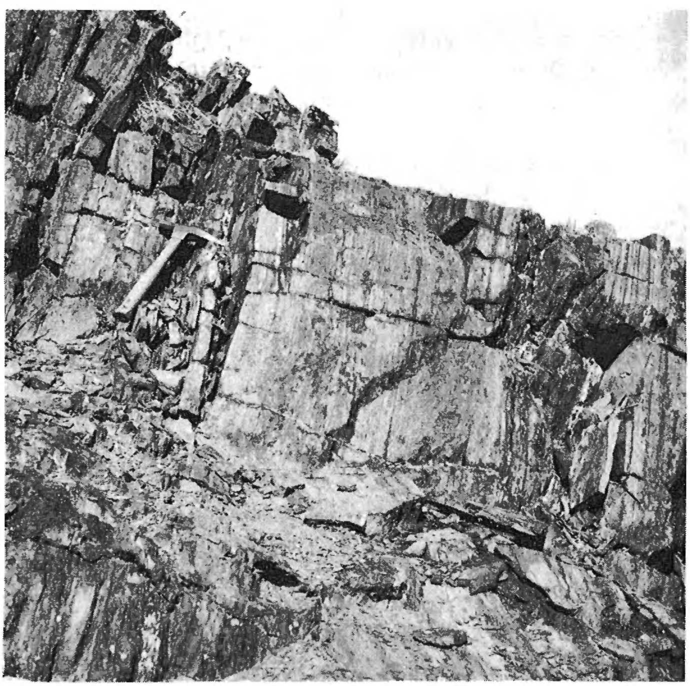

PLATE IV.
Aligned pods of sillimanite needles in pelitic schist on Saddle Mountain. Lineation parallels arrow, plunges 20°S67°E.

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Diopsidic Quartzites (2)

This most distinctive unit (2) in the high-grade metamorphic rocks is uniform in field appearance. The rocks are white and strikingly layered (a quarter inch to 2 inches thick) in weathered exposures (*see* Pl. V), where calcite-bearing beds are leached, but are massive on fresh surfaces. Schistosity and lineation are marked on weathered surfaces as flat and elongate grains of quartz a few millimetres long. The gently dipping schistosity parallels the bedding except where the latter is folded, and there the lineation follows the line of intersection of schistosity and bedding. Quartz is by far the most obvious mineral in hand specimens, followed in turn by small green specks of diopside, white calcite, and in some areas small black flakes of graphite.

This unit is well exposed in the cliffs on the north face of Scalping Knife Mountain and caps the twin peaks of Saddle Mountain. It is unknown elsewhere in the area, but should make an excellent marker horizon outside the area.

Amphibolites (5, 9, 4)

Amphibolites and hornblende-rich schists resulting from metamorphism under conditions of the sillimanite subfacies (units 5, 4) are medium-grained and to some extent moderately fine-grained rocks, consisting of about equal amounts of dark green to black hornblende and white plagioclase. A schistosity is in most cases moderately well developed, as also is a mineral lineation. Biotite appears in some rocks on schistosity surfaces, and garnet is present in a few as small equant red crystals. One amphibolite on the west side of Saddle Mountain consists of aligned

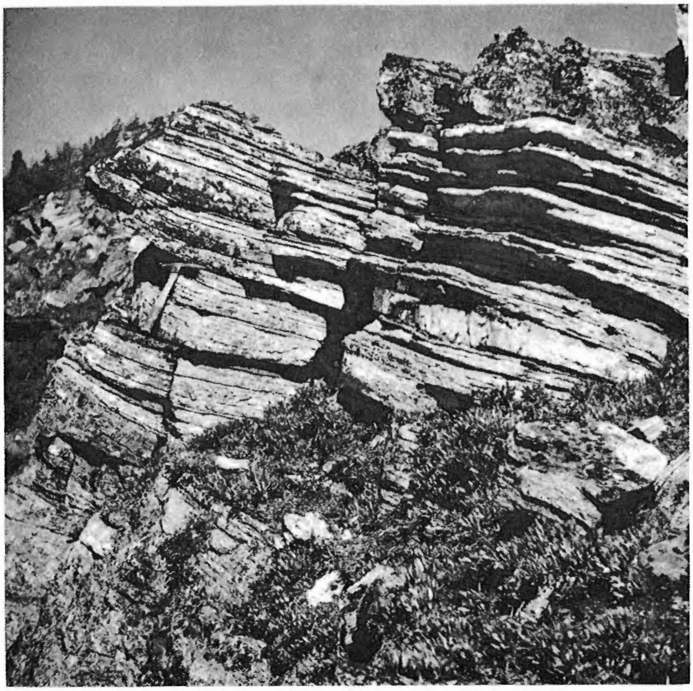
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PLATE V.
Diopsidic quartzite on Saddle Mountain. Bedding emphasized by weathering.

pencils of garnet (1 cm to 2 cm by 2 mm) in medium-grained black hornblende.

Amphibolites in the staurolite–almandine subfacies of the almandine amphibolite facies (unit 9) are fine-grained rocks rich in dark green to almost black amphibole and what appears in hand specimen to be a smaller percentage of white feldspar. Schistosity is commonly well developed and a mineral lineation less so. Biotite is visible in many rocks. The amphibole appears as fine, evenly distributed, prismatic grains or as felty mats of overlapping acicular grains. In outcrop the unit is dark, greyish green to black. Some sections contain interspersed pelitic layers and mineralogical gradations exist adjacent to some pelitic schist or calc-silicate members.

Amphibolite (unit 5) is present in a narrow east-west band 200 to 300 feet wide across Scalping Knife Mountain, and has been mapped separately. A thicker layer is exposed across and west of the ridge between Rodd and Mineral Creeks. Elsewhere the unit has not been mapped separately but it occurs in many places (posibly repeated structurally) on the Saddle Mountain block, especially in the northwestern portion. It is present especially with unit 4a in the succession on the west side of Saddle Mountain.

Calc-silicate Unit (6B, 7, 4)

A group of high-grade metamorphic rocks distinguished in the field by the presence of calc-silicate minerals and by very thin, compositional lamination (or bedding) forms a recognizable, though less distinctive, map unit (unit 4a). Thin layers (1 mm to 5 cm or more) rich in medium-grained quartz, white feldspar, and equant grains of green diopside or dark green hornblende alternate with laminae rich in biotite, or with different proportions of the same minerals. These layers are in some samples quite striking (alternating greenish white and dark greyish brown), in others indistinct, thin paler grey streaks. The rock also contains a moderate to good metamorphic schistosity but lineation is generally poor. Disseminated flakes of graphite form an obvious, though quantitatively minor, part of some specimens.

Lower grade parts of the "calc-silicate unit" (6B), immediately overlying the amphibolites of Scalping Knife Mountain, are characterized mainly by their laminated (or bedded) nature, just as in the higher grade rocks of the unit. Grain-size is for the most part fine, though the common presence of small, dark green crystals of actinolite in the light-coloured layers aid in recognition of the unit in the field. The layers are generally diffuse alternations of medium or light grey or buff colour. The calc-silicate unit commonly contains interbeds of schist and, to a minor extent, marble.

Exposures of the calc-silicate unit form a narrow band (about 500 to 700 feet thick) across Scalping Knife Mountain, and a thicker band (about 1,500 feet, in part resulting from internal folding) across the ridge between Mineral and Rodd Creeks, and west of it. Several thinner bands (100 to 200 feet) are exposed on the west and northwest sides of Saddle Mountain (especially in the dotted succession with unit 4a), and along the hillside north of Snow Creek. What appear to be the continuation of the latter bands to the northeast are exposed on the ridge east of Hailstorm Peak and north of Snowslide Creek.

Pegmatites and Aplites

Pegmatites and aplites that are closely associated with the high-grade metamorphic rocks are not mapped separately but form parts of units 1 to 7. Pegmatites consisting of 20 to 30 per cent grey to glassy white quartz and 70 to 80 per cent white feldspars dominate the group. All are mineralogically simple. Accessory minerals (present in almost half of such rocks) are, in order of abundance, most commonly biotite, muscovite, red garnet, and black tourmaline (schorlite). In one locality, a few grains of pale yellowish green apatite are associated with schorlite. Grain-size in the pegmatites ranges from less than a cm to more than 6 cm, except for garnet which is rarely larger than 3 mm. Pegmatite layers range in thickness from less than a cm to more than 200 feet. Concordant layers of more than a few feet in thickness tend to be sub-equally spaced in the section. Many are schistose; few show textural layering.

The nature of the pegmatites varies with increasing grade of metamorphism as shown on Figure 2. In general, the percentage of the metamorphic section that consists of pegmatite increases with increasing grade. With increase in metamorphic grade the percentage of pegmatites carrying tourmaline, garnet, and biotite increases; the number carrying muscovite increases to the sillimanite–almandine–muscovite subfacies, then decreases to the sillimanite–almandine–orthoclase subfacies; the number of rocks with no mica decreases. The percentage of pegmatites that crosscut the country rocks (as opposed to those that parallel the schistosity) is much less in the sillimanite subfacies than in the staurolite–almandine subfacies. Some of those crosscutting pegmatites in the staurolite–almandine subfacies may be

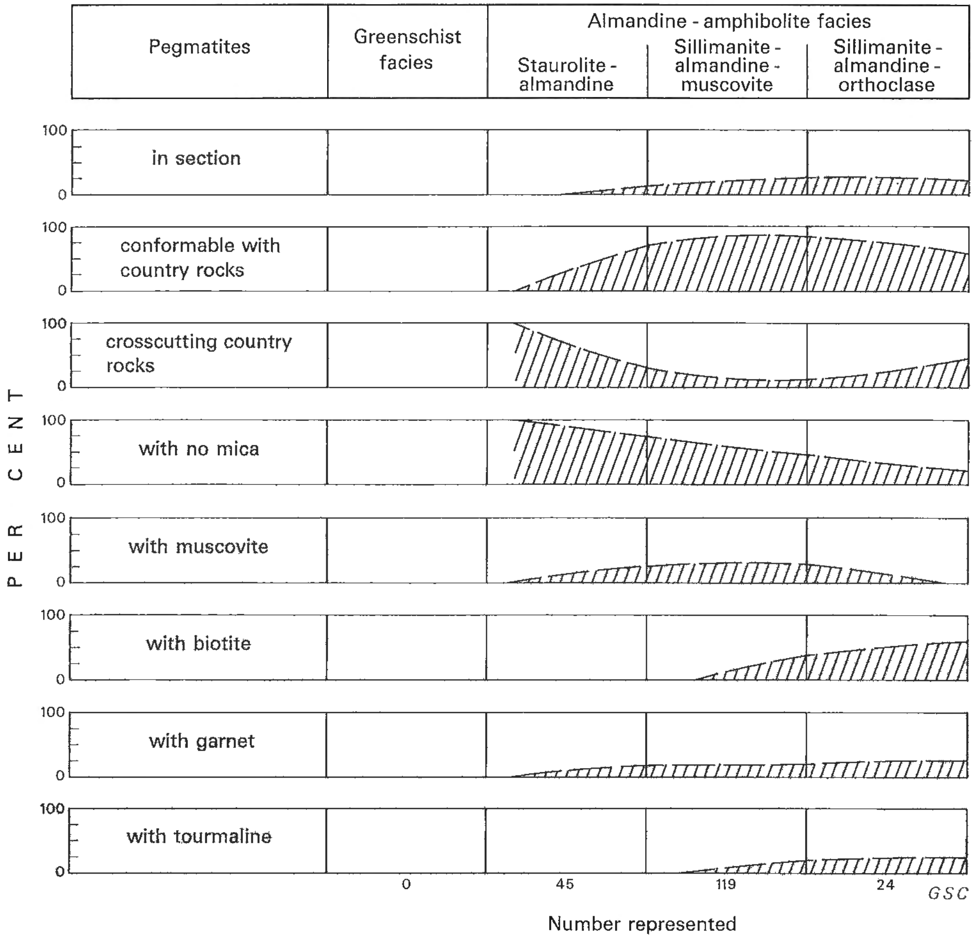


FIGURE 2. Nature of the pegmatites with respect to grade of metamorphism. Pegmatites clearly related to granitic intrusions are omitted.

associated with intrusion of the quartz monzonite stock underlying lower Caribou Creek. Rocks of the greenschist facies contain only minor pegmatites associated with the intrusion of granitic stocks, and these are limited to within a few feet of the contacts.

Lineated Quartz Monzonites

Included with the high-grade metamorphic rocks because of their association, occurrence, and texture is a group (unit 13) of granitic rocks of fine (<1 mm) to medium (1 mm to 5 mm) grain-size. Most characteristic is a pronounced mineral lineation (strongly aligned prismatic hornblende or elongate biotite crystals) with little or no associated schistosity. A cursory glance at an outcrop of this unit gives the impression of either a massive rock (approximately normal to the lineation), or a strongly schistose rock (approximately parallel with the lineation). These rocks are white to pale buff in outcrops and thinly streaked with black mafic minerals that form one to five per cent of the rock.

Where mapped separately on Scalping Knife Mountain, these lineated granitic rocks form most of the exposures in a thickness of 500 to 600 feet. Scattered sills of the same rock are found in the diopsidic quartzites for about 1,000 feet below and in the pelitic schists for about 1,000 feet above. Elsewhere, lineated quartz monzonites occur at scattered localities in the Saddle Mountain block (northern and southeastern parts) and near Wee Sandy Lake.

TABLE I — *Modes of High-Grade Metamorphic Rocks (visual estimates in volume per cent (averages))*

Map unit[1]	2	1,3(A_3)	1,3(A_2)	6A(A_1)	13	5($A_{2,3}$)	5A_1	(4A)$A_{2,3}$	(6B)A_1	Pegmatites	8
No. of Thin Sections	14	5	25	30	11	10	9	8	25	4	6
Quartz	67	63	48	44	24	7		46	44	41	18
Orthoclase	1	6	5	7	31	.2	.5	2	11		
Microcline										24	tr
Plagioclase	2	15	21	22	41	43	39	22	25	32	.2
Biotite		11	15	16	1.5	3	5	5	3	.2	.4
Muscovite	tr	3	4	6	.5				.3	2	
Hornblende				1	1	41	44	8			
Tremolite–actinolite	.9			.4					7		.9
Diopside	9					1	3	8	7		3
Aegirinaugite					.4						
Epidote	tr			.3			4	tr	.5		3
Calcite	15			.1				5	2		73
Garnet		.3	1	.5	.2	4		tr	.1	tr	2
Sillimanite		1.5	3								
Andalusite			.1	.2							
kyanite				.1							
Staurolite			.1	.2							
Chloritoid				.3							
Scapolite	3							2			
Graphite	.2	1	.7	.9				1	.9		
Chlorite ∓		.6			.4				.7		
			.9	.8		.8	2	1		.5	.2
Sphene	.6	.2	tr	.4	.4	.5	.5	.6	.4	tr	.2
Apatite	.3	.4	.2	.2	.2	.3	.3	.3	.2		tr
Tourmaline			.3	.4					tr		
Allanite			tr	tr	tr				tr		
Zircon	tr	tr	tr	tr	tr			tr	tr		
Magnetite–ilmenite				.1	tr	.7	.4	.3	.1		.1
Hematite	tr	.1	.1	.1	.2	.1	.2	.1	.6		.6
Pyrrhotite–pyrite	tr	.1	tr	.1	.1	.1	.1	.6	.5		.1
% An of plagioclase	48	27	28	35	23	42	29	46	39	26	
An variation ±	87	31	49	47	29	78	42	67	87	28	
	17	23	16	25	17	21	21	26	26	24	
No. of plagioclase sections	6	5	23	14	11	10	6	8	18	3	

[1] A_3 = sillimanite–almandine–orthoclase subfacies; A_2 = sillimanite–almandine–muscovite subfacies; A_1 = staurolite–almandine subfacies, kyanite–almandine–muscovite subfacies.
tr = trace.

Mineralogy and Petrography

The mineralogy of the high-grade metamorphic rocks has been determined optically in thin section, supplemented, in the case of a few fine-grained rocks of the staurolite–almandine subfacies[1], with x-ray diffractometer patterns. The anorthite content of plagioclase was determined with the universal stage, using the curves of Slemmons (1962). Average percentages, visual estimates in thin section, are listed in Table I. Each is considered to be representative of the unit except for the pegmatites[2]. Each of the map-units and rocks represented is described individually below as a supplement to Table I. Rocks are named for their essential or characterizing minerals. Other minerals are classed as accessory.

Phase diagrams (ACF and AKF diagrams) for the successive metamorphic zones in the Nakusp area, as determined in thin section, are shown on Figure 3. Coexisting minerals showing no apparent reaction or disequilibrium are joined by tie-lines. Equilibrium assemblages, therefore, are represented by these tie-lines or by triangles enclosed by them; quartz is always included as shown. A, C, F, and K are, respectively, $Al_2O_3+Fe_2O_3-(Na_2O+K_2O$ or $Na_2O+K_2O+CaO)$, CaO, (Mg, Fe, Mn)O and K_2O.

Units 1, 3, 4, 6A: Pelitic Schists (see Fig. 3)

In the staurolite–almandine subfacies (A_1) quartz and biotite are present in every section, plagioclase in all except four.

The characteristic assemblages are as follows:

A_3: quartz–plagioclase–biotite–orthoclase–garnet–sillimanite
(apatite ±sphene)
quartz–biotite–orthoclase–plagioclase–muscovite–sillimanite

A_2: quartz–plagioclase–biotite–muscovite–sillimanite (±tourmaline)
quartz–plagioclase–biotite–sillimanite–garnet
(±muscovite ±relict staurolite ±tourmaline ±apatite)
quartz–plagioclase–biotite (±apatite)
quartz–plagioclase–orthoclase–biotite–muscovite (±apatite)
quartz–plagioclase–orthoclase–biotite (apatite)

A_1: plagioclase–quartz–biotite–K-feldspar–amphibole
(sphene ±epidote ±apatite)
quartz–K-feldspar–biotite (±plagioclase ±tourmaline ±sphene)
quartz–plagioclase–biotite–garnet
quartz–biotite (±muscovite ±plagioclase ±tourmaline)
quartz–muscovite–biotite–staurolite
(±plagioclase ±garnet ±chloritoid)

Other accessory minerals include: calcite (in A_1), graphite, allanite, zircon, magnetite and/or ilmenite (in A_1), hematite, and pyrrhotite or pyrite (especially in A_1). Kyanite

[1]As used here, the staurolite–almandine subfacies includes the kyanite–almandine–muscovite subfacies. These subfacies could not be divided in this area. They are combined as subfacies designation A.

[2]These rocks are coarse grained and only a few thin sections were made. The data of column 11 (Table I) are valid for anorthite content of plagioclase and show that quartz, potassium feldspar, and plagioclase are subequal in amount.

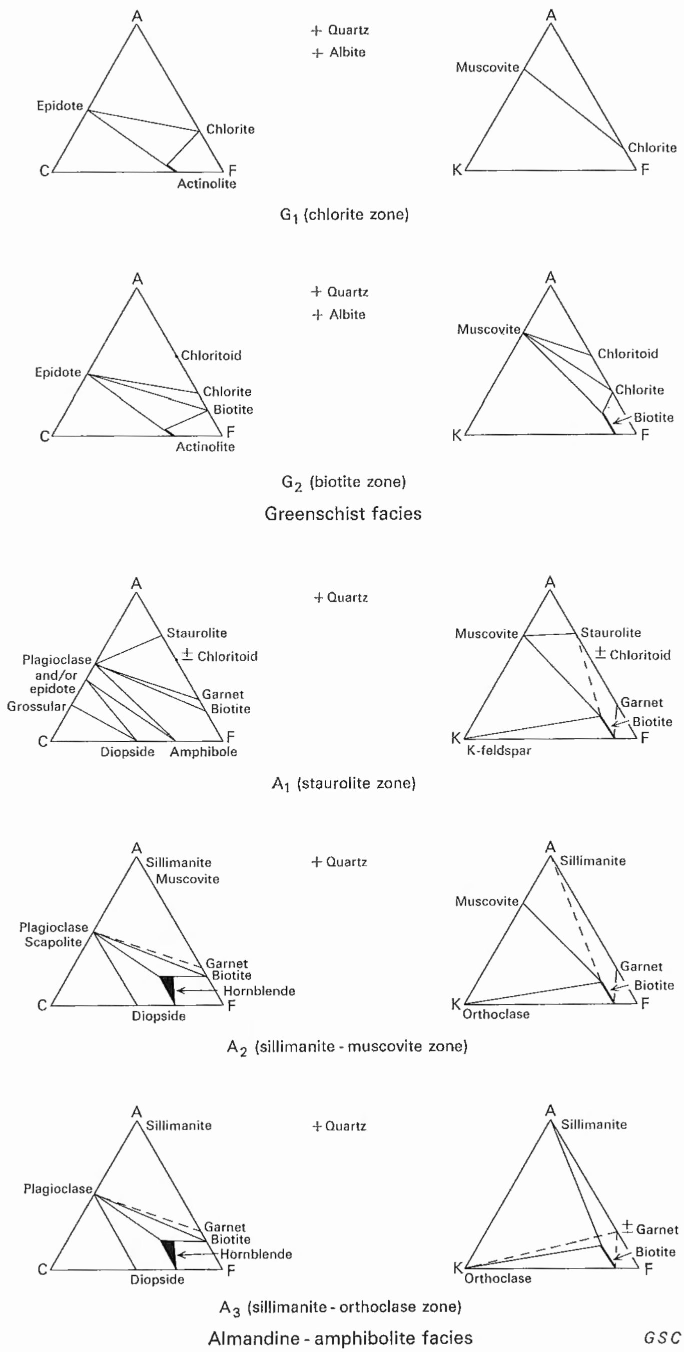


FIGURE 3.
ACF and AKF diagrams for the facies of regional metamorphism as deduced in the Nakusp area.

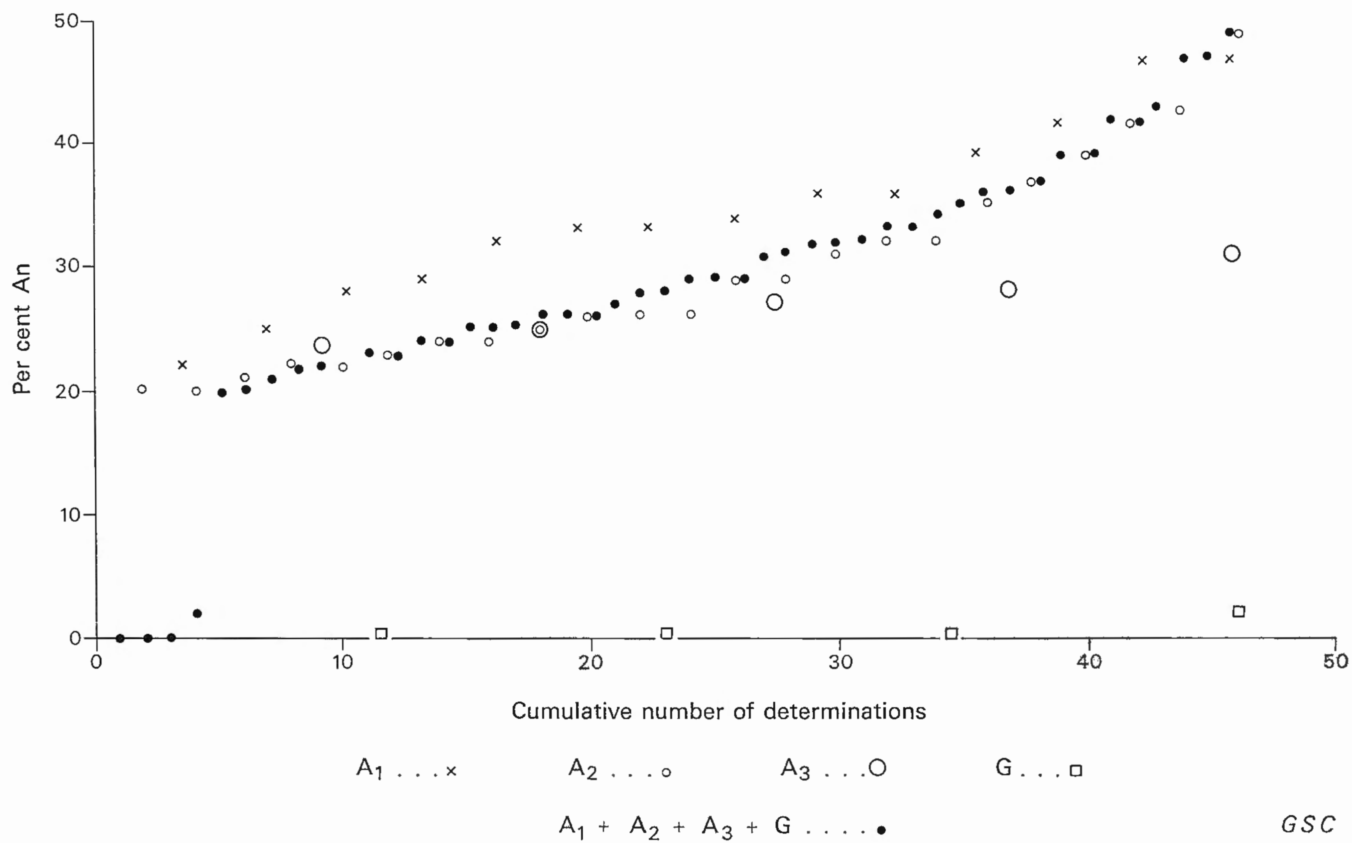


FIGURE 4. Composition of plagioclase in the pelitic schists.

is rare but occurs in one rock with staurolite. Andalusite has crystallized subsequent to regional deformation, as the wrinkled schistosity passes through the undeformed crystals. The plagioclase of rocks in the greenschist facies is almost pure albite. The anorthite content rises suddenly to between 20 and 45 per cent in the almandine–amphibolite facies, but within this facies there is no systematic increase in anorthite content with rising grade of metamorphism (*see* Fig. 4). A similar jump in the anorthite content of plagioclase has been reported in metamorphic rocks elsewhere (e.g., de Waard, 1959, p. 559).

The colour (Z) of biotite changes in general with increasing metamorphic grade, from orange-brown in the greenschist facies (G_2), through brownish orange in (A_1), more reddish orange-brown in (A_2), and orange-brown to brownish red in (A_3), an increase in red shades with increasing grade of metamorphism. Such red colours have been attributed to high TiO_2 and high Fe^{++} to Fe^{+++} in the biotite (Hall, 1941 and Hayama, 1959).

Tourmaline has essentially the same colour in every rock: $\varepsilon =$ colourless, $\omega =$ olive green to olive brown. The cores of a few crystals in (A_2) are more yellow or brown.

Chlorite in the almandine–amphibolite facies is in every instance a product of partial alteration of biotite (mostly $<10\%$), and to a minor extent of garnet. A Mg–Fe (greater Fe) variety, to use the generalization of Albee (1962)—negative optic sign, anomalous blue or violet interference colour—is common in each of the subfacies (after biotite). A Fe–Mg variety—positive, anomalous brown interference

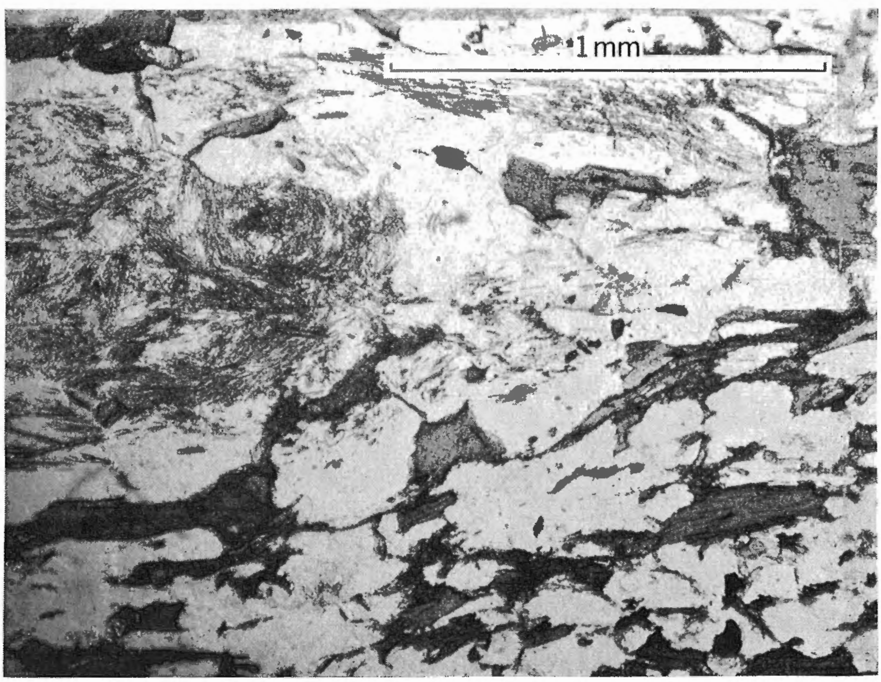


PLATE VI. Photomicrograph perpendicular to lineation of pelitic schist in sillimanite zone. Aligned biotite determines schistosity. Needles of sillimanite form matted pod. (plane light)

—is moderately common, though in almost every case it is separated from the parent biotite by a thin transitional layer of Mg–Fe(-) chlorite. Every section (six in A_1) containing garnet (and accompanying lack of K-feldspar) shows such a relationship. Relatively minor alterations are plagioclase to a "dusty" alteration or sericite, and andalusite to sericite.

Many rocks show thin banding (indistinct lamination in hand specimen) due to variation in concentration of minerals (especially biotite, quartz, opaque minerals, and sillimanite), differences in mineralogy (e.g., biotite–hornblende or muscovite–plagioclase), or variations in grain-size. The well-developed schistosity, designated S_2, is a reflection of dimensional alignment of biotite (especially), muscovite, sillimanite (in A_2 and A_3), and to a minor extent graphite, tourmaline, hornblende, and tremolite (*see* Pl. VI). S_2 is commonly parallel with compositional banding except on noses of early folds. Quartz, in most rocks, shows moderately strong preferred orientation.

Lineation in the pelitic schists consists predominantly of wrinkled S_2 folia. In (A_1), folia are deformed by fine, even wrinkles or strain-slip cleavage (*see* Pl. VII) whose axial surfaces are planar on a small scale. The axial planes (S_3) are generally 45° to 90° to the schistosity, S_2. In (A_2), on the other hand, folia are deformed by indistinct wrinkles. Axial surfaces are inclined to S_1 at angles ranging from nearly 0° (isoclinal) to 70°. Mineral lineation in (A_2) and (A_3) is represented by aligned prisms of sillimanite. Post-recrystallization strain is indicated by undulose extinction and segmentation in quartz and to a lesser extent in orthoclase and plagioclase.

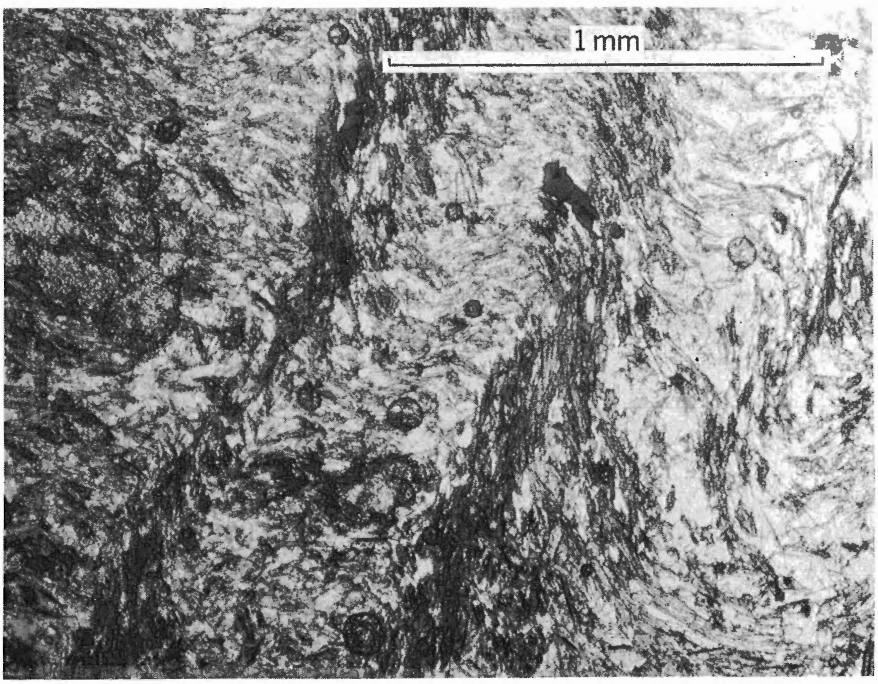


PLATE VII. Photomicrograph of pelitic schist in staurolite zone. Well-developed strain-slip cleavage in schistosity formed by biotite. Staurolite on left edge of photo. (plane light)

This effect is shown to a greater extent in (A_2) than (A_1), and to a still greater extent in (A_3).

Unit 2: Diopsidic Quartzites

Quartz (>50%), diopside (<30%), and sphene (<2%) are present in every thin section. The most common assemblages are:

quartz–calcite–diopside–scapolite–plagioclase (orthoclase)
quartz–calcite–diopside–orthoclase–plagioclase (no scapolite)

Accessory minerals include: white mica, tremolite (all in wispy outgrowths from diopside), epidote (colourless to pale yellow, replacing plagioclase), graphite, apatite (colourless), olivine, zircon, hematite, and pyrite or pyrrhotite. Calcite, though prominent in most thin sections, is absent in two.

Plagioclase and scapolite are, in almost every rock, confined to separate layers rather than intermingled. In two thin sections, however, scapolite appears to have replaced parts of a few plagioclase grains. Diopside, calcite, and feldspars are in some samples concentrated in layers poor in quartz alternating with highly quartzose layers. Schistosity is represented by dimensional alignment of calcite, diopside, quartz, plagioclase, scapolite, and sphene, in order of importance. This schistosity parallels the axial surfaces of tight folds in the layers. Quartz shows strong preferred orientation of the lattice, moderate to strong undulose extinction, and some segmentation. In some sections, calcite and plagioclase show slight undulose extinction.

Units 5 and 9: Amphibolites

Amphibole (>15%) and plagioclase (>5%) are present in every section. The most common assemblages are:

$A_{2,3}$: hornblende–quartz–plagioclase[$An_{70\text{-}78}$]–garnet
(biotite–apatite)
hornblende–plagioclase[$An_{26\text{-}38}$]–quartz
($\pm$biotite $\pm$sphene $\pm$apatite)
plagioclase[$An_{15\text{-}46}$]–hornblende–biotite
($\pm$orthoclase $\pm$sphene $\pm$apatite) (no quartz)

A_1: plagioclase–hornblende–epidote–biotite
(sphene $\pm$apatite)
amphibole–plagioclase–biotite
($\pm$epidote $\pm$orthoclase $\pm$sphene)
plagioclase–amphibole–biotite–diopside–epidote
(apatite)

Amphibole in ($A_{2,3}$) is hornblende (X′=pale yellow to pale brown, Z′=green to greenish brown), whereas in (A_1) it includes hornblende (X′=pale yellow to greenish yellow, Z′=brownish green to dark green) and actinolite (X′=colourless to pale yellow, Z′=pale green to green). Biotite in ($A_{2,3}$) is dark brown to red-brown (Z), and in (A_1) is orange-brown to dark brown. Chlorite, the common alteration of biotite, is optically negative except in a few rocks of (A_1), where it is positive with a thin negative layer immediately adjacent to the biotite. Prehnite occurs in (A_1), in part at least as an alteration of biotite. Other accessory minerals are orthoclase, diopside, epidote (in A_1), garnet (in $A_{2,3}$), sphene, apatite, magnetite and/or ilmenite, hematite, and pyrite or pyrrhotite.

Lamination in rocks of units 5 and 9 is rare. Diopside and biotite (in A_1) occur in contact without visible reaction. Lineation and/or schistosity, both common in the amphibolites, are due to alignment of hornblende and biotite, whichever is dominant. This mineral lineation parallels the wrinkle lineation in associated pelitic schists. Quartz, in a few of those amphibolites that contain it, shows some crystallographic preferred orientation. Plagioclase, hornblende, and quartz show slight to moderate undulose extinction, and in a few cases reduction in grain-size of margins of the grains.

Units 4a and 6B: "Calc-Silicate Unit"

Quartz, amphibole, and/or diopside are present in every section. The commonest assemblages are:

$A_{2,3}$: quartz–calcite–diopside–scapolite–graphite–plagioclase (sphene)

quartz$\left<\begin{array}{l}\text{diopside } \pm\text{hornblende}\\ \text{biotite}\end{array}\right>$(in separate bands)–plagioclase
($\pm$orthoclase $\pm$graphite $\pm$sphene $\pm$apatite)

A_1: quartz–plagioclase–actinolite$\left<\begin{array}{l}\text{diopside}\\ \text{biotite}\end{array}\right>$(mostly in separate bands)
($\pm$K–feldspar $\pm$epidote $\pm$sphene $\pm$apatite)

quartz–diopside–actinolite–calcite–orthoclase ($\pm$plagioclase $\pm$epidote)

plagioclase–quartz–actinolite ($\pm$graphite $\pm$orthoclase $\pm$epidote)

Amphibole in ($A_{2,3}$) is hornblende (X'=colourless to pale brown, Z'=colourless to brownish or greyish green), whereas in (A_1) it is actinolite (X'=colourless to pale yellow, Z'=colourless to pale yellowish green, green, or bluish green). Biotite in ($A_{2,3}$) is brownish orange to brownish red, and in (A_1) is orange-brown to brown. Chlorite, the product of alteration of biotite, is optically negative in (A_1) but negative and/or positive in ($A_{2,3}$). Other accessory minerals include graphite, garnet, zircon, tourmaline (in A_1), allanite (in A_1, red-brown), magnetite and/or ilmenite, hematite, and pyrite or pyrrhotite. Diopside and biotite, though associated in the same thin section, are generally relegated to separate bands. In one rock (A_1), however, they are closely associated without visible reaction. Actinolite (in A_1) and biotite occur in separate bands and tend to avoid direct contact.

Schistosity in units 4a and 6B results from alignment (parallel with banding) of tremolite (in A_1) and biotite, and to a lesser extent of graphite, diopside, hornblende, and calcite. Lineation, generally due to alignment of hornblende (in $A_{2,3}$), tends to be poor. Quartz in some sections, shows moderate preferred orientation of crystal lattices. Many rocks show moderate to strong undulose extinction in quartz, and a few show open, wavy wrinkling of biotite folia.

Units 1 to 7: Pegmatites and Aplites

The mineralogy of pegmatites associated with high-grade metamorphic rocks is described in the section on field description, and is supplemented here. Quartz, plagioclase, and orthoclase (and/or microcline) are essential minerals. Quartz, estimated in the field, ranges from 10 to 35 per cent, averaging about 25 per cent. Accessory minerals form less than 1 per cent of all members. Brown to red-brown biotite shows partial alteration to chlorite. Tourmaline has ε=colourless and ω=olive brown (n_{ω}=1.646 ± .003: dravite 80%, schorlite 20%, using the curves of Winchell and Winchell, 1951, p. 468). The identification was confirmed by x-ray diffractometer. Fluorapatite, colourless in thin section, has n_{ω}=1.637 ± .003 and gave an x-ray diffractometer pattern in excellent agreement with that of ASTM card number 3-0736.

Unit 8: "Limestone", Marble, and Skarn

Calcite (except in the single skarn) and quartz are present in every rock. Minor constituents include plagioclase, phlogopite (X=colourless, Z=colourless to pale orange), diopside, tremolite, epidote, and garnet. Chlorite occurs as a partial alteration of mica.

Calcite occurs as an equigranular mosaic, the grains ranging in size from less than 0.1 mm in the greenschist facies to 1 mm to 2 mm in the higher grades. Other minerals form evenly scattered, subequant, anhedral grains. One section shows alternating quartz- and calcite-rich laminae; in another, lamination is enhanced by difference in grain-size. Quartz shows weak to moderately strong preferred orientation and undulose extinction.

Unit 13: Lineated Quartz Monzonites

Plagioclase, orthoclase, and quartz are the essential minerals of unit 13. As shown on Figure 7, the rocks are classed as quartz monzonites. They are characterized by a pronounced mineral lineation and little or no schistosity. They belong to 127″ (6 thin sections), 227″ (3 thin sections), 127 (1 thin section), and 126 (1 thin section) of Johannsen's classification (Johannsen, 1939, p. 141 ff.).

The rocks of unit 13 are all leucocratic, having mafic mineral contents of 1 to 5 per cent. Characterizing accessory minerals are biotite (Z=brown to red-brown), hornblende (X′=greenish yellow to brown, Z′=dark green), aegirine–augite (pale green), and muscovite. Other accessory minerals are garnet (pyralspite), sphene, apatite (colourless; ε=pale grey, ω=pale brown), allanite (X′=pale brown, Z′=reddish brown), zircon, magnetite and/or ilmenite, hematite, and pyrite or pyrrhotite. Chlorite (X=colourless, Z=green, negative, grey interference colour) is in every case an alteration of biotite.

Quartz in every rock shows moderate to strong undulose extinction and some segmentation. In some rocks, orthoclase and plagioclase show slight to moderate undulose extinction. Potassium feldspar in several sections shows diffuse, patchy distribution of plaid (microcline) twinning in close association with parts of crystals that show undulose extinction.

The lineated quartz monzonite occurs with schists belonging to the sillimanite–almandine–muscovite subfacies. A chemical analysis (by the Geological Survey of

Canada) of a typical aegirine-augite–hornblende member is tabulated with other granitic rocks in Table VIII. The analysis by 'Rapid' methods is given here for convenience.

SiO_2	66.9
Al_2O_3	16.1
Fe_2O_3	0.2
FeO	1.1
CaO	2.0
MgO	2.0
Na_2O	5.4
K_2O	5.0
H_2O	0.1
TiO_2	0.3
P_2O_5	0.1
MnO	0.1
CO_2	0.3
Total	99.6%

Low-Grade Metamorphic Rocks

Field Description and Distribution

Sedimentary and volcanic rocks least affected by regional metamorphism form, in gross aspect, a wide belt trending east-west through the central part of the area, and extending well beyond the area to the east-southeast. The encompassing trough or synclinorium, generally referred to as the Slocan fold (e.g., Little, 1960, p. 104), ends abruptly to the west at the south end of Upper Arrow Lake. Rocks included here are dominantly pelitic (shales, argillites, slates, phyllites, argillaceous quartzites), but there are some volcanic rocks.

Pelitic Sedimentary Rocks

Low-grade metamorphic derivatives of fine-grained pelitic sedimentary rocks (unit 10) have been divided into two groups in the field: phyllitic rocks (10A) and non-phyllitic rocks (10B). Both groups are extremely fine grained, predominantly dark grey, and pelitic. Visible detrital sand grains are rare; conglomerates are unknown.

The phyllite belt overlies and is surrounded by the higher grade metamorphic rocks and surrounds the non-phyllitic rocks which occupy a belt about five miles wide along the valley from Nakusp to Bonanza Creek, the hillside south of Shannon Creek, east of the south end of Upper Arrow Lake, and part of the hillsides east of Swan Island and west of Mineral Creek.

Rocks of the "phyllite belt" (10A) are characterized by the presence of a phyllitic schistosity (*see* Pl. VIII), parallel with which most highly pelitic specimens have a distinct sheen and cleave easily (slaty cleavage). Paler, more silty members are more massive but almost invariably there is at least incipient schistosity. Bedding is rarely obvious. The schistosity is in some places smooth and planar, but more

PLATE VIII.
Phyllites of the lower part of the Slocan Group. East end of Summit Lake.

D.W.H. 1-7-62

commonly it is rippled by small, open wrinkles as much as two inches across, or lined by a "striation" lineation, representing the trace of a crosscutting strain-slip cleavage.

Non-phyllitic rocks (10B) of the unit are more massive: argillites, shales, and siltstones. Freshly broken surfaces of these rocks are dull. They are, as in the phyllite belt, indistinctly bedded except at a few localities, where well-defined shale and siltstone or thin limestone beds are exposed. Scattered thin layers (sills or flows) of massive green volcanic rocks occur in some areas. The non-phyllitic rocks are even less well exposed than the phyllitic ones. Over large areas the exposures are confined almost entirely to road cuts and creek gullies.

Grey Volcanic Rocks

Aphanitic to fine-grained, granular, predominantly massive, grey volcanic rocks have been mapped as unit 11. Small (1 mm–2 mm) phenocrysts of feldspar, in some samples comprising as much as 60 per cent of the rock, are visible in some localities (especially near the head of Independence Creek). Many and perhaps most of the rocks were probably tuffs.

Such rocks are best represented on top of Silver Mountain and the adjacent ridge to the northwest. This "grey volcanic" unit underlies much of an area 3 miles wide and 7 miles long, from Mineral Creek east to the north fork of Caribou Creek. It is also present in a narrower, less distinct belt, along the north side of the ridge south of Slewiskin Creek, east to the ridge north of Shannon Creek.

Greenstones

Volcanic rocks that are predominantly green to greenish grey have been separated as map-unit 12. Included are both tuffs and flows, but, except in a few localities, the highly altered condition of the rocks makes it difficult to recognize their original nature. They are usually massive and most of them are aphanitic, though grains 1 mm to 2 mm across are common in the widespread flows or crystal tuffs. Rock fragments in the tuffs are angular, usually the size of lapilli, but as much as a few inches. The most distinctive member (12a) of this group is an aphanitic greyish green rock, studded with dark green, equant crystals of pyroxene. These euhedral phenocrysts range, mostly, from 1 mm to 8 mm in diameter.

This greenstone unit underlies the ridge crest south of Summit Lake, culminating to the east in the blocky cliffs of Rugged Peak. The latter represent the main exposures of the pyroxene basalt member (12a). These appear, at least in part, to be flow breccias, the matrix of the same composition as the angular fragments and

TABLE II — *Modes of Low-grade Metamorphic Rocks*
(visual estimates in volume per cent (averages))

Map unit	10A	10B	11	12a	12b	8
No. of Thin Sections	12	8	21	4	9	2
Quartz	51	35	18		10	15
Orthoclase	.1					
Microcline			.4	2	.6	
Plagioclase	11	37	44	58	52	3
Biotite	3	1	7		.5	
Muscovite–sericite	24	10	8		5	1
Hornblende			.2	.5		
Tremolite–actinolite	.4	4	9	2	21	
Augite				19		
Epidote	.8	2	3	9	3	
Calcite	5	5	4	2	4	81
Dolomite			1		1	
Andalusite	.7	1				
Chloritoid	.1					
Talc					.3	
Chlorite −	4	1	5	3	2	
Chlorite +	0.3					
Sphene		.2	tr	2	.4	
Apatite	tr		.2			
Tourmaline	.2	tr	.1		tr	
Pyrrhotite–pyrite	.3	.3	.6	.6	tr	
Magnetite–ilmenite	.7	3	.2		.4	
Hematite	.1	.1			tr	
% An of plagioclase		0	.3	2	4	
An variation +		2	2	5	7	
An variation −		0	0	0	0	
No. of plagioclase sections		4	6	2	4	

blocks. Other parts, such as the main mass of Rugged Peak, may be intrusive. Green volcanic rocks are also found along the crest of the Ruby Range (12b), around the Allshouse syenite mass, and as thin, scattered layers in the non-phyllitic sedimentary rocks of unit 10. The latter layers may represent an early phase of unit 12.

Mineralogy and Petrography

The mineralogy of the low-grade metamorphic rocks was determined in thin sections, supplemented in most instances with x-ray diffractometer patterns of the same rocks. Patterns of rocks cut normal to the schistosity (if present), facilitated identification of most minerals and rough estimation of the percentages of minerals difficult to distinguish in thin section. It was also possible to confirm the composition of plagioclase (2θ:131 $\wedge$ 1$\bar{3}$1 for low-temperature structural state) using the data of Smith and Yoder (1956), and in a few rocks to identify "muscovite" as the 2M form. Patterns of rocks cut parallel with the schistosity facilitated identification of micaceous minerals. The anorthite content of plagioclase was determined, where possible, with the universal stage. Table II lists the average mineralogical composition for each unit.

S-surfaces (planar structural elements) described are:

S_1: lithological layering (including bedding)
S_2: metamorphic schistosity
S_3: strain-slip cleavage
S_4: axial plane of folds and wrinkles in S_2

Unit 10: Pelitic Sedimentary Rocks

Quartz (>30% in 10A, >15% in 10B), albite, and muscovite are present in every rock except one. The commonest assemblages are:

10A: "phyllite belt":
quartz–muscovite–albite–calcite
(±chlorite ±chloritoid)
quartz–muscovite–albite–biotite
(±chlorite ±actinolite ±epidote? ±chloritoid)
quartz–muscovite–albite
(±chlorite ±garnet pseudomorphs)

10B: "non-phyllitic pelites":
quartz–albite–calcite–muscovite
(±chlorite)
albite–quartz–biotite–chlorite
(±muscovite)

Accessory minerals include: tourmaline (ε=colourless or pale brownish, ω=olive green or dark olive brown), orthoclase (in 10A) and apatite (in 10A, colourless), magnetite and/or ilmenite and pyrrhotite. Some rocks adjacent to granitic plutons contain andalusite.

White mica appears, in most (or all?) samples, to be muscovite. Although every sample was checked for paragonite (x-ray determination of basal spacing), none was found. In those samples (5) for which a distinction between 1M ("sericite") and 2M (muscovite) white micas could be made (by x-ray), each indicated the 2M form. Biotite in these rocks has X=colourless and Z=orange-brown (*see also* Fig. 3). Chlorite appears, in some cases to be a prograde mineral but in others, to be a product of alteration of biotite (retrograde). Andalusite shows partial replacement by muscovite.

Lamination is not common, but does occur in a few rocks as a variation in the concentration of quartz, muscovite, carbonaceous material, or actinolite. In rocks of the phyllite belt (10A) alignment of muscovite, biotite, opaque streaks, chlorite, and chloritoid (in order of importance) gives rise to planar schistosity (Pl. IX). Lamination if present is subparallel with the schistosity. In the same rocks, elongate minerals that are not aligned include chloritoid, chlorite, biotite, and actinolite. Quartz is crystallographically oriented in a few rocks. A few of the non-phyllitic pelites (10B) have parallel, wavy streaks of carbonaceous material, but other minerals show little or no alignment. Many of the rocks of the phyllite belt have a strain-slip "cleavage", at 45 to 80 degrees to the schistosity. Many show undulose extinction in quartz. A few rocks in 10B show undulose extinction in quartz and in albite. A summary of the paragenesis as ascertained in thin section is shown on Figure 5. This sequence is based on whether or not minerals are aligned in the

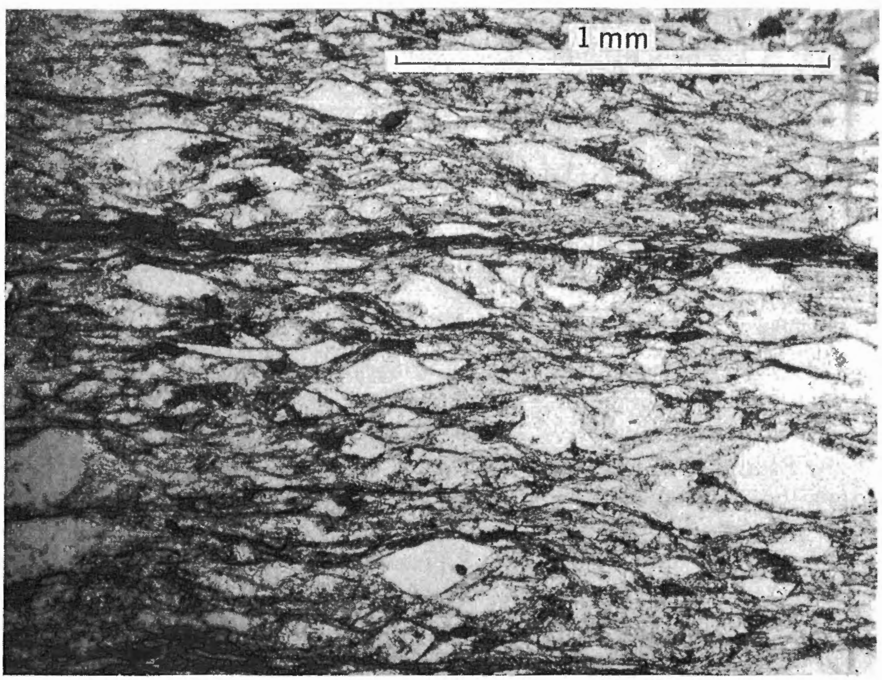


PLATE IX. Photomicrograph of phyllite from Slocan Group. Well-developed schistosity marked by parallel alignment of muscovite tablets and lenticular grains of quartz. (plane light) schistosity, are deformed by strain-slip, or contain inclusions that are deformed or undeformed by strain-slip of the schistosity.

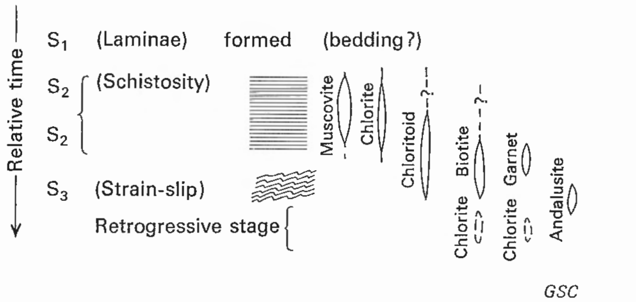


FIGURE 5.
Paragenesis of Slocan Group rocks, map-unit 10B.

Unit 11: Grey Volcanic Rocks

Quartz and albite are present in every rock. The most common assemblages are:

albite–biotite–actinolite–epidote–quartz
(±muscovite ±calcite ±microcline ±chlorite)
albite–actinolite–biotite–quartz
(±chlorite ±calcite)
albite–quartz–biotite
(±muscovite ±calcite ±chlorite ±epidote)
albite–quartz–white mica–calcite
(±epidote ±chlorite)
albite–quartz–dolomite–muscovite
(±actinolite ±calcite)

Accessory minerals include: apatite (ε=pale grey to brownish red, ω=pale brownish grey to pale brownish red, some with colourless overgrowths, some colourless crystals), tourmaline (ε=colourless, ω=olive brown to greenish blue), sphene, "leucoxene", magnetite and/or ilmenite, pyrite and/or pyrrhotite. Relict igneous hornblende (X'=pale brown, Z'=brown or green) occurs in three sections. A single case was noted, of relict high temperature igneous plagioclase, An_{40} (only partly albitized). Actinolite has X'=colourless to pale yellow, Z'=pale greenish grey to bluish green. Biotite has X=colourless to pale yellowish brown, Z=brownish orange to greenish brown.

In the Ruby Range east of Mineral Creek, to the ridge one mile west of Silver Mountain, the "grey volcanic rocks" are dominantly porphyritic (1 mm euhedral to subhedral plagioclase crystals, *see* Pl. X). Relict phenocrysts are aligned in some rocks. Though the textures are poorly preserved, what appear to be tuffaceous volcanic rocks are predominant on the hillsides north of Caribou Creek, from lower Mineral Creek, east to the north fork of Caribou Creek, and probably including Silver Mountain. There appears to be no significant difference in mineralogy between the porphyritic and tuffaceous groups. From the mineralogy and chemical analysis of a "porphyritic" sample (Table III, unit 11), the rocks are andesites or dacites.

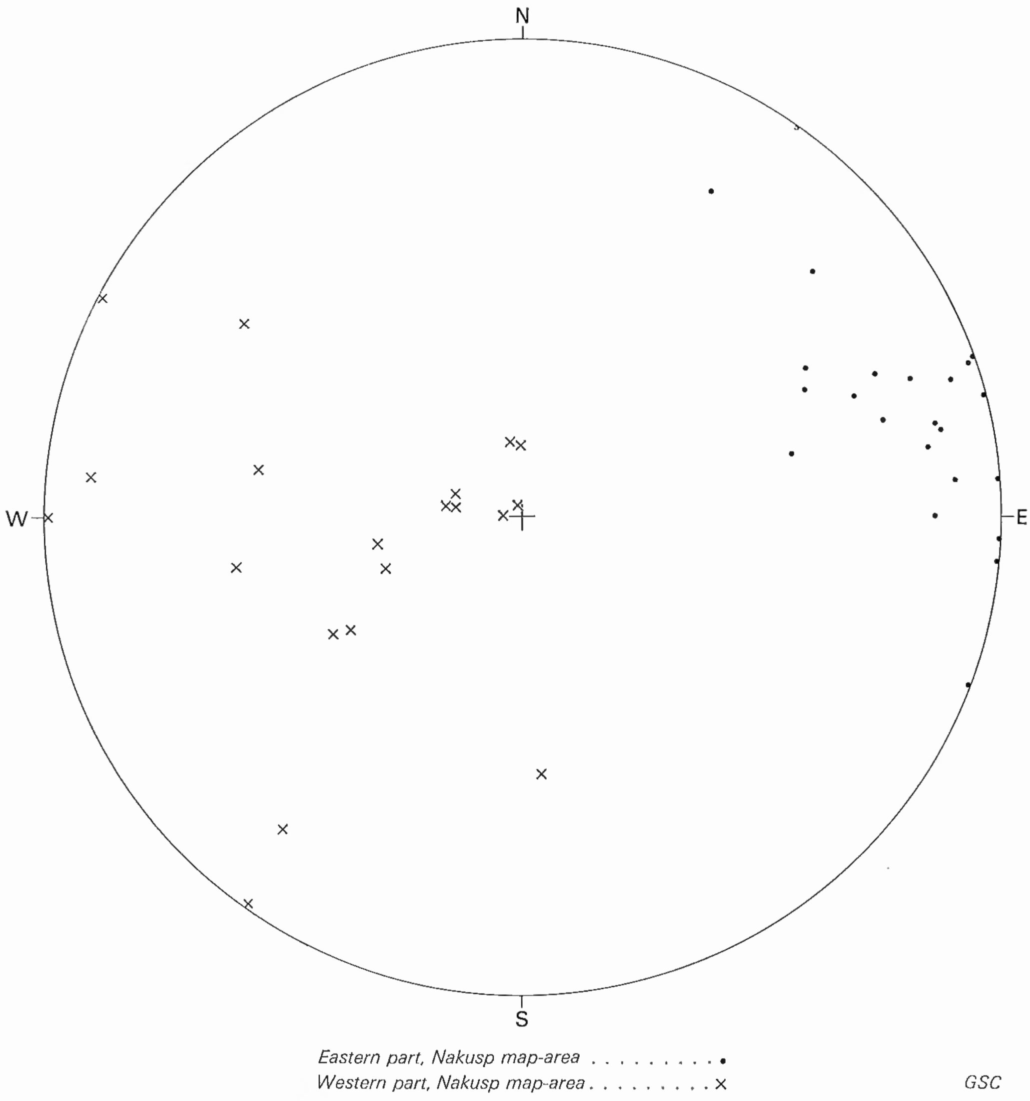


FIGURE 6. Equal area plot of poles to contacts of dykes.

Most rocks within unit 11 lack schistosity but a few show alignment of sericite, and to a lesser extent of biotite, chlorite, and actinolite. Quartz shows slight to moderate undulose extinction in several rocks.

Unit 12: "Greenstones"

Albite (20%) is the only mineral common to every rock in this unit. The most common assemblages are:

12a: augite basalts

albite–epidote–chlorite–calcite
(±actinolite), with relict augite

TABLE III — *Chemical Analyses and Norms of Volcanic Rocks (by rapid methods) (Geological Survey of Canada (J. A. Maxwell in charge))*

Map unit	11	12a	12b
Sample No.	HQ 119-7	HQ 54-3	HQ 119-6
SiO_2	55.8	48.2	55.7
Al_2O_3	16.9	18.1	17.1
Fe_2O_3	2.4	2.2	5.0
FeO	4.4	6.84	0.7
CaO	5.3	9.6	5.2
MgO	2.2	4.9	1.4
Na_2O	5.0	3.5	3.7
K_2O	2.6	1.8	3.0
H_2O+ / H_2O-	1.4	3.0	2.0
TiO_2	0.8	0.56	0.8
P_2O_5	0.3	0.36	0.3
MnO	0.2	0.17	0.1
CO_2	1.5	0.60	2.3
Total	98.8	99.8	97.3
Norm			
ap	.65	.78	.68
il	1.15	.80	1.20
ne		3.90	
or	15.93	11.00	19.20
ab	46.46	25.94	35.90
an	16.53	29.26	22.87
mt	2.59	2.37	.20
hm			3.62
wo	3.48		1.17
en	6.34		4.21
fs	4.49	14.05	
ol		11.90	
qtz	2.38		10.94
$\frac{\text{Orthoclase}}{\text{Feldspar}}$	20.19	16.62	24.62
$\frac{\text{An}}{\text{An+Ab}}$	26.24	53.00	38.92

12b: other "greenstones"
albite–quartz–carbonate–chlorite
(±"sericite" ±epidote ±talc)
albite–epidote–quartz–"sericite"–calcite–biotite
(±chlorite)
actinolite–albite
(±chlorite)

Accessory minerals in 12a include: microcline (in groundmass), sphene, pyrrhotite, and chalcopyrite. Accessory minerals in 12b include: microcline, sphene, tourmaline,

TABLE IIIa | *Trace Element Analyses of Volcanic Rocks*

Map unit	11	12a	12b
Sample No.	HQ 119-7	HQ 54-3	HQ 119-6
% Rb	.004	nd	.005
% Sr	.064	.114	.048
% Ba	.04	.12	.04
% Zr	nd	.025	.007
% Cr	tr	nd	nd
% V	.005	nd	nd
% Y	nd	nd	nd
% Ni	nd	tr	nd

Analyst: G. R. Lachance, GSC.

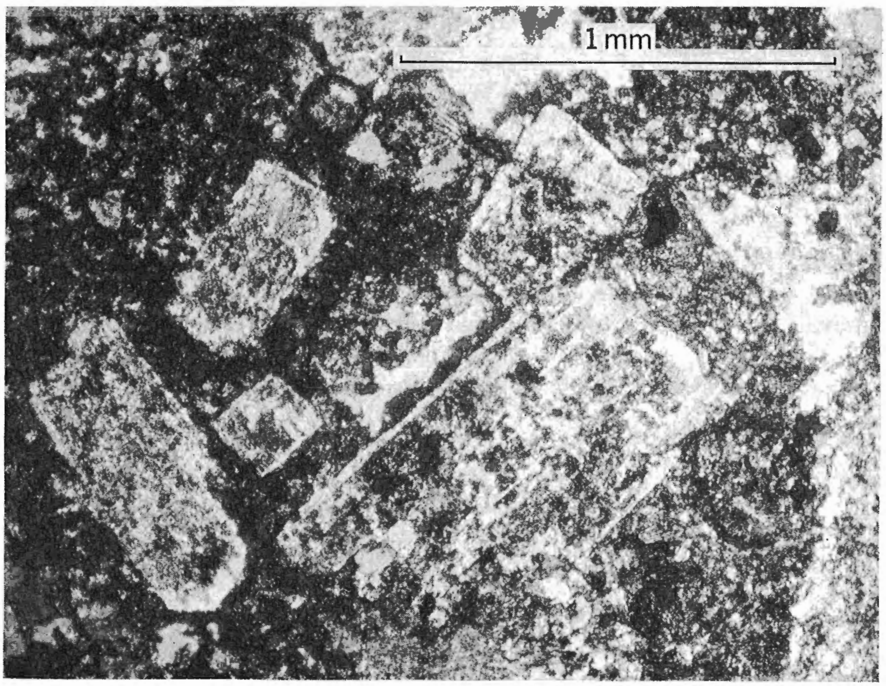


PLATE X. Photomicrograph showing relict phenocrysts of plagioclase in metavolcanic rock from unit 11. Greenschist facies. (crossed nicols)

(ε=colourless, ω=olive green), pyrrhotite, and magnetite and/or ilmenite. Since members 12a and 12b differ texturally in many ways, they will be described separately.

Augite (12a) (colourless to pale yellowish green, $Z \wedge C = 44° \pm 1°$) occurs as euhedral, relict phenocrysts with overgrowths of actinolite (colourless to pale green). Relict plagioclase phenocrysts are still clearly visible but they have been completely replaced by albite, epidote, and calcite. Chlorite (colourless to pale green) occurs primarily in amygdules with albite and calcite, and in the groundmass. Epidote is colourless with a moderate birefringence. Preferred orientation of relict "phenocrysts", though absent in most rocks, gives rise in some to a streaky schistosity. Some may be shears, others appear to be flattened pumice fragments or shards. Some samples are fragmental and probably tuffs. The chemical analysis of a typical sample (Table III) and the mineralogy suggest that the rock is an alkaline olivine basalt.

Epidote (12b) has X'=colourless and Z'=pale yellow. Pale green and pale yellow chlorite (optic sign negative and positive, respectively) appears to be partly prograde and partly retrograde after biotite. Actinolite has X'=colourless, Z'= colourless to light green. Biotite has X=pale yellow, Z=brown. The carbonate is calcite, except in one section which contains dolomite. Some sections consist of numerous highly altered fragments. Others contain relict plagioclase "phenocrysts" which are fairly well aligned. Layering is not apparent. Sericite produces a fair schistosity in one section. Other sections show no apparent preferred orientation. Quartz in a few sections shows moderate to strong undulose extinction. The chemical analysis of a typical sample (Table III) and the mineralogy suggest an andesitic composition.

Metamorphic Summary and Conclusions

Distribution of Facies of Metamorphism

Figure 16 (*in pocket*) shows the distribution of five metamorphic facies and subfacies corresponding to five grades of progressive regional metamorphism. Diagnostic assemblages of metamorphic minerals in quartz-bearing rocks (Fig. 3), with few exceptions, are as described by Turner and Verhoogen (1960, pp. 531–553). The zones mapped are, in order of increasing metamorphic grade, as follows:

G_1: Greenschist facies—quartz–albite–muscovite–chlorite subfacies:
recognized especially by the presence of albite or chlorite, and lack of biotite, oligoclase, or other minerals diagnostic of higher grades of metamorphism.

G_2: Greenschist facies—quartz–albite–epidote–biotite subfacies and/or quartz–albite–epidote–almandine subfacies:
recognized especially by the presence of biotite with albite, and absence of oligoclase, diopside, or other minerals diagnostic of higher grades.

A_1: Almandine–amphibolite facies—staurolite–almandine subfacies:
recognized especially by the presence of oligoclase or more calcic plagioclase, of diopside with epidote, or staurolite, of uniformly fine grain-size, always without sillimanite.

A_2: Almandine–amphibolite facies—sillimanite–almandine–muscovite subfacies:
recognized especially by the presence of sillimanite, usually with muscovite and always without potassium feldspar.

A_3: Almandine–amphibolite facies—sillimanite–almandine–orthoclase subfacies:

recognized especially by the presence of sillimanite with orthoclase, and usually without muscovite.

The isograds of regional metamorphism are essentially parallel with the lithological contacts, i.e., rocks lower in stratigraphic succession are higher in metamorphic grade. The resolution of mapping of these isograds, however, is not sufficient to rule out an inaccuracy in most places of several hundred feet in the position of any isograd.

That there was a single culminating episode of regional metamorphism, essentially synchronous throughout the area (though perhaps continuing longer in some places than others), is suggested by the distribution of metamorphic facies. Except across the Rodd Creek fault, the metamorphic gradation is continuous from the highest grade (e.g., on Saddle Mountain) to the lowest grade (e.g., along Slewiskin Creek). This Rodd Creek discontinuity, however, is bridged to the south, where there is complete gradation from the sillimanite–almandine–muscovite subfacies, on Snow Creek, and around Wee Sandy Lake, through the lower grades, to the quartz–albite–muscovite–chlorite subfacies on Slewiskin Creek. The sillimanite–almandine-muscovite subfacies continues south of Wee Sandy Lake, to just north of Beatrice Lake (about 7 miles), where the sillimanite–almandine–orthoclase subfacies appears (J. E. Reesor, personal communication, October, 1963).

Effects of superimposed contact metamorphism have been distinguished where granitic stocks have intruded low-grade country rocks. It is difficult, however, to recognize weak contact metamorphism of rocks regionally metamorphosed to a higher grade. Such is the case, especially, on the hillside north of Snow Creek.

Age of Metamorphism

In rocks with a wrinkled schistosity (S_2), the biotite and/or muscovite forming the schistosity of the rock is attributed to regional metamorphism. Where undeformed porphyroblasts (andalusite, and less commonly chloritoid and chlorite) contain inclusions in the form of a wrinkled (strain-slip) schistosity, they are attributed to a contact metamorphism superimposed on the regional metamorphism. Also referred to contact metamorphism are wrinkled micas (commonly traces of strain-slip cleavage) which have been recrystallized to straight-sided, polygonal arcs; for elsewhere in the absence of contact metamorphism, the micas are bent smoothly around the wrinkles.

The stocks thus related to contact metamorphism superimposed on regional metamorphism are as follows:

Lower Caribou Creek quartz monzonite stock
Snowslide and Wragge Creeks quartz monzonite stocks
East Caribou Creek quartz monzonite stock
Nakusp Range and Allshouse Peak leucogranite stocks
Shannon Lake (leuco) granite stock

All other granitic stocks for which these data were not available have recognizable aureoles of hornfels. These are tentatively, though indefinitely, regarded as post-regional metamorphism. There is no clear evidence for regional metamorphism of any of the granitic stocks themselves. Stilpnomelane, occurring as an alteration in the leucogranite of Nakusp Range and in the syenite on Box Mountain, is regarded, as suggested by the texture, not as a metamorphic mineral, but as a deuteric alteration.

The time of the culminating regional metamorphism within the present area must be post-Triassic, as it definitely affects rocks of the Slocan Group, and probably post-Lower Jurassic (Rossland Formation). The time at which the temperature fell below a critical value of about 300°C[1] must be, in turn, prior to 70 (and probably to 120) million years ago (potassium–argon ages on granitic stocks). So the limiting possible dates lie between 70, probably 120, m. y. and less than 180 m. y. ago (time-scale of Holmes, 1959). The question of whether the 120 m. y. age is right depends on whether or not the stock dated is post-regional metamorphism. These figures are somewhat at variance with potassium–argon ages from metamorphic rocks in the Monashee Group (Shuswap Terrane), 52 to 102 m. y., and from the Valhalla Complex (south of the Nakusp area), 11 to 62 m. y., reported in Lowdon (1960, 1961), Lowdon, *et al.* (1963), and Leech, *et al.* (1963). The difficulty may be resolved by assuming that the high-grade metamorphic rocks cooled more slowly than did the granites intruded into low-grade metamorphic rocks; for the critical isotherm below which argon is retained in the biotite lattice (the rate of argon diffusion becoming ineffectively slow) might then have been reached later in the high-grade metamorphic rocks than in the granitic plutons. Another alternative is that the Ruby Range stock (K–Ar: 123 m.y.) and the Goatcanyon–Halifax Creeks stock (K–Ar: 107 m.y.) were intruded prior to or during regional metamorphism.

The elongate shape of the Ruby Range pluton (isotopic age=123 m.y.) is peculiar. Though there is no direct evidence for its time of emplacement with respect to regional metamorphism or to deformation association with metamorphism, the surface trace of the pluton is parallel with that of the axial plane of the later folds in that area. This could be taken to indicate either that the pluton was intruded synchronous with regional deformation (of the later episode during which the cleavage or schistosity of the rock was folded), or that it was intruded along the axial zone of a fold subsequent to this deformation. In either event, the pluton would be post-regional metamorphism.

These conclusions, based on data from the Nakusp area, thus agree with those of Cairnes (1939, p. 271) that the Shuswap represents a metamorphism of Mesozoic age, affecting all earlier rocks.

Origin of the Pegmatites

Pegmatites associated with the high-grade metamorphic rocks are thought to be the product of anatexis, the low-melting fraction being stewed off from the schists and gneisses during metamorphism. Supporting such a conclusion are the regular spacing of the veins, their dominantly concordant nature, the presence of garnet,

[1]Evernden, *et al.* (1960, p. 600), based on argon diffusion experiments in phlogopite.

variation in mineralogy with grade of regional metamorphism, absence from the largest sections of non-pelitic rocks (e.g., diopsidic quartzites on Scalping Knife Mountain and thick sections of amphibolite), and remote distance from granitic plutons. However, pelitic schists, contrary to expectation, are not notably more "basic" or mafic-rich, nor is the plagioclase more calcic (*see* Fig. 4) in the sillimanite zone than in the staurolite zone. Some injection or migration of material from below and/or along strike seems likely, as the thickness of many of the bands is too large to be attributed to partial fusion of the immediately adjacent schists and gneisses[1]. As many of the pegmatites are foliated, others concordant but not schistose, and still others discordant, they are thought to have crystallized during and after the peak of regional metamorphism and deformation. Pegmatites in rocks of the staurolite–almandine subfacies are largely crosscutting and probably moved into place from lower levels. Some were intruded from adjacent stocks.

Significance of Selected Metamorphic Minerals

Scapolite, occurring as a prominent mineral in the diopsidic quartzites, shows no apparent relationship to the proximity of exposed granitic plutons from which its chlorine might have been derived. It is equally prominent on top of Saddle Mountain and southeast of Arrow Park. It is absent from some samples (which are generally low in plagioclase) nearest the lower Caribou Creek quartz monzonite. The presence of plagioclase and scapolite in different parts of the same rock, showing partial replacement where in contact, may be due to insufficient chlorine for complete replacement of plagioclase. Scapolite appears to belong to the high-grade episode of regional metamorphism, which is the most usual type of occurrence as reported (Shaw, 1960, p. 279).

Coexisting biotite and sillimanite in the high-grade rocks, rather than the assemblage garnet–muscovite or garnet–orthoclase, is attributed to a relatively low FeO/MgO ratio. The "AFM" projection of Thompson (1957, p. 851), for the lower sillimanite zone, shows this effect to advantage. As the ACF diagrams plotted here treat FeO and MgO as a single component, their behaviour as independent components is not apparent.

Sillimanite, in the high-grade metamorphic rocks, occurs as swarms especially in biotite, and less commonly in muscovite, orthoclase, plagioclase, or quartz. Most commonly biotite appears to have been replaced by the sillimanite, some parts of the biotite grain existing only as hazy pleochroic streaks scattered through a pod of matted sillimanite needles. Sillimanite also forms fuzzy fibrolitic rims around the ragged edges of some biotite grains. Similar relations between biotite and sillimanite have been reported in many high-grade rocks elsewhere (e.g., Harker, 1932, pp. 228–229, and Turner, 1948, p. 87).

[1](Note added in proof, 1968). Compositional work in progress also suggests that the granitic melt which formed the calc-alkalic granitic plutons was developed by partial melting of high grade metamorphic rocks below the levels exposed in the present area. The more plagioclase-rich paragneisses, described by J. E. Reeser (G.S.C. Bulletin 129, 1965) from the Valhalla dome immediately south of the Nakusp area, appear to be the most reasonable choice.

Plagioclase in the amphibolites and calc-silicate rocks (units 4a, 5, and 6B) is generally richer in anorthite in the higher grade facies (*see* Table I). No such relation is apparent in the pelitic schists (unit 1) as the composition of plagioclase is a reflection, not only of the grade of metamorphism, but also of the composition of the rock, and the pelitic schists have a wider range of composition. There is, however, a pronounced jump in anorthite content from the greenschist facies (An_{0-2}) to the almandine–amphibolite facies (An_{20-50}), as shown on Figure 4. This must be attributed to the grade of metamorphism. A similar jump has been shown by other workers, for example de Waard (1959), in regional metamorphic rocks from Timor.

Graphite forms a significant part of most pelitic and calc-silicate members of the high-grade metamorphic rocks. It is absent, however, from the amphibolites and granitic units. *Magnetite and ilmenite* are absent from pelitic schists in the sillimanite zones. *Hematite* appears to have an antipathetic relationship to graphite. With a few minor exceptions, hematite is absent from those samples containing graphite and vice versa. *Pyrite* is invariably rimmed by hematite. Hematite, being therefore later, may have formed during the retrogressive metamorphism. Such a conclusion is supported by a reasonably good (though not perfect) correlation between the presence of hematite and other minerals more clearly attributed to retrogressive metamorphism.

Chinner (1961), in a detailed study of the *iron oxides* and associated minerals in the high-grade regionally metamorphosed rocks of Glen Clova, Scotland, found that in all the hematite-free (ilmenite–magnetite) gneisses he studied, graphite was present (p. 187). The generalizations noted above for the Nakusp area are in substantial agreement with this. He also noted that the oxidation ratio of biotite increases with that of the rock, and with the green (versus brown) colour of biotite (op. cit., p. 196). Increases in the oxidation of iron (increase in hematite), also correlate with increases in the contents of muscovite and iron oxides, at the expense of garnet and biotite (op. cit., p. 189). The dominance of brown to red (versus green) colours in biotite, and the paucity of iron oxides and muscovite in the present area, could perhaps be due to a lower oxidation ratio of biotite and rock (and/or a higher Ti content) than in Glen Clova. This would agree with a retrogressive origin for hematite in the schists of the Nakusp area.

Chloritoid and *andalusite* in the Nakusp area are apparently contact metamorphic minerals, crystallized after the regional metamorphism, and presumably (lack of preferred orientation) grown without appreciable shearing stress.

Retrogressive Metamorphism

Retrograde effects are apparent in most of the metamorphic rocks of the Nakusp area. More precisely, of the 200 thin sections of metamorphic rocks examined, 46 per cent show replacement of more than 10 per cent of the mafic minerals by lower grade minerals, 28 per cent show 1 to 10 per cent replacement, and 26 per cent show less than 1 per cent replacement. The minerals replaced and the retrograde minerals produced follow.

Minerals	No. of sections represented	Retrograde minerals	% sections represented
biotite	74	chlorite	91
		chlorite + sphene	(22)
		white mica	4
		prehnite	4
diopside	40	tremolite or actinol	45
garnet	25	chlorite	20
hornblende	24	biotite and/or chlorite	4
scapolite	10	"sericite"	20
andalusite	4	muscovite	100

The retrograde minerals recorded above are, as a rule, those corresponding to the lower part of the greenschist facies. However, as can be seen from the data above, retrogressive metamorphism is far from complete. The most complete example from the rocks examined is from a pelitic schist (unit 3) less than 10 feet below a thrust fault, on the hillside east of Swan Island. In this rock, more than half the original biotite content (20 per cent) has been altered to chlorite and sphene.

Stratigraphic Correlations

Correlation of lithological units mapped in Nakusp map-area with those mapped in nearby areas in southeastern British Columbia was based largely on lithological similarity and similarity of the succession of geological units, because of the near absence of fossils and lack of continuity with areas in which the sequence is established. Conclusions reached on this basis (Table IV) must be to some extent tentative. The formations to which correlation is made, and the evidence for their ages, are described in Little (1960, pp. 52–67) and Frebold and Little (1962). Rocks of the "phyllite belt" of Nakusp area are continuous with the "slate belt" of the Slocan Group, in Slocan area to the southeast. Correlation with the Slocan Group is thus regarded as securely established. Less secure is correlation of younger rocks with the Rossland Group, of older Nakusp units with the Kaslo and Milford Groups, and of the Shuswap Terrane with still older formations. The evidence for these correlations will be treated in the order given below.

Slocan Group (Triassic and Lower Jurassic)

The phyllite belt of the Slocan Group outcrops for almost the full length of the valley from Nakusp to the north end of Slocan Lake. Farther east it (the "slate belt" of Hedley, 1945, pp. 7–10) is exposed along much of the valley between New Denver and Kaslo on Kootenay Lake.

Overlying the "slate belt" west of Zincton (Slocan area) are "thickly bedded, non-fissile argillites", grey in colour, and contrasting "sharply in appearance with the underlying slates". Higher in the section east of Slocan Lake, as reported by Little (1960, p. 55), are more arenaceous, well-bedded argillites. These are in turn overlain by tuffaceous beds. The section so described closely resembles that on the

TABLE IV *Stratigraphic Correlation Table*

Era and Period	Group or Formation	Lithology: Cairnes, 1934	Lithology: Little, 1960	Nakusp map-area: unit	Nakusp map-area
Middle and/? Upper Jurassic	Rossland Group: Hall Formation[1]		argillite, sandstone, conglomerate		Not mapped
Late Lower Jurassic	Rossland Group: Elise Formation[1]		andesite, latite, basalt, flow breccia, augite porphyry, agglomerate	12	greenstone, andesite, basalt, augite porphyry
Early Lower Jurassic	Slocan Group: Archibald Formation[1]		Sinemurian beds: argillite, argillaceous quartzite, minor volcanic	11	andesite, dacite, tuffs and flows, Sinemurian ammonite
Triassic	Archibald Formation[1]	slate, argillite, quartzite, limestone, conglomerate, tuffaceous sediments	slate, argillite, quartzite, limestone, conglomerate, tuff	10B 10A	argillite, shale, siltstone minor volcanics phyllite, slate, siltstone
Triassic	Kaslo Group	andesitic volcanic rocks, related basic intrusions (greenstone), serpentine, tuffaceous sediments	greenstone, minor slate	9	amphibolite (metavolcanic rocks)
Triassic and Carboniferous	Milford Group	chert: massive and banded, slate, fissile argillite, cherty greenstone, limestone, andesite		6A, 6B	calc-silicate metasedimentary rocks, pelitic schist, limestone
pre-Triassic	(correlation with earlier formations unknown) Shuswap Terrane			5 3 2 4	amphibolite pelitic schists diopsidic quartzite biotite–plagioclase–quartz schist and paragneiss, calc-silicate rocks, amphibolite

[1]As defined in Frebold and Little (1962).

hillside south of Summit Lake, in Nakusp area. The Nakusp lithology differs in detail, especially in the upper part of the section, but this would be expected from the rapid changes that apparently take place along strike.

The phyllites east of Swan Island are also overlain by non-phyllitic argillaceous rocks (unit 10B), and in turn by rocks of the grey volcanic unit (unit 11), near the crest of the Ruby Range (south of Slewiskin Creek). The grey volcanic rocks underlie most of the southern part of Ruby Range, north of Caribou Creek. Cairnes' (1934, p. 56) description of the tuff from the upper part of the Slocan Group from east of Slocan Lake could just as well apply to these rocks north of Caribou Creek. He described the tuff as:

> light to dark grey and yellowish brown, massive rocks which in the outcrop or hand specimen might readily be classed as quartzitic or calcareous argillites. Microscopically they consist of large and small fragments of feldspar crystals; or feldspar crystals and rock fragments. Some of the rocks are fine grained, dense, and of indeterminate origin, but others are porphyritic and distinctly resemble volcanic rocks.

The one fossil recorded from Nakusp area is from a piece of float from near the Millie Mac mine on Blue Grouse Mountain. Frebold (1959, pp. 5, 29) reported it to be the ammonite *Arnioceras* sp. indet., and said that "This rock belongs to the Rossland Group, which is exposed in this area, and a Sinemurian (early Lower Jurassic) age is indicated". This was revised in Frebold and Little (1962) so as to be included in the Archibald Formation of the Ymir Group (Slocan Group). If the rock is from the upper part of the grey volcanic unit (rather than from the klippe above Fig. 15), the upper part of the Slocan Group, as here mapped, is of Sinemurian age. This unit is overlain on Blue Grouse Mountain, by green volcanic rocks of unit 12 (*see* Rossland Group below).

The absence of a mapped lithological unit 11 to the northeast may be a result of a facies change in the upper part of 10B or possibly an unconformity.

North of Box Lake, the phyllitic rocks here correlated with the lower part of the Slocan Group are underlain by very fine grained schists containing a few thin limestone beds. Though the bedding dips to the north, bedding cleavage relations where determined indicate that the beds are overturned (i.e., tops to the south). These rocks are thought to belong to the basal part of the Slocan Group.

The Slocan Group in Nakusp area, therefore, comprises three mappable members, units 10A, 10B, and 11, in upward succession. Though presumably younger, rocks of the Slocan and Rossland Groups resemble Divisions A to B of the Upper Palaeozoic Cache Creek Group, as described by Jones (1959, pp. 38–42). Such rocks occur 15 miles west of Nakusp map-area and along strike.

Rossland Group (Lower Jurassic)

On Rugged Peak and westward along the same ridge, rocks of the Slocan Group are overlain by the augite "basalt" member (12a) of the "greenstone" unit. Lithologically, the latter rocks are identical with those described by Little (1960, p. 65) as augite porphyry (Rossland). Their stratigraphic position also is consistent with their identification as Rossland.

North of Caribou Creek, from Mineral Creek east, unit 12 also overlies tuffaceous rocks of the upper part of the Slocan Group and so is also correlated with the

Rossland Group. There the rocks are more highly altered, but the lower parts (e.g., on Blue Grouse Mountain) appear on a weathered surface to consist of agglomerate which grades upward to a fine-grained, probably tuffaceous, volcanic rock.

In summary, the "greenstone" unit (12) is correlated tentatively with the lower part (at least) of the Rossland Group.

Kaslo Group (Triassic)

Immediately north of Box Lake is a belt of amphibolite (unit 9) half a mile wide, underlying the Slocan Group. This belt has been mapped for about 5 miles eastward to the east end of Wilson Lake. It presumably connects farther east with the Kaslo Group, which Cairnes (1934) showed trending northwestward from the ridge north of Kaslo Creek (Slocan area), and (1929) in an area 6 miles northeast of Slocan Lake. The stratigraphic position of the amphibolite supports this interpretation.

Cairnes (1934, pp. 43–48) described the Kaslo 'Series' in detail and, though his rocks are somewhat finer grained and lower in metamorphic grade, his descriptions are compatible with a less altered version of the unit in the area of Wilson Lake. Cairnes described the rocks as being made up of generally schistose, green, altered " . . . volcanic flows, pyroclastic deposits, and tuffaceous sediments associated with sheets, dykes, plugs and laccolithic masses of related intrusives".

South of Caribou Creek, a small patch of rocks on Tillicum Mountain probably belongs to the Kaslo Group. West of lower Mineral Creek, to the ridge crest west of Rodd Creek, is a 2,000- to 2,500-foot-thick band of amphibolite, which is tentatively correlated with the Kaslo Group.

Milford(?) Group (?Pennsylvanian to Triassic)

The amphibolite band west of Rodd Creek described in the previous section is bordered (underlain?) on the north by fine-grained, thin-bedded, calc-silicate-bearing metasediments of unit 6B, followed by fine-grained pelitic schists of unit 6A, and in turn, by a thinner layer of unit 6B. The calcareous, thin-bedded nature of the rocks is reminiscent of the Milford Group (underlying the Kaslo Group) as described by Cairnes (1934, pp. 38–41). Though they are presumably of the same age, these rocks do not resemble, clearly, any of the divisions of the Cache Creek Group, in the Cherryville area to the west, as described by Jones (1959, pp. 38–49).

It is possible, however, as the structure is not well known, that the upper and lower calc-silicate members (unit 6B), described above, are mutually equivalent, and the amphibolite on lower Rodd Creek is equivalent to that on Scalping Knife Mountain. On the other hand, an upright synform of rather large amplitude would have to exist immediately south of the recumbent antiform on Scalping Knife Mountain (*see* Fig. 14). Also, the respective thicknesses of the two sections differ greatly; no quartz was found in the amphibolite on Rodd Creek, but an average of 12 per cent biotite was seen, in contrast with an average of 2 per cent quartz and only 1 per cent biotite in the Scalping Knife band.

Underlying almost the entire hillside north of Snow Creek, and continuing northeast to the ridge northwest of Mount Niord and perhaps farther north, is a group of rocks lithologically like those of the Milford Group. Notably, they are fine-grained pelitic schists, with widespread occurrences of calc-silicate-rich rocks. The patch of Kaslo(?) Group rocks on Tillicum Mountain borders and seems to overlie these rocks on the north. Little (1960), however, mapped these rocks as Slocan Group, also on the basis of lithological similarity.

Pre-Milford Group Rocks (except Shuswap Terrane)

The amphibolite on Scalping Knife Mountain could not be definitely correlated with any of the map-units described in the literature, except for brief mention of such a unit by Read (*in* Jenness, 1964, p. 23) in the Poplar Creek area to the northeast. J. E. Reesor (personal communication, June, 1964) has found a similar section on Upper Arrow Lake, north of Nakusp.

Monashee Group of the Shuswap Terrane (pre-Triassic)

The high-grade schists and gneisses on Saddle Mountain, and those underlying the amphibolite on Scalping Knife Mountain, clearly form part of the Monashee Group (probably of its upper region) of the Shuswap Terrane, as described by Jones (1959) for Vernon map-area. The lithology, high-grade regional metamorphism, and penetrative deformation characteristic of the Shuswap Terrane, are also characteristic of this part of the Nakusp area. That the high-grade metamorphism is clearly regional in aspect and not related to exposed granitic intrusions is apparent from the following evidence:

(1) The grade of metamorphism is highest at points most remote from exposed granitic plutons.

(2) A regionally prevalent schistosity and lineation with constant orientation is present on all of Saddle and Scalping Knife Mountains.

(3) Contact metamorphism related to granitic stocks in the area has produced fine-grained hornfels in low-grade rocks, for less than a mile from the contacts.

Tight isoclinal recumbent folds of the type shown on Figure 10 (Jones' "Older deformation") are of the style and orientation considered by Jones (1959, p. 128) to exist exclusively within the Shuswap Terrane.

The rocks and metamorphism of the Shuswap Terrane are regarded by Jones (1959, pp. 127–133) as being of pre-Permian, and probably pre-Windermere (Proterozoic), age. The main arguments recorded by Jones in support of his conclusions are as follows:

(1) Folds of the type and orientation belonging to the "older deformation" are found exclusively within the Shuswap Terrane (not, for example, in Cache Creek or Windermere rocks).

(2) "The Shuswap Terrane is unconformably overlain by rocks of the Cache Creek Group" (Permian and (?)Carboniferous). The relationships are not clear, however, because in his descriptions of each of the unconformities, Jones records features that might be taken as evidence for faulting: "The base of the overlying conglomerate contains angular pieces of the underlying rocks, but most of it contains angular to subangular pebbles of grey quartzite," i.e., of the overlying rocks? (p. 29); also, the overlying rocks

" . . . are erratic in strike and dip due to folding and are almost certainly disrupted by faults" (p. 29); and, "A consolidated breccia of the underlying phyllite marks the contact and is partly leached and altered to a white, rusty weathering, vesicular rock composed of quartz and sericite. Lying immediately above the weathered breccia is a massive rather fresh looking lava of green, andesitic augite porphyry . . . " (pp. 47–48); finally, "The unconformable contact is marked by a lithified regolith of the underlying rocks that are weathered, leached and brecciated" (p. 48). Little (*in* Lowdon, 1961, p. 5) visited one of these localities (the one on p. 47 *in* Jones), and notes that the basal breccia " . . . may be interpreted as a fault breccia".

(3) "The Shuswap Terrane is lithologically distinct." In particular, no rocks of volcanic ancestry have been found in the Monashee Group. Though they do occur in the Mount Ida Group of the Shuswap Terrane, the stratigraphic sequence and thickness differs from that in the Cache Creek Group. Amphibolites are known on the west side of Saddle Mountain (present area) but they are also known at three horizons on the south slope of the Thor–Odin dome (Vernon map-area) according to more recent mapping by J. E. Reesor (written communication, June, 1964).

(4) "The Shuswap Terrane is metamorphically distinct." The metamorphism is not related to granitic intrusions, as it is " . . . in the Cache Creek Group" and " . . . in the rocks east of the Shuswap Terrane" (p. 130).

The age of the rocks of the Shuswap Terrane, from the evidence presented in this report, appears to be pre-Triassic, and therefore compatible with the age suggested by Jones. A post-Shuswap unconformity of appreciable angular discordance seems to be ruled out for the Nakusp area, but a pre-metamorphic disconformity, though not apparent, cannot be ruled out. The writer does not mean to imply, however, that he thinks one exists. The age of the culminating regional metamorphism affecting these rocks, however, must be post-Triassic, as it undoubtedly affects the phyllite belt of the Slocan Group, and appears to affect rocks as young as the Rossland Group. Jones considered that his "Older deformation", though based mainly on orientation of folds, occurs simultaneously with the regional metamorphism, and if so it also appears to affect the phyllite belt of the Slocan Group, and hence must be younger than these rocks. This places no restrictions, however, on any earlier, less widespread metamorphic episode in the Monashee Group. The final culminating metamorphic and concurrent structural episode affecting the Monashee Group, however, must be younger than Slocan Group rocks.

Chapter III

INTRUSIVE ROCKS

Metamorphic rocks of the Nakusp area have acted as host to a remarkable variety of granitic rocks, mainly in the form of small stocks that outcrop over about 108 square miles of the 370 square miles mapped. These plutons exhibit a tendency to east-west elongation by a length to breadth ratio of less than two to more than fifteen. Most contacts with the country rocks tend to be regular, sharp, and concordant on the scale of an outcrop.

Alkalic Types (Units 14A, 14B, 15, 21)

Field Description and Distribution

Unit 21: Box Mountain Syenite Stock

This stock occupies a 7½ square mile, east-west belt on the ridge north of Dog Creek, and east to the valley northwest of Summit Lake. In the field, the rocks are medium to coarse grained, pale brownish grey in colour, and low in mafic minerals

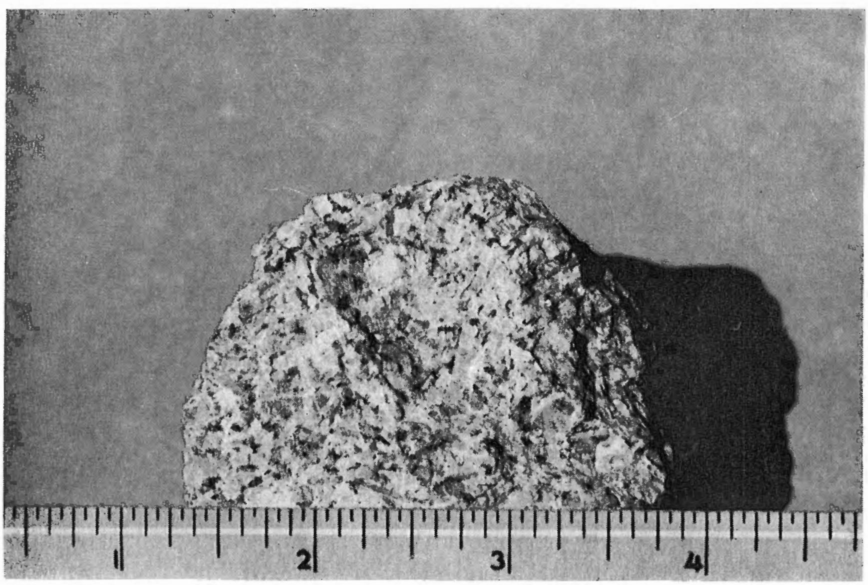


PLATE XI. Hand specimen from unit 21; syenite.

(*see* Pl. XI). Potassium feldspar as euhedral grains ranges from 0.2 cm to 4 cm in length, and dominates the rocks. Grains in a single outcrop are of similar size, though scattered phenocrysts do occur. Coarse grains are lath-shaped with length-to-width ratios between 2 and 7. Medium-sized grains are generally almost square in outline, having length-to-width ratios between 1 and 2. Coarse grains commonly show distinct colour zoning, with darker (more grey) cores and paler (more buff) rims.

Mafic minerals constitute between 2 and 8 per cent of most rocks, and are confined to the interstices between feldspar grains. Fine-grained, subequant, dark green to black pyroxene is the most common mafic mineral. A few grains of quartz were seen near the contact, at the southwestern extremity of the stock. A faint foliation is visible in some areas, due to parallelism of laths of potassium feldspar.

Contacts in most places are sharp, most somewhat irregular. Sills and dykes, less than 6 inches to more than 30 feet thick, cut the country rocks, especially near the southwest corner of the pluton. A very few, ½- to 3-inch pegmatitic dykes cut nearby country rocks. Small sericitized porphyroblasts of andalusite occur in pelitic country rocks as much as 40 feet from the contact, and small crystals of actinolite are developed in volcanic country rocks.

The pluton is cut by several buff-coloured dykes of aplite (probably derived from the syenite itself) and by at least one dyke of fine-grained leucocratic granite (resembling that of the Kuskanax batholith?).

Units 14A, 14B, 15: South Wragge Creek, Shannon Lake, and Nakusp Range Leucocratic Plutons

The South Wragge Creek and Shannon Lake plutons underlie 1.3 and 3 square miles, respectively, of the area mapped. The Nakusp Range and Allshouse Peak

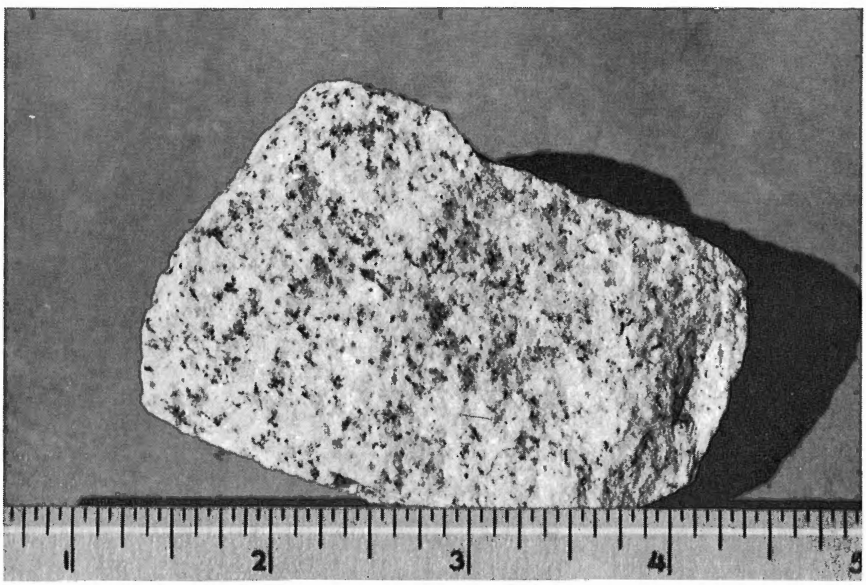


PLATE XII. Hand specimen from unit 14A; (leuco)quartz monzonite.

leucogranite bodies are part of the southwestern corner of the Kuskanax batholith (*see* Fig. 1). They underlie 14 and 3.3 square miles, respectively, of the area mapped.

In the field, all these rocks are leucocratic, massive, fine to medium grained, and white to buff in colour (*see* Pls. XII, XIII, and XIV). Fine- to medium-grained subequant feldspars are the dominant minerals, being mostly fine grained in the Nakusp Range pluton. Fine-grained mafic minerals (black hornblende, pyroxene, and yellowish green epidote) constitute 2 to 4 per cent of most rocks. Red-brown garnet occurs in a few rocks in unit 15. Glassy grains of quartz are clearly visible with a hand lens but not prominent except in unit 14A, where they are coarser and more obvious. Small drusy cavities are moderately common in each of these units. A few in unit 15 contain grains of purple fluorite.

Contacts with the meta-pelitic country rocks are very sharp (gradational over less than half an inch), exceedingly so where the country rocks are of low metamorphic grade, and generally concordant. In some places, however, the granitic rock feathers out *en échelon* across the schistosity of the country rocks, and on a regional scale some beds are truncated. Contacts of units 14A and 14B with the Wragge Creek quartz monzonite stock (unit 18), however, are gradational over 1 foot to 10 feet. Units 14A, 14B, and 18 are cut, within about 100 feet of the contact, by numerous 2- to 6-inch quartz–feldspar pegmatite bodies. The unit from which the pegmatites were derived cannot be determined from the field relations.

A few sills, less than an inch to more than 10 feet thick and at least one 30-foot dyke of leucogranite cut the pelitic country rocks. Inclusions of country rocks are not common but swarms of ½- to 2-inch angular, sharply bounded, hornblende-rich inclusions were found in as many as three places in each pluton. Contact metamorphic effects appear limited. Low-grade argillaceous rocks adjacent to unit 15

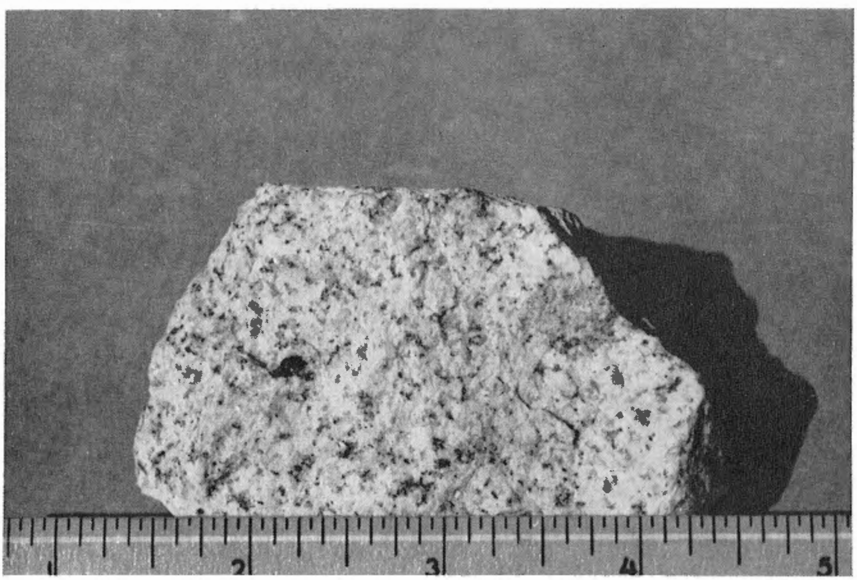


PLATE XIII. Hand specimen from unit 14B; (leuco)granite.

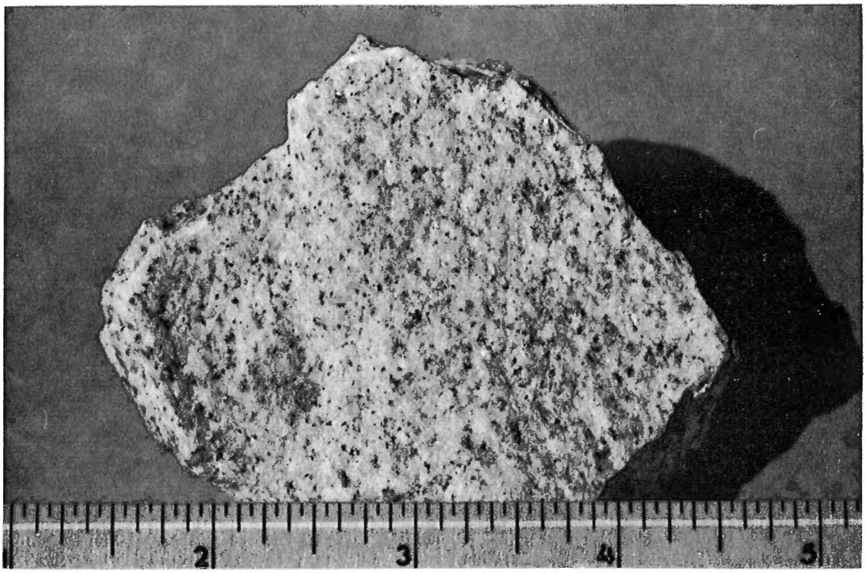


PLATE XIV. Hand specimen, Nakusp Range–Allshouse Peak stocks; leucogranite.

appear more phyllitic at the contact than a few inches away. Chiastolite crystals (as much as 1 cm by 4 cm) occur in phyllites just north of Shannon Lake, near the leucogranite.

Mineralogy and Petrography

The mineralogical content of the granitic rocks and basic dykes has been determined in thin section, and the anorthite content of plagioclase using the universal stage and the curves of Slemmons (1962). Average percentages (Table V) are visual estimates in thin section, supplemented in every sample by estimates on stained slabs. Included in the average for each of units 14 to 21 are as many as three modes, determined by the point count method of Chayes (1949) (2,500 points minimum) upon sections of chemically analyzed rocks. Chemical analyses and norms for 16 large samples (20 pounds each) of the granitic rocks were determined in the laboratories of the Geological Survey of Canada (Table VII; for their corresponding modes *see* Table VIII). Megacrysts, because of their large size, were estimated in the field by grid-counts of 400 to 2,400 points (units 16A and 20). One sample of lineated quartz monzonite (unit 13) from the high-grade metamorphic rocks is included for comparison.

Each of the map-units is described below as a supplement to Table V and represented on Figures 7 and 8. Rock names correspond to the classification used by the Geological Survey of Canada.

Unit 21

The Box Mountain stock consists of microcline syenite (Fig. 7) containing albite, quartz, and green aegirine–augite as constant minor constituents. The

TABLE V *Modes of Granitic Rocks*
(visual estimates in volume per cent (averages))

Map unit	13	21	14A	14B	15	16A	16B	17	18	19	19a	20
No. of Thin Sections	11	6	4	4	10	5	7	8	11	10	4	13
Quartz	24	4	15	14	14	12	15	11	25	18	7	24
K-Feldspar	31	73	28	33	62	18	20	21	27	28	6	29
Plagioclase	41	18	52	48	20	47	45	44	41	42	51	39
Biotite	1	.9[1]	.4	.1	.5[1]	1	4	7	4	6	12	4
Hornblende	1	.2	2	2	.2	19	11	13	.7	4	14	4
Chlorite	.4		tr	.1	tr	1	.8	1	.4	.4	7	1
Epidote		tr	2	1	.7	.6	3	2	1	.7	1	.2
Clinopyroxene	.4	4		.5	1	.2					1	
Sphene	.4	.4	.2	.2	.4	.5	.6	.4	.5	.5	.9	.6
Apatite	.2	.1	.2	tr	.4	.5	.4	.2	tr	.3	.7	.3
Allanite	tr	tr	tr		tr	tr	.1	tr	.1	tr		tr
Zircon	tr	tr	tr		tr				tr		tr	tr
Tourmaline										tr		
Fluorite					tr							
Garnet	.2				.2							
Prehnite								tr			.2	tr
Muscovite	.6											
Magnetite–ilmenite	.1	.1	tr		.3	.3	1	.4	.2	.2	.3	.4
Hematite	.1	.2		tr	.1	.2	.2	.2	.2	.1	.1	.1
Pyrite	.1	.1		tr		.1	.4[2]	tr	.1	.1	.1	.1
% An of Plagioclase	23	.5	20	5	3	34	34	38	28	26	39	27
An variation +	29	2	29	10	9	43	39	51	38	36	56	31
An variation −	17	0	11	1	0	28	27	30	16	19	31	19
No. of sections represented	11	6	4	4	10	5	7	8	11	10	4	13

[1]Includes stilpnomelane.
[2]Includes minor pyrrhotite.
tr = trace.

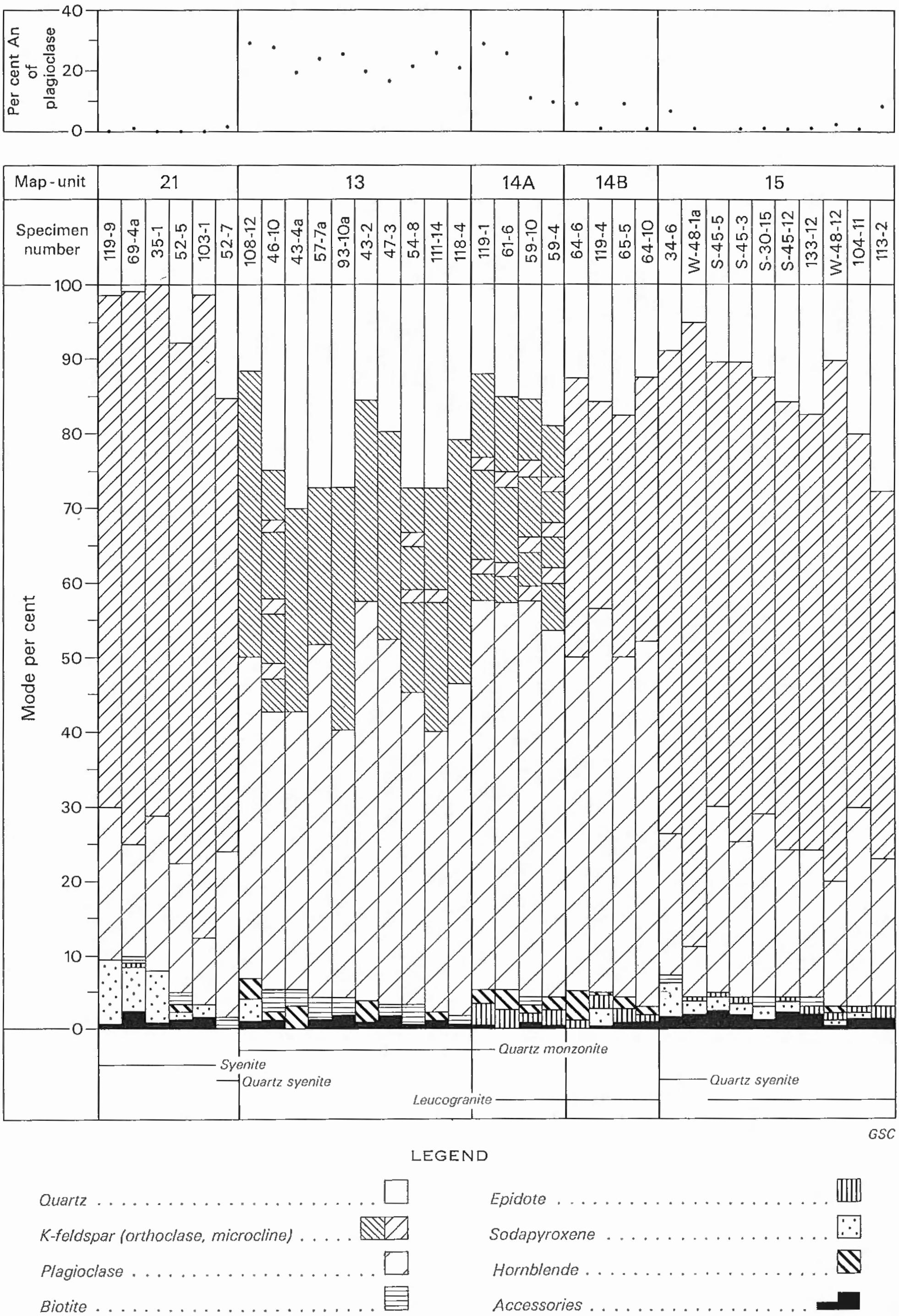


FIGURE 7. "Alkalic" suite mineralogy.

content of quartz characteristically is less than 1 per cent except in two specimens from near the southwestern contact where it rises to 7 and 15 per cent. In Johannsen's classification (1939, p. 141 ff.), the Box Mountain syenites belong to classes 117 (3 TS) and 217 (3 TS).

The texture is hypidiomorphic-granular, rarely inclining to trachytoid. The dominant mineral, perthitic microcline, occurs in large subhedral crystals (1 mm to 16 mm long). Exsolved albite, typically in the form of streaks, irregular patches, and veinlets, forms 1 to 15 per cent (characteristically 5 per cent) of the perthitic crystals. Albite (perhaps, too, a product of exsolution) also occurs as small interstitial grains or granular rims to the microcline. It may be twinned on the albite and/or pericline laws. Ubiquitous minor accessory minerals are sphene and brown biotite and possibly stilpnomelane, sometimes bordering aegirine-augite. Sporadically present are pale blue amphibole, tending to develop as fringes to crystals of pyroxene; green epidote, some with cores of brown allanite; zoisite; apatite; zircon; and opaque ores (hematite, magnetite, ilmenite, or pyrite).

Units 14A, 14B, 15

The South Wragge Creek stock (unit 14A) and Shannon Lake stock (unit 14B) both consist of quartz monzonite, whereas the southern end of the Kuskanax batholith (unit 15) consists largely of microcline granite (*see* Fig. 7). Epidote and hornblende are characteristic minerals in units 14A and 14B, as are epidote and aegirine-augite in unit 15. Aegirine-augite and hornblende are also present in some rocks of units 14B and 15, respectively. In Johannsen's classification, the rocks belong to 127/7″ (unit 14A), 117″ (unit 14B), 116, and to a minor extent 116″ (unit 15).

The texture is hypidiomorphic to allotriomorphic granular and, in most sections of units 14B and 15, distinctly microporphyritic (microcline). Where the margins of the larger grains are segmented in unit 15, the texture is more allotriomorphic. Some larger grains of poikilitic microcline contain inclusions of other minerals. Mafic minerals tend to be clustered into small groups. The rocks are massive except in one section where grains of hornblende are fairly well aligned (unit 14A), and in one where the larger grains of microcline are aligned (unit 15). Post-crystallization strain is apparent from undulose extinction of quartz in many rocks, local undulose extinction in potassium feldspar, and bent twin lamellae in plagioclase.

The potassium feldspar is microcline except in unit 14A, where it is untwinned orthoclase which has developed microcline (grid) twinning where much strained, for example, at irregularities in the borders of a crystal. Confirmation that the untwinned grains are orthoclase was that $Y \wedge \perp$cleavage$=7°$ and $2V_X=66°$. Exsolved perthitic albite, typically in the form of fine streaks or small ragged patches, constitutes from 0 to 7 per cent of the perthitic grains. Less commonly, the perthitic albite has formed minute "gash veins" where the microcline is most strained. The plagioclase (albite in units 14B and 15 and oligoclase in unit 14A) also occurs as small discrete grains and as partial to complete rims on the microcline grains, and in optical continuity with them (*see* Pl. XV). The plagioclase is unzoned and twinned on the albite, carlsbad, and albite-carlsbad laws. The grains tend to be subequant and without preferred crystallographic orientation.

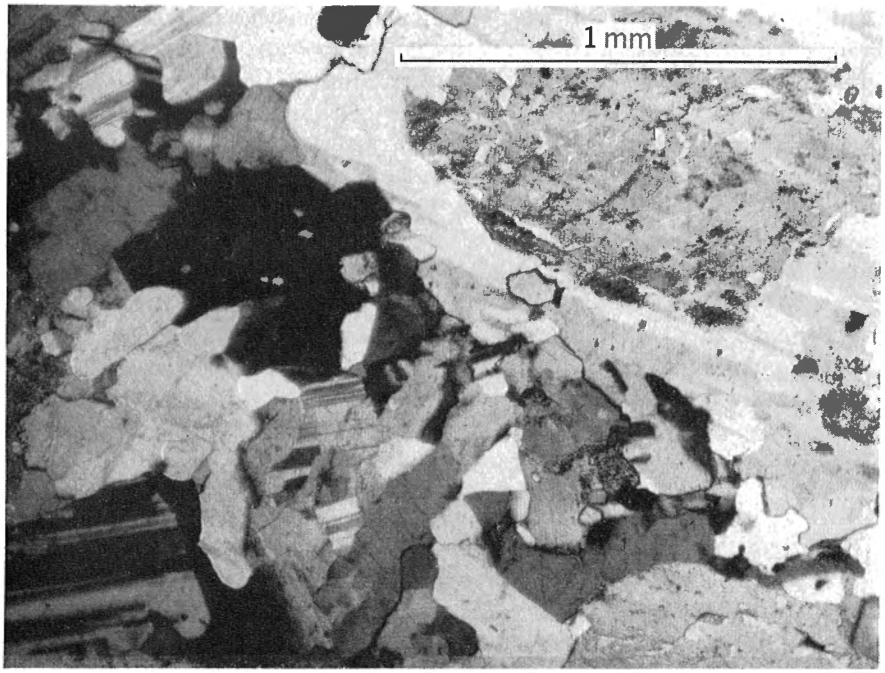


PLATE XV. Photomicrograph of leucogranite showing microcline rimmed by albite and surrounded by subequant grains of albite and quartz. Unit 15. (crossed nicols)

Accessory minerals include aegirine–augite (except in unit 14A) with gradationally colourless cores richer in augite, epidote (pistacite), hornblende, biotite and the chlorite altered from it, sphene, apatite, brown allanite (rimmed by epidote), zircon, and opaque ores (magnetite and/or ilmenite, hematite, and ?pyrite). Unit 15 also contains some strongly brownish pink garnet and orange ?stilpnomelane developed from aegirine–augite.

Stilpnomelane in the alkalic granites and syenites of unit 15, appears to be a deuteric or late magmatic alteration of aegirine–augite. The only reported deposit known to the writer that in any way resembles this is in granophyre inclusions in the marginal border group of the Skaergaard intrusion (Wager and Deer, 1939, pp. 187–190). There, the stilpnomelane is in the groundmass and in drusy cavities in the granophyre.

Hornblende and epidote in one section in unit 14B may be a replacement of clinopyroxene.

Calc-Alkalic Types (Units 16A to 20)

Field Description and Distribution

Units 16A and 16B: Mountain Meadow and East Caribou Quartz Diorite Plutons

Unit 16A is a small, steep-sided granitic body with a pronounced east-west elongation. It parallels the Ruby Range stock on the north and is about 4½ miles long but only a quarter mile wide. It is well exposed at the head of the westernmost, north-flowing tributary of Slewiskin Creek. Unit 16B is a small stock, about 4 square miles in area, ovoid in outline, and centred 2 miles north of Mount Niord. It is separated from the Wragge Creek stock by a narrow septum of pelitic country rock.

In the field, the rocks of both these units are medium grained, contain about 20 per cent mafic minerals, and are characterized by the presence of distinctive megacrysts of potassium feldspar. These megacrysts are prominent and moderately large (1 cm to 4 cm long and half as wide) in unit 16A and less distinct and smaller (5 cm to 15 mm long) in unit 16B (*see* Pls. XVI and XVII). In unit 16A the potassium feldspar crystals are euhedral to subhedral and constitute as much as 20 per cent of the rock. In unit 16B, on the other hand, they tend to be subhedral and comprise as much as 15 per cent of the rock. The megacrysts of unit 16A contain small inclusions of mafic minerals arranged in zones parallel with the external boundaries of the potassium feldspar. As many as four distinct zones have been observed in large crystals, especially in the eastern part of the body. The megacrysts of unit 16B are also poikilitic but their relatively small size prevents clearly distinguishable zoning.

White, more opaque than the translucent greyish white potassium feldspar, subhedral to euhedral plagioclase grains 2 mm to 10 mm long and half as wide form 20 to 45 per cent of most rocks. Mafic minerals, black hornblende, and lesser black biotite constitute 15 to 20 per cent of most rocks. In unit 16A, the hornblende is medium grained (1 mm to 5 mm long and a quarter as wide), whereas in unit 16B it is fine grained. Yellowish green epidote is visible in some rocks in unit 16B. Grains of hornblende and plagioclase, and megacrysts of potassium feldspar are in some parts moderately aligned, in others almost massive.

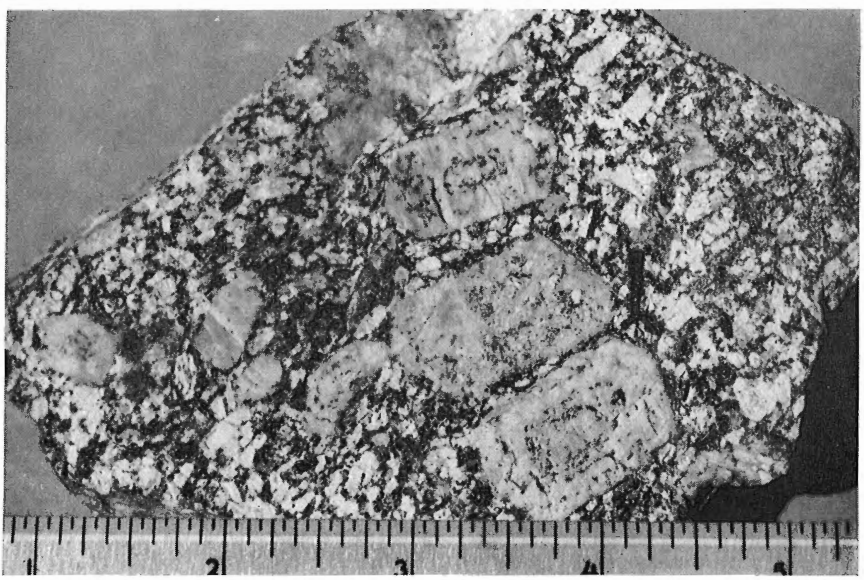


PLATE XVI. Hand specimen from unit 16A; (quartz) diorite. Note zones of mafic minerals in megacrysts of potassium feldspar.

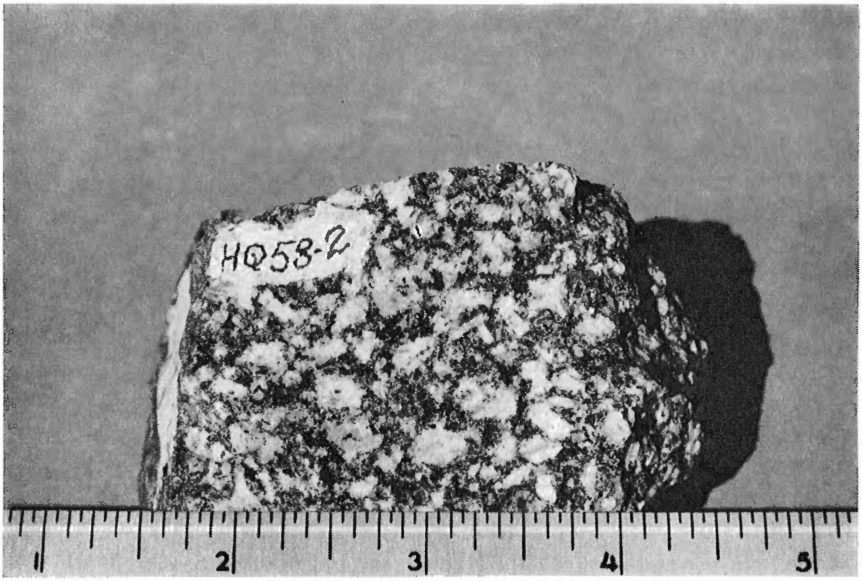


PLATE XVII. Hand specimen from unit 16B; quartz diorite.

Contacts of these plutons are, in general, sharp, have less than one-eighth inch gradation in parts of unit 16B, and are conformable with both schistosity and lamination of the country rocks. In a few places an irregular contact cuts across the foliation of the schist, and the quartz diorite there is quite homogeneous. In one place, the East Caribou Creek stock (16B) is cut by numerous dykes (a quarter inch to a foot thick) of quartz monzonite from the nearby Wragge Creek stock (unit 18). The quartz diorite also occurs as small inclusions in these dykes, and is invaded by thin apophyses from them.

Units 17–20: Quartz Monzonites and Quartz Diorites of the Ruby Range, Snowslide and Wragge Creeks, Goatcanyon–Halifax Creeks, and Lower Caribou Creek Plutons

The Ruby Range stock (unit 17) underlies 9 square miles of the crestal to northerly parts of the Ruby Range, for almost the full length of Slewiskin Creek to the north. Exposures of the unit are most easily accessible on the east side of upper Rodd Creek.

The plutons of Snowslide and Wragge Creeks (unit 18) are unconnected at the surface, but essentially identical in general appearance. The former, about 5½ square miles of which is in the area mapped, underlies the headwaters of Caribou and Snowslide Creeks at the southern edge of the map-area. Two and a half miles northeast, the other stock underlies 14½ square miles of the map-area in the drainages of Wragge and lower Shannon Creeks. The eastern part of the stock was not mapped.

The Goatcanyon–Halifax Creeks pluton (unit 19) underlies most of Goatcanyon, lower Londonderry, and Halifax Creeks. Representative sections of it are well exposed near lower Halifax Creek.

The Lower Caribou Creek stock (unit 20) underlies a 22-square-mile area immediately adjoining the Goatcanyon–Halifax Creeks pluton (unit 19) on the northwest. It occupies much of the ridge south of Scalping Knife Mountain and the lower reaches of Caribou Creek to Rodd Creek, and is well exposed and easily accessible at the bridge across Caribou Creek at the mouth of Goatcanyon Creek.

In the field, rocks of these units (*see* Pls. XVIII–XXI) are grey (unit 17), to pale grey (units 18–20), to pinkish (unit 20); they are medium grained and massive, except in some parts of units 17 and 20, which show a weak primary foliation and/or lineation resulting from preferential alignment of mafic minerals and (in 20) potassium feldspar megacrysts. Mafic minerals constitute 15 to 25 per cent of most rocks in unit 17 (hornblende:biotite about 2:1), 10 per cent of units 19 and 20 (hornblende: biotite about 1:1), and 6 per cent of unit 18 (biotite dominant). The biotite and hornblende are jet black where fresh but somewhat greenish or brownish black where altered or weathered. Fine grains of yellowish green epidote, closely associated with hornblende, are apparent in some rocks of units 17 and 18. Medium-grained, pale grey quartz is clearly visible in most samples and prominent in those of unit 18, where it forms about 25 per cent of the rock.

The medium-grained feldspars are white, the potassium feldspar being a little more transparent and greyish than the chalky white plagioclase. Indistinct, subhedral, poikilitic crystals of potassium feldspar, 1 cm to 2 cm long, form a widespread though minor constituent of unit 18.

Unit 20 is characterized by euhedral to subhedral megacrysts of pinkish white potassium feldspar. Most commonly these form 15 to 20 per cent of the rock (by grid counts in the field), but range from less than 1 per cent (especially adjacent to the non-porphyritic quartz monzonite of unit 19 to the southeast) to more than 29 per cent. These megacrysts average an inch to 1½ inches in length, and about

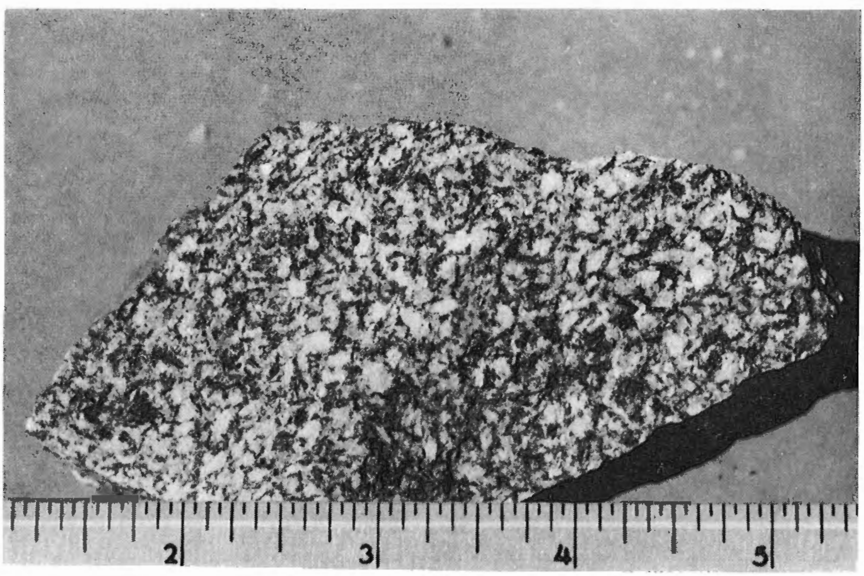


PLATE XVIII. Hand specimen from unit 17; quartz monzonite–quartz diorite.

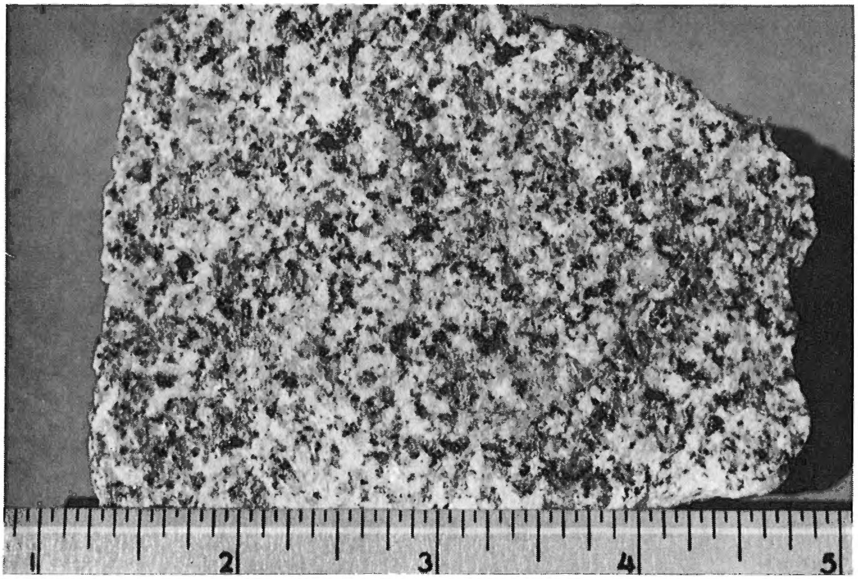


PLATE XIX. Hand specimen from unit 18; quartz monzonite.

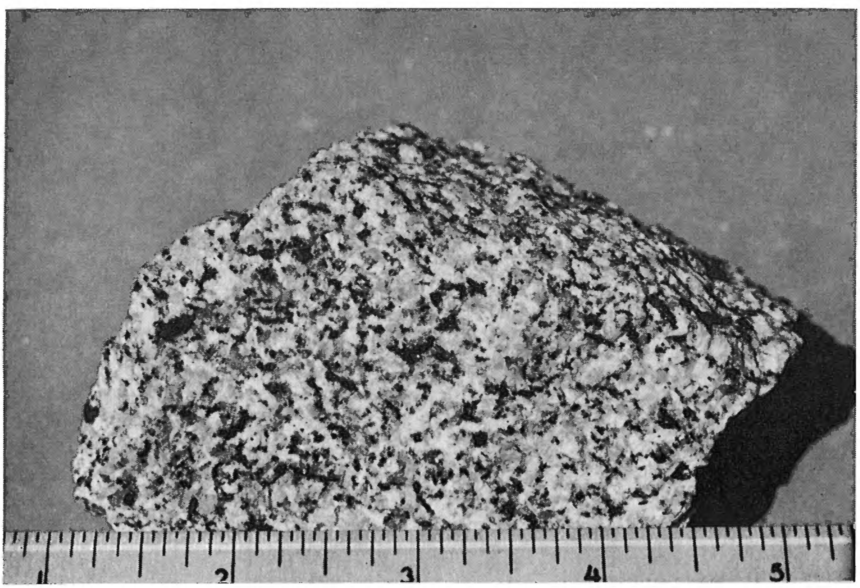


PLATE XX. Hand specimen from unit 19; quartz monzonite.

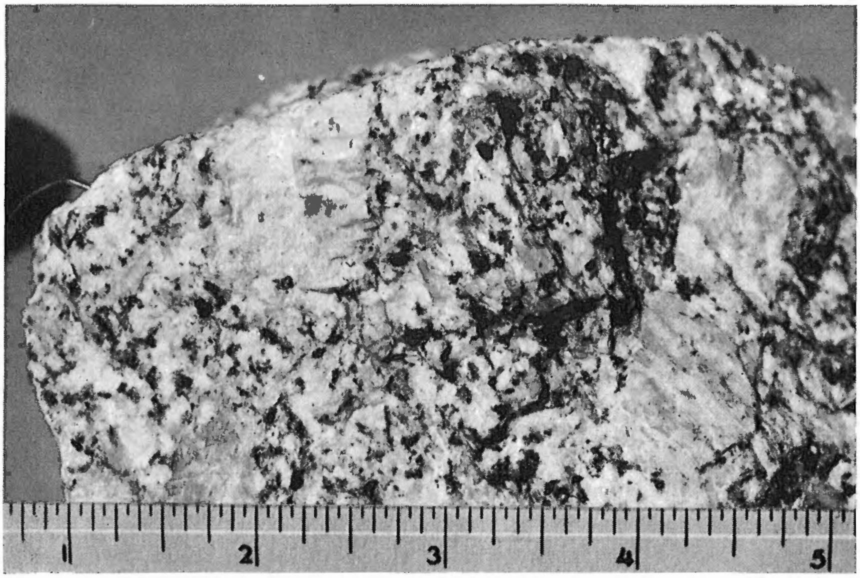


PLATE XXI. Hand specimen from unit 20; quartz monzonite containing megacrysts of potassium feldspar.

half this in width. The largest seen was 3 inches long. Some show carlsbad twins. Enclosed mafic minerals are common (1 to 2 per cent of a megacryst), and are arranged in as many as three discontinuous and somewhat indistinct zones parallel with the borders of the megacrysts. Megacrysts neither increase nor decrease in number or size adjacent to the metamorphic country rocks, except locally where they are absent within a few inches to a few tens of feet from the contact. They are gradationally less distinct, more poikilitic, smaller and fewer in number, however, within about a mile of the megacryst-free quartz monzonite (unit 19) to the southeast. Porphyroblasts of potassium feldspar are absent from the country rocks.

Sheets of more mafic-rich schist, gneiss, and lineated quartz monzonite, generally an inch to 5 feet thick, but as much as 50 feet, are enclosed in the megacryst-bearing quartz monzonite of unit 20 in many places on the hillside east of Columbia River and on the south end on the same ridge above Caribou Creek. Most have sharp contacts, but a few have diffuse contacts including some that have been almost completely assimilated although retaining their shape.

Contacts of these granitic plutons with the metasedimentary country rocks are generally concordant but locally discordant, cutting abruptly across the schistosity for several feet or more. On a regional scale, they tend to be concordant. The pronounced east-west elongation of the Ruby Range pluton (unit 17) is parallel with the surface trace of the axial plane of megascopic folding of the country rocks. The contacts are sharp, though some are diffused over as much as several inches.

Adjacent to contacts with country rocks, the granitic rocks are, in units 17 and 18, homogeneous except locally where a few sharply bounded inclusions 2 inches to 6 feet long are present. Some of these are definitely misoriented with respect to trends of foliation in the enclosing country rock. In unit 17, the content of mafic minerals especially biotite tends to increase in a few places in the quartz diorite near the contact. Adjacent to the contacts of unit 19 with the country rocks, the quartz monzonite is more heterogeneous, is richer in mafic minerals, and becomes dioritic in composition (unit 19a). A few small inclusions, some angular and sharply bounded, others angular to rounded and diffusely bounded, are moderately common within a few hundred feet of the contacts.

Pegmatite (except in unit 17) and minor aplite dykes an inch to 20 feet across (250 feet in unit 20), derived from the adjacent granitic pluton, are moderately common cutting the country rocks for a few hundred feet from the contact. Most consist mainly of feldspar with lesser quartz. Some of those associated with units 17 and 20 contain biotite or garnet. Most truncate the foliation in the adjacent country rocks but some parallel it and others are irregular. The pegmatite and dykes cutting the higher grade metamorphic rocks, such as those adjacent to unit 20, are indistinguishable in the field from crosscutting, mafic-free pegmatites, tentatively thought to be associated with metamorphism, except that the former decrease in number away from the granitic contact. Similar, but generally narrower dykes and patches of pegmatite cut and in part grade into the quartz monzonite, to which they are probably related. These are more common as the schist contact is approached. The pegmatites tend to have more irregular borders than the aplites.

A few sharply bounded quartz monzonite dykes, 2 inches to 150 feet across, cut the country rocks adjacent to these plutons (except unit 20). Fine-grained pelitic and volcanic country rocks are clearly altered to hornfels with a coarser grain and small porphyroblasts of biotite, muscovite, garnet, or andalusite within 100 to 1,000 feet of the granitic contacts.

The Lower Caribou Creek quartz monzonite (unit 20) near the contact with the amphibolite near lower Rodd Creek shows a pronounced, near-vertical secondary lineation and foliation, consisting of streaked out mafic minerals aligned parallel with the contact.

Mineralogy and Petrography

Units 16A and 16B

The Mountain Meadow pluton (unit 16A) consists of quartz diorite and the east Caribou stock (unit 16B) of quartz diorite and quartz monzonite. The megacrysts are microcline in unit 16A, and plagioclase and, to a lesser extent, potassium feldspar in unit 16B. Hornblende (X'=pale brown, Z'=dark green) is characteristic and amounts to 4 to 30 per cent of unit 16A and 3 to 15 per cent of unit 16B. In Johannsen's classification, the rocks belong to class 227 and some of unit 16B to 227''.

The texture is hypidiomorphic-granular to porphyritic. Grains tend to be more anhedral where their margins have been segmented by later deformation. Plagioclase and, to a lesser extent, hornblende and biotite are in some specimens fairly well aligned to form a primary foliation.

The potassium feldspar in unit 16A is microcline, most of which occurs as poikilitic anhedral to euhedral megacrysts. The smaller potassium feldspar megacrysts in unit 16B are predominantly orthoclase without visible twinning, but every rock, where strained, shows at least minor development of indistinctly bounded grid twinning (microcline). The poikilitically enclosed grains in unit 16A of every other mineral species found in the rock constitute as much as 15 per cent of a megacryst and as much as 50 per cent of its border part. Inclusions in some subhedral or euhedral megacrysts are arranged in zones and aligned parallel with the borders of the megacryst. Though the potassium feldspar in unit 16B is equally poikilitic, the tendency for the inclusions to be arranged in zones is less pronounced than in unit 16A. Exsolved albite in the form of micro-gash veins localized in strained areas of a perthitic crystal, streaks, and fine blebs constitute 0 to 5 (locally 10) per cent of the perthitic microcline grains.

Plagioclase (andesine) occurs as medium to coarse, subhedral grains and, in unit 16B, small phenocrysts. Most show progressive zoning (e.g., An_{41} to An_{28}), some with numerous slight reversals. Twinning is on the albite, pericline, carlsbad, and albite–carlsbad laws. Myrmekite exists as minor patches and partial overgrowths on plagioclase.

Post-crystallization strain is apparent from undulose extinction and some segmentation in quartz, microcline, and biotite, and bent twin lamellae in plagioclase. This effect is especially prominent in a sample from the western end of unit 16A.

Accessory minerals include dark brown biotite and the optically negative alteration product chlorite, ubiquitous epidote (pistacite) and sphene, pale green clinopyroxene (in unit 16A only), colourless apatite (some in unit 16A has pleochroic cores with ε=pale grey, ω=pale brown), allanite (some rimmed with epidote), and opaque ores (magnetite and/or ilmenite, hematite, pyrite rimmed with hematite, and pyrrhotite). Plagioclase is partly saussuritized.

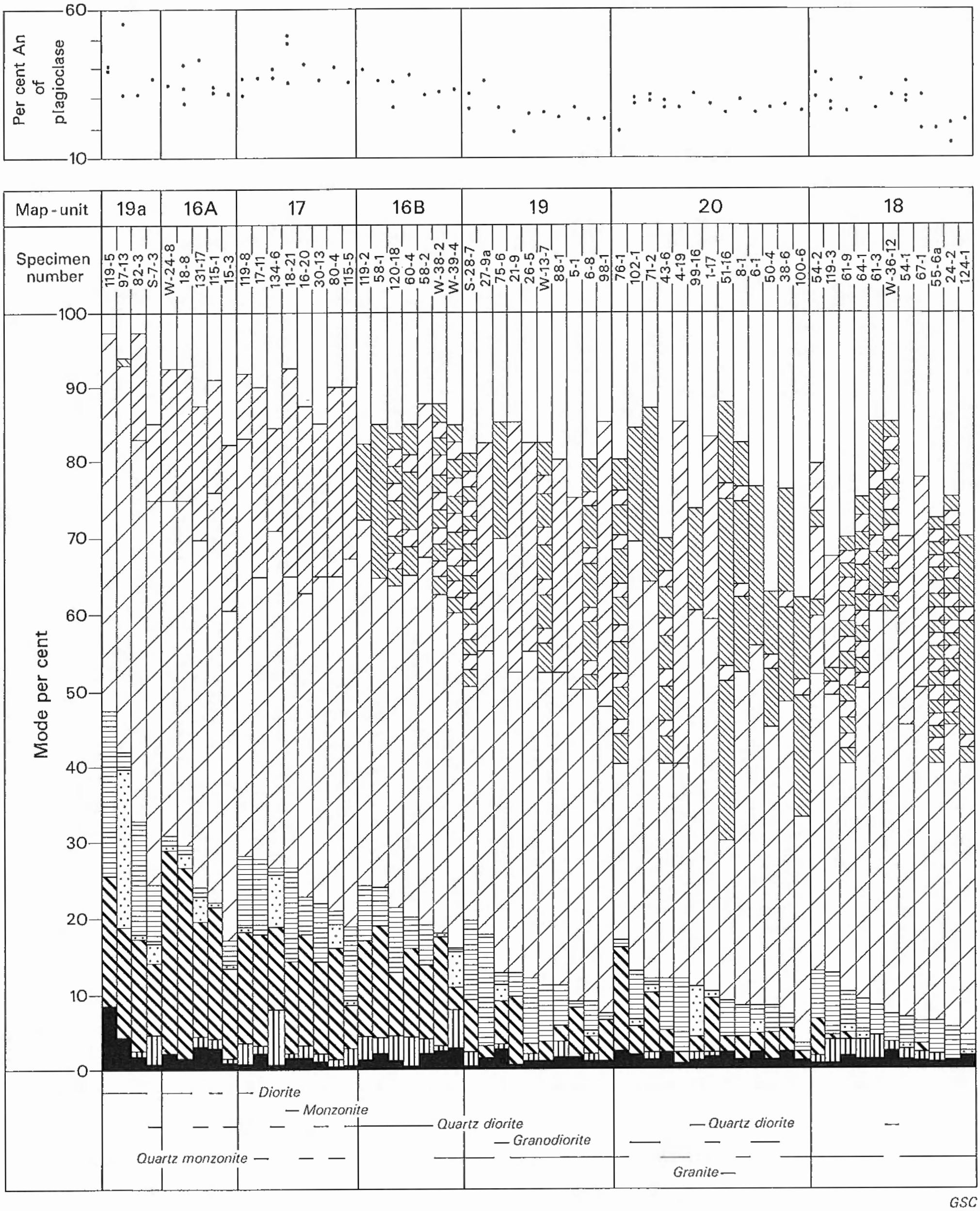
Units 17–20

The Ruby Range stock (unit 17) consists of quartz monzonite, quartz diorite, and diorite (Fig. 8), characteristically containing hornblende (6 to 15%) and biotite (5 to 13%). In Johannsen's classification, the rocks belong to classes 227 and 227″.

The stocks of Snowslide and Wragge Creeks (unit 18) consist of quartz monzonite and quartz diorite. In the Wragge Creek stock, the plagioclase is oligoclase–andesine (An_{26} to An_{38}), and biotite and dark green hornblende are characteristic minerals; in the Snowslide Creek stock, the plagioclase is oligoclase (An_{16} to An_{31}), biotite is a characteristic mineral, and hornblende is almost absent. In Johannsen's classification, the rocks of these stocks belong to classes 227″ (six thin sections), 227 (three thin sections), and 127″ (two thin sections).

The Goatcanyon–Halifax Creeks stock (unit 19) consists of quartz monzonite with a contaminated border phase (19a) of diorite, quartz diorite, and granodiorite. In the stock, the plagioclase is oligoclase to andesine, and characterizing minerals are hornblende (1 to 9%) and biotite (1 to 15%). In the border phase, the plagioclase is andesine to labradorite, and characterizing minerals are hornblende (10 to 18%) and biotite (16 to 25%). In Johannsen's classification, the rocks of the stock belong to classes 227″ (nine thin sections) and 227 (one thin section) except in the border phase where they belong to classes 227, 228, 2211, and 2212 (one thin section each).

The Lower Caribou Creek stock (unit 20) consists of "porphyritic" (potassium feldspar) quartz monzonite and granodiorite, with minor amounts of granite and



LEGEND

Quartz . . . .

K-feldspar (orthoclase, microcline) . . . . .

Plagioclase . . . .

Biotite . . . .

Epidote . . . .

Chlorite . . . .

Hornblende . . . .

Accessories . . . .

FIGURE 8. "Calc-alkalic" suite mineralogy.

quartz diorite (*see* Fig. 8). Dark green hornblende (1 to 10%) and brown biotite (<1 to 10%) are characteristic constituents. In Johannsen's classification, the rocks belong to classes 227 (six thin sections), 227″ (three thin sections), 226″ (three thin sections), and 226 (one thin section).

The texture in all these units is hypidiomorphic-granular, except where later deformation and segmentation of the borders of grains have made them more anhedral. Plagioclase generally shows some progressive zoning with slight oscillations (e.g., An_{51} to An_{35}, An_{31} to An_{20}) in units 17 and 18, and less so in units 19 and 20. It is twinned on the albite, pericline, carlsbad, albite–carlsbad, and manebach laws. Myrmekite is common in unit 18 and present in a few rocks of unit 19 as patches and partial rims in optical continuity on plagioclase. In some samples of unit 18, plagioclase, where in contact with potassium feldspar, is marked by thin rims of albite.

Potassium feldspar occurs in unit 17 as microcline, and in units 18, 19, and 20 as orthoclase in some rocks, microcline in others, in still others as orthoclase with diffuse patches of grid twinning, which when strained show partial conversion to microcline. Perthitic albite forms fine gash vein-like streaks in the potassium feldspar, especially around inclusions and irregularities in the borders of grains showing the same relationship to strain as the grid twinning. It also occurs as fine streaks and blebs arranged in zones parallel with the borders of megacrysts, as in unit 20. The larger grains of potassium feldspar enclose grains, and aggregates of grains, of every other mineral species present in the rock (*see* Pl. XXII). Rocks from

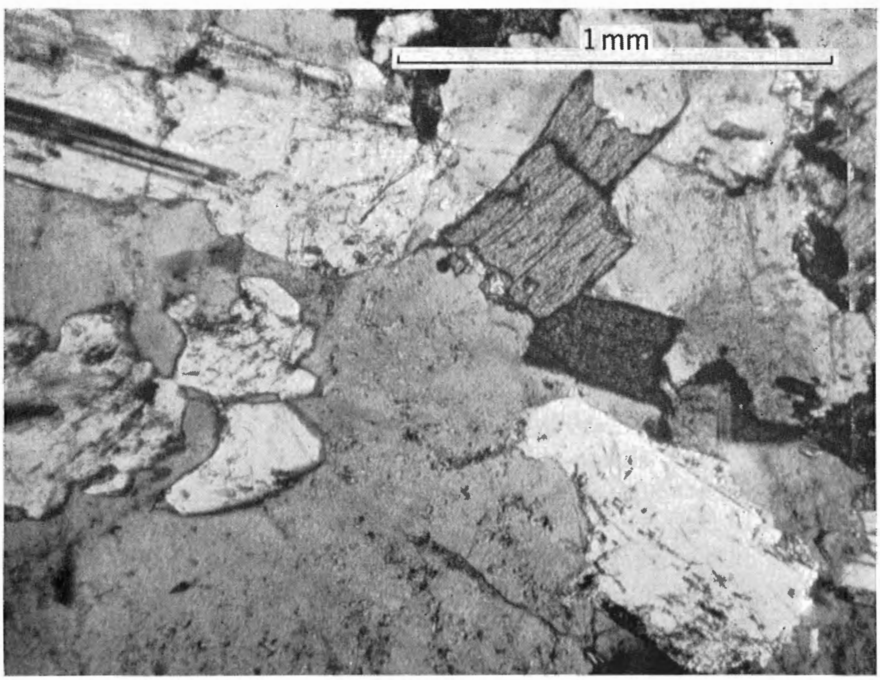


PLATE XXII. Photomicrograph showing potassium feldspar megacryst enveloping grains of plagioclase, biotite, and quartz; unit 20 (crossed nicols).

the transitional zone between the megacryst-bearing quartz monzonite (unit 20) and the megacryst-free quartz monzonite (unit 19) form a textural gradation between the two units. They contain some small, poikilitic megacrysts in amounts from 10 to 15 per cent and in a proportion similar to the "groundmass". Inclusions (1 to 2%) in the megacrysts of unit 20 tend to be arranged in zones parallel with the megacryst boundaries.

Post-crystallization strain is reflected in undulose extinction and segmentation in quartz, to a lesser extent in potassium feldspar, as noted above, and by bent flakes of biotite and bent twin lamellae of plagioclase. Samples from the central to eastern parts of unit 17 are almost unstrained. Quartz in some parts of unit 20 shows pronounced attenuation, and in many rocks secondary preferred orientation of the crystal lattice.

Accessory minerals include epidote (pistacite), chlorite (optically negative, after biotite), sphene, colourless apatite (some with cores having ε=grey, ω= brownish grey), allanite (commonly rimmed by epidote), zircon, prehnite (after biotite except in unit 18), tourmaline in unit 19 (ε=pale yellow-brown, ω=dark blue to greenish brown), and opaque ores (magnetite and/or ilmenite, hematite, and pyrite rimmed by hematite). Plagioclase is somewhat saussuritized, especially in rocks of the border zone (unit 19a).

Other Intrusive Rocks

Field Description and Distribution

Unit 22: Lamprophyric Dykes

Scattered widely throughout the southern half of the map-area are melanocratic dykes ranging in width from less than a foot to more than 200 feet. They cut both granitic and metamorphic rocks.

In the field, these rocks are massive and dark grey to black; some are rather greenish. In size, the grains range from medium to aphanitic (*see* Pl. XXIII). Small phenocrysts of black pyroxene or biotite, in some samples altered to a dark green, felty material, are visible in many such rocks. Some samples contain small, rounded inclusions of granitic material or quartz.

In the eastern part of the map-area, these dykes dip steeply to the east and trend between N20°E and N10°W; in the western part of the map-area (*see* Fig. 6), they dip various amounts to the west and strike between N55°E and N35°W. Granitic stocks south of the Ruby Range quartz diorite are all cut by basic dykes, whereas those to the north are not.

Contacts of the dykes with the country rocks tend to be sharp and straight, though a few with gentle dips are irregular. Several follow faults (transverse contacts offset), and some are themselves sheared and some not. Others follow joint sets. Some dykes, including many of those that are sheared, are deeply weathered, leaving deep clefts through ridges in the surrounding rocks. Some inclusions of granitic country rocks are not uncommon.

TABLE VI | *Modes of Lamprophyric Dykes and Serpentinized Dunite (visual estimates in volume per cent (averages))*

Rock type	Map-unit 22[1]		Dunite[2]
Mineral	Composition	Range	Composition
Quartz	.1	0 – .5	
Plagioclase	52	35 – 63	
Biotite	9	.5 – 25	
Hornblende	17	0 – 40	
Actinolite	7	0 – 18	5
Chlorite	.7	0 – 2	1
Epidote	1	0 – 3	
Augite	11	0 – 30	
Olivine	.8	0 – 3	88
Calcite	.6	0 – 2	
Talc	2	0 – 15	2
Apatite	.4	0 – 1	
Sphene	.1	0 – .5	
Nepheline	.3	0 – 2	
Garnet	tr	0 – tr	
Serpentine			4
Magnetite–ilmenite	.6		1
Hematite	.4		
Pyrite	.4		
% An of plagioclase	62	50 – 78	
No. of sections represented	4		

[1]Seven thin sections examined.
[2]One thin section examined.
tr = trace.

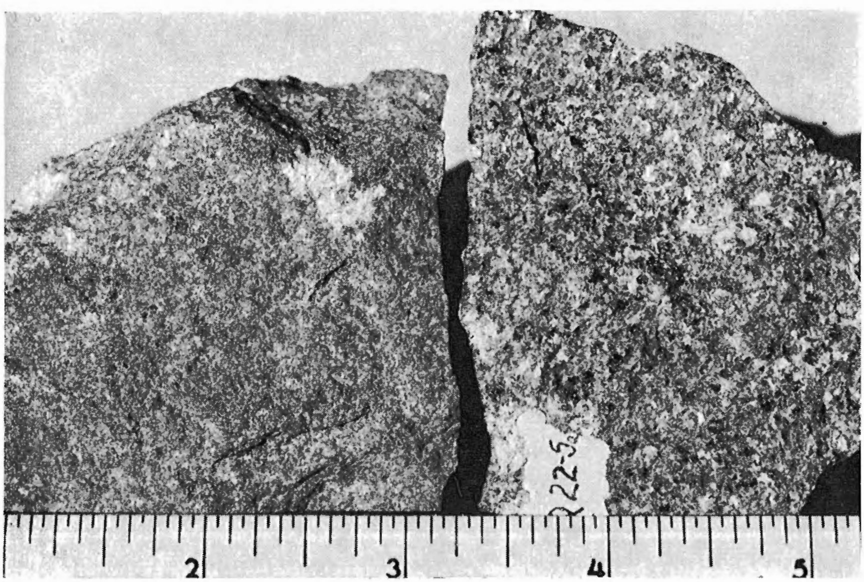


PLATE XXIII. Hand specimens from unit 22; lamprophyre.

Serpentinized Dunite

This rock is exposed only within the amphibolite, just west of the top of Scalping Knife Mountain. It forms a conformable band about 5 to 50 feet thick, and was followed for some 2,000 feet. The weathered surface shows a rough, streaky banding and a secondary foliation parallel with the contacts. Fresh surfaces are rough and almost massive, except where scattered, $\frac{1}{4}$- to $\frac{1}{2}$-inch, subradiating groups of actinolite "spatter" the surface (*see* Pl. XXIV). No sign of slickensides was found between the dunite and the bordering amphibolite.

Mineralogy and Petrography

Unit 22: Lamprophyric Dykes

The lamprophyric dykes are composed of spessartite grading to kersanite, in which plagioclase (labradorite or bytownite) is an essential mineral and the dominant mafic mineral (augite, hornblende, or olivine) occurs in two generations (*see* Pl. XXV). The most common rock type contains about 50 per cent plagioclase, 25 per cent augite, in two generations, and 15 to 20 per cent biotite.

The texture, largely reflected in the prominent mafic minerals, is idiomorphic, inclining to hypidiomorphic. Early-formed phenocrysts of colourless to pale green augite, brown to red-brown hornblende, or colourless olivine, are generally euhedral and highly altered. Small later-formed grains of augite and hornblende are euhedral to subhedral, and those of olivine are subhedral to anhedral. They are almost unaltered. Biotite, present in every rock, is usually euhedral. Plagioclase occurs as

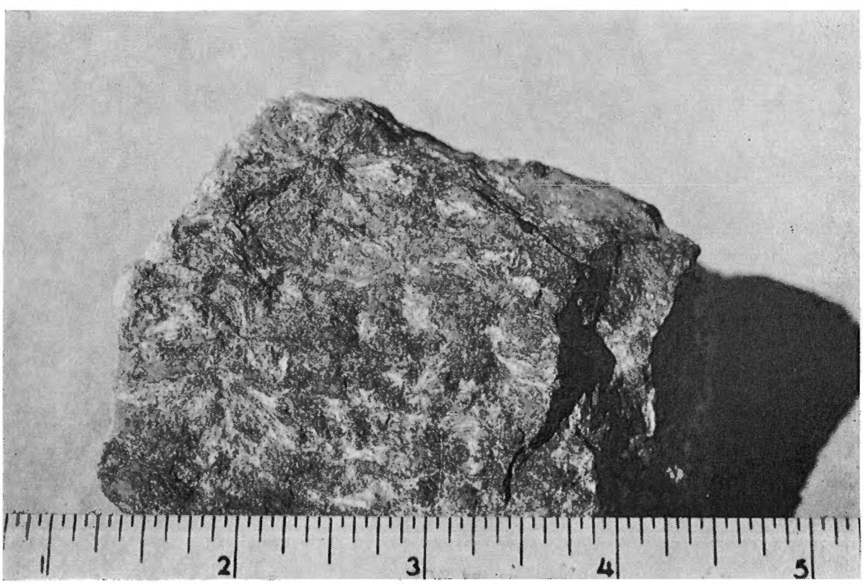


PLATE XXIV. Hand specimen of serpentinized dunite.

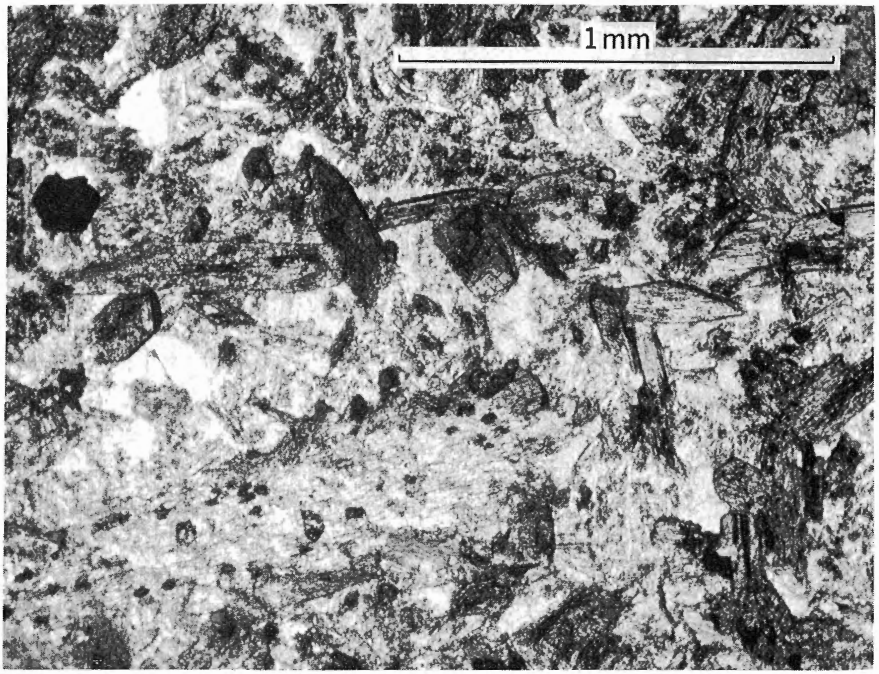


PLATE XXV. Photomicrograph of lamprophyre showing two generations of amphibole. One coarse (early) pseudomorph of actinolite after hornblende occupies much of the lower left quarter of the photo. (plane light).

anhedral to almost euhedral grains, some of which are lath-shaped. It is zoned, commonly, to more sodic rims and twinned on the albite, carlsbad, and pericline laws. The rocks show no apparent preferred orientation of mineral grains. Post-crystallization strain in some rocks is shown, though quartz is almost absent, by bent or broken grains of biotite.

Accessory minerals include actinolite pseudomorphous after phenocrysts of augite and hornblende, talc after phenocrysts of olivine, chlorite after biotite, and epidote (pistacite), calcite, nepheline, apatite, sphene, garnet, and opaque ores (magnetite and/or ilmenite, hematite, and "pyrite" rimmed by hematite). The plagioclase is partly saussuritized.

Serpentinized Dunite

These rocks comprise almost entirely anhedral, subequant grains of forsterite ($Fo_{96\pm4}$ $Fa_{4\pm4}$, by x-ray, using the determinative curve of Yoder and Sahama, 1957, p. 484), $\frac{1}{2}$ cm to 1 cm across. The rock is streaked by a set of subparallel shears and the olivine shows undulose extinction and segmentation. The olivine has been partly replaced by actinolite, serpentine (along fractures), talc, and colourless chlorite ($2V_Z$=35° ±4, probably "clinochlore"). Actinolite shows preferred orientation, and some grains are slightly bent.

TABLE VII | *Chemical Analyses and Norms of Granitic Rocks*

Map unit	13	21	21	14A	14B	15	16A	16B	16B
Chemical Analysis	108-12	35-1	119-9	119-1	119-4	K23-RA1	15-3	119-2	120-18
SiO_2	66.9	62.4	63.2	66.2	68.8	65.6	59.7	60.0	62.8
Al_2O_3	16.1	18.5	15.6	16.3	15.3	16.6	17.5	16.0	15.4
Fe_2O_3	0.2	1.7	1.5	0.1	< 0.1	1.0	1.6	1.3	0.3
FeO	1.1	1.18	0.9	0.6	0.4	0.89	3.76	3.4	2.7
CaO	2.0	1.9	2.0	1.7	1.3	1.5	4.6	5.3	4.7
MgO	2.0	0.77	2.0	2.9	2.0	0.90	2.0	3.4	3.2
Na_2O	5.4	3.5	3.9	5.2	6.0	5.3	3.7	2.8	3.4
K_2O	5.0	8.9	8.1	3.5	3.5	7.0	3.5	3.2	3.0
H_2O	0.1	0.28	0.4	0.3	0.4	0.24	1.0	0.9	0.7
TiO_2	0.3	0.36	0.4	0.2	0.1	0.22	0.62	0.6	0.4
P_2O_5	< 0.1	0.04	0.1	< 0.1	0.1	0.06	0.34	0.4	0.3
MnO	< 0.1	0.13	0.1	< 0.1	< 0.1	0.06	0.14	0.1	0.1
CO_2	0.3		0.6	0.1	< 0.1		0.31	0.1	< 0.1
Total	99.4	99.7	98.8	97.2	97.9	99.4	98.8	97.5	97.0
Norm									
ap	0.21	0.08	0.21	0.21	0.21	0.1	0.73	0.87	0.65
il	0.41	0.50	0.56	0.28	0.14	0.3	0.89	0.87	0.58
or	29.20	52.52	48.35	20.88	20.70	41.0	21.27	19.68	18.36
ab	47.82	31.31	35.30	47.04	53.80	47.0	34.09	26.11	31.55
an	4.82	8.39	1.09	7.85	4.45	0.8	21.17	22.45	18.48
cor				1.20			0.06		
mt	0.21	1.77	1.50	0.11	0.10	1.0	1.71	1.41	0.32
hem			0.05						
wo	1.74	0.30	3.31		0.54	2.6		0.88	1.46
en	5.49	2.14	5.61	8.13	5.56	2.4	5.71	9.83	9.21
fs	1.28	0.34		0.74	0.57	0.4	4.16	3.82	3.69
qtz	8.82	2.64	4.02	13.55	13.94	4.4	10.21	14.10	15.71
di									
ol									
$\frac{\text{orthoclase}}{\text{feldspar}}$	35.68	56.95	57.06	27.56	26.22	46.6	27.79	28.84	26.85
$\frac{\text{An}}{\text{An + Ab}}$	9.16	21.13	2.98	14.31	7.63	1.67	38.32	46.32	36.93

Key to Table VII

HQ 108-12: quartz monzonite from 6¾ miles due west of Nakusp, lat. 50°14′15½″, long. 117°57′38″, elev. 2,200 feet.

HQ 35-1: syenite from south side of highway, three-quarters of a mile northwest of Summit Lake, elev. 2,450 feet.

HQ 119-9: syenite from top of Allshouse Peak, lat. 50°10′44″, long. 117°42′26″, elev. 6,050 feet.

HQ 119-1: quartz monzonite from 1¼ miles south-southeast of Wragge Lake, lat. 50°00′44″, long. 117°32′05″, elev. 7,520 feet.

HQ 119-4: quartz monzonite from 1¼ miles west of the south end of Shannon Lake, lat. 50°03′17″, long. 117°36′36″, elev. 7,420 feet.

K23-RA1: quartz monzonite from a mile east-northeast of the west end of Wilson Lake, elev. 3,900 feet.

HQ 15-3: quartz diorite from head of the westernmost north-flowing tributary of Slewiskin Creek.

HQ 119-2: quartz diorite from south end of small lake a mile southwest of Wragge Lake, lat. 50°00′54½″, long. 117°33′47″, elev. 7,050 feet.

HQ 120-18: quartz diorite from north side of ridge, 1½ miles south of Shannon Lake, lat. 50°02′05½″, long. 117°35′42″, elev. 7,200 feet.

17	17	18	18	18	19	19a	20	20	Map unit
119-8	134-6	54-1	54-2	119-3	S28-7	119-5	6-1a	102-1	Chemical Analysis
57.3	62.0	69.7	69.9	68.3	67.1	49.8	66.8	63.5	SiO_2
18.0	16.0	17.5	16.6	16.0	15.6	18.0	18.1	16.8	Al_2O_3
0.3	1.2	0.88	0.84	0.6	0.9	< 0.1	1.6	1.1	Fe_2O_3
3.8	3.3	1.54	1.56	1.6	2.1	8.0	1.59	2.3	FeO
5.4	5.0	2.6	3.3	3.1	2.9	7.7	3.2	3.8	CaO
3.0	4.1	0.77	0.31	2.0	2.3	5.9	0.83	2.7	MgO
5.5	3.4	3.9	3.4	3.3	3.2	3.0	4.0	4.6	Na_2O
2.4	3.2	3.1	3.5	3.5	4.2	2.6	3.6	2.7	K_2O
1.0	1.0	0.55	0.64	0.5	0.9	1.4	0.58	0.5	H_2O
0.8	0.6	0.32	0.35	0.4	0.4	0.1	0.42	0.6	TiO_2
0.3	0.3	0.15	0.16	0.2	0.2	0.7	0.15	< 0.1	P_2O_5
0.1	0.1	0.06	0.16	0.1	0.1	0.2	0.11	0.1	MnO
0.3	< 0.1	0.03		< 0.1	< 0.1	0.1	0.10	0.1	CO_2
98.2	100.2	101.1	100.7	99.6	99.9	97.5	101.1	98.8	Total
									Norm
0.63	0.63	0.31	0.34	0.42	0.42	1.51	0.31	0.21	ap
1.12	0.84	0.44	0.49	0.56	0.56	0.41	0.58	0.84	il
14.34	19.01	18.31	20.89	20.95	25.16	15.84	21.24	16.09	or
49.84	30.63	34.92	30.77	29.95	29.07	27.71	35.79	41.57	ab
17.48	18.98	11.91	15.48	14.25	13.26	28.75	14.87	17.31	an
		3.64	1.74	1.77	1.08		2.33		cor
0.32	1.26	0.92	0.88	0.63	0.95	0.11	1.66	1.16	mt
									hem
3.05	1.59							0.42	wo
8.43	11.45	2.14	0.87	5.63	6.48	1.59	2.30	7.56	en
4.75	3.60	1.41	1.60	1.67	2.25	1.20	0.93	2.13	fs
0.04	12.01	26.01	26.94	24.16	20.78		19.97	12.72	qtz
						4.72			di
						18.43			ol
17.57	27.71	28.11	31.12	32.16	37.29	21.91	29.55	21.47	$\frac{\text{orthoclase}}{\text{feldspar}}$
25.97	38.27	25.43	33.47	32.24	31.32	50.93	29.35	29.40	$\frac{\text{An}}{\text{An + Ab}}$

HQ 119-8: diorite from three-quarters of a mile east of saddle at head of Blue Grouse Creek, lat. 50°04′57½″, long. 117°43′59″, elev. 6,600 feet.

HQ 134-6: quartz diorite from road cut on east side of upper Rodd Creek, lat. 50°04′24″, long. 117°48′59″, elev. 4,400 feet.

HQ 54-1: quartz monzonite from west side of small cirque, a mile east of Shannon Lake, elev. 6,950 feet.

HQ 54-2: quartz monzonite from head of cirque, extreme headwaters of Wragge Creek, elev. 6,920 feet.

HQ 119-3: quartz monzonite from a third of a mile west of divide at westernmost headwaters of Wragge Creek, lat. 50°02′17″, long. 117°35′19″, elev. 7,200 feet.

HQS 28-7: quartz monzonite from a quarter mile northeast of main bend in Halifax Creek, lat. 50°01′23″, long. 117°42′23″, elev. 5,500 feet.

HQ 119-5: diorite from 1¼ miles north of headwaters of Halifax Creek, lat. 50°01′25″, long. 117°39′53″, elev. 6,950 feet.

HQ 6-1a: granodiorite from Caribou Creek, 2 miles east of Burton, elev. 1,800 feet.

HQ 102-1: granodiorite from 1¼ miles northeast of Sand Island, lat. 50°03′32″, long. 117°53′45½″, elev. 2,600 feet.

TABLE VIII — *Modes of Chemically Analyzed Granitic Rocks (by grain count of 2,500 points minimum)*

Map unit	13	21	21	14A	14B	15[2]	16A	16A	16B	16B
Mode	108-12	35-1	119-9	119-1	119-4	K 23-RA 1	15-3[1]	15-3	119-2	120-18
Quartz	11.4	0.1	0.7	11.7	15.3	14.6	21.6	18.4	17.4	16.5
K-feldspar	38.6	71.1	68.9	30.7	28.2	43.6	6.8	20.8	10.3	20.1
Plagioclase	43.3	21.2	21.7	52.4	51.7	37.9	51.3	43.6	48.1	42.2
Biotite		0.3	0.1	0.2			3.7	3.1	7.0	8.3
Hornblende	2.9			1.9	0.6		14.8	12.6	12.8	8.7
Chlorite				<0.1			0.3	0.3	0.1	0.1
Apatite	<0.1	<0.1	<0.1	<0.1			0.1	0.1	0.3	0.2
Sphene	0.5	0.3	<0.1	0.1	0.1		0.6	0.5	0.3	0.1
Clinopyroxene	3.3	7.0	8.3		2.2	2.9				
Allanite				<0.1					<0.1	<0.1
Zircon	<0.1	<0.1		<0.1						
Prehnite										
Epidote				3.0	1.9		0.4	0.3	3.2	3.3
Tourmaline										
Magnetite–ilmenite	tr		tr	tr			0.4	0.3	0.3	0.2
Hematite			tr						0.1	0.2
Pyrite–pyrrhotite									0.1	0.2
Light accessory						0.1				
Dark accessory						0.9				
K-feldspar megacryst							15.			
An of plagioclase	29	0	0	29	1	2	31		39	31
Trace elements										
% Rb	.005	.020	.008	.003	.003		.010		.004	.004
% Sr	.14	.109	.089	.16	.018		.08		.069	.068
% Ba	.06	.06	.20	.07	.11		.21		.10	.10
% Zr	tr	.030	.010	nd	.025		.035		nd	nd
% Cr	nd	nd	nd	nd	tr		nd		tr	tr
% V	nd	nd	nd	nd	nd		nd		.008	.005
% Y	nd	≈.002	nd	nd	nd		nd		nd	nd
% Ni	nd	tr	nd	nd	nd		tr		nd	nd

[1]Excluding megacrysts of K-feldspar.
[2]Rosiwal Determination by J. E. Reesor.
tr = trace.
nd = not determined.

Compositional Grouping

The granitic stocks in the Nakusp area fall into two major compositional groups, possibly representing distinct "magma series".

(1) Generally leucocratic, hornblende, aegirine–augite and/or epidote granite, quartz monzonite, and possibly syenite. Stocks of this group (units 14A, 14B, 15, 21) are exposed in the northern part of the area, except for two small stocks in the eastern part. The lineated quartz monzonites, in the

17	17	18	18	18	19	19a	20	20	20	20	Map unit
119-8	134-6	54-1	54-2	119-3	S28-7	119-5	6-1a[1]	6-1a	102-1[1]	102-1	Mode
7.3	15.6	29.9	20.9	32.8	19.1	2.6	29.2	23.4	17.2	15.6	Quartz
9.7	13.2	25.2	27.3	17.9	30.4		1.2	21.0	6.2	15.1	K-feldspar
54.5	44.0	38.2	39.0	36.3	31.0	49.8	58.7	47.0	61.9	56.0	Plagioclase
9.5	0.9	3.6	6.5	8.6	10.3	21.8	2.1	1.7	6.8	6.2	Biotite
14.9	11.2	0.2	4.6	0.4	7.2	17.3	3.6	2.9	4.0	3.6	Hornblende
0.5	7.1	0.6	<0.1	0.1	<0.1	0.1	2.1	1.7	1.2	1.1	Chlorite
0.1	<0.1		<0.1	0.1	0.1	0.9	0.2	0.2	0.3	0.3	Apatite
0.2	0.5	0.4	0.4	0.2	0.1	2.1	0.8	0.6	0.8	0.7	Sphene
						5.4					Clinopyroxene
				0.1					0.1	0.1	Allanite
											Zircon
	0.2						<0.1	<0.1			Prehnite
2.8	7.0	1.6	1.1	3.2	1.8						Epidote
					<0.1						Tourmaline
0.5		0.1	0.1	0.2		<0.1	1.0	0.8	1.2	1.0	Magnetite–ilmenite
		0.1	0.1								Hematite
				0.1							Pyrite–pyrrhotite
											Light accessory
											Dark accessory
							20.0		9.5		K-feldspar megacryst
33	39	33	34	32	30	40	25		29		An of plagioclase
											Trace elements
.003	.004	.017	.017	.007	.007	.006	.012		.002		% Rb
.054	.065	.075	.075	.068	.057	.012	.08		.087		% Sr
.05	.07	.16	.20	.08	.06	.10	.20		.05		% Ba
.014	nd	.035	.030	.007	.007	.009	.04		.010		% Zr
tr	tr	nd	nd	tr	tr	nd	nd		.02		% Cr
nd	nd	nd	nd	nd	nd	.008	nd		nd		% V
nd	nd	≈.001	<.001	nd	nd	nd	<.001		nd		% Y
nd	nd	tr	tr	nd	nd	nd	tr		nd		% Ni

high-grade metamorphic rocks in the northwestern corner of the area, are also included here. This "alkalic suite" is of the type referred to in earlier works (e.g., Cairnes, 1929) as "Kuskanax granite".

(2) Biotite and hornblende quartz monzonite, granodiorite, and quartz diorite. Stocks of this group (units 16A to 20) are exposed in the southern half of the area. This "calc-alkalic suite" is of the type referred to in earlier works (e.g., Little, 1960) as "Nelson plutonic rocks", except for unit 18 which is probably the type referred to as "Valhalla Plutonic rocks".

Isotopic Ages and Time of Intrusion

The ages of biotite from four samples from granitic plutons in the Nakusp area have been determined by the potassium–argon (K–Ar) radioactive decay method in the laboratories of the Geological Survey of Canada. The samples were chosen from those taken for chemical analysis, and have the same field numbers (*see* Tables VII and VIII); their age, location, and nature are as follows:

Sample from unit 17: HQ 119-8

K–Ar age: 123 m.y. ($\pm$10 m.y.)

Location: ridge crest three-quarters of a mile east of saddle at the head of Blue Grouse Creek. Elevation 6,600 feet.

(Ref.: Wanless, *et al.*, 1965, p. 18)

Nature of sample: The rock is a biotite–hornblende diorite. It is medium grained, hypidiomorphic- to allotriomorphic-granular, as the mafic and felsic minerals, except for most of the plagioclase, have been reduced in grain-size.

Sample from unit 18: HQ 119-3

K–Ar age: 74 m.y. ($\pm$6 m.y.)

Location: a third of a mile west of divide at the westernmost headwaters of Wragge Creek.

(Ref.: Wanless, *et al.*, 1965, p. 20)

Nature of sample: The rock is an epidote–biotite quartz monzonite. It is medium grained, hypidiomorphic-granular, and massive. Microcline is present to a small extent as coarser, poikilitic grains. Biotite occurs as scattered grains (0.2 mm to 2 mm) closely associated with pleochroic epidote. Some of the biotite is slightly bent and quartz shows undulose extinction. Chlorite in the analyzed biotite amounts to about 1 per cent.

Sample from unit 19: HQS 28-7

K–Ar age: 107 m.y. ($\pm$8 m.y.)

Location: ridge crest 1.2 miles east-northeast of the mouth of Halifax Creek.

(Ref.: Wanless, *et al.*, 1965, p. 19)

Nature of sample: The rock is a non-porphyritic hornblende–biotite quartz monzonite. It is medium grained, hypidiomorphic-granular, and massive. The mafic minerals tend to occur in small groups. Biotite grains (0.1 mm to 2 mm) are somewhat bent and quartz shows strong undulose extinction. Chlorite in the analyzed biotite amounts to about 3 per cent.

Sample from unit 20: HQ 6-1a

K–Ar age: 69 m.y. ($\pm$6 m.y.)

Location: Caribou Creek at bridge 2.8 miles east of Burton.

(Ref.: Leech, *et al.*, 1963, pp. 28–29)

Nature of sample: The rock is a megacryst-bearing (potassium feldspar) biotite–hornblende quartz monzonite. It is medium grained and essentially massive. Biotite is present as small clusters of grains ($\frac{1}{2}$ mm to 2 mm) interstitial to the felsic minerals (2 mm to 5 mm), commonly associated with sphene and to a lesser extent hornblende. It is strongly pleochroic, red-brown to pale yellow. The whole rock has suffered intergranular "crushing". Edges of biotite grains are ragged and commonly chloritized (about 6% of the analyzed biotite). Quartz has been segmented into a mosaic of small grains, with complexly interlocking boundaries. Modes and chemical analyses for each of these samples are given in Tables VII and VIII.

Though these isotopic ages could be younger than the rocks from which they were derived (because of later argon loss), there is no clear evidence from geological relationships that such is the case.

Each of the granitic plutons intrudes and/or alters the surrounding rocks and is therefore younger. It has been shown (Chapter II, Age of Metamorphism) that the plutons are younger than the regional metamorphism affecting the country rocks (including Triassic and probably lower Jurassic rocks). Potassium–argon ages from two granitic plutons whose contact metamorphism is younger than the regional metamorphism are 69 $\pm$ 6 and 74 $\pm$ 6 m.y. Those from two other plutons, less certainly younger than the regional metamorphism, are 107 $\pm$ 8 and 123 $\pm$ 10 m.y. These "absolute" ages, within the limits of accuracy quoted, presumably represent the youngest date at which the specimen could have crystallized. The time of intrusion of these quartz monzonite plutons was therefore during the Jurassic and/or Lower (and possibly Upper) Cretaceous periods. Other stocks could, of course, be younger.

Sequence of Intrusion

The field relationships described in this report permit the following conclusions to be drawn regarding the relative ages of the various intrusions:

(1) The lineated leuco-quartz monzonite (unit 13) is enclosed as sheets in part of the megacryst-bearing Lower Caribou Creek quartz monzonite (unit 20), and is therefore older.

(2) The Wragge Creek stock (unit 18) has gradational contacts with the Shannon Lake and the South Wragge Creek stocks. Pegmatite dykes cutting both stocks probably originated in the Wragge Creek stock for the following reasons: similar dykes emerge from it to intrude the country rocks elsewhere; no such dykes have been seen to originate in the leucocratic stocks; and the hydrous mafic minerals of unit 18 (biotite) suggest a 'normal' water content, whereas those of unit 14 (hornblende and epidote) suggest a lower water content.

(3) The East Caribou stock (16B) is intruded by dykes of quartz monzonite from the Wragge Creek stock (18), and occurs as inclusions in them; therefore, it is the older.

(4) The Box Mountain stock (21) is cut by a dyke of fine-grained leucocratic granite texturally resembling that of the Allshouse Peak pluton (unit 15). Correlation is not certain because no sodic hornblende nor pyroxene was seen in the dyke, but it at least suggests that the Allshouse Peak body is younger than the syenite.

(5) Lamprophyre dykes (unit 22) cut granitic units 14, 16B, 18, 19, and 20.

(6) Lithological similarity suggests that the following groups of granitic units are contemporaneous, or nearly so, relative to the other units: units 14A, 14B, and probably 15; units 16A and 16B; and units 18 and 19.

The data on the relative age of each of the plutons is sketchy, primarily because few are in mutual contact. Nonetheless the considerations listed above suggest the following tentative sequence of intrusion.

Youngest
lamprophyre dykes (unit 22)
Lower Caribou Creek stock (20)
Goatcanyon–Halifax Creeks stock (19)
and Snowslide and Wragge Creeks stocks (18)
Ruby Range stock (17), (?)Mountain Meadow pluton (16A),
and East Caribou stock (16B)
South Wragge Creek stock (14A), Shannon Lake stock (14B),
and (?)Kuskanax batholith (15)
?Box Mountain stock (21)
Oldest

In the absence of definite field evidence, the position of the Box Mountain syenite is uncertain. Lithologically, it is like the Coryell syenite that intrudes Nelson and Valhalla plutonic rocks south of Nakusp area (Little, 1960, p. 93), and has been assigned a Tertiary age. Tentatively, therefore, the Box Mountain syenite is considered to be the youngest granitic pluton in the area (post-unit 20).

The nature and correlation of the lineated leuco-quartz monzonite (unit 13) remains a problem. These rocks in hand specimen are virtually identical with those of the Shannon Lake, south Wragge Creek, and Kuskanax stocks (units 14A, 14B, and 15), except that they have a characteristic strong mineral lineation parallel with the mineral and wrinkle lineation in the enclosing metamorphic rocks. The mineralogical compositions of these stocks (especially units 14A and 14B (*see* Table V)) and the chemical analyses of representative samples (Table VII) are also essentially identical with the lineated quartz monzonite. Of particular interest is the presence of aegirine–augite in the northernmost exposures of the lineated rocks north-northwest of Saddle Mountain, as well as in the Kuskanax leucogranite. The only recognizable difference between the lineated quartz monzonite and the stocks (units 14A and 14B) is the absence of epidote in the lineated rocks. The lineated leuco-quartz monzonites are considered to be an early syntectonic phase of the Kuskanax type, intruded before the end of regional metamorphism. The massive leucocratic alkalic stocks, on the other hand, are clearly post-regional metamorphism.

Significance of Feldspars

Three problems are raised by the feldspars of the granitic rocks: (1) the origin (magmatic or post-magmatic) of the potassium feldspar megacrysts of the Lower Caribou Creek stock; (2) the origin (by magmatic crystallization or exsolution) of albite in leucogranites of the Kuskanax type; (3) the relation of orthoclase to microcline in rocks containing both minerals.

Megacrysts of the Lower Caribou Creek Stock

The gradational contact between the Lower Caribou Creek stock and the Goatcanyon–Halifax Creeks stock has been described. The following evidence appears to indicate that the megacrysts of potassium feldspar, at least in the transitional zone, have developed after consolidation of the rock: (1) a gradational contact through an indistinct poikilitic zone over half a mile to a mile wide is present between the 'non-porphyritic' quartz monzonite and a rock containing several per cent of well-developed megacrysts; (2) the mode of the rock containing megacrysts is essentially the same as that of the rock lacking megacrysts, potassium feldspar occurring largely as megacrysts in one, and in the groundmass in the other; (3) the

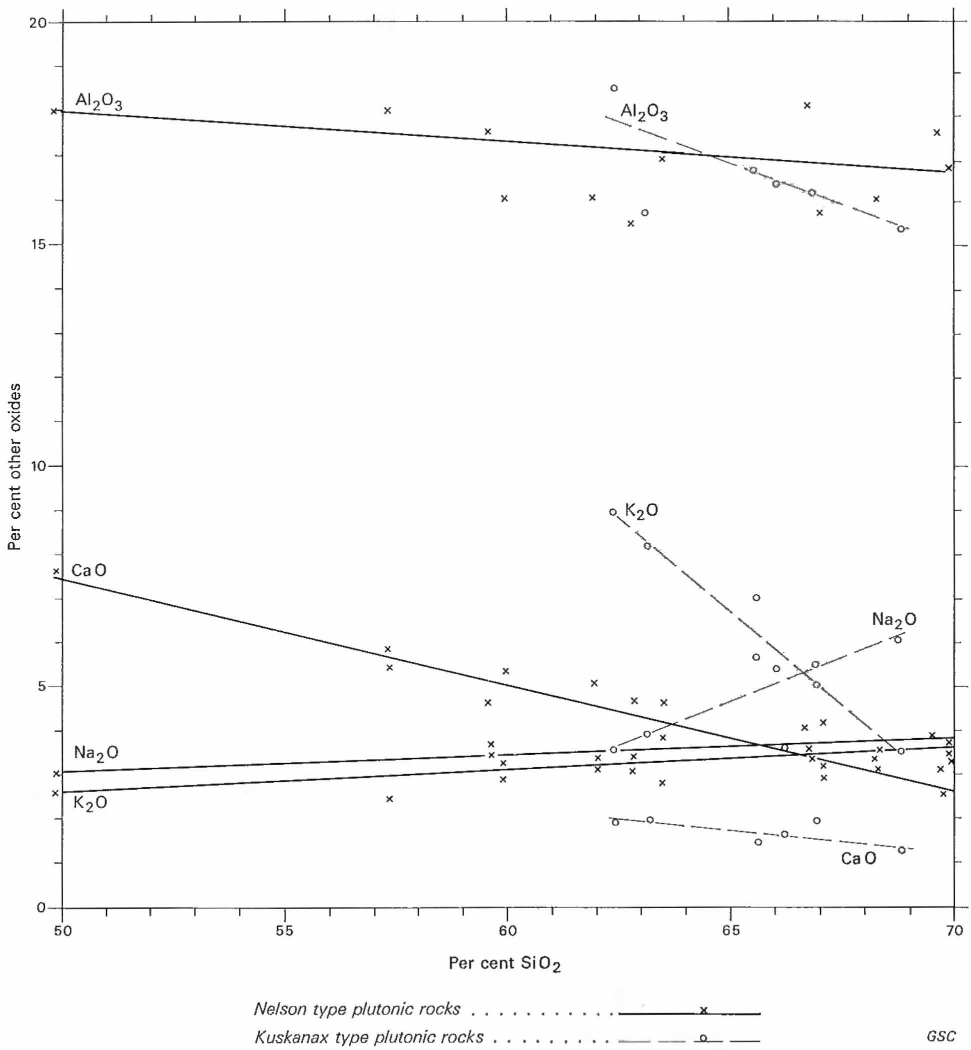


FIGURE 9. **Variation diagram for some of the important oxides in the two main types of granitic rocks in Nakusp area.**

composition of the rock is such that plagioclase would crystallize first and phenocrysts of potassium feldspar would not be expected, as shown in an empirical diagram by Heald (1950, p. 85) and in recent experimental work by Yoder, *et al.* (1957); (4) the percentage, type, and distribution of mafic minerals in megacrysts of the transitional zone is the same as in the groundmass; (5) porphyroblasts of potassium feldspar are absent from the country rocks.

This evidence suggests that the stocks were intruded as a single unit, and the potassium feldspar was remobilized into megacrysts during a late stage of consolidation, or subsequent to it.

Albite in Leucogranites of the Kuskanax Type

In leucocratic granites of the Kuskanax type, some of the albite, present as perthitic streaks enclosed in potassium feldspar, can be attributed with confidence to exsolution in the course of cooling. Some of the albitic rims to crystals of potassium feldspar may well have a similar origin (cf. Tuttle, 1952, p. 115, Pl. II), but it is also possible that they represent late magmatic crystallization from a residual soda-rich interstitial melt. The interstitial mosaic of albite grains observed in some granites of unit 15 would normally be interpreted as magmatic in origin, but it is still possible, if Tuttle's (1952, p. 115) reasoning is accepted, that this albite too is due to exsolution during very slow cooling. Such might be expected if the magma had been intruded into relatively hot rock in the later stages of regional metamorphism. If any of the albite is indeed magmatic, then a low temperature ($<700°C$) of final crystallization is implied, for in the alkali feldspar system at 5,000 bars P_{H_2O}, the solvus cuts the solidus at about 700°C (Yoder, *et al.*, 1957, pp. 206–214). Coexistence of albite and potassium feldspar is possible only below this temperature.

The Relation of Orthoclase to Microcline

In several of the granitic rocks, orthoclase and microcline are closely associated within individual crystals. "Orthoclase" was identified only by absence of visible twinning, and by straight extinction in the (010) zone. This, however, does not preclude a small degree of triclinicity in the potassium feldspar. The evidence here for the association of microcline twinning with strain supports the contention of Laves (1950, p. 556) that microcline crystallizes first with monoclinic symmetry and subsequently acquires triclinic symmetry. The observation that perthitic albite also is commonly associated spatially with optical evidence of strain, may indicate, as suggested by MacKenzie (1954, p. 365), that exsolution of albite may be necessary to permit the lattice angles to " . . . approach those of a 'maximum' microcline". The presence of albite in solid solution may perhaps stabilize the "orthoclase" structure.

Chemical Variation

The range of chemical composition in the two major groups of granitic rocks is summarized on Figure 9. Rocks of the "Kuskanax" suite are higher in Na_2O and K_2O, and lower in CaO, than those of the calc-alkalic plutonic suite. In the "Kuskanax" suite Na_2O increases with increasing SiO_2, but K_2O shows a pronounced decrease with increasing SiO_2. The variation in composition of the rocks of the calc-alkalic suite can probably be attributed to assimilation of somewhat variable country rocks, by a common magma, perhaps with some differentiation in the 'magma chamber'. The reason for the compositional difference between the two main groups is not known.

The peripheral, more mafic parts of the Halifax Creek stock (19) are also the parts that are heterogeneous and contain many inclusions of the adjacent metasedimentary country rocks. Since the border phases grade into the rest of the stock, they probably resulted from assimilation of country rock by the quartz monzonite that makes up the bulk of the stock.

Chapter IV

STRUCTURAL GEOLOGY

The major structure of Nakusp map-area is a synclinorium trending east-west through the central part. On the south, the synclinorium is flanked by the Valhalla dome, the northernmost fringe of which reaches the area; on the north it is flanked by the Kuskanax batholith. The west end of the synclinorium is truncated by the Rodd Creek fault and by part of a dome to the northwest in the Shuswap metamorphic terrane. Structures of Nakusp map-area are described in terms of mesoscopic structures measured and examined in the field and of the macroscopic structures inferred from these measurements.

Mesoscopic Structures

In this section are described the type of structures measured in the field, their nature, attitude, and distribution. The scale is that of a hand specimen or an outcrop (Turner and Weiss, 1963, p. 76). S-surfaces (planar structural elements) measured include bedding, schistosity, and cleavage. Lineations measured include intersections of s-surfaces, axes of folded and wrinkled s-surfaces, elongate and aligned mineral grains, and elongate patches of grains. The various structural elements recognized are tabulated below:

S-surface	Defined by
S_1	lithological layering (including bedding)
S_2	metamorphic schistosity (cleavage in non-schistose rocks)
S_3	strain-slip cleavage
S_4	axial plane of folds and wrinkles in S_2
Lineation	**Defined by**
L_1	mineral lineation and crenulation formed at intersection of S_1 and S_2
L_2	fine crenulations in S_2, formed at intersection of S_2 and S_3
L_3	crenulations in S_2, thought to be younger than L_2

The sequence of structures, earliest to latest, is S_1, S_2 and L_1, S_3 and L_2, S_4 and L_3.

Style of Mesoscopic Structures: Form as Seen in Profile

The style of structures is a reflection of the way the rocks behaved during deformation (Turner and Weiss, 1963, pp. 78–79). Styles of mesoscopic folds are commonly similar to the macroscopic folds to which they are related. Figure 10

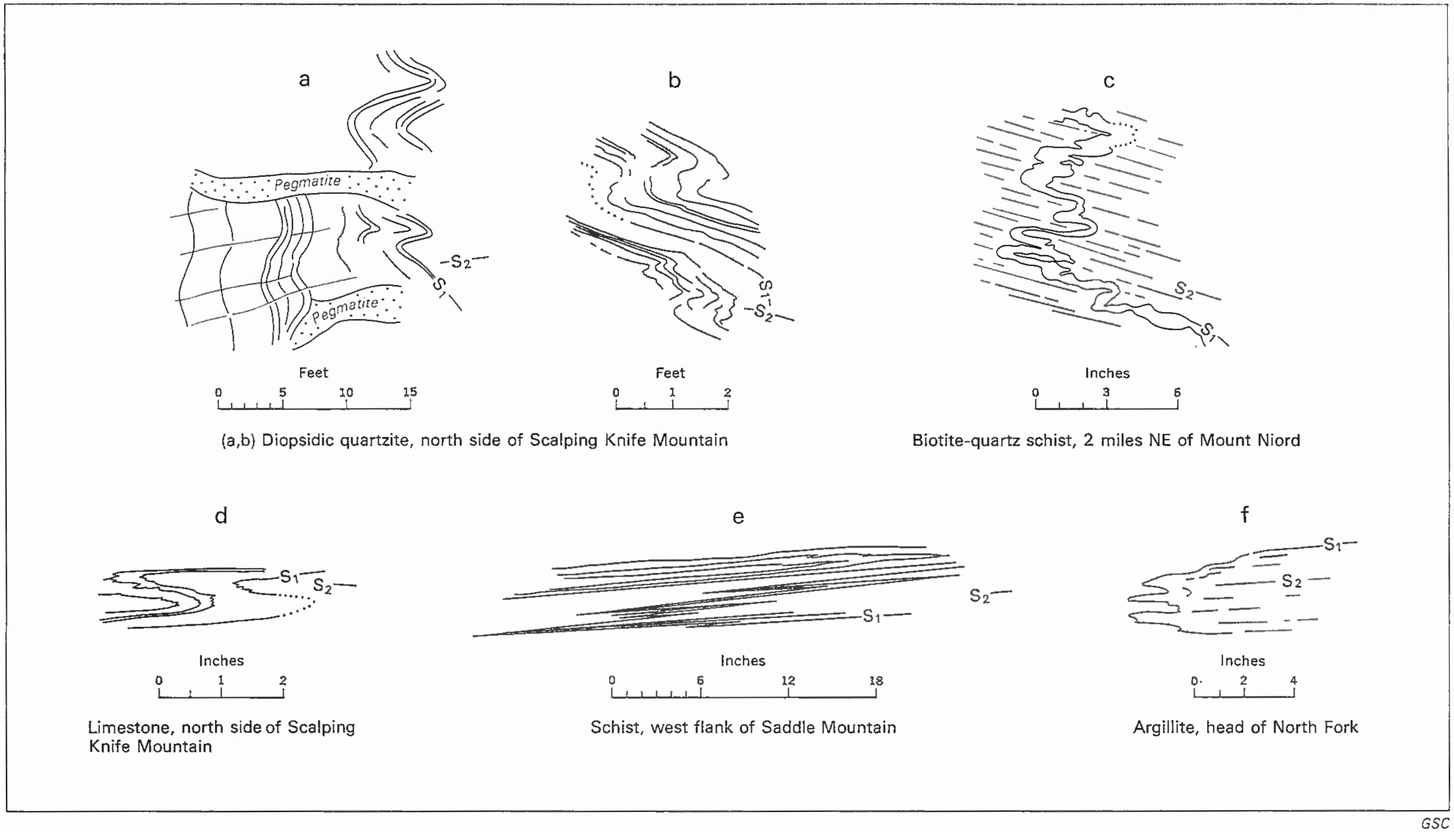


FIGURE 10. Mesoscopic folds in which the schistosity (S_2) of the rock is parallel with the axial surfaces of the folds. S_1 is the folded surface. Sections are normal to the fold axis, viewed down-plunge.

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PLATE XXVI.
Recumbent similar-style folds in diopsidic quartzite on north side of Scalping Knife Mountain. Calcite-rich beds strongly leached.

and Plate XXVI show representative examples of mesoscopic folds in rocks in which the schistosity is parallel with the axial planes of folds in an earlier s-surface. The earliest surface (S_1) is layering, at least some of which is bedding. On Fig. 10c, S_1 is defined by the parallel walls of a dyke of aplitic granite. On 10e, S_1 is almost transposed into the schistosity (S_2). All examples shown on Figure 10 are in rocks of amphibolite grade of metamorphism, except for 10f which is in the greenschist facies.

Figure 11 shows representative examples of mesoscopic folds in which the schistosity S_2 is folded. Bedding S_1 appears to be inclined to the schistosity at a few degrees or, more commonly, to be essentially parallel with it. Some such "bedding" is transposed lithological layering. Axial surfaces of the folds in S_2 are emphasized, locally on Figure 11g by development of an axial-plane cleavage (S_3). S_1 is well developed and S_2 poorly so, in examples 11f and 11g. On a smaller scale, deformation of S_2 has resulted in the formation of fine crenulations (L_2) accompanying the formation of a strain-slip (or fracture) cleavage. Such strain-slip cleavages (*see* Pl. VII) are best developed in rocks of the phyllite belt. A few examples of a fine crease-like lineation have been seen in the phyllite belt. This lineation (L_1) may represent an intersection of bedding (S_1) and schistosity (S_2).

The style of the folds shown on Figure 10 is predominantly similar and essentially isoclinal, although 10c might better be described as ptygmatic. Those folds, however, in which the schistosity is folded (Fig. 11), include kink, similar, and concentric styles.

The presence of bedding at a very low though distinct angle to the schistosity, even where the latter is folded (e.g., in the phyllite belt), suggests an early probably

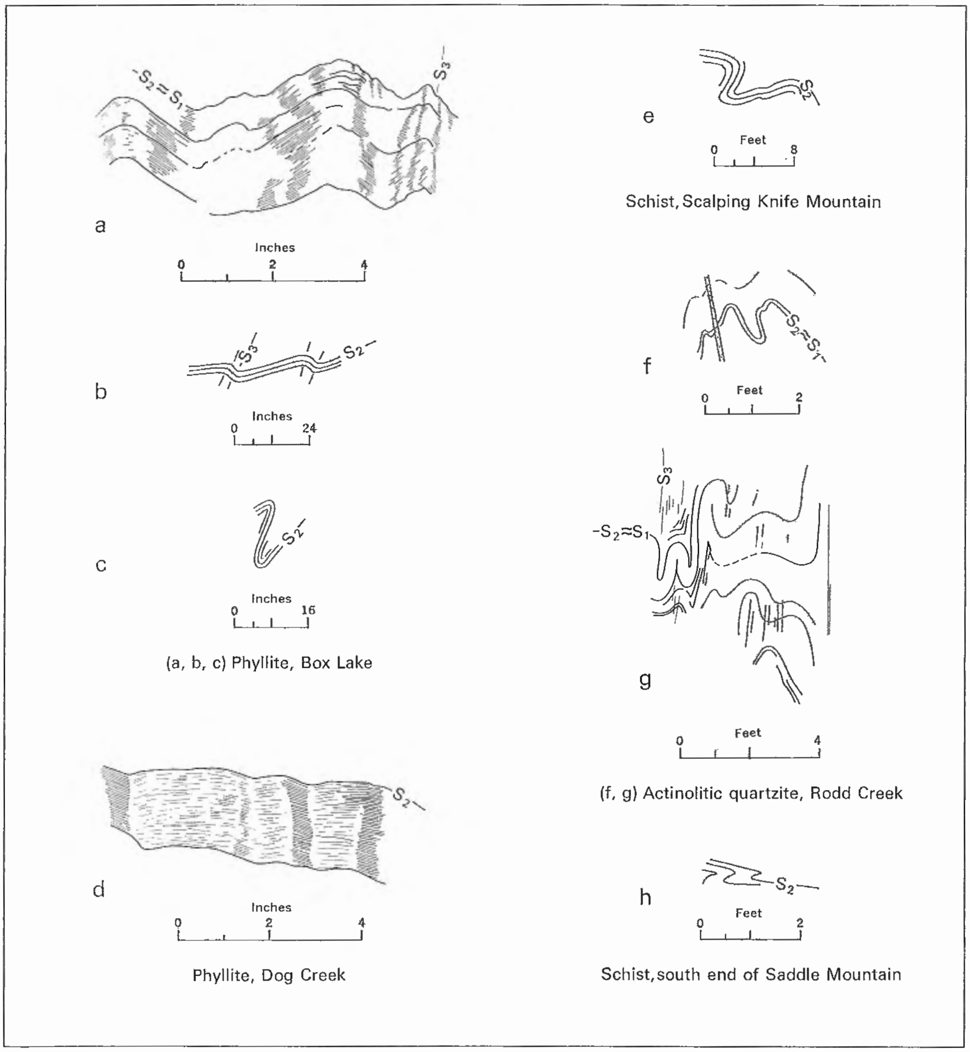


FIGURE 11. Mesoscopic folds in which the schistosity (S_2) of the rock is folded. S_1 appears to be bedding. S_3 is the axial surface to folds in S_2. Sections are normal to the fold axis, viewed down-plunge.

isoclinal folding. Where strain-slip crenulations and kink bands occur in the same rock, the strain-slip wrinkles are very poorly developed or absent in the kink bands (as seen in thin section).

Disharmonic folds that die out rapidly above and below are described as intrafolial. Though less common than the other styles, they are in both the high- and low-grade rocks. Some of these having concentric style and axial planes nearly perpendicular to the adjacent foliation may be pre-consolidation slump structures.

A common type of deformation on the mesoscopic scale is boudinage and segmentation of competent layers of rock, especially pegmatite and aplite, in less competent rock, especially schist or limestone. A few examples are shown on Figure 12. Deformation of the competent layers ranges from attenuation (12a) to fracture (12c).

Orientation of Mesoscopic Structures

Metamorphic rocks of Nakusp map-area have been divided into 25 homogeneous domains or areas in which folding of the schistosity is approximately cylindrical on the scale considered. Poles to the most prominent schistosity or cleavage S_2 in each of these domains (except domain 11, and possibly 8 and 13) lie on a great circle, the pole of which is βs_2. Corresponding lineations in each domain lie in a somewhat diffuse maximum approximately coinciding with βs_2. Figure 16 (*in pocket*) is a map of these domains, showing a small equal-area projection of the lineations and poles to schistosity and cleavage, for each domain. The s-surfaces plotted may have a different significance or age in some of the domains (e.g., where schistosity is dominant in one and cleavage in another), but the similarity of orientation between such domains suggests that this is not the case. The adjacent subdomains, 14

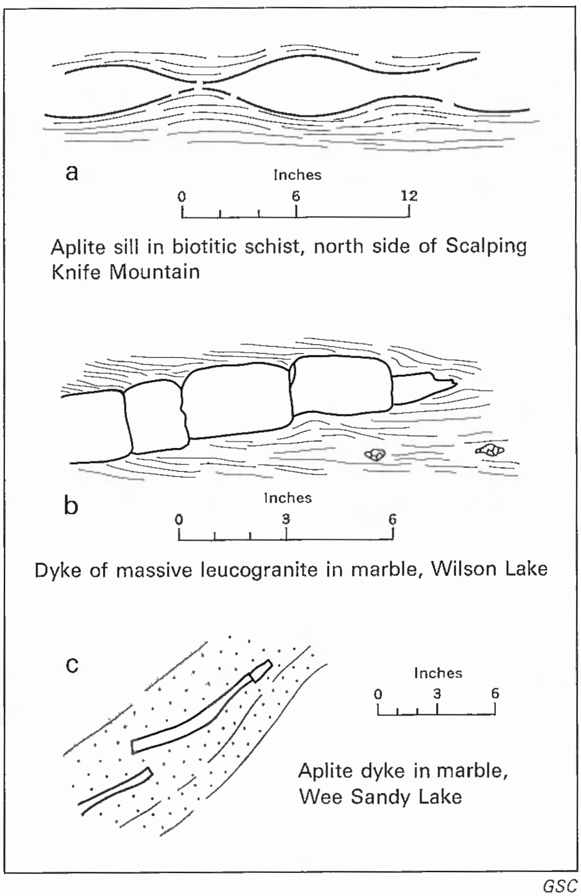
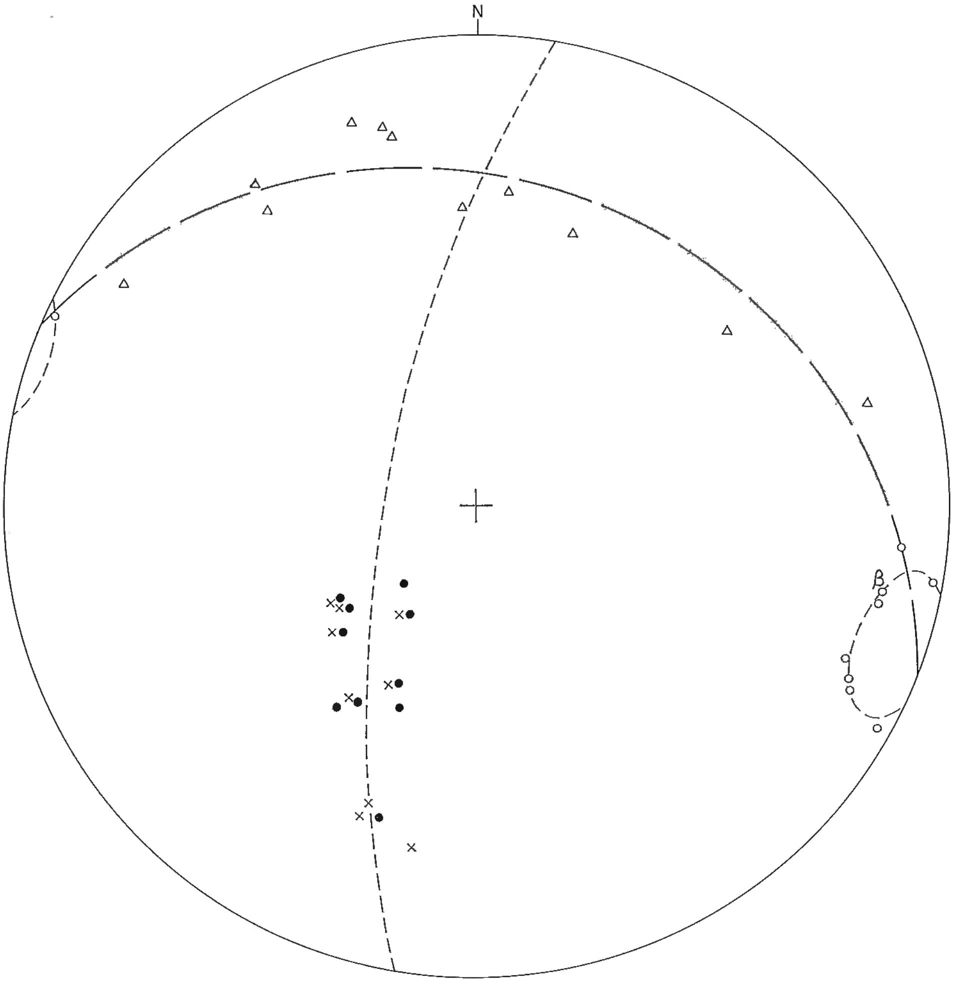


FIGURE 12.
Boudinage and segmentation.



Striation lineation L_2: intersection of schistosity S_2 with strain-slip cleavage S_3 . . . . o

Phyllitic schistosity S_2 containing the above lineation (poles plotted) . . . . ×

Other lineations L_3: axis of kink bands, folds, crenulations . . . . △

Phyllitic schistosity S_2 containing the above lineation (poles plotted) . . . . ●

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FIGURE 13. Equal-area lower hemisphere projection of attitudes measured in domain 10.

(dominantly cleavage) and 14a (schistosity), for example, plot along great circles that are essentially coincident.

Within a single domain the schistosity appears to vary in orientation continuously from one place to another, suggesting that folds are present. β would thus be the axis of folding. In domain 8, however, though the foliation is strongly developed, there is very little spread of attitudes and folding of S_2 is almost absent. As an example of the variation in orientation of different foliations and lineations within a single domain, domain 10 is considered below. Figure 13 is an equal-area projection of attitudes measured in domain 10. These relationships are clear only in the Slocan phyllites, domains 10, 11, and to a lesser extent 25; they are not clear in higher or lower grade rocks.

As shown on Figure 13, the lineation L_2 lies on a small circle in projection, whereas the lineation L_3 (*see* Pl. XXVII) lies on a great circle in projection. Crenulations forming lineation L_3 are generally small and the attitude of cross lineations (L_2) was measured as an "average" across the crests of such "wrinkles". On a larger scale within the same domain, however, the poles to schistosity lie along a great circle in projection (Fig. 13). The pole (β) to this great circle is almost coincident with the centre of the small circle of lineations noted above. In thin section, strain-slip crenulations are absent or poorly developed in the kink bands, suggesting obliteration by slip in the latter. This textural relationship with the geometrical relationships noted above suggests that the kink bands and folds are later than the strain-slip crenulations.

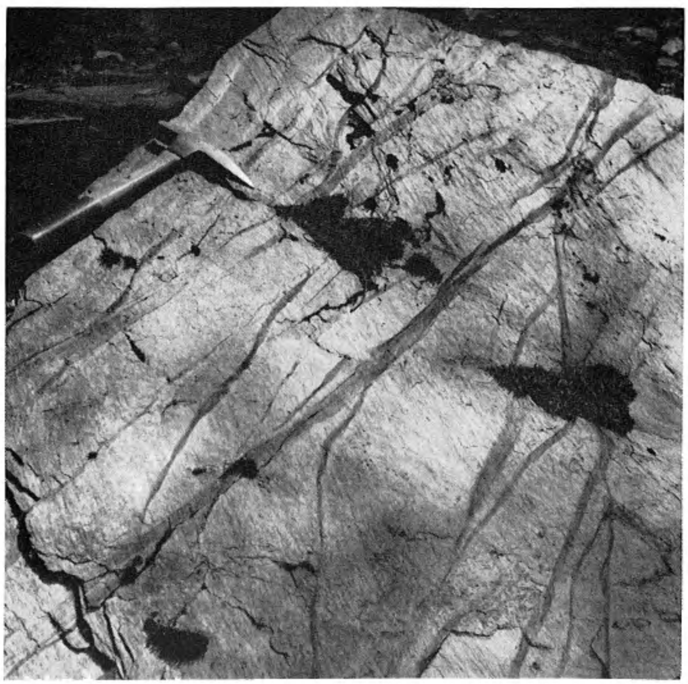

PLATE XXVII.
Phyllite of the Slocan Group. Note variable trend L_3 of kink bands (parallel with hammer handle) in schistosity S_2. Fine striation lineation L_2 in lower right (trending to upper left) is trace of strain-slip S_3 on schistosity.

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It therefore appears that the striation lineation (L_2) was formed first, with a gentle plunge east-southeast, by strain-slip of the metamorphic schistosity. This was followed by small scale kinking and crenulation of the schistosity and many axes (L_3) lying in a plane. Larger scale folding deformed L_2 into a small circle.

Macroscopic Structures

This section describes structures on a scale greater than that observable in a single exposure (Turner and Weiss, 1963, p. 144). Individual structural domains or groups of domains (*see* Fig. 16, *in pocket*) are described separately in terms of their mesoscopic structures, and some major structures are shown in sections A–B and C–D on Map 1234A.

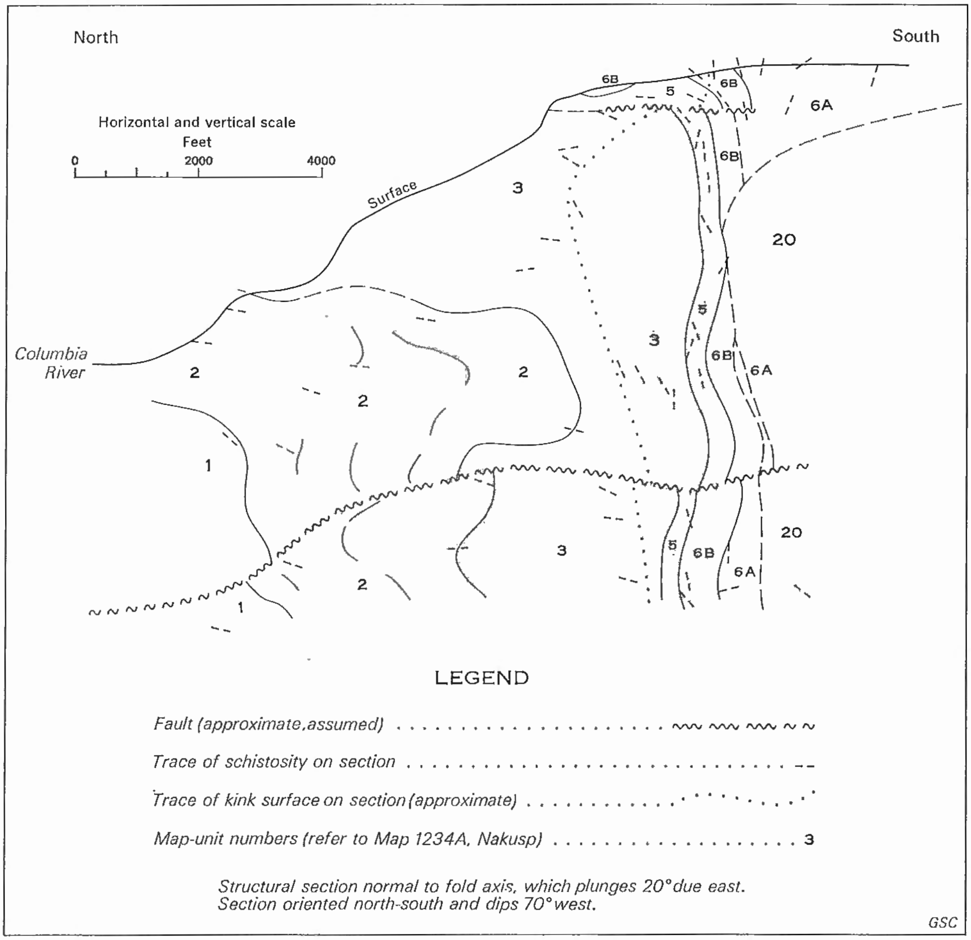


FIGURE 14. Section of the fold on Scalping Knife Mountain.

Fold on Scalping Knife Mountain (Domains 1 and 2)

Figure 14 is a structural section through the fold on Scalping Knife Mountain. The contacts of lithological units (numbers of units correspond with those on the geological map) are parallel with the attitudes of bedding projected into the plane of the section. The schistosity, parallel with the axial surfaces of the macroscopic folds (*see* Fig. 10; a, b, d), appears also to be parallel with the axial surface of the macroscopic fold (Fig. 14), at least within the "diopsidic quartzites" (unit 2). The schistosity and axial surface of the fold in unit 2 and adjacent parts of unit 1 are subhorizontal in projection, whereas the bedding conforms to a large, recumbent fold. Farther south in the schists (unit 1) and in units 5 and 6B, the schistosity dips steeply south, to almost vertical.

The radius of curvature of the fold hinge at the crest of Scalping Knife Mountain is less than 10 feet, an unusually sharp bend for so large a fold. This abrupt "kink" is exposed about 500 yards southeast of the top of Scalping Knife Mountain. The "kink surface" is about 2,000 to 2,500 feet from the nearly vertical contact with the quartz monzonite body on the south (*see* Fig. 14). This suggests that intrusion of the quartz monzonite flattened the end of the recumbent fold and caused the major kink in the schistosity.

Folds in the Vicinity of Rodd Creek (Domains 3 and 4)

The outcrop pattern, the lithological sequence shown in the structure section A–B across Scalping Knife Mountain, and the general attitudes of bedding and foliation suggest the presence of a synform and probably an antiform in domain 3 plunging about 40°E. Within these the rocks have been tightly, even isoclinally, folded (Fig. 11; f, g). Axial surfaces of the macroscopic fold(s) may well have the same orientation.

The Structure of Saddle Mountain (Domains 5 to 9)

In a general way, the structure on Saddle Mountain is an open antiform plunging gently to the east or, if much regional significance is attached to the attitudes in domain 7, the structure may represent the eastern half of a dome in the metamorphic rocks. Comparison of the equal-area projections of each of the domains on Saddle Mountain or the attitudes on Map 1234A shows that the schistosity in domain 6 dips to the south appreciably more than that in adjacent domains 5 and 8a. Near the eastern end of domain 6, this limb of the fold appears to be overturned. North and south of domain 6, at least along the crest of the mountain, the schistosity and bedding form wide, gentle undulations over large areas, almost parallel with the eastern slope of the mountain. Projection of the lower contact of the "diopsidic quartzite" between the foot of Scalping Knife Mountain and the peaks on Saddle Mountain gives a good "fit", with no apparent major structural discordance. Mesoscopic folds on Saddle Mountain range from extremely tight isoclinal recumbent folds with planar schistosity (e.g., Fig. 10e), through gentle warps of schistosity, to tightly appressed folds (e.g., Fig. 11h). These younger folds in the schistosity are overturned to the south.

These different types of folds indicate recumbent folding during metamorphism and post-metamorphic warping and folding in which the higher beds moved southward.

The Phyllite Belt near Dog Creek (Domain 10)

Attitudes of both bedding and schistosity in this area dip to the north, the schistosity in most parts dipping about 20° more steeply than the bedding. If the schistosity was formed as an axial plane cleavage to folds in the bedding, the latter was presumably not overturned by this folding. Both schistosity and bedding have steeper dips in the southern part of the domain, suggesting the southern portion of a large open syncline. The contrast of this to the antiform across Upper Arrow Lake is due to the Rodd Creek fault.

The Phyllite Belt North of Box Lake (Domain 11)

Lineations L_2 and L_3 in projection fall on a small circle and a great circle, respectively, having similar orientation to those in domain 10, but with slightly steeper plunge of the small circle and steeper dip of the great circle. Schistosity and cleavage within the domain dip moderately to steeply north to northeast. Where seen, bedding at the north end of the domain is slightly steeper than the schistosity, whereas that at the south end is slightly flatter. These relationships suggest a syncline overturned slightly to the south or southwest.

The Westernmost Low-grade Rocks of the Ruby Range (Domain 12)

Poles to schistosity in this area lie on a great circle almost coincident with that of the underlying higher grade rocks of domain 2. In the northern segment of domain 12, the schistosity dips moderately to the north or northeast, except in a narrow, approximately east-west belt due east of Swan Island. This change in attitudes suggests a fold in the schistosity, overturned slightly to the south.

The Ruby Range West of Silver Mountain (Domain 13)

The attitude of cleavage in this area is fairly constant with a moderate dip to the south. More than half a mile north of the Mountain Meadow pluton (unit 16A), beds dip gently to the south, whereas farther south they dip, most commonly, gently to the north. There are, however, a few reversals, especially next to the Ruby Range pluton (unit 17). Distribution of the lithological types in domain 13 suggests a synform on the south, an antiform at the Ruby Range pluton and a small synform at the Mountain Meadow pluton (to the north). Such a group of east-west folds is compatible, in general, with the attitudes described above. These plutons as suggested by their shape, may have been intruded parallel with the axial planes of folds as they formed.

The small body of argillaceous rocks (unit 10B) capping Blue Grouse Mountain has an almost planar lower contact (from the outcrop pattern) dipping gently to the south. The structure of this body, a syncline plunging to the south, is discordant to both the subhorizontal lower contact and the structure of the underlying rocks. This klippe will be described in more detail under the heading "Faults".

Upper Caribou Creek, Western Part (Domain 14, 14a)

Poles to cleavage in domain 14 fall on a great circle essentially coincident with that for the poles of schistosity in domain 14a. Considering the schistosity and cleavage as equivalent, the foliation conforms, in a general way, to an open warp plunging to the west or southwest around the end of the Halifax Creek stock. At the southern end of this, at Grey Wolf Mountain, the schistosity is warped into an antiform plunging to the west-southwest over the corner of the Caribou–Snowslide Creeks stock. Most of the lineations in this part of the domain conform closely in attitude to the axis of the macroscopic fold. There appears to be a similar antiform in the cleavage southeast of the mouth of North Fork of Caribou Creek. 'Bedding', where seen, appears to be parallel with the schistosity.

North of Lower Snow Creek (Domain 15)

The schistosity in this area appears to represent an antiform plunging gently to the east. The trace of its axial surface is just north of Snow Creek. This structure has a form and trend similar to those at Grey Wolf Mountain, but the plunges are opposite. Bedding, where seen, is almost parallel with the schistosity.

East of Caribou Creek to Wee Sandy Lake (Domain 18)

This domain includes areas fringing widespread parts of the East Caribou stock. The schistosity, essentially parallel with bedding, forms a prominent antiform plunging to the west-northwest over the head of Wee Sandy Creek. A synform, largely conformable with the East Caribou stock, and underlying its east end, borders the antiform on the north. A distinctive marker layer (or layers) of marble outlines the same folds. Most lineations, largely wrinkles and open warps, in this part of the domain have a similar trend and plunge.

South and West Wragge Creek (Domain 19a)

Fringing domain 18 on the northeast, this area includes part of the synform described above. Indeed, the only feature distinguishing the attitudes in domain 19a from those in 18 is a gentler component (regardless of strike) of dip to the west.

Shannon Creek–Upper Slewiskin Creek (Domain 19)

The poles of slaty cleavage (schistosity near Shannon Lake) in this large area fall on the same great circle as the poles to schistosity in domain 19a. These domains are separated only by the rocks of two granitic plutons but may well be parts of a single domain. Attitudes in the central part of domain 19 suggest a series of west-northwest plunging folds in the cleavage—two synforms separated by an antiform.

Hillside South of Summit Lake and Bonanza Creek (Domains 23 and 24)

The cleavage in domains 23 and 24 has a constant, fairly steep dip to the south, of about 75 and 60 degrees, respectively. In both, it appears to be warped slightly on steep, southerly plunging axes.

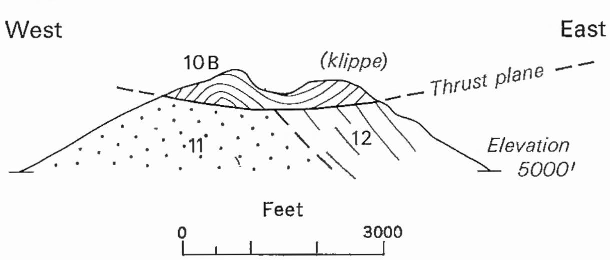
Summit Lake Area (Domain 25)

As elsewhere in the valley of Summit Lake, the cleavage dips steeply to moderately south. In domain 25, it appears to be warped on an axis plunging gently to the west-southwest. A few lineations conform to this axis but more do not. The rocks are, at least to some extent, folded isoclinally as such mesoscopic folds were seen near the centre of the domain. There the cleavage parallels the axial planes of isoclinal folds plunging steeply to the southeast. Bedding nearby appears to be parallel with the cleavage.

Synopsis of Macroscopic Structures

The β diagrams plotted on Figure 15 show that, in general, β for the western half of the area plunges to the east or southeast, whereas that for the eastern part plunges to the west. As suggested in the section "Orientation of Mesoscopic Structures", β probably represents the most prominent axis of folding of schistosity and cleavage in each domain. As the schistosity and cleavage in each domain are folded, the bedding must be deformed no less, and probably much more so (*see*, for example, Fig. 10f and domain 25).

β's for domains 1 to 6, in the western part of the area, appear to fall on a small circle whose centre or "axis" plunges 23 degrees S70°E. β's for the domains in the southeastern part of the area (14, 14a, 18, 19, 19a, 22, and possibly 25) appear to fall on a small circle plunging 46 degrees due west. Though the granitic stocks are largely concordant, they appear to have had either little effect on the structures immediately bordering them or a rather uniform effect over a large area. Locally, for example along the southeastern contact of the Goatcanyon–Halifax Creeks stock, there appears to be effects attributable to intrusion. For the most part, concentric or kink folding and emplacement of the granitic plutons are considered to be synchronous, but nonetheless no pronounced effect on the enclosing rock is to be expected. Therefore, if one disregards the effects of intrusion, although the dominant folds trend generally east-west, there appears to be a broad north-trending warp. It consists of a depression up the centre of the area near longitude 117°45′, with culminations of either side.



An east-west vertical section showing the relationships of the klippe to the underlying rocks. It appears to be allochthonous but whence it came is unknown. Numbers refer to map-units, (refer to Map 1234A, Nakusp)

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FIGURE 15. **East-west section showing the klippe on Blue Grouse Mountain.**

Faults

The Rodd Creek Fault Zone

The contact between the high-grade metamorphic rocks and the overlying low-grade rocks on the hillside east of Swan Island, though ill-exposed, gives an outcrop pattern suggestive of a moderate, generally eastward dip. A few hundred feet above and below are slivers of lithological units that are out of place in the section. A few exposed faults, across one of which there is an obvious change in metamorphic grade, dip 50°E and SE.

Farther south along the same zone, the west end of the Ruby Range stock (unit 17) is cut off at Rodd Creek. One prominent fault, exposed across 20 feet, dips 58°E–NE. Still farther south on the hillside east of lower Mineral Creek, shear zones in the low-grade rocks dip, for example, 35°E and 10°S. North of Swan Island, the contact is obscured by Upper Arrow Lake.

This zone also truncates the zones of regional metamorphism, the staurolite–almandine subfacies being cut out almost entirely north of upper Rodd Creek (*see* Fig. 16, *in pocket*). Displacement along this zone is evidently large with an apparent normal sense of movement. However, the amount of strike-slip movement is unknown.

Steeply Dipping, North-south Faults

The most common faults in the area have a nearly north-south strike and a near-vertical dip. Faults in the high-grade rocks west of the Rodd Creek fault to the top of Scalping Knife Mountain have left lateral movement. Farther west, the faults are largely right lateral. The boundaries between metamorphic zones are offset by these faults. The margins of the granitic stocks in the area are offset by near-vertical, north-south faults. Lamprophyric dykes follow many of these faults, especially in the southern half of the area.

The Klippe on Blue Grouse Mountain

The position and synclinal structure of the mass of argillaceous rocks (10B) capping Blue Grouse Mountain does not seem to fit into the structure of domain 13. The trace of the flattish lower contact around the mountain is marked almost everywhere by pronounced shearing in the overlying rocks (Fig. 15). Scattered adits in the base of this mass of argillaceous rocks are now inaccessible, but a report by A. G. Langley, in the "Annual Report, Minister of Mines of British Columbia" for 1917 (p. F174), notes the following, in reference to the Millie Mac mine: "This zone lying nearly horizontal on an igneous rock classified as andesite is between 60 and 100 feet thick and apparently marks the line of contact between the igneous and sedimentary rocks." In the Annual Report for 1923 (p. A234), he adds: "This igneous base dips at a slight angle to the east, while the overlying slates, apparently not having been greatly disturbed above the contact, have a fairly uniform northerly and southerly strike and a dip of about 35° to the west. This cap of argillaceous rocks thus appears to be an isolated block, separated from the underlying volcanic rocks by a gently dipping fault.

Faults on Silver Mountain

A closely spaced series of northwest-trending faults crosses the northeast flank of Silver Mountain. Most appear to be steep, but immediately to the southwest faults dip in turn 62° and 28°SW. A fault across the head of Independence Creek has a similar trend and a dip of 56 degrees to the southwest, and may belong to this group.

Summary of Deformation and Conclusions

Episodes of Folding

The sedimentary rocks around Upper Arrow Lake have been affected by at least three episodes of deformation.

First episode: Formation, during regional metamorphism, of the schistosity (S_2) in the high-grade metamorphic rocks of Saddle and Scalping Knife Mountains, and the low-grade phyllites east and south of Nakusp. Formed presumably at the same time were the small, tight, isoclinal, recumbent folds in S_1, mineral and wrinkle lineation (L_1) in the Shuswap Terrane, and the large recumbent fold in S_1 on Scalping Knife Mountain, all with eastward trends. Intersection of schistosity (S_2) and bedding (S_1) at a very small angle in the low-grade rocks demonstrates an early, isoclinal deformation there as well. The general orientation of the schistosity and lineation in the high-grade rocks on Saddle Mountain is similar to that in the low-grade rocks of the phyllite belt, to the east.

Second episode: Development of strain-slip cleavage (S_3), and accompanying lineation in S_2, in the low-grade phyllites. The macroscopic folds in S_2 (including the Saddle Mountain fold and Slocan syncline), with gently plunging, east-west axes, probably took place at that time.

Third episode: Formation of mesoscopic folds (in S_2 and S_1), whose axes, in any single domain, are coplanar. They, therefore, have not been deformed by any later folding on a different axis. The earlier lineations, L_1 and L_2, of nearly constant orientation were deformed into small cones whose gently plunging axes trend between due west and N30°W. The large fold on Scalping Knife Mountain was probably refolded as a major kink in the schistosity S_2, during this third phase, perhaps by forceful intrusion of the adjacent quartz monzonite (unit 20).

Time of Deformation in Relation to Intrusion

Contact metamorphism accompanying intrusion of the granitic plutons postdates the formation of the strain-slip cleavage S_3 in the second episode of deformation. As the contacts of the stocks are generally concordant with the schistosity S_2, intrusion probably occurred while deformation was still in progress, presumably during the third episode. Large-scale warping of the schistosity of the basal Slocan Group into a vertical attitude adjacent to the Kuskanax batholith is attributed to intrusion of that pluton.

The Rodd Creek fault truncates the regional metamorphic zones and the Ruby Range stock. It must therefore be younger than both. Steep faults elsewhere offset the contacts of most of the stocks, including the lower Caribou Creek stock (20), which is regarded as the youngest of the stocks. Evidence for faulting prior to the intrusion of any of the stocks has not been recognized. The lamprophyric dykes follow many of these zones and some dykes are themselves sheared.

The vertical, streaky lineation in the quartz monzonite along the northeastern margins of the lower Caribou Creek stock is at least in part post-consolidation, but may also be in part pre-consolidation. It may well represent vertical movement of the border of the stock with respect to the host rocks in the late stages of intrusion.

Faulting seems, then, to have occurred subsequent to intrusion of the granitic stocks but prior to intrusion of the basic dykes, and to have continued after their intrusion. The remnant of a thrust fault on Blue Grouse Mountain is probably post-regional metamorphism, as the latter does not appear to have affected the sheared zone.

In summary then, the third episode of deformation accompanied intrusion of the granitic stocks, whereas faulting followed their intrusion. The post-granitic basic dykes were both preceded and followed by faulting.

Emplacement of the Stocks

The stocks of the Nakusp map-area, though discordant to some extent in detail, are generally concordant on a regional scale. Contacts in the eastern part of the area are commonly sharp and also concordant in detail. Emplacement of these stocks must, therefore, have involved forceful shouldering aside of the country rocks, permissive intrusion into rocks undergoing deformation, and/or stoping of major proportions controlled by the schistosity of the country rocks. Absence of inclusions, except locally on a minor scale, and compositional zoning of the stocks, seems to preclude stoping at the level of emplacement, as a major factor, except in the stocks of Lower Caribou and Halifax Creeks.

Chapter V

GEOLOGICAL HISTORY

A summary of the geological history of Nakusp map-area, as deduced from the field, petrographical, and structural data, follows (*see* Table IX).

Triassic and earlier: Deposition of the pelitic and calcareous sediments forming the Shuswap Terrane, followed by those of the Milford Group; extrusion of volcanic rocks of the Kaslo Group.

Triassic and (?)*Lower Jurassic*: Deposition of the shales and silts of the Slocan Group, followed by tuffs and some flows.

Lower Jurassic: Extrusion of tuffs and flows, of volcanic rocks of the Rossland Formation; some members may be intrusive.

Jurassic and/or Lower Cretaceous: (1) Regional metamorphism of all earlier rocks. Penetrative deformation of the phyllites of the Slocan Group and underlying rocks by shear folding on east-west axes and flat axial planes. This is the first and main episode of deformation. The large recumbent fold on Scalping Knife Mountain formed at this time. Prior to the end of deformation, sills of leucocratic quartz monzonite, related to the Kuskanax batholith, were intruded as sills into the high-grade metamorphic rocks. Subsequent to the regional metamorphism and the first episode of deformation, steeply dipping strain-slip cleavage formed fine wrinkles in the metamorphic schistosity (second deformation episode). Axes of these wrinkles are nearly east-west. Probably formed at the same time are the large, east-west trending Saddle Mountain and Slocan folds. (2) Intrusion of leucocratic alkali-rich stocks of the "Kuskanax" type, with contact metamorphism and recrystallization of adjacent country rocks.

Jurassic and/or Cretaceous: Intrusion of alkali-calcic quartz monzonite to quartz diorite stocks of the "Nelson" type. These, too, resulted in contact metamorphism and recrystallization of adjacent country rocks. Accompanying intrusion was mesoscopic folding, the earlier east-west lineations being thereby deformed (third episode of deformation). Kinking of the crest of the fold on Scalping Knife Mountain resulted from intrusion of the lower Caribou Creek stock.

Cretaceous(?) *and later*: High angle, predominantly north-south faulting, accompanied by intrusion of basaltic and lamprophyric dykes. Erosion.

Pleistocene and later: Continental and valley glaciation, erosion and deposition, to develop the present topography.

The main lines of evidence for a Jurassic and/or Early Cretaceous age for at least the culminating high- to low-grade regional metamorphism of the Shuswap

TABLE IX | *Geological History*

Era	Period	Formation	Rock Unit	Lithology	Deformation
Cenozoic	Recent and Pleistocene			Glacial debris, lake silts and clays Stream gravel, sand and silt	
	u n c o n f o r m i t y				
	Tertiary?		22	Lamprophyre dykes	High angle faulting
	i n t r u s i v e c o n t a c t				
Mesozoic		Box Mountain stock	21	Syenite	
	pre-69 m.y. Cretaceous *pre-107 m.y.* and/or *pre-74 m.y.*	Lower Caribou Creek stock	20	Quartz monzonite with K-feldspar megacrysts	Concentric and kink folding including refolding of the Scalping Knife Mountain fold; including? Slocan fold
		Goatcanyon–Halifax Creeks stock and	19		
		Snowslide–Wragge Creeks stocks	18	Quartz monzonite	
	pre-123 m.y. possibly	Ruby Range stock	17	Quartz monzonite–quartz diorite	
		Mountain Meadow pluton,	16A	Quartz diorite	
		East Caribou stock	16B		(3rd phase)
	Jurassic?	Nakusp Range–Allshouse Peak stocks	15	Leucogranite	?
		South Wragge Creek,	14A		
		Shannon Lake stocks	14B	(Leuco) quartz monzonite	?
		i n t r u s i v e c o n t a c t			Strain-slip cleavage & (?) Saddle Mountain fold & (?) Slocan fold (2nd phase)
		r e g i o n a l	13	Lineated (leuco) quartz monzonite	Penetrative similar folding including recumbent Scalping Knife fold (1st phase)
		m e t a m o r p h i s m			
	Lower Jurassic	Rossland Group	12	Greenstone	
	Triassic and/? Lower Jurassic	Slocan Group	11	Grey volcanic rocks	
			10B	Non-phyllitic argillaceous rocks	
			10A	Grey phyllite	
	Triassic	Kaslo Group	9	Amphibolite (metavolcanic rocks)	
Palaeozoic and/or Precambrian	?Pennsylvanian to Triassic	Milford Group(?)	6B	Calc-silicate metasedimentary rocks	
			6A	Pelitic schist	
	pre-Triassic		5	Amphibolite	
		Monashee Group (Shuswap Terrane)	3	Pelitic schist	
			2	Diopsidic quartzite	
			1, 4	Undivided metasediments (pelitic schist, paragneiss, calc-silicate rock, amphibolite, marble)	

Terrane (Monashee Group) and overlying rocks within Nakusp map-area are as follows:

1. The regional metamorphism affects Lower Jurassic rocks of the uppermost Slocan Group, in which a Sinemurian ammonite has been found, and all earlier rocks (including the Monashee Group) in the area. The culmination of this metamorphism is therefore post-Early Jurassic.

2. The age of the granitic plutons is presumably no younger than isotopic ages determined for them but various possible means of argon loss do not preclude an older true age. Potassium–argon ages of 69, 74, 107, and 123 $\pm$ 10 m.y. therefore indicate intrusion prior to latest or mid-Cretaceous.

3. Granitic plutons intruded into the metamorphic rocks are post-regional metamorphism because:
   (a) there is no evidence for metamorphism of the granitic rocks.
   (b) the granitic rocks have altered the country rocks to hornfels, recrystallizing deformed regional metamorphic minerals (e.g., crenulated biotite) and crystallizing new minerals (e.g., andalusite) that are clearly later than the minerals, schistosity, and structures produced by regional metamorphism.

Although there is no evidence, at present, of an earlier regional metamorphism and/or deformation of rocks comprising the Shuswap Terrane in this area, there is no compelling reason why there could not have been one. Such a multiple metamorphism has been inferred, for example, for the Baltimore Gneiss in the Appalachian Mountains (Tilton, *et al.*, 1958). Isotopic ages from zircon (U–Pb) and microcline (Rb–Sr) from these rocks gave 1,000 to 1,100 m.y., whereas those from biotite (K–Ar and Rb–Sr) from the same rocks gave 300 to 350 m.y.

The Jurassic and/or Early Cretaceous regional metamorphism of these rocks is presumably an expression of the Coast Range (or Nevadan) orogeny (White, 1959, pp. 78–89). The later granitic plutons are probably a later, generally higher level, expression of the same orogeny.

BIBLIOGRAPHY

Albee, A. L.

1962: Relationships between the mineral association, chemical composition and physical properties of the chlorite series; *Am. Mineralogist*, Vol. 47, pp. 851–870.

Barrow, G.

1912: On the geology of Lower Deeside and the southern Highland Border; *Proc. Geologist's Assoc.*, Vol. 23, pp. 274–290.

Bostock, H. S.

1948: Physiography of the Canadian Cordillera; *Geol. Surv. Can.*, Mem. 247.

Brock, B. B.

1934: The metamorphism of the Shuswap Terrane of British Columbia; *J. Geol.*, Vol. 42, pp. 673–699.

Brown, I. C., and Shaw, D. M.

1962: Guide to nomenclature of igneous and metamorphic rock; *Geol. Surv. Can.*, pamphlet.

Cairnes, C. E.

1929: Geological reconnaissance in Slocan and Upper Arrow Lakes area, Kootenay district, British Columbia; *Geol. Surv. Can.*, Sum. Rept. 1928, pt. A, pp. 94A–108A.

1934: Slocan Mining Camp, British Columbia; *Geol. Surv. Can.*, Mem. 173.

1939: The Shuswap rocks of southern British Columbia; *Proc. Sixth Pacific Sci. Congr.*, Vol. 1, pp. 259–272.

Chayes, F.

1949: A simple point-counter for thin section analysis; *Am. Mineralogist*, Vol. 34, pp. 1–11.

Chinner, G. A.

1961: The origin of sillimanite in Glen Clova, Angus; *J. Petrol.*, Vol. 2, pp. 312–323.

Dawson, G. M.

1879: Preliminary report of the physical and geological features of the southern portion of the interior of British Columbia; *Geol. Surv. Can.*, Rept. Prog., 1877–78, pp. 96B–101B.

1890: On a portion of the West Kootenay district, British Columbia; *Geol. Surv. Can.*, Ann. Rept. 1888–89, Vol. 4, pp. 7A–12A, 5B–66B.

Department of Transport

1960–62: Monthly Record, Meteorological observations in Canada; Meteorological Branch, Canada.

de Waard, D.

1959: Anorthite content of plagioclase in basic and pelitic crystalline schists as related to metamorphic zoning in the Usu Massif, Timor; *Am. J. Sci.*, Vol. 257, pp. 553–562.

Evernden, J. F., *et al.*

1960: Argon diffusion in glauconite, microcline, sanidine, leucite, and phlogopite; *Am. J. Sci.*, Vol. 258, pp. 583–604.

Frebold, H.

1959: The marine Jurassic rocks in Nelson and Salmo areas, southern British Columbia; *Geol. Surv. Can.*, Bull. 49, p. 7.

Frebold, H., and Little, H. W.

1962: Palaeontology, stratigraphy, and structure of the Jurassic rocks in Salmo map-area, British Columbia; *Geol. Surv. Can.*, Bull. 81.

Geological Survey of Canada

1962: Geological Map of British Columbia; *Geol. Surv. Can.*, Map 932A.

Gillully, J.

1934: Mineral orientation in some rocks of the Shuswap Terrane as a clue to their metamorphism; *Am. J. Sci.*, Vol. 228, pp. 182–201.

Hall, A. J.

1941: The relation between colour and chemical composition in the biotites; *Am. Mineralogist*, Vol. 26, pp. 29–33.

Harker, A.

1932: Metamorphism; London, Methuen and Co., Ltd.

Hayama, Y.

1959: Some considerations on the colour of biotite and its relation to metamorphism; *J. Geol. Soc. Japan*, Vol. 65, pp. 21–30.

Heald, M. T.

1950: Structure and petrology of the Lovewell Mountain Quadrangle, New Hampshire; *Bull. Geol. Soc. Amer.*, Vol. 61, pp. 43–89.

Hedley, M. S.

1945: Geology of the Whitewater and Lucky Jim Mine areas, Slocan district, British Columbia; *B. C. Dept. Mines*, Bull. 22.

1952: Geology and ore deposits of the Sandon area, Slocan Mining Camp, British Columbia; *B. C. Dept. Mines*, Bull. 29.

Holmes, A.

1959: A revised geological time-scale; *Trans. Edinburgh Geol. Soc.*, Vol. 17, pt. 3, pp. 183–216.

Jenness, J. E.

1964: Summary of Activities: Field, 1963; *Geol. Surv. Can.*, Paper 64-1.

Johannsen, A.

1939: A descriptive petrography of the igneous rocks, Vol. 1, Introduction, textures, classifications and glossary; Univ. Chicago Press.

Jones, A. G.

1959: Vernon map-area, British Columbia; *Geol. Surv. Can.*, Mem. 296.

Laves, F.

1950: The lattice and twinning of microcline and other potash feldspars; *J. Geol.*, Vol. 58, pp. 548–571.

Leech, G. B., *et al.*

1963: Age determinations and geological studies (including isotopic ages—Rept. 4); *Geol. Surv. Can.*, Paper 63-17.

Little, H. W.

1957: Kettle River, East Half, British Columbia; *Geol. Surv. Can.*, Map 6-1957.

1960: Nelson map-area, West Half, British Columbia; *Geol. Surv. Can.*, Mem. 308.

Lowdon, J. A. (comp.)

1960: Age determinations by the Geological Survey of Canada, Rept. 1—Isotopic Ages; *Geol. Surv. Can.*, Paper 60-17.

1961: Age determinations by the Geological Survey of Canada, Rept. 2—Isotopic Ages; *Geol. Surv. Can.*, Paper 61-17.

Lowdon, J. A., *et al.*

1963: Age determinations and geological studies (including isotopic ages—Rept. 3); *Geol. Surv. Can.*, Paper 62-17.

McConnell, R. G., and Brock, R. W.

1904: West Kootenay sheet, British Columbia; *Geol. Surv. Can.*, Map 792.

MacKenzie, W. S.

1954: The orthoclase-microcline inversion; *Min. Mag.*, Vol. 30, pp. 354–366.

Minister of Mines of British Columbia

1899–1960: Annual Reports

Shaw, D. M.

1960: The geochemistry of scapolite, Pt. II. Trace elements, petrology, and general geochemistry; *J. Petrology*, Vol. 1, pp. 261–285.

Slemmons, D. B.

1962: Determination of volcanic and plutonic plagioclases using a three- or four-axis universal stage; *Geol. Soc. Amer.*, Spec. Paper 69.

Smith, J. R., and Yoder, H. S.

1956: Variations in X-ray powder diffraction patterns of plagioclase feldspars; *Am. Mineralogist.*, Vol. 41, pp. 632–647.

Smith, J. V., and Gay, P.

1953: The powder patterns and lattice parameters of plagioclase feldspars, II; *Min. Mag.*, Vol. 31, pp. 744–762.

Thompson, J. B., Jr.

1957: The graphical analysis of mineral assemblages in pelitic schists; *Am. Mineralogist*, Vol. 42, pp. 842–858.

Tilton, G. R., *et al.*

1958: Ages of minerals from the Baltimore gneiss near Baltimore, Maryland; *Bull. Geol. Soc. Amer.*, Vol. 69, pp. 1469–1474.

Turner, F. J.

1948: Mineralogical and structural evolution of the metamorphic rocks; *Geol. Soc. Amer.*, Mem. 30.

Turner, F. J., and Verhoogen, J.

1960: Igneous and metamorphic petrology, 2nd ed.; McGraw-Hill Co., Inc., N.Y.

Turner, F. J., and Weiss, L. E.

1963: Structural analysis of metamorphic tectonites; McGraw-Hill Co., Inc., N.Y.

Tuttle, O. F.

1952: Origin of the contrasting mineralogy of extrusive and plutonic salic rocks; *J. Geol.*, Vol. 60, pp. 107–124.

Tuttle, O. F., and Bowen, N. L.

1958: Origin of granite in the light of experimental studies in the system $NaAlSi_3O_8$–$KAlSi_3O_8$–SiO_2-H_2O; *Geol. Soc. Amer.*, Mem. 74.

Wager, L. R., and Deer, W. A.

1939: Geological investigations in East Greenland, pt. III. The petrology of the Skaergaard intrusion, Kangerdlugssuaq, East Greenland; *Medd. om Gronland*, Vol. 105, pp. 1–352.

Walker, J. F., Bancroft, M. F., and Gunning, N. C.

1928: Lardeau map-area, British Columbia; *Geol. Surv. Can.*, Mem. 161.

Wanless, R. K., *et al.*

1965: Age determinations and geological studies; pt. 1, Isotopic Ages, Rept. 5; *Geol. Surv. Can.*, Paper 64-17.

White, W. H.

1959: Cordilleran Tectonics in British Columbia; *Bull. Am. Assoc. Petrol. Geol.*, Vol. 43, pp. 60–100.

Winchell, A. N., and Winchell, H.

1951: Elements of optical mineralogy, pt. II. Descriptions of minerals; John Wiley and Sons, Inc., N.Y.

Yoder, H. S., Jr., and Sahama, Th. G.

1957: Olivine x-ray determination curve; *Am. Mineralogist*, Vol. 42, pp. 475–491.

Yoder, H. S., Stewart, D. B., and Smith, J. R.

1957: Ternary feldspars; *Carnegie Inst. Wash. Yearbook*, Vol. 56, pp. 206–214.

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